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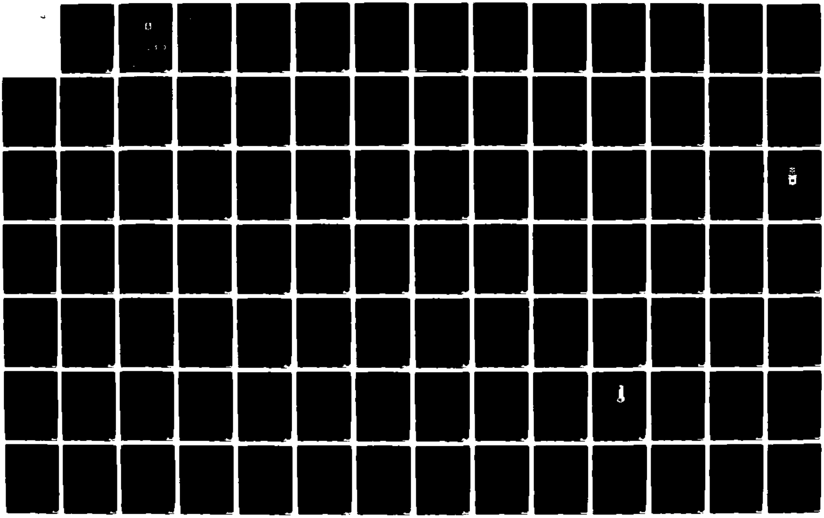

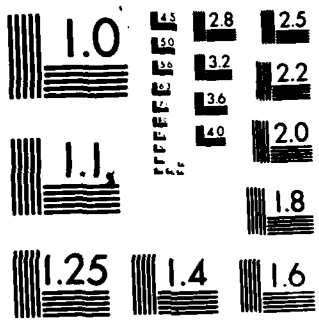

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FOREIGN TECHNOLOGY DIVISION

STABILITY OF PERMANENT MAGNETS

by

A. V. Mitkevich

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

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STABILITY OF PERMANENT MAGNETS.

A. V. Mitkevich.

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Is examined the vast experimental material, obtained by the author, which relates in essence to the investigation of the stability of permanent magnets and magnetic systems in the time and with a change in the temperature. The effect of impacts, vibrations and external magnetic fields in less detail is illuminated. The new, accelerated methods of the study of the stability of magnets and systems are proposed. Is introduced the universal straight line of instability and the instability coefficient, necessary as criterion for the evaluation/estimate of stability in the time. Magnetometers of the increased sensitivity and reproducibilities, used are described and are analyzed by the author. Economically advisable magnetic and temperature agings are given to recommendation for the selection.

The book is intended for the wide circle of scientific workers and engineers, who deal concerning production and use/application of permanent magnets.

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Preface.

Permanent magnets extensively are used in the leading areas of contemporary technology - electrical engineering, radio engineering, data-measuring technology, automation, missile construction, cosmonautics. Therefore the guarantee of stability of permanent magnets is extremely urgent task. On the other hand, the great technical difficulties, which appear during the investigation of the stability of magnets and magnetic systems, until now, did not make it possible to obtain experimental data, with a sufficient completeness characterizing their stability. This did not give the possibility to soundly select the magnetic and temperature aging of magnets and systems and with the confidence to apply them.

Thus, it is necessary to systematize available experimental data, to select criteria for the evaluation/estimate of the stability of magnets and systems and to outline the promising way of resolution of this problem.

In the present monograph are generalized the results of the original work of the author for the years 1931-1940, the dedicated to investigation manifestations of magnetic viscosity in the ferromagnetic media, including in the nickel-aluminum alloys, and also the large experimental material, obtained by the author for the years 1950-1970, on the stability of permanent magnets and magnetic systems with the magnets from the nickel-aluminum alloys under the varied conditions. Furthermore, are set forth the new accelerated methods, developed by the author of the study of the stability of magnets and systems, which do not require prolonged time intervals, especially complicated equipment and metrological situations of experiments, and some methods of the measurements of the magnetic induction, suitable for the investigation of stability, are examined. Vast bibliography is given.

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Being the first monograph, dedicated to this question, this book, naturally, cannot pretend to the comprehensive and comprehensive illumination of the problem of the stability of magnets. Nevertheless the author hopes that the given here experimental material will prove to be useful during the development of new equipment and measuring meters, and the introduction of the accelerated methods proposed to them of the study of the stability of magnets will contribute to the accumulation of experimental results and to further development of scientific research work in this region.

In conclusion the author expresses his gratitude to professor N. N. Razumovskiy, professor K. S. Demirchyan and docent V. M. Yurinov for the useful criticism of the manuscript and the series/row of valuable observations.

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Chapter One.

PROBLEM OF THE STABILITY OF PERMANENT MAGNETS.

1-1. Introduction. Fundamental tasks. Criteria for the evaluation/estimate of magnets according to stability.

The instrument accuracy and equipment with the permanent magnets depends on the stability of these magnets. Consequently, the problem of the stability of permanent magnets is one of the important problems of contemporary instrument manufacture. However, until recently it remained insufficiently studied and virtually unresolved in connection with the great technical difficulties, which appear during the investigation of stability. Actually/really, very low in the percent ratio changes of the magnetic induction, caused by the instability of magnets, usually they were defined as a difference in two very close values of magnetic induction. Therefore it was necessary to strongly raise sensitivity and reproducibility of the special measuring installations/settings up, the so-called magnetometers, utilized for induction measurement. As a result, the required almost metrological situation of experiments did not make it possible to widely supply the investigations of the stability of magnets and magnetic systems with the permanent magnets. Such works were conducted only in a few laboratories of research institutes. A relatively small number of permanent magnets and sy ems underwent tests for stability, and there was obtained limited uantity of experimental data.

The plants which make permanent magnets were deprived of the possibility to monitor the stability of magnets and to develop/process technology, its improving. Enterprises, which apply magnets, did not have on the same reasons for the comprehensive information about the stability of magnets and systems under the varied conditions for operation. Were absent even criteria for the comparison between themselves of magnets on the stability, with exception of temperature coefficient. The stability of permanent magnets, until now, was not connected with appropriate manuals and GOST [ГОСТ - All-Union State Standard].

At the same time requirements on the stability of magnets are imposed ever more and more rigid. It is sometimes necessary to ensure their stability of the order of the hundredth and even thousandths of percentage during the long time under the severe conditions (large temperature range, the effect of impacts, vibrations, irradiation).

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Thus, it is possible to arrive at the conclusion that the need for the posing of problems of the stability of permanent magnets, systematization of already available experimental data and selection of the promising methods of solution of this problem at present ripened.

Basic problems, which are subject to study, and also proposed criteria of evaluation of magnets and magnetic systems according to the stability are conveniently schematically represented in the form Table 1-1.

Separate tasks and proposed criteria will be in detail examined below, with exception of the study of reversible permeability, which relates faster to the calculation of magnets and magnetic systems, and effect of irradiation. Determination of the proposed new term - instability coefficient, characterizing a change of the magnetic induction of magnets in the time, is given into § 3-4; by irreversibility the irreversible changes in the magnetic induction, caused by different external agencies, are implied.

1-2. Contemporary state of a question about the stability of permanent magnets.

The investigations of the stability of permanent magnets, carried out to the discovery/opening of nickel-aluminum alloys, are not at present of special interest, since even best of that applying are earlier alloys, for example cobalt and tungsten, no longer are utilized. Therefore there are no foundations for stopping on the specific special features/peculiarities of the metallurgical aging of such magnets and their behavior under varied conditions [1-4].

Table 1-1.

(1) Стабильность магнитов и магнитных систем				
(2) Влияние времени		(3) Влияние внешних воздействий		
(4) После намагничивания	(5) После стабилизации	(6) Температуры	(7) Ударов, вибраций и облучения	(8) Магнитных полей
		(9) Обратимые изменения индукции	(10) Необратимые изменения индукции	(11) Обратимые изменения индукции
(12) Критерии				
(13) Коэффициент нестабильности		(14) Температурный коэффициент	(15) Необратимость	(16) Обратимая магнитная проницаемость

Key: (1). Stability of magnets and magnetic systems. (2). Effect of time. (3). Effect of external agencies. (4). After magnetization. (5). After stabilization. (6). Temperatures. (7). Impacts, vibrations and irradiation. (8). magnetic fields. (9). Reversible changes in the induction. (10). Irreversible changes in the induction. (11). Reversible changes in the induction. (12). Criteria. (13). Instability coefficient. (14). Temperature coefficient. (15). Irreversibility. (16). Reversible magnetic permeability.

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On the other hand, to contemporary nickel-aluminum materials and to alloys, as is known, virtually characteristically metallurgical aging at temperatures, which reach 300°C and above. This makes it possible to disregard the effect of this aging during the study of the stability of magnets in the time at a room temperature.

The changes of the magnetic induction caused by magnetic viscosity with time in bar magnets from the nickel-aluminum alloys were for the first time discovered by the author in 1940. In this case was investigated the dependence the manifestation of magnetic viscosity on varied conditions [5-15]. Some results of tests and series/row of the conclusions/outputs, useful during the study of the stability of magnets in the time are examined in Chapter 3.

Of the made by the author in the latter/last 20 years investigations of the stability of permanent magnets and magnetic systems with the magnets from different nickel-aluminum alloys for the time intervals, which reached of up to 4 years, in the presence of temperature effects, impacts, the vibrations also of external magnetic fields were partially published [16-25]. It was possible to obtain partly this very vast experimental material because of the use/application of different accelerated methods of the study of the stability of magnets and magnetic systems. The based on it practical recommendations, which have in certain cases large economic effect, are set forth into 4, 5 and by the 6th chapters.

Increments in the magnetic induction of the order of several percentages were determined during the investigation of the effect of temperature cycles and impacts on the magnets from the alloy of Alni [26], temperature effect on the magnets from the alloy of Alnico [27] and stability in the time of magnets from the alloy of Alni [28].

General/common/total considerations about the stability of magnets from different nickel-aluminum alloys, and also about the need for their magnetic and temperature aging were voiced by different authors [29-32]. according to Tyrell [33], partial demagnetization during the stabilization of magnets from the alloy of Alnico must not exceed 10%, since during the larger demagnetization tendency toward the increase of magnetic flux in the time occurs. This observation of Tyrell long time forced to avoid the demagnetization, which exceeds 10%, which led to the rejection of strong magnets, i.e., it proved to be economically extremely unfavorable. The results of the experiences of the author, given in § 5-4, disprove the opinion of Tyrell.

The experiments of Barbier and Libutri [34-36] confirmed that forecast earlier by Becker, by Daring [37], by Smith, by Street, Uuley [sp.] [38-43] and by Neel [44-46] the logarithmic law expressing the dependence of the magnetic induction of permanent magnets on the time, which was experimentally established/installed in the work of Street and Uuley [40] for the magnets from the alloy of Alnico.

Utilizing a differential ballistic method, Tenser developed the magnetometer of high sensitivity (with a reproducibility which reaches to 0.01%) and used it for studying the stability of permanent magnets [47, 48].

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He investigated temperature effect on the order of 550°C on permanent magnets [49], and he also participated in other works on the investigation of the stability of the magnets, which were being performed in the United States of America.

Kronenberg studied the stability of permanent magnets with the aid of the magnetometer, proposed by Tenser [47, 48]. Experimentally he obtained the following to logarithmic law the dependence of magnetic induction on the time and noted the absence of metallurgical aging in nickel-aluminum alloys. Furthermore, Kronenberg together with Boyleman investigated the prolonged temporary/time stability of magnets from the alloy of Alnico, cermet magnets and barium ferrites [50-52].

Kleg studied the effect of coolings of order of -60°C on the magnetic induction of rod permanent magnets from the nickel-aluminum alloys with the aid of the astatic magnetometer. It indicated the dependence of temperature coefficient on the position of operating point in demagnetization curve [53]. Kleg and the McCaig utilized a differential ballistic method for the investigation of the effect of the high temperatures, which reached 550°C, to permanent magnets [54, 55]. The behavior of magnets at temperatures, which exceed 550°C, is examined in the works of McCaig [56, 57]. Influence on the magnets of vibrations and high temperature, which reaches 600°C was investigated by Roberts [58]. It noted that the severe vibration in the wide frequency range leads to changes in the magnetic induction of the magnets of order 1%.

The investigation of the effect of mechanical jolts, alternating magnetic fields and particular cycles for the magnetic induction of anisotropic nickel-aluminum magnets was realized by Mishimo and Makimo. Results of the tests allowed the authors to assert that the decrease of induction is proportional to the logarithm of a number of separate short-term effects on magnets [59].

For the study of the effect of temperature and external magnetic field to the stability of rod permanent magnets from the nickel-aluminum alloys Ye. A. Andreyevskiy, B. I. Blazhkevich and V.

N. Mikhaylovskiy utilized ferromagnetic probes [60, 61].

The reversible and irreversible changes in the magnetic induction with a change in the temperatures, which occur in bar magnets and magnetic systems with the magnets from the nickel-aluminum alloys, were studied by R. S. Bobrovskaya, A. M. Morozova and F. I. Feygina [62].

Dependence of intensity of magnetization on the temperature and temperature hysteresis were investigated by Ya. S. Schur, N. A. Baranova and A. S. Yermolenko [63, 64]. The special features/peculiarities of the temperature characteristics of nickel-aluminum alloys are explained to them as the result of the presence of two phases with the different Curie points and different dependences of saturization magnetization on the temperature.

Gould examined different experimental results on the stability of magnets in the time and in the presence of external agencies.

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It arrived at the conclusion that for guaranteeing the stability it is necessary to select the operating point of magnetic systems in demagnetization curve of faster higher than point $(BH)_{max}$, than it is lower. In this case it indicated that it is possible to accept the logarithmic law of a change of the magnetic induction with time for the magnets of the nickel-aluminum alloys and to somewhat extrapolate available empirical curves [65, 66].

The effect of humidity, temperature and others external agency on the permanent magnets from the single blast-furnace/single domain particles was investigated with the metallic and organic fillers. Reproducibility the measurement of magnetic induction not exceeding 0.1% [67].

Tushinskiy studied the stability of magnetic systems for the prolonged time intervals (of up to 3 years) in different partial demagnetization and presence of temperature effects. Using the mechanical magnetometer, proposed by Knight [32], that Tushinskiy showed that the stabilization by temperature cycles of -20-+60°C proves to be insufficient for the systems, which did not pass partial demagnetization. Changes of the magnetic induction with time in these systems are only two times less than in the systems, which did not obtain magnetic and temperature aging, moreover dependence induction change on the time behaves logarithmically [68, 69].

Webb [70] made the investigation of the stability of magnetic systems with the magnets from different alloys also with the aid of mechanical magnetometers [32]. Measuring the magnetic induction of magnetic systems for the time intervals on the order of 3 years, Webb confirmed the presence of the logarithmic law of the dependence of magnetic induction on the time for the systems with the magnets from the nickel-aluminum alloys and the absence in these alloys of metallurgical aging. Webb studied also the influence of external agencies on the stability of magnetic systems.

Magnetometer for the precise measurements of magnetic induction in nonuniform field, in which the Hall pickup, controlled/inspected in uniform field of electromagnet with the aid of NMR, is applied proposed by by Zingeri. Together with his colleagues, Zingeri developed also the measuring device, suitable for studying the stability of multipole magnetic systems, together with which was utilized mechanical magnetometer. In the opinion of Zingeri, an increase in reproducibility of different measuring devices is limited purely by the mechanical difficulties, connected with the guarantee of accuracy of the installation/setting up of magnetic systems in the repeated measurements. Zingeri and his colleagues studied stability in the time of magnetic systems with the magnets from different nickel-aluminum alloys, which passed partial demagnetization by alternating magnetic field to 5 and 15% during the year. The changes in the magnetic induction for these systems not exceeding several thousandths of percentage.

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The experimental results of Webb and Kronenberg, which concern the magnetic systems, which obtained the heterogeneous partial demagnetization were confirmed also by them: the magnetic induction of such systems somewhat grows/rises in time [71-74].

The analysis of the stability of magnetic materials at a high temperature was made by Pavlik [75]. The logarithmic law of a change of the magnetic induction with time in permanent magnets was confirmed by Vial [76]. Asayag studied the effect of temperature effects on the magnetic induction of magnets from the barium ferrite and the different nickel-aluminum alloys. It examines the procedure, which makes it possible to decrease the value of the temperature coefficient of magnets with the aid of the magnetic shunt. Some experimental results, which relate to the effect of mechanical jolts on the stability of permanent magnets [77], are given also by it.

Dietrich investigated high temperature effect on the nickel-aluminum magnet alloys. He noted that at high temperatures the irreversible structural changes undergo these alloys and it gave recommendation by choice of the alloys, suitable for the work at elevated temperatures. Furthermore, as a result of the detailed study of the effect of external agencies on the induction of magnetic systems with the magnets from different high-coercivity alloys, and also their stability in the time, Dietrich established that the magnetic systems are very stable in the time after strong demagnetization by alternating magnetic field [78-82].

The effect of temperature effects on the stability of permanent magnets was investigated by T. I. Bulygina, I. A. Vevyurko, K. T. Makarov and V. V. Sergeyev. The measurements of magnetic induction were made by them both by the differential induction method with the second standard magnet and with the aid of ewing permeability balance. The dependence of temperature coefficient and irreversible changes in the induction on temperature and position of operating point in demagnetization curve for the rod permanent magnets from the different alloys in very detail was studied. In this case the reasons for the reversible and irreversible changes in the magnetic induction with a change in temperature [83-86] were revealed/detected.

The logarithmic law, which expresses the dependence of the magnetic induction of permanent magnets on the time, Zaks proposes to write/record in relative values. The accepted by it proportionality factor is close to the instability coefficient, previously introduced by the author ([21] and S 3-4 of this work). Furthermore the effect of vibrations and impacts on the magnetic induction of magnets from different nickel-aluminum alloys [87] was examined by Zaks.

Sasaki Dzasiki Denki studied the dependence of the constant of magnetic viscosity on the coercive force. This constant, which is the proportionality factor, analogous to the instability coefficient ([21] mentioned above and § 3-4 of this work), was determined for the alloy of Alnico with different heat treatment and other alloys. Moreover it was shown that in certain cases the constant of magnetic viscosity does not depend on the coercive force of sample/specimen [88] being investigated.

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The analysis of the effect of the composition of nickel-aluminum alloy on the stability of magnets was made by Falenbrach. The dependence of intensity of magnetization on temperature [89] was studied by him. Schimura gives the common survey/coverage of different experimental results on the stability of permanent magnets [90].

The work of L. V. Kirenskiy, A. I. Drokin and D. A. Laptey is dedicated to temperature hysteresis of ferromagnetic materials and ferrites; in it temperature hysteresis in nickel-aluminum alloys [91] is set forth briefly also.

In the monograph of B. G. Lifshits and V. S. L'vov, some data, which relate to the stability of magnets from nickel-aluminum alloys [92], are given, whereas aging magnet alloys at temperatures of 550-700°C was in detail studied by B. G. Lifshits and L. A. Kavalerova [93].

It should be noted that under the logarithmic law it is necessary to indicate the reference point of the time intervals in question, otherwise the calculation of such temporary/time processes does not make sense [94, 120].

The difficulties, connected with the use/application of measuring devices of high sensitivity and reproducibility, in the known degree limited a quantity of the samples/specimens being investigated, that also was an overall deficiency/lack in the larger part of the experimental works on the investigation of stability. On the other hand, the magnets of one and the same alloy and even one and the same melting are sometimes heterogeneous in their properties, including in the stability. This stability depending on many factors, whose effect must be demarcated. In order to study this dependence and by the joint efforts/forces of physicists, metallographers, technologists and meters to learn to attain the highest possible stability of magnets and systems, should be ensured the accumulation of large experimental material.

In connection with that presented it is necessary to examine different methods of the study of the stability of permanent magnets and magnetic systems and to select those of them, which would allow sufficient simply and rapidly to obtain the fundamental characteristics of magnets on the stability.

1-3. Accelerated methods of the study of the stability of magnets and magnetic systems as promising path and to the resolution of the problem of stability.

One of the possible approaches for obtaining of a large quantity of experimental data, it would seem, could be the organization of the series issue of those magnetometers, which already had time to recommend well themselves, and the development of the new magnetometers of increased sensitivity and reproducibility. But fulfillment only of this program will not give satisfactory results.

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The series issue of sensitive magnetometers will require 1-2 years, their mastery/adoption and conducting of the investigations of stability will engage still several years, but the defined conclusions/outputs on the basis of the produced investigations it will be possible to make not earlier as through the time interval on the order of 3-4 years. Moreover the tests, made even with the aid of a comparatively large number of sensitive magnetometers, they will not nevertheless be actually/really mass, since for the repeated measurements of magnetic induction is necessary the installation/setting up of permanent magnets or magnetic systems on the special precision mounts/mandrels, which, in turn, are fastened in the magnetometers with the aid of the special fixatives. Of course to establish to the mounts/mandrels, prepared with the very low tolerances, is possible ten or, at best, hundreds of magnets and systems, but this it is insufficient for the more or less comprehensive investigation of the stability of magnets from the different alloys, which possess moreover, large spread along the stability.

An improvement in the sensitivity of magnetometers, if it can be carried out, will also little change the existing position, since reproducibility is determined in essence by the mechanical feature of the magnetometers, moreover mainly by the work of the fixatives mentioned above.

Furthermore, a considerable deficiency/lack in the tests of magnets and the systems, which were being carried out with the aid of the magnetometers of high sensitivity, was the fact that the complicated situation of experiment and prolonged time intervals, usual during the investigation stabilities in the time, delayed the results of tests. The conclusions obtained with the high expenditures sometimes related to already obsolete alloys and technology, obsolete.

It is clear, of course, that some investigations of the stabilities of magnets or systems, conducted with the aid of magnetometers of increased sensitivity and reproducibility best according to their indices, will have known value in the general/common/total complex of research works on the study of stability. However, since these tests for stability cannot ensure sufficiently rapid obtaining of the necessary quantity of experimental data, they must be compulsorily supplemented by more rational methods.

In principle by other means to the accumulation of experimental materials is the development of the new, accelerated methods of the study of the stability of magnets and systems, which could make it possible to comparatively simply and rapidly reveal/detect the most essential characteristics of stability.

What simplifications can be introduced into the procedure of the study of the stability of magnets and magnetic systems and into the procedure of the measurements of magnetic induction? What it is necessary to accelerate in these tests?

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First, since the measurements of magnetic induction with high sensitivity and reproducibility are nevertheless sometimes necessary for the investigation of the stability of magnets and systems, should be developed/processed such magnetometers, which combine simplicity in the rotation/access and in the adjustment with the operating speed, since in the specific cases, accelerating several times the first measurement of magnetic induction, we in so many once we accelerate entire prolonged experiment (§ 5-1).

In the second place, it is very essential to utilize the already known laws, which are determining the stability of magnets and systems in the time, and, instead of each time during the prolonged time intervals removing/taking of the curves, which express the dependence of magnetic induction on the time, to find these dependences for the short time intervals.

Thirdly, transition/junction to the direct measurement of very increments in the magnetic induction, caused by the disturbance/breakdown of stability, is the most important simplification, which can be introduced into the procedure of the study of the stability of magnets, and sometimes also magnetic systems. In this case we have be satisfied to right by considerably larger error, than when such increments are defined as a difference in two close values of induction. Special, unique equipment here no longer is required. Increments in the magnetic induction, caused by instability in the time, can be measured with the aid of the ballistic galvanometer (S 4-1).

It is comparatively easy to measure the increments in the induction, which appear because of a change in the temperature, by the photoelectronic microweber meter (S 6-1), whereas during the study of the effect of irradiation it is possible to study the behavior of magnets during the very low time interval, short-term including at different moments of time measuring windings or even one and the same winding to the different photoelectronic microweber meters or the ballistic galvanometers.

Fourthly, it is desirable, when this is possible, to replace the tests of magnetic systems by the analogous tests of magnets themselves, selecting in this case the appropriate values of the coefficients of demagnetization and taking into account the special effect on the stability of magnetic systems, which sometimes has a magnetic circuit (S 6-5).

It is possible to assume that introduction of the accelerated methods of the study of the stability of permanent magnets and magnetic systems will make possible to actually/really widely sweep research work in this region, to partially remove it into the plant laboratories and to adjust quality control of magnets and systems on the stability at the plants, which make magnets, and enterprises, their using.

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Chapter Two.

SOME METHODS OF MEASUREMENTS OF MAGNETIC INDUCTION. Subjects of investigation.

2-1. General requirements, presented to the procedure of the measurements of magnetic induction, suitable for the investigation of the stability of magnets and magnetic systems.

Developing/processing procedure and equipment for the investigation of the stability of magnets and systems, should be paid special attention to those tasks, for solving which they are intended, and from this point of view to rate/estimate their possibilities and requirements, for them presented.

As is known, for studying the stability there is no necessity to find the absolute values of magnetic induction with the high accuracy. It is possible even to measure the magnetic induction in the arbitrary units. During the determination of the relative values of the changes in the magnetic induction, caused by the instability, greater it is partly sufficiently to be limited to one, at the worst, two significant places. Furthermore, if systematic relative error remains constant for the separate series of observations interesting us, then it can have comparatively large values, since constant/invariable systematic relative error, generally speaking, does not affect the relative increments in the magnetic induction being investigated. The nonlinearity of the dependence, which connects magnetic induction and those values, by means of which it is determined, can be considered permissible when the change in the systematic relative error, caused by nonlinearity, will be by an order less than the corresponding relative value of induction change.

The study of stability during the prolonged time intervals requires the establishment of the invariability of magnetic induction or the determination of very low ones its change during the repeated installations/settings up of magnets and systems in the measuring device. Repeated measurements during the repeated installations/settings up are necessary also for studying the increments in the induction, which appear after different external agencies. Such tests possible to realize only in the presence of high sensitivity and reproducibility of measuring unit, and also comparative constancy of its systematic relative error for those examined/considered induction change.

As is known, an improvement in the sensitivity of measuring devices is usually connected with the use/application of zero differential methods of the measurements, which require the prolonged procedure of balancing. Moreover the acceleration of measurements is possible only under the previously selected conditions for mutual compensation, which is also connected with the high expenditure of time.

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If any research work wins upon the acceleration of measurements, then the study of the stability of magnets in the time to be found in this respect on the special position: here the realization of the rapid measurements of magnetic induction is extremely important. Actually/really, accelerating the first measurement of induction several times, we in so many once accelerate entire experiment (S 5-1). Thus, in similar investigations it is necessary to utilize differential methods of the measurements of the magnetic induction, which do not require complete balancing and making it possible to rate/estimate imbalance.

It should be noted that the determination of temperature coefficient no longer connected with the repeated tests and does not require good reproducibility during the repeated installation/setting up of magnets and systems, which makes it possible to apply the measuring devices, to which it cannot be used for the investigation of stability in the time. Nevertheless speed in the realization of measurements here has high value. However, the magnetometers, which possess during the repeated tests by a good sensitivity and by reproducibility, can prove to be unsuitable for determining the temperature coefficient of magnets due to the presence of high their own temperature coefficient. Furthermore, in air gap of magnetic system at temperatures of lower than zero drops out the hoarfrost, which blocks the free displacement/movement of the measuring framework.

In the present work the in detail only utilized by the author methods of the measurements of magnetic induction are set forth, and many other known methods are not examined, since the magnetometers based on them either are somewhat inconvenient in the use or have other deficiencies/lacks. For example, methods with the use/application of ferromagnetic probes [60, 61] and so-called ewing permeability balances [83-86], the developed for the investigation stabilities of rod permanent magnets with a change in the temperature, cannot be utilized for the establishment of stability during the repeated tests due to large zero drift. In the vibrating coil magnetometers it is comparatively difficult to attain the complete balancing of emf of different form in the presence of two jarring coils, located in the investigated and control magnetic field, and in this case it is not possible to rate/estimate imbalance [95]. Magnetic nuclear resonance is unsuitable for the direct measurement of magnetic induction in the heterogeneous magnetic field, and for the inspection of the pickups of Hall [71] and in the differential methods of measurements [96] introduction NMR, apparently, it does not give explicit advantages. Furthermore, applying the Hall pickups, it is necessary to consider their inherent temperature coefficient. On the other hand, it is very probable that NMR successfully it is possible to utilize during the investigation of the stability of magnets, if we apply it for the precise measurement of magnetic induction in air gap of ewing permeability balance with the well controlled uniform magnetic field.

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Are not described also mechanical magnetometers [32], which are the unbalanced weights, whose balancing is realized with the aid of a change of the current in the framework, situated in air gap of the magnetic system being investigated. One of such magnetometers with reproducibility of order 0.03% was partially used by the author of this work for the investigation of the stability of magnetic systems. However, the very high temperature coefficient of the most mechanical magnetometer did not make it possible to apply it for determining the temperature coefficient of magnets, but the need for in each measurement producing very prolonged balancing forced generally to forego the use/application of this magnetometer.

Are examined below only two of comparatively well recommended itself with the execution numerous repeated tests of differential ones of the method of the measurements of magnetic induction. Moreover one of them - electrodynamic - is null method and needs complete balancing. This method makes it possible to conduct the continuous measurements of induction in air gap of magnetic systems with the radial magnetic field. The second method (quasi-balanced induction) does not require complete balancing, gives the possibility to rate/estimate imbalance and to comparatively rapidly fulfill induction measurements both in air gap of the magnetic systems of different layout and in the rod permanent magnets.

2-2. Zero differential electrodynamic method.

This method of measuring the magnetic induction is based on the balancing of the moments/torques, created, on one hand, by astatic electrodynamic measuring mechanism and, on the other - with interaction of current within the framework with the magnetic flux of the magnetic system being investigated. Both moments/torques operate on one and the same moving element and are directed towards each other. With the equality of two moments/torques or in the absence of current the instrument is located in zero position [19]. The appearance of electrodynamic magnetometer is given in Fig. 2-1.

The electrodynamic moment/torque, created by astatic electrodynamic measuring mechanism with series connection of its mobile and fixed coils is proportional to the square of current i in the coils:

$$M_{эд} = k_1 i^2.$$

The magnetoelectric moment/torque, which appears because of interaction of current in the search coil, connected in series with the coils of electrodynamic mechanism, and magnetic flux and in air gap of magnetic system, is proportional to the product of gap density of system and current in the search coil:

$$M_{мэ} = k_2 wBi,$$

where k_1 and k_2 - constants, which depend on the construction/design of measuring unit, and w - number of turns of search coil.

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With the equality of two moments/torques, which operate on the moving element, $k_1 i^2 = k_2 wBi$, whence $B = k_3 i$. Here $k_3 = k_1/k_2 w$.

Thus, gap density of the system being investigated is proportional to current in the position of equilibrium. Measuring with compensator current, we measure the magnetic induction in the arbitrary units. Let us determine the sensitivity of this measuring installation/setting up. For this purpose at equilibrium, i.e., in the zero position, let us give to current certain increment, equal to ξi where $\xi \ll 1$, and let us find excessive turning moment ΔM, which will deflect moving element of the position of equilibrium:

$$\Delta M = k_1 (i + \xi i)^2 - k_2 wB (i + \xi i) = \\ = k_1 \xi i^2,$$

since at equilibrium $k_1 i^2 - k_2 wB = 0$, and the term ξ^2 can be disregarded/neglected.

With the small divergence from the position of equilibrium the angle of deflection α is proportional to moment/torque ΔM, or $\alpha = k_4 \Delta M$, where k_4 - coefficient determined by the properties of suspension.

Taking into account that from the condition of the equilibrium

$$i = \frac{k_2}{k_1} wB,$$

we will obtain

$$\alpha = k_4 \Delta M = k_4 k_1 \xi i^2 = k \xi w^2 B^2,$$

where

$$k = k_4 \frac{k_2^2}{k_1}.$$

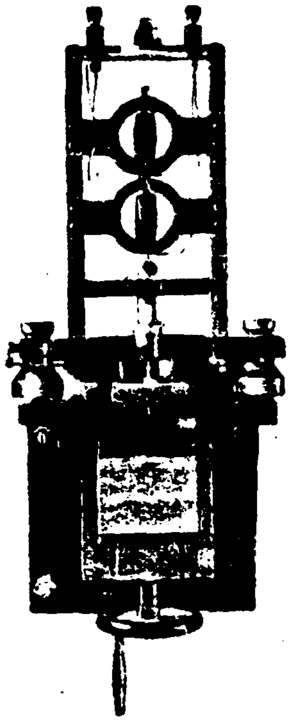

Fig. 2-1. Electrodynamic magnetometer.

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Scale value can be defined as

$$\frac{\xi 100}{\alpha}=\frac{100}{k_4 k_1 i^2}=\frac{100}{k w^2 B^2}\ \frac{\%}{\text{дел}}.$$

Consequently, scale value is inversely proportional to the square of current or to product from the square of a number of turns of the measuring framework and square of the measured magnetic induction. Thus, the evaluation/estimate of imbalance with the incomplete balancing proves to be very complicated.

An improvement in the sensitivity is limited to the fact that an increase of the number of turns w in n of times causes the need of increasing the current i also in n of times, as this follows from the condition of equilibrium. With the constant/invariable magnetic induction B magnetoelectric turning moment grows/rises in this case in n^2 times. An increase in turning moment, generally speaking, is useful, since it raises the quality of measuring device and they make it possible less to consider the possible blockage/soiling of air gap of magnetic systems. However, it is not possible to unlimitedly raise current within the measuring framework, since during the disturbance of the centering of the framework appear the forces, proportional to current, which attempt to even more increase this disturbance/breakdown of centering.

In connection with the fact that the proposed method is zero and induction measurements are made always during one and the same mutual location of the coils of the electrodynamic part of the magnetometer, which create compensating turning moment, apparently, it is possible to accept constant k_1, which characterizes the design features of this part of the instrument, constant/invariable and to disregard after the smallness the appropriate relative error. The relative error, connected with a change in the temperature, does not exceed

±0.005% during the maintenance of temperature with the accuracy ±0.2°C, since the temperature coefficient of quite electrodynamic magnetometer is close to zero, while the relative error, which occurs in the measurement of current by potentiometer; also it is approximately/exemplarily equal to ±0.005%.

It is necessary to note that the so-called mechanical error, caused by the malfunctioning of the fixatives, which must provide a strict centering and the invariability of the position of the measuring framework in air gap of the magnetic system being investigated during its repeated installation/setting up, has the prevailing value in a relative error in the electrodynamic magnetometer.

During the especially careful manufacture of mounts/mandrels and fixatives for the magnetic systems it is possible to attain comparatively good reproducibility of electrodynamic magnetometers, which reaches to 0.01-0.02% during the repeated installation/setting up of magnetic systems, and the sensitivity of order 0.05%. Similar experimental results were obtained only for the relatively wide (not less than 13 mm) measuring framework.

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Whereas with the thin core of the magnetic system with the external magnets with a diameter of 6 mm even the low disturbances of the centering of the framework were manifested so strongly which not at all could not utilize an electrodynamic magnetometer for the execution of the measurements of magnetic induction.

Comparative simplicity of the fulfillment of measurement and possibility of the continuous measurement of magnetic induction are the advantages of electrodynamic magnetometers, which makes it possible to determine the temperature coefficient of magnetic systems with a continuous change in the temperature and to investigate changes in the magnetic induction with time into the first minutes after magnetization.

To deficiencies/lacks in the electrodynamic magnetometers can be attributed, first of all, the need for the very strict centering of search coil with respect to the magnetic system being investigated, which requires the identity of systems and high class of precision during the manufacture of special mounts/mandrels and the installation/setting up on them of magnetic systems. Very essential deficiency/lack during the use of such measuring devices is comparatively low turning moment, which does not allow/assume the least blockage/soiling of air gap of system. Furthermore, electrodynamic magnetometers, generally speaking, are intended only for the investigation of systems with the radial magnetic field and cannot be used for the tests of the systems of other layouts.

In spite of the difficulties, which appear during the guarantee of a good centering of the measuring framework of electrodynamic magnetometers, four such electrodynamic magnetometers were used by the author for the execution of the number of the investigations of the stability of magnetic systems. The obtained results of tests are examined below.

2-3. Quasi-balanced differential induction method.

The differential induction method of the measurements of magnetic flux is based on the balancing of two current pulses, supplied towards each other, of which one appears in the search coil, driven out from the magnetic field being investigated, and the second - compensating impulse/momentum/pulse - it can be created with the aid of one [47, 48] or two [23] coils of mutual induction, and also in the second coil, moving in known magnetic field [55]. Ballistic galvanometer with the sufficiently large oscillatory period usually serves as the null indicator. Despite the fact that this method successfully is applied for the investigation of the stability of permanent magnets [47, 48, 50, 51], the possibility of its use for the precise measurements of magnetic flux is questioned [97, 98].

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It is completely obvious that complete compensation at any moment of time for two oppositely directed current pulses one should expect only if they begin simultaneously and are identical in form and area, i.e., when one of them is the mirror image of another. On the basis of these considerations, and also because in certain cases researchers did not succeed in counterbalancing the current pulses of different sign, shifted in the time or distinct in form, it was considered that the complete compensation for them is in principle impossible and different methods, which make it possible with certain error to assume/set such impulses/momenta/pulses were developed/processed by approximately/exemplarily equal ones by the area. Toward the approximation methods of the mutual compensation for two oppositely directed current pulses relates reducing of the maximum divergence of ballistic galvanometer to the smallest possible value or the guarantee of equality to zero divergences of a galvanometer only at the specific moment of time [97]. Sometimes it is proposed even to count the balancing of impulses/momenta/pulses, completed, if only first divergence is compensated, and then galvanometer gives essential divergence to opposite side [98]. It seems scarcely probable that, modifying in this way the character of the divergences of ballistic galvanometer, we actually/really will be able to be assured that the areas of the counterbalanced impulses/momenta/pulses are equivalent and the accuracy of measurements will be sufficient.

At the same time experimentally comparatively simply it is possible to beat itself the virtually fixed null indicator of ballistic galvanometer with current pulses [47, 48, 23] sharply the distinct in form and shifted in the time. Therefore there are no special foundations for rejecting this method. However, so that with the confidence of it both in that balanced and in the quasi-balanced mode/conditions, it was necessary to investigate expression for diverging the galvanometer, to theoretically determine conditions, with which a similar compensation was possible, and to approximately/exemplarily rate/estimate an error of measurement.

The differential equation of motion of the framework of galvanometer is written/recorded, as is known, as follows:

$$J\alpha'' + P\alpha' + W\alpha = \Psi i,$$

where J - moment of the inertia of the moving element of the galvanometer, P - the coefficient of damping, W - the specific reactionary torque, Ψ - the flux linkage of the framework of galvanometer, i - the instantaneous value of the current, flowing through the framework of galvanometer, and α, α' and α'' - the divergence of galvanometer and its time derivatives.

Applying Duhamel integral we will obtain the divergence of the galvanometer

$$\alpha(t) = q(0)\,h(t) + \int_0^t q'(x)\,h(t-x)\,dx.$$

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Here X - certain value t in the range from 0 to t; q (0) - the initial value of the charge, which passed through the galvanometer; q' (X)=i (X) - the current, flôwing through the galvanometer; h (t) - transient function.

During the aperiodic process the value of the transient function

$$h(t) = \frac{\Psi}{J(\gamma_1 - \gamma_2)}\left(e^{\gamma_1 t} - e^{\gamma_2 t}\right),$$

where

$$\gamma_1 = -\delta + \sqrt{\delta^2 - \frac{W}{J}},$$

$$\gamma_2 = -\delta - \sqrt{\delta^2 - \frac{W}{J}}$$

and

$$\delta = \frac{P}{2J}.$$

For the limiting case of aperiodic mode/conditions we will obtain

$$h(t) = \frac{\Psi}{J}\,te^{-\delta t}.$$

And in the case of the oscillating process

$$h(t) = \frac{\Psi}{J\omega'} e^{-\delta t} \sin \omega' t.$$

Here

$$\omega' = \sqrt{\frac{W}{J} - \delta^2}.$$

The counterbalancing current pulse larger is partly either the exponent [47, 48], or by difference two exponents [23] and the measured impulse/momentum/pulse usually can be approximately depicted in the form of difference two exponent. It is natural that it would be desirable record in the exponential form all current pulses, but this reduces to the transcendental equation, which it is difficult to utilize. It is expedient to produce conditional linearization, replacing separate current pulses by stepped curves or even rectangles, that it is possible to consider it completely permissible with the short pulse duration.

Let us assume that a difference in the current pulses being investigated can be represented in the form of three square pulses, which differ in the height/altitude (Fig. 2-2). For simplification in the calculation let us accept the duration of these separate pulses identical and equal to T; the height/altitude of the first of them - Q/T, the second - mQ/T and the third - nQ/T. Here Q - a quantity of electricity, m and n - some coefficients.

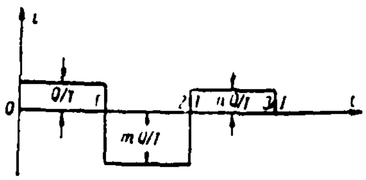

Fig. 2-2. Three rectangular current pulses, for which the condition for mutual compensation is determined.

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In this case along the axis of abscissas is plotted/deposited time t, and along the axis of ordinates current i. Solving the equation of galvanometer for the current pulses, given in Fig. 2-2, one should consider that we examine more general problem thus, namely: we obtain solution for a whole series of different cases, which have the identical form of the resulting current pulses, whereas the shape of positive and negative pulses in them can be very diverse.

For the limiting case of aperiodic process in the case of t≥3T we will obtain

$$\alpha(t) = C\left[\int_0^T (t-x)e^{-\delta(t-x)}dx - m\int_T^{2T}(t-x)e^{-\delta(t-x)}dx + n\int_{2T}^{3T}(t-x)e^{-\delta(t-x)}dx\right] = C\frac{e^{-\delta t}}{\delta^2}(\delta tA + A + B),$$

moreover here just as it is further,

$$C = \frac{\Psi Q}{JT}, \qquad (2\text{-}1)$$

whereas values for A and B sometimes will be different; in the expression

$$A = (e^{\delta T} - 1)(1 - me^{\delta T} + ne^{2\delta T}) \quad (2\text{-}2)$$

and

$$B = -\delta Te^{\delta T}[1 - m(2e^{\delta T} - 1) + ne^{\delta T}(3e^{\delta T} - 2)] \cdot \quad (2\text{-}3)$$

in question. The divergence of galvanometer with t≥3T will be equal to zero only if simultaneously A=0 and B=0. From these two equations in two unknowns we obtain the extremely simple condition for the compensation for current pulses:

$$m = 2e^{-\delta T} \quad (2\text{-}4)$$

and

$$n = e^{-2\delta T}. \quad (2\text{-}5)$$

For the triple resulting impulses/momenta/pulses, which have the different duration of separate pulses, compensation condition easily can be derived in a similar manner, but expressions for m and n will be somewhat more complicated. It is necessary to note that with the dual resulting impulse/momentum/pulse with the identical duration of the positive and negative pulses, which follow one after another, with n=0 a similar condition for compensation already does not succeed in obtaining, since, changing one the arbitrary constant m, it is not possible to ensure equality to zero for A and B. Thus, with some by the specific shape of those selected to form, duration and the mutual location of impulses/momenta/pulses, actually/really it can prove to be impossible to attain complete compensation by scaling in area of one of them.

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In the case of aperiodic mode/conditions for the current pulses, represented in Fig. 2-2, we will obtain with t≥3T

$$\alpha(t) = D\left[\int_0^T \left(e^{\gamma_1(t-x)} - e^{\gamma_2(t-x)}\right) dx - \right.$$
$$\left. - m\int_T^{2T} \left(e^{\gamma_1(t-x)} - e^{\gamma_2(t-x)}\right) dx + n\int_{2T}^{3T} \left(e^{\gamma_1(t-x)} - e^{\gamma_2(t-x)}\right) dx\right] =$$
$$= D\left(\frac{e^{\gamma_1 t}}{\gamma_1} A + \frac{e^{\gamma_2 t}}{\gamma_2} B\right),$$

where

$$D = \frac{\Psi Q}{(\gamma_1 - \gamma_2)\, TJ},$$

$$A = -\left(e^{-\gamma_1 T} - 1\right)\left(1 - me^{-\gamma_1 T} + ne^{-2\gamma_1 T}\right)$$

and

$$B = \left(e^{-\gamma_2 T} - 1\right)\left(1 - me^{-\gamma_2 T} + ne^{-2\gamma_2 T}\right).$$

As can be seen, values for A and B are here analogous in the structure to expression for A (2-2), obtained for diverging the galvanometer in the extreme case of aperiodic process. The condition for the mutual compensation for impulses/momenta/pulses will be in this case the following: A=0 and B=0. Hence we obtain $m = e^{\gamma_1 T} + e^{\gamma_2 T}$ and n= $e^{-2\delta T}$.

Let us determine the conditions for mutual compensation for the same current pulses during the oscillatory mode/conditions of galvanometer and t≥3T. The divergence of galvanometer can be recorded as

$$\alpha(t)=\frac{C}{\omega'}\left[\int_0^T e^{-\delta(t-x)}\sin\omega'(t-x)\,dx-\right.$$
$$\left.-m\int_T^{2T} e^{-\delta(t-x)}\sin\omega'(t-x)\,dx+n\int_{2T}^{3T} e^{-\delta(t-x)}\sin\omega'(t-x)\,dx\right].$$

Assuming that the period of free oscillations of galvanometer $T_0=20$ s, we will obtain angular natural frequency $\omega_0=2\pi/t_0\approx0.3$ 1/s, then $\omega'=\sqrt{\omega_0^2-\delta^2}<0{,}3$ 1/s.

Consequently, for the low ones value T≤10 of s and, correspondingly, low values X we have to right accept $\sin\omega'x\approx\omega'x$ and $\cos\omega'x\approx1$.

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As can be seen, integrals in the coefficients with sin ω't and cos ω't will take the same form under these conditions, that also in the extreme case of aperiodic mode/conditions, and we will obtain

$$\alpha(t)\approx C\frac{e^{-\delta t}}{\omega'}\left[\left(\int_0^T e^{\delta x}dx-m\int_T^{2T}e^{\delta x}dx+n\int_{2T}^{3T}e^{\delta x}dx\right)\sin\omega't-\right.$$
$$\left.-\omega'\left(\int_0^T xe^{\delta x}dx-m\int_T^{2T}xe^{\delta x}dx+n\int_{2T}^{3T}xe^{\delta x}dx\right)\cos\omega't\right]=$$
$$=C\frac{e^{-\delta t}}{\omega'\delta^2}\left[\delta A\sin\omega't+\omega'(A+B)\cos\omega't\right].$$

Here A, B and C are determined by the same expressions, as in the extreme case of aperiodic mode/conditions, i.e. (2-2) (2-3) and

(2-1). Therefore with A=0 and B=0 value for m and n they will be - (2-4) and (2-5).

Thus, we obtained the condition for the complete mutual compensation for the current pulses of opposite sign, which differ in form, for any value of time, which exceeds the duration of these pulses, and for different modes of operation of galvanometer. Moreover for the short duration of current pulses the condition for their mutual compensation, obtained during the oscillating process, is analogous with that condition for compensation, which relates to the limiting case of aperiodic mode/conditions, which has simpler expression for diverging the galvanometer. On this foundation, and also because the galvanometer of great partly works during the resistor/resistance, close to the critical, separate particular tasks will be examined subsequently for the the maximum case of aperiodic mode/conditions.

Let us find the values of coefficients $m = 2e^{-\delta T}$ and $n = e^{-2\delta T}$ at the different values of T for the current pulses (Fig. 2-2). Taking into account that in the extreme case of aperiodic mode/conditions $\delta = \omega_0$ we can accept $\delta = 2\pi/t_0 \approx 0.3$ 1/s.

Table 2-1 gives values m and n, and also systematic relative errors of measurement, obtained for one of the possible versions of the mutually compensated oppositely directed current pulses (Fig. 2-3), where the area of positive pulse is equal to 3Q, and negative -(2+m-n) Q.

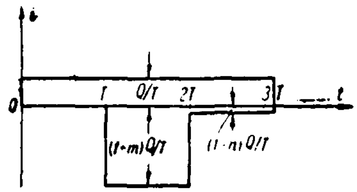

Fig. 2-3. Two current pulses, that result of which are the impulses/momenta/pulses, constructed in Fig. 2-2.

Table 2-1.

(1) T, сек	m	n	(2) Относительная погрешность, %
10^{-3}	1,9994	0,9994	0,000
10^{-2}	1,9940	0,9940	0,000
10^{-1}	1,9408	0,9418	0,03
1	1,4816	0,5488	2,2

Key: (1). s. (2). Relative error, %.

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As it was indicated above, summation of these impulses/momenta/pulses gives the resulting impulses/momenta/pulses, analogous to those represented in Fig. 2-2. Relative error in this case will be equal to:

$$\frac{3Q-(2+m-n)\,Q}{3Q}\,100\approx 33\,(1-m+n)\,\%.$$

Systematic relative error during this compensation proves to be less than 0.001% for the duration of the pulses of the order of several hundredths of second, but if the pulse duration grows/rises, then this error sharply increases.

In the presence of the shift/shear in the time and of differences in the form of positive and negative current pulses, naturally, should be expected the short-term surge of the null indicator of galvanometer in the interval $0 \leq t \leq 3T$, since condition $\alpha(t)=0$ have obtained we only for $t \geq 3T$. On this foundation it is necessary to investigate the behavior of the null indicator of galvanometer with $t \leq 3T$, that it is possible to fulfill, after constructing the curves, which express $\alpha_1(t)$, $\alpha_2(t)$ and $\alpha_3(t)$ for each of the separate current pulses, represented in Fig. 2-2, and then to obtain total curve $\alpha(t) = \alpha_1(t) + \alpha_2(t) + \alpha_3(t)$. Moreover $\alpha_1(t)$ is caused by the first, positive current pulse, by height/altitude Q/T, $\alpha_2(t)$ - by the second, negative, by height/altitude mQ/T, and $\alpha_3(t)$ - by the third, positive, by height/altitude nQ/T.

In the case of $t \geq T$ we will obtain

$$\alpha_1(t) = C\int_0^T (t-x)e^{-\delta(t-x)}dx = C\frac{e^{-\delta t}}{\delta^2}\left[(\delta t + 1)(e^{\delta T} - 1) - \delta T e^{\delta T}\right],$$

where C - (2-1).

When $t = T$ $\alpha_1(T) \approx \Psi QT/2Je^{\delta T}$,

when $t = 2T$ $\alpha_1(2T) \approx 3\Psi QT/2Je^{2\delta T}$

and when $t = 3T$ $\alpha_1(3T) \approx 5\Psi QT/2Je^{3\delta T}$.

Multiplying α_1(T) and α_1(2T) by $m = 2e^{-\delta T}$, and α_1(T) by $n = e^{-2\delta T}$ and taking into account the shift/shear in the time, we will obtain the appropriate values for α_2(t) and α_3(t).

It is most convenient to construct such dependences in relative values, after dividing α_1(t), α_2(t) and α_3(t) to the maximum divergence of galvanometer, which can occur under the influence of one positive pulse (for example, for positive pulse, represented in Fig. 2-3).

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For this impulse/momentum/pulse we will obtain the divergence of the galvanometer:

$$\alpha_0(t) = C\int_0^{3T} (t-x)\, e^{-\delta(t-x)}\, dx = C\,\frac{e^{-\delta t}}{\delta^2}(\delta t A_0 + A_0 + B_0), \qquad (2\text{-}6)$$

moreover

$$A_0 = \left(e^{3\delta T} - 1\right), \qquad (2\text{-}7)$$

$$B_0 = -3\delta T e^{3\delta T}. \qquad (2\text{-}8)$$

Equalizing $\alpha'_0(t)$ to zero, we can find the time, with which the divergence of galvanometer reaches maximum value; for the low values of T

$$t_{0m} = -\frac{B_0}{\delta A_0} = \frac{3Te^{3\delta T}}{e^{3\delta T} - 1} \approx \frac{1}{\delta}. \qquad (2\text{-}9)$$

The maximum divergence of galvanometer for one positive current pulse with a total area of 3Q and duration 3T will be

$$\alpha_0(t_{0m}) = C\frac{e^{-\delta t_{0m}}}{\delta^2}(e^{3\delta T} - 1) \approx 3{,}68\frac{\Psi Q}{J}. \qquad (2\text{-}10)$$

Table 2-2 gives relative values $\alpha_1(t)$, $\alpha_2(t)$ and $\alpha_3(t)$ in the percentages of α_0 (t_{0m}) with t equal T, 2T and 3T and different values T.

In Fig. 2-4 are constructed for $3t=10^{-3}$ s curves, which depict $\alpha_1(t)$, $\alpha_2(t)$ and $\alpha_3(t)$ percentages of $\alpha_0(t_{0m})$, and total curved $\alpha(t) = \alpha_1(t) + \alpha_2(t) + \alpha_3(t)$, being the divergence of galvanometer in the range of time from 0 to 3T. From the given curves it follows that the greatest divergence of galvanometer in this time interval proves to be equal to the significance of a deviation of galvanometer, caused by the first positive current pulse, at the moment of including the second negative pulse. Thus, $\alpha_1(T)$ can be considered as the value, which is determining short surge or simply the quivering of the indicator of galvanometer with the compensated current pulses. Since $\alpha_1(T)$ is approximately/exemplarily proportional T and the duration of the surge of this indicator is limited to time interval 3T, the low value T is one of the fundamental conditions, which ensure reaching/achievement of the practical immobility of the indicator of galvanometer.

Table 2-2.

(1) 3T, сек	$\frac{\alpha_1(T)}{\alpha_0(t_{0m})}$	$\frac{\alpha_1(2T)}{\alpha_0(t_{0m})}$	$\frac{\alpha_1(3T)}{\alpha_0(t_{0m})}$	$\frac{\alpha_2(2T)}{\alpha_0(t_{0m})}$	$\frac{\alpha_2(3T)}{\alpha_0(t_{0m})}$	$\frac{\alpha_3(3T)}{\alpha_0(t_{0m})}$
10^{-3}	0,005	0,014	0,022	−0.009	−0,027	0,005
10^{-2}	0,045	0,136	0,225	−0,09	−0,27	0,045
10^{-1}	0,44	1,31	2,17	−0,88	−2,6	0,44
1	4,06	11,03	16,7	−7,34	−20	3,3

Key: (1). s.

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It is necessary to note that with another form of investigated and compensating current pulses the relative value α(t) will be, of course, other. Increasing, for example, the areas of positive and negative pulses with the retention/preservation/maintaining of the resulting impulse/momentum/pulse, represented in Fig. 2-2, we can considerably decrease α(T).

However, similarly one should use for the estimation of error in the quasi-balanced differential induction method of the measurements of magnetic flux [23], with which excess of one of the charges (in the case of undercompensation) is determined according to the appropriate maximum divergence of galvanometer. As it will be shown below, in order to apply this quasi-balanced method, it is first of all necessary to fit form, area and moment/torque of including the compensating impulse/momentum/pulse and to attain complete compensation, i.e., the divergence of the galvanometer, equal to 0.

Let us examine the current pulses, depicted in Fig. 2-3, for which, as there was already noted,the result is the triplet impulse, given in Fig. 2-2. Let us assume that we ensured conditions (2-4) and (2-5) and as a result was obtained the divergence of galvanometer with $t \geq 3T$, equal to zero.

Let us determine the now maximum divergence of galvanometer, which will occur, if positive charge changes, moreover its new value will be equally $3\lambda Q$, where λ - certain coefficient. Such current pulses are constructed in Fig. 2-5. The increment in the positive charge, in reference to this charge, will be equally $(\lambda-1)$ and 100%.

In connection with the fact that to a change in positive charge both impulses/momenta/pulses were mutually balanced, it is possible to substantially simplify expression for diverging the galvanometer, which appears because of a change in the charge; it will take the following form:

$$\alpha_{\lambda}(t) = (\lambda - 1)\alpha_{0}(t), \qquad (2\text{-}11)$$

where $\alpha_0(t)$ - (2-6).

Hence it follows that the ratio of the maximum divergence of galvanometer for the impulses/momenta/pulses, given in Fig. 2-5, to $\alpha_0(t_{0m})$ (2-10) will be:

$$\frac{\alpha_\lambda(t_{\lambda m})}{\alpha_0(t_{0m})}100=(\lambda-1)\,100\%.$$

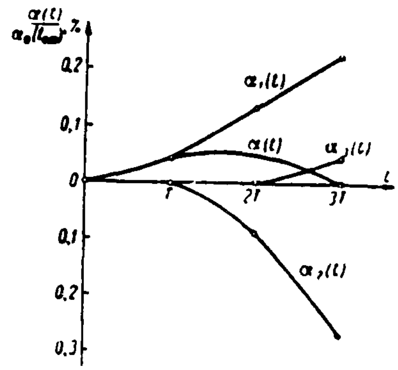

Fig. 2-4. Divergence of galvanometer for the current pulses, constructed in Fig. 2-2.

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Thus, if after reaching/achievement of the complete compensation for current pulses to change charge of one of them, appearing maximum divergence of galvanometer, as one would expect, it will be proportional to this increment in the charge.

Very desirable to also determine relative error which will appear with a change of the shift/shear with time between that measured and that counterbalancing by current pulses. A similar change of the shift/shear with time, caused by the malfunctioning of the device/equipment, which ensures the timely inclusion/connection of the compensating impulse/momentum/pulse, can carry both systematic and random character.

Let us take the same initial two current pulses (Fig. 2-3), for which conditions (2-4) are observed and (2-5) and the divergence of galvanometer with $t \geq 3T$ is equal to zero. Let us find the maximum divergence of galvanometer, caused by the bias/displacement of positive current pulse on the time interval τ relative to our previous position. Current pulses for this case are constructed in

Fig. 2-6. Here just as earlier, it is possible to use that fact that to the bias/displacement of positive pulse their mutual balancing occurred. Then the divergence of galvanometer, caused by the shift/shear of positive pulse, is defined as

$$\alpha_\tau(t) = C\left(-\int_0^\tau (t-x)e^{-\delta(t-x)}dx + \int_{3T}^{3T+\tau}(t-x)e^{-\delta(t-x)}dx\right) = \\ = C\frac{e^{-\delta t}}{\delta^2}(\delta t A_\tau + A_\tau + B_\tau). \qquad (2\text{-}12)$$

In this case

$$A_\tau = (e^{3\delta T}-1)(e^{\delta\tau}-1),$$

$$B_\tau = -3\delta T e^{3\delta T}(e^{\delta\tau}-1) - \delta\tau e^{\delta\tau}(e^{3\delta T}-1) \text{ и } C-(2-1).$$

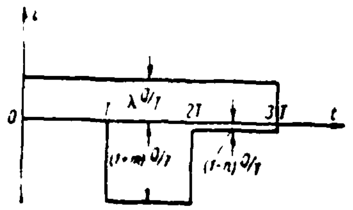

Fig. 2-5.

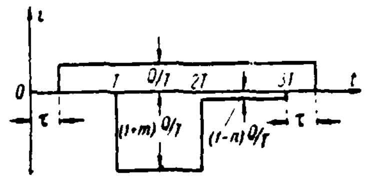

Fig. 2-6.

Fig. 2-5. Change in area of one of two preliminarily compensated impulses/momenta/pulses.

Fig. 2-6. Introduction of shift/shear to time between two preliminarily compensated impulses/momenta/pulses.

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The time, with which the divergence of galvanometer will be maximum

$$t_{\tau m} = -\frac{B_\tau}{\delta A_\tau} \approx \frac{2}{\delta},$$

and the maximum divergence of galvanometer will be respectively equally

$$\alpha_\tau(t_{\tau m}) = C\,\frac{e^{-\delta t_{\tau m}}}{\delta^3}\,(e^{3\delta T}-1)(e^{\delta\tau}-1).$$

In relative values we will have

$$\frac{\alpha_\tau(t_{\tau m})}{\alpha_0(t_{0m})}\,100 \approx 11\tau\%,$$

where $\alpha_0(t_{0m})$ — (2-10), and τ - in the seconds.

Consequently, bias/displacement of one of the current pulses on the time interval τ relative to that position, which it had during the complete compensation, will lead to the onset of the divergence of the galvanometer, whose maximum value will be proportional τ. Thus, bias/displacement of one of the current pulses, for example, on 10^{-3} s will give the same maximum divergence of galvanometer, which could occur with change in one of the counterbalanced charges to 0.011%.

It is not difficult to be convinced, in the fact that, having mutually balanced current pulses and shifting/shearing one of them from the position during the complete compensation on certain interval of time τ, we will not be able to attain complete balancing only with the aid of scaling in the area of any of them without a change in its duration. Of two balanced current pulses (Fig. 2-3), for which are observed conditions (2-4) and (2-5), let us shift positive pulse on the time interval τ and we will attempt to ensure the mutual compensation for current pulses only with the aid of scaling in the area of positive pulse. Let the new value of the height/altitude of positive pulse (Fig. 2-7) be $\lambda Q/T$.

Let us examine expression for diverging the galvanometer with

$t \geq 3T+\tau$. In this case it is possible to utilize the results, obtained for the impulses/momenta/pulses, represented in Fig. 2-5 and 2-6. Actually/really, if we take the impulses/momenta/pulses, constructed in Fig. 2-3, and will change the area of positive pulse, then we will obtain the divergence of galvanometer, equal to $\alpha_\lambda(t)$ — (2-11), and the impulses/momenta/pulses, given in Fig. 2-5. After displacing then changed positive pulse on τ, we will introduce the appropriate change in the divergence of galvanometer, which can be recorded as $\lambda\alpha_\tau(t)$, moreover $\alpha_\tau(t)$ — (2-12).

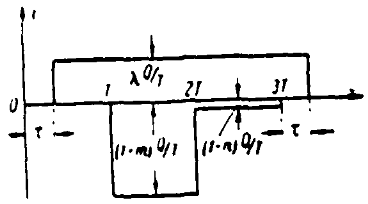

Fig. 2-7. Simultaneous introduction of the shift/shear to time and of change in the area in one of two preliminarily compensated impulses/momenta/pulses.

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Summarizing these expressions, we will obtain

$$\alpha_{\lambda\tau}(t) = \alpha_{\lambda}(t) + \lambda\alpha_{\tau}(t) = (\lambda - 1)\alpha_0(t) + \lambda\alpha_{\tau}(t) = \\ = C\frac{e^{-\delta t}}{\delta^2}(\delta t A_{\lambda\tau} + A_{\lambda\tau} + B_{\lambda\tau}). \qquad (2\text{-}13)$$

Here

$$A_{\lambda\tau} = (\lambda e^{\delta\tau} - 1)(e^{3\delta T} - 1),$$

$$B_{\lambda\tau} = -3\delta T e^{3\delta T}(\lambda e^{\delta\tau} - 1) - \lambda\delta\tau e^{\delta\tau}(e^{3\delta T} - 1) \text{ и } C - (2\text{-}1).$$

At the given values of m and n now already it is not possible to obtain the again complete compensation for current pulses only with the aid of the change λ. From condition $A_{\lambda\tau} = 0$ we will obtain $\lambda_1 = e^{-\delta\tau}$, while from $B_{\lambda\tau} = 0$ we will have

$$\lambda_2 = \frac{3Te^{3\delta T}}{e^{\delta\tau}[(3T + \tau)e^{3\delta T} - \tau]},$$

moreover $\lambda_1 \neq \lambda_2$.

Thus, systematically repeating biases/displacements of one of the current pulses from the position, selected during the complete compensation, can be always discovered, since under these conditions already it cannot be it will be mutually compensated for impulses/momenta/pulses only with the aid of scaling in area of one of them, if the pulse duration and their mutual location remain constant/invariable.

As can be seen, the divergence of galvanometer $\alpha_{\lambda\tau}(t)$ (2-13) depends both on λ and on τ. The character of the dependence in question not making it possible to determine change λ in the increment in the divergence of galvanometer, caused by this change. Analogous results it is easy to obtain, also, in the simplest case of the unbalanced current pulses, namely: for two square pulses of identical duration and different sign, shifted in the time. Consequently, the use/application of the quasi-balanced method of measurements is inadmissible when it was not preliminarily achieved/reached the complete mutual balancing of investigated and compensating for impulses/momenta/pulses.

Furthermore, on the basis of that obtained for $\alpha_{\lambda\tau}(t)$ expression (2-13) it is possible to conclude that at the smallest value of the maximum divergence of galvanometer or reducing to zero of its first divergence we will not have equalities of investigated and compensating charges and we will not be able even approximately/exemplarily to rate/estimate λ. Therefore the mentioned earlier criteria for the evaluation of the balancing of the impulses/momenta/pulses of different sign, shifted in time [97, 98], it cannot be utilized. Apparently, with the assigned form of the current pulse being investigated, i.e., for separate party/batch of the magnetic systems of the specific layout, and the selected rate of the displacement/movement of coil in the measured magnetic field it is useful to have the capability to change the shape of the compensating pulse and to find optimum, that makes it possible with the appropriate shift/shear in the time to attain the closest approach to a complete mutual compensation.

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This can be realized with the aid of two coils of mutual induction, whose primary windings with different time constants are connected in parallel, and secondary - towards each other [23]. During the short circuit of the primary windings of the coils of mutual induction on the terminals/grippers of secondary windings the impulses/momenta/pulses of emf, which are changed in the time on the exponents with the different time constants, appear. A difference in these of two exponent gives the impulse/momentum/pulse of emf, whose form can be changed over wide limits, changing the time constants of primary windings.

The use of two coils of mutual induction possesses still and the great advantage that in this case the compensating impulse/momentum/pulse does not have this distinct maximum as in one coil of mutual induction. As a result it is possible to avoid the quivering of the null indicator during the complete compensation.

Fig. 2-8 gives the schematic diagram of the magnetometer, in which two coils of mutual induction are applied. Here L, L - identical its own primary inductances; L', L' - identical its own secondary inductance; and M, M - identical mutual inductance of two coils of mutual induction; r_1 r_2 - the adjustable resistors, into which enter the resistors/resistances of the primary windings of these coils; K - key/wrench, the short-circuiting primary windings of coils; i_1 i_2 - initial values of currents in these windings, which take place in them before closing/shorting of key/wrench K; i - total operating current, $i=i_1+i_2$; r - resistor/resistance, control current; A - storage batteries/accumulators; W - measuring winding, which can be driven out from air gap of the magnetic system being investigated or be pulled off from magnet NS, and G - sufficiently inertial meter. It is most convenient to utilize as the meter the ballistic galvanometer, which has the oscillatory period considerably more than the duration of the measured pulse, whose duration does not usually exceed several hundredths of second.

Load voltage of the primary windings of the coils of mutual induction can be expressed through summed currents i and resistors/resistances r_1 and r_2.

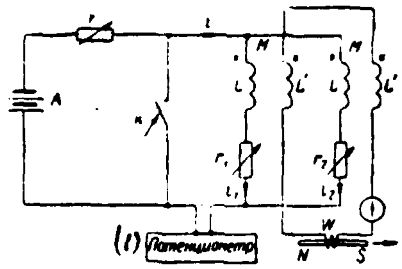

Fig. 2-8. Schematic diagram of the magnetometer, based on the quasi-balanced differential induction method.

Key: (1). Potentiometer.

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During the short circuit of key/wrench K, resistor/resistance of which can be disregarded/neglected, the transient currents in the primary windings will be equal respectively:

$$i_1'' = i\frac{r_2}{r_1+r_2}e^{-\frac{r_1}{L}t} \quad \text{and} \quad i_2'' = i\frac{r_1}{r_1+r_2}e^{-\frac{r_2}{L}t}.$$

The difference of emf, induced in secondary windings coils

$$M\left(\frac{di_1}{dt}-\frac{di_2}{dt}\right)=\frac{iMr_1r_2}{L(r_1+r_2)}\left(e^{-\frac{r_2}{L}t}-e^{-\frac{r_1}{L}t}\right),$$

if we disregard/neglect the current in secondary windings, which depends on the rate of the displacement/movement of the search coil and framework of galvanometer, actually it does not change the character of transient process and it does not completely affect the initial values interesting us of the flux linkages of mutual induction.

Difference in these initial ones value the flux linkage of mutual induction

$$\Psi_{M1} - \Psi_{M2} = Mi_1 - Mi_2 = Mi \frac{r_2 - r_1}{r_2 + r_1} = C_1 i,$$

where

$$C_1 = M \frac{r_2 - r_1}{r_2 + r_1}.$$

With the complete balancing and the fixed null indicator the flux linkage of search coil Ψ_w will be proportional to current $\Psi_w = C_1 i$. Whereas during the undercompensation, the quasi-balanced mode/conditions and with the divergence of galvanometer from the zero position on α divisions the flux linkage of search coil Ψ_w is defined as the sum

$$\Psi_w = C_1 i + C_2 \alpha.$$

Here C_2 - constant of galvanometer.

Calibration of galvanometer gives value of C_2, and the relationship/ratio, which connects C_1 and C_2, it can be obtained experimentally which will make it possible to find the measured magnetic flux according to the absolute value, if in this need is encountered. For example, during the use of the quasi-balanced method for determining the parameters of magnets or coils of mutual induction.

Examining a relative error in the magnetometer, based on the quasi-balanced method, it is possible to virtually not consider the effect of the fluctuations of temperature on the constant c_1, if we then fit the relationships/ratios between the resistors/resistances to copper also of Manganin in r_1 and r_2 so that the temperature coefficients of numerator and denominator C_1 would be identical. On the other hand, constant C_2, connected with nonlinear dependence with the divergence of galvanometer α, can introduce in the high values α the essential relative error, which reaches the hundredth of percentage. It is most convenient to select current in such a way that the significance of a deviation α would be small.

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Actually/really, with the small α nonlinearity C_2 no longer is manifested, but the measurement of magnetic induction it is possible to realize considerably more rapid.

The relative error, caused by the malfunctioning of the fixatives, which ensure the mutual location of search coil and magnet or magnetic system, in essence, determines reproducibility of the magnetometer in question. This error depends on the tolerances, accepted during the manufacture of fixatives. Can have also vital importance and the error, caused by shift/shear in the time of the moment of operation of key/wrench K. Therefore contact device must be sufficient to reliable ones. Furthermore, should be considered the error, which appears in the measurement of current i by potentiometer, the error, caused by the fluctuations of the temperature of the magnet being investigated, and also the error, connected with the difference in the form of the measured and compensating impulse/momentum/pulse. These separate components of relative error can be as systematic, constant/invariable for certain series of observations, and then them it is possible to disregard, so also random, that lead to a decrease in reproducibility.

In conclusion let us note that during the maintenance of the temperature within the limits ±0.2°C and the careful manufacture of fixatives and contact device of key/wrench K it is possible to attain reproducibility, close to 0.01% during the repeated installations/settings up of magnetic systems and order of several thousandths of percentage in the constant/invariable position of these systems.

Small/miniature, compact magnetometer (Fig. 2-9) is actually the attachment to the ballistic galvanometer, which raises its sensitivity and reproducibility ten, and sometimes even hundreds of times. Installation/setting up in the initial position and the removal/distance of search coil from the magnetic field being investigated in this magnetometer they are automated. Is provided the possibility of smooth position control of the magnet being investigated or system relative to the moving element of the instrument, and also the moment/torque of the start of key/wrench K, which is necessary for simplification in the adjustment of magnetometer, which should be produced for each party/batch of magnets or systems of the specific layout.

Fig. 2-9. The appearance of the magnetometer, based on the quasi-balanced differential induction method.

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The advantages of this magnetometer include exceptional simplicity and speed in the carrying out of measurements and in the adjustment. The use/application of the quasi-balanced method makes it possible to utilize the differential method of measurements, which sharply raises sensitivity, and to avoid in this case the prolonged procedure of balancing, complete compensation necessary for the setting. Furthermore, the magnetometer in question is suitable for measuring the induction as of bar magnets, so also magnetic systems of the different ones of construction/design with the radial or uniform magnetic field. It is clear that this installation/setting up can be used with the establishment of the stability of magnets and systems during comparatively prolonged time intervals, determination of irreversibility, and also for the determination of temperature coefficient. Very advantageous is the fact that the disturbances/breakdowns in the centering of the magnets being investigated or systems relative to the search coil, which do not cause the interfering of coil, do not block conducting measurement and is not descended reproducibility, if these disturbances/breakdowns have systematic character. However, at reduced frost points, which appears in air gap of the magnetic systems being investigated, somewhat impedes the execution of the precise measurements of magnetic induction, in particular this becomes noticeable in the case of low air gaps and temperatures of order -50°C and below.

2-4. Permanent magnets and the magnetic systems, which were undergoing investigation.

Tests for stability underwent more than 60 rod permanent magnets of square section from the following 10 alloys: ЮНД4, ЮНД8, ЮНДК24, ЮНДК24Т2, ЮНДК24А, ЮНДК25БА, ЮНДК35Т5, ЮНДК18С and ЮНДК20С. The length of magnets l was equal to 30-100 mm, and their thickness d was on the order of 10-30 mm.

For the magnets, the results of tests of which are given, ratio l/d did not exceed the limits of 2.5-3.3. Were investigated also cylindrical samples/specimens from the barium ferrites l/d=0.15-0.4.

The study of stability was conducted for 500 magnetic systems of different layout with the magnets of 13 alloys: ЮНД8, ЮНД12, ЮНДК15, ЮНДК18, ЮНДК18С, ЮНДК20, ЮНДК24, ЮНДК24Т2, ЮНДК24ТС.5, ЮНДК24А, ЮНДК25БА, ЮНДК35Т5 and АНКО1.

Fig. 2-10 gives the general view of the investigated magnetic systems, whose basic dimensions are given in Table 2-3. In this case the magnetic systems with the external magnets, and also with the inner frame magnets had different sizes/dimensions. Thus, were investigated the magnetic systems of 10 different versions. The calculation of magnetic induction in air gap of these magnetic systems does not enter into the problems, stated in the present work.

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However, in the case of necessity it easily can be made for the separate system with the magnets of specific alloy [99-101, 120]. It is at the same time necessary to note that the systems tested with magnets of one and the same alloy were somewhat heterogeneous in the magnetic induction. Moreover in systems with the magnets from the alloy ЮНДК24А this heterogeneity sometimes reached to ±20%.

For guaranteeing good reproducibility in the repeated measurements all investigated magnetic systems were fastened to the special precision mounts/mandrels, which were being made with the very low tolerances. The special fixatives, which made it possible to sufficiently accurately establish/install these systems in the measuring devices were provided also.

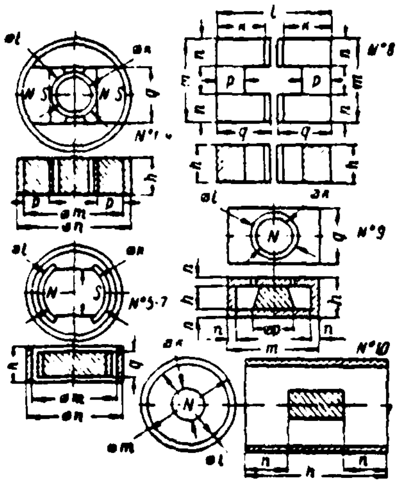

Fig. 2-10. The general view of the magnetic systems, which were undergoing investigation.

Table 2-3.

(1) Магнитная система		(2) Размеры, мм						
№	(3) Конструкция	*h*	*k*	*l*	*m*	*n*	*p*	*q*
1	(4) с внешними магнитами	40	16	20	90	110	30	30
2		30	12,8	16	82	100	28	28
3		18	12	15,6	56	68	19	22
4		19	12	15,6	62	74	22	20
5	(5) с внутрирамочными магнитами	24	13	16	19,6	28	10	12
6		12	13	16	19,6	24	10	12
7		45	34	34	39	47	24	25
8	(6) с П-образными магнитами	15	30	68	50	15	15	33
9	(7) с радиальным магнитным полем	22	12	16	48	5	21	30
10	(8) с цилиндрическим магнитом с экраном	105	- 10	44	48	40		

Key: (1). Magnetic system. (2). Sizes/dimensions, mm. (3). Construction/design. (4). with the external magnets. (5). with the inner frame magnets. (6). with the U-shaped magnets. (7). with the radial magnetic field. (8). with the cylindrical magnet with the screen.

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The magnetization of bar magnets and magnetic systems of all layouts, except systems with the U-shaped magnets, was conducted between the poles of the electromagnet of direct current. Systems with the U-shaped magnets were magnetized with the aid of pulse installation/setting up [100]. In this case the magnetizing coil, evenly distributed on these magnets, was utilized. In all cases, except those specially stipulated, the magnets and systems were magnetized before the saturation.

The partial demagnetization of magnets and systems was realized both between the poles of a-c electromagnet and with the aid of the core made of sheet steel with the winding, to which alternating current was supplied. Moreover alternating coil current of electromagnet or core was raised from 0 to the greatest value, then it was smoothly reduced again to 0. Furthermore, sometimes demagnetization was performed by magnetostatic field of opposite direction in comparison with the field during the magnetization in the locked and extended magnetic circuit (S4-4 and S5-4), and also with the aid of the special windings, wound up to magnets or magnetic circuits of systems, on which alternating current with a frequency of 0.5 and 50 Hz (S5-5 and S6-5) is passed.

Chapter Three.

TEMPORARY/TIME PROCESSES IN FERROMAGNETIC MATERIALS.

3-1. Magnetic viscosity.

Ewing first in detail investigated the changes in the magnetic induction with time in the annealed iron in the weak fields, which were sharply differing from the results of retarding eddy-current effect. He called this time lag of magnetic induction magnetic viscosity. Observing the manifestations of magnetic viscosity during the time intervals of the order of seconds, minutes and even hours, Ewing revealed/detected the influence of time delay at certain value of magnetic intensity for the manifestations of magnetic viscosity after a supplementary change in intensity/strength [102-104]. For several decades could not be repeated Ewing's experiences. However, Bozort assumed that magnetic viscosity nevertheless actually/really exists despite the fact that for it very could not observe this phenomenon [105].

In the thirties was realized the number of the investigations of magnetic viscosity [5-15, 105-110], in which with a certainty very existence of this phenomenon was established/installed, and some of its properties were also studied. The work of the author, initiated in 1931 because of the need for the substantiation of the procedure of the stabilization of permanent magnets at the Leningrad plant "electric appliance", were conducted first for the tori/Torr from thin iron wire [5-14], and then for the permanent magnets.

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In this case the manifestations of magnetic viscosity in the rod permanent magnets made of tungsten and nickel-aluminum steel [15] were for the first time discovered and investigated in 1940.

On the basis of the investigations of magnetic viscosity made by the author it was possible to arrive at the specific conclusions, which, generally speaking, did not lose their urgency up to now and they can be in the known degree used during the study of the stability of permanent magnets. Most essential of these conclusions/outputs are given below.

1. Magnetic viscosity occurs both in the weak ones and in comparatively strong fields in the case of diverse compositions and structural states of the ferromagnetic samples/specimens being investigated.

2. The manifestations of magnetic viscosity, other conditions being equal, are approximately/exemplarily proportional to differential magnetic permeability.

3. The phenomenon of magnetic viscosity possesses different qualitative characteristics at different points of fundamental curve. If in the weak fields the manifestations of magnetic viscosity to the known degree are subordinated to superposition principle, then on the steep/abrupt part of the fundamental curve they do not follow this principle and prove to be more unstable with respect to the external agencies.

4. The intensity of the manifestations of magnetic viscosity in certain cases does not depend on the value of the preceded change in the magnetic intensity.

5. Mechanical jolts, weak alternating magnetic fields, and sometimes also spark into the circuits of exciting current, introduced after a change in the magnetic field, very strongly decrease the subsequent manifestations of magnetic viscosity.

6. The phenomenon of anomalous magnetic viscosity discovered by the author, which is the peculiar result of the imposition of several consecutive processes, which take place in the time, can occur both

in soft iron and in high-coercivity nickel-aluminum steel.

Subsequently it is necessary in more detail to examine some of these conclusions/outputs, but even now it should be noted that points/items 2 and 4 were used by Telesnin in the rules of magnetic viscosity [111] formulated by it. However, introduction to one of these rules of absolute temperature and time somewhat decreased their value, since predicted it dependence of magnetic viscosity on the temperature does not always have place [112], but the dependence of the manifestations of magnetic viscosity on the time follows another law.

Becker and Daring in 1939, summing up the series/row of experimental works, they note the presence of general/common/total features in magnetic viscosity in the ferromagnetic media, mechanical aftereffect in the metals and aftereffect in the dielectrics. Under specific conditions they obtain a change of the magnetic induction with time by the proportional to the logarithm of time, applying during the calculation the equivalent diagram, which consists of the series/row of self-inductors with different time constants [37].

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Street and Uuley, utilizing the theory of mechanical aftereffect developed by Smith, they proposed in 1948 the theory of magnetic viscosity, based on the thermal activation of elementary regions [38-43]. The dependence of intensity of magnetization obtained by them on the time is expressed as follows:

$$\Delta I = ipkT \lg t + C,$$

where ΔI - change in the intensity of magnetization, caused by thermal fluctuations, i - change in the intensity of magnetization, introduced by each separate region, p - the function of the distribution of regions according to the energies of activation, k - constant of Boltzmann, T - absolute temperature, t - time, and C - constant. Despite the fact that Street and Uuley was created their theory for the high-coercivity nickel-aluminum alloys on the assumption that basic part of the process of magnetization in these alloys is realized due to the rotation of the vector magnetizations of separate regions, it turned out that this dependence of intensity of magnetization on the time occurs also for other ferromagnetic materials, for example, for soft iron in the weak magnetic fields, tested in tested in experiences Ewing's experiences [40].

To the investigation of the manifestations of magnetic viscosity in the permanent magnets from the nickel-aluminum alloys was dedicated in 1949 the experimental work of Bulgakov and Kondorskiy [113]. In this work is presented the hypothesis that the shift of the boundaries of elementary regions plays the significant role in the process of the magnetic reversal of permanent magnets, since the relaxation time of the processes of rotation, apparently, cannot be considerable.

In his monograph of Snoyek both magnetic viscosity and change of magnetic permeability with time are understood under the aftereffect. It assumes that the aftereffect can be developed in a countless quantity of different forms and can be the consequence of the very different reasons for both the trivial ones and the very complicated ones. In this case Snoyek comes to the conclusion that the effects of aftereffect are always caused by the delaying restoration/reduction of thermodynamic equilibrium, which was disrupted by the action of the external force. This restoration/reduction in the general case is realized with the aid of the process of the diffusion of substance or energy and in the ferromagnetic materials is closely related to the elastic after-effect and magnetostriction [114].

Neel examines two physical phenomena, that sometimes occurring simultaneously, call a change of the magnetic induction with time. First, reversible magnetic viscosity, connected with the diffusion of material particles and which is subordinated to superposition principle. In the second place, irreversible magnetic viscosity, which appears because of the presence of the temperature fluctuations, which facilitate the transition/junction of the boundaries between the separate regions through the potential thresholds, which block the shift of these boundaries.

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Irreversible magnetic viscosity relies on the basis of statistical processing of random processes, is not subordinated to superposition principle, comparatively little it depends on temperature and follows logarithmic law [44-46].

The investigation of the dependence of magnetic viscosity on the structural state of nickel-aluminum alloys was made by Getling. The results of experiments make it possible for it to assert that study of magnetic viscosity gives the supplementary possibilities to analyze the processes, which occur in the alloys during their heat treatment [115].

It is necessary to note that very much attention is given to magnetic viscosity in the monographs of S. V. Vonsovskiy and Ya. S. Shurao [116], S. V. Vonsovskiy [117] and R. Bozort [118], where some special properties of magnetic viscosity in the ferromagnetic materials in detail are examined.

On the basis of that presented it is possible to arrive at the conclusion that the manifestations of magnetic viscosity are caused by the temporary/time processes, which are subordinated stochastic laws. These manifestations depending on time according to the logarithmic law. Apparently, besides the shift of the boundaries between the domains, which are described by Neel, thermal fluctuations must cause the rotations delaying in the time of vector magnetizations, which were being studied in the work of Street, Smith and Uuley. It is little probable that the changes in the magnetic induction, caused by the rotation of vector magnetizations, completely would conclude for the very short time intervals. Actually/really, induction change is accompanied because of the magnetostriction by elastic after-effect, somewhat braking this change. It is possible that during the analysis of different temporary/time phenomena should be considered also magnetic interaction between the separate domains and their layouts.

As is known, the elastic after-effect, which can appear as consequence, so also reason for a change of the magnetic induction with time, is random process, follows superposition principle at the low value of total deformation and takes active part in any change in the magnetic induction. It is possible to assume that in the weak fields the temporary/time phenomena of magnetostrictive character, connected with the shift of domain walls, have the prevailing value and cause the effects of temporary/time magnetic prehistory. Thus, anomalous magnetic viscosity, examined/considered in S3-5, possibly, is explained precisely by the presence of elastic after-effect.

On the other hand, on the steep/abrupt part of the fundamental curve the avalanche-like developing process of changing the magnetic induction, connected with the rotation of vector magnetizations, somewhat shields the effect of elastic after-effect.

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The manifestations of magnetic viscosity, caused by this process, are instable with respect to the external agencies and do not depend on temporary/time magnetic prehistory. The introduction of spark to the circuit of exciting current during its disconnection makes it possible to divide these two components of magnetic viscosity, to dump unstable part and to observe the anomalous manifestations of viscosity/ductility/toughness in exactly the same way just as in weak fields [13-15].

3-2. Experimental method of separation of retarding eddy-current effect and manifestations of magnetic viscosity.

The changes of the magnetic induction with time, caused by the instability of permanent magnets, are actually the manifestations of magnetic viscosity. Therefore, investigating the stability of magnets in the time with the low time intervals (S4-1-4-4), it is completely necessary to know how to clearly demarcate retarding eddy-current effect and result of the presence of magnetic viscosity. However, as is known, the calculation of eddy-current effect for the ferromagnetic samples/specimens, which possess nonlinear characteristics, always cannot be made with a sufficient accuracy.

The proposed experimental method is based on what two temporary/time processes - eddy-current effect and manifestation of magnetic viscosity - differently depend on the previous change in the magnetic induction. Moreover retarding eddy-current effect is proportional to the preceding/previous change in the magnetic induction, but the manifestations of magnetic viscosity in certain cases on these change do not depend.

Investigating the temporary/time processes, which occur during the magnetization of ferromagnetic samples/specimens, it is possible to realize transition/junction from the maximum value of the intensity/strength of external magnetic field H_m to H=0 both directly and with the stop with certain $H' < H_m$. Then the corresponding changes in the magnetic induction will be: $B_m - B_r$ or, in the presence of stop with H': $B' - B_r$, which can be several times less $B_m - B_r$, where B_m - peak flux density, B_r - remanent induction, and B' - value of induction with H'. It is natural that the result of retarding eddy-current effect, proportional to the preceding/previous change in the induction, will depend on stop with H'. Completely it is a different matter concerning the manifestations of magnetic viscosity, which do not decrease during the introduction of stop with H', if, of course, H' is not too small.

Demonstrative test work of this method was made with the aid of the study of temporary/time processes in the toroidal core from the thin carbon-free iron wire with a diameter of 0.1 mm, isolated/insulated by shellac with coercive force H_c =750 a/m. The calculation of eddy-current effect shows that in this case it is possible to disregard eddy currents with the time intervals of the order of the hundredth fractions of a second.

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For amplifying the eddy currents the supplementary winding wound up on the toroid short with a large number of turns and a low resistor/resistance. Thus, were created conditions, to a certain degree equivalent to the intense development of eddy currents, similar to those conditions, which occur in the continuous cores.

Table 3-1 gives changes in the magnetic induction ΔB, measured

AD-A139 471 STABILITY OF PERMANENT MAGNETS(U) FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH A V MITKEVICH 06 MAR 84 FTD-ID(RS)T-1344-83

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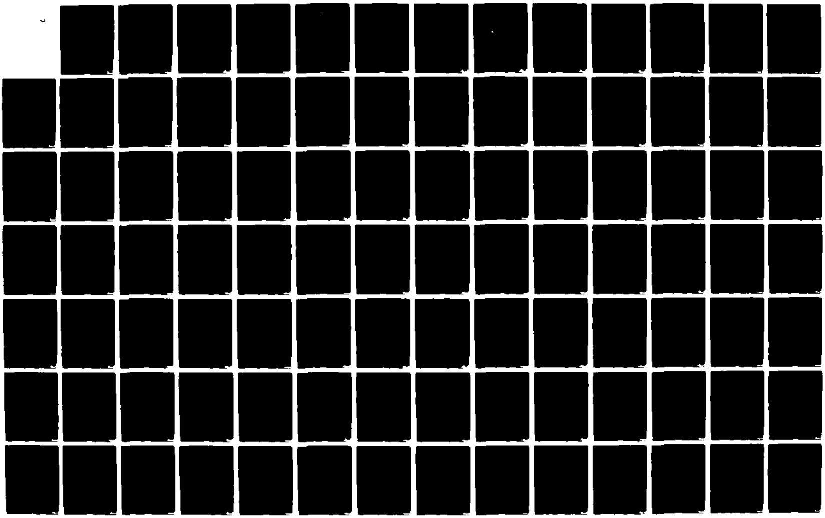

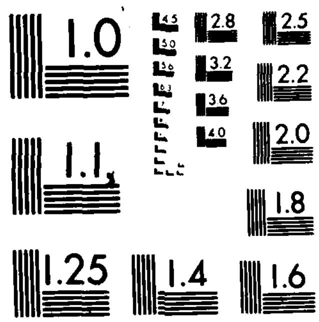

MICROCOPY RESOLUTION TEST CHART
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upon transfer to H=0 both directly from H_m, and from H'. Furthermore, are given the divergences of galvanometer α_1 and α_2 upon its automatic connection/attachment to the measuring winding, wound up around the toroid, through the time interval of the order of thousandth of a second after interrupting of magnetizing coil. The divergences of galvanometer α_1 correspond to short-circuited supplementary winding, and to α_2 in the extended supplementary winding. Values α_3 - the divergences, obtained upon the inclusion/connection of the galvanometer 10 s after interrupting of magnetizing coil. Consequently, α_1 is the result of retarding eddy-current effect in quadrature winding, to the approximately/exemplarily preceded scalings of the magnetic induction ΔB; α_2 - manifestation of magnetic viscosity with superimposed retarding eddy-current effect in the toroidal core; α_3 - manifestation of magnetic viscosity in the pure form. In all cases hysteresis cycle preliminarily passed, and time delays when $-H_m$ and $+H_m$ were always identical and equal to 5 s. In this case the disconnection of exciting current was performed automatically with the aid of the pendulum, which smoothly reduced during 0.5 s exciting current up to zero and then broken the circuit of magnetizing coil.

It should be noted that an increase of the resistor/resistance of the circuit of magnetizing coil 5 times did not completely affect the values α_3, caused by magnetic viscosity; values α_1 - results of retarding eddy-current effect - somewhat decreased, without changing in this case the character of dependence on the preceding/previous change in the magnetic induction; values α_1 changed sharply, namely: because of the more rapid drop of exciting current eddy-current effect, which was being superimposed earlier on the manifestations of magnetic viscosity, virtually disappeared, and the divergences of galvanometer α_1 no longer depended on the preceding/previous changes in the magnetic induction.

Table 3-1.

H_m	H'	ΔB	α_1	α_2	α_3
a/m		(1) mT			
1250	—	215	17,8	0,42	0,11
	625	143	11,1	0,37	0,11
	250	74	5,9	0,36	0,11
	125	37	2,9	0,35	0,11
	62	17	1,4	0,33	0,11

Key: (1). mT.

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It is clear, of course, that the effect of stop with H' on the manifestations of magnetic viscosity in the case of transition/junction to H=0 appears with the the low H'. However, as the detailed investigation, carried out for the cores from the thin iron wires or from sheet transformer steel and samples/specimens made from contemporary nickel-aluminum alloys, showed, always it is possible to fit value of H' of order $(0{,}1-0{,}2)H_m$, with which the manifestations of magnetic viscosity do not decrease with the introduction of this stop. By correspondingly, apparently, it is possible to realize a separation of eddy-current effect and manifestations of magnetic viscosity, also, at other points of hysteresis cycle.

Consequently, during the study of the stability of permanent magnets in the time, in the case of low time intervals, eddy-current effect placed on the manifestations of magnetic viscosity can be discovered because of the onset of the specific dependence of the results of observations on the value of the previous changes in the magnetic induction.

3-3. Some conditions, which facilitate the manifestation of magnetic viscosity.

During the investigation of the stability of magnets in the time immediately after magnetization should be considered the fact that sometimes this stability depends on the condition of the disconnection of current during magnetization [7]. Actually/really, during interrupting of the circuit of magnetizing coil with the spark, in this circuit appears the weak oscillatory transient process, which can under specific conditions somewhat stabilize the magnet being investigated and as a result decrease the subsequent manifestations of magnetic viscosity. The effect of this oscillatory transient process especially strongly is manifested when during the disconnection of exciting current do not receive sufficient development the eddy currents, to the known degree which screen the sample/specimen being investigated. This is possible easily to show with the aid of the study of the manifestations of magnetic viscosity in the toroidal core from the thin iron wire, analogous to the core, described above (S3-2), which makes it possible to determine the effect of different factors on magnetic viscosity.

Let us examine the case, when the magnetizing coil, wound up around this toroidal core with series-connected knife switch A, is locked to certain resistor/resistance. To the same terminals/grippers of this resistor/resistance the storage battery with series-connected knife switch D is connected. Exciting current can be brought to zero two methods: with the aid of knife switch A, i.e., by the direct interrupting of magnetizing coil, and with the aid of interrupting of knife switch D, i.e., interrupting the circuit of battery.

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During interrupting of knife switch A exciting current sharply is dropped to zero from the spark, and consequently, from the weak oscillatory transient process. Whereas in the case of interrupting the knife switch D exciting current descends to zero smoothly, moreover the effect of spark and its accompanying oscillating process here must be manifested considerably weaker.

In order to study eddy-current effect, which occur both in magnets themselves and in the magnetic circuit during the magnetization in closed magnetic circuit, was investigated the effect of closed loops, wound up on the toroidal core mentioned above, on the subsequent manifestations of magnetic viscosity with different methods of interrupting the circuit of magnetizing coil.

For simplification in the comparison of results supplementary windings virtually short only to the period of reducing of exciting current to zero. The knife switch, short the specific supplementary winding, was switched on in 1 s to reducing of current to zero, and then 1 s after interrupting of knife switch A the knife switch of quadrature winding also was broken. However, in the case of the preliminary interrupting of knife switch D two knife switches, of which one in the circuit of quadrature winding and the second - knife switch A - in the circuit of magnetizing coil were broken one second after interrupting of knife switch D. Measuring winding was connected to the galvanometer in all cases after 10 s, counting from the moment/torque of interrupting the latter/last knife switch, i.e., from the moment/torque of interrupting latter/last re-entrant winding. Therefore during interrupting of exciting current by knife switch A, when the preliminary short circuit of supplementary windings was not used, the onset accelerated on 1 s of the moment/torque of the connection/attachment of galvanometer could only increase the observed manifestations of magnetic viscosity. In all cases the transition/junction to H=0 was realized from $H_m = 2500$ a/m, and before each measurement hysteresis cycle passed. Here H_m - maximum value of the intensity/strength of external magnetic field.

The manifestations of magnetic viscosity with smooth reducing of current to zero (knife switch D) in all cases examined were equal to 140 μT. The experimental data, obtained during the disconnection of current with the spark (knife switch A), are given below:

(1)Число витков короткозамкнутой обмотки	0	4	5	6	10	20	165
(2)[redacted]ние магнитной вязкости, ...	5	8	30—125	129	131	134	139

Key: (1). Number of turns of quadrature winding. (2). Manifestation of magnetic viscosity, μT.

The fact calls attention to itself that with 5 closed loops (case A) the observed divergences of galvanometer had very unstable character and clearly they depended on the most insignificant, purely random differences in the rate of interrupting knife switch A.

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A similar instability was considerably weaker expressed with a smaller number of closed loops and virtually did not have place, beginning from 6 turns even more.

It should be noted that if during interrupting of knife switch A the supplementary winding with the greatest number of turns remained entire time of that locked, value the manifestation of magnetic viscosity proved to be by the same as during interrupting of the circuit of supplementary winding in 10 s to the measurements. For this comparison the time was counted off from the moment/torque of interrupting the knife switch A. Since the effect of magnetic viscosity/ductility/toughness quantitatively did not change due to the introduction of quadrature winding on 10 s, which preceded to the observation of magnetic viscosity, and to the period of measurement, then it is possible to assume that magnetic viscosity in effect is not found in the direct dependence on the greater or smaller intensity of the eddy currents, which can arise during very changes in the magnetic induction, caused by magnetic viscosity. Thus, magnetic viscosity must not directly depend on the thickness of test specimens, if in this case optimum conditions for the manifestations of magnetic viscosity (for example, transition/junction to H=0 it is conducted with the aid of knife switch D) are provided. At the same time with the sharp interrupting of exciting current with the spark and the onset of oscillatory transient process the subsequent manifestations of magnetic viscosity will already depend on the intensity of eddy currents and thickness of sample/specimen.

The effect of spark in the circuit of magnetizing coil during the disconnection of current on the stability in the time of bar magnets from some alloys can be easily discovered during the magnetization of these magnets in the extended magnetic circuit in the solenoidal coil. In this case this stabilizing effect of spark can be excluded not only with the aid of closed loops, but also by the introduction of supplementary stop with certain H', considerably smaller H_m, upon transfer from H_m to H=0. It is natural that with comparatively low H' will be substantially reduced intensity of transient process, but itself stop with H' does not affect the manifestations of magnetic viscosity with H=0 (S3-2). Hence it is possible to draw the conclusion that in certain cases the stop with H' during the transition/junction from $+H_m$ to H=0 can not only not decrease, but on the contrary, to increase several times the subsequent manifestations of magnetic viscosity with H=0, as it takes place in magnets from the alloy ЮНДК24А (Table 4-1).

3-4. Universal straight/direct instabilities, instability coefficient.

On the basis of large experimental material it is possible to consider it established/installed that in the absence of the external action of magnetic induction in the permanent magnets from the contemporary alloys because of the presence of magnetic viscosity varies in proproportion to the logarithm of time for the time intervals from seconds to several years.

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Therefore the characteristics, which express the dependence of increments in the magnetic induction on the time, with the logarithmic scale are straight lines. Further it will be shown that the equations of such characteristics must be written/recorded in relative values.

As is known, immediately after magnetic perturbation, for example, of magnetization, the passage of particular cycle and so forth occurs a comparatively very rapid fundamental change of the induction with time, usually accompanied by eddy currents and the following to their, special laws. At first this rapid change in the induction completely shields the manifestations of magnetic viscosity. Then, somewhat later, can be revealed/detected them, when a fundamental change in the induction already concludes. The logarithmic law, which these manifestations of viscosity/ductility/toughness follow, was obtained both theoretical and experimentally when the calculated off magnetic perturbation time $t>0$. Moreover this time is sufficiently great so that it would be possible to count the fundamental process of induction change that by more or less completed. Consequently, we have right to determine with the aid of the logarithmic law of an increment in the induction, caused by magnetic viscosity, only for such time intervals, which begin from the specific, sufficiently high value of time. It is most convenient to find these increments in the induction relative to one and the same moment of time and, which can have any value, which satisfies the requirements mentioned above. Let us na e/call t_1 basal time. Let us designate through B_1 the value of magn ic induction at the moment of time t_1, and B_t - its value with cert t. Then it is possible to write:

$$B_1 = A + C\lg t_1 \text{ and } B_t = A + C\lg t,$$

where A and C do not depend on t.

Hence it is possible to obtain an increment in the magnetic induction for the time interval $t-t_1$

$$\Delta B = B_t - B_1 = C\lg\frac{t}{t_1}.$$

In order to characterize the intensity of temporary/time processes, it is expedient to determine the relative values of increments in the magnetic induction in the percentages of the initial value of induction B_1. In this case we will obtain

$$\frac{B_t - B_1}{B_1}100 = \frac{C}{B_1}100\lg\frac{t}{t_1} = \eta\lg\frac{t}{t_1}\ \%,$$

if we designate C/B_1 100 through η, which let us name/call instability coefficient.

As a result we will have the following equation:

$$\frac{\Delta B}{B_1} 100 = \eta \lg \frac{t}{t_1} \%. \qquad (3.1)$$

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Plotting/depositing along the axis of ordinates $\Delta B/B_1$ 100 in the percentages, and along the axis of abscissas lg t/t_1, we will obtain the straight lines, which characterize the instability of the magnets, which therefore should be named/called the straight lines of instability. The inclination/slope of these straight lines is determined by the instability coefficient η, which are an increment in the magnetic induction in the percentages for the time interval from t_1 to $10t_1$, moreover $\eta>0$ with the increase of magnetic induction in the time and $\eta<0$ with its decrease. It is natural that should be accepted the instability coefficient η as criterion for the evaluation/estimate of permanent magnets and magnetic systems according to the stability in the time. However, for the clarity it is possible to use also the straight lines of instability.

The universality of such straight lines of instability, constructed in relative values, attention is drawn to. After determining instability coefficient η for comparatively small time intervals, the order of seconds and minutes, it is possible to utilize the constructed straight lines for other, considerably wide intervals of time - days, months, years. For this should be only accepted for the basal time t_1 certain another value, which can be into ten, hundred and are even thousands of times more than the initial value of t_1, for which the straight line of instability was constructed. The fact that the instability coefficient η depends on B_1 and, it would seem, changing t_1 we let us change and η, does not have vital importance. Actually/really, replacing the basal time t_1 by the new basal period $10^4 t_1$, we will change the magnetic induction B_1 in all by several percentages, since for the magnets from the contemporary alloys under the normal conditions η does not exceed the tenths of percentage. It is obvious that since for the construction of the universal straight/direct instability, suitable virtually for any time intervals in the range from the seconds to several years, it suffices to obtain the pair of points for the relatively short time intervals, to the known degree the need for the systematic endurance tests of permanent magnets and magnetic systems for the stability in the time is eliminated.

3-5. Normal and anomalous magnetic viscosity at different points of hysteresis cycle.

In connection with the fact that the manifestations of magnetic viscosity cause the disturbance/breakdown of the stability of permanent magnets, it is useful to know how to rate/estimate the effect of differential magnetic permeability and magnetic temporary/time prehistory on magnetic viscosity.

The dependence of the instability coefficient η, which characterizes the intensity of the manifestations of magnetic viscosity (S3-4), on differential magnetic permeability μ_d at different points of normal magnetization curve comparatively simply succeeds in investigating for the same tori/Torr, the results of tests of which are given in S3-2 and 3-3.

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In all cases preliminarily several times passed hysteresis cycle, then 0.25 s after setting of the maximum positive value of magnetic intensity $+H_m$ to the specific time interval to the measuring winding ballistic galvanometer was connected and on the basis of obtained experimental data the instability coefficient was calculated. In this case it was discovered, that in the weak fields of the manifestation of magnetic viscosity when $+H_m$ they depend on time delay T_1 when $-H_m$. For example, changing T_1 from 0.25 to 30 s, we increase the divergences of galvanometer with $+H_m = 0{,}2$ A/cm approximately/exemplarily two times, whereas on the steep/abrupt part the fundamental curved effect T_1 already became little noticeable.

In Fig. 3-1 along the axis of abscissas is plotted/deposited magnetic intensity H, and along the axis of ordinates the magnetic induction B, differential magnetic permeability μ_d and coefficient of instability η, moreover η' is the instability coefficient, calculated for T_1=0.25 s, and η'' - for T_1=30 s. From the given curves it follows that in comparatively strong fields the curves η' and η'' for the selected scale approximately/exemplarily coincide with curve μ_d, and under these conditions it is possible to consider that the instability coefficient η is proportional to differential magnetic permeability μ_d. It is necessary to note that in the weak fields the dependence η on μ_d has more complicated character. Being subordinated to superposition principle, the manifestations of magnetic viscosity when $+H_m$ depend on time delay T_1, i.e., from that, how strongly temporary/time process when $-H_m$. moved. In connection with this the curves for η' and η'' diverge, since $\eta'<\eta''$.

Analogous curves were obtained for the magnets from the nickel-aluminum alloys. However, in permanent magnets the effect of temporary/time magnetic prehistory, namely: the effect of time delay when $-H_m$ on the manifestations of magnetic viscosity when $+H_m$ is manifested considerably less than in toroids from the annealed iron wire.

It is possible to show that from the time delay T_1 when $-H_m$ the manifestations of magnetic viscosity in entire section of hysteresis cycle depend on $+H_m$ to H=0, if, of course, time delay T_2, when $+H_m$ is sufficiently low. In Fig. 3-2-3-6 are constructed the hysteresis cycles, on which they are depicted on the increased scale of a change of the magnetic induction in time 1-1' and 2-2' at points $-H_m$ and $+H_m$.

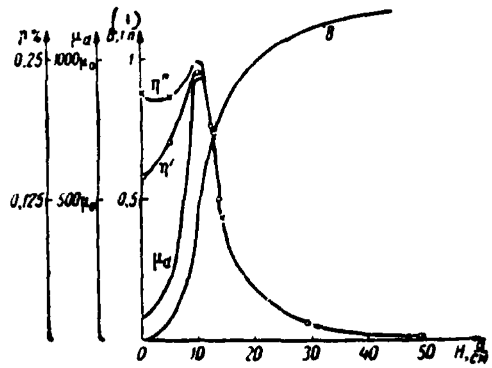

Fig. 3-1. Dependence of instability coefficient on the differential magnetic permeability.

Key: (1). B, T.

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Furthermore, in these figures are indicated those changes in the inductions with time, which can occur with certain $H' < H_m$ — 3-3', and when H=0 - 4-4'.

With $T_1<T_2$ (Fig. 3-2), magnetic induction first rapidly drops in the section of hysteresis cycle 3-2, and then the manifestations of magnetic viscosity of the same sign are observed and induction decreases in the time, section/segment 3-3'.

On the other hand, with $T_1>T_2$ will occur the rapid drop of induction in section 2-3 (Fig. 3-3), which a comparatively slow increase of induction in the time (section 3-3') now already follows. In order to isolate the manifestations of magnetic viscosity, which have opposite sign in comparison with the preceding/previous changes in the induction, by the author it was proposed to call their anomalous. Under the same conditions ($T_1>T_2$) it is possible to obtain the increase of induction in the time and with H=0 (Fig. 3-4, section 4-4').

Is obvious that with the aid of the appropriate selection T_1 and T_2 it is possible to achieve conditions for observing the unstable equilibrium with certain H', i.e., more or less to compensate for effect T_1 and T_2. In this case it is possible to observe the very peculiar manifestations of magnetic viscosity. After the rapid fundamental drop of magnetic induction in the section curved 2-3 (Fig. 3-5) we will have first normal manifestations of magnetic viscosity (section 3-3') and induction will slowly drop in the time, after which the predominance of the anomalous manifestations of viscosity/ductility/toughness will be begun and induction will begin to grow (section 3'-3"). The relationship/ratio of sections/segments 3-3' and 3'-3", i.e., the relationship/ratio between the intensity of the normal and anomalous manifestations of magnetic viscosity, very simply yields to adjustment by the appropriate change in values T_1 and T_2.

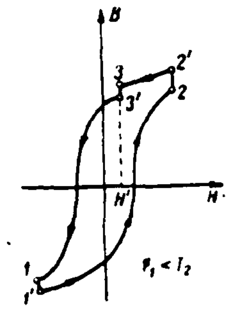

Fig. 3-2.

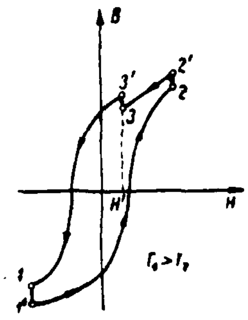

Fig. 3-3.

Fig. 3-2. Normal manifestations of magnetic viscosity with $T_1<T_2$.

Fig. 3-3. Anomalous manifestations of magnetic viscosity with $T_1>T_2$.

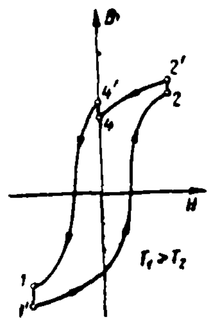

Fig. 3-4. Anomalous manifestations of magnetic viscosity with $T_1>T_2$ and $H=0$.

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It was possible to directly observe manifestations examined above of anomalous magnetic viscosity in the torus/Torr from the annealed iron wire in entire section of hysteresis cycle from $+H_m$ to H=0 in the weak fields. Upon transfer to the steep/abrupt part of the fundamental curve such observations could be realized only on the small part of AC of section AD of hysteresis cycle (Fig. 3-6). On this figure are schematically depicted those manifestations of magnetic viscosity, which could be directly revealed/detected under the condition $T_1<T_2$. In bar magnets made of nickel-aluminum steel the anomalous manifestations of viscosity/ductility/toughness it was possible to directly observe in the weak fields so - only in certain section AC (Fig. 3-6). However, in the case of comparatively large value H_m almost at each point of section AD can be established/installed the presence of anomalous magnetic viscosity. For example, it is possible to determine sign the manifestation of magnetic viscosity with H' at point 3 (Fig. 3-2-3-3) by indirect method, in the value the manifestation of viscosity/ductility/toughness with H=0, if transition/junction from $+H_m$ to H=0 is realized with the stop at point H', at we which change time delay. Furthermore, anomalous magnetic viscosity easily can be revealed/detected with H=0, i.e., at point 4 (Fig. 3-4). It proves to be that in the case of the tori/Torr mentioned above from the thin iron wire, the spark in the circuit of magnetizing coil during interrupting of current (S3-3) changes the general character of physical process, and instead of the very intense normal

manifestations of magnetic viscosity at point 4 it is possible to observe because of the spark into dozens of times less in the value of a change of the magnetic induction with time, which depending on values T_1 and T_2 can have both normal and anomalous character [15].

As it was indicated above, here we deal concerning two categories of viscosities/ductilities/toughness, which can be divided with the aid of the oscillating process, caused by the spark, which appears during the disconnection of current. It is possible to assume that on the effect of magnetic viscosity, subordinated to superposition principle, which occurs in the weak fields, the intense, but unstable with respect to the spark manifestations of magnetic viscosity, which have normal character, are placed upon transfer to the stronger fields.

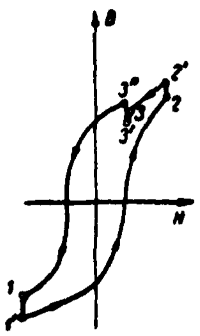

Fig. 3-5.

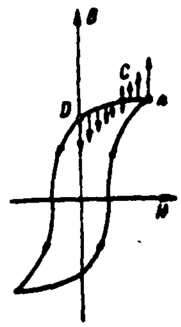

Fig. 3-6.

Fig. 3-5. Manifestations of magnetic viscosity, which have first normal, and then anomalous character.

Fig. 3-6. Character of the manifestations of magnetic viscosity, observed at comparatively large value

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Chapter Four.

STABILITY OF PERMANENT MAGNETS IN TIME.

4-1. Accelerated method of the study of the stability of magnets in the time, based on the measurement of increments in the magnetic induction.

As is known, the study of the stability of permanent magnets in the time usually was conducted during the prolonged time intervals with the aid of the repeated measurements of magnetic induction. In this case it was necessary to impose on measuring devices very high requirements, that did not make it possible in a sufficient measure to develop such investigations.

The proposed accelerated method gives the possibility to extremely rapidly determine the time characteristics of permanent magnets. It is based on the measurement of a very increment in the magnetic induction for a comparatively short time interval. The obtained result makes it possible to calculate instability coefficient and to construct the universal straight line of instability (S3-4).

Most simply such increments in the magnetic induction can be investigated with the aid of the ballistic galvanometer. However, one must take into account that the use of a ballistic galvanometer for the quantitative determination of changes of the magnetic induction with time is admissible only if the time, during which the measurement is made, is considerably less than the period of the natural oscillations of galvanometer. Otherwise only the possible qualitative investigation of temporary/time phenomena. Furthermore, in connection with the fact that the constant of ballistic galvanometer decreases with a circuit break, should be, turning off/disconnecting galvanometer, closed it to the resistor/resistance, equal to the resistor/resistance of measuring winding. To apply for such measurements photoelectronic microweber meters is less convenient in connection with the zero drift of these instruments.

Investigating the stability of magnets in the time with the low time intervals, it is necessary to divide the manifestations of magnetic viscosity in the permanent magnet and retarding eddy-current effect, which can occur both in the magnet itself and in magnet core, if magnets test in closed magnetic circuit. This can be easily made with the aid of experimental method examined above (S3-2). Furthermore, should be considered the manifestations of magnetic viscosity in magnet core, which can be rated/estimated, if to remove permanent magnet and to ensure the same value of magnetic intensity, which was in it during the investigation of magnet in this core.

Task is simplified, when the study of stability in the time is conducted immediately after the magnetization of magnet, i.e., at the operating point in demagnetization curve.

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Under these conditions it suffices to only rapidly remove permanent magnet from the field of electromagnet and to establish it in the measuring winding, connected to the specific time interval to the ballistic galvanometer. Comparatively simple proves to be the investigation of the stability of magnets in the time with remanent induction B_r and the intensity/strength of the external magnetic field H=0. Here just as in the preceding case, is eliminated the need for supporting a strict constancy of exciting current.

Universal straight/direct instabilities (S3-4) for bar magnet from the alloy ЮНДК24 of the square section with a length of l=60 mm and with a thickness of d=24 mm are represented in Fig. 4-1. Along the axis of ordinates are plotted/deposited the relative values of increments in the magnetic induction - $\Delta B/B_1$ in the percentages, while along the axis of abscissas - lg t/t_1, where B_1 the value of magnetic induction when t_1 - basal time, t - time, and ΔB - increment in the magnetic induction in the interval of time $t-t_1$. Straight line a corresponds to the decrease of magnetic induction in the time immediately after magnetization and removal/distance of permanent magnet from the field of electromagnet, i.e., to operating point on the back of hysteresis cycle; at this point instability coefficient η=-0.18%. The straight line b corresponds to the decrease of magnetic induction upon transfer from the intensity/strength of external magnetic field H_m to H=0 in closed magnetic circuit; instability coefficient here already is considerably less: η=-0.02%. Special examination/inspection showed that in this case the manifestations of magnetic viscosity in magnet core are comparatively low and them can be disregarded/neglected.

On the straight line a are shown increments in the magnetic induction, which correspond to the value of basal time t_1=1 s and to the time interval of 2 s, which can be measured, including on this time interval ballistic galvanometer at the different moments of time t, for example, t=2 s and t=4 s. As can be seen, for the construction of the universal straight lines of instability and determination η it suffices to take only the one measurement of an increment in the magnetic induction, moreover for the checking it is sometimes useful to repeat such measurements. So it is possible to investigate the manifestations of magnetic viscosity at different points of hysteresis cycle and to obtain the confirmation of the logarithmic law of the dependence of magnetic induction on the time under the varied conditions.

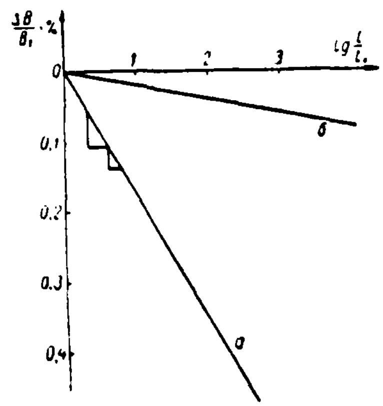

Fig. 4-1. Universal straight/direct instabilities for bar magnet from the alloy ЮНДК24.

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In preceding/previous works [12, 15] the author noted, that the manifestations of magnetic viscosity, other conditions being equal, will be greater, the greater the differential magnetic permeability. As can be seen from Fig. 4-1, this dependence remains valid and in this case. Actually/really, with the remanent induction the coefficient η is approximately/exemplarily 9 times less than after magnetization and removal/distance of magnet from the field of electromagnet, i.e., upon transfer into the operating point on the back of hysteresis cycle, which lies/rests comparatively low.

By the same accelerated method it was possible to investigate stability in the time and in some magnetic systems, whose construction/design made it possible to arrange the necessary measuring windings with a large number of turns. Straight/direct instabilities obtained in this way were analogous to the straight lines, taken with the aid of the special magnetometers, which made it possible measure the magnetic induction in air gap of these systems with high sensitivity and reproducibility.

Thus, with the aid of the proposed accelerated method of the study of the stability of permanent magnets, based on the measurement of very increments in the magnetic induction, it is possible to study stability in the time of permanent magnets, and sometimes also magnetic systems.

4-2. Stability of magnets in the time at the different points of demagnetization curve.

Stability in the time of rod permanent magnets of three different alloys was investigated with the aid of accelerated of method (§4-1) with remanent induction B_r in closed magnetic circuit and at the operating point in demagnetization curve in the extended magnetic circuit. Determining instability coefficient at these points, we obtain the extreme values of instability coefficient for this section of hysteresis cycle. For the intermediate points values

η will lie/rest, as it is possible to assume/set on the basis of the results of experiments conducted, in the limits of this range. For the magnetic systems with the magnets from the alloys being investigated and the operating points of systems, which lie in the section of hysteresis cycle in question, the instability coefficients will also lie/rest at this interval.

As the results of the made special investigation (S3-2) for the time intervals of order 5-20 s showed, by eddy-current effect under the working conditions for this already it was possible to disregard/neglect just as the manifestations of magnetic viscosity in magnet core.

20 Rod permanent magnets were subjected to investigation. From them 11 magnets with the length of l=50 mm and the thickness of 15 mm were from the alloy ЮНД12, 4 - from the alloy ЮНДК24А and 5 - from the alloy ЮНДК24. Length and thickness of magnets from the alloys ЮНДК24 and ЮНДК24А varied within the limits: l=(50-75) mm and d=(20-30) mm in the ratio l/d=2.5.

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Tests underwent several cylindrical magnets of different sizes/dimensions of the barium ferrite. Demagnetization curve for these alloys and exemplary/approximate position of operating points are given in Fig. 4-2, and 4-3 average/mean universal straight/direct instabilities are constructed for them. Here t - time, which passed after transition/junction to B_r or to the operating point in demagnetization curve, moreover this time was counted off from the cutoff of exciting current or from the moment/torque of the removal/distance of magnet from the electromagnet and, therefore, transition/junction into the operating point.

Vertical sections/segments on the average/mean straight lines of instability show the spread of these straight lines for this alloy. Dotted line constructed average/mean straight/direct instabilities for the case of transition/junction to B_r, and by solid lines - average/mean straight/direct instabilities, obtained at the operating point. The very low value of the instability coefficient, determined for the magnets from the alloy ЮНДК24А in closed magnetic circuit when B_r, makes it possible with the confidence to assert that under these conditions the effect of the core of powerful/thick electromagnet on the temporary/time processes being investigated in the permanent magnets actually/really can be disregarded/neglected.

As can be seen from Fig. 4-3, in bar magnets from the alloy ЮНД12 the instability coefficient η has approximately/exemplarily identical values when B_r and at the operating point in demagnetization curve.

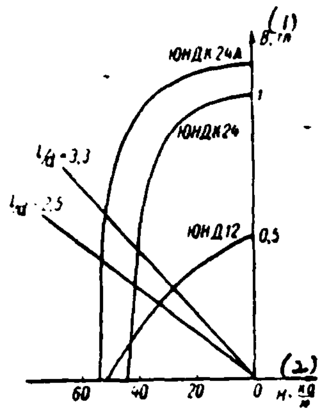

Fig. 4-2.

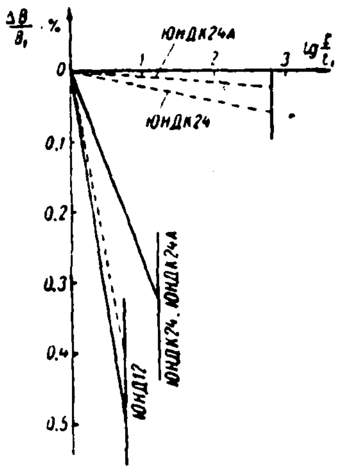

Fig. 4-3.

Fig. 4-2. Demagnetization curve for the alloys ЮНД12, ЮНДК24 and ЮНДК24А.

Key: (1). T. (2). H, kA/m.

Fig. 4-3. Average/mean universal straight/direct instabilities for bar magnets from different alloys.

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This could be expected, since alloy ЮНДК12 possesses relative to the flat demagnetizing part of the hysteresis cycle and with comparatively close values of differential magnetic permeability at these points, and the manifestations of magnetic viscosity, other conditions being equal, are proportional to the differential magnetic permeability (S3-5). However, instability coefficients in magnets from the alloys ЮНДК24 and ЮНДК24А very strongly depend on that, it is determined η when B_r or at the operating point of demagnetization curve. Especially sharply this difference is expressed in magnets from the alloy ЮНДК24А. In some of them η when B_r has negligibly low value, order -0.005%. Taking into account, that demagnetization curve in these alloys has almost rectangular form, it seems natural that in terms of the absolute value η when B_r considerably less than at the operating point.

The relationships/ratios, obtained for the values of instability coefficients at the operating points of the back of hysteresis cycle in magnets from the alloy ЮНДК12 and the magnets from the alloys ЮНДК24 and ЮНДК24А, are confirmed by the results of the tests of the magnetic systems, obtained with the aid of the electrodynamic magnetometer (Fig. 5-1, 5-2).

In connection with the fact that sometimes can be used the magnets or the systems, magnetized not before the saturation, stability in the time at the operating point in demagnetization curve was investigated for the magnets so magnetized, that the values of magnetic induction at the operating point of demagnetization curve were 2-3 times less than in the magnets, magnetized before the saturation. In this case was not discovered especially noticeable changes in the instability coefficient.

Furthermore, was studied the stability of magnets in the time at the extreme points of the particular cycles, which the magnet is passed about B_r or about the operating point. In this case it is necessary to note the sharp decrease of instability coefficient in the absolute value with the repeated passages of these particular cycles. The greatest decrease occurred after the first cycles, and then the effect of such effects gradually became increasingly less and less perceived, moreover after several particular cycles instability coefficient sometimes decreased even 10 times. The effect of these repeated effects by weak external magnetic field affects very strongly value η, whereas between the changes in the magnetic induction, caused by the first particular cycle and by the tenth, difference is negligibly low. It is very probable, that having approximately/exemplarily the same value of magnetic induction through several particular cycles, that also after the first cycle, we pass to energetically the steadier state of magnet, which decreases the intensity of temporary/time processes.

The investigation of the stability of cylindrical samples/specimens from the anisotropic and isotropic barium ferrite did not make it possible with a sufficient accuracy to determine their instability coefficient in connection with its smallness. It was possible to only approximately/exemplarily rate/estimate the order of this coefficient. As showed experimental data, $|\eta|<0.01\%$.

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4-3. Stability of magnets in the time at different temperature.

The investigation of the dependence of the manifestations of magnetic viscosity in the permanent magnets from the different alloys on the temperature represents as certain theoretical, so also purely practical interest. Actually/really, permanent magnets sometimes are applied at strongly reduced temperatures, moreover it is necessary to ensure their high stability in the time under these conditions.

Are given below the results of the investigation of stability in the time, carried out for 18 rod permanent magnets of 8 different alloys by the accelerated method (S4-1). Increments in the magnetic induction, caused by instability, were determined under the identical temporary/time conditions for the temperatures +20°C and -180°C.

In spite of the preferability of the magnetization of bar magnets in the uniform magnetic field in closed magnetic circuit of electromagnet with the subsequent removal/distance of magnets from the electromagnet, in this case it was necessary from this to refuse, since with the realization of this magnetization it is difficult to keep the temperature of magnets during their strong cooling constant. It is natural that, magnetizing magnets in the extended magnetic circuit, we actually magnetize them into a somewhat heterogeneous magnetic field due to the back induction of the ends/leads of the magnet. However, if the comparison of the manifestations of magnetic viscosity, which occur with different temperatures and under other equal conditions, interests us in essence, then we are forced to be satisfied by magnetization in the broken circuit.

The measurement of increments in the magnetic induction was performed with the aid of the measuring winding put on to the magnet, which was connected to the ballistic galvanometer on 2 s, 2 s after the disconnection of current in magnetizing coil, along axis of which permanent magnet was arranged/located. The separation of the manifestations of magnetic viscosity and retarding eddy-current effect was conducted by the experimental method (S3-2). The disconnection of exciting current was realized as directly with the aid of interrupting of knife switch in the circuit of magnetizing coil and transition/junction from H_m to H=0 (where H_m - maximum value of the intensity/strength of external magnetic field), so also with the stop on 2 s at certain value of external magnetic field and the subsequent final disconnection of the current of magnetizing coil. This checking showed that for the time intervals of order 2 s we measure the pure/clean manifestations of magnetic viscosity. Subsequently for simplicity the degaussing field of magnets will not be considered, and under H=0 will be implied equal to zero external magnetic field with switched-off exciting current.

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During the tests it was discovered, that in magnets from some alloys of the manifestation of magnetic viscosity with H=0 they very strongly depend on stop with H', the presence of this stop substantially increasing them. The fact is especially interesting that this dependence in some magnets occurs only with -180°C and disappears at +20°C. Therefore the manifestations of magnetic viscosity at the operating point of magnet, i.e., with switched-off exciting current, were measured for all magnets, which were being tested both upon direct transfer from H_m to H=0 and upon transfer from H_m to H=0 with the intermediate stop with H'. In all cases the intensity/strength of external magnetic field in middle of magnetizing coil H_m=120 kA/m, and H'=10 kA/m. Time delay when H_m and H' was equal to 2 s, moreover each time passed hysteresis cycle.

The ratio of length to the thickness for the larger part of the magnets was l/d=3.3, and for the magnets from the alloys ЮНДК24 and ЮНДК24А l/d=2.5. Reproducibility of the measurements of increments in the magnetic induction was order 5% of the measured value, and sometimes also it is above upon transfer from H_m to H=0 with the stop with H'. However, the disconnection of exciting current with the spark sharply decreased reproducibility when this spark had a great effect on the observed manifestations of magnetic viscosity, for example, for samples/specimens No 1-8 and 15. Under such conditions reproducibility already proved to be close to 20%. In all cases of measurement 5-10 times were repeated and the average/mean significance of a deviation of galvanometer was determined.

Table 4-1 gives the instability coefficients for the magnets from the different alloys, obtained for two cases: the simple disconnection of exciting current and transition/junction from H_m to H=0 (instability coefficient η), and also transition/junction to H=0 with the stop with H' (instability coefficient η'). Furthermore, is given the value of magnetic induction in the mean section of bar magnet with the intensity/strength of the external magnetic field H=0 and 20°C.

Induction measurements were made with the aid of 1 turns, pulled off from the neutral section of magnet. As can be seen, the magnets being investigated were magnetized not before the saturation. Whereas the determination of the values of induction, required for calculating the instability coefficient η was performed with the aid of the same winding with a number of turns 4000, which served for the measurements of increments in the magnetic induction.

From the results of tests, given in table 4-1, it follows that the instability coefficient η, which characterizes the intensity of temporary/time processes, is approximately/exemplaril, proportional to absolute temperature T. This dependence occurs almost for all samples/specimens. Only in some separate magnets this relationship/ratio somewhat is disrupted and η' proves to be proportional $T^{1}/_{2}$, for example for samples/specimens No 5 and 6.

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In S3-1 is given the general formula, which expresses logarithmic law the dependence of intensity of magnetization on the time, which was obtained by Smith, Street and Uuley [38-43]. According to these authors, changes in the intensity of magnetization for the specific time interval, the manifestations of magnetic viscosity being, are proportional to the absolute temperature T. This proportionality was found by them also experimentally for bar magnets from the alloy of Alnico. This experimental confirmation of the relationship/ratio, derived theoretically, allowed Street, Smith and Uuley to arrive at the conclusion that the manifestation of magnetic viscosity actually/really can be considered as the result of the presence of the thermal fluctuations, which provide the activation energy, necessary for the transition/junction to the more stable orientation, the elementary regions of those locating in the unstable equilibrium. Experimental data, obtained by Barbier, in essence also are in accordance with the formula of Street, Smith and Uuley [34, 35, 43].

Table 4-1.

Номер магнита (1)	Сплав (2)	B, тл (3)	+20° C η	+20° C η'	−180° C η	−180° C η'
			(4) проценты			
1	ЮНДК18С	0,55	−0,03	−0,2	−0,016	−0,06
2		0,50	−0,02	−0,18	−0,01	−0,04
3	ЮНДК20С	0,54	−0,14	−0,45	−0,02	−0,15
4		0,53	−0,16	−0,5	−0,02	−0,16
5	ЮНДК24	0,29	−0,07	−0,24	−0,02	−0,11
6		0,28	−0,05	−0,22	−0,03	−0,13
7	ЮНДК24А	0,31	−0,05	−0,22	−0,01	−0,1
8		0,34	−0,04	−0,23	−0,01	−0,07
9	ЮНДК35Т5	0,22	−0,55	−0,6	−0,1	−0,2
10		0,18	−0,4	−0,55	−0,12	−0,2
11	ЮНД4	0,2	−0,34	−0,52	−0,03	−0,15
12		0,23	−0,45	−0,7	−0,05	−0,2
13	ЮНД8	0,25	−0,9	−0,9	−0,25	−0,25
14		0,23	−0,98	−0,98	−0,3	−0,3
15	ЮНД12	0,16	−0,06	−0,32	−0,02	−0,12
16		0,26	−0,58	−0,58	−0,17	−0,25
17		0,23	−0,6	−0,6	−0,2	−0,2
18		0,25	−0,72	−0,72	−0,23	−0,23

Key: (1). Number of magnet. (2). Alloy. (3). B, T. (4). percentages.

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The fact attention is drawn to that the magnets from the alloys, which possess a comparatively flat demagnetizing part of the hysteresis cycle ЮНД8 and ЮНД12, as a rule, do not decrease the manifestations of magnetic viscosity in the presence of spark $\varkappa$ in the circuit of exciting current $\eta'=\eta$. Exception/elimination are only one of the samples/specimens, No 15, which has the lowered/reduced magnetic induction. Magnets from alloys ЮНД4 and ЮНДК35Т5, whose introduction of spark comparatively weakly is manifested, occupy intermediate position in this respect. On the other hand, the magnets from the alloys ЮНДК18С, ЮНДК20С, ЮНДК24 and ЮНДК24А just as sharply decrease the manifestations of magnetic viscosity in the presence of spark, that $\eta'>>\eta$. Therefore the tests of such magnets must be carried out always either during the introduction of supplementary stop when $H' < H_m$, or with reducing of exciting current to zero without the spark with the aid of the short circuit of magnetizing coils or smooth reduction in current and its subsequent interrupting.

The calculated values of instability coefficient in the majority of the cases approximately/exemplarily correspond to those values, which can be determined according to the straight lines of instability, taken for the magnetic systems with the permanent magnets from the same alloys (Fig. 5-1, 5-2). It is necessary to also note that the special checking confirmed also at a temperature -180°C the observance of the proportionality of increments in the magnetic induction to the logarithm of time.

Thus, on the basis of the results of the present investigation it is possible with the larger confidence to apply permanent magnets at low temperatures, since in this case there are no foundations for expecting the especially sharp disturbances/breakdowns of the stability of magnets in the time.

4-4. Stabilities of magnets in the time after magnetic aging.

The results of the detailed investigation of the effect of different magnetic aging on the subsequent stability in the time of magnetic systems with the magnets of the different alloys are given below (S5-2). However, the fulfillment of analogous investigation for the rod permanent magnets also has known practical value. Furthermore, it it is possible to consider and as testing experimental data, obtained for the magnetic systems.

The magnetic aging of permanent magnets and magnetic systems consists in the partial demagnetization by stationary or alternating magnetic field to (6-10%). In the recommendations of planning organizations it is usually indicated that the demagnetization is less than to 6%, or more than to 10%, it will lead to a deterioration in the stability in the time. The partial demagnetization of magnets or systems by alternating magnetic field is conducted by larger part with the aid of the coil with ferromagnetic core, which will be brought to the magnet, while the current in this coil increases from zero to the specific value and then it reduces to zero.

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Whereas for the partial demagnetization by magnetostatic field it is required to introduce magnet or system into the weak magnetostatic field of opposite direction in comparison with the external magnetic field during the magnetization and then to reduce this magnetostatic field to zero, without changing its direction. Consequently, after passing open particular cycle, we is decreased the magnetic induction of magnet or system and to the known degree we stabilize them.

Several bar magnets of the alloys ЮНДК24 and ЮНД8 were subjected to investigation. The ratio of length to the thickness of magnets was on the order of 3.3 (ЮНД8) and 2.5 (ЮНДК24). Universal straight/direct instabilities were obtained with the aid of the accelerated method (S4-1; just as in the investigation, described in S4-3, bar magnets during the magnetization were arranged/located along the axis of crossover coil, the intensity/strength of external magnetic field of which was equal at this $12 \cdot 10^4$ a/m, the disconnection of exciting current was conducted with the stop on 2 s with certain $H' = 1 \cdot 10^4$ a/m. During each testing hysteresis cycle with the time delay at the maximum values of the intensity/strength of external magnetic field on 2 s passed. In the absence of partial demagnetization ballistic galvanometer was switched on 2 s 10 s after the disconnection of exciting current. Partial demagnetization was conducted immediately after the disconnection of exciting current. Demagnetization by an alternating magnetic field with a frequency of 50 Hz was realized in 2 s. Particular cycle during the demagnetization by stationary field passed with the time delay in the connected weak magnetostatic field, equal to 2 s. In the presence of partial demagnetization ballistic galvanometer was switched on 2 s 10 s after the disconnection of the demagnetizing current.

The investigation of the effect of demagnetization by alternating magnetic field showed that with the degree of demagnetization, which exceeds several percentages, the stability of magnets by the time is completely satisfactory. In this case occurred the drop of magnetic induction in the time, but very insignificant, approximately/exemplarily into dozens of times it is less than change of the induction with time immediately after magnetization. With an increase in the degree of demagnetization to 50% and above magnets were also very stable. It was possible to reveal/detect the low drop of magnetic induction in the time negligible, moreover increases in the induction in the time was not observed.

On the other hand, investigation of the stability of magnets after demagnetization by open particular cycle (magnetostatic field) gave completely different results. In this case a sharp increase of magnetic induction in the time during the partial demagnetization, which exceeds several percentages appeared.

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The corresponding universal straight/direct instabilities are constructed for two bar magnets: from the alloys ЮНДК24 (Fig. 4-4) and ЮНД8 (Fig. 4-5). On the straight lines is indicated the degree partial of demagnetization in the percentages.

From the examination of these straight lines it follows that the tendency toward an increase in the magnetic induction in the time after demagnetization by magnetostatic field actually/really exists. Moreover, if in the case deep partial of demagnetization by alternating magnetic field, that reaches to 50%, do not succeed in revealing/detecting deteriorations in the stability in the time in comparison with the demagnetization to 6-10%, then during the demagnetization by magnetostatic field, that exceeds several percentages, it is possible to distinctly observe the increase of magnetic induction by the time: here during the strong demagnetization instability coefficient is positive and attains several percentages.

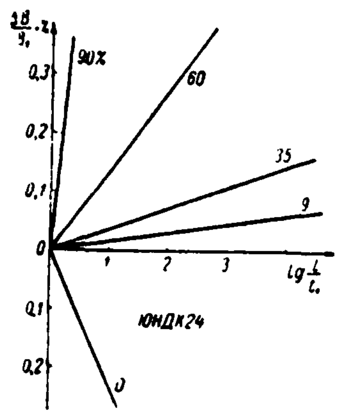

Fig. 4-4.

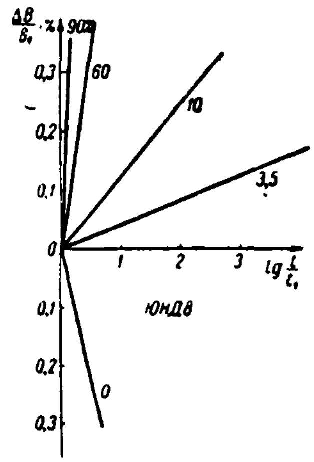

Fig. 4-5.

Fig. 4-4. Universal straight/direct instabilities of bar magnet from the alloy ЮНДК24, demagnetized with magnetostatic field.

Fig. 4-5. Universal straight/direct instabilities of bar magnet from the alloy ЮНД8, demagnetized with magnetostatic field.

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Chapter Five.

STABILITY OF MAGNETIC SYSTEMS IN TIME.

5-1. Accelerated method of the study of the stability of magnetic systems in time, based on the acceleration of the first measurement of magnetic induction.

The investigations of stability in the time of magnets and magnetic systems usually were conducted with the aid of the magnetometers of increased sensitivity and reproducibility with the prolonged time intervals. This did not make it possible to in sufficient detail study stability in the time of magnets and systems, which passed different magnetic aging. Therefore number of questions, connected with their partial demagnetization, remained unexplained, which impeded the selection of magnetic aging.

The accelerated method of the study of the stability of magnets and systems in the time, based on the measurement of increments in the magnetic induction (S4-1), not always is conveniently applied for the magnetic systems. This method requires the presence of the measuring winding established/installed on the magnet with a large number of turns, which is attained only for sufficiently large bar magnets and some systems of the specific layout.

On the other hand, it is possible to utilize magnetometers with high sensitivity and reproducibility for obtaining the initial part of the universal straight/direct instability and then to extrapolate it. However, it is necessary to note that, being limited to the definition of the initial part of the universal straight/direct instability, we can conduct such tests both for a few minutes and for several days or months. Actually/really, measuring the magnetic induction for the first time 2 min after magnetization and partial demagnetization with the basal time t_1=2 min and for the second time through day with t=720 t_1, we will obtain the same values of lg t/t_1 and increment in the magnetic induction $\Delta B/B_1$ as when the first measurement is made in the hour, and the second in a month, or the first measurement through day, and the second through 2 years (S3-4). This fact it is necessary to always have in mind with the execution of the investigation of the stability of permanent magnets and magnetic systems in the time, since the duration of tests for stability in the time, it be into several months or even years, it has the specific value only when the first measurement of magnetic induction after any magnetic perturbation it was conducted sufficiently rapidly. By magnetic perturbation should be implied the magnetization as well as partial demagnetization, passage of particular cycle, repeated dismantling and assembly of magnetic system and different external agencies, accompanied by a change in the magnetic induction.

Consequently, for accelerating the investigation of the stability of magnetic systems in the time it is necessary to accelerate the very first measurement of magnetic induction, which occurs after magnetic perturbation. Accelerating this first measurement several times, we are respectively accelerated in so many once and entire experiment. On this foundation the guarantee of an operating speed in the magnetometers, intended for the investigation of the stability of magnets and systems is especially important.

Immediately after magnetization straight/direct instabilities can be obtained relatively simply. Comparatively large changes of the magnetic induction with time, which occur in the absence of magnetic aging, easily can be determined.

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In this case the values of instability coefficient lie/rest approximately/exemplarily within the limits - (0.1-0.5)% for the usual magnetic systems, utilized in the measuring meters.

After satisfactory magnetic aging we have virtually very insignificant changes of the magnetic induction with time and negligibly low values of the instability coefficient of the order of several thousandths of percentage. To study increments in the magnetic induction, commensurated with an error in the measuring unit it goes without saying extremely difficultly. It is possible to only approximately/exemplarily determine the order of instability coefficient. However, this is not deficiency/lack, it is given by the inherent precisely nomu accelerated method. Rejecting from the accelerated test procedure and increasing the duration of investigation to several years, we do not simplify task, since during the endurance tests, which require the repeated repeated installations/settings up of systems in the magnetometer, its reproducibility descends.

5-2. Of the stabilities of magnetic systems in the time immediately after magnetization.

The universal straight/direct instabilities, obtained immediately after magnetization, characterize great changes of the magnetic induction with time, which can occur in the systems of the given construction/design with the magnets of the alloy being investigated. Furthermore, the study of such straight lines of instability is very useful on another reason. After the appropriate magnetic and temperature aging the magnetic systems with the magnets from different alloys possess a comparatively good stability in the time. The values of instability coefficient lie/rest within the limits of the hundredth and even thousandths of percentage. The investigations of stability in the time are reduced here only to the establishment of stability. Moreover to determine the dependence of stability in the time on different factors in that case is no longer possible, since this stability proves to be virtually identical for any alloys.

On the other hand, investigating the behavior of magnetic systems immediately after magnetization, without any stabilization, we obtain the possibility to study the dependence of stability in the time on the composition of the alloy of magnets and technology of their manufacture. This is very substantial because, as it will be shown below, magnetic systems, more stable immediately after magnetization, they prove to be more stable, also, after supplementary magnetic perturbation (for example, the shift of shunt) or after the magnetic aging, which consists in the very weak partial demagnetization, in all by several percentages.

Universal straight/direct instabilities immediately after magnetization were taken for 300 systems; their general view was given in Fig. 2-10, and sizes/dimensions were indicated in Table 2-3. Moreover systems with the inner frame magnets and with bar magnets with the screen tested on several/somewhat times: for them straight/direct instabilities were removed/taken with the magnetic circuit and without it, with the screen and without the screen.

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Consequently, stability in time at two values of the coefficient of the demagnetization of these systems was studied. Furthermore, several systems with the inner frame magnets underwent tests with three magnetic circuits of different thickness, and also without the magnetic circuit, which gave the already 4 values of the coefficient of demagnetization.

Despite the fact that for the construction of straight/direct instability sufficient to measure the magnetic induction of systems only twice, usually such straight lines were constructed on 3-4 points, which completely satisfactorily were arranged/located on the straight line. For the control/checking some straight/direct instabilities were removed/taken repeatedly. In the majority of the cases initial time interval between the magnetization and the first measurement of induction was equal to 1-5 min. The part of the given straight lines of instability was removed/taken during 30 min, remaining straight lines were obtained more rapid, for example, in 10 min. several ten straight/direct instability were removed/taken during the more prolonged time intervals: with t_1=2-5 min latter/last measurement was performed 5-10 days after magnetization. For the separate systems such tests were conducted even for several years. It is interesting to note that in this case no digressions from the logarithmic law were discovered.

To give obtained for all 300 investigated systems straight/direct instabilities, which give more demonstrative representation about the stability in the time, than instability coefficient η, is impossible. Therefore all taken straight/direct instabilities are given below only for some separate systems (Fig. 5-3-5-11), whereas in the majority of the cases it is necessary to be limited to the construction of the average/mean straight lines of instability.

Thus, for instance, Fig. 5-1 presents average/mean straight/direct instabilities for 120 magnetic systems with the external magnets (sizes/dimensions see in table 2-3, systems 3 and 4) of 10 different alloys: ЮМД8, ЮНД12, ЮНДК15, ЮНДК18, ЮНДК18С, ЮНДК24, ЮНДК24А, ЮНДК24Т2, ЮНДК35Т5 and АНКО1. At the ends/leads of these straight lines the vertical sections/segments, which show spread in the inclination/slope of the straight lines of instability, i.e., are constructed in the instability coefficient.

The best stability in the time immediately after magnetization (as can be seen from Fig. 5-1) possess magnetic systems with the external magnets from the alloys ЮНДК18С, ЮНДК24Т2 and ЮНДК24, whose part has an instability coefficient, close to 0.02%. However, it should be noted that in systems with the magnets of the alloy ЮНДК24 sufficiently large spread along the instability coefficient. Worst on the stability in the time of system with the magnets ЮНДК24 approximately/exemplarily corresponding to systems with the magnets АНКО1, ЮНДК18, ЮНДК24А and best of the systems with the magnets from the alloys ЮНДК15 and ЮНДК35Т5.

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As far as magnetic systems with the magnets from the alloy ЮНД8 are concerned, best of them have a stability in the time of the same order as as in least stable systems with the magnets from the alloys ЮНДК15 and ЮНДК35Т5, whereas remaining systems with the magnets from the alloy ЮНД8 are close in the stability to systems with the magnets from the alloys ЮНД12.

In Fig. 5-2 are constructed average/mean straight/direct instabilities for 180 magnetic systems with the inner frame magnets of 4 alloys: ЮНД12, ЮНДК24, ЮНДК25БА and ЮНДК35Т5 (sizes/dimensions see in table 2-3, system 5). The straight lines, taken with the magnetic circuit, are carried out

by solid line, and without the magnetic circuit - dash. As in the preceding/previous figure, vertical sections/segments at the ends/leads of the average/mean straight lines of instability give representations about the spread in the instability coefficient for these systems. From the comparison of straight lines it follows that the removal/distance of magnetic circuit, which sharply lowers operating point by the demagnetizing curve, worsens/impairs stability in the time. Thus, in systems with the magnets from the alloy ЮНДК24, ЮНДК25БА and ЮНДК35Т5 instability coefficient is doubled. As far as systems with the inner frame magnets from the alloy ЮНД12 are concerned, in them during the removal/distance of magnetic circuit instability coefficient grows/rises somewhat less.

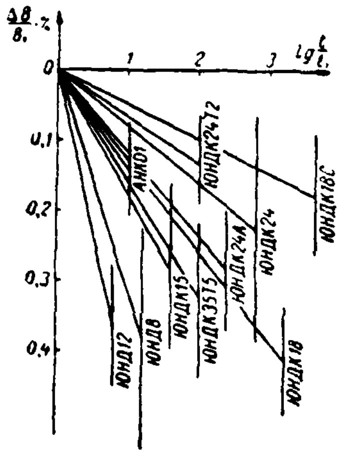

Fig. 5-1.

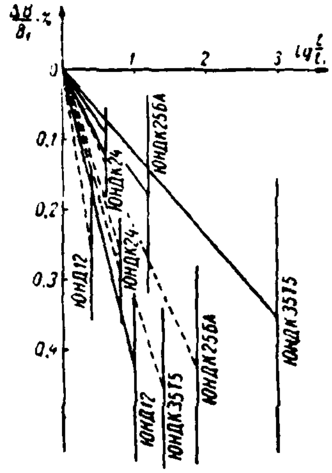

Fig. 5-2.

Fig. 5-1. Average/mean universal straight/direct instabilities of magnetic systems with the external magnets from different alloys, obtained immediately after magnetization.

Fig. 5-2. Average/mean universal straight/direct instabilities of magnetic systems with the inner frame magnets from different alloys, obtained immediately after magnetization.

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This could be expected, taking into account comparatively flatter demagnetization curve in alloy ЮНД12 (Fig. 4-4) and the fact that the manifestations of magnetic viscosity are approximately/exemplarily proportional to differential magnetic permeability. It should be noted that the stability in the time in bar magnets from the alloy ЮНД12 barely depends on the position of operating point in demagnetization curve, but in magnets from the alloys ЮНДК24 and ЮНДК24А, on the contrary, a sharp decrease in the operating point strongly affects stability (Fig. 4-3).

In order to ascertain that magnetic systems, more stable immediately after magnetization, they will be actually/really more stable, also, after small supplementary magnetic perturbation, were investigated 6 magnetic systems with the external magnets (sizes/dimensions see in table 2-3, system 3). From them

Into the systems with the magnets from the alloy АНКО1 (Fig. 5-3) and 3 - with the magnets from the alloy ЮНД12 (Fig. 5-4). Magnetic perturbation during installation/setting up and removal/distance of magnetic shunt decreased the magnetic induction in air gap of systems by 1-1.5%.

Examining the straight lines, constructed in Fig. 5-3 and 5-4, it is possible to arrive at the conclusion that more stable in the time, after supplementary magnetic perturbation prove to be those systems, which showed themselves more stable and immediately after magnetization, and consequently, such systems must be more advantageous, also, for the work after stabilization.

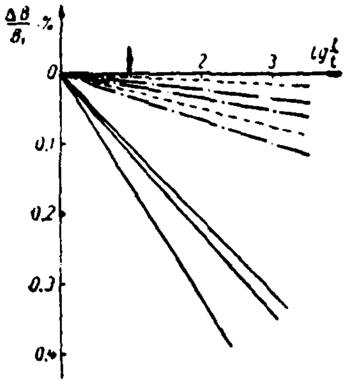

Fig. 5-3.

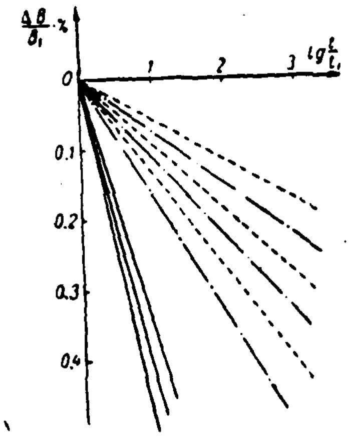

Fig. 5-4.

Fig. 5-3. Universal straight/direct instabilities of magnetic systems with the external magnets from the alloy AHKO1, obtained immediately after magnetization (solid lines), after demagnetization to 1% (dash) and after installation/setting up and removal/distance of magnetic shunt (dot-dash).

Fig. 5-4. Universal straight/direct instabilities for the magnetic systems with the external magnets from the alloy ЮНД8. Designations are the same as in Fig. 5-3.

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The investigation of stability in the time immediately after magnetization for the magnetic systems with the inner frame magnets was performed also with the different magnetic circuits. 10 magnetic systems were subjected to tests. From them systems 1-6 had magnets from the alloy ЮНДК24, 7-9 - from the alloy ЮНДК24Т2, and 10 - from the alloy ЮНДК24Т0,5. In this case systems 1-9 were investigated with three different magnetic circuits: 1) of steel 10 (sizes/dimensions see in table 2-3, system 6), to what it corresponds in Fig. 5-5 index 1 in the number of magnet; 2) made of armco steel (sizes/dimensions of magnetic circuit are the same as in the first case) - index 2; 3) magnetic circuit made of armco steel, but is more massive (sizes/dimensions see in table 2-3, system 5) - index 3. System 10 tested only with the magnetic circuit of the increased sizes/dimensions, and also entirely without the magnetic circuit - index 4. During the replacement of the 3rd version of magnetic circuit on the 2nd induction in the gap of magnetic system decreased by 6-10%, while during the replacement of the 3rd on the 1st - to 10-15%. When magnetic circuit entirely was driven out, induction decreased by 70%.

The universal straight/direct instabilities of these 10 systems are constructed in Fig. 5-5. In all cases the first measurement of magnetic induction was made 5 min after magnetization, i.e., basal time t_1=5 min. From Fig. 5-5 it is evident that the instability coefficient virtually remains identical during the replacement of magnetic circuit, if in this case a change in the magnetic induction composes 10-15% approximately/exemplarily. But if magnetic circuit is driven out and thereby induction decreases by 70%, then stability in the time sharply deteriorates and instability coefficient grows/rises.

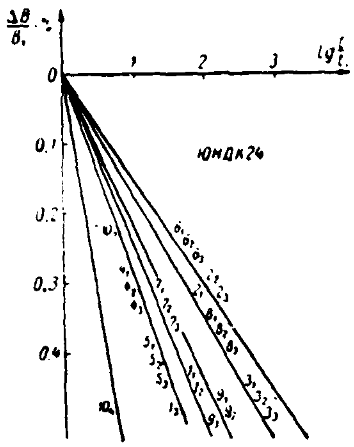

Fig. 5-5.

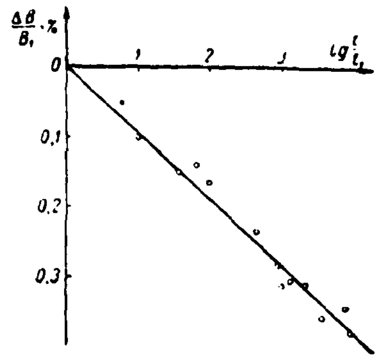

Fig. 5-6.

Fig. 5-5. Universal straight/direct instabilities of magnetic systems with the inner frame magnets with different magnetic circuits, obtained immediately after magnetization.

Fig. 5-6. Universal straight line of the instability of magnetic system with the external magnets from the alloy ЮНДК24, obtained immediately after magnetization.

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Thus, a change in the coefficient of the demagnetization of magnetic system barely is reflected in the value of instability coefficient, if the shift of the operating point of system occurs in the upper section of demagnetization curve and is connected with a change in the magnetic induction of order 10-15%. But when a change in the coefficient of demagnetization leads to the transition in the steep section of demagnetization curve and it is accompanied by a considerably larger change in the induction, instability coefficient sharply grows/rises in the absolute value.

The investigation of stability on the time magnetization was immediately after conducted also with the prolonged time intervals of the order of several years for some magnetic systems with the external magnets from the alloy ЮНДК24 and АНКО1 (sizes/dimensions see in table 2-3, system 2). Fig. 5-6 presents the universal straight/direct instability of magnetic system with the external magnets ЮНДК24 and the duration of tests, which reaches of up to 4 years. The first measurement of induction was realized the hour after magnetization. As experimental results have shown, with the logarithmic scale experimental points satisfactorily are arranged/located on the straight line. Certain spread them it is possible to explain by low (about 0.03%) reproducibility of applied in this case mechanical magnetometer, mentioned above (§2-1).

5-3. Stability of magnetic systems in the time after dismantling and assembly.

In connection with the fact that the need for partial dismantling and assembly of the magnetized and magnetic-stabilized magnetic system sometimes appears, it is interesting to check, what disturbances/breakdowns of stability in the time it is possible to expect under such conditions. For this purpose the investigation of stability in the time for two magnetic systems with the inner frame magnets from the alloys ЮНДК24Т0,5 (sizes/dimensions see in table 2-3, system 5) was carried out and ЮНДК25БА (table 2-3, system 7).

The straight/direct instabilities of system with the inner frame magnet from the alloy ЮНДК24Т0,5 (Fig. 5-7, solid lines) were obtained during the magnetization with the magnetic circuit (straight line 1) when magnetic circuit was removed/taken 30 min after magnetization (straight line 2) and again in the case, when magnetic circuit again dressed 30 min after it was taken (straight line 3). For the comparison is given the straight line of instability for this system, magnetized without the magnetic circuit (straight line 4). The same figure gives straight/direct instabilities for the system with the inner frame magnet from the alloy ЮНДК25БА (broken lines).

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These straight lines are constructed for magnetic system, magnetized and tested with the magnetic circuit (straight line 5), for the system, magnetized with the magnetic circuit, in which then is driven out the magnetic circuit 1 s after magnetization (straight line 6), and finally for the system, magnetized without the magnetic circuit, in which 1 s after magnetization the magnetic circuit (straight line 7) was established/installed. Straight line 8 relates to the system, magnetized and tested without the magnetic circuit, while straight line 9 to the system, magnetized with the magnetic circuit, in which 1 s after magnetization the magnetic circuit was taken and again dressed.

The straight/direct instabilities, obtained for 5 bar magnets from the alloy ЮНДК25БА (sizes/dimensions see in table 2-3, system 10), which were investigated without the screen (broken lines), also, after installation/setting up into the mounts/mandrels with the screen during 1-2 s after magnetization (solid lines), they were given in Fig. 5-8.

The stabilizing effect of the installation/setting up of screen or magnet wire in systems with the inner frame magnets is connected with the fact that the operating point during the installation/setting up of screen or magnetic circuit is displaced upward on demagnetization curve in connection with a change in the coefficient of demagnetization. Examining the obtained straight/direct instabilities (Fig. 5-8), it is possible to arrive at the conclusion that the operation/process of the removal/distance and the installations/settings up of magnetic circuit or screen, which are dismantling and assembly or it is simple the assembly of magnetic system, to its known degree they stabilize.

The investigation of stability in the time after dismantling and assembly, which occurred in the magnetic systems, which passed temperature stabilization, is examined in S5-5 (Fig. 5-24).

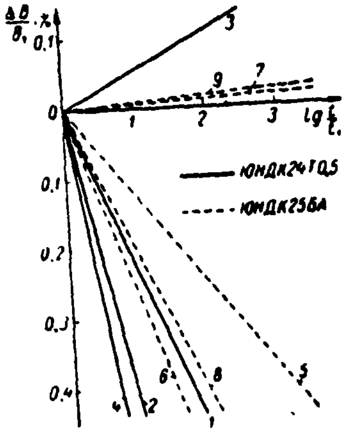

Fig. 5-7.

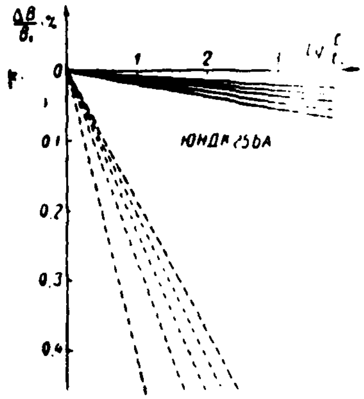

Fig. 5-8.

Fig. 5-7. Universal straight/direct instabilities of systems with the inner frame magnets, obtained after dismantling and assembly of these systems.

Fig. 5-8. Universal straight/direct instabilities of bar magnets from the alloys ЮНДК25БА with the screen.

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5-4. Stability of magnetic systems in the time after magnetic aging.

As is known, the magnetic aging of systems with the permanent magnets usually is realized with the aid of the partial demagnetization to 6-10% by variable or magnetostatic field, moreover it is assumed that both the decrease and the increase in the degree of demagnetization beyond the limits this of interval causes a deterioration in the stability of magnetic systems in the time. They sometimes assert even that an increase in the degree of demagnetization beyond limits of 10% leads to the increase of induction in time [33]. In the presence of spread in magnetic systems by the magnetic induction a strict observance of the degree of demagnetization to 6-10% leads to the rejection of certain quantity of magnetic systems. This spread in systems with the isotropic magnets does not of larger partly exceed 5-10%, but in the systems with the anisotropic magnets it can reach 30%. Generally speaking, known spread along the magnetic induction, apparently, is permitted by GOST [ГОСТ - All-Union State Standard] 9575-60 to the cast permanent magnets, which allows/assumes the decrease in the magnetic characteristics of permanent magnets, adjusted by the agreement of sides, but not more than to 15%. However, an increase in the properties of magnets in this GOST is not stipulated. Consequently, an increase in the magnetic induction in a large number of magnets of the specific party/batch (for example, to 20%) is not occasion for the presentation of reclamations to manufacturing plant. However, this increase requires either the appropriate change in the permissible limits of partial demagnetization to 6-30%, or the rejection of all strong magnets.

Very probable also that in magnets from some alloys the lowest degree of demagnetization from 6 can be changed under the known conditions to 4%. This decrease is admissible, if during the operation magnets do not fall into the especially strong external magnetic fields. This will make it possible to utilize somewhat weaker magnets. The magnets, for which the degree of demagnetization 6-10% is not suitable, sometimes there is comparatively much and their rejection leads to the undesirable overexpenditure of means and scarce materials. Thus, from a purely economic point of view it is very important to investigate the possibility of expanding the range of partial demagnetization, i.e., the possibility of the more complete utilization of magnets, obtained from the manufacturing plant.

Conducting the investigation of the stability of magnetic systems in the time after different magnetic aging is desirable and on other reasons. Very frequently with the troubles in the moving element of measuring permanent magnet instruments of change in the readings completely unjustifiably they explain by the instability of magnets. From this point of view it is very essential to show, what greatest possible changes of the magnetic induction with time can occur in magnetic systems with different degree of partial demagnetization.

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This investigation will make it possible to demarcate the effect of the instability of magnets and instability of the separate parts of the moving element of the instruments, it will make possible to reveal/detect the true reasons for troubles and to contribute to their elimination.

As it was indicated above (S5-1), the investigation of the stability in the time of magnetic systems requires the realizations of the sufficiently rapid first measurement of magnetic induction. However, after magnetic aging alternating magnetic field it is necessary to consider heating of systems under the action of eddy currents. To avoid an increase in the temperature of magnets and for the purpose of the acceleration of the first measurement of magnetic induction was carried out very rapid partial demagnetization by alternating magnetic field with a frequency of 50 Hz. Entire process of demagnetization, which consists in an increase in the variable field from zero to maximum value and a decrease in it again up to zero, occupied approximately/exemplarily 1 s. Under these conditions heating magnets already could be disregarded/neglected.

Special investigation showed that after the rapid partial demagnetization, carried out in 1 s, the repeated, slower partial demagnetization by the same alternating magnetic field virtually no longer changes magnetic induction. The effect of the duration of the effect of a comparatively weak alternating magnetic field to the subsequent stability of magnetic induction in the time was studied also, moreover the time delay of alternating magnetic field vary within the range of 1 to 10 s. No differences in the stability of magnetic systems in the time in this case was discovered.

Partial demagnetization by an alternating magnetic field was realized approximately/exemplarily so, as this is done at the plants, which make measuring meters, namely: to the magnetic circuit of the demagnetized magnetic system about the magnet the core of the demagnetizing coil, which creates alternating magnetic field, was brought.

It was desirable to investigate, does affect the subsequent stability in the time how will be brought to the magnetic circuit this core: on one hand, alternately from two sides or core is conducted in the process of demagnetization on the magnet itself. Furthermore, since to drive out core with the demagnetizing current in its winding possible differently, for 15 magnetic systems with the radial magnetic field with the magnets from the alloy ЮНДК24 (sizes/dimensions see in Table 2-3, system 9), demagnetized to 6-10%, stability in the time in two characteristic cases was determined.

1. During the demagnetization with the core, tightly applied to the magnet, then driven out from the magnet simultaneously with a decrease in the demagnetizing current to zero. Thus, with the demagnetizing current, yet not equal to zero, core is already distant from the magnet. Universal straight/direct instabilities for this case are represented in Fig. 5-9 (solid lines). Magnetic systems are very stable in the time, instability coefficient does not exceed ±0.01.

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2. The demagnetizing current descends to zero when core still

close lies/rests on the magnet. Only after current is brought up to zero, core is broken away from the magnet. Consequently, during the removal/distance of core after magnetic aging operating point in demagnetization curve is displaced down and magnetic aging carried out earlier is somewhat disrupted by this. As it was possible to expect, under such conditions the stability in the time in magnetic systems is already worse than in the first case: instability coefficient was negative and close to -0.04%. Straight/direct instabilities (broken lines) are given in Fig. 5-9.

Partial demagnetization was realized also with the aid of the core, which was brought to the magnetic circuit of the demagnetized systems with the inner frame magnets from different alloys on one side, whereas current in the coil of core increased from zero to maximum value and again decreased to zero after the removal/distance of core. Sometimes core during the demagnetization moved on magnets themselves or it was brought to the magnetic circuit alternately from two sides, and the time of the effect by alternating magnetic field increased 2-3 times. In this case the core was always driven out from the magnet to reducing of the demagnetizing current to zero. For the latter/last versions the results were approximately/exemplarily analogous, instability coefficient was completely satisfactory, approximately/exemplarily ±0.01%.

Thus, it is possible to assume that the rapid (in 1 s) partial demagnetization with the aid of that brought to the magnetic circuit of the magnetic system of the core, over winding of which alternating current with a frequency of 50 Hz flows/occurs/lasts, with reducing of current to zero after the removal/distance of core is completely permissible.

Partial demagnetization by magnetostatic field was carried out with the aid of the same electromagnet, which was applied during the magnetization. Demagnetization in closed magnetic circuit was realized in the same position of magnetic system, as during the magnetization, moreover system underwent the effect of a comparatively weak magnetostatic field of opposite direction in comparison with the field during the magnetization.

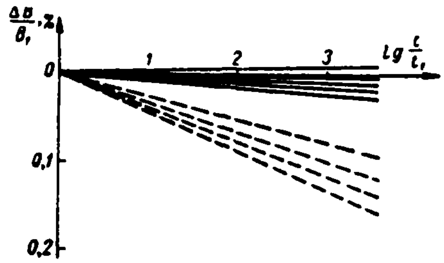

Fig. 5-9. Universal straight/direct instabilities of magnetic systems with the radial field with the magnets from the alloy ЮНДК24 with different procedure of partial demagnetization by alternating magnetic field.

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In the case of demagnetization in the extended magnetic circuit of the pole of electromagnet after magnetization strongly they were separated/expanded, and only then magnetic systems underwent the effect of the demagnetizing stationary field of the same order and the same direction, as in the case of demagnetization in closed magnetic circuit.

From experiments, set up for several magnetic systems, demagnetized with alternating magnetic field to 0.1-2%, it followed that during a comparatively weak demagnetization decay in the induction in the time after magnetization plays the dominant role;

therefore it is necessary to count off time intervals not from the moment/torque of completion of demagnetization, but from the beginning of magnetization. Only with this countdown we actually/really obtain straight/direct instabilities without the fracture. It is possible to assume that during the strong demagnetization the countdown should be conducted from the moment/torque of the termination of demagnetization. Therefore any partial demagnetization was conducted 1-2 s after magnetization and occupied about 1 s during the demagnetization by variable field and several seconds under the influence by stationary field. Thus, virtually already it was possible for all cases of partial demagnetization by variable or magnetostatic field to count off time from the moment/torque of magnetization.

The investigation of stability in the time with different degree of demagnetization was carried out with the aid of four electrodynamic magnetometers (S2-2) for 40 different magnetic systems. From them 22 systems with the inner frame magnets from the alloy ЮНДК24 (sizes/dimensions see in Table 2-3, system 5) 18 - with the external magnets (sizes/dimensions see in Table 2-3, system 3) from different alloys: 2 - with the magnets from the alloy АНКО1, 7 - from the alloy ЮНДК15, 5 - ЮНД8 and 4 systems with the magnets from the alloy ЮНД12.

On the whole for these systems were obtained more than 500 straight/direct instabilities, which required great preparatory work and numerous monitoring tests. Straight/direct instabilities were removed/taken for the larger part of the systems with the same degree of demagnetization repeatedly, on are several/somewhat once. Certain part of the straight lines of instability was constructed on two-three points; the first measurement was made 2-5 min after the magnetizations, which follow - with the interval 10-20 min. However, approximately/exemplarily for one third of these straight lines were removed/taken the 1-2 additional points through several days after the first measurement of induction. Obtained experimental data, as one would expect, with the logarithmic scale they were arranged/located approximately/exemplarily on the straight line. In Fig. 5-10-5-18 straight/direct instabilities for these systems are constructed, moreover on the separate straight lines is indicated the degree of partial demagnetization by alternating magnetic field in the percentages.

It should be noted that in the very weak degaussing field it can take place and increase in the magnetic induction in air gap of systems, which is explained by the effect of this degaussing field to the magnetic circuit of systems (56-5). On the appropriate straight lines is noted this increase in the induction by the introduction of plus sign (for example, +0.3% in the second straight line to the left in Fig. 5-11).

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Despite the fact that the very weak partial demagnetization in practice is not applied, nevertheless for the separate systems regularly were removed/taken straight/direct instabilities with the degree of the demagnetization of the order of several percentages and even tenths of percentage. This was desirable to realize in order to systematically monitor the effect of the degree of demagnetization on the stability in the time and to determine the degree of demagnetization, with which the systems become sufficiently stable. The absence of partial demagnetization is noted as by 0%; such straight/direct instabilities, taken/removed immediately after magnetization; it is also necessary for the comparison.

During the partial demagnetization, which exceeds 5%, changes in the magnetic induction, which should have been trapped for the time interval $1000t_1$, were order +-(0.01-0.03)%. Moreover reproducibility of measuring unit in the majority of the cases was close to 0.01%, but it somewhat deteriorated with an increase in the duration of experiment, since this entailed the need for the realization of the repeated installations/settings up of magnetic systems. It is natural that, determining instability coefficient η by this method, at its low values we can obtain only the order of its magnitude.

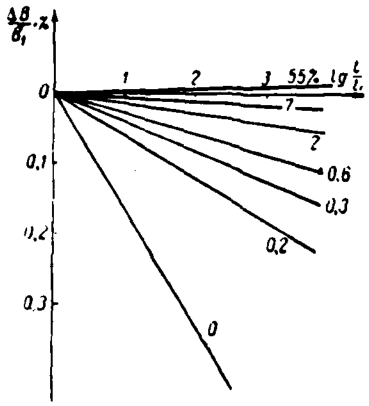

Fig. 5-10.

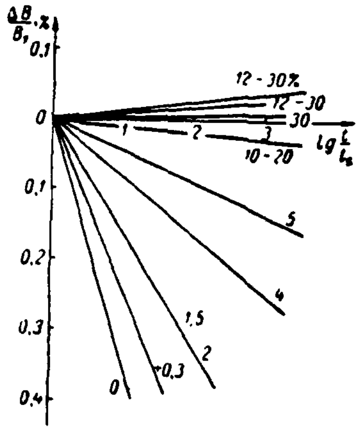

Fig. 5-11.

Fig. 5-10. Universal straight/direct instabilities of magnetic system with the external magnets from the alloy ЮНДК24 with different degree of demagnetization.

Fig. 5-11. Universal straight/direct instabilities of magnetic system with the external magnets from the alloy ЮНД12 with different degree of demagnetization.

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To give entire vast experimental material after a lack in space is impossible; therefore in Fig. 5-10 and 5-11 are constructed for an example experimental straight/direct instabilities only for two systems: with the inner frame magnet from the alloy ЮНДК24 (Fig. 5-10) and with the external magnets from the alloy ЮНД12 (Fig. 5-11). The fact attention is drawn to that more stable without the magnetic aging system with the magnet of the alloy ЮНДК24 is more stable and during the weak demagnetization as this was indicated above (§5-2). Furthermore, in Fig. 5-11 it is possible to see the spread, which occurred during the repeated tests for stability for the degree of demagnetization, equal to 30%. Taking into account reproducibility of such measurements, this spread can be recognized as regular.

The experimental results, obtained for the remaining 38 magnetic systems, are given in Fig. 5-12-5-18. Moreover for each individual batch of magnetic systems straight/direct instabilities are constructed according to the average/mean values of instability coefficients for this batch.

Examining the straight/direct instabilities, constructed according to the average/mean values of the instability coefficients of 22 systems with the inner frame magnets ЮНДК24 (Fig. 5-12), it is possible to arrive at the conclusion that with an increase in the degree of the demagnetization of system become all more and more stable. In the absence of demagnetization average instability coefficient η=-0.2%. Consequently, without the magnetic aging the decrease of magnetic induction for the time interval 10^3t_1 can reach

1%. For the degree of demagnetization in the range 4-55% system it is approximately/exemplarily equally stable in the time.

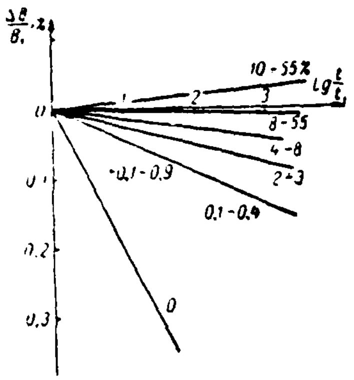

Fig. 5-12.

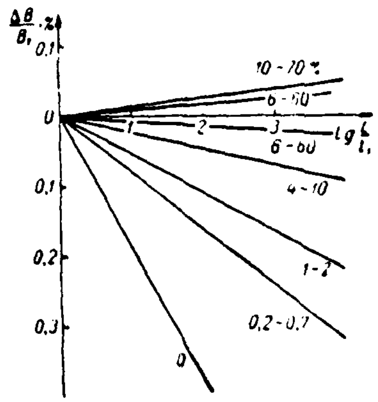

Fig. 5-13.

Fig. 5-12. Average/mean universal straight/direct instabilities of magnetic systems with the external magnets from the alloy ЮНДК24 with different degree of demagnetization.

Fig. 5-13. Average/mean universal straight/direct instabilities of magnetic systems with the external magnets from the alloy ЮНДК15 with different degree of demagnetization.

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Instability coefficient in this case is very low - it is close to ±0.01%. A change in the magnetic induction after $10' t_1$ lies/rests within limits of ±0.05%.

Straight/direct instabilities for 7 magnetic systems with the external magnets from the alloy ЮНДК15 (Fig. 5-13) have approximately/exemplarily the same inclination/slope, as the straight lines, constructed in Fig. 5-12. Coefficient of instability varies within the range of -0.19% in the absence of stabilization to ±0.15% during the partial demagnetization in interval of 4-70%. Demagnetization even to 60-70% does not disrupt stability in the time.

The strongly demagnetized systems with the external magnets from the alloy ЮНД8 (Fig. 5-14), as in the preceding/previous cases, it is comparatively stable in the time, the value of instability coefficient η are within the limits of ±0,015%. Somewhat less stable are the systems, demagnetized to 1-2%: the straight/direct instabilities, obtained immediately after magnetization, for these systems they lie/rest comparatively low, and average instability coefficient proves to be order - 0.06%.

Fig. 5-15 gives average/mean straight/direct instabilities for 4 systems with the external magnets ЮНД12. In the absence of demagnetization, i.e., for the straight/direct instability, obtained immediately after magnetization, η it is approximately/exemplarily equal to -0.4%. During the strong demagnetization (to 8-40%) of system are stable in the time, η=±0,015%. But during the demagnetization to 1-5% these systems it is already less stable, η lie/rest at the range from - 0.06 to -0.16%.

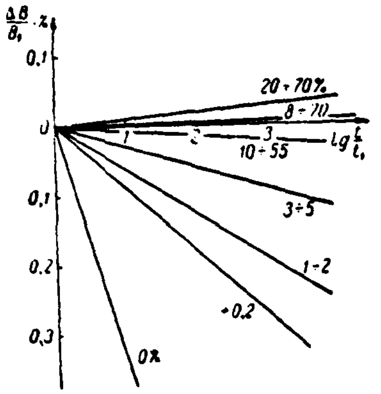

Fig. 5-14.

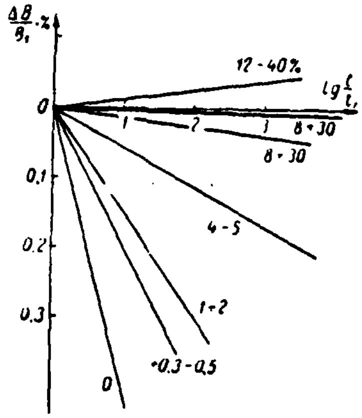

Fig. 5-15.

Fig. 5-14. Average/mean universal straight/direct instabilities of magnetic systems with the external magnets from the alloy ЮНД8 with different degree of demagnetization.

Fig. 5-15. Average/mean universal straight/direct instabilities of magnetic systems with the external magnets from the alloy ЮНД12 with different degree of demagnetization.

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During the strong (to 10-50%) demagnetization of systems with the external magnets from the alloy АНКО1 straight/direct instabilities are arranged/located near the axis of abscissas (Fig. 5-16).

Instability coefficient somewhat increases with the degree of the demagnetization of order 3-6%, η proves to be close to -0.02%; with the decrease of the degree of demagnetization to 2% η reaches to -0.05%, and in the absence of demagnetization η is approximately/exemplarily equal to -0.16%.

From the comparison of the given straight lines of instability (Fig. 5-10-5-16) it follows that an increase in the degree of demagnetization by alternating magnetic field even to 60% does not cause the sharp disturbance/breakdown of stability in the time. Thus, magnetic systems with the magnets, which are characterized by their high magnetic induction, apparently, can undergo stronger demagnetization by alternating magnetic field, than to 6-10%.

In connection with the fact that is sometimes applied the partial demagnetization by magnetostatic field [118], was carried out the investigation of stability in the time for the magnetic systems with the external and inner frame magnets during the demagnetization by stationary field in the locked and extended magnetic circuits. For the larger part of these systems straight/direct instabilities were taken/removed with different degree of demagnetization with the aid of the effect by the weak stationary field of opposite direction in comparison with the magnetic field during the magnetization. These straight lines usually lay/rested the considerably higher than straight lines of instability, obtained during the demagnetization by variable field. Was especially strongly disrupted stability in the time during the partial demagnetization by stationary field, that exceeded 30%.

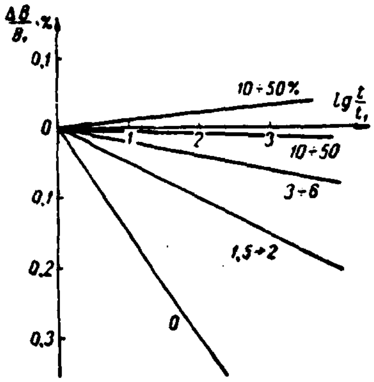

Fig. 5-16.

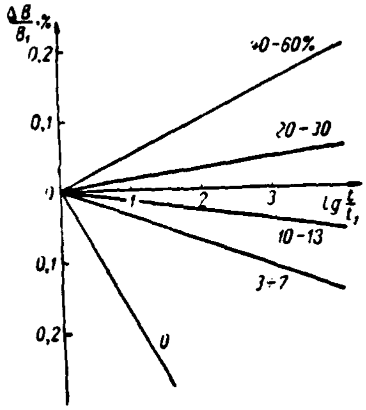

Fig. 5-17.

Fig. 5-16. Average/mean universal straight/direct instabilities of magnetic systems with the external magnets from the alloy АНКО1 with different degree of demagnetization.

Fig. 5-17. Average/mean universal straight/direct instabilities of magnetic systems with the external magnets from the alloy ЮНДК24 with demagnetization by magnetostatic field in closed magnetic circuit.

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In order more distinctly to determine the effect of demagnetization by stationary field, 49 straight/direct instabilities for 9 systems with the inner frame magnets from the alloy ЮНДК24 (Fig. 5-17 and 5-18) were taken/removed. During the demagnetization with the aid of the effect by weak stationary field in closed magnetic circuit, i.e., for the magnetic systems, arranged/located between the closely fitted poles of the electromagnet, which preliminarily served for the magnetization, were obtained 17 straight lines; average/mean straight lines constructed on their basis were given in Fig. 5-17. As is evident, during the demagnetization to 40-60% the tendency toward an increase in the induction in the time occurs. Fig. 5-18 presents average/mean (of 32 that obtained) straight/direct instabilities for the systems, demagnetized with magnetostatic field in the extended magnetic circuit, i.e., with the strongly moved apart pole pieces of the electromagnet, which served for the magnetization. Here the increase of induction in the time is expressed even more sharply than on the straight lines, given in Fig. 5-17. Instability coefficient for the straight lines, constructed in Fig. 5-18, has a value of order +0.1% with the degree of demagnetization, approximately/exemplarily equal to 50%, and reaches to +0.2% during the demagnetization to 80%. Approximately/exemplarily the same results were obtained for the rod permanent magnets during the demagnetization by their stationary field (S4-4).

It is possible to assume that the increase of magnetic induction in the time actually/really must be the stationary field most considerable during the demagnetization between the strongly moved apart poles of electromagnet. Realizing in this case transition/junction on the particular cycle, i.e., involving the stationary field of opposite direction in comparison with the field during the magnetization, we then, on the disconnection of this field, pass directly into the operating point, induction by which is considerably higher than induction in the connected degaussing field. Apparently, induction will then attempt to grow/rise in the time and this increase will be larger, the greater will be the degaussing field.

At the same time during the demagnetization by the stationary field of the system, arranged/located between the closely fitted poles of electromagnet, the conditions of demagnetization will be somewhat different.

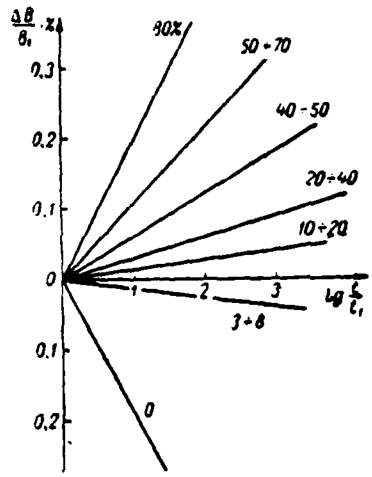

Fig. 5-18. Average/mean universal straight/direct instabilities of magnetic systems with the external magnets from the alloy ЮНДК24 during the demagnetization by magnetostatic field in the extended magnetic circuit.

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Transition/junction on the particular cycle during inclusion/connection and disconnection of the demagnetizing stationary field will be first almost the same as in the preceding case, but then the magnetic system is removed away from snug earlier the poles of electromagnet and this fact causes appropriate, although very low, decrease in the induction in air gap of system. A supplementary small decrease in the induction must to the known degree stabilize it and block intense increase in the time.

On the basis of the obtained experimental results it is possible to conclude that the disturbance/breakdown of stability in the time during the strong demagnetization, which exceeds 10%, sometimes actually/really has place. The deterioration in the stability in the time appearing during the demagnetization with the aid of the open particular cycle by magnetostatic field. Whereas partial demagnetization by alternating magnetic field during the removal/distance of the demagnetizing core to reducing of alternating current to zero provides completely satisfactory stability in the time for the magnetic systems, demagnetized to 6-70%.

5-5. Stability of magnetic systems in the time after magnetic and temperature aging, with the prolonged time intervals.

Since usually the magnetic systems are utilized precisely after magnetic and temperature aging, the investigation of stability in the time under such conditions is of great interest. It is obvious that the temperature stabilization, which consists in several temperature cycles, no longer makes it possible to strongly accelerate the first measurement of magnetic induction, since in this case appears the need for attaining setting the corresponding temperature of the system being investigated. As a result the first measurement of magnetic induction usually was performed the days after heating or cooling. Subsequently for simplicity we will call the irreversible changes in the magnetic induction, caused by a change in the temperature, irreversibility. In the figures given below along the axis of ordinates is plotted/deposited the increment in the magnetic induction $\Delta B/B_1$ in the percentages of the initial value of induction B_1, which is irreversibility when it o relates to the temperature effects; along the axis of abscissas are indicated the heatings and coolings, and also time. Magnetic aging was realized with the aid of the partial demagnetization by an alternating magnetic field with a frequency of 50 Hz in all cases, except those specially stipulated, when the effect of different methods of partial demagnetization on the subsequent stability of system was investigated. Only some most characteristic results of tests are given below.

Stability in the time of magnetic systems with the external magnets from the alloys ЮНДК24 and АНКО1 (sizes/dimensions see in Table 2-3, system 2) was studied after magnetic and temperature aging for the time intervals, which reached of up to four years.

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For the measurements of magnetic induction the mentioned above (S2-1) mechanical magnetometer with reproducibility, close to 0.03%, was utilized. Tests for stability in the time after temperature stabilization passed the magnetic systems, demagnetized to 3-70%.

In Fig. 5-19 the curves, taken for 7 magnetic systems with the external magnets from the alloy ЮНДК24 with the different degree of the demagnetization are constructed: 2 systems were demagnetized to 6% (curves 1, 2), 2 - to 55% (curves 4, 5), but 2 did not pass demagnetization (curves 6, 7). All these systems were warmed thoroughly for 1 h with 80°C. Furthermore, the seventh system, demagnetized to 6%, was not heated (curve 3). As can be seen, irreversibility after heating to 80°C in the systems, demagnetized to 6%, is close to +0.1%, whereas the systems, demagnetized to 55%, have the negative irreversibility of order -0.05%. In this case the systems, demagnetized to 55%, approximately/exemplarily are so stable in the time as system demagnetized to 6%, which confirms the obtained earlier results testing (§5-4).

It should be noted that of 3 systems, demagnetized to 6%, that system is most stable in the time, which heating did not obtain, but in remaining 2 systems tendency toward the drop of induction in the time during the first 100 days is observed.

AD-A139 471 STABILITY OF PERMANENT MAGNETS(U) FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH A V MITKEVICH 06 MAR 84 FTD-ID(RS)T-1344-83 3/4

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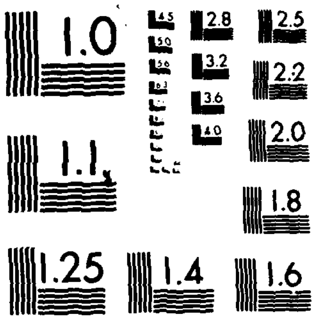

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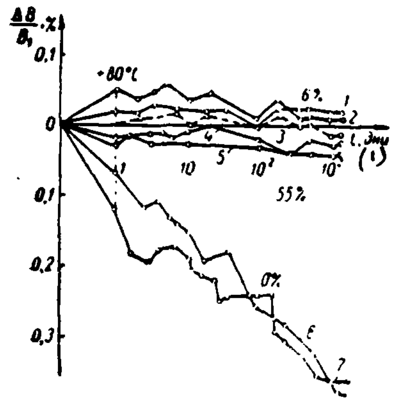

Fig. 5-19.

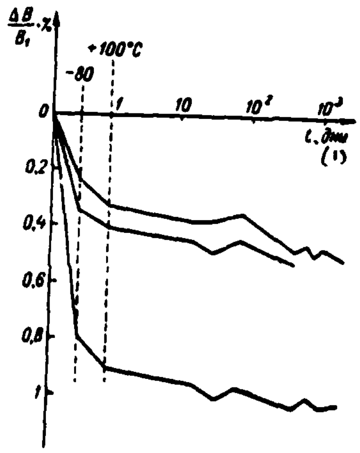

Fig. 5-20.

Fig. 5-19. Change of the magnetic induction in the time in magnetic systems with the external magnets from the alloy ЮНДК24 with different degree of demagnetization and one heating.

Key: (1). days.

Fig. 5-20. Change of the magnetic induction with time the magnetic systems with the external magnets from the alloy ЮНДК24 after cooling and the heating has in the absence of partial demagnetization.

Key: (1). days.

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The systems, which did not pass demagnetization, differ significantly from rest in the stability in the time (curves 6, 7). In this case the instability coefficient η is approximately/exemplarily equal to -0.01%. Taking into account reproducibility of mechanical magnetometer, curves 6 and 7, constructed on the logarithmic scale, it is possible to recognize as sufficiently close ones to straight lines.

The results of the tests of three magnetic systems with the external magnets from the alloy ЮНДК24, which were not undergoing partial demagnetization, are represented in Fig. 5-20. All systems passed after demagnetization cooling down to -80°C and heating to +100°C with a duration of temperature effects of 2 h each, after which magnetic induction was measured in the time. In the absence of demagnetization the irreversibility after cooling down to -80°C reaches -0.8%. Moreover after heating to +100°C, the following after the cooling down to -80°C, irreversibility already is considerably less. On the logarithmic scale the obtained segments of curves, which illustrate a change of the magnetic induction with time, are very close to straight lines. It is very significant that the cooling and heating systems much better stabilizes their than one heating (Fig. 5-19). The system, which did not obtain temperature effects and which did not pass demagnetization (Fig. 5-6), is less stable in the time than those systems, which underwent such effects.

Some plants, manufacture electric measuring instruments, sometimes introduce, just in case, supplementary temperature stabilization, conducted to the magnetization. Moreover it is assumed that this stabilization, which consists of several temperature cycles, to the known degree improves the subsequent stability of systems. Therefore it was desirably show on experiment that the temperature cycles do not completely affect the stability of systems, if them are realized before the magnetization.

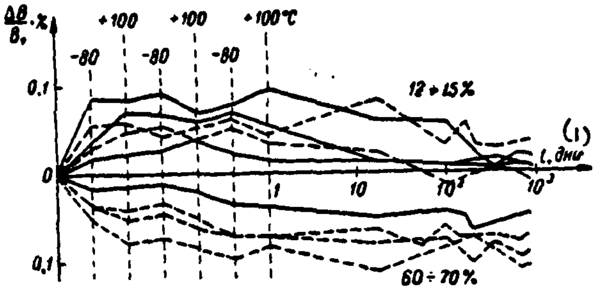

Fig. 5-21. Change of the magnetic induction in the time in magnetic systems with the external magnets from the alloy ЮНДК24 with different degree of demagnetization and the repeated temperature effects.

Key: (1). days.

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Fig. 5-21 gives the results of the tests of 9 magnetic systems with the magnets from the alloy ЮНДК24, from which 4 did not pass temperature cycles before the magnetization (solid lines), but 5 passed the thermal treatment, which consisted of ten cycles (-80°, +100°C) with the time delay on 2 h (broken lines). Then all systems were magnetized, 5 of them were demagnetized to 12-15% (upper curves), and 4 - to 60-70% (lower curves), after which all systems again obtained three temperature cycles (-80°, +100°C) with the delay on 2 h.

From given curves (Fig. 5-21) it follows that the preliminary thermal treatment of magnetic systems, conducted to the magnetization, does not affect not only their irreversibility after heatings and coolings, but also on the stability in the time. In exactly the same way, as the magnetic systems, demagnetized by 6% and which passed heating (Fig. 5-19), in this case the systems, demagnetized by 12-15%, decrease their induction by several the hundredths of percentage in the first 100 days. Analogous results were obtained for the magnetic systems from the same party/batch, demagnetized for 6% and the obtained series/row temperature effects.

On the other hand, the investigation of stability in the time of magnetic systems with the inner frame magnets from the alloy ЮНДК24 (Fig. 5-25 and 5-26) and the systems with the external magnets from the same alloy, but another party/batch, they do not give grounds to assert that this decrease in the induction in the time after temperature effects always occurs.

Stability in the time with the prolonged time intervals was studied also for the systems with the external magnets from the alloy ЮНДК24, demagnetized to 20 and 45% and passed temperature cycles -80°-+80°C. The curves, arranged/located in the gap/interval between the upper and lower beams of the curves, depicted in Fig. 5-21, were obtained. On some of these systems before the magnetization were set the derived magnetic shunts, which then were introduced after magnetization and temperature effects. The subsequent stability in the time in these systems did not differ from the stability of the systems, which did not have shunts.

Fig. 5-22 gives the curves, obtained for 6 systems with the external magnets from the alloy AHKO1, the demagnetized to 6-10% and passed six heatings to +80°C, moreover 3 systems were heated on 1 h (solid lines), and 3 systems - on 4 h (dash), after which of all 6 systems they tested in the time for three years. From the comparison of curves it follows that the heatings with a duration of 1 h and in 4 h approximately/exemplarily equally affect the magnetic induction of systems, moreover further (after the second) heatings are generally manifested comparatively little. Stability in the time of all 6 systems is completely satisfactory, η close to zero.

It is necessary to note one of the systems (upper dotted curves), which in its irreversibility sharply differs from others.

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For the testing two weeks after the first the second curve was taken for the same system. As it proved to be, difference in the sign of irreversibility after heating was preserved. In the same party/batch one additional magnetic system, which has analogous irreversibility after heating, was discovered. However, on the magnetic induction and the stability in the time both these systems in no way differed from the remaining systems of this party/batch.

As is known, magnetic systems usually are magnetized in the assembled form between the poles of electromagnet and, as a rule, are partially demagnetized with the alternating magnetic field between the poles of another electromagnet or variable field with the aid of the coil with the core, brought to the demagnetized system. Thus, magnetic systems are magnetized and are demagnetized under the conditions, which differ from working conditions for their subsequently. Furthermore, alternating magnetic field with a frequency of 50 Hz causes a somewhat heterogeneous magnetic aging over the section of magnet. In connection with this the different methods of the demagnetization of magnetic systems were investigated and is simultaneously studied the effect of the preliminary thermal treatment, carried out before the magnetization, and also the effect of the displacement of magnetic shunt on the stability in the time.

Of 11 magnetic systems with the external magnets from the alloy AHKO1, which were being tested, 6 systems did not pass before the magnetization of preliminary thermal treatment (Fig. 5-23, solid lines), but 5 systems obtained 11 temperature cycles (-30°C-+120°C) with the delay on 2 h (dash or dot-and-dash lines) before the magnetization. Then all 11 systems were magnetized, demagnetized with different methods to 6-10% and they were thoroughly heated for 4 h with +80°C.

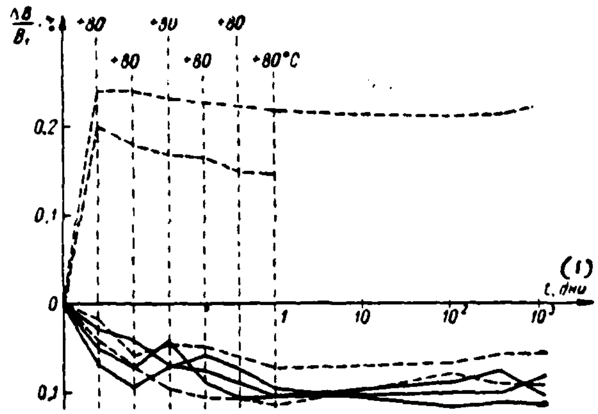

Fig. 5-22. Change of the magnetic induction with time in magnetic systems with the external magnets from the alloy AHKO1 after demagnetization to 6-10% and repeated heatings.

Key: (1). days.

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In this case 3 systems (3 upper curves) were demagnetized with alternating magnetic field at the frequency of 0.5 Hz with the aid of the same electromagnet, which was applied for the magnetization; 3 systems were demagnetized with the aid of another electromagnet with the small pole pieces at the frequency of 50 Hz, and rest 5 - with the aid of the windings, wound up around the magnets of these systems, moreover 2 systems - at the frequency of 0.5 Hz, and 3 - at the frequency of 50 Hz. For the latter/last 8 systems in Fig. 5-23 lower curves are constructed.

Before the magnetization to 6 systems of 11 magnetic shunts were set. In 5 systems these shunts after demagnetization and heating were introduced, which in any way did not affect the subsequent stability in the time. Whereas in one of the systems shunt was derived, as a result of which its stability in the time sharply deteriorated (dot-dash curve).

As can be seen from Fig. 5-23, the systems, demagnetized at frequency 0.5 and 50 Hz with alternating magnetic field with the aid of the windings, wound up around the magnets, i.e., those subjected to magnetic aging under the conditions, close to the working conditions for their further, behave with respect to subsequent heating and in the time equally and just as the systems, which were demagnetized with alternating magnetic field with a frequency of 50 Hz in the electromagnet: they somewhat decrease their magnetic induction after heating to +80°C and it is comparatively stable in the time, η is close to zero. Exception is one of them (dot-dash curve), the disturbance/breakdown of stability in the time in this case is caused by the removal of magnetic shunt. Instability coefficient here is already approximately/exemplarily equal to -0.04%. Generally speaking, a small deterioration in the stability in the time with the removal of magnetic shunt it was possible to expect, since the downward bias of the operating point of system in demagnetization curve must worsen/impair the subsequent stability in the time in exactly the same way just as during the removal/distance of magnetic circuit in systems with the inner frame magnets (S5-3).

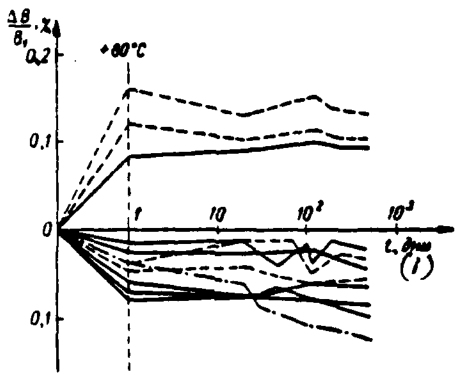

Fig. 5-23. Change of the magnetic induction with time in the magnetic systems with the magnets from the alloy AHKO1, which were undergoing demagnetization to 6-10% by stationary or alternating magnetic field under the varied conditions and to heating.

Key: (1). days.

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It must be noted that sharply distinct reaction for the heating in 3 systems, demagnetized at the frequency of 0.5 Hz in the electromagnet, which served for the magnetization (Fig. 5-23, upper curves), it is very probably connected with the fact that the closely fitted massive pole pieces of this electromagnet contributed to closing/shorting the magnetic flux of the permanent magnets through magnet core. The subsequent removal/distance of magnetic systems from the electromagnet led to a small supplementary decrease in the induction, which disrupted the magnetic aging of systems. At the same time on the basis of the results of tests (Fig. 5-23) it is possible to assume that the conducted before the magnetization thermal treatment does not affect the subsequent behavior of magnetic systems with the external magnets from the alloy AHKO1 and is not necessary, just as for the systems with the external magnets from the alloy ЮНДК24 (Fig. 5-21).

During the installation/setting up of magnets in the ring of magnetic circuit it is applied both hot and cold landing; therefore was made the investigation of its effect on the reaction of magnetic systems with the external magnets from alloy AHKO1 to the heating and further stability in the time. Tests were carried out for 11 systems: from them 6 obtained shrink fit, and 5 - cold. All systems were magnetized, demagnetized to 6-10%, they were subjected to threefold heating to +80°C on 4 h each, then their magnetic induction was measured approximately/exemplarily during the year. The examination of the obtained empirical curves, analogous to the lower curves, constructed in Fig. 5-21, makes it possible to arrive at the conclusion that all these of 11 magnetic systems behave more or less equally. Moreover their stability in the time is completely satisfactory - instability coefficient is close to zero.

Stability in the time after magnetic and temperature aging was studied also in the presence of the supplementary ones of dismantling and assembly of magnetic systems with the external magnets, which sometimes it is necessary to realize. As is known, in order to take out and to again station the core of magnetic system with the external magnets, without descending with this operation/process its magnetic induction, are commonly used two steel cheeks, adjusted from two sides of core along the filling from the silumin, that fastens the pole pieces of magnetic system. Such two cheeks virtually completely close to themselves the magnetic flux of magnets and magnetic induction in air gap of system proves to be negligibly low. Then core is extracted, the necessary works are conducted, then core again is placed on its place and these cheeks they are removed. Curves (Fig. 5-24) were removed/taken after all such effects on magnetic systems.

In this case changes in the magnetic induction, caused by heating or dismantling and assembly in connection with the incongruously high values of such changes are not indicated. Of those 8 undergone the tests of magnetic systems with external magnets 7 had magnets from the alloy АНКО1, and 1 - from the alloy ЮНДК24. All 8 systems were magnetized, demagnetized to 6-10% with alternating magnetic field and they were thoroughly heated three times on 4 h with +80°C.

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Then 3 magnetic systems with the magnets AHKO1 simply tested in the time (upper solid lines). The rest of 5 magnetic systems passed dismantling and assembly. From them 2 systems with the magnets from the alloy AHKO1 after dismantling and the assembly tested in the time (lower solid lines). Remaining 3 systems after dismantling and assembly again were warmed thoroughly for 4 h with +80°C, after which also they tested in the time (dash - system with the magnets from the alloy AHKO1, dot-dash line - from the alloy ЮНДК24).

Irreversibilities after different effects on these systems were the following: after three heatings to +80°C the irreversibility they were negative, order -(0.05-0.1%); after dismantling and assembly the irreversibilities already proved to be positive and they were within the limits of 0.5-1%, and after latter/last (fourth) heating to +80%, irreversibility they were again negative, close to -0.2%.

As can be seen from Fig. 5-24, instability coefficient reaches to -0.08% in the system, which passed dismantling and assembly after magnetic and temperature aging. Whereas in those systems, which this dismantling and assembly did not pass, induction remains almost constant/invariable, and instability coefficient does not exceed -0.02%. The systems, which after dismantling and assembly passed one additional supplementary heating to +80°C, are somewhat more stable in the time, than those, which did not have this fourth heating after assembly. Apparently, in the cases of the forced dismantling and assembly of the magnetic systems, realized after magnetic and temperature aging, it is expedient to produce the supplementary temperature stabilization (heating to +80°C), which will somewhat improve stability in the time.

8 magnetic systems with the external magnets from the alloy *АНКО1* and 8 - with the magnets *from* the *alloy* ЮНДК24, that passed partial demagnetization to 10-20% and threefold heating to +80°C, were through several months after the passage of this magnetic and temperature aging heated to +60°C and they were cooled to -40°C with a duration of these effects of 2 h each. As showed the measurements of the magnetic induction, carried out with the aid of the mechanical magnetometer mentioned above, irreversibilities in this case were so/such low (±0.03%), that they lay/rested within the limits of reproducibility of magnetometer.

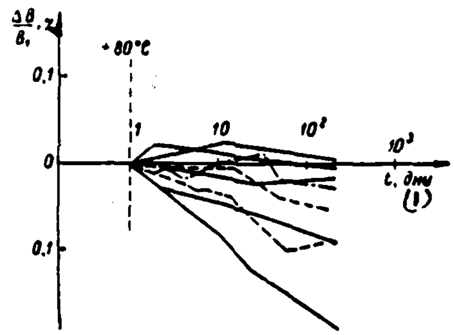

Fig. 5-24. Change of the magnetic induction with time in magnetic systems with the external magnets from the alloys AHKO1 and ЮНДК24 (dot-dash curve), demagnetized to 6-10%, after dismantling and assembly of these systems and heatings.

Key: (1). days.

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Stability in the time after magnetic and temperature aging was investigated in systems with the inner frame magnets from the alloys ЮНДК24, ЮНДК24Т0,5, ЮНДК24Т2, ЮНДК24 with the additive of ferrotitanium, ЮНДК25БА, ЮНДК35Т5 and ЮНД12 (sizes/dimensions see in table 2-3, system 5), and also systems with the external magnets from the alloy ЮНД12 (sizes/dimensions see in table 2-3, system 3). Induction measurements were made with the aid of several electrodynamic magnetometers (S2-2).

The results of the tests of 9 systems with the inner frame magnets from the alloy ЮНДК24, partially demagnetized for 6-10% and which passed the series/row of temperature effects with the time delay on 4 h are given in Fig. 5-25. As can be seen from figure, after sixfold heating to +80°C the cooling down to -70°C some systems affects very strongly: irreversibility after cooling reaches in them to -0.4%. The repeated cooling down to -40°C, carried out at the end of the tests, also noticeably affects induction, decreasing it in all systems approximately/exemplarily to 0.06%. The stability of these systems in the time proved to be completely satisfactory in the course of one month, instability coefficient was close to zero.

Analogous investigations were made for 24 systems with the inner frame magnets from the alloys ЮНДК24 and ЮНДК24Т2, which after magnetization and partial demagnetization to 10-25% passed threefold heating to +80°C and single cooling down to - 40°C with duration of 4 h each, after which the magnetic induction of these systems was measured in the course of one month.

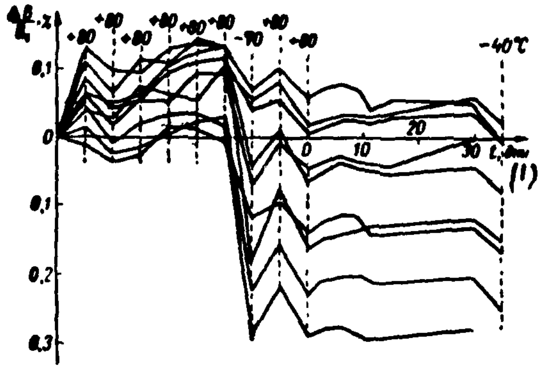

Fig. 5-25. Change of the magnetic induction with time in the partially demagnetized magnetic systems with the inner frame magnets from the alloy ЮНДК24, demagnetized to 6-10%, after temperature effects.

Key: (1). days.

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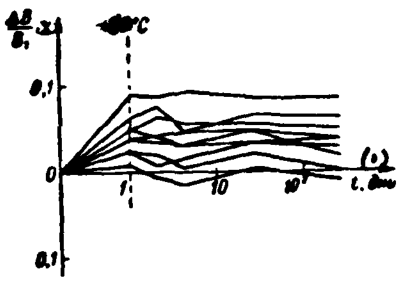

Fig. 5-26.

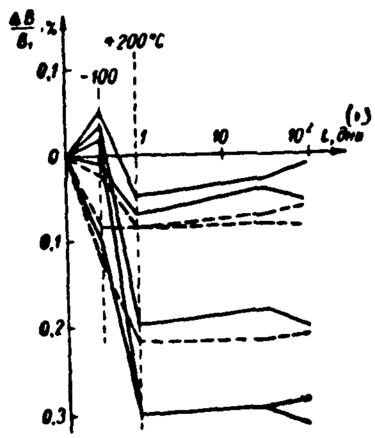

Fig. 5-27.

Fig. 5-26. Change of the magnetic induction with time in the demagnetized to 6-10% magnetic systems with the inner frame magnets from the alloy ЮНДК24, the passed three heatings.

Key: (1). days.

Fig. 5-27. Change of the magnetic induction with time in magnetic systems with the external (unbroken curves) and inner frame (dash) magnets from the alloy ЮНД12 after demagnetization to 10% and temperature effects.

Key: (1). days.

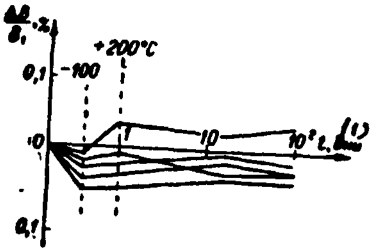

Fig. 5-28.

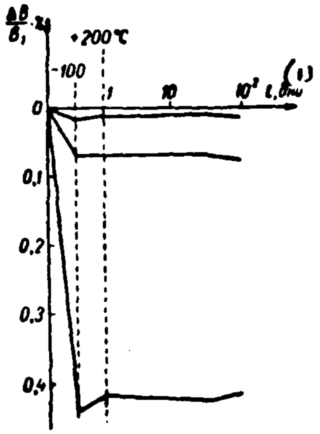

Fig. 5-29.

Fig. 5-28. Change of the magnetic induction with time in magnetic systems with the inner frame magnets from the alloy ЮНДК35Т5 after demagnetization to 10% and temperature effects.

Key: (1). days.

Fig. 5-29. Change of the magnetic induction with time in magnetic systems with the inner frame magnets from the alloy ЮНДК25БА after demagnetization to 10% and temperature effects.

Key: (1). days.

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With this in half of magnetic systems the pole pieces were fastened with filling from the silumin, in rest - they were soldered by brass. No difference in the behavior of the systems, which had different attachments of the pole pieces, it was discovered. Stability in the time in all systems was the same, as in the preceding case, instability coefficient was close to zero.

Those testing of 9 magnetic systems with the inner frame magnets from the alloy ЮНДК24 after magnetization and the partial demagnetization to 6-10% were three times thoroughly heated to +80°C with the delay on 4 h, then their induction was measured in the course of 8 months. As can be seen from curves (Fig. 5-26), irreversibility after threefold heating to +80°C in the systems being investigated is close to +0.1%. Stability in the time is completely satisfactory, instability coefficient close to zero. Accurately the same tests, carried out for the magnetic systems with the inner frame magnets from the alloy ЮНДК24Т0.5 and ЮНДК24 with the additive of ferrotitanium, showed, that irreversibility in these magnetic systems after heating and their stability in the time of the same order as as in systems with the magnets ЮНДК24.

Stability in the time was studied also for the magnetic systems with the external and inner frame magnets from the alloy ЮНД12 (Fig. 5-27), with the inner frame magnets from the alloy ЮНДК35Т5 (Fig. 5-28) and ЮНДК25БА (Fig. 5-29). All of 14 magnetic systems were magnetized and demagnetized to 6-10%, then they passed cooling down to -100°C and heating to +200°C with duration on 4 h, after which they tested in the time more than 3 months. As it follows from obtained experimental data, the instability coefficient of these systems is close to zero.

Thus, stability in the time of magnetic systems with the magnets from different alloys proves to be completely satisfactory after different temperature effects with exception of the systems, which did not pass magnetic aging, or such systems, which after temperature cycles as a result of dismantling and assembly or removal of magnetic shunt obtained supplementary changes in the magnetic induction.

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Chapter Six.

STABILITY OF PERMANENT MAGNETS AND MAGNETIC SYSTEMS IN THE PRESENCE OF EXTERNAL AGENCIES.

6-1. Accelerated method of the study of the stability of permanent magnets and magnetic systems with a change in the temperature, based on the measurement of increments in the magnetic induction.

The dependence of the magnetic induction of magnets and magnetic systems on the temperature of larger is partly very undesirable factor during their operation. Of course it is possible to introduce temperature compensation. However, large spread in the values of temperature coefficient, even for the magnets from one and the same melting, does not make it possible to ensure the invariability of magnetic induction in that measure, in which this sometimes is required. Therefore in the especially critical cases it is necessary to investigate the temperature coefficient of magnets and systems and to monitor it. It is very important also during the development of new magnetic alloys to know how sufficient simply to define both the temperature coefficient and irreversible changes in the induction with a change in the temperature. The proposed accelerated method can be used for this purpose.

As is known, studying the stability of permanent magnets with a change in the temperature, usually find very low increments in the magnetic induction as a difference in two close values of induction. Relative error during the determination of these increments can prove to be into ten and hundreds of times of more than the relative error, with which magnetic induction itself is measured. The use/application of special magnetometers of high sensitivity does not make it possible to strongly expand temperature range, since at reduced temperatures the magnets being investigated are covered/coated with hoarfrost. Furthermore, temperature at the tests it is necessary to change comparatively slowly in connection with the fact that the precise measurements of magnetic induction, in particular with the zero differential method, are connected with the wide intervals of time. As a result the determination of temperature coefficient with the aid of the highly sensitive magnetometers proves to be very labor-consuming. Ewing permeability balances [83, 86] and measuring units with ferromagnetic probes [60, 61] make it possible to investigate the temperature coefficient of bar magnets also with a relatively slow change in the temperature and do not give the possibility to produce the tests of magnetic systems.

On the other hand, directly measuring increments in the magnetic induction with a rapid, shock change in the temperature, we can be satisfied by considerably larger error. Contemporary photoelectronic microweber meters with the measuring winding, established/installed on the magnet, give the possibility to observe and to investigate these increments in the magnetic induction. This accelerated method makes it possible comparatively simply to determine the temperature coefficient of magnets and systems, and also irreversible changes in the magnetic induction, if they are sufficiently great.

The required shock changes in the temperature can be provided with the aid of the insertion/immersion of magnet or system into the medium, which possesses a good thermal conductivity. As such media it is possible to utilize, for example, water - for the temperature range from 0 to 100°C, the mixture of alcohol with the dry ice - for temperatures on the order of -70°C or liquid nitrogen - for the cooling down to -180°C. For guaranteeing a good insulation of measuring windings should be applied the heat-resistant Viniflex, which wonderfully maintains/withstands the temperature differentials from +100° to -180°C or the special thin jackets, which shield windings.

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As it will be shown below (S6-2), temperature coefficient and irreversibility with slow and rapid shock changes in the temperature prove to be approximately/exemplarily identical in these temperature ranges.

Rate of change in the temperature of the magnets being investigated, generally speaking, does not have the special vital importance during the determination of temperature coefficient. But due to the zero drift microweber meters, which sometimes can cause large error, it is desirably possible to more rapidly perform similar tests. In this case it is possible to be satisfied only by the rough estimate of the time interval, necessary for setting of identical temperature by entire space of magnet and it is essential to simplify the solution of the differential equation of thermal conductivity, accepting boundary first-order conditions. Under such conditions, as is known, they assume that the surface of samples/specimens during the insertion/immersion into the medium, which differs in the temperature, instantly accepts the temperature of this medium and remains then constant/invariable during entire process of heat exchange just as the temperature of medium.

In connection with the fact that rate of change in the temperature depends in essence on the thickness of the samples/specimens being investigated (small changes in their form they are manifested little), it is expedient for obtaining calculation data to replace the magnetic system of complex layout and bar magnet of square section by the unlimited plate, the sphere and the unlimited cylinder. Furthermore, during the calculation completely admissibly for the permanent magnets to accept the coefficient of the thermal diffusivity of steel, physical constants to which were known and, apparently, close to the appropriate values for the ferromagnetic alloys. Then a number of Fourier $Fo=a\tau/R^2$ can be determined on available calculated curve [119], utilizing a solution of the differential equation of thermal conductivity for the boundary first-order conditions. Here the coefficient of the thermal diffusivity of steel $a \approx 10^{-5}$ m²/s, R - half of the thickness of plate, a radius of cylinder or sphere, τ - time.

For the case, when temperature already approximately/exemplarily was leveled at all points of section, we obtain the appropriate values of a number of Fourier on the curves, and for different values of R we find τ, that is the time interval, after which the temperature can be considered being steady throughout entire sample/specimen being investigated. Table 6-1 gives the obtained values for the isolated special cases.

Thus, for instance, with R=10 mm we will obtain τ, not exceeding 20 s.

Boundary first-order conditions can occur during the natural mixing of boiling water or liquid nitrogen. However, one must take into account that in the latter case the gas layer first appears, which is held by 5-10 s, then it disappears, and in violently boiling nitrogen the temperature rapidly is established/installed. In the water with 0°C or in the mixture of alcohol with dry ice with -70°C it is necessary to provide intense mixing in order to obtain the largest possible approximation/approach to boundary first-order conditions.

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Moreover transition/junction to 0°C and -70°C should be realized only from the positive temperatures, since cooled to -180°C magnets o systems during the insertion/immersion into cold water or cooled alcohol are covered/coated with the solid shell, which impedes heat exchange. In this case, and also during the unsatisfactory mixing we pass to the boundary third-order conditions with the undetermined coefficients of heat exchange, which must be determined experimentally.

The experimental check of the rate of temperature balance showed that the temperature for bar magnets is established/installed by the sizes/dimensions 10x10x50 mm^3 in 10-20 s. Whereas for the systems with internal frame magnets (sizes/dimensions see in Table 2-3, system 7) this time interval increased to 1-2 min. The increase of the time of temperature balance in comparison with the results, obtained according to the calculation, is connected both with the partial heat insulation, which creates the measuring winding and with the fact that the true situation of experiments differs somewhat from the idealized boundary first-order conditions.

The temperature of magnets or systems on the extreme points of the temperature cycles, which pass during the investigation of temperature coefficient, can be found as the temperature of the medium, which surrounds magnets or systems, determined after setting of the temperature of magnets, that causes no difficulties. Moreover in the individual sections of the temperature cycles between these extreme points we can use certain averaged temperature, measured with the aid of the thermocouple, established/installed on the magnet.

The considerable sources of error in the method in question they are the zero drift microweber meters, which must be systematically monitored, and emf, which appears because of the Thomson's effect. For decreasing the effect of this emf it is desirable to apply not very thin wires for the measuring windings and not to subject these winding to mechanical stresses. Furthermore, it is possible to utilize a measuring winding of two sections, connected so that the measured magnetic fluxes store/add up, and Thomson's emf average out.

Table 6-1.

(1) Форма образца	Fo	R, мм	(2) τ, сек
(3) Неограниченная пластина	2	5	5
		10	20
		20	80
(4) Неограниченный цилиндр	1	5	2,5
		10	10
		20	40
(5) Шар	0,8	5	2
		10	8
		20	32

Key: (1). Form of sample/specimen. (2). s. (3). Unlimited plate. (4). Unlimited cylinder. (5). Sphere.

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Summarizing the fundamental component of the relative error, which appears in the measurement of increments in the magnetic induction, most magnetic induction and temperature, it is possible to accept relative error during the determination of temperature coefficient as the described above accelerated method of the approximately/exemplarily equal to 5-10%, which is completely admissible, since the temperature coefficient of magnets has large spread.

6-2. Reversible and irreversible changes of changing the magnetic permanent magnets and in the magnetic systems with a change in the temperatures, investigated by the accelerated method.

The dependence of magnetic induction on the temperature was studied by the accelerated method for 45 magnetic systems, whose general view was given in Fig. 2-10, and sizes/dimensions were given in table 2-3. From them 15 systems with the inner frame magnets from the alloy ЮНДК25БА (sizes/dimensions see in table 2-3, system 7), 15 systems with the U-shaped magnets from the alloy ЮНДК20 (sizes/dimensions see in table 2-3, system 8) and 15 systems with the radial magnetic field with the magnets from the alloy ЮНДК24 (sizes/dimensions see in table 2-3, system 9). Furthermore, tested cylindrical flat/plane magnets with the diameter of 20-80 mm and with the thickness of 8-12 mm of the anisotropic barium ferrite and several ten bar magnets with the section of 225 mm^2 and 600 mm^2 and with the length of 30-100 mm from different alloys. Only certain part of the obtained curves is given below.

In Fig. 6-1-6-10 along the axis of abscissas the temperature is plotted/deposited, along the axis of ordinates in Fig. 6-1-6-9 - increment in the magnetic induction in the percentages, while in Fig. 6-10 - magnetic induction in T. In the separate curves is indicated in the percentages the degree of partial demagnetization by alternating magnetic field with a frequency of 50 Hz.

In the presence of the clearly expressed nonlinearity of the dependence of magnetic induction on the temperature it is necessary to select differential temperature coefficient α_d, by the fundamental criterion of evaluation of this dependence at a specific temperature which in the general case is multiple-valued; it it is possible to record as follows:

$$\alpha_d = \frac{\frac{dB}{dt}}{B} 100\%/1^\circ C,$$

where B - magnetic induction, and t - temperature.

As is known, in the small temperature ranges we have to right sometimes disregard nonlinearity and to use the temperature coefficient, determined from the extreme values of induction for this interval.

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Usually the magnetic induction B_2 at a temperature t_2 is expressed as the magnetic induction B_1 at a temperature t_1 and as follows:

$$B_2 = B_1\left[1 + \frac{\alpha}{100}(t_2 - t_1)\right]$$

and

$$\alpha = \frac{B_2 - B_1}{B_1(t_2 - t_1)} 100\%/1^\circ C,$$

where α - temperature coefficient in the percentages to 1°C, that characterizes the dependence of magnetic induction on the temperature at the linearization of this dependence in the temperature range in question.

The selection of different mathematical expressions for the nonlinear sections of such curves with the use of the quadratic dependence and other, more complicated dependences, apparently, must be acknowledged unsuitable. Actually/really, the character of these nonlinear curves depends very greatly on the coefficient of the demagnetization of magnet or system and on their magnetic and temperature prehistory, i.e., from the degree of partial demagnetization and preceding/previous temperature cycles. Furthermore, for the separate magnets of one and the same alloy, even for one and the same melting, value of differential temperature coefficient they can sometimes differ not only in the value, but even on the sign.

Fig. 6-1 gives the results of the investigation of 15 magnetic systems with the inner frame magnets ЮНДК25БА. For fulfilling the measurements was utilized the measuring winding, which consists of several ten turns, which was slipped over the neutral section of magnet and there was secured. After which the magnet was established/installed in its magnetic circuit and magnetic system was magnetized, partially was demagnetized and was placed in the special holder, which made it possible it to transfer and the at the same time not impeded heat exchange. Magnetic system passed one-two preparatory temperature cycle, it was maintained/withstood for a while, necessary for the compensation for the zero drift of photoelectronic microweber meters, at a temperature, close to +100°C. Then it was immersed in the water with ice with the temperature, equal to 0°C and in the mixture of alcohol and dry ice with the temperature of order -70°C.

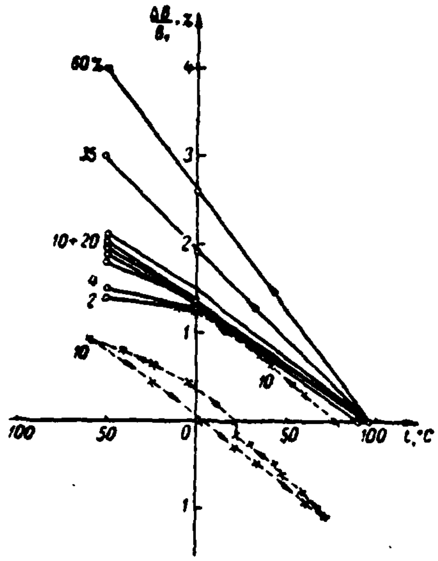

Fig. 6-1. Dependence of magnetic induction on the temperature in magnetic system with the inner frame magnet from the alloy ЮНДК25БА with different degree of demagnetization.

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The measurement of the increments in the magnetic induction, caused by a change in the temperature, was made with the aid of the microweber meter.

Obtained by the curves (Fig. 6-1) accelerated method for one and the same magnetic system, each of which consists of two rectilinear sections/segments (solid lines), attest to the fact that the magnetic induction is connected with the temperature with nonlinear dependence, moreover the degree of demagnetization strongly affects the inclination/slope of these curves. For the comparison primes constructed analogous curves for the same magnetic system, demagnetized to 10%, taken with the aid of the magnetometer, based on the quasi-balanced method (Sec. 2-3). One of the dashed curves begins from +20°C and is the first temperature cycle, in which so-called temperature hysteresis is developed. The second begins from +80°C and is already the part of the repeated temperature cycle; it is very close to the appropriate curve, obtained by the accelerated method for the system, demagnetized to 10%. Of course during the comparison of these curves one must take into account that one of them begins from +80°C but others from somewhat higher temperature.

Thus, experimental data, obtained with a shock change in the temperature, approximately/exemplarily correspond to the results, obtained with a slow change in the temperature. The analogous characteristics, taken with the aid of the same magnetometer, were obtained for different systems of this party/batch, which passed partial demagnetization to 6-10% (Fig. 6-2). The curves, taken by the accelerated method for all 15 magnetic systems, which passed different demagnetization (Fig. 6-3), confirm the dependence of the inclination/slope of curves on the degree of partial demagnetization.

Fig. 6-4 gives the curve, which expresses the dependence of magnetic induction on the temperature for one of the systems of the same party/batch, demagnetized to 10%. In this system the magnetic circuit was distant before the magnetization and the demagnetization, and to investigation was subjected magnet itself. Before the tests this magnet passed several temperature cycles +100, -100° C. Experimental results obtained with the shock (solid line) and slow (broken line) changes of temperature, approximately/exemplarily coincide.

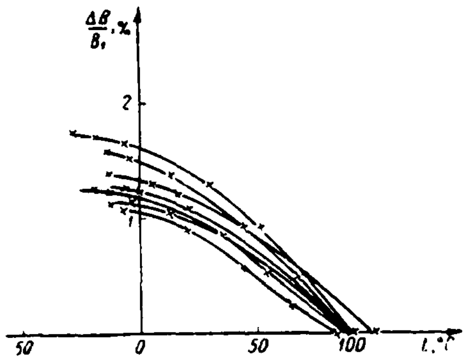

Fig. 6-2. Dependence of magnetic induction on the temperature in the magnetic systems with the inner frame magnets from the alloy ЮНДК25БА, demagnetized to 6-10%.

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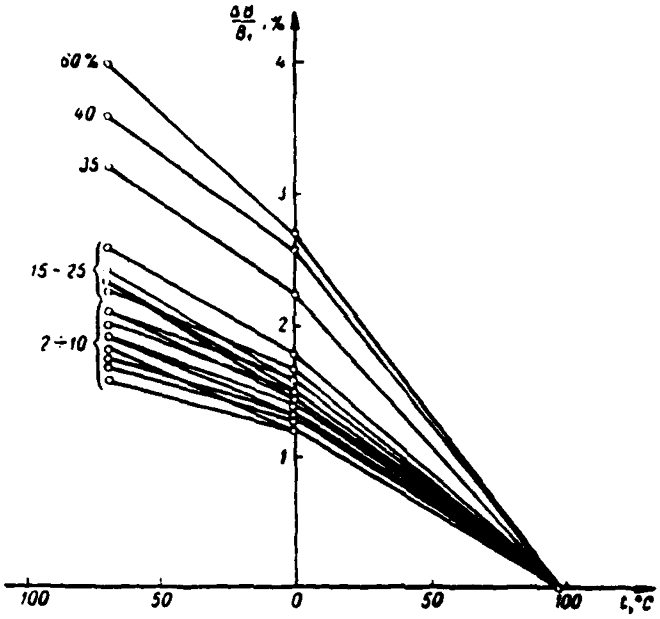

Fig. 6-3. Dependence of magnetic induction on the temperature in magnetic systems with the inner frame magnets from the alloy ЮНДК25БА with different degree of demagnetization.

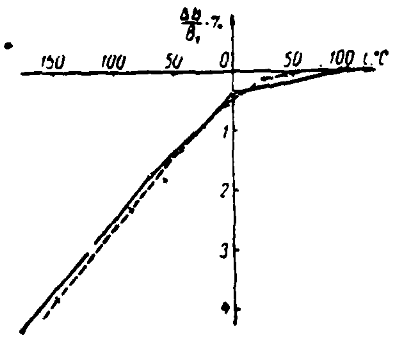

Fig. 6-4.

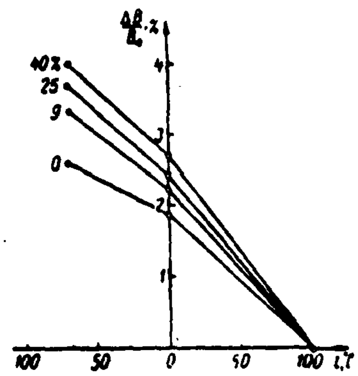

Fig. 6-5.

Fig. 6-4. Dependence of magnetic induction on the temperature in the magnetic system with the inner frame magnet from the alloy ЮНДК25БА, demagnetized to 10%, with the taken magnetic circuit.

Fig. 6-5. Dependence of magnetic induction on the temperature in magnetic system with the radial magnetic field with the magnet from the alloy ЮНДК24 with different degree of demagnetization.

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Sign change of temperature coefficient in connection with the removal/distance of the magnetic circuit of the experienced/tested system is in the complete agreement with the work of other authors. As is known, Clagg [53] showed that some contemporary magnet alloys have the remanent induction, which increases with a temperature decrease, and the coercive force, on the contrary, which falls under these conditions. Thus, the taken at different temperatures demagnetizing parts of the hysteresis cycle intersect, and at the point of intersection temperature coefficient is equal to zero. Moreover depending on the value of the coefficient of demagnetization and position of operating point in demagnetization curve, the temperature coefficient of the magnet being investigated or system can be negative or positive.

On the basis of the results of the investigation of 15 magnetic systems with the magnets from the alloy ЮНДК24 with the radial magnetic field it is possible to arrive at the conclusion that the reversible changes in the magnetic induction with a change in the temperature from +100° to -70°C and in this case depend on the degree of partial demagnetization. Fig. 6-5 gives the curves, obtained for one of these systems with the different degree of demagnetization. From them it follows that in such systems somewhat less is manifested the degree of partial demagnetization, and all curves are arranged/located somewhat higher than those, which are given in Fig. 6-1 and 6-3.

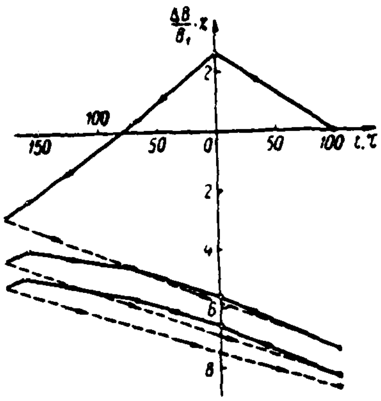

Fig. 6-6.

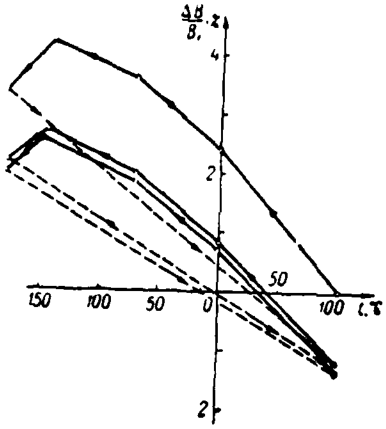

Fig. 6-7.

Fig. 6-6. Cycles of magnetic hysteresis for the magnetic system with the radial magnetic field with the magnet from the alloy ЮНДК24 in the absence of partial demagnetization.

Fig. 6-7. Cycles of magnetic hysteresis for the magnetic system with the radial magnetic field with the magnet from the alloy ЮНДК24, demagnetized to 9%.

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In Fig. 6-6-6-8 temperature cycles for one of the systems of the same party/batch are constructed. Transition/junction from +100 to -180°C was realized with the stop with 0 and -70°C (solid lines), whereas return from -180 to +100°C was conducted without the intermediate stops (dotted line). The curves, represented in Fig. 6-6, are obtained for the system, which did not pass partial demagnetization. Should be noted a comparatively large irreversibility after passage to note a comparatively large irreversibility after (+100°, -180°, +100°C), equal to -7.4%. After the same second cycle it descends to -1%, and then after the third and fourth cycles this irreversibility is already close to zero.

Temperature coefficient for the section of curve from +100 to 0°C the approximately/exemplarily equal to -0.022%/1°, proves to be almost identical in this interval for all temperature cycles, moreover in the first cycle the sign of differential temperature coefficient changes with 0°C, whereas in remaining cycles this sign is changed already with -160°C.

Temperature cycles for the magnetic system, demagnetized to 9% are constructed in Fig. 6-7. Here irreversibility after the first cooling down to -180°C already considerably less: it is equal to -1.2%. In the limits from +100° to -70°C temperature coefficient can be considered identical for all cycles, beginning from the first and with equal to -0.024%/1°C. With a temperature decrease the value of differential temperature coefficient decreases in the absolute value; at a temperature, close to -140°C, it reverses the sign and it becomes positive.

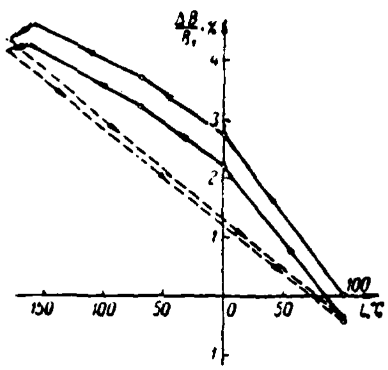

Fig. 6-8.

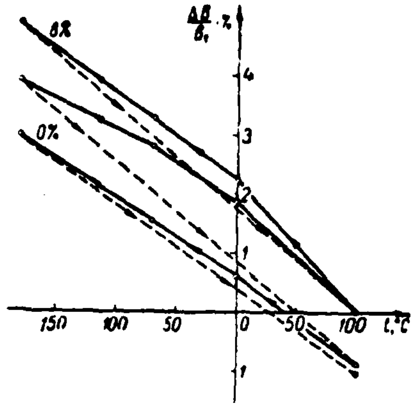

Fig. 6-9.

Fig. 6-8. Cycles of magnetic hysteresis for the magnetic system with the radial magnetic field with the magnet from the alloy ЮНДК24, demagnetized to 40%.

Fig. 6-9. Cycles of magnetic hysteresis for the magnetic system with the U-shaped magnets from the alloy ЮНДК20.

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The temperature cycles, given in Fig. 6-8, relate to the same magnetic system, demagnetized to 40%. As can be seen, temperature coefficient in this case is close to 0.028%/1°C for the range of temperatures from +100 to -70°C, the differential temperature coefficient reversing the sign at -160°C. Irreversibility after cooling down to -180°C becomes already insignificant, order -0.4% for the first cycle and close to zero for the rest.

The temperature cycles, which relate to the investigation of magnetic systems with the U-shaped magnets from the alloy ЮНДК20 (Fig. 6-9 and 6-10), show that the degree of partial demagnetization somewhat affects the temperature coefficient of these systems. However, an increase in the temperature coefficient with an increase in the degree of partial demagnetization in them is less than in the systems, examined higher. In system without the demagnetization the irreversibility after cooling to -180° proves to be order 1%, whereas in the same system, demagnetized to 8%, this irreversibility is very low - it does not exceed several hundredths of percentage (Fig. 6-9). Similar experimental data were obtained also for other systems from the same party/batch. Furthermore, the results of tests, executed with the aid of the magnetometer, based on the quasi-balanced method, showed that also during the prolonged, multihour cooling down to -180°C the irreversibility of such systems after the demagnetization, which exceeds 6%, proves to be close to several hundredths of percentage (Fig. 6-27).

Temperature cycles for one of these systems, demagnetized to 6, 10 and 50%, are given in Fig. 6-10. And here we have negligibly low irreversibility after coolings down to -180°C. Moreover the degree of partial demagnetization somewhat affects the value of temperature coefficient.

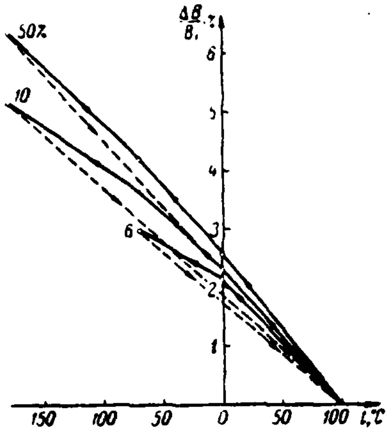

Fig. 6-10.

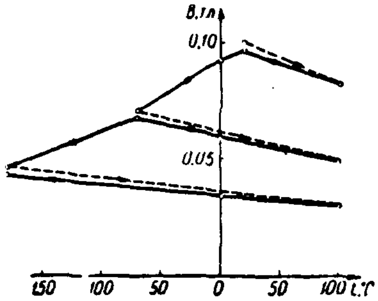

Fig. 6-11.

Fig. 6-10. Cycles of magnetic hysteresis for the magnetic system with the U-shaped magnets from the alloy ЮНДК20 with different degree of demagnetization.

Fig. 6-11. the curves of magnetic hysteresis for the cylindrical sample/specimen from the anisotropic barium ferrite in the absence of demagnetization.

Key: (1). T.

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As it follows from the obtained curves, in the interval from 0 to

+100°C temperature coefficient varies from -0.022 to - 0.026%/1°C with the increase of partial demagnetization from 6 to 50%.

In Fig. 6-11 temperature cycles for the cylindrical barium ferrite with a diameter of 36 mm and with a thickness of 12 mm are constructed. It is necessary to note that in contrast to the curves, given in Fig. 6-10, the magnetic induction in the neutral section of magnet here along the axis of ordinates is plotted/deposited. As this usually occurs, magnetic induction sharply falls after coolings, and differential temperature coefficient reverses the sign with the passage of the first temperature cycle. Approximately/exemplarily the same temperature cycles were taken, also, for the remaining ferrite disks.

On the basis of experiments conducted it is possible to conclude that the accelerated method of the study of the reversible and irreversible changes in the magnetic induction in question is very promising.

Obtained experimental data make it possible to assert that the temperature coefficient of magnetic systems depends on the degree of partial demagnetization. An increase in the degree of demagnetization with alternating magnetic field in the investigated magnetic systems leads to an increase of the temperature coefficient in the range of temperatures from +100 to -180°C. In this case the first temperature cycle and irreversibility after the first cooling also depend very greatly on the degree of partial demagnetization.

6-3. Reversible changes in the magnetic induction of magnetic systems with a change in the temperatures, investigated with the aid of the measurements of magnetic induction.

The electrodynamic magnetometer (Sec. 2-2) it was possible to apply for the measurements of magnetic induction only in a comparatively small range of temperatures, approximately/exemplarily from -5 to +60°C. This limitation was connected with the fact that at reduced temperatures in air gap of the magnetic system being investigated dropped out the hoarfrost, which impeded the displacement of the measuring framework, and the strong heating of magnetic system caused the motion of hot air and also somewhat upset the operation of magnetometer. In this narrow temperature range the dependence of magnetic induction on the temperature for the partially demagnetized magnetic systems, which pass repeated temperature cycles, it is possible to assume/set by linear, to consider temperature coefficient as constant and to determine it in the extreme values of magnetic induction for each separate temperature range.

The temperature coefficient of magnetic induction was determined by this method for 194 magnetic systems with the external and inner frame magnets, which obtained the magnetic aging, which consisted in the partial demagnetization to 6-10% by alternating magnetic field with a frequency of 50 Hz.

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With the external magnets were investigated 109 systems. From them 16 systems with the magnets from the alloy ЮНДК15 (sizes/dimensions see in table 2-3, system 1), rest - with the magnets from the alloys ЮНД8, ЮНД12, ЮНДК15, ЮНДК18, ЮНДК24, ЮНДК24А, ЮНДК25БА, ЮНДК35Т5 and АНК01 (sizes/dimensions see in table 2-3, systems 3 and 4). Of 85 magnetic systems with inner frame magnets 15 had the magnets from the alloy ЮНДК25БА (sizes/dimensions see in table 2-3, system 7), rest - from the alloys ЮНД12, ЮНДК15, ЮНДК24, ЮНДК25БА, ЮНДК35Т5 (sizes/dimensions see in table 2-3, system 5).

The measurement of magnetic induction in air gap in the larger part of magnetic systems was realized with the aid of 4 electrodynamic magnetometers (Сеч. 2-2), whose its own temperature coefficient was negligible. In 15 systems with the inner frame magnets from the alloy ЮНДК25БА magnetic induction was measured by the magnetometer, based on the quasi-balanced method (Section Сеч. 2-3), which has also very low its own temperature coefficient. In this case the temperature vary within the range of -150 to +80°C. However, the dependence of magnetic induction on the temperature was close to the linear only in the range from +80 to 0°C, for which is given temperature coefficient.

Heating all magnetic systems being investigated was conducted with the aid of the heating element with the double winding, dressed to the magnetic circuit of system, and for cooling the systems insertion/immersion was applied into liquid nitrogen of the part of the mount/mandrel, on which was established/installed the system being investigated. Temperature was measured by the thermocouple, which was fastened on the magnet of the experienced/tested system (for example, it was established/installed in the opening/aperture on the polar at the end of system with the external magnets).

Table 6-2 gives the average/mean values of temperature coefficients, and also their scatter for the individual parties/batches of magnetic systems. For each party/batch the number of system on table 2-3 is indicated, to which the sizes/dimensions of the investigated magnetic systems correspond. Total relative error during the determination of temperature coefficient could be approximately/exemplarily rated/estimated in 5-10%.

As follows from table 6-2, the average/mean value of temperature coefficient lies/rests within the limits -(0.015-0.03) %/1°C with the scatter about the average/mean value of order ±40%. Only one of the parties/batches of systems with the magnets АНКО1 has comparatively small scatter, which does not exceed ±8%. In the table are given the results testing the two parties/batches of systems with the inner frame magnets from one and the same alloy ЮНДК35Т5, obtained from the different producers. The temperature coefficients of these parties/batches proved to be different. On the other hand, three individual parties/batches with the external magnets from the alloy ЮНДК15, also prepared in the different places, possess the little distinguished temperature coefficients. The magnetic systems with external and inner frame magnets from the alloy ЮНД12, obtained from one and the same producer, having the same average temperature coefficient and identical scatter.

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The heterogeneity of the investigated magnetic systems according to the temperature coefficient is one of the extremely undesirable factors, since it does not make it possible to previously develop the necessary temperature compensation. Therefore all temperature coefficients, which sharply differ from average/mean value for this party/batch, were checked using 2-3 times (also on other magnetometer) in order to exclude possible random error. From this point of view it is of great interest by one of the parties/batches of 7 magnetic systems with the inner frame magnets from the alloy ЮНДК24, in which proved to be two magnetic systems (11 and 12) with the temperature coefficient, close to zero (Fig. 6-12). These results were not used in table 6-2 for the calculation of scatter for the systems with the inner frame magnets from the alloy ЮНДК24, since they no longer were repeated in other parties/batches and, possibly, they are not characteristic for this alloy.

The curves, which express the dependence of increments in the magnetic induction on the temperature (Fig. 6-13), characterize 4 magnetic systems with the inner frame magnets from the alloy ЮНДК24, which did not pass magnetic aging. Three of them (11-13) relate to the party/batch of 7 systems, above (Fig. 6-12) examined.

Table 6-2.

(1) Конструкция магнитной системы	(2) Номер системы по табл. 2-3	(3) Сплав постоянных магнитов	(4) Число систем в партии	(5) Температурный коэффициент	
				(6) среднее значение, %/1 °С	(7) разброс от среднего значения, %
(8) с внешними магнитами	5	ЮНД12	13	—0,03	±30
	5	ЮНДК24	22	—0,025	±40
	5	ЮНДК25БА	6	—0,02	±25
	7	ЮНДК25БА	15	—0,016	±15
	5	ЮНДК35Т5	11	—0,015	±35
	5	ЮНДК35Т5	18	—0,03	±60
(9) с внутрирамочными магнитами	4	ЮНД8	5	—0,04	±25
	3	ЮНД8	14	—0,015	±40
	3	ЮНД12	20	—0,03	±30
	3	ЮНДК15	10	—0,02	±50
	4	ЮНДК15	6	—0,018	±30
	1	ЮНДК15	16	—0,025	±40
	4	ЮНДК18	5	—0,035	±30
	3	ЮНДК24	4	—0,02	±25
	3	ЮНДК24А	10	—0,02	±50
	4	ЮНДК24Т2	5	—0,04	±25
	3	АНКО1	10	—0,02	± 8
	4	АНКО1	4	—0,025	±20

Key: (1). Construction/design of magnetic system. (2). Number of system on tables 2-3. (3). Alloy of permanent magnets. (4). Number of systems in party/batch. (5). Temperature coefficient. (6). average/mean value, %/1°C. (7). scatter from the mean value, %. (8). with the external magnets. (9). with the inner frame magnets.

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All 4 systems underwent the temperature effects through several hours after magnetization. As can be seen from Fig. 6-13, reaction to changes in the temperature was different: in systems 11 and 12 differential temperature coefficient in the initial segment of a curve was close to zero, and irreversibility is very great. While system 13, possessing differential temperature coefficient, close to the average/mean value of temperature coefficient for the systems with the magnets from this alloy, has negligibly low irreversibility with a change in the temperature within the limits from +40 to 0°C; in system 14 they have comparatively large value both differential temperature coefficient and irreversibility.

The curves, represented in Fig. 6-13, show that the systems with the magnets from the alloy ЮНДК24, which did not pass partial of demagnetization, larger partly possess many-valued differential temperature coefficient even in the limits from 0 to +40°C. The curves, which relate to systems 11 and 14, attesting to the fact that their magnetic induction decreases both after the heating and after cooling. Furthermore, it is possible to note also that there is no direct proportionality between the reversible and irreversible phenomena with a change in the temperature, and each of these sides actually of single physical process needs study.

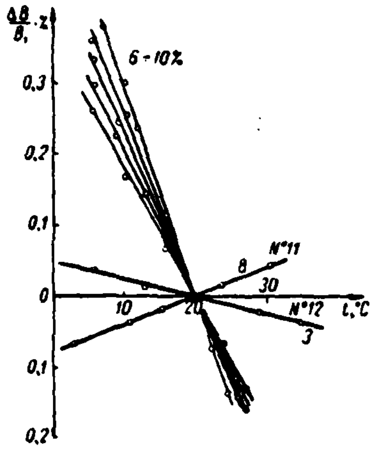

Fig. 6-12.

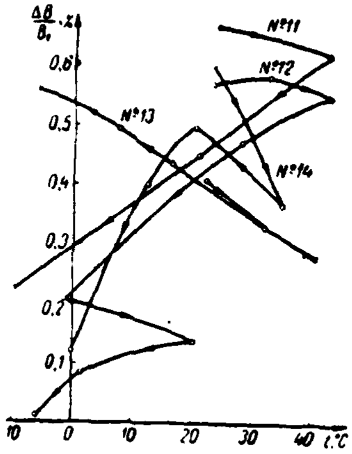

Fig. 6-13.

Fig. 6-12. Dependence of magnetic induction on the temperature in magnetic systems with the inner frame magnets from the alloy ЮНДК24 at the different values of temperature coefficient.

Fig. 6-13. Dependence of magnetic induction on the temperature in magnetic systems with the inner frame magnets from the alloy ЮНДК24 in the absence of demagnetization.

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For 3 systems (12, 13, 14) were investigated the irreversible changes in the induction after partial demagnetization. As it proved to be, magnetic system 13 possesses very low irreversibility after cooling or heatings, also, in the case of partial demagnetization. The results of tests are given below (Fig. 6-18).

System 14 was subjected to more detailed study. Temperature hysteresis was investigated several times with different degree of partial demagnetization. Fig. 6-14 gives the temperature cycle, obtained during the partial demagnetization to 2.5%. In this case the irreversibility is already comparatively small. Temperature coefficient for this temperature range in this system can be taken as equal to -0.027%/1°C. The same system, demagnetized to 26% (Fig. 6-15), already does not have decrease of magnetic induction after the cooling, which follows after the heating, and after the first heating temperature cycle it becomes comparatively narrow, close to straight line, and the value of temperature coefficient proves to be equal to -0.044%/1°C.

For 10 magnetic systems with the inner frame magnets the investigation of the effect of difference in the magnetic circuit on the temperature coefficient was carried out. Obtained experimental data are given in table 6-3.

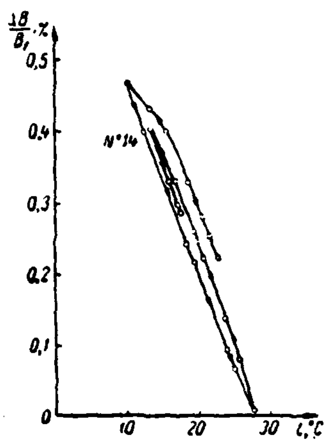

Fig. 6-14.

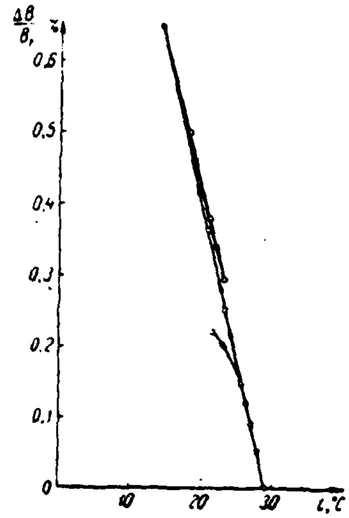

Fig. 6-15.

Fig. 6-14. Cycle of magnetic hysteresis for the magnetic system with the inner frame magnet from the alloy ЮНДК24, demagnetized to 2.5%.

Fig. 6-15. Cycle of magnetic hysteresis for the magnetic system with the inner frame magnet from the alloy ЮНДК24, demagnetized to 26%.

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The results of the tests of the same magnetic systems for the stability in the time are given above (Fig. 5-5). Systems 1-6 had magnets from the alloy ЮНДК24, in systems 7-9 magnets were from the alloy ЮНДК24Т2, and in system 10 - from the alloy ЮНДК24Т0.5. In this case systems 1-9 tested with three different magnetic circuits: with the 1st - made of steel 10 (sizes/dimensions see in table 2-3, system 6); the 2nd - from the Armco (sizes/dimensions the same); the 3rd - from the Armco (sizes/dimensions see in table 2-3, system 5). As it was already indicated, the replacement of the 1st magnetic circuit by the 3rd increased the induction of system by 10-15%, and the transition/junction of the 2nd to the 3rd raised it by 6-10%. System 10 tested without the magnetic circuit or with the most massive 3rd magnetic circuit, whose removal/distance led to a decrease in the induction to 70%.

From the data, given in table 6-3 it follows that upon transfer from the 1st magnetic circuit to the 3rd the temperature coefficient grows/rises in the value by 20-30%. At the same time the values of temperature coefficient for the 2nd magnetic circuit lie/rest, as one would expect, in the gap/interval between the appropriate values for the 1st and 3rd magnetic circuits. Moreover in magnetic system 10 removal/distance of magnetic circuit leads to the decrease of temperature coefficient up to zero. Analogous results for another system with the taken magnetic circuit were obtained during the study of the dependence of magnetic induction on the temperature by the accelerated method; its temperature coefficient in the range from +100 to 0°C is also close to zero (Fig. 6-4).

Table 6-3.

(1) Номер магнитной системы	(2) Температурные коэффициенты (в % на 1° C)		
	(3) Магнитопроводы		
	1-й	2-й	3-й
1	—0,016	—0,017	—0,022
2	—0,018	—0,02	—0,023
3	—0,018	—0,021	—0,025
4	—0,035	—0,035	—0,045
5	—0,02	—0,022	—0,029
6	—0,015	—0,015	—0,018
7	—0,045	—0,053	—0,055
8	—0,021	—0,034	—0,035
9	—0,034	—0,038	—0,044
10	—	—	—0,04

Key: (1). Number of magnetic system. (2). Temperature coefficients (in % on 1°C). (3). Magnetic circuits.

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6-4. Irreversible changes in the magnetic induction of magnetic systems with a change in the temperatures, investigated with the aid of the measurements of magnetic induction.

As is known, for the purpose of decrease in the magnetic systems of the irreversible changes in the induction, caused by changes in the temperature, the temperature stabilization, which consists of several heatings, is been commonly used. Since the temperature stabilization of system is passed, as a rule, already after assembly, together with the measuring part of the instruments, they protect them from especially chillings, which can badly/poorly affect instrument itself. However, during the transportation, and sometimes also under operating conditions magnetic systems undergo the coolings, which reach -50°C. Therefore it is necessary during the development of temperature stabilization to be guided by tentative experimental data, which show, for what precisely alloys and with what degree of partial demagnetization it is not possible to be limited to some heatings should be compulsorily introduced temperature stabilization by coolings.

The study of the irreversible increments in the magnetic induction, caused by changes in the temperature, was performed for different magnetic systems, whose general view was given in Fig. 2-10, and sizes/dimensions - table 2-3. From them 64 systems with the external magnets from the alloys ЮНД8, ЮНД12, ЮНДК15, ЮНДК24, ЮНДК24А and АНКО1 had sizes/dimensions, given for the system 3 in Table 2-3, and 15 of more massive systems with the external magnets from the alloy ЮНДК15 (sizes/dimensions see in table 2-3, system 1). Furthermore, were investigated 93 systems with the inner frame magnets from the alloys ЮНД12, ЮНДК24, ЮНДК25БА and ЮНДК35Т5 (sizes/dimensions see in table 2-3, system 5), 15 systems with the inner frame magnets from the alloy ЮНДК25БА (sizes/dimensions see in table 2-3, system 7), 15 systems with the U-shaped magnets from the alloy ЮНДК20 (sizes/dimensions see in table 2-3, system 8), and also

15 systems with the magnets from the alloy ЮНДК24 (sizes/dimensions see in table 2-3, system 9).

Magnetic systems with the inner frame magnets from the alloy ЮНДК24 were most in detail investigated. First of all 12 systems of them were divided into 4 groups of 3 systems, which passed heating and cooling to different sequence. All of these 12 systems were magnetized, were demagnetized to 6-10% and underwent quintuple temperature effects with duration of 3 h each. Then anew they were magnetized, were demagnetized to 6-10% and were obtained twofold temperature effects. After which they were magnetized for the third time; again they were demagnetized to 6-10%, are passed quintuple temperature effects, lay/rested 5 days, was obtained latter/last temperature effect and again lay/rested 5 days.

For the clarity the results of tests are given in the form of graphs/curves (Fig. 6-16-6-19). In this case on the axis of abscissas the heatings and coolings are indicated, while with the time delay - time in the days; along the axis of ordinates are plotted/deposited increments in the magnetic induction in the percentages of its initial value, which are irreversibility when these increments are caused by temperature effects. In the separate curves the number of magnetic system is noted, so that it would be possible to trace its behavior under further temperature influences.

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The first group of the investigated systems passed heating down to +80°C only and only quite latter/last temperature effect was cooling down to -40°C (Fig. 6-16). From the figure it follows that the magnetic systems, which obtained the temperature stabilization, which consists of some heatings to +80°C, sharply react to the cooling down to -40°C: for example, one of the systems as a result of cooling decreased its induction by 0.2%.

The second group of magnetic systems passed the heatings to 280°C, which alternate with the coolings down to -40°C (Fig. 6-17). In this case the reactions to the latter/last temperature effect - cooling down to -40°C - are considerably weaker.

In the third group of magnetic systems were only some coolings down to -40°C, and heating to +80°C (Fig. 6-18) was here quite latter/last temperature effect.

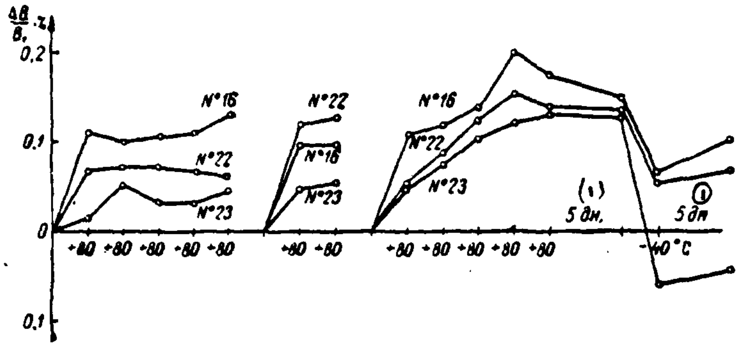

Fig. 6-16. Irreversibility after repeated heatings in the demagnetized to 6-10% magnetic systems with the inner frame magnets from the alloy ЮНДК24.

Key: (1). day.

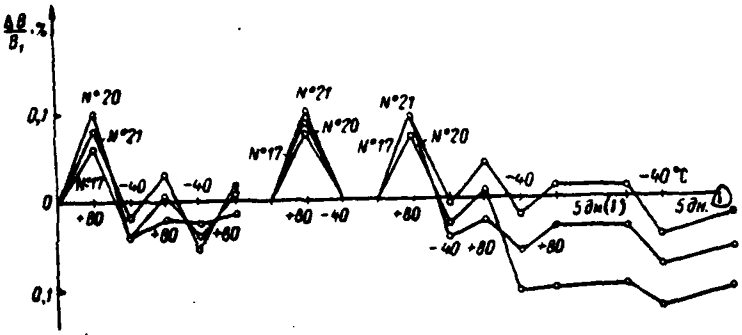

Fig. 6-17. Irreversibility after the heatings, which alternate with the coolings, in the demagnetized to 6-10% magnetic systems with the inner frame magnets from the alloy ЮНДК24.

Key: (1). day.

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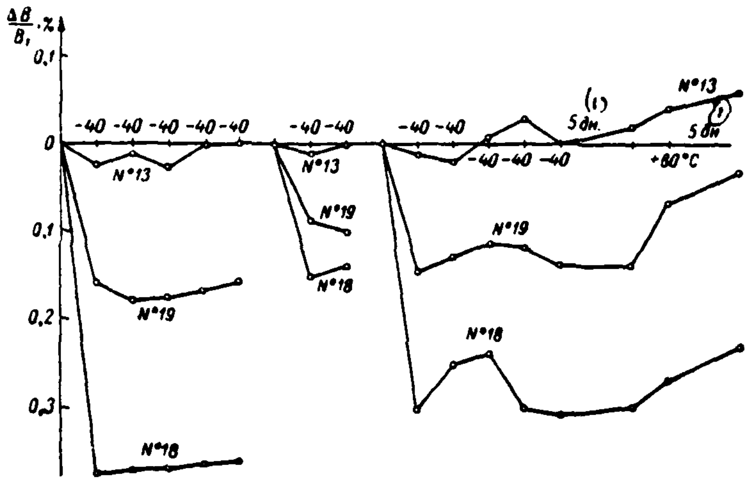

Fig. 6-18. Irreversibility after repeated coolings in the demagnetized to 6-10% magnetic systems with the inner frame magnets from the alloy ЮНДК24.

Key: (1). day.

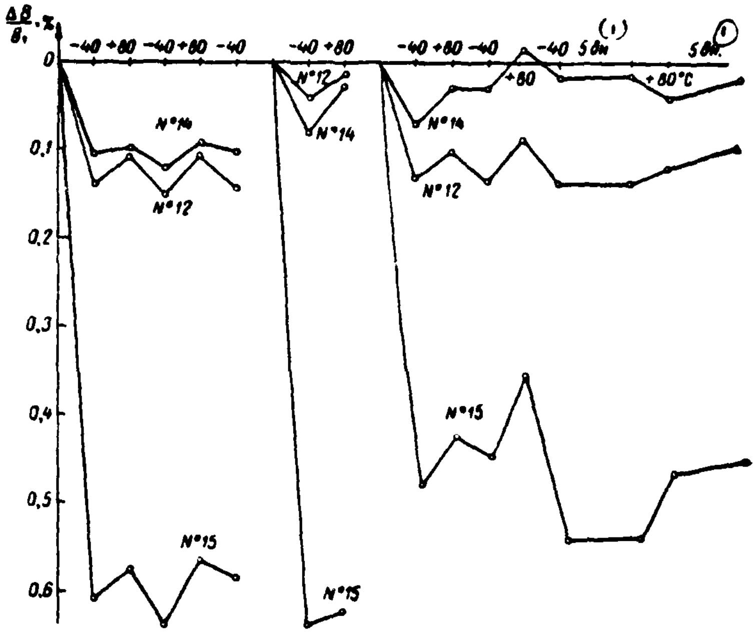

Fig. 6-19. Irreversibility after the coolings, which alternate with the heatings in the demagnetized to 6-10% magnetic systems with the inner frame magnets from the alloy ЮНДК24.

Key: (1). day.

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The fact attention is drawn to that in the systems in question are repeated the curves during the repetition of temperature conditions. System 13, for which the dependence of magnetic induction on the temperature in the absence of the partial demagnetization (see Fig.

6-13) was taken has both there and here, very low irreversibility and it sharply differs in terms of this from other systems.

The latter/last, fourth group of magnetic systems obtained the coolings down to -40°C, which alternate with the heatings to +80°C; latter/last temperature effect was here heating to +80°C (Fig. 6-19). Curves for the separate systems and in this case are repeated, and system 15 has very large irreversibility in comparison with systems 12 and 14, the results of tests of which without the partial demagnetization are given in Fig. 6-13. Furthermore, in this case just as during the heatings, which alternate with the coolings (Fig. 6-17), occurs the saw-tooth temperature dependence, which is retained also after the first temperature cycle. This saw-tooth curve testifies about the very undesirable phenomenon, namely about the fact that the temperature stabilization, which consists of the heatings and the coolings, carried out for example twice, does not shield these systems from the irreversibility, but only somewhat decreases it.

The values of irreversibility after heatings to +80°C, and also after coolings down to -40°C are given in the curves, which relate to the investigation of stability in the time after magnetic and temperature aging, Fig. 5-19-5-26. It is possible to note that the systems with the inner frame magnets from the alloy ЮНДК24 (Fig.

5-25), demagnetized to 6-10% and the passed repeated heatings to +80°C, have comparatively large irreversibility after cooling down to -70°C, as it takes place also in the curves, given in Fig. 6-16.

As is known, magnetic systems very frequently differ in their induction and this difference sometimes reaches to ±20%, and it can prove to be even more. It seems very probable that so that all systems would have identical induction, some of them can be demagnetized to 20-30%, whereas others, with the smaller induction, will be demagnetized in all to 1-2%.

It is clear, of course, which to judge the effectiveness of temperature stabilization for different systems is possible only by having a dependence of irreversibility on the degree of demagnetization. During the study of this dependence the determination of irreversibility for the magnetic systems, which did not pass partial demagnetization, is very substantial, since it makes it possible to rate/estimate the greatest possible value, which can occur for the magnetic systems of the given construction/design with the magnets of the alloy being investigated. It is necessary to also investigate irreversibility during the strong demagnetization in order with a sufficient completeness to describe the effect of the degree of demagnetization. It is especially important to study the effect of coolings on the magnetic systems in this case, since into usual temperature stabilization they frequently do not enter.

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The investigation of the effect of the degree of demagnetization on the irreversibility after temperature effects was made for 140 magnetic systems with the external and inner frame magnets from alloys ЮНД8, ЮНД12, ЮНДК15, ЮНДК24, ЮНДК24А, ЮНДК35Т5 and АНКО1. The investigated systems were divided on 4 parties/batches. First party passed two heatings to +80°C the second - heating to +80°C and cooling down to -40°C, the third - two coolings down to -40°C, the fourth - first cooling down to -40°C and then heating to +80°C. All temperature effects were duration on 4 h. Moreover all systems tested on 5 times: first without the partial demagnetization, and then during the partial demagnetization, equal to 2-3; 6-8; 16-20; and 30-40%. It was thus possible to find the optimum degree of demagnetization.

For an example Fig. 6-20-6-23 gives the results of the tests of 12 magnetic systems with the inner frame magnets from the alloy ЮНДК24.

On the basis of the obtained curves it is possible to arrive at the conclusion that the systems with the inner frame magnets ЮНДК24, not completely demagnetized or demagnetized to 1-3%, possess, as a rule, the increased reaction for the cooling down to -40°C even when it preceded heating to +80°C. Consequently, temperature stabilization with +80°C is insufficient for the nondemagnetized and weakly-demagnetized systems, if it is possible to expect subsequently of coolings down to -40°C. At the same time in the systems, demagnetized by 16-38%, induction does not decrease after these coolings. Reaction for the heating is also different for the systems, nondemagnetized and demagnetized to the different degree.

The rest of 128 magnetic systems with the external and inner frame magnets from the different alloys underwent analogous tests. For these systems were constructed the same curves, as in Fig. 6-20-6-23. In connection with a lack in space they cannot be given. However, since different alloys possess different irreversibility after temperature effects, it was necessary to give these experimental data at least, also, in the abbreviated/reduced form. Therefore on the basis of the results of tests was determined the average/mean irreversibility, which is given in Fig. 6-24-6-27.

In essence the experimental data, which relate to the individual batch of systems with the magnets from one and the same alloy, that obtained identical temperature effects, more or less coincided. At the same time some systems differed in the irreversibility from other systems of the party/batch in question. These differences most sharply were developed in the absence of partial demagnetization and in the known degree were retained during the weak demagnetization.

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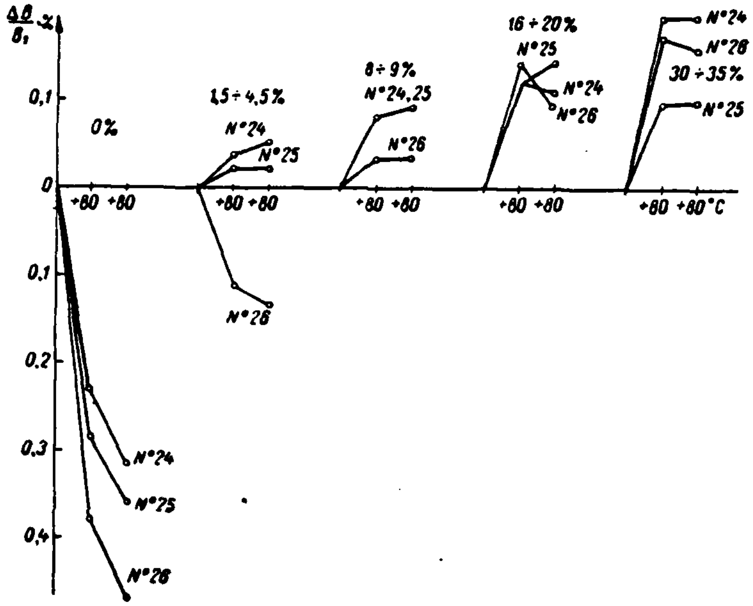

Fig. 6-20. Irreversibility after heatings in the magnetic systems with the inner frame magnets from the alloy ЮНДК24, which passed different partial demagnetization.

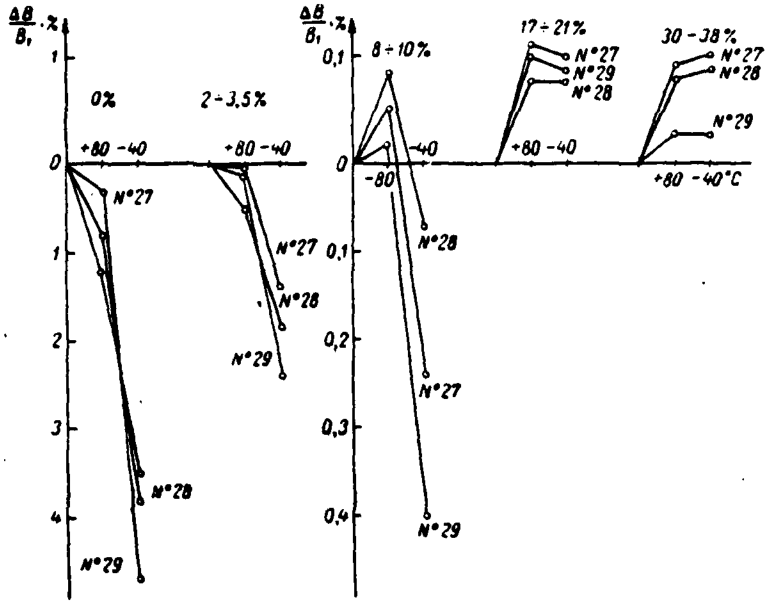

Fig. 6-21. Irreversibility after the heating, which follows the cooling, in the magnetic systems with the inner frame magnets from the alloy ЮНДК24, which passed different partial demagnetization.

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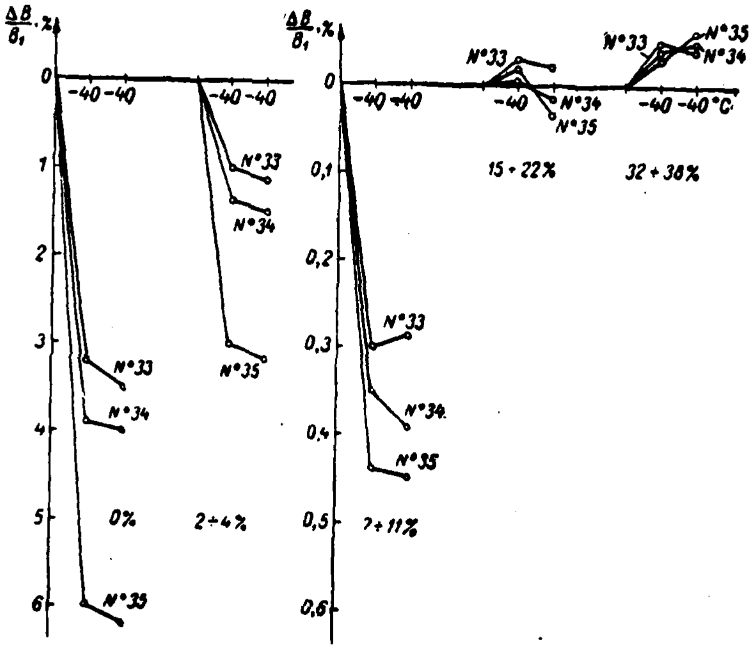

Fig. 6-22. Irreversibility after coolings in the magnetic systems with the inner frame magnets from the alloy ЮНДК24, which passed different partial demagnetization.

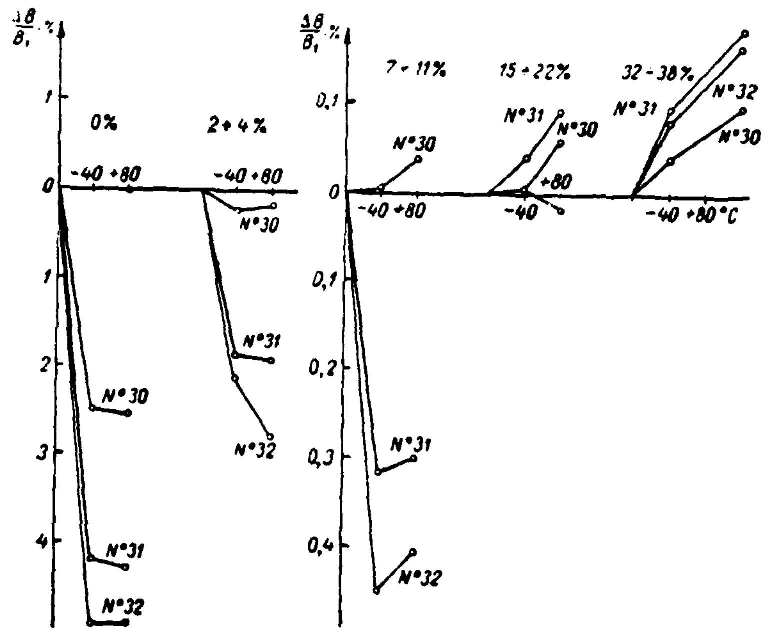

Fig. 6-23. Irreversibility after the cooling, which follows the heating, in the magnetic systems with the inner frame magnets from the alloy ЮНДК24, which passed different partial demagnetization.

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The systems with the inner frame and external magnets, demagnetized to 10-30%, and the passed heatings to +80°C comparatively little change the magnetic induction (Fig. 6-24). Irreversibilities in this case do not exceed 0.1-0.2%. The systems with the magnets from the alloy АНКО1 having approximately/exemplarily identical irreversibility after heating to

+80°C both in the absence of demagnetization and during the partial demagnetization of order 40%.

The magnetic systems with the inner frame and external magnets from the alloys ЮНД8 and АНКО1, which passed demagnetization to 10-25% and cooling down to -40°C have also very low irreversibility, the order of several hundredths of percentage (Fig. 6-25). Whereas for the systems with the magnets from the alloys ЮНД12, ЮНДК15 and ЮНДК35Т5 after the same cooling and the demagnetization it is close in the value to the irreversibility after heatings to +80°C (Fig. 6-24).

Analogous curves for the systems with the inner frame magnets from the alloys ЮНДК24 and ЮНДК25БА and the systems with the external magnets from the alloy ЮНДК24А, which obtained cooling down to -40°C, are represented in Fig. 6-26. Scale along the axis of ordinates for these systems is 8 times more than scale for the curves, given in Fig. 6-24 and 6-25. It is necessary to pay special attention to comparatively large irreversibilities after cooling down to -40°C in systems with the magnets from these alloys; only with the degree of the demagnetization of order 15% they are close to 0.1%.

Reheatings to +80°C and the cooling down to -40°C caused comparatively low irreversibilities in all investigated systems.

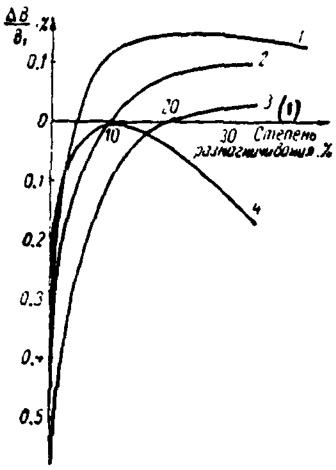

Fig. 6-24.

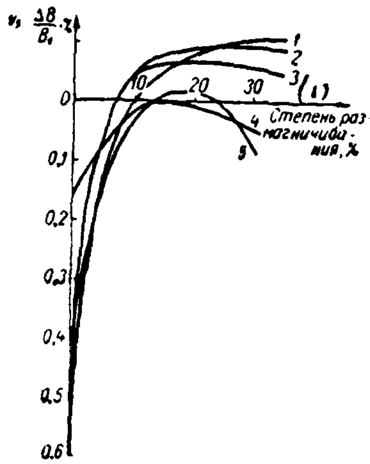

Fig. 6-25.

Fig. 6-24. The dependence of average/mean irreversibility after heating to 80°C on the degree of partial demagnetization in magnetic systems with the magnets from different alloys: 1 - ЮНДК24, ЮНДК24А, ЮНДК35Т5, ЮНДК15; 2 - ЮНДК25БА; 3 - ЮНД8, ЮНД12; 4 - АНКО1.

Key: (1). Degree of demagnetization, %.

Fig. 6-25. The dependence of average/mean irreversibility after cooling down to -40°C on the degree of partial demagnetization in magnetic systems with the magnets from different alloys: 1 - ЮНДК15; 2 - ЮНД12; 3 - ЮНДК3Т5; 4 - АНКО1; 5 - ЮНД8.

Key: (1). Degree of demagnetization, %.

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In this case the irreversibility after the second heating or cooling was already approximately/exemplarily equal to one fifth that irreversibility, which took place after the first temperature effect as this it is possible to see from the curves, constructed for the systems with the inner frame magnets from the alloy ЮНДК24 (Fig. 6-20 and 6-22).

In magnetic systems with the magnets from the alloys ЮНД8, ЮНД12, ЮНДК15, ЮНДК35Т5 and АНКО1 the irreversibilities after coolings down to -40°C, the following after the heatings to +80°C, and also after the heatings, which alternate with the coolings, were of the same order as as in the case of repeated coolings or reheatings.

Matter for the magnetic systems concerning the magnets from the alloy ЮНДК24, ЮНДК24А and ЮНДК25БА otherwise was. These systems had the increased reaction for the cooling down to -40°C even when it preceded heating to +80°C. The curves, given in Fig. 6-26, can characterize also the irreversibility of these systems after cooling down to -40°C, the following after the heating to +80°C. On the other hand, for the same systems with the magnets from the alloys ЮНДК24, ЮНДК24А and ЮНДК25БА the irreversibility after the heatings to +80°C, conducted after cooling down to -40°C is already negligibly low and it approximately/exemplarily corresponds to that irreversibility, which occurs after reheating to +80°C.

Irreversibility after coolings down to -100°C and the heatings to +200°C was also investigated for the magnetic systems with the external and inner frame magnets from the alloys ЮНД12, ЮНДК15, ЮНДК35Т5 and ЮНДК25БА. The results of tests are partially given in S 5-5.

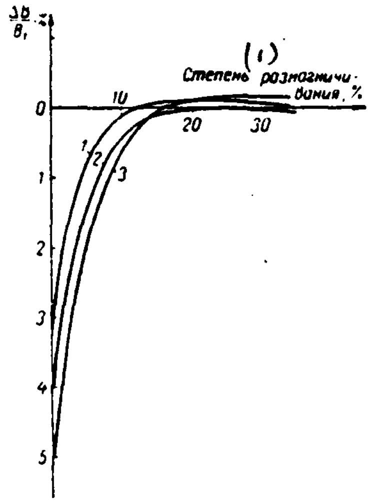

Fig. 6-26.

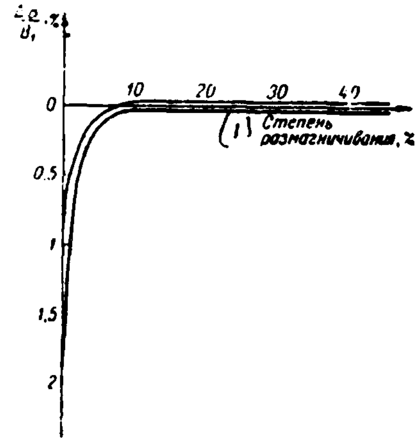

Fig. 6-27.

Fig. 6-26. The dependence of average/mean irreversibility after cooling down to -40°C on the degree of partial demagnetization in magnetic systems with the magnets from the alloys: 1 - ЮНДК25БА; 2 - ЮНДК24А; 3 - ЮНДК24.

Key: (1). Degree of demagnetization, %.

Fig. 6-27. Dependence of average/mean irreversibility after cooling down to -180°C in systems with the U-shaped magnets from the alloy ЮНДК20.

Key: (1). Degree of demagnetization, %.

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As it is possible to conclude on the basis of obtained experimental data, the expansion of the range of temperature effects little changes the irreversibility of the systems, demagnetized to 10%. In magnetic systems with the inner frame magnets from the alloy ЮНДК35Т5 the irreversibility after coolings down to -100°C or the heatings to +200°C does not exceed ±0.04% (Fig. 5-28), whereas magnetic systems with the external and inner frame magnets of the alloy ЮНД12 somewhat more sharply react to the heating to +200°C than for the cooling down to -100°C (Fig. 5-27), but nevertheless their irreversibility is relatively small, it ranges from 0.05 to 0.3%. At the same time irreversibility after cooling down to -100°C in magnetic systems with the inner frame magnets of the alloy ЮНДК25БА comparatively more. For one of the systems it reaches -0.43% (Fig. 5-29).

Irreversibility after cooling down to -180°C with the delay at this temperature for 1 h was studied for the systems with the radial magnetic field with the magnets from the alloy ЮНДК24. The results of tests were identical experimental data, obtained accelerated method (Fig. 6-6-6-8).

Two curves (Fig. 6-27) show the scatter of the dependence of average/mean irreversibility after cooling down to -180°C on the degree of partial demagnetization for 15 magnetic systems with the U-shaped magnets from the alloy ЮНДК20. Delay with -180°C in all cases was equal to 1 h. From the curves it follows that the systems, which did not obtain demagnetization, have an irreversibility after cooling down to -180°C, that is changed within the limits from -0.7 to -2%. During the demagnetization, equal to 4%, this irreversibility lies/rests at the range from -0.1 to -0.2%, while with an increase in the demagnetization to 10-50% it no longer exceeds ±0.03%.

Irreversibility after heatings to +100°C with the delay, equal to 3 h, during the demagnetization, which exceeds 10%, has for these systems the same value - it is found in the range ±0.03%. Whereas in the systems, which did not pass demagnetization, irreversibility after the same heatings to +100°C lies/rests at the range from -0.2 to -0.5%.

The comparison of the results of the prolonged effect of heatings and coolings with the appropriate curves for the case of a rapid, shock change in the temperature (Fig. 6-9 and 6-10) shows that in systems with the magnets from the alloy ЮНДК20 irreversibility both in that and in other case of approximately/exemplarily one order.

For the same systems with the magnets ЮНДК20, demagnetized to 6-10%, was determined the irreversibility during, the alternating coolings down to -70°C and heatings to +100°C and +200°C with the delay on 3 h. Changes in the magnetic induction were under such temperature influences of order ±0.02%. In this case the saw-tooth characteristic, obtained for the systems with the inner frame magnets from the alloy ЮНДК24 (Fig. 6-17, 6-19), was absent.

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Thus, on the basis of given experimental data it is possible to arrive at the conclusion that the investigated systems with the magnets from the alloy ЮНДК20 possess very low irreversibility after temperature effects. Consequently, these magnets it is desirable to apply when it is necessary to ensure the especially high stability of magnetic systems when different temperature effects, for example, of the alternating heatings are present, and coolings.

6-5. Effect of external magnetic fields to the permanent magnets and the magnetic systems.

The study of the effect of external alternating magnetic fields was performed both for bar magnets from the alloys ЮНДК25БА with the steel screen (sizes/dimensions see in Table 2-3, system 10) and for the magnetic systems with the external magnets from the alloys ЮНДК24 and АНКО1 (sizes/dimensions see in Table 2-3, system 2) and the systems with the inner frame magnets from the alloys ЮНДК24 and ЮНДК24Т2 (sizes/dimensions see in Table 2-3, systems 5 and 6). In essence the effect of alternating magnetic fields with a frequency of 50 and 400 Hz was studied and the effect of stationary fields only in some experiments was studied. Uniform external alternating magnetic field was created with the aid of Helmholtz's coils or crossover coil, alternating current in which increased from zero to the specific value and then smoothly it reduced to zero, moreover the magnets being investigated or the systems were turned for the averaging of the effect of magnetic field. The effect of alternating magnetic field underwent 15 bar magnets from the alloy ЮНДК25БА under the varied conditions:

1) without the screen and without the magnetic aging:

2) without the screen, but with the magnetic aging by alternating magnetic field with a frequency of 50 Hz, which demagnetized magnets to 10%;

3) with the screen, without the stabilization;

4) with the screen in the presence of stabilization with partial demagnetization to 10% by alternating magnetic field with a frequency of 50 Hz.

In this case was taken the dependence of the irreversibility, which appears after the effect by alternating magnetic field 50 and 400 Hz on the amplitude of magnetic intensity.

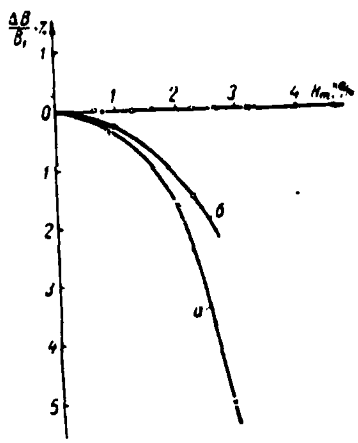

Fig. 6-28

Fig. 6-28. Dependence of irreversibility on the amplitude of the intensity/strength of external alternating magnetic field in bar magnets from the alloy ЮНДК25БА with the screen (point on the axis of abscissas) and without screen (a) with 50, b) with 400 Hz).

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Fig. 6-28 gives the curves, which express the dependence of irreversibility on the intensity/strength of external alternating magnetic field. Two lower curves characterize the irreversibility of magnet without the screen and without the magnetic aging at the frequencies, equal to 50 and 400 Hz, and on the axis of abscissas are shown the points, which were obtained at the appropriate values of the amplitude of magnetic intensity in the remaining three cases (condition 2-4).

On the basis of obtained experimental data, it is possible to conclude that the effect of external alternating magnetic fields; with a frequency of 50 Hz and the amplitude of the intensity/strength, which reaches to 4 to kA/m, and also with a frequency of 400 Hz and an amplitude of the magnetic intensity on the order of 2.5 kA/m, noticeably affects only such bar magnets from the alloy ЮНДК25БА, which did not pass partial demagnetization and do not have screen. Whereas the presence of steel screen or partial demagnetization leads to the fact that at the same values H_m and frequency the irreversibility is in effect equal to zero.

The magnetic systems with the external magnets from the alloys ЮНДК24 and АНКО1 (sizes/dimensions see in Table 2-3, system 2), which passed partial demagnetization to 10% as alternating magnetic field with a frequency of 50 Hz, they underwent the effect of the external magnetic field of both the constant with intensity/strength H=400 a/m and the variable with a frequency of 50 Hz and intensity/strength $H_m = 400$ a/m. In both cases the irreversibility was in effect equal to zero for tens of investigated magnetic systems with an error of measurement of the order of several hundredths of percentage.

For the confirmation of assumption about the fact that the demagnetization by several percentages and less than a hundred percent is admissible from the point of view of the effect of external alternating magnetic fields, was undertaken the study of the effect of these fields for the magnetic induction of the systems, demagnetized to different degree, and for the comparison - not completely demagnetized. For this purpose was studied the effect of external uniform alternating magnetic field with intensity/strength H_m, of that reached to 5 kA/m, and by the frequency of 50 Hz to the irreversibility of systems with the external magnets from the alloys

ЮНДК24 and AHKO1 both nondemagnetized and demagnetized in limits of 1-60%.

Fig. 6-29 gives the curves, taken for the magnetic systems with the magnets from the alloy ЮНДК24, while in Fig. 6-30 - for the systems with the magnets AHKO1. As can be seen from of the curved, the irreversibility magnetic systems being investigated is positive and reaches in certain cases to +0.24% under the effect of external alternating magnetic field. Exception/elimination are the systems with magnets AHKO1, demagnetized to 30 and 60%, whose induction somewhat falls, that, apparently, it is connected with the fact that the induction in these systems is 1.5-2 times less than in systems with the magnets ЮНДК24. However, if systems with the magnets AHKO1 were demagnetized to 6-10% with alternating magnetic field with a frequency of 0.5 Hz between the closely fitted poles of electromagnet, then irreversibility after the effect of external alternating magnetic field with intensity/strength on the order of 5 kA/m was still more and reached to 0.4%.

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The same systems, demagnetized with the same method in the electromagnet, gave sharply distinct reaction for the heating, namely: the irreversibility of such systems after heatings to +80°C was positive (Fig. 5-23). One should note also that during the attempt to partially demagnetize the magnetized magnetic systems with very weak variable field with a frequency of 50 or 0.5 Hz between the poles of electromagnet it was possible to obtain not decrease, but an increase of the gap density of the order of the tenths of percentage. During the investigation of the magnetic systems of other layouts, for example systems with the inner frame magnets from the alloy ЮНДК24 either from the alloy ЮНДК24T2, it was possible to also observe the increase of induction in the gap of systems after the effect by weak external variable field or during the attempt to partially demagnetize the system between the poles of electromagnet with very weak variable field, this irreversibility reaching to 1%.

The observed increase of magnetic induction, it is very probably, is connected with the fact that we deal concerning the magnetic system, in which permanent magnets compose the part of the magnetic circuit only. Therefore the effect of external magnetic fields can be manifested differently in the dependence on the layout and the magnetic state of entire system.

It must be noted that if the magnetic system during the magnetization is found between the poles of electromagnet, then the magnetic flux of the magnets of this system is closed through magnet core, and magnetic flux in the magnetic circuit is directed to opposite side with respect to that to direction which a flow will have in the magnetic circuit after the magnetization of system and removal/distance from the electromagnet.

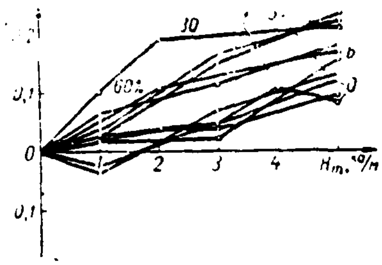

Fig. 6-29.

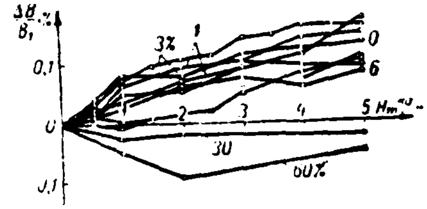

Fig. 6-30.

Fig. 6-29. Dependence of irreversibility on the amplitude of the intensity/strength of external alternating magnetic field in magnetic systems with the external magnets from the alloy ЮНДК24.

Fig. 6-30. Dependence of irreversibility on the amplitude of the intensity/strength of external alternating magnetic field in magnetic systems with the external magnets from the alloy AHKO1.

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Even after partial demagnetization, when coil current of electromagnet is equal to zero magnetic flux of the magnets of system partially it is closed through magnet core, and magnetic flux in the magnetic circuit differs from that, which will there be after the removal/distance of system from the electromagnet.

AD-A139 471 STABILITY OF PERMANENT MAGNETS(U) FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH A V MITKEVICH 06 MAR 84 FTD-ID(RS)T-1344-83 4/4

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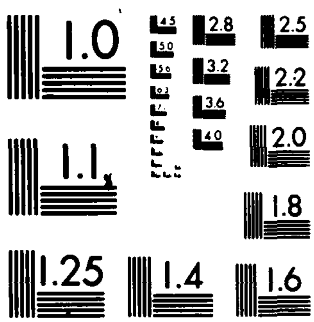

MICROCOPY RESOLUTION TEST CHART

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Usually this redistribution of magnetic flux is considered magnetic aging as not lowering, since they examine the stabilization of magnets only and disregard working conditions of magnetic circuit. As a result the system, which passed stabilization between the sufficiently closely fitted poles of electromagnet, proves to be insufficient that stabilized.

In the magnetic systems with the external or inner frame magnets with the sufficiently large sizes/dimensions of these systems it is possible to investigate the effect of alternating magnetic fields to the air-gap flux, if we divide the effect of variable field to the magnets and to the magnetic circuit. This was carried out for the magnetic systems with the external magnets AHK01 (sizes/dimensions see in Table 2-3, system 2).

For the direct observation of a change in the magnetic flux of these magnets to winding 1 (Fig. 6-31), wound up around the magnets near the gap, the sufficiently inertial ballistic galvanometer, which did not virtually react to the very weak alternating magnetic field with the frequency of external 50 Hz, was connected. With a gradual increase of alternating coil current by 2, wound up on the magnets, was observed flux exclusion both on the smooth displacement of the indicator of galvanometer during the increase of alternating current and from readings/indications of magnetometer, obtained in the measurement of the magnetic induction of system to the effect by alternating coil current by 2, also, after it. A gradual increase of alternating coil current by 3, wound up by the magnetic circuit, produced, on the contrary, the increase of the magnetic flux of magnets, which was being observed on the smooth displacement of the indicator of galvanometer to opposite side and from the appropriate readings/indications of magnetometer. This increase of the flow in the gap reached 0.5-1%, and in some systems even 3%.

Furthermore, to affect by the weak variable, which decreases up to zero, by magnetic field to the magnetic circuit is possible between the poles of electromagnet, if we install magnetic systems across the field of electromagnet, i.e., to turn them from the usual position on 90°. In this case the increase of induction in the gap was order 0.4-0.8%.

It is obvious that strongly by increasing alternating coil current by 3 or transverse variable field of electromagnet, we will obtain further already the decrease of magnetic induction.

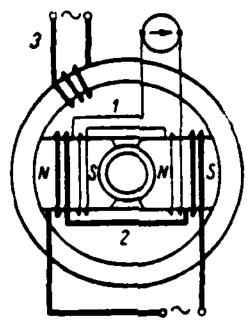

Fig. 6-31. Magnetic system with the external magnets with the windings, arranged/located in the different sections of this system.

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So that it would be possible to again observe its increase under the influence by variable field to the magnetic circuit, it is necessary to anew magnetize system or even only to establish/install it between the poles of electromagnet (in the absence of current in its windings) closely fitted to the magnetic circuit and to retract. This operation/process gave magnetic system again into the state, in which an increase in the induction under the influence by alternating magnetic field to the magnetic circuit of system is possible.

The increase of the gap density, caused by the effect of variable field to the magnetic circuit of the system of the same sizes/dimensions with the external magnets from the alloy ЮНДК24, could not directly observe when these systems were magnetized before the saturation, but in the same systems, magnetized approximately/exemplarily to 50%, this increase occurred and reached to 1%.

It seems very probable that since in the systems with the magnets ЮНДК24, magnetized before the saturation, the magnetic induction 1.5-2 times exceeds the induction of systems with the magnets АНКО1, working conditions of magnetic circuit must be different from the appropriate conditions for the systems with the magnets АНКО1. At the same time in the systems with the magnets ЮНДК24, magnetized not before the saturation, these conditions are nearer to those which occur in systems with the magnets АНКО1.

As it was possible to expect, external alternating magnetic field with intensity/strength $H_m = 5$ kA/m does not already virtually affect induction in the gap of the magnetic systems in question, demagnetized by several percentages with variable field with the aid of winding by 2 (Fig. 6-31) or by transverse ones by the variable field between the poles of electromagnet.

Thus, the increase of magnetic induction under the influence by external alternating magnetic field was absent in the partially demagnetized systems under the conditions, when there was no change in the layout of magnetic flux after the partial demagnetization, and therefore close to those in which the magnetic systems will work subsequently.

Partial demagnetization under the conditions, in which the magnetic systems will more lately work, always cannot be sufficiently simply realized. Therefore the effect of external variable field to the systems, demagnetized by several percentages with usual variable field in the electromagnet and which passed another treatment by weak transverse variable field in the same electromagnet was studied after this. In that case, as one would expect, the effect of external alternating magnetic field with the intensity/strength to 5 kA/m for the induction in the gap of systems virtually was absent.

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On the basis of entire of that outlined above it is possible to arrive at the conclusion that the frequently used partial demagnetization of magnetic systems with variable field under the conditions, when after demagnetization the layout of the magnetic flux of these systems is changed, leads to the fact that the magnetic aging by partial demagnetization proves to be insufficient, if these systems will more lately undergo the effect of external magnetic field with intensity/strength on the order of 2-5 kA/m. Therefore, if it is possible to expect the effect of similar external magnetic fields, it is necessary to provide under such conditions the partial demagnetization of systems so that after the demagnetization the redistributions of magnetic flux would not appear.

In the same cases, when changes in magnetic flux distribution (for example, during the demagnetization between the closely fitted poles of a-c electromagnet), accompany the partial demagnetization of magnetic systems, should be introduced supplementary treatment by the weak, smoothly decreasing transverse variable field between the poles of the same electromagnet. After this supplementary treatment external magnetic fields with the intensity/strength to 5 kA/m virtually no longer have an effect on the magnetic induction of systems.

6-6. Effect of impacts and vibrations on the permanent magnets and the magnetic systems.

Permanent magnets and magnetic systems sometimes undergo very intense impacts and vibrations; therefore it was necessary to obtain experimental data, which characterize irreversibility under such influences. To widely supply such investigations for the magnetic systems of different layouts with the magnets from the different alloys was impossible due to the great difficulties, which appeared with the realization of impacts and vibrations.

Several ten magnetic systems with the external magnets of the alloys ЮНДК24 and АНКО1 (sizes/dimensions see in Table 2-3, system 2) after partial demagnetization by alternating magnetic field to 10% underwent on the vibration stand vibrations with a frequency of 30 Hz upon the acceleration 7g. No changes in the magnetic induction revealed/detected could not be and it was possible to assume that the irreversibility after such effects does not exceed one hundredths of a percent, since the relative error in these measurements, carried out with the aid of the mechanical magnetometer (§ 2-1), was of the order of 0.03%.

Furthermore, to investigation were subjected 4 bar magnets from the alloy ЮНДК25БА (sizes/dimensions see in Table 2-3, system 10), magnetized, set in the screens, partially demagnetized to 10% and fastened/strengthened in the mounts/mandrels by epoxy resin. Magnetic induction was measured in this case with the aid of the magnetometer, based on the quasi-balanced method (§ 2-3). Mounts/mandrels together with the magnets and the screens, in turn, were installed on the vibration stands with the aid of the special ones attachment, which had to avoid the damage of mounts/mandrels and screens during the tests.

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Magnets underwent different vibrations with the intensity/strength of alternating magnetic field $H_m = 1,2$ kA/m and a frequency of 50 Hz. The modes/conditions of vibrations are given in Table 6-4. After each effect magnetic induction was measured and irreversibility was determined.

For the clarity the obtained results are represented in the form of the graphs/curves (Fig. 6-32), from which it is evident that the irreversibility after vibrations does not exceed $\pm$ 0.3%. It is necessary, however, to note that experimental data do not make it possible to determine any laws governing the effect of different modes/conditions of vibrations.

In Fig. 6-33 the analogous graphs/curves, which show the effect of impacts on the magnetic induction for the same 4 bar magnets, fastened/strengthened by epoxy resin in the mounts/mandrels, are constructed.

Table 6-4.

(1) Режимы вибраций	(2) Амплитуда, мм	(3) Частота, гц	(4) Ускорение	(5) Время, ч
I	2,5	10	0,6g	1,5
II	2,5	10	0,6g	10
	0,9	20	0,9g	1
	0,4	30	0,4g	1
III	2,2	40	2,2g	1
	0,15	50	0,15g	1
	0,1	60	0,1g	1

Key: (1). Modes/conditions of vibrations. (2). Amplitude, mm. (3). Frequency, Hz. (4). Acceleration. (5). Time, h.

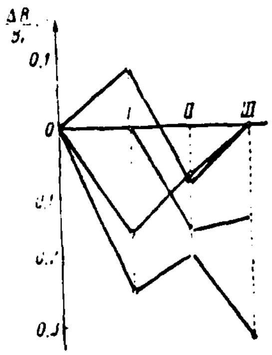

Fig. 6-32.

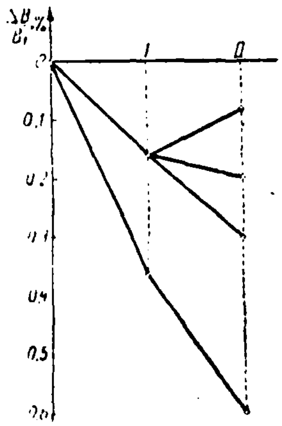

Fig. 6-33.

Fig. 6-32. Irreversibility after the effect of vibrations in bar magnets from the alloy НЮДК25БА with the screen.

Fig. 6-33. Irreversibility after impacts in bar magnets from the alloy ЮНДК25БА with the screen.

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Magnets were magnetized again, set in the screens and they were demagnetized to 10%. Both cycles of the impacts, which consisted of 3 impacts on each of 3 coordinate axes with an identical acceleration of 1000g, were realized on the special stands. Magnetic induction was measured after each cycle of impacts. The irreversibilities appearing after impacts were within the limits -(0.2-0.3)% for three of four magnets; for one of them the irreversibility reached -0.6%.

In spite of the limitedness of the obtained experimental results they nevertheless are of definite interest, since they give the possibility to approximately/exemplarily rate/estimate probable changes in the magnetic induction in magnets from the nickel-aluminum alloys, which can occur in the presence of different vibrations and impacts.

REFERENCES.

Pages 123-127.

1. Strouhal V., Barus C. Über den Einfluss der Härte des Stahles auf dessen Magnetisirbarkeit. Wied. Ann. der Phys. und Chemie, 1883, 20, N 12.
2. Evershed S. Permanent magnets in theory and practice. J. Inst. Electr. Engrs., 1925, 63, N 344.
3. Wall T. E. Applied magnetism. L., E. Benn L., 1927.
4. Honda K. Magnetic properties of matter. Tokyo, Syokawa and Co., 1928.
5. Миткевич А. В. Новый метод изучения магнитной вязкости и некоторые результаты его применения. «Электричество», 1933, № 10.
6. Миткевич А. В. О магнитной вязкости. Тр. ЛЭМИ. Л. Кубуч, № 2, 1934.
7. Миткевич А. В. О некоторых условиях, способствующих проявлению магнитной вязкости. ДАН СССР, 1934, I, № 9.
8. Миткевич А. В. К вопросу о влиянии токов Фуко на магнитную вязкость. ДАН СССР, 1934, III, № 2.
9. Миткевич А. В. Аномальный случай магнитной вязкости. ДАН СССР, 1934, III, № 6.
10. Миткевич А. В. Влияние механических сотрясений на последующие проявления магнитной вязкости. ДАН СССР, 1935, II, № 1.
11. Миткевич А. В. О разделении магнитной вязкости и задерживающего влияния токов Фуко. ДАН СССР, 1935, III, № 5.
12. Миткевич А. В. О магнитной вязкости в различных точках основной кривой. ДАН СССР, 1936, II, № 5.
13. Mitkewitch A. Sur la viscositè magnetique anomale. J. de Phys. et le Rad., 1936, 7, 3.
14. Миткевич А. В. Об аномальной магнитной вязкости. «Электричество», 1936, № 7.
15. Миткевич А. В. О нормальной и аномальной магнитной вязкости. Сб. работ молодых ученых, премированных на конкурсах ЦК и ЛОК ВЛКСМ. Изд. Ленингр. индустр. ин-та, 1940.
16. Ковалев Н. Б., Миткевич А. В., Шрамков Е. Г. Исследование методов стабилизации магнитных систем с постоянными магнитами из сплава на основе железо-никель-алюминий. Тр. ЛПИ, № 184, ГЭИ, 1956.
17. Ковалев Н. Б., Миткевич А. В., Шрамков Е. Г. Стабильность магнитных систем электроизмерительных приборов с магнико и альнико. «Электричество», 1957, № 3.
18. Миткевич А. В., Шрамков Е. Г. Исследование стабильности магнитных систем с внутрирамочными магнитами и определение их температурного коэффициента. «Электричество», 1962, № 1.

19. Миткевич А. В., Шрамков Е. Г. Аппаратура для исследования магнитных систем с постоянными магнитами. Тр. ВНИИМ, вып. 64 (124), 1962.

20. Миткевич А. В., Шрамков Е. Г. Стабильность магнитных систем с литыми магнитами для электроизмерительных приборов. Тр. совещ. по постоянным магнитам. Саратов, 1964. Изд. Сарат. политехн. ин-та.

21. Миткевич А. В. Ускоренный метод испытания постоянных магнитов на стабильность во времени. «Электричество», 1965, № 5.

22. Миткевич А. В. Ускоренный метод испытания постоянных магнитов во времени и некоторые результаты его применения. Тр. 6-й конф. по автомат. контр. и методам электр. измер., «Наука», Сиб. отд., 1967, 2, 320.

23. Миткевич А. В. Проблема стабильности постоянных магнитов и выбор рационального пути к ее решению. Тр. Ин-та физики металлов АН СССР. Исследования в области теоретического и прикладного магнетизма. Свердловск, 1967, 26.

24. Миткевич А. В., Шрамков Е. Г. Исследование стабильности магнитных систем с постоянными магнитами из различных сплавов. Тр. ЛПИ, № 294, «Энергия», 1968.

25. Миткевич А. В. Ускоренный метод исследования стабильности постоянных магнитов при изменении температуры. Тр. ЛПИ, № 294, «Энергия», 1968.

26. Займовский А. С., Денисов П. И., Берконяч Е. С., Дроздов Н. Я. Улучшение магнитных свойств железоникель-алюминиевых сплавов. «Электричество», 1937, № 20.

27. Кузнецов А. А. Метод определения остаточного магнетизма постоянных прямолинейных магнитов. «Заводская лаборатория», 1939, № 10.

28. Львова Л. М. Старение Fe-Ni-Al магнитов. «Электричество», 1944, № 4.

29. Hoselitz K. Modern hard magnetic materials. J. Scient. Instrum., 1946, 23, N 4.

30. Goss J. H. Permanent magnet materials. Mech. Engng., 1948, 70, 671.

31. Studders R. J. Permanent magnet stability. Prod. Engng., P. 1, 1948, N 11; P. 2, 1948, N 12.

32. Knight S. F. A sensitive balance for stability tests on permanent magnets. Proc. Inst. Electr. Engrs., 1949, 96, N 52.

33. Tyrell A. J. The performance and stability of permanent magnets. J. Brit. Inst. Radio Engrs., 1950, N 10.

34. Barbier J. C. Trainage magnétique dans le domaine de Rayleigh. C. Rendue, 1950, 230C, N 10.

35. Barbier J. C. Étude de la constante de trainage dans tout le domaine d'hystérésis. C. Rendue, 1952, 234C, N 3.

36. Lliboutry M. Quelque lois relatives au traînage magnétique. C. Rendue, 1950, 230C, N 10.

37. Becker R., Döring W. Ferromagnetismus. B., J. Springer, 1939.

38. Smith C. L. A theory of transient creep in metals. Proc. Phys. Soc., 1948, 61, N 345.

39. Street R., Wooley J. C. A note on the ΔE-effect in alnico. Proc. Phys. Soc., 1948, 61, N 346.

40. Street R., Wooley J. C. A note on magnetic viscosity in alnico. Proc. Phys. Soc., B., 1949, 62, N 350.

41. Street R., Wooley J. C. A study of magnetic viscosity. 1. Proc. Phys. Soc., A. 1949, 62, N 357.

42. Street R., Wooley J. C. A study of magnetic viscosity. 2. Proc. Phys. Soc., B., 1950, 63, N 367.

43. Street R., Wooley J. C., Smith C. L. Magnetic viscosity under discontinuously and continuously variable field conditions. Proc. Phys. Soc., B., 1952, 65, N 393.
44. Néel L. Theorie du trainage magnétique des substances massives dans le domaine de Rayleigh. J. phys. et radium, 1950, 11, N 2.
45. Néel L. Le trainage magnétique. J. phys. et radium, 1951, 12, N 3.
46. Néel L. Théorie du trainage magnétique de diffusion J. phys. et radium, 1952, 13, N 5.
47. Tenzer R. R. Beitrag zum ballistischen Nullverfahren für die Präzisionsmessung der magnetischen Induction. Arch. Elektrotechnik, 1952, 40, N 7.
48. Tenzer R. R. Eine Präzisionmesseinrichtung für Alterungsuntersuchungen an Dauermagneten. Arch. techn. Messen, 1955, 239, N 285.
49. Tenzer R. R. Influence of various heat exposures on Alnico V Magnets. J. Appl. Phys., 1959, S, 30, N 4.
50. Kronenberg K. J. Untersuchungen über Alterungsvorgänge an Dauermagneten. Z. angew Phys., 1953, 5, N 9.
51. Kronenberg K. J. Alterungsuntersuchungen an Stabförmigen Dauermagneten bei verschiedenen Temperaturen. Arch. Eisenhüttenwesen, 1953, 24, N 9.
52. Kronenberg K. J., Bohlmann M. A. Long term magnetic stability of Alnico and Barrium ferrite magnets. J. Appl. Phys., 1960, 31, N 5.
53. Clegg A. G. Effect of low temperature on the stability of permanent magnets. Brit. J. Appl. Phys., 1955, 6, N 4.
54. Clegg A. G., Mc Caig M. Procceses occuring during the heat treatment of Alcomax. Proc. Phys. Soc., B., 1957, 70, N 452.
55. Clegg A. G., Mc Caig M. The high temperature stability of permanent magnets of the iron-nickel-aluminium system. Brit. J. Phys., 1958, 9, N 5.
56. Mc Caig M. Phasenveränderungen in Höhekoerzitivkraft — Legierungen. Z. angew. Phys., 1966, 21, N 2.
57. Mc Caig M. Comportement des aimants permanents au delà de 550° C. «Cobalt», 1968, N 41.
58. Roberts W. H. Performance of permanent magnets at elevated temperatures. J. Appl. Phys., 1958, 29, N 3.
59. Mishima T., Makino N. Studies on anisotropic MK permanent magnets. Tetsu to Hagane, 1957, 43, N 1.
60. Андриевский Е. А., Блажкевич Б. И. Применение магнитомодуляционных датчиков для изучения температурных коэффициентов постоянных магнитов. Авт. контр. и измер. техн., 1957, № 1.
61. Андриевский Е. А., Михайловский В. Н. О влиянии температуры и внешнего магнитного поля на стабильность постоянных магнитов из Fe-Ni-Al сплавов. Докл. Львовского Политехн. ин-та, 1958, 9, № 1—2.
62. Бобровская Р. С., Морозова А. М., Фейгина Ф. И. О температурном старении высококоэрцитивных сплавов. «Электричество», 1958, № 3.
63. Баранова Н. А. и Шур Я. С. Температурная зависимость кривых намагничивания и петель гистерезиса высококоэрцитивных сплавов. ДАН СССР, 1950, 74, № 2.
64. Ермоленко А. С., Шур Я. С. Магнитный структурный анализ высококоэрцитивного сплава альнико. «Физика металлов и металловедение», 1964, 17, № 1.
65. Gould J. E. Permanents magnet stability. Instrum. Practice, 1958, 12, N 10.
66. Gould J. E. Permanents magnet at extreme temperatures. «Electronics», 1959, N 7.
67. Yamartino E., Broadley H., Lever R. Stability

of magnets composed of elongated single—domain iron particles. J. Appl. Phys., 1954, S.30, N 4, 144.

68. Tuszinski J. Dokladne metody pomiaru indukcji magnetyczne stosowane przy badaniach starzenia magnesów trwalych. «Pomiary automatica kontrola», 1958, N 11.

69. Tuszinski J. Magnezowanie i stabilizowanie obwodów magnetycznych z magnesami trwalymi AN2 do precyzyjnych mierników magnetoelektrycznych. «Pomiary automatika kontrola», 1965, N 1.

70. Webb C. E. The stability of permanent magnets. Proc. Instn. Electr. Engrs., 1961, C, M, N 14.

71. Zingery W. L. System for the precision measurement of long—time change of an inhomogeneous magnetic field. Rev. Scient. Instrum., 1961, 32, N 6.

72. Zingery W. L., Scarborough W. M., Wilcox D. E. Flexure mounted beam balance for long-term magnetic stability measurements. Rev. Scient. Instrum., 1961, 32, N 9.

73. Zingery W. L., Wirt T. M., Belland A., Reves T. V Realisation of long-term magnetic stability of 10^{-5} per month for a permanent magnets assembly. Canad. J. Phys., 1962, 40, N 2.

74. Zingery W. L., Whalley W. B., Romberg E. B., Wheeler F. W. Evaluation of long-term magnet stability. J. Appl. Phys., 1966. 37, N 3.

75. Pavlic N. The stability of magnetic materials at high temperature. J. Appl. Phys., 1961, 32, N 3.

76. Vial H. Über die Stabilität von Dauermagneten. ETZ B, 1962, 14, N 17.

77. Assayag P. Comportement des aimants permanent sous l'effect de differents facteurs de desaimantation. Stabilisation des aimants. Bull. Soc. Franc. Electr. 1963, 8, N 4.

78. Dietrich H. Temperatur und Zeitabhängigkeit der Dauermagnetwerkstoffen. Z. angew. Phys., 1966, 21, N 2.

79. Dietrich H. Zur Temperaturabhängigkeit der magnetischen Eigenschaften von Dauermagnetwerkstoffen. ETZ A, 1967, 88, N 21.

80. Dietrich H. Contribution a l'étude de l'influence de la temperature sur les propriétés des materiaux pour aimant permanents. «Cobalt», 1967, N 35.

81. Dietrich H. Einfluss verschiedener Stabilisierungsbehandlungen auf die natürliche Alterung von Dauermagnetsystemen. «Feinwerktechnik», 1968, 72, N 9.

82. Dietrich H. Alterungsverhalten von kunststoffgebundenen Al-Ni-Co — Dauermagneten. ETZ A, 1969, 90, N 22.

83. Булыгина Т. И., Макаров К. Т. Стабильность постоянных магнитов из сплавов марок ЮНДК24Б и ЮНДК35Т5 при высокой температуре. «Электротехника», 1967, № 4.

84. Булыгина Т. И., Макаров К. Т., Сергеев В. В. Стабильность постоянных магнитов из сплавов ЮНДК24Б, ЮНДК25БА, ЮНДК35Т5 при низких температурах. «Электротехника», 1968, № 6.

85. Булыгина Т. И., Вевюрко И. А., Сергеев В. В. Исследование температурной стабильности постоянных магнитов в интервале —60 ÷ +100° С. «Электротехника», 1968, № 10.

86. Sergeyev V., Bulygina T. Magnetic properties of Alnico alloy phases and temperature instability of permanent magnets. Abstr. J. Appl. Phys., 1969, 40, N 3.

87. Zach M. Stabilita trvalých magnetů. Slaboproudny obzor, 1967, 28, N 10.

88. Sasaki Zasiki Denki. Thermal fluctuations of magnetic viscosity in permanent magnets. J. Inst. Electr. Engrs., Japan, 1968, 88, N 3.

89. Fahlenbrach H. Untersuchungen an isotropen Alniko-Le-

gierungen mit kleinem Kobalt gehalt und höher Koerzitivfeldstärke und an Kobalt-Aluminium Dauermagnetlegierungen. Tech. Mitt. Krupp Forschungsber., 1968, 26, N 2.

90. Czymura S. O stabilnosci lanych magnesow trwalych typu Alni, Alnico. Hutnik (Polska), 1968, 35, N 3.

91. Киренский Л. В., Дрокин А. И., Лаптей Д. А. Температурный магнитный гистерезис ферромагнетиков. Новосибирск, изд. Сиб. отд. АН СССР, 1965.

92. Лившиц Б. Г., Львов В. С. Высококоэрцитивные сплавы. Металлургиздат, 1960.

93. Кавалерова Л. А., Лившиц Б. Г. Старение сплавов для постоянных магнитов при температуре 550 — 700° С. «Электричество», 1968, № 12.

94. Кавалерова Л. А., Кавалеров Г. И. Расчет магнитного старения постоянных магнитов. «Приборы и техника управления», 1969, № 7.

95. Зайцев В. И., Новицкий П. В., Пресняков П. Д., Спектор С. А. Измерение малых изменений магнитной индукции вибрационным магнитометром. Тр. ЛПИ, № 294, «Энергия», 1968.

96. Зайцев В. И., Спектор С. А. Измерение неоднородных магнитных полей постоянных магнитов в широком диапазоне температур методом ядерного магнитного резонанса. Тр. ЛПИ, № 256, «Энергия», 1965.

97. Тарасов С. И. Измерение параметров магнитных сердечников. Тр. вычислительного центра АН СССР. М., 1967.

98. Зайцев В. И., Хабалов В. В. К применению баллистического гальванометра в качестве нулевого указателя. Изв. вузов. «Приборостроение», 1967, № 10.

99. Разумовский Н. Н. Расчет магнитной системы измерительного прибора с внутрирамочным магнитом. «Вестник электропромышленности», 1957, № 5.

100. Мельников Ю. А. Постоянные магниты электровакуумных СВЧ приборов. «Советское радио», 1967.

101. Постоянные магниты. Справочник. Пер. с англ. под ред. Л. Ш. Казарновского. Госэнергоиздат, 1963.

102. Ewing J. A. Experimental researches in magnetism. Philos. Tranc. Roy. Soc., L., 1885, 176, 523.

103. Ewing J. A. On time lag in the magnetization of iron. Proc. Roy. Soc., 1889, 46, 283.

104. Ewing J. A. Magnetic induction in iron and other metals. L., The Electrician, 1900.

105. Bozorth K. Magnetic viscosity in magnetisation. Phys. Rev., 1928, 32, N 1.

106. Preisach F. Über die magnetische Nachwirkung. Z. Phys., 1935, 94, N 5—6.

107. Wittke H. Eine vorläufige Mitteilung über magnetische Nachwirkung. Ann. Phys., 1936, 5, N 27.

108. Richter G. Über die magnetische Nacwirkung am Carbonyleisen. Ann. Phys., 1937, 29, N 7.

109. Телеснин Р. В. Динамические кривые намагничивания и перемагничивания железа, ЖЭТФ, 1937, 7, № 1.

110. Heaps C. W. Measurements of magnetic viscosity in iron. Phys. Rew., 1938, 54, N 4.

111. Телеснин Р. В. О некоторых закономерностях магнитной вязкости. ДАН СССР, 1950, 75, № 6.

112. Курицына Е. Ф. О температурной зависимости магнитной вязкости ферромагнитных металлов. ДАН СССР, 1951, 79, № 2.

113. Булгаков Н. В., Кондорский Е. И. Магнитная вязкость и роль смещения границ между доменами в процессе перемагничивания высококоэрцитивных сплавов. ДАН СССР, 1949, 69, № 2.

114. Сноек Я. Исследования в области новых ферромагнитных материалов. Пер. с англ. Изд-во иностр. лит., 1949.
115. Гетлинг Б. В. К методике измерения относительной магнитной вязкости высококоэрцитивных сплавов. «Заводская лаборатория», 1957, № 1.
116. Вонсовский С. В., Шур Я. С. Ферромагнетизм. М., Гостехиздат, 1948.
117. Вонсовский С. В. Современное учение о магнетизме. Гостехиздат, 1953.
118. Бозорт Р. Ферромагнетизм. Пер. с англ. Изд-во иностр. лит., 1956.
119. Лыков А. В. Теория теплопроводности. «Высшая школа», 1967.
120. Постоянные магниты. Справочник. «Энергия», 1971.

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