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USSR Report

ENGINEERING AND EQUIPMENT

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ENGINEERING AND EQUIPMENT

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MARINE SHIPBUILDING

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PRESENT-DAY SOVIET SHIP DESIGN PRACTICES

Leningrad SUDOSTROYENIYE in Russian No 9, Sep 85, pp 3-5

[Article by N. P. Sytov and Ye. G. Frid]

[Text] The 60th anniversary of Soviet shipbuilding is being observed in the present year coincident with the 60th anniversary of the oldest design organization in the industrial sector; namely, the Order of Labor Red Banner Central Design Bureau [TsKB] Baltsudoproyekt. Over these years the personnel of the TsKB have developed more than 130 designs from which about 2,500 ships of various types were built having a total displacement of 11 million tons.

The following is far from a complete list of the ships built and being built according to the designs of the bureau:

the first Soviet timber carriers launched at the Baltic Shipyard in Leningrad in 1925,

the "Abkhaziya" class of cargo-passenger motorships for the Crimea-Caucasus line,

dry cargo and refrigerated ships,

the powerful "I. Stalin" class icebreakers of pre-war construction,

the large-series "Vytegrales" class of timber carriers,

the general-purpose dry cargo ships of the "Pyatidesyatiletiye komsomola" and "Nikolay Zhukov" classes,

the "Kazbek","Velikiy Oktyabr",and "Sofiya" class tankers,

the largest ships in the history of domestic shipbuilding - the "Krym" class tankers and the "Pobeda" class of ecologically pure tankers now being built,

large series of port and roadstead tugs, the "Dmitriy Dudchenko" class of seagoing salvage tugs and the powerful "Yaguar" class oceangoing salvage tugs,

unique scientific research ships, and

the first nuclear powered lighter and container carrier in the world for Arctic navigation: the "Sevmorput".

The great and varied experience in designing ships, the successes in the development of equipment and technology for shipbuilding, the introduction of computer equipment, the improvement of mathematical economic methods for designing ships - these and other achievements in the development of the scientific and technical base of shipbuilding and also certain social factors, have determined the modern level of the technology and organization for designing ships and are reflected in particular in the practices of the TsKB [Central Design Bureau] Baltsudoproyekt.

The principal distinguishing features of a modern organization for designing ships are:

the widespread introduction of mathematical economic design methods using computer-aided design or CAD [SAPR is the Soviet equivalent]

the decisive importance of standardization between designs and within a design, and the creation of reference designs as the most effective means of raising the technical level and quality of the design and construction of ships,

the development of planning and working design documentation fully in conformance with the block-modular method of construction,

the development and operation of a comprehensive system for controlling the efficiency of production and the quality of the work,

the introduction of progressive methods of organizing the work of designers into independently accountable units with pay for work according to the indicator of labor participation.

Let us consider these principal features of the modern process of ship design in more detail.

AUTOMATING DESIGN BY MEANS OF COMPUTERS. THE DEVELOPMENT AND INTRODUCTION OF CAD. The high demands on modern ships from the point of view of their cost benefit to the economy, which is determined on the one hand by the growing volume of tasks being carried out by the fleet, and, on the other, by the growing demands for the safety of navigation and preservation of the environment, have brought about the necessity for conducting multivariant research at all stages of design, and, in the first place, in the early stages; that is, during the critical analysis for the engineering proposal for the design of a ship. In this, the need has arisen for a systems approach to design and the working out of the engineering solutions for all the subsystems of the ship in order to achieve the maximum cost benefit of the ship as a whole. The solution of this labor-consuming problem of optimization is impossible without the use of mathematical economic methods and computers. Therefore, these methods of design, which emerged at the end of the 1960s, have now received universal distribution.

The basis of the CAD system being developed at present consists of the first stage of the SAPR "Proyekt 1". In the beginning it was oriented toward the solution of questions on selecting the elements and substantiating the characteristics of the principal types of ships (in the preliminary and engineering designs), and also toward automating calculation of the statics and dynamics of a ship and weights, and toward automated design and the output of design and technological documentation for pipelines and the electrical engineering department.

Later on, it was supplemented with the FORAN licensed system of automated hull design, and with subsystems which had received further development; namely, ASTRA for the design of shipboard pipelines, ESKAP for the electrical engineering part of ships. and GROGOS for the circuits of public address systems. It also was supplemented with an improved system for calculating and monitoring loadings and a system (the subsystem "Obstroyka") for the automated output of specifications for working drawings on deck coverings, insulation, the building and equipping of shipboard compartments, deck outfits, doors, port lights, ladders, etc. and lists for the MSCh [Medical and Sanitation Areas]. Thanks to this, the system used in the TsKB became a means for raising the productivity of the work of the designers and improving the quality of design.

As the result of the widespread introduction of computers into the TsKB's design practices, the proportion of documents in engineering and working designs developed and produced with the aid of computers, by the beginning of 1985 had reached about 30 percent of the total volume of design documentation. At present, the efforts of the associates of the design bureau are directed toward deepening and widening the sphere of automated design work. There is talk about the development of a unified base of reference and design data on the basis of a unified Data Base Management System for the industrial sector; about automating graphical design work for all specialties in the TsKB; about automating document development for the hull; about automating the design of general shipboard systems, and the means of shipboard communications and signalling; about automating calculations of the consumption of materials and the completeness of shipboard equipment; and so on. This will permit substantially increasing the proportion of automated design work and bring it up to 50 percent in 1985.

One of the most important advantages of the automation of design and the introduction of computers is the possibility of the development, simultaneously with the design work, of a part of the technological documentation; or transferring design documentation, primarily specifications for blueprints, to the building shipyard on computer output media having the requisites for carrrying out automated production of planning -and-accounting and other production and technological documentation within the framework of ASTPP [Automated System for Technological Preparation for Production] without the laborious preliminary processing of design documents by the production engineering service of the shipyard as this has been done up to now. The Central Design Bureau took the first step in this direction in a creative collaboration with the production engineering services of the Leningrad Shipyard imeni A. A. Zhdanov in developing the design of a 12,000-ton deadweight roll-on/roll-off ship.

INTERDESIGN AND INTERNAL DESIGN STANDARDIZATION. THE DEVELOPMENT OF REFERENCE DESIGNS. The problem of interdesign and internal design standardization is one of the keys in reducing the labor consumption of building ships and raising the efficiency of shipbuilding as a whole. Even in the prewar years, time and again efforts were undertaken for the design of ships of some types on the basis of others. For example, the hulls of the large "Volgoles" class which were being built to the design of the TsKB in the years of the 1st Five-Year Plan, were used later on for bulding the ore carriers "A. Serov" and "P.Osipenko".

At the present time in the TsKB, special attention is being given to interdesign standardization. This has been brought about by the wide circle of tasks placed upon ships and by the fact that the idea of the general standardization of ships, which was advocated at the end of the 1960s and the beginning of the 1970s, has not proved its value from an operational and economic point of view.

A large step in the direction of interdesign standardization appeared in the 1970s with the construction, at the Vyborg Shipyard, to designs of the TsKB, of six types of ships; namely, a timber and packetized cargo carrier, a general-purpose dry cargo ship, two types of cellular container ships, and two types of auxiliary ships. All these ships had identical stern ends including the stern superstructure and machinery compartment except for one ship which had a different make of main engine. Five of the types of ships have identical hulls, and only the general-purpose dry cargo ship differs in hull length and the shape of the bow. Such interdesign standardization yielded a significant economic gain and permitted building and placing in operation several series of specialized ships having various purposes in a relatively short period of time.

In these same years, on the basis of the designs of two transport ships - a tanker and a timber carrier - four series of scientific research ships of various purposes were developed; on the basis of the design of one oceangoing salvage ship, two types of ships were developed; and on the basis of the design of one seagoing salvage tug, four series of seagoing salvage ships of differing purposes were developed.

This direction in the design of new ships will remain dominant in TsKB Baltsudoproyekt also in the near future. In particular, the new 12,000-ton deadweight roll-on/roll-off ship which will be built at the Zhdanov Shipyard in the 12th Five-Year Plan, has been designed so that if necessary, scientific research ships, transport ships, or any other kind of ship whose principal elements will be near to the requirements of the client, can be built on its basis.

Adopting the idea of developing reference designs as most fully responding to the demands placed on shipbuilding in the area of lowering labor consumption, costs, and building time per ship, specialists of the TsKB in the study of plans for an extended period, proceed in the first place from the possibility of consolidating ships planned to be built into groups the design of which can be carried out on the basis of a single reference design. As to internal design standardization, the TsKB makes widespread use of typical design solutions, the number of which in a single design is reduced to a judicious minimum. They also use the other achievements in the field of unification and standardization which are known in the industrial sector but whose description is beyond the scope of this article.

THE INTRODUCTION OF THE BLOCK-MODULAR TECHNOLOGY OF CONSTRUCTION WITH THE DEVELOPMENT OF PLANNING AND DESIGN DOCUMENTATION. Modular shipbuilding, being the most effective means of raising productive efficiency, provides for a substantial curtailment of the time for designing and building ships, and for economy of labor and material resources. It also creates the conditions for a rapid and flexible response of the shipbuilding industry to the changing needs for ships of different types and dimensions.

The introduction of block-modular hull construction and the modular-unit method of machinery and equipment installation in ship construction has required changes in the methods and organization of design, particularly in beginning to produce fundamentally new design documents that reflect the principles of modularity. Thus, the planning and working-design documentation being produced contains the information necessary for carrying out manufacture in specialized sections of the shipyard (modular building technology requires definite organizational reconstruction also at the shipyard). It also contains information for the comprehensive fitting out with mechanisms and piping of large sections and blocks, and individual zones of the machinery and boiler compartments and other regions of the ship.

One of the principal conditions assuring high-quality development of working-design documentation in modular designing is the manufacture, on the basis of the engineering-design materials, of scale models. They are made in the model shop of the TsKB and they simulate the machinery and boiler compartments, the piping tunnels, deckhouses, and other fitted-out compartments. Scale models permit three-dimensional design of the compartments of a ship and serve as the basis for the preparation of dimensioned working drawings with the coordinates of routes for pipelines, ventilation ducts, electrical circuits, and so on. Dimensioned drawings are the basic drawings for modular units and they permit manufacture of the units in shop conditions at the shipyard or, with industrial sector specialization, at supplier enterprises.

At the present time, the TsKB has developed and introduced the block-modular technology in design to the fullest extent. Baltsudoproyekt is the first planning and design organization in the industry which has changed over to the production of working-design documentation completely corresponding to the block-modular technology for building ships.

THE DEVELOPMENT AND OPERATION OF AN INTEGRATED MANAGEMENT SYSTEM FOR PRODUCTION EFFICIENCY AND WORK QUALITY. An integrated management system for production efficiency and work quality (IMSPE&WQ) has been developed in the TsKB and is operating. It consists of 90 enterprise standards covering all organizational and technical questions of the activities of the TsKB including:

- management of the utilization of personnel,
- effective management of the design of ships,
- management of the development of blueprints for the construction of ships and of the metrological provisions,
- control of the technical and economic activities of the enterprise,
- quality control of documentation and work,
- management of financial activity, accounting, and material and technical supply,
- management of ideological and educational work and socialist competition,
- management of the socialist development of personnel,
- management of the long-range development of personnel.

The IMSPE&WQ is directed toward increasing the technical level and quality of designs, raising the productivity of labor, reducing labor consumption in designing, increasing the fund yields for improvement of work quality, improving the organization for the control of production, and the efficient utilization of all material and energy resources. The main purpose of IMSPE&WQ is the achievement of high final results for the activities of the TsKB; that is, development of ship designs corresponding in operational and technical characteristics to the best domestic and foreign models.

The organizational structure operating in the IMSPE&WQ of the TsKB includes:

- the objects of control (the processes for establishing the quality of designs, the quality of work, and the efficiency of production),
- the controlling bodies (the executives of the TsKB and the design subdivisions, and a subdivision for managing the TsKB itself],
- the means of control (directives, and organizational and administrative documents, standards of all categories, plans for social and economic development, and so on).

A permanently active commission under the leadership of the chief engineer of the TsKB controls the system as a whole.

PROGRESSIVE METHODS OF ORGANIZING AND PAYING DESIGNERS. With the purpose of intensifying design work and raising its productivity and quality, certain basic aspects of the brigade organization of labor are applied in the TsKB. The method of work of the design departments as independently accountable units with rewarding of the executives according to the indicator of labor participation, has been introduced since 1982. Already, in the first periods of its introduction, the effectiveness of the method was confirmed. Designers became more seriously concerned with the fulfillment of individual assignments, with the deadlines and quality of the fulfillment of the work, and losses of working time have diminished. A half year after the beginning of work according to the new method, the amount of completed fundamental operations rose, in comparison to a similar period of the previous year, by 7 percent with a somewhat reduced number of workers.

At the same time, the method has not been free of deficiencies which are being eliminated gradually on the basis of a correlation of accumulated experience and proposals for the improvement of it from the managers and the active members of the design subdivisions. It should be noted that a further increase in the effectiveness of the operations of the design departments and the TsKB as a whole according to independent accountability, up until recent times was held back by a number of general statutes about the planning of operations and the pay of designers. The decrees adopted by the CPSU Central Committee and the USSR Council of Ministers about improving the work of Scientific Research Institutes and Design Bureaus, make possible the reduction of the number of workers and the provision of incentives for designers achieving the highest indicators. The specific clauses worked out in the elaboration of these decrees by a number of Scientific Research Institutes and Design Bureaus, will, after their realization, promote increased efficiency in design work in the TsKB as a whole.

The basic directions for the improvement of the technology and organization of designing in the modern stage presented above, is only a part of the general problem of increasing the effectiveness of operations. A significant reduction in the volume of planning and design documentation which has grown several fold in the past decade, must play a substantial role. At the present time, about 70 percent of the so-called "routine" documentation being produced is not required either for the manufacture of parts and structures nor for their installation on the ship. Apparently, the unified system for conducting design documentation in shipbuilding should be distinguished from that of the All-Union system on account of the specifics of the industrial sector - the relatively small amount of serial production and the high complexity of the products such as modern ships are. Also, the procedure for review, adjustment, and approval of designs is in need of simplification as also is that for orders for materials and acquiring equipment and so on.

The solution of these and a number of other problems, the improvement of the system of moral and material incentives, and also raising the prestige of design work will sharply increase the effectiveness of planning and design organizations and will lift the technical level and the national economic efficiency of the shipbuilding sector.

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DEVELOPMENT OF MODULAR METHOD OF BUILDING SHIPS

Leningrad SUDOSTROYENIYE in Russian No 9, Sep 85 pp 35-36

[Article by V. N. Kruglov, F. Kh. Gabaydulin, and I. L. Dolgopolskiy]

[Text] The modular method of designing and building ships which includes the erection of the hull from block-modules, the modular-unit method of installing shipboard equipment and mechanisms, and the finishing of compartments according to the M100 modular system, in recent years has been finding ever more development in the designs of the TsKB [Central Design Bureau] Baltsudoproyekt. Directed toward reducing labor consumption and shortening the length of time for building each ship, it also increases the quality of ships, improves working conditions at shipyards, and raises the efficiency of production as a whole.

The realization of the modular method in designs of ships called for the reexamination of the approach to the whole process of designing, for organizational and structural changes in the design subdivisions, for the development of fundamentally new design documents, and for the introduction on a broad scale of automated designing. Instead of the pure design documents which were being developed before, nowadays detailed design-and-production documentation is prepared which provides for the manufacture and installation not only of the traditional assembly units such as hull sections, but also of large sections including various equipment for installation and zonal blocks, and of sections and even whole zones of a ship (e.g., the boiler or machinery areas) with integrated mechanisms and pipe fittings. For the manufacture of assembly units without refinement of dimensions in situ, blueprints are made having dimensioned parts and the coordinates of the routes of pipelines,electrical cables, and ventilation ducts. Other kinds of documents also are produced.

The advantages of the modular method of construction can be seen in the example of the design of a 12,000-ton deadweight roll-on/roll-off ship.

The basic technology and the organization for production provide for the block-modular method of assembling the hull and the modular-unit method of erecting the machinery spaces - the stern "island" (see Figure 1).

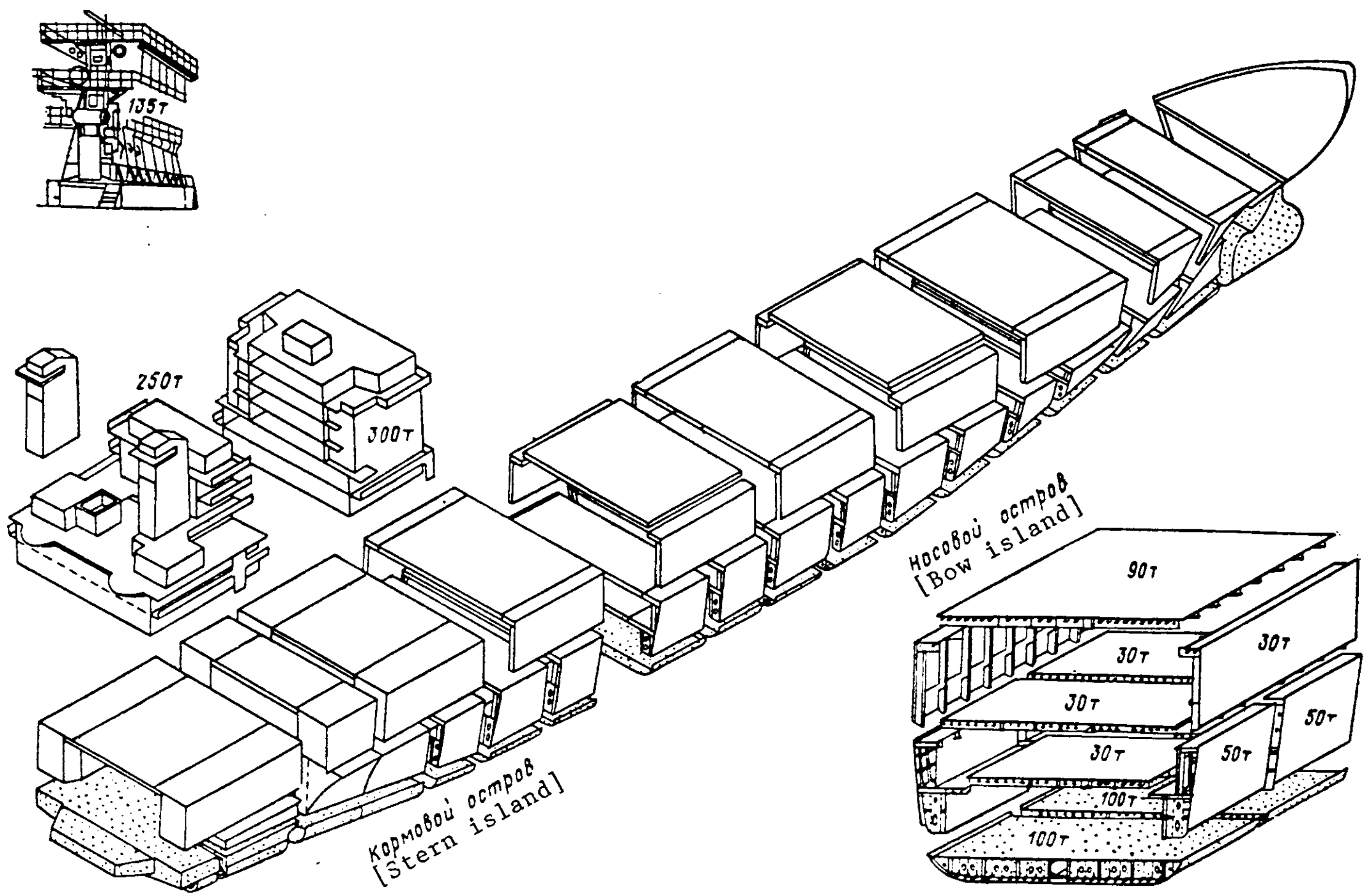

Figure 1. Diagram for the building of a ship from modular elements.

Modular sections: side - 24, bottom - 4, deck pcs. Integrated fitting out of sections: piping 10% secured and welded in fittings - 100%. Amount of unitization 95% (units and installation blocks - 24, main engines assembled - 2, subassemblies and panels of piping - 50 pcs.). Amount of pipe installation work in shop conditions -70% (by weight). Amount of electrical installation work done in "islands" - 60%. Amount of modular finishing of living compartments - 100% (all 31 cabins are standard, of the 6 living blocks, 4 are standard).

Meanwhile, a single mathematical model of the hull worked out together with the building yard is used in the production of the blueprints, carries out engineering calculations, and the mold-loft and technological preparations for production. The hull is erected according to a "two-island" system; that is, from a stern "island" and a bow "island" which are assembled from plane and 3-D sections with integrated fittings. The erection of the stern island is specified to be carried out at a specified building place by the flowing-position method from sections with integrated fittings. Meanwhile, mechanical installation work is carried out in parallel with the assembly of the hull structures. In this, supplied units comprise 14.2 percent, but installation-blocks, put together at the building yard, comprise 80.8 percent of the mechanisms and equipment. In addition, the indicated blocks include more than 30 percent of the pipe, and more than 18 percent of the piping goes into the sections with integrated fittings of this region.

A significant amount of the pipe-preparation and pipe-installation work is planned to be transferred into shop conditions in the early stages of construction (see Figure 2).

The blocks of superstructure are put into place on the hull by a floating crane. Both the blocks of superstructure and the sections fabricated at the positions for preliminary assembly have integrated fittings. Practically the whole amount (95 percent) of the unitized equipment and mechanisms are provided in them and the securing of piping systems is done. The main engine is assembled on a stand and loaded into the readied machinery compartment.

In building the cabins and rooms, the M100 modular system and modular sanitary units supplied by Polandare used. Great attention is paid to the unification and standardization of parts, subassemblies, and sections of the hull. In this, flat sections comprise 70 percent of the weight of the hull.

Electrical installation work is organized on the principles of modernized autonomous regions with parts from unit-block technology and with the application of special connectors for the main cables between islands. Simulated tests of mechanisms and equipment without going to sea will be widely used along with a number of other organizational and technical measures shortening the duration of trials.

It should be noted that there are substantially less than the standard number of types and sizes of materials, mechanisms, and sets of articles than usual in a design (see Table).

To lower the labor consumption of design work and of the technological preparation for construction, special attention has been given to automating the process of design. The automated production of design documentation provides at the same time for transmission of information on computer output media to the building yard, in particular, specifications for working drawings used in the development of planning-and-accounting and technological documentation in the process of preparations for production.

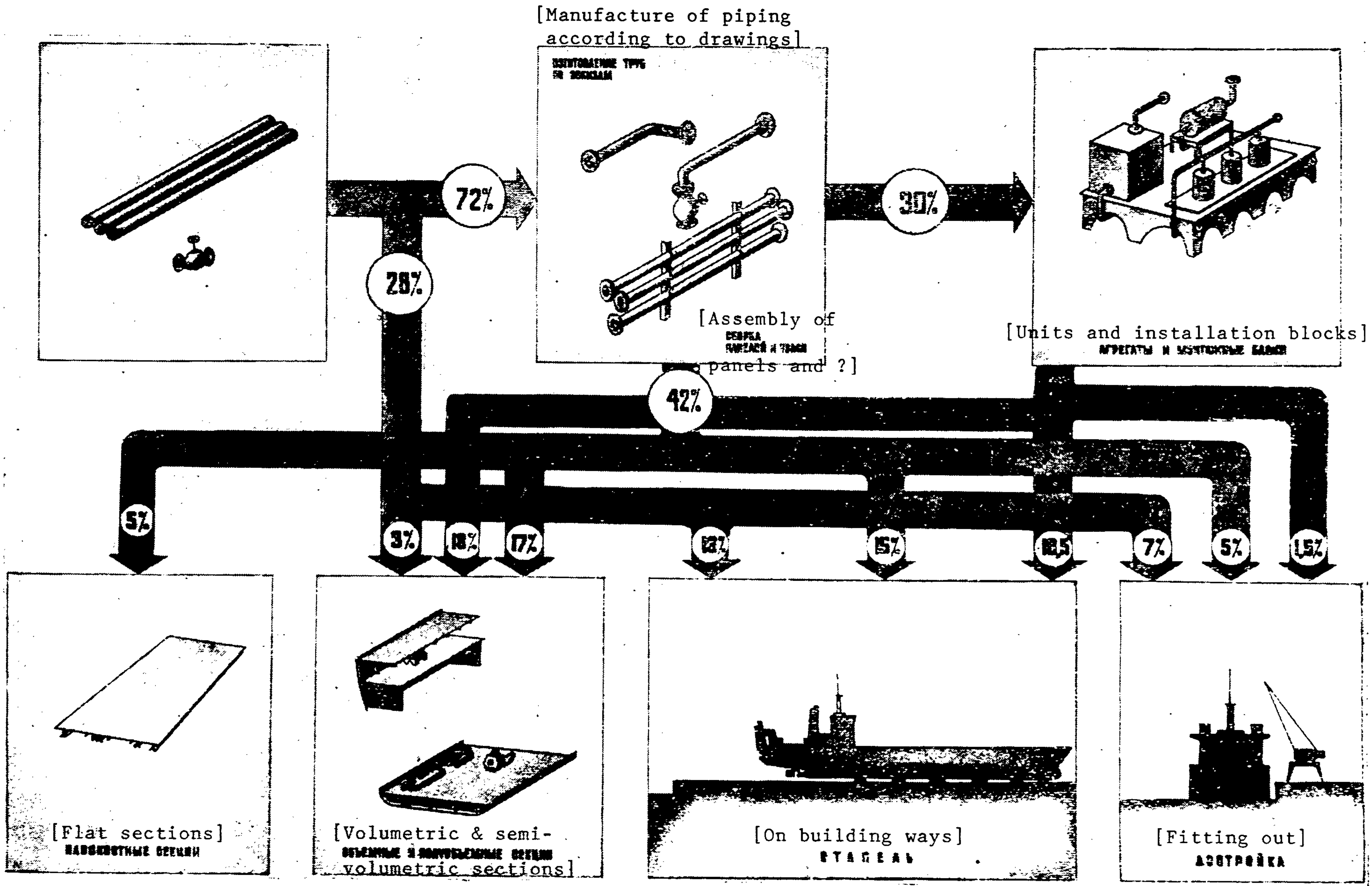

Figure 2. The manufacture and installation of piping at various stages in building a ship.

The Number of Types and Sizes of Materials, Mechanisms, and Articles

Name of articles or divisions	Standard and Unified	Custom made	Total	K_{np}, %	K_{cn}, %
Hull: materials			20		
rolled plates			34		
rolled shapes			49		
Doors, portlights, ladders, windows, etc.	65	10	75	86.7	43.4
Parts for shipboard gear	55	24	79	74.2	61.5
Compartment equipments	275	-	275	100	63.2
Mechanisms	100	-	100	100	78.0
System pipe fittings and pipelines	492	-	492	100	100
Electrical equipment	434	2	436	100	60
Radio and electronic equipment and control systems	73	-	73	100	98.8
Pipes: steel			39		
made of nonferrous alloys			48		
Coefficient of use of standardized articles, K_{np}				97	
Coefficient of scope of specialized production, K_{cn}					76

Automation of the production of design and technological documentation consists of the following. With the aid of the subsystems "Kompass" and the ASTPP [Automated System for the Production Process Planning] "Korpus", developed by the Leningrad Shipyard imeni A. A. Zhdanov, a mathematical model of the hull is developed on the basis of which production of blanks for working drawings of the hull is provided for and also the production of technological documentation and patterns for cutting out metal.

The subsystem "Obstroyka" is used in automating the production of specifications and lists for the delivery, complete, of parts for blocks of insulation and lists for the cost of materials for the technical equipment set, and also for making the production-standardizing charts. Using the subsystem ASTRA-2, design documents are developed for pipelines (charts and drawings of pipes, specifications and so on) which enable the preparation of 18 kinds of technological documentation. For the electrical engineering department, the production of technological documentation is carried out on the basis of design documents obtained with the aid of the subsystems ESKAP and GROGOS (cable lists, specifications and so on).

Design indicators of the adaptability to production of a new ship are presented below. They characterize the high degree of adaptability to production of the development of design achieved by the joint creative work of specialists of the TsKB Baltsudoproyekt, the A. A. Zhdanov Shipyard, the NPO [Scientific Production Association] Ritm, and other organizations.

Indicators of Adaptability to Production

Specific labor consumption in building a series-produced ship, man hours per ton	132
Coefficient of the use of flat structures	0.70
Coefficient of metal consumption in the hull relative to the product LengthXBeamXDepth in kilograms per cubic meter	96
Coefficient of the adaptability of hull structure to fabrication on mechanized production lines	0.80
Coefficient of the use of mechanized forms of welding in building the hull	0.87
Coefficient of the use of a modular system for building and finishing cabins, rooms, etc	1
Percent of unitized mechanisms and equipment	95
Percent of piping prepared from drawings made by the designer (for the leading ship)	72
Percent electrical installation work completed in "islands"	60

The total reduction of labor consumption in the design, productive adaptability, and organizational measures which amounts to 231,000 norm-hours, permits shortening the duration of construction by 4 months compared to the traditional technology.

The Reduction of Labor Consumption Because of the Realization of Design, Productive Adaptability, and Organizational Measures, in thousands of norm-hours

The modular subdivision of the hull, mechanized fabrication of hull structures, enlarged sections, broad use of flat structures analytical methods of obtaining charts for pattern layouts and control programs for NC machine tools having ChPU [numerically programmed controls]	80
The unitizing of mechanisms and equipment, integrated fitting out of hull sections and blocks, simulated testing of series-built ships	18
The securing of pipelines in panels, the drawing of their parts, the laying of main pipelines in special tunnels in the hull	34
The standardization of living and service compartments, modular methods of their finishing and equipping, the use of thixotropic painting materials, reduction of painting work	65
The autonomous-region principle of carrying out electrical installation work according to modernized technology, the use of connectors for main cables between "islands", laying main cables in special tunnels, arranging electrical equipment in niches	34
Total:	231

The further improvement of the modular method of designing and building ships depends on the solution of a number of important organizational and technical questions. Very urgent is the problem of providing for interindustry supplies of standardized and unitized auxiliary equipment and mechanisms for main power plants, or adjustment of the production of these units on cooperative bases, which still have not found practical solution. Urgent also is the need to organize the manufacture of block-modules of shipboard equipment at specialized enterprises. This would permit shortening the time, and increasing the quality of designing because of eliminating the researching of solutions for the individual unitized assembly-and-installation units (types of installation blocks) developed for each design and would make possible the delivery of the power complex as a complete set of such standardized assembly-and-installation units and the working out only of their mutual arrangement and optimization of the electrical and hydraulic connections.

The positive solution of these questions will permit broad introduction of the modular method of designing and building ships with the use of SAPR [Soviet CAD system] and ASTPP which is a step forward in the development of complete, integrated design and production systems.

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DESIGN PREDICTION OF SUPERSTRUCTURE VIBRATION LEVELS FOR TRANSPORT SHIPS

Leningrad SUDOSTROYENIYE in Russian No 5, May 86

[Article by V. I. Polyakov, I. M. Belov, and V. S. Boyanovskiy]

[Text] The superstructure of a transport ship is the location of the majority of the living, domestic service, and public compartments; therefore, its vibrations are determined to a significant degree by habitability (Ref. 1). The necessity to reduce vibrations to the levels established by the public health norms SN-1103-73 have raised the problem of reliably predicting the parameters of the underway vibrations of the tiers of a superstrucrure by calculation in the process of design. The solution of this problem has turned out to be associated with a series of features, to the consideration of which, this paper is devoted.

The public health norms regulate a broad frequency band of vibrations (1.4 - 90 Hz); however, it is most difficult of all to satisfy the existing requirements in the bands of frequencies of 8 and 16 Hz (Ref. 2). This circumstance permits narrowing the range of calculated predictions which simplifies the problem somewhat. At the same time, for carrying out the calculations in the frequency octaves of 8 and especially 16 Hz, the well developed apparatus for determining the parameters of the overall vibration of the hulls of ships is not successfully applied because it was intended for the lowest frequencies and is based on simplified calculating schemes. The classical beam schemes do not permit trustworthy modelling of the superstructure or trustworthy representation of its dynamic interaction with the hull of the ship. Besides that, the calculations for the overall vibrations are oriented toward the determination of the peak values of the vibration movements at a fixed value of the frequency of the exciting force, whereas, calculations for superstructures carried out in ensuring the requirements of SN-1103-73 must predict the root-mean-square of the level of the velocities or accelerations in octave bands of frequencies.

The indicated circumstances demanded the development of a special technique for determining the levels of vibration of the tiers of superstructures in the scope of which the following questions were solved:

- development of an effective calculating algorithm;

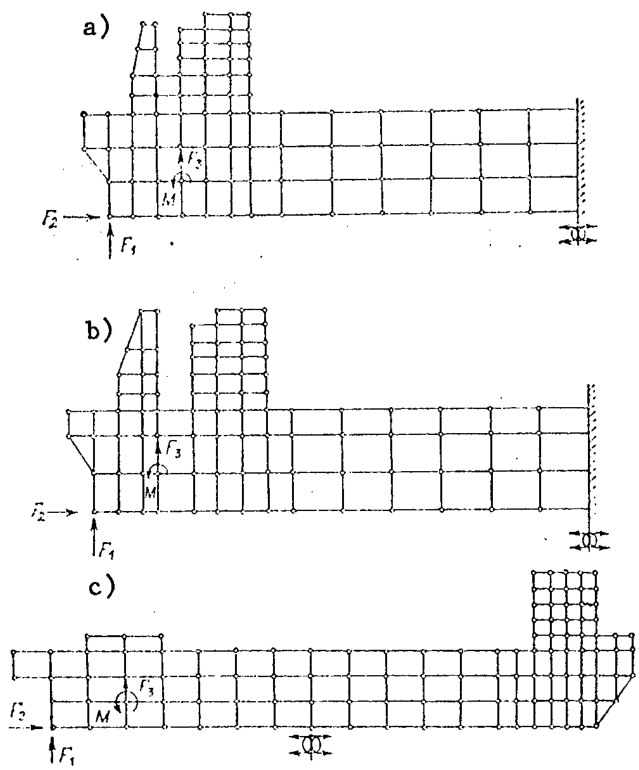
- determination of the contributions of the various sources of exciting forces to the total level of the vibration of the superstructure;
- the development of software for solution by a computer.

The mathematical algorithm for the solution of the problem being considered involves the construction of a physical model of the system: "hull - superstructure" and of a calculating scheme and also, naturally, calculation by the method of finite elements. The physical model is understood to be a conventional plate and rod structure which adequately reflects those parameters of the real structure which detemine its dynamic characteristics. The calculating scheme is understood to be the physical model represented in the form of an aggregate of joined-together finite elements.

Modern mathematical methods and computers permit, at least in principle, consideration of models of any complexity up to real similarity. Their utilization, however, is accompanied by a large consumption of time in the preparation of the initial data and in the calculations which, in a number of cases, makes difficult their practical application. Inasmuch as the algorithm being developed was planned for use in a design bureau, it was decided to go along the path of building simplified models which, however, reflect, with the necessary completeness, all parameters of the full-scale structure which affect its dynamic characteristics. As the limiting criterion in the construction of a physical model, was the proposition that the time for forming a model must not exceed 5 man-days.

Most completely complying with the noted requirements is a planar plate and rod system whose metrical characteristics are determined by the frequency range of the calculations and the distribution of the superstructure along the length of the hull. Thus, in predicting the vibration level of a stern superstructure in a frequency range exceeding the lower boundary of the 8-Hz octave, the hull, from the midship section to the stern and the superstructure installed upon it, is included in the physical model. In so doing, the hull is modeled by a flat plate of varying thickness and weight and the height of the plate equals the height of the side of the ship and its length equals the distance from the midship section to the stern cut-off. At the midship section, the plate is rigidly fixed. The superstructure is modeled by a flat plate or a plate reinforced at the level of the tiers by rods (Ref. 4). The plate modeling the superstructure is connected with the plate modeling the hull at the place of the actual disposition of the projection of the superstructure on a longitudinal cross section of the hull of the ship. With a bow dispositon of the superstructure, the physical model includes the whole hull of the ship.

In predicting the levels of vibration levels in a frequency range lying below the lower boundary of the 8-Hz octave, the physical model includes the whole hull independent of the location of the superstructure. In this case, it is modeled by a flat plate reinforced at deck level by rods working in tension and compression. It should be noted that the latter of the described physical models is versatile and can be used in predicting the superstructure vibration parameters in the whole frequency range regulated by the public health norms.



Schemes for the Calculation of the Superstructure Vibrations of:
a) tanker "Pobeda", b) ore carrier "Khariton Greku",
and c) lighter carrier "Aleksey Kosygin".

The calculation scheme for the system "hull-superstructure" is formed by the subdivision of the appropriate physical model into finite elements. As such, plates and rods are used whose stiffness matrix is obtained based on inelastic resistance.

The structure of the calculations for the determination of the superstructure vibration levels in octave bands of frequency has the following form:

- by the method of finite elements, on the basis of the planar scheme of the system "hull-superstructure", a calculation is made of the vibration induced under the action of exciting forces whose frequencies are in the octave being considered. The peak values of the levels of vibration of the tiers of superstructure are determined at each of the frequency components of the exciting forces;
- on the basis of the peak values, the root-mean-square levels of the vibration of the tiers in the octave being considered are calculated;
- the levels of the induced vibration of the tiers are determined. The levels of the longitudinal vibration of the decks are taken as equal to the levels of vibration in the longitudinal direction of the corresponding tiers of the superstructure, and the levels of the vertical vibration are made up of the levels of vertical vibration of the superstructure itself and of the levels of vertical vibration of the decks relative to the superstructure.

One of the main parameters determining vibration is the intensity of the exciting forces. The principal sources of these forces on modern transport ships are the propellers and slow-speed diesels. Propellers induce unbalanced forces in the whole range of frequencies regulated by the pulic health norms. In addition, on new fast-transport ships, the propellers frequently operate in cavitating conditions and, at the second blade frequency and higher harmonics, the forces, even in the initial stages of cavitation turn out to have a significant effect. Investigations show that in vibration calculations made for the requirements of the public health norms, it is necessary to take into account forces whose frequencies do not exceed the upper boundary of the 16-Hz octave band.

Slow-speed main diesel engines bring the the greatest contribution to superstructure vibration at frequencies from the fifth to the twelfth orders. At the same time, the classical dynamics of diesels considers unbalanced forces only of the first and second orders and turning moments the order of which equals the number of cylinders (in two-cycle engines) or one half the number of cylinders (in four-cycle engines), assuming that all the remaining orders either are absent or negligibly small. Investigations of the vibration activity of marine diesels (Ref. 5) have shown that as a consequence of the deformability of the framework of an engine, additional forces and moments arise with a broad spectrum of frequencies. The presence of resonances of transverse and vertical vibrations of the framework leads to dynamic reinforcement of externally unbalanced forces and moments and furthermore, to the transmission to the hull of a number of forces which formerly it was customary to consider as externally balanced.

Thus, the prediction of the levels of vibration of superstructures in all frequency octaves is done on the basis of the simultaneous action of forces induced by the propeller and main diesel. In the calculating scheme the forces from the propeller are applied to the lower edge of the plate modeling hull of the ship at the same section as the propeller disk, and the forces from the diesel are applied at a point corresponding to its center of gravity with the moments of the diesel applied relative to the center of gravity.

Practical calculations were carried out with the aid of the "Neva" software (Ref. 4) which is a specialized system for determining the parameters of the natural and induced vibrations of ship superstructures by the method of finite elements.

The stated algorithm and its software were used for calculations of the vibration levels in the 8- and 16-Hz octave bands of the superstructures of transport ships of three types; namely, the tanker "Pobeda", the ore carrier "Khariton Greku", and the lighter carrier "Aleksey Kosygin" (See illustration and Table 1). Results of the calculations and full-scale trial data are presented in Table 2.

The accuracy of a prediction calculated within the framework of the algorithm being considered is determined by the following basic factors:

- the accuracy of the given magnitudes of the exciting forces;
- the accurcy of the given characteristics of the inelastic damping;

Table 1. The principal characteristics of ships whose superstructure vibration levels were determined in calculated and experimental ways.

Ship name	Ship type	Superstructure position	Deadweight, Tons	Main engine type (power, kW)	Propeller data rpm	Propeller data No. blades
"Pobeda"	Tanker	stern	60,500	7DKRN 80/160-4 (12,360)	122	4
"Khariton Greku"	Ore carrier	>>	52,500	8DKRN 74/160-3 (10,080)	120	4
"Aleksey Kosygin"	Lighter carrier	bow	40,000	Two 7DKRN 80/160-4 (2 X 12,360)	122	4

Table 2. Comparison of calculated and experimental values of superstructure vibration-acceleration levels of transport ships in the pilot house region (dB)

Ship name	Vibration Direction	8-Hz Octave			16-Hz Octave		
		Calcultd	Expermnt	Error	Calcultd	Expermnt	Error
"Pobeda"	Vertical	48	45	4	40	46	6
	Longitudinal	59	57	2	39	45	6
"Khariton Greku"	Vertical	35	34	1	35	32	3
	Longitudinal	43	51	8	36	-	-
"Aleksey Kosygin"	Vertical	26	32	6	37	38	1
	Longitudinal	41	36	5	33	32	1

- the completeness of the physical model and the correctness of the calculating scheme corresponding to it;
- the accuracy of the solution of the system of equations of the conjugation of the finite elements.

While two of the latter factors to a significant degree are controlled by the designer, the values of the exciting forces in the high frequency octaves, their mutual phasing, and also the values of the coefficients of damping are introduced, with the modern level of knowledge, with a total error reaching 100 percent in some cases. In these conditions an accuracy of a calculated prediction of the vibration levels of the tiers of superstrucures of 6-8 dB, can be considered satisfactory.

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IMPROVING THE MANUFACTURE AND APPLICATION OF SHIPBUILDING HULL STEEL

Leningrad SUDOSTROYENIYE in Russian No 5, May 86

[Article by A. I. Baluyev, A. F. Goncharov, A. A. Kroshkin, V. A. Nikitin, A. A. Pigenko and V. I. Sheiko]

[Text] The creation of a modern domestic transport fleet and of qualitatively new types of ships (oil bulkers carriers, containerships, lighter carriers, and so on) has been accompanied by a reconsideration of the traditional approach to design, and a transition to design methods with a more detailed consideration of such technical and economic ship characteristics as hull weight, cargo capacity, and so on. The new architectural design solutions, the complication of the operating conditions of ships (especially in the northern latitudes), the necessity to satisfy a number of new international regulations, and the effort to reduce the metal consumption of hull structures have led to a decisive change in the requirements for the properties of hull steels and for a suitable sort of composition for them.

Until recently, the principal demands of domestic shipbuilding for hull steels were satisfied by rolled plates, bars, and shapes of steels of the sorts: VSt.3sp, 09Mn2, and 10CrSiNiD having elastic limits of 235, 295, and 390 MPa respectively. More than thirty years of experience in the construction and operation of seagoing ships built of these steels confirmed the high reliability of these steels as materials for welded hull structures. The technical possibilities, however, for further improvements of ships built using the given steels were practically exhausted. This is explained primarily by the relatively large intervals between the values of the elastic limits in the transition from one sort of steel to another, by the necessity for the satisfaction of extremely rigid requirements for materials working in low temperature conditions, and by the somewhat increased tendency of 09Mn2 steel to corrosion in the heat-affected zone of welds, especially during operation in ice.

The enumerated circumstances dictated the conduct by shipbuilders and metallurgists of a large amount of work on improving of domestic steels and the creation, in essence, of a new series of shipbuilding materials providing for fulfillment of the shipbuilding program and satisfying modern international requirements in all respects.

In carrying out this work, the requirements for shipbuilding steels promoted by the International Association of Classification Societies (IACS), of which the USSR is a member, were taken into account. In international practice within the framework of IACS, unified categories of hull steels have been adopted which are defined according to elastic limit and the impact work in the course of tests at different temperatures. These characteristics rather fully reflect the work capacity of a material under different operational conditions, and therefore, they were taken into account first of all in the development of the new steels.

An analysis of the conformity of the domestic steels with the categories adopted in international practice showed the following. According to IACS requirements, steels of normal strength (elastic limit not less the 235 MPa) are differentiated by the tendency to brittle failure evaluated according to the magnitude of the impact work on specimens with a sharp notch at a specific low temperature. Steel of the highest category, designated by the letter "E", is tested at a temperature of - 40 C. Steel of the next category, "D" is tested at - 20 C, and that of category "B", at 0 C. Steel of the lowest category, "A", is supplied without these tests. In this, for steels of categories "E", "D", and "B", the impact work must not be less than 27 J at the indicated test conditions. Domestic analogues of these steels, to some degree, were VSt.3sp2, and VSt.3sp4 which also have a guaranteed elastic limit of 235 MPa. In the requirements for cold resistance, however, they do not conform to the first three categories which dictated the necessity for a reconsideration of the chemical composition of the steels, for a substantial improvement in the deoxidation part of the technology for their production, for modification of the smelting, and, in some cases, for heat treatment of the rolled product.

Steels of increased strength according to the value of the elastic limit are made in three types having guaranteed elastic limits of 315, 355, and 390 MPa. For these steels, IACS established categories "A", "D", and "E" respectively. For the first steel (315 MPa), the impact work must be not less than 31 J, for the second (355 MPa), not less than 34 J, and for the third (390 MPa), not less than 36 J. The impact test for category "A" is conducted at a temperature of 0 C, for category "D", at -20 C, and for category "E", at -40 C. 09Mn2 steel can serve as a domestic analogue of the IACS steel with 315 MPa elastic limit, and 10CrSiNiD steel as that for the steel with elastic limit 390 MPa. Here also, however, it was necessary to conduct supplementary work connected with providing for the requirements of the impact work at low temperatures. As for a steel with an elastic limit of 355 MPa, there was no domestic analogue.

On the basis of laboratory investigations and tests of specimens obtained from the metal of a number of experimental melts, new compositions of shipbuilding steels were developed with strictly regulated parameters for their smelting, rolling and heat treatment. The results of the investigations carried out permitted preparing suitable requirements for the steels included in GOST [State Standard] 5521-76 entitled "Weldable Steel for Shipbuilding" as in part 4 of "Requirements for Hull Steel Delivered According to the Rules of the USSR Register of Shipping".

In the new steels, the range of the content of the basic alloying elements was expanded which permitted correlating the consumption of alloying additives with a specific assortment of rolled product and assuring the receipt of like values of the mechanical properties for a whole assortment series. The chemical consistencies were chosen with regard for the requirements of international standards and for the peculiarities of domestic practice in metallugical production. Thus, in particular, for steels of normal strength, the upper limit of manganese content of was raised to 1.5 percent, additions of aluminum and titanium were regulated (to 0.06 percent), and the heat treatment of steels of categories "B", "D", and "E" was reexamined. For steels with an elastic limit of 315 and 355 MPa, the manganese content was limited to 1.6 percent and additions of niobium (to 0.05 percent) and vanadium (to 0.1 percent) were stipulated as well as a suitable heat treatment. The former chemical composition for steel 10CrSiNiD with an elastic limit of 390 MPa, was retained.

It should be noted that the tests by impact specified in GOST 5521-76 for specimens with a sharp notch are more rigorous than the determination of impact toughness on Menazhe specimens even if the latter were conducted at a temperature 20 C lower. For instance, rolled plate of steel 10CrSiNiD which is acceptable according to impact resistance at - 40 C, by far does not always withstand tests for impact on specimens with a sharp notch at - 20 C. At the same time, a steel passing tests for impact on specimens with a sharp notch at - 20 C, always has satisfactory parameters of impact resistance in its monitoring by Menazhe specimens at - 40 C.

The improvement of the production of steels of normal strength and of low-alloy steels of increased strength in combination with the regulation of manganese content led to an improved structure of the steels, a reduction of their tendency to brittle failure and to local corrosion (in particular, to corrosion in the heat-affected zone of welds).

Observance of the new requirements of the GOST, increasing the structural stability of steels and providing a guaranteed cold resistance and a reduction of the tendency to local corrosion cannot be realized while retaining the traditional technology of production. The broad verification undertaken several years ago of the quality of the shipbuilding steels of the old sorts showed the nonconformance of the actual level of impact work with the international requirements. This nonconformance was observed, basically, at those plants where the production of steel was accomplished by obsolete metallurgical equipment and without the technological methods for improving the quality of the material.

The increased requirements for the new steels caused substantial difficulties in the organization for their production at metallurgical plants. A substantial reexamination was needed of the established technology for smelting steel, and the development and introduction of measures for increasing the quality of the rolled stock were required. The parameters for smelting steel began to be more rigidly regulated in new oxygen converters. The pouring of steel in heavier ingots was introduced and also the casting of slabs on continuous casting installations. The conditions of heating for rolling and the technology of the rolling itself were refined on the various plate rolling machines including the powerful new "Kvarto" rolling mill of the Azovstal metallurgical plant. Thickness tolerances for plate steel were substantially tightened, and the production of heat treated rolled product was significantly expanded. At the Azovstal plant the production of large-sized rolled plate with a width up to 3.2 m and a length up to 14 m after quenching and tempering and up to 16 m long in normalized condition was developed and mastered.

Organizationally, the formation of one or another assortment of shipbuilding steel framing was begun at each supplying plant with inspection of its production by the USSR Register. The possibility of producing one or another kind of product was verified by data from monitoring tests whose volume was specified by a specially developed program. Positive results from these tests served as the basis for issuance of a certificate of the USSR Register on the acceptance of a given enterprise as a supplier of shipbuilding steel of a given assortment. In so doing, the limiting mandatory parameters of the technology frequently were stipulated in the certificate.

At present, the production of steel hull plating and rolled shapes has been mastered and approved by the USSR Register at a number of metallurgical plants. Based on established regional communications, the range of rolled products in ferrous metallurgy production is providing for the demands of the industrial sector.

On the basis of experience in the production and use of the new hull materials, in 1981 and then in 1983 changes were introduced in GOST 5521-76 by which a practically new standard for hull steel was formulated. The indicated changes served as the technical and organizational basis for the transition to the production and use of the new steel according to unified standards. On the basis of the domestic standard for hull steel, the Council of Economic Mutual Assistance standard ST SEV 3619-82 entitled "Rolled Steel for Shipbuilding" was developed.

A large quantity of rolled hull plate and shape products of all categories, obtained in accordance with the new technology, already has been used by the enterprises of the industrial sector for building ships. The Azovstal plant has delivered a substantial quantity of large-sized plates with dimensions of 3.2 X 11.5 m. The range of elastic limits of the steels (235 - 390 MPa) fully satisfies the demands for transport shipbuilding, and their guaranteed values significantly broaden the possibilities for designers in the business of building ship hulls of minimum weight.

The mastery of the industrial production of the new shipbuilding steels at metallurgical plants has permitted the realization of the mathematical method of the design of the hulls of ships of the new types.

The norms for the strength and rules for the design of seagoing ships and also the techniques for calculating the strength of the principal hull structures which have been developed by specialists and scientists, primarily of the TsNII [Central Scientific Research Institute] imeni Academician A. N. Krylov, permit determining with sufficient accuracy the stress condition of structures under the action of various operational loadings and finding their minimum dimensions. For increasing the coefficient of the utilization of material, the principle of differentiation of structures according to their stress levels is used.

For the most highly loaded structures (the upper deck, the bottom, and so on), steels of higher mechanical properties are used than for internal and less stressed structures. The classification of steels by category makes it possible to affect significantly the reliability of the hulls of ships specially intended for operation in the Arctic. The development of steels of Category "E" and their use in highly stressed structures guarantees the absence of brittle failure in them.

The use of steels delivered according to GOST 5521-76 in conjunction with the modern mathematical methods of design permits, in an efficient design, reducing the weight of the hull by 3 - 6 percent or more. In particular, according to data of TsKB [Central Design Bureau] designers, on a number of ships designed and built using the mathematical methods of determining the dimensions of hull structures and the application of the new steels, substantial savings of metal already have been obtained.

Savings of Steel on One Ship in Tons and Percent

Tanker (deadweight 68,000 t, length 228 m)	450 (3.8)
Lighter carrier (31,900 t, 228 m)	760 (4.8)
Roll-on/Roll-off ship (6,800 t, 142 m)	250 (4.7)
Lighter carrier (40,000 t, 232 m)	690 (5.3)
Refrigerated cargo ship (4,900 t, 115 m)	150 (6.5)
Icebreaker-transport ship (10,650 t, 142 m)	300 (6.0)

The total annual saving of metal in shipbuilding because of the indicated measures amounts to several thousand tons.

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MOORING OPERATIONS ON DRILLING SHIPS

Moscow GAZOVAYA PROMYSHLENNOST in Russian No 3, Mar 86 p 17.

[Article by V. K. Kozyrev, captain-director, drilling ship Valentin Shashin]

[Text] When at the drilling site , drilling ships of the Valentin Shashin class, with a displacement of 17,000 tons, are constantly being resupplied with fuel, fresh water, food and various engineering and operating supplies necessary for well construction. Such supplies are delivered by supply tugs, while passenger ships are used for crew changes.

When drilling, the drilling ship is linked to the wellhead by a marine riser and underwater blowout prevention equipment. The drilling ship is kept at the drilling site with the help of dynamic positioning systems. which include three 32 kilobyte computers, two of which are working and one in reserve, and an IMR-4 on-board receiver for satellite navigation which uses the "Tranzit" satellite navigation system. It is a highly accurate two channel receiver with two working modes: reception (during drilling) and navigation. The dynamic navigation system also includes the HPR hydroacoustic orientation system, the "POOL MOON"/"TAUT WIRE", doppler shift and a SYLEDIS range-only radar. The dynamic positioning system is automatically controlled by a movement system consisting of three bow and two stern thrusters and two screws which keep the ship at the drilling site at winds of up to 25 meters per second with a safety circle of 5-12 percent of ocean depth, i. e. within the limits of the ship's working depth (60-300 meters).

In optimal conditions, when the drilling ship is stabilized on course, opposed by equal winds and currents, the thrusters form wake zones along frames 160 to 180 forward and 5 to 25 aft. These hinder, and at times make impossible the mooring of supply tugs and passenger ships. This is because, in accordance with its specifications and other documents, the drilling ship should be stablized on course so as to assure reliable standing over the wellhead and keeping within the limits of the safety circle. This is to prevent damage to the well mouth, riser or blowout preventer.

Foreign practice does not allow the mooring of supply tugs and other ships by the contact method when the drilling ship is at the drilling site or engaged in drilling operations. The supply tugs have their own dynamic positioning systems, making it possible to stabilize their positions at a sufficient distance in order to carry out cargo handling work, taking into account the maximum boom reach of the drilling ship crane. In its turn, the drilling ship does not need to change position because of winds or current. Crews are changed by helicopter, the drilling ship having a helipad.

Because all supply tugs and passenger ships were ordered and received without dynamic positioning systems, back in 1982 there arose the question of how to moor supply tugs or passenger ships to drilling ships in order to handle cargo or crew. The latter problem arises because drilling sites on the Arctic shelf are too remote to use helicopters.

When we began to moor supply tugs and passenger ships to a drilling ship without changing the drilling ship's position relative to wind and current it immediately became obvious that when adjusting for wind or current, the wakes from the drilling ship 's five thrusters shifted to the right or left, and when a ship approached to make fast it was deflected by these wakes, sometimes moving to a position almost perpendicular to the drilling ship, the lines had to be cut loose and the maneuver tried several times. All this increased the difficulty of approach, mooring, cargo handling and departure operations. Under such conditions, the ship being made fast suffered damage to bulwarks, boat davits and other structures.

Practice shows the need to find ways of stabilizing drilling ships on course so that, when a supply tug of passenger ship approaches, the wake from the thrusters will be ejected on the opposite side until the end of mooring and will not hinder the ship being made fast. Also, wind and current should help these operations.

In 1983 the following scheme for drilling ship stabilization on course was proposed. It has two stages. The first is the approach and mooring of the supply tug or passenger ship; while the second is the change in drilling ship course orientation and its stabilization in a new position in order to take on cargo from the supply tug, or to transfer personnel. It was also necessary to give consideration to the safety of drilling operations and the drilling ship itself, forcing constant corrections in course stability, taking into account changing hydrometeorological conditions, as it often takes more than a day to unload stores from supply tugs.

Thus, in the first stage the drilling ship turns around and steadies its course so that the wind and current are coming from the mooring side and at an angle to the center line of the drilling ship , depending upon their force (Figure 1.). With the drilling ship course made steady, the thrusters begin operation to compensate for wind and current. Their wakes flow away from the side opposite the mooring. They do this steadily until the drilling ship changes course. This does not hinder the mooring ships, in fact, the current flowing towards the mooring side helps them.

Having obtained permission from the drilling ship to moor, the mooring ship moves parallel to the drilling ship where protective fenders have been hung and at a distance depending upon wind and current. Holding parallel to the drilling ship centerline, it waits until it drifts into the fenders, after which lines (leaders) are tossed.

When the ship is made fast, the second stage begins. The drilling ship changes position and steadies its course so that the wind and sea are coming from the side opposite the mooring side at an angle to the drilling ship center line. The moored ship is protected by the drilling ship from the wind and waves, making possible safe cargo handling operations and crew transfer. The wakes from the thrusters, which in this case the drilling ship is directing towards the mooring side, do not hinder the moored ship, as they only have an effect during approach and departure.

When cargo operations or crew transfer are completed, upon permission from the drill ship, the moored ship casts off lines and starts drifting, under the influence of wind and sea, from the drilling ship. When it reaches the thrusters wake zone, they also push it away from the drilling ship .

Over a two year period this scheme has been used hundreds of times to moor ships to the Valentin Shashin and Viktor Muravlenko. Practice has shown the safety of this scheme. None of the other schemes had positive results.

In time we came to the conclusion that prior to the other ship making fast, the drilling ship should steady its course so that at wind speeds over 15 m/s, wind direction relative to the drilling ship centerline should be around 15-20 degrees, at windspeeds of 10-15 m/s -- from 20 to 45 degrees and at wind speeds less than 10 m/s, up to 90 degrees.

At wind speeds of up to 15 m/s the ship to be moored should stand off from the drilling ship at least 20-30 meters, at 10-15 m/s windspeeds -- 10-15 meters and at windspeeds less than 10 m/s, 5-10 meters.

Mooring lines are fed out by the drilling ship and by the supply tug or passenger ship. A kapron bow line or propylene line (lead) is fed from the forward bilge hawsehole of the drilling ship to the bilge hawsehole, forward spring and retainer ropes of the ship being moored. The ship being moored feeds a bow and spring to the forward part of the ship.

Inflatable fenders, 1.8 meters in diameter and bunched in groups of 3 are used for fender protection (Figure 2). However, this scheme can be changed, depending upon the length of the ship being moored.

When loading and unloading containers full of slurry, sacked cargo, chemical reagents and other supplies, the supply tug is moored to the port side of the drilling ship under way under the 25 ton capacity forward cargo crane. When changing crews, passenger ships are moored under way along the starboard side, under the forward cargo crane.

It must be stressed that mooring lines made from any material can be used for making fast to the drilling ship, however, practice shows that it is better to use kapron or propylene lines. Greater preference should be given to

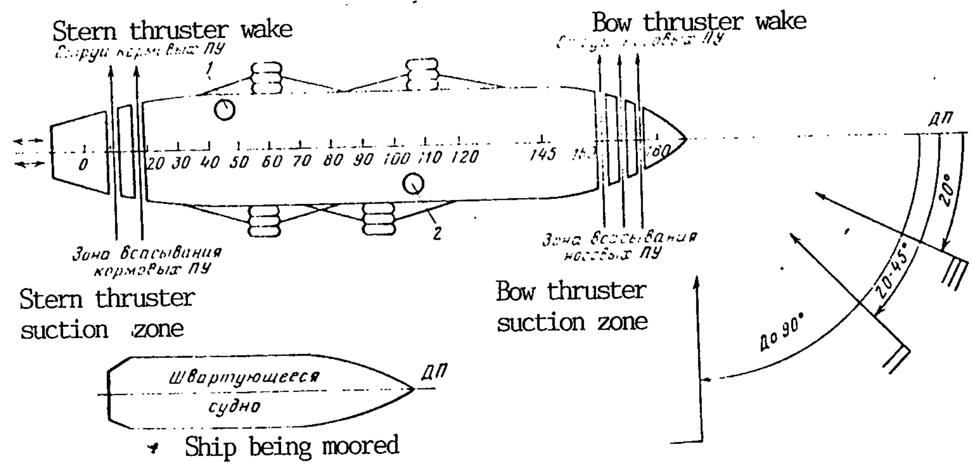

Figure 1. Mooring supply tugs or passenger ships to drilling ship
1,2. Aft and forward cargo cranes

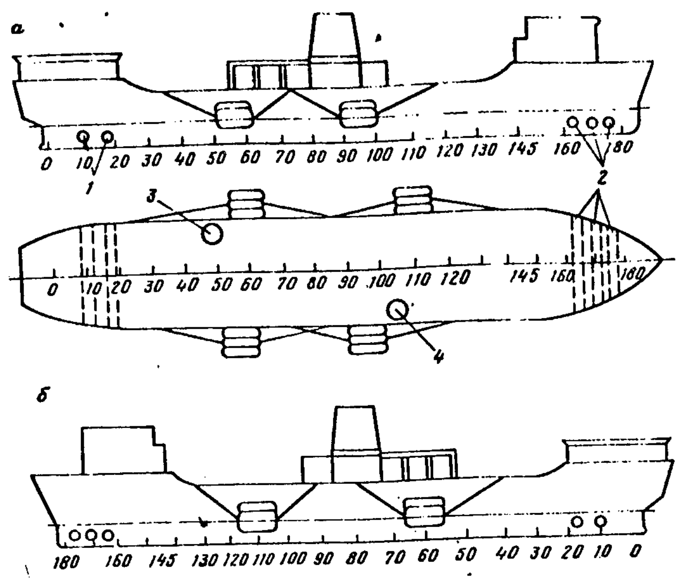

Figure 2. Arrangement of protective fenders on drill ship Valentin Shashin:
a. starboard b. port, 1,2 stern and bow thruster tubes
3, 4 aft and forward cargo cranes

propylene lines as they have more buoyancy than do kapron lines. Sometimes, when a supply tug or passenger ship is coming up alongside a drill ship, the wakes from the thrusters along the mooring side, which flow to the side opposite the mooring, in the areas around the bow and stern thrusters, create a suction zone There have been cases where a kapron line, up to 100 meters long, fed to the ship being made fast, cannot be caught. It sinks into the forward pipes of the thrusters and winds around the thrusters screw. Such a situation requires that the drilling ship rapidly break away from the wellhead in order to unwind the line. One such case put the drilling ship out of operation for a day.

As a result of this, when working with kapron lines (leads), we have started to use additional backup lines both in the line loop and length, to give the line additional buoyancy as it is attached to the cleat of the ship being made fast. The end of the line remains on board the drilling ship and is constantly observed by a sailor, who can haul it on board during changes in ship position or if the line breaks. When the drilling ship changes position to carry out cargo operations or to transfer personnel, and later when the other ship departs, the suction zone will be on the side opposite that ship and there will be no danger of the mooring line winding around the screw.

11574
CSO: 1861/284

PROBLEMS WITH IMPLEMENTATION OF PATENT ON SHIP'S PROPELLER

Moscow IZOBRETATEL I RATSIONALIZATOR in Russian No 1, Jan 86 pp 12-14

[Article by S. Panasenko, Leningrad-Moscow correspondent]

[Abstract] In 1970 a patent was granted to M.I. Dvorkin of the Kanonerskiy shipyard in Leningrad for a method of coating propeller screw blades, steel or brass, which would protect them against both corrosion and cavitation. Although this method has been applied successfully since 1970 at this shipyard and later also at the "Pregol" Kaliningrad and other shipyards, although even the USSR Ministry of the Maritime Fleet has shown interest, in 1976 the coating facility was ... closed down. This, according to Dvorkin himself, is not puzzling but a logical step in a campaign waged by the Scientific Research Institute to discredit and downgrade ideas conceived by shipbuilders in the yard. As a result, the blueprints for a full-fledged coating workshop were still not ready in 1981 and will perhaps not be ready as promised by June 1986. Meanwhile, propeller screws and blades are being coated by the Dvorkin method at various shipyards on an arbitrary rather than systematic basis so that its benefits are by far not fully realized. This is an example of roadblocking and evasion, of deliberate delays and specious excuses, of Science and Academia not helping but thwarting Industry and Production. Another example is the fate of the new screw invented by N.M. Nikitin jointly with S.V. Yakonovskiy and Z.L. Golubeva at Leningrad Central Design Engineering Office, a screw with an involute-epicyclic edge which does not chop but bounces obstacles. Such a screw is of no use on icebreakers in the Arctic Sea, according to expert opinion of academicians, but what about ships in the Gulf of Riga? It is time to put an end to this opposition and jealousy, Science must be supportive, but neither must Industry be domineering. Scientific research institutes, just as design engineering and technological enterprises, must become more production-oriented rather than remain aloof in ivory towers. Only then can real progress be accelerated, as correctly stated by M.S. Gorbachev at a meeting of the CPSU Central Committee.

2415/13046
CSO: 1861/216

UDC 629.123.56.06:614.84

INERT GAS SYSTEM OF A MODERN TANKER

Leningrad SUDOSTROYENIYE in Russian No 9, Sep 85 pp 25-27

[Article by V.P. Mokretsov, A.A. Mundinger, and A.G. Novikov

[Abstract] To provide a noncombustible atmosphere within cargo tanks, in accordance with the SOLAS-74/78 requirements all modern Soviet tankers are equipped with an Inert Gas System. The upgraded system which was installed on Pobeda-class tankers is intended to prevent explosions by limiting the oxygen content in all cargo tanks below 8 percent by volume. The uptake from one of the ship's auxiliary boilers is used as a source of inert gas. Cooling and partial cleaning of the flue gas take place in a scrubber which provides direct contact of a flow of cooling water with the upward flow of gas. After two-step cleaning to remove soot, mechanical solids and sulphur oxides, the inert gas can be expected to be up to 97 percent sulphur-free. After cooling and cleaning, the flue gas undergoes a double water separation. Ready-to-use inert gas is delivered by a blower into the deck distribution main through the deck water seal which prevents the backflow of hydrocarbons and other gases from the cargo tanks to the inert gas system and the boiler. There are five operational modes of the system: before cargo loading, loaded or ballast voyage, cargo discharge, tank washing, and exhausting. A control program supervises all five modes of the plant operation on board the Pobeda-class tankers. The future development and betterment of the system will proceed in two directions: improvement of cooling by intensification of the direct contact of the flue gas with sea water in a two-step cooler, and upgrading of cleaning by introduction of steam and special inhibitors. Figures 6.

12896/13046
CSO: 1861/137

UDC 629.128.72

EXPERIENCE IN INCREASING THE EFFICIENCY OF UTILIZING FLOATING DRYDOCKS

Leningrad SUDOSTROYENIYE in Russian No 4, Apr 86

[Article by G. A. Megrabov and A. M. Yakovlev, under the rubric: "Repairs and Alterations to Ships"]

[Text] The main dry-docking facilities at the ship repair yards of the country are floating two-sidewall docks with various capacities. Inasmuch as all seagoing ships are dry-docked regularly, curtailing the duration of this operation and increasing the efficiency of utilizing floating dry docks has economic importance.

At present in this field, the following trends have been noted. First is the docking and undocking of ships having an inherent trim; that is, docking them without taking on water ballast to put the ship on even keel before entering and exiting from dry dock. Formerly, the necessity to twice take on ballast water and pump it out consumed a substantial amount of time and electrical energy, and brought about additional work - for instance, the removal from the dock floor of ice formed during the discharge of water. All these faults attend the docking and undocking of ships with an inherent trim. The second trend is the mechanization of dry dock work including that on the rudder and propellers. The third trend is the creation of a favorable microclimate in dry docks by the installation of wind protections and other devices which promote improved working conditions, increase the productivity of labor, and assure high quality in carrying out the series of dry dock operations. Fourth, is the introduction of the brigade contract for dry dock work.

On all these trends investigations are being conducted by the Technology and Organization of Ship Repair Department of the Far-East Higher Marine Engineering School imeni G. I. Nevelskiy which is the main body for increasing the efficiency of the utilization of the floating dry docks of the MMF [Ministry of the Maritime Fleet]. In particular, the possibility has been substantiated of docking and undocking ships with inherent trim by metal floating dry docks with lifting capacities of 800, 1500, 2500, 4000, 4500, 7000, 12000, 25000, 27000, 28000, and 30000 tons; by composite dry docks designed for 8500 tons; and by reinforced concrete dry docks with capacities of 6000 and 6500 tons. The adoption of the results of these investigations at many ship repair yards permitted obtaining a substantial economic gain.

Besides the enumerated organizational and technical trends which are common for all floating dry docks, however, special cases can occur where the efficiency of utilizing dry docks can be increased. Let us consider two of them.

First, consider the dry-docking of "Stroptivyy"-class icebreaking salvage tugs in a composite dry dock with an 8500-ton capacity. These ships, which operate in the Far-Eastern basin, are dry-docked once every two years. Because of the specific nature of their lines, for carrying out these dry-dockings the ships usually have made a special passage to an SRZ [Ship Repair Yard] having a floating dry dock with a 27,000-ton capacity.

To eliminate the supplemenary costs connected with the ferrying of these ships from their base port to the dry-docking place and return, and also to eliminate payment of the fee for use of the rather large dry dock, the ship owners proposed consideration of the possibility of dry-docking ships of this class in floating dry docks with capacities of 4500 and 8500 tons. The complexity of this problem consisted of the fact that no more than 45 m of the length of this 71.6 m long ship with a beam of 18 m and a docking weight of 4,190 tons can be placed on the centerline blocking-support track of the dry dock. In so doing, the side blocking, which provides the transverse stability of the ship in dry dock, turns out to be between the central and side blocking support tracks; that is, in the regions of the dry dock floor upon which only a relatively small loading is permitted.

In the consideration of the possibility of docking "Stroptivyy"-class ships in a 4500-ton capacity floating dry dock, it turned out that although the dry dock is 30 m longer than the ship and its capacity is greater than the weight of the ship, still, the dock could not be used to dry-dock these ships because of substantially exceeding the allowable loadings transmitted by the keel blocks to the dry dock floor. The keel blocks in this dry dock are installed with a one meter spacing and the allowable loading on each block on the centerline blocking-support track is 500 kN and on the side tracks 250 kN. Consequently, under the bearing part of the icebreaker, 45 blocks can be installed on the centerline keel blocking-support track capable of receiving an allowable loading of 22,500 kN which is barely half that required for the 4,190-ton docking weight of the ship which corresponds to 41,900 kN.

The composite floating dry dock of 8500-ton capacity has a length, without the propeller guards, of 140 m and the allowable loading on the centerline blocking-support tracks is 900 and on the side tracks - 450 kN per running meter. Keel blocks are installed with a 1.5-meter spacing; therefore the allowable loading for each keel block is 1,350 kN and for each side block, 675 kN. Since 30 keel blocks can be under the bearing part of the ship, the load transmitted by them onto the dock floor on the centerline keel blocking-support track should not exceed 40,500 kN which is a little less than the required amount.

If, in accordance with the "Stroptivyy"-class builder's docking plan (Figure 1), 12 side blocks were installed on the dry dock floor, each of which could accept 500 kN, then the total allowable loading on the dock structure amounts

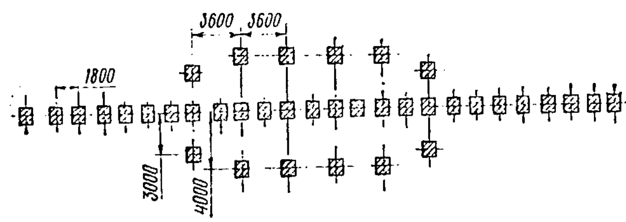

Figure 1. Arrangement of keel and side blocking in the building of "Stroptivyy"-class ships.

to 46,500 kN which is more than the docking weight of the ship. In this case, however, the side blocks must be installed on the dock floor at a distance of 3-4 m from the centerline plane, whereas the side blocking-support track for this dock is 6.7 m from the centerline plane. In the intermediate space between the side and centerline blocking-support tracks, side blocks cannot be installed as the allowable loading here is only 50 kN per square meter. Therefore, a way out of the situation is the installation of the side blocking on special beams (Figure 2) which rest upon the side and centerline blocking-support tracks. In so doing, only about half the loading received by the side blocks is transmitted to the side blocking-support tracks. Consequently, the total loading from the ship onto the dock floor amounts to 40,500 + (500 X 2)/2 = 43,500 kN, and the problem of docking "Stroptivyy"-class ships in this dry dock is solved.

In practice, it is necessary to install 14 side blocks on the dry dock floor (see Figure 2) instead of the 12 envisaged by the builder's drawing (see Figure 1). This was brought about by the fact that with a frame spacing on the icebreaker of 0.6 m, the side blocks in the builder's docking plan were spaced at 3.6 meter intervals; that is, every six frame spaces. But, as the keel blocks on the composite dry dock being considered are installed on the dry dock floor at 1.5 m spacing, then two or four keel block spaces - 3 or 6 meters - are whole multiples of the frame spacing. As 6 meters is too large, the spacing of the side blocks was taken at 3 meters. In so doing, the two additional side blocks permit increasing somewhat the allowable loading on the dock floor under the bearing part of the ship.

During the dry-docking of ships of this class which have an inherent trim of 41 minutes, the dry dock should be trimmed to the same angle so that the bottom of the ship is seated simulateously on all keel and side blocking.

The economic gain from dry-docking "Stroptivyy"-class ships in the 8500-ton capacity dry dock can be determined by the formula:

$$Э = [(Д_{T_{27000}} - Д_{T_{8500}})\, t_{д} + c t_{пер}]\, n - K E_{н},$$

where: $D_{T_{27000}}$ and $D_{T_{8500}}$ are the daily docking fees for floating dry docks with

capacities of 27,000- and 8,500-ton capacity, $t_{д}$ and $t_{пер}$ are the time the ship is in dry dock and the time consumed in the passage to and return from the docking place, n is the number of ships docked per year, $E_{н}$ is the standard coefficient of the effectiveness of capital investment (0.15), K is the cost of the materials and of the preparation of the supporting block arrangement, and c is the daily pay for the ship.

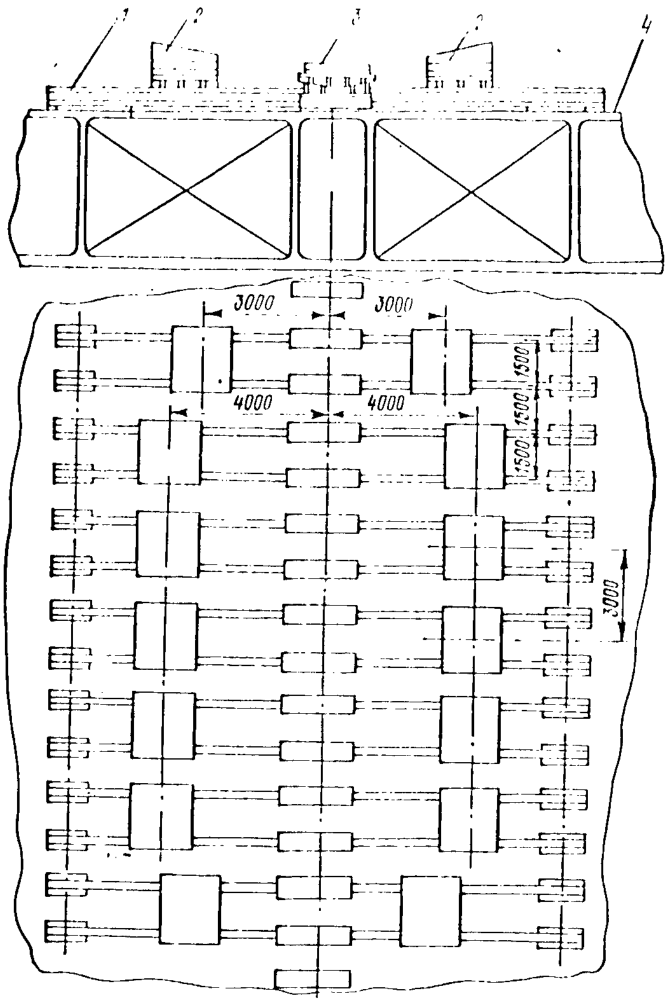

Figure 2. Diagram of the installation of side blocks on special beams for dry-docking "Stroptivyy"-class ships.

1 - beams, 2 - side blocks, 3 - keel blocks, 4 - dry dock floor.

In the case given, the annual economic gain amounts to several tens of thousands of rubles. In addition, as the lifting capacity and length of the floating dry dock considered are both larger by a factor of two than the docking weight and length of "Stroptivyy"-class ships, a pair of ships can be dry-docked as a unit. In this case the effectiveness of the utilization of the dry dock is increased approximately by a factor of two.

Repairing the pontoons of a sectional dry dock without removing it from service. During the dry-docking of a large refrigerated fishing trawler, the No. 3 pontoon of a six-section floating dry dock was damaged. The damage consisted of dents in the dry dock floor with depths up to 250 mm, deformations of the centerline, longitudinal, transverse, and end bulkheads of up to 100 mm, and the loss of stabiltiy and even the breakage of vertical pillars of the framing. During the subsequent examination of the structure of this pontoon, it turned out also that as the result of corrosion the thickness of the plates of the dock floor had been reduced by 36-50 percent as compared with the thickness as built.

In avoiding the large losses and delays in the production plan of the plant which could have taken place during self-dry-docking, the possibility of carrying out restoration operations on this pontoon without removing the dry dock from service was considered and substantiated. To solve this problem, the calculation of the longitudinal strength of the side walls of the dock and the local strength of the bottom of the pontoon was required.

Inasmuch as the pontoons of this dry dock are not a monolithic structure, only the side walls provide resistance to overall bending. According to certificate data, the allowable bending moment for the dry dock is 280,000 kN m. The dry dock had been in service for 13 years, and as the result of corrosion, the thickness of its principal hull structures, according to the TsNIIMF [Central Scientific Research Institute of the Ministry of the Maritime Fleet], should have been reduced by 0.10-0.12 mm annually. Proceeding from this, the moment of inertia and the resistance of the transverse cross section of the dry dock was determined and the allowable bending moment became $M_{доп}$ = 196,000 kN m.

For the empty dry dock the bending moment acting on the side walls is nil since the side walls repose uniformly on all the pontoons. With the disassembly of structures of the third pontoon and the dry-docking of ships on the remaining pontoons, the side walls can be considered as cantilevers fixed at the ends of the No. 3 pontoon (Figure 3.). The allowable loading on the dry dock on both sides of the No. 3 pontoon can be determined from the relation $M_{доп} = Ql/2$, whence: $Q = 2M_{доп}/l$. With the lengths of the cantilevered parts as indicated on Figure 3, $Q_1 =$ 11,700 kN and $Q_2 =$ 7,800 kN. In the scheme considered, the forces of the pressure of the water acting on the bottom of the pontoons are not taken into account. By taking them into account, the allowable loads will be somewhat larger.

On the right hand part of the dry dock, RS-300-class ships can be placed which have a length between perpendiculars of 30 m and a docking weight of 2,980 kN which is much less than the 11,700 kN allowable loading. On the left hand part of the dry dock, other ships being used in the region can be placed which have a length of 40-50.4 m and docking weights of 4,800 and 6,440 kN - also less than the 7,800 kN allowable loading. Thus, during No. 3 or No. 4 pontoon repairs, the dock's longitudinal strength is fully sufficient for docking ships with a length equal to that of the remaining pontoons.

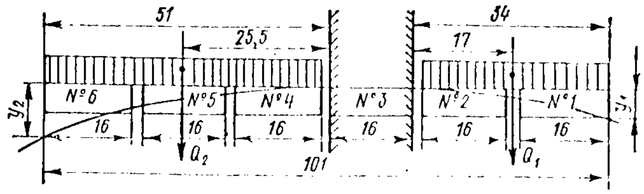

Figure 3. Diagram for calculating the longitudinal strength of the dry dock during the absence of pontoon No. 3 and with dry-docked ships on the remaining pontoons.

For the final solution of the possibility of repair of the pontoon without self-docking, a calculation of the local strength of its bottom should be carried out. This is called for by the fact that during the disassembly of a number of the internal structural elements, the carrying capability of the pontoon drops sharply. Inasmuch as water pressure, whose magnitude depends on the depth of submersion of the dry dock, acts on the bottom of the pontoon, it is necessary to determine the capability of the pontoon's bottom (Figure 4) to resist this loading without permanent deformation during the removal of the damaged elements which had added to its strength and rigidity.

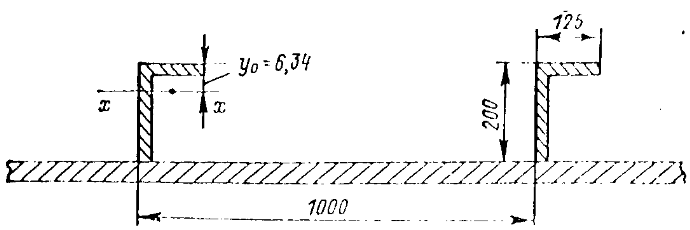

Figure 4. Sketch of pontoon bottom framing.

Taking into account the loss from corrosion of 30 percent of the thickness of bottom plates and framing, the moment of inertia and the section modulus of a one-meter wide element of the bottom section amounted to I = 5,600 cm^4 and W_{min} = 350 cm^3 ; and the allowable bending moment $M_{изг_{доп}}$ = 59.5 kN·m with the allowable stress $[\sigma_{доп}]$ = 170 MPa. The length of an element of the bottom with framing capable of resisting the maximum allowable bending moment can be determined by considering it as a beam fixed at both ends and loaded with the uniformly distributed loading of the supporting force (Figure 5).

Then $M_{изг_{доп}} = \frac{Q_{эл} l}{24}$, whence $l = \frac{24 M_{изг_{доп}}}{Q_{эл}}$. In this, $Q_{эл} = ql$, where q is the intensity of the load acting on a one-meter element of the bottom of the pontoon. It can be determined from a knowledge of the draft of the dry dock with the ships on it.

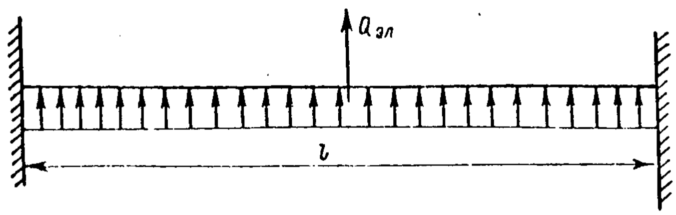

Figure 5. Diagram of loading on an element of the bottom of the pontoon.

Substituting ql for $Q_{эл}$ in the formula for determining the length of an element of the bottom of the pontoon capable of resisting the allowable bending moment, we obtain:

$$l = \sqrt{\frac{24M_{изг_{доп}}}{q}}.$$

In the case considered, the length of the sought-for bottom element amounted to 8.8 meters. Taking into account that the distance between the side walls of the dry dock is 21.6 meters and the length of a pontoon is 16 meters, in the replacement of the structural elements of the pontoon, it is advisable that the area of its dry dock floor be divided into 16 sections. Then a section of the floor being replaced will have dimensions of approximately 5 X 4 meters. Consequently, the length of the bottom of the pontoon during the removal from above it of structural elements giving it strength and rigidity also will amount to approximately 5 meters. This means that the resulting bending moment will be much less than the allowable. In this case it amounts to 19.2 kN m.

Thus, for the case presented, the replacement of the damaged structural elements of the pontoons without removing the dock from service is completely possible and the economic gain from this is obvious.

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DEVELOPMENT OF LASER CUTTING OF SHEET METAL

Leningrad SUDOSTROYENIYE in Russian No 10, Oct 85

[Article by A. N. Bagno, D. F. Barybin, N. S. Talala under the rubric: "The Technology of Shipbuilding and Machine Building"]

[Text] One of the fundamental technological processes of hull-part production in shipbuilding is the cutting out of hull parts from rolled plates. A large number of such parts are obtained in modern, comprehensively mechanized production bays and production lines equipped with high-productivity machines having numerical control (NC) for the thermal (oxy-acetylene and plasma) cutting. At the same time, about 35-40 percent of hull parts (up to 20 percent by weight) are manufactured by mechanical methods. This has been brought about by the industrial sector's restrictions on the thermal cutting of plates of small thickness because of the impossibility of assuring the quality of the edges. Despite the fact that the mechanical processing is done on special machine tools with the blanks fed into them by means of bridge cranes, almost all the remaining operations are done manually. Efforts to mechanize these operations have not given substantial results because of the varieties of shape and dimensions of the parts. At some shipyards devices have been introduced for the mechanized resetting of blanks under guillotine shears; but they do not permit fully mechanizing the process of cutting thin sheets of metal, especially as the mechanical cutting requires the marking out of the parts beforehand which is done manually as a rule.

In this connection, a fundamental change was required in the technological process of working sheet metal to provide the possibility of its mechanization and automation. Gas-laser cutting answers this requirement. Thanks to such advantages as contactless processing of the metal, small dimensions for the heated zone, chemical purity of the heat carrier, and insensitivity of the beam to electrical and magnetic fields, the laser is becoming an effective tool for processing metals (Ref. 1).

Abroad, the gas-laser cutting of metal has found rather widespread application. For instance, about 500 powerful lasers are being used in the production of the Japanese firm, Mitsubishi Denki Gikho, 62.5 percent of them for cutting (Ref. 2). In 1983, the world market for laser production equipment was evaluated at 560 million dollars (Ref. 3). At the present time, more than 680 CO_2 lasers are being used in the U. S. A. (Ref. 4).

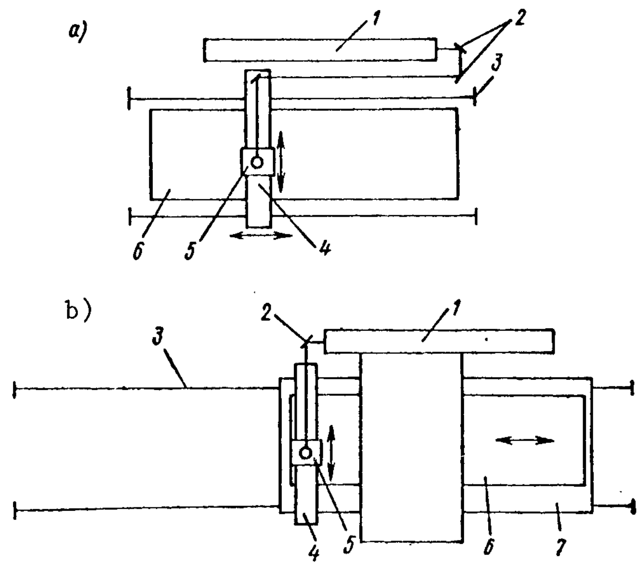

Figure 1. The principal component arrangements of laser machines:
a - the gantry type, b - the stationary type.

1 - laser, 2 - mirror, 3 - rail way, 4 - gantry, 5 - carriage with cutter
6 - plate being processed, 7 - moving platform.

Study of the potentialities of various types of lasers has shown that the most acceptable for the gas-laser processing of metal are CO_2 lasers. In this group of lasers there are the following differences: operating regime (CW and pulse periodic), the kinds of excitation of the active medium (electrical-discharge, electrical-ionization, gas-dynamic), speeds of pumping (slow, fast), and the direction of motion of the working gas mixture relative to the direction of radiation.

In the USSR and abroad work is being done intensively on the development of CO_2 lasers of all types; however, up to the present time, there are not sufficiently clear and established criteria for the selection of any one type for a specific production process. CW, electrical discharge CO_2 lasers with longitudinal and transverse pumping have found the most widespread use for laser cutting. In recent years, work has been done on the development of pulse periodic CO_2 lasers. It is anticipated that the use of such lasers will raise the productivity of cutting and will increase the thickness of metal being processed by a factor of 2-3 compared with CW lasers. As yet, however, this work is experimental. At present therefore, practical application is limited to CW electrical-discharge CO_2 lasers with slow and fast longitudinal and transverse pumping. In relatively small sizes, they make it possible to obtain the necessary output power in the continuous-wave lasing mode (Ref. 5).

The first efforts at developing gas-laser machines were done by way of building lasers into the structures of existing gas-cutting machines. So was developed the installation whose principal elements are the "Kardamon" type quantum optical generator [laser] and the "Almaz" type of NC gantry machine (Ref. 6), as well as the "Topaz-2.5" gas-laser machine developed on the base of the "Kristall" gas-cutting machine and the "Katun" CO_2 laser (Ref. 7). In the process of the experimental use of these machines, it was established that quality cutting of metal was possible in a definite zone (2-2.5 m) along the length of the sheet. It was also observed that the gantry-type machine (Figure 1a) leads to a substantial change of the length of the laser beam during operation, to an increase of its diameter, and some vibration, because of the movement of the machine along the rails.

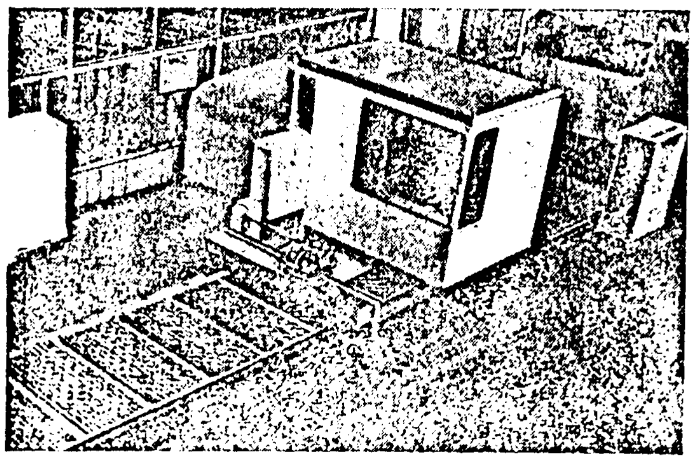

Figure 2. General view of the "Biryuza-2" laser cutting machine.

The indicated features of the dispersion, focusing, and interaction of the laser beam with the material being processed, required other design solutions and arrangements for laser machines, and careful analysis of design variants from the point of view of assuring the stability of the technological process. As the result, the "Biryuza-2" laser machine shown in Figure 2 was developed. The machine was made stationary, and the motion of the cutter relative to the plate along two coordinates is accomplished by moving the cutter itself in the transverse direction and providing for longitudinal movement of the plate relative to the cutter (Figure 1b). A CO_2 laser is used as the source of radiation. The experience of foreign firms also confirms that placing the emitter on a stationary gantry substantially improves the quality of laser machines (Ref. 2, 4).

As practice shows, the quality of the laser cutting of metals depends on a multiplicity of interrelated factors, and one of the principal ones affecting the productivity and quality of cutting is the power of the laser radiation. Analysis of experimental data shows that the cutting speed is directly proportional to the power of the radiation and inversely proportional to the thickness of the plate being cut. The corresponding dependencies, obtained by experiment are presented in Figure 3.

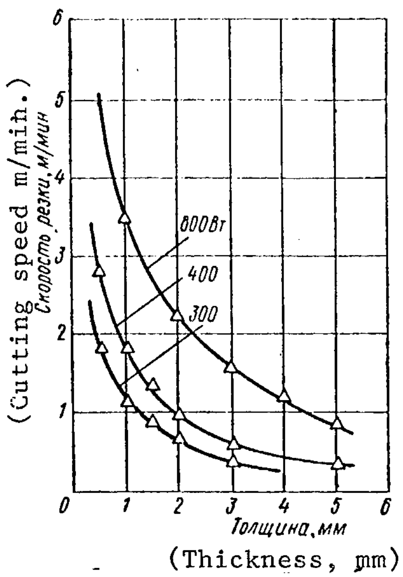

Figure 3. The dependence of cutting speed on thickness of steel and different laser radiation powers.

The achievement, however, of the necessary power of laser radiation still does not determine the suitability of the laser for cutting metals. Thus, the striving of laser developers to obtain maximum power without regulating and providing for the other characteristics which substantially affect the productivity, stability, and quality of laser cutting has lead to the fact that many lasers appear unsuitable for this production operation.

The following are characteristics of lasers which determine the productivity and quality of cutting in addition to the operating regimes and radiating power noted above: the type of resonator, the diameter of the laser radiation beam, the mode content of the radiation, the dispersion of the beam, and the degree of polarization of the radiation.

In lasers, stable and unstable resonators are used which differ in design and principle of operation. An unstable resonator has deficiencies in the distribution of the intensity of radiation at the focal point. Therefore a CO_2 laser with an average power of 1-5 kW must have a stable resonator which assures obtaining a higher intensity of radiation at the focal point.

In accordance with GOST [State Standard] 24453-80, the diameter of a laser beam is defined as the diameter of the cross section of the beam carrying a given proportion of the radiation power. Considering that the presence of so-called wings of weak radiation is undesirable for laser cutting, it is recommended that all the parameters of laser radiation be determined for 86 percent of the power. It is well known that the diameter of the beam is the important characteristic of a laser determining the power density at the focal point. Thus, the model 6000 laser of the American firm, Photon Sources, with a radiation power of 4 kW has a focal point diameter of 16 mm. The less the diameter of the focal point, which is governed by the standards of manufacture and the quality of the optical materials, the higher the cutting quality.

The characteristic which enlarges the diameter of the beam and affects obtaining the maximum average power density at the focal point, is the dispersion of the laser radiation. Its magnitude is determined by the ratio of the diameter of the focal point to the focal length of the lenses. The physical meaning of the term: dispersion, consists of the ability of the beam to be focussed in a spot of specific diameter.

The distribution of power density in the focal point is determined by the mode content of the radiation. On the basis of the studies of domestic and foreign scientists it has been established that a laser for cutting should operate only in a single mode regime since other regimes, including multimode regimes, reduce cutting speed by a factor of 3-5, and lower the quality of the edges of the cut.

During experimental use of the "Biryuza-2" machine, it developed that the quality of the edges of the cuts made in different directions relative to the laser beam were not identical. This phenomenon takes place, basically, because of the polarization of the radiation in the laser beam.

To provide identical quality in laser cutting of metal in all directions, the laser beam should have circular polarization. At the same time, a high degree of polarization permits increasing cutting speed by 40-50 percent with the same power and increasing the quality. In this, however, the plane of polarization of the radiation should always coincide with the direction of the motion of the cutter relative to the plate.

Besides the laser radiation characteristics on which stability and quality of cut depend, reliability and convenience of servicing are important, and also the efficiency which, for now for CO_2 lasers amounts to 12-15 percent. Work is now being done to raise the efficiency of lasers to 28-30 percent.

Thus, laser cutting is a complex, as yet insufficiently studied process depending on many complexly interacting factors. But the main condition for a high-quality cut is the provision of the maximum mean power density at the focal point. In this connection, all lasers, in relation to their suitability for use in cutting metals, can be evaluated and compared by the magnitude of the coefficient of the quality of radiation :

$$k_{\text{H}} = \frac{P}{Q^2 d^2},$$

where: P is the mean power of the laser radiation in Watts, Q is the dispersion of the laser radiation in mrad, and d is the diameter of the beam in mm.

The physical significance of this coefficient consists of the ability of a laser to create a mean power density at the focal point not less than 5 million Watts per square centimeter. If the coefficient is equal or larger, then the laser is most suitable for cutting. Lasers being used which have a coefficient equal to 0.1-0.4 cannot provide for high-quality industrial cutting; they require substantial modification. Industrial lasers having the required coefficient of radiation quality assure the greatest gain in the introduction of gas-laser cutting of shipbuilding steel.

The experimental industrial use of the "Topaz-2.5" and "Biryuza-2" machines indicates the potential for the widepsread use of gas-laser cutting in shipbuilding. The surface of a cut is obtained without microcracks and without gas inclusions. The microstructure of the base metal is ferritic and pearlitic, with spots having the Widmanstatten orientation. In the heat-affected zone (its width is 0.1-0.2 mm) - at the edge - there is troostite, then troostite and ferrite and then ferrite. Investigation of the weldability of parts obtained by laser cutting, showed that welding is permissible without cleaning the edge beforehand.

As a result of analysis of the potentials of gas-laser machines and their experimental industrial use, the area for their rational use in shipbuilding was determined. In Figure 4, for comparison, curves are shown of the speed of different kinds of thermal cutting as a function of the thickness of the metal being cut. The curve for laser cutting was constructed from experimental data obtained on the "Biryuza-2" machine. As can be seen from Figure 4, laser cutting is inferior to plasma cutting in speed. Economic calculations, taking into account the present relatively high cost of laser cutting equipment, show that in the range of thicknesses above 5 mm where plasma cutting is used, it is not practical to use lasers as yet. At the same time, experience indicates that for plates of small thickness (up to 5 mm), the use of laser cutting instead of mechanical cutting is more advantageous both technologically and economically.

Thus, laser cutting has found its place in the technology of fabricating hull parts, supplementing but not replacing thermal kinds of cutting. With the introduction of machines with lasers, the prospect is opened up for comprehensive mechanization and automation of the production processes for working thin-plate hull steels because of the curtailment or complete rejection of mechanical cutting. As experience is accumulated in the practical use of gas-laser machines and the equipment is improved, the limits for the rational use of laser cutting unquestionably will be defined more exactly.

The new arrangement solutions adopted in the development of the "Biryuza-2" laser machines required the development of new component arrangements for production lines and new means of equipping for production. In this, the need for the completion on the production lines of the following operations was taken into account:

- receiving and accumulating in bundles, separated according to "start-ups", of straightened, cleaned, and primed plates,

- feeding plates to each gas-laser machine and smoothly laying them on the cutting frame of the moving platform,

- orienting the edges of the plates being processed relative to the coordinate axes of the gas-laser machine and securing the plates,

- processing the plates according to the program in the gas-laser machine; that is, laying out the contour lines, marking, and cutting out of hull parts,

- removing the parts and scrap from the moving platform and delivering them for sorting by dimensional groups and processing routes.

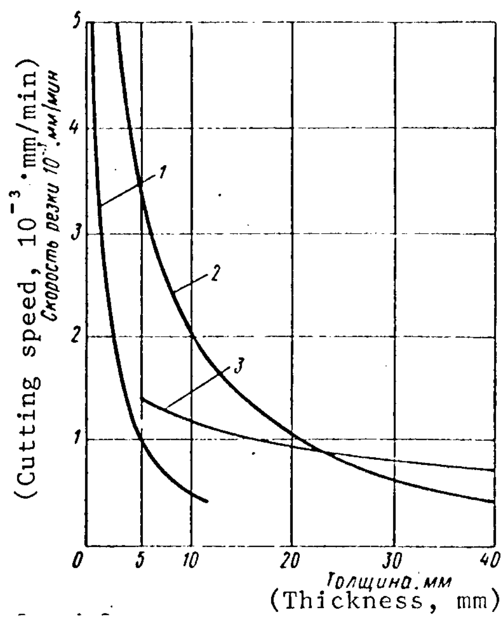

Figure 4. The speed of various kinds of cutting as a function of the thickness of steel plate.

1 - laser, 2 - plasma, 3 - gas

To determine the number of gas-laser machines needed in production lines, the demands for thin rolled plates were studied. For more than half of the enterprises, one or two laser machines are needed, and, shipyards building small-tonnage ships, should have three or four or more machines. From the point of view of assuring the reliability of the operation of production lines or bays, there should be not less than two machines in their composition.

In the development of variant arrangements for the laser cutting of thin metal plate for production lines and bays, experience in the development of production lines for the thermal cutting of plate steel was taken into account and also principal arrangement solutions verified by practice. The design version for gas-laser machines permits installing them in lines according to one- or two-front schemes of disposition (Figure 5 a,b). In this, the following nonstandard equipment and means of mechanization are required: plate loaders, loaders for plates and cut parts, gang-roller conveyors, belt conveyors, and gang-roller carriages. Design documentation for these means of technological outfitting have been developed by the TsNIITS [Central Scientific Research Institute for the Technology of Shipbuilding]. Depending on the design arrangement of the equipment and the area disposition of a production line, its composition can be changed. Thus, a plate loader (5) is used with a storage at a production bay, and a gang-roller carriage is necessary only for the rigid connection of the laser cutting bay with the section for sorting hull parts.

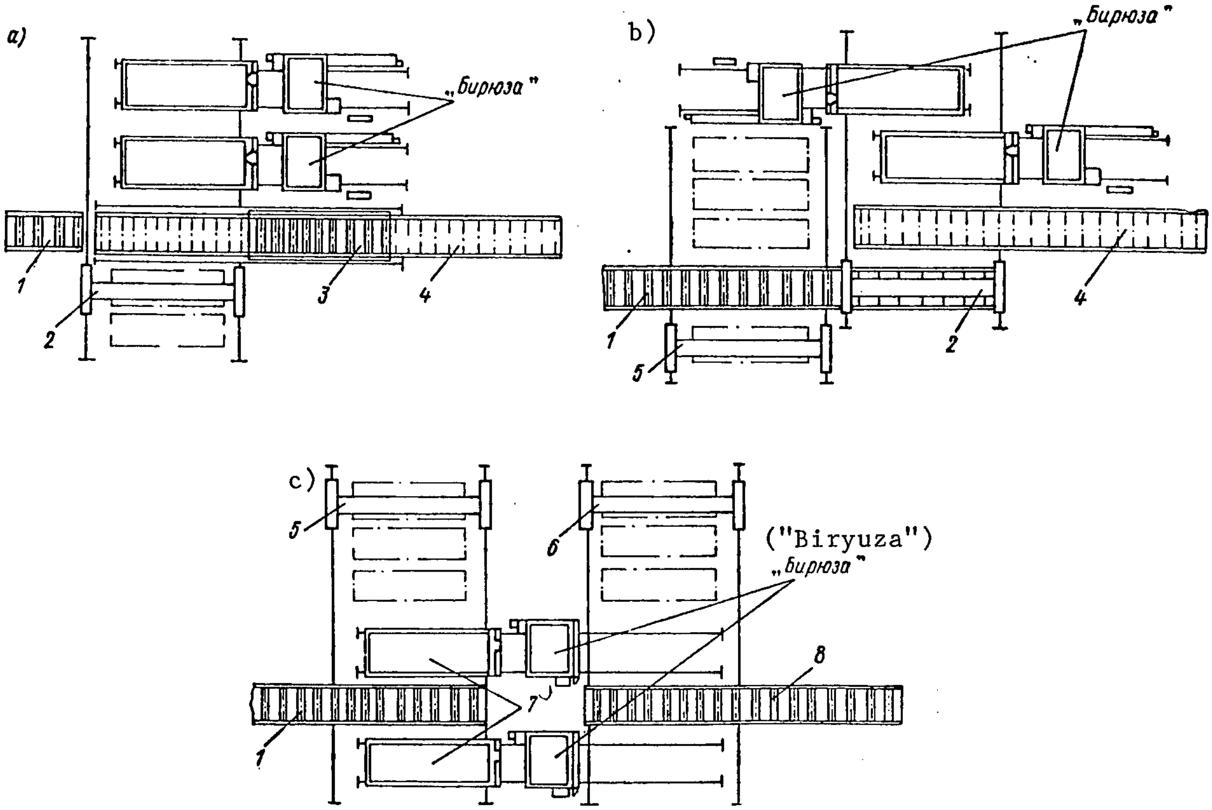

Figure 5. The principal arrangement schemes for accommodating "Biryuza" type machines in a production line: a - one-front disposition, b - two-front disposition, c - broadside disposition.

1- gang-roller conveyor, 2- loader for plates and cut parts, 3- gang-roller carriage, 4- belt conveyor, 5- plate loader, 6- loader for cutting frames, 7- retreivable cutting frames, 8- gang-roller conveyor for cutting frames.

For processing nonmagnetic or low-magnetic materials (Figure 5,c) loaders for cutting frames, detachable cutting frames, and gang-roller carriages for cutting frames must be used. In this case, the laser machines must be modified, and securing devices must be provided on the moving platform to orient the cutting frame with the plate.

Experience in the use of gas-laser machines for cutting thin metal plates has permitted working out guidance for their further improvement. In the first place, it is necessary to raise the effectiveness of the fundamental characteristics of the lasers (the diameter of the laser beam, the size of the laser, the stability of its operation in production conditions, the quality of the optics and mirrors). In the second place, the construction of laser machines should be improved; that is, improve the accommodation of the laser for the purpose of reducing the area occupied, expand the potentials for processing nonmagnetic metals, automate the auxiliary operations, develop a special device for orienting and securing plates of different sizes (from 1X1.4 to 1.6X6 m and more) on the cutting frame. In the third place, it is rquired to develop gamma gas-laser machines with gradations of them in laser radiation power (from 1 to 5 kW) and in the length of plates processed (from 1 to 8 meters).

Calculations of the economic effectiveness of production lines and bays for the laser cutting of sheet metal confirm their advantages compared to bays for mechanical cutting. Laser cutting raises the productivity of labor in processing thin plates and reduces buckling and temperature deformations (with observance of the rules for cutting out parts) which is extremely important for thin plate parts. Laser cutting yields a small heat-affected zone with minimal mechanical effects on the metal during cutting. Besides, the accuracy of the parts cut out is increased which decreases the amount of assembly and welding operations; and limitations on the coincidence of cuts are absent. Hand labor is substantially reduced because of the elimination of the manual marking out of parts. Laser cutting permits further automation of the processing of thin metal plates, and assures reduction of the industrial area occupied as compared with that for mechanical cutting (which is a favorable circumstance in creating laser cutting bays in existing hull-part fabricating shops). It raises the attractiveness and sophistication of production.

In Figure 6, curves are prsented of the relationship of the economic effectiveness of creating production lines and bays for laser cutting of hull steel as functions of the number of machines in the line and the coefficient of their utilization. It is seen that with a coefficient of the utilization of the machines of more than 0.7, with any number of machines in the line, they are economically advantageous .

Further development of laser equipment and improvement of the gas-laser machines will provide for increased effectiveness and an expansion of the introduction of production lines for laser cutting.

CONCLUSIONS.1. Laser cutting is a progressive technological process supplementing other forms of thermal cutting of rolled plate and opening prospects for the comprehensive mechanization and automation of the processing of thin metal plates.

2. Further improvement of CO_2 lasers by increasing the stability of their operation in industrial conditions and providing values of the coefficient of

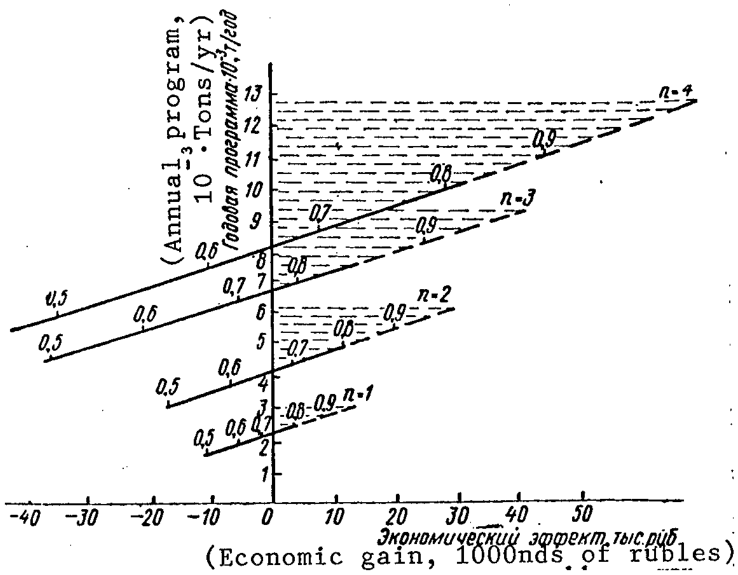

Figure 6. The annual economic gain in the use of laser cutting production lines as a function of the annual volume of production and the number of machines in the line. (0.5, 0.6, 0.7, 0.8, 0.9, 1.0 are the coefficients of equipment use) n - is the number of "Biryuza" machines in the line.

radiation quality not less than 1.5-2 and also improving other properties, opens up the possiblity of the widespread introduction of laser cutting in shipbuilding.

3. The level of development of design, organizational , and technological documentation permits creating comprehensively mechanized production lines and bays for processing thin plates of metal by the reconstruction and technical reequipping of existing hull-part fabricating shops and the construction of new ones.

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LASER TESTING AND MEASUREMENT SYSTEMS: PROBLEMS AND PROSPECTS

Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 6, Jun 86 pp 52-62

[Article by Doctor of Physical and Mathematical Sciences V.A. Katulin and Candidate of Physical and Mathematical Sciences A.N. Malov]

[Text] It is no longer necessary to prove the necessity of using lasers when conducting testing and measurement operations; their diverse applications for such purposes are well known. With the appearance of lasers, holography has arisen, a revolutionary change in interferometric methods has taken place, laser rangers have been created, and laser detection and ranging of the moon have been carried out for a long time. However, the current stage in the use of lasers is still characterized by a great disconnection of research. Moreover, the economic factors also dictate the necessity of accomplishing the tasks of testing and measuring industrial products. It is well known that at the present time the cost of implementing testing and measurement operations in machine building constitutes about 10 to 20 percent of the product's cost. In the more demanding cases (for example, when manufacturing turbine vanes and especially precise bearings), the cost of testing reaches 50 to 60 percent of the total cost.

We will briefly examine the main methods of laser diagnosis and metrology that are based on the unique properties of laser radiation (high coherence, monochromaticity, brightness, and low spread), as well as their current status and areas of use (factual material has been taken from literature sources).

Methods of Laser Diagnosis and Metrology

The so-called shadow method, obtaining information about the geometric parameters of a product on the basis of measuring its image is one of the oldest and most widespread methods of optical diagnosis. A modern laser shadow measurement system containing an Elektronika-60 minicomputer and a matrix of charge-coupled device [CCD] photodetectors may make up to 1,800 measurements per minute with a precision corresponding to the resolution of an optical system.

The precision focusing method is frequently used to measure linear distances and analyze the relief of a product. The distance from a controlled point where the laser radiation is focused to the base plane of the meter, the optical system, is held constant with the help of a servo system that determines the degree of defocusing of a spot in the observation plane and eliminates it by tuning the optical system. This same signal contains information about the distance to a component being tested. A real system makes it possible to make measurements with a precision of 7.6 μm in the dynamic range up to 5 mm and with a speed of 1 μs. Using two systems makes it possible to measure the profile of turbine blades. A complete examination of any size vane takes no more than 1 minute with an error of no more than 2.5 μm [1].

With the aforementioned measurement methods, the precision is always limited by the resolution of the optical systems. However, the high brightness of laser radiation makes it possible to measure an object not by the dimensions of its image, but by the distribution of the intensity of light that has been diffracted on it and collected by a lens in a focal plane. This distribution has an invariance to the displacement of an object, which makes it possible in principle to use the method to measure components moving, for example, along a conveyer.

Information about geometric dimensions is extracted from an analysis of the structure of the diffraction distribution. In this case the precision of the measurement is determined not by the resolution of the optical system but by the attained precision of the analysis of the diffraction distribution. The laser diffractometer [LDI] produced in the USSR makes it possible to determine the dimensions of cylindrical components with a diameter of 0.1 to 10 m with an eror of 0.05 to 2 percent and a rate of 50 measurements per second. Using the method of optical matched filtration in a laser holographic test device makes it possible to measure five to seven parameters of a product with dimensions up to 20 mm simultaneously with an error of 5 to 7 μm and a speed of up to 1,200 products per minute.

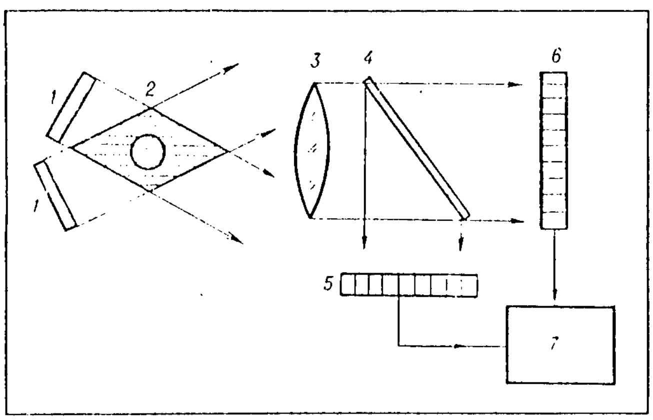

Figure 1. Shadow method of measuring the dimensions of a component.

Key:
1. Planar wave fronts
2. Component being measured
3. Objective
4. Half-silvered mirror
5. Photodetector matrix
6. Photodetector matrix
7. Minicomputer

Lasers have found their greatest use in the operations of tuning, leveling, and marking off large products in residential, aircraft, and ship construction and in agriculture. Boeing's use of lasers to assemble large jet aircraft has made it possible to increase the precision of assembly tenfold and to provide a tolerance of ± 50 μm at a distance up to 60 m. Using lasers to align pipelines makes it possible to increase labor productivity by 30 to 50 percent (analogous figures may also be presented for other sectors of industry) [3].

Controlling the quality of the surface of products is one of the most labor-intensive and complex operations in industry. Up to now, visual testing has been the most effective and widely used method of defectoscopy. With the help of the phenomena of diffraction and interference, the coherence of laser light illuminating a product makes it possible to preserve and transmit for practically any distance very small changes in the phases of light oscillations caused by the reflection of light from the surface being tested and to visualize them easily. Therefore, using lasers as light sources in defectoscopy makes it possible to obtain a bright, high-contrast image of the surface being tested, which may be effectively analyzed by means of modern computer technology.

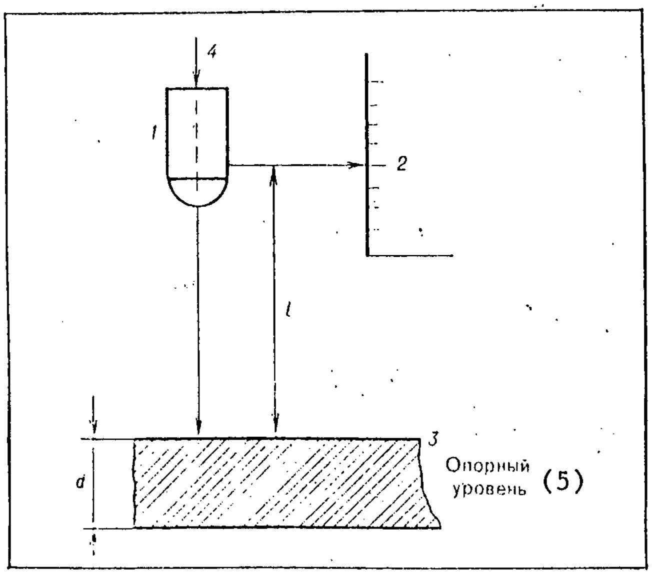

Figure 2. Determination of the position of a surface by the precision focusing method. The dimension being tested d (3) of a component is determined on the basis of the position of an objective (1) that is read according to the scale (2); the magnitude and direction of the deviation from the assigned value is determined based on a defocused laser beam (4) along the surface of the component being tested (3). (5), designates the reference level.

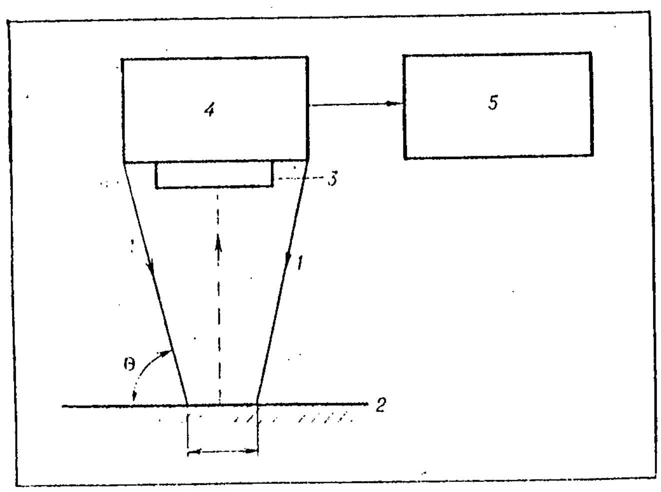

Figure 3. Testing the profile of a product

Key:

1. Laser beams
2. Surface of the object being tested
3. Objective
4. Matrix photodetector
5. Electronic device for analyzing the image and computing the distance to the surface of the object (2) from the objective (3)

Real operational laser defectoscopes that identify defects based on the difference in the optical properties of defective and defectless surfaces do exist. For example, the Japanese defectoscope SDB makes it possible to identify such defects as dirt, bubbles, an eruption, and holes with a size between 50 and 100 μm at a linear displacement rate of the material being tested (hot- and cold-rolled steels materials, as well as paper strips, fabric, polymer films, foil, etc.) up to 3.3 m/s. With the help of a minicomputer, the Swedish automatic surface analyzer ASC can determine 13 types of surface defects and register scratches with a width of 20 μm and a depth of 2 μm. This device's testing speed is 1,200 m of steel strip per minute, whereas visual testing providing the same results may only be conducted at a speed not exceeding 0.2 m/min [4].

Up to now, in industry the main parameters of the surface roughness of products have been determined by the contact method, registering the relief of a surface with the help of a diamond microneedle tracer. However, the so-called speckle method of analysis, which is based on the interference of coherent light reflected from different sections of a rough surface, has been developed. The image of each point of the surface, which is usually formed by some optical system, represents a diffraction picture of finite dimensions that are determined by the aperture of the system. Because of the interference of these diffraction pictures, the illuminated surface of the object seems spotty and consists of so-called speckle spots.

The structure of the speckle picture formed by the coherent light reflected from the object depends not only on the surface roughness but also on the orientation of the illuminating laser beam and on the wavelength of the radiation. Therefore, it is possible to obtain information about the roughness of the object being tested by analyzing the degree of convergence of the two speckle pictures obtained from one surface or the other but under various illumination conditions (either the wavelength or orientation of the laser beam is changed). Speckle optics methods make it possible to measure roughness with a precision up to 92 percent and are most suitable for real-time measurement of rough surfaces with a mean square deviation of 1 to 30 μm. It is possible to measure less rough surfaces; however, then the analysis of speckle structures becomes more complex and necessitates using a computer [5].

At present speckle optics can help in measuring the roughness of metal products in the end stage of machining when it is necessary to test microsmoothness at a height up to 0.025 μm. A registered height of microsmoothness of about 0.1 nm should be considered the record value demonstrating the capabilities of laser surface defectoscopy [6].

The greatest successes in using lasers in testing and measurement in industry are connected with interference methods and especially with holographic interferometry. Various types of interferometers were also widely used in industry (especially in opticomechanical production) in the prelaser era. However, their suitability was limited by the absence of high-coherence and sufficiently bright light sources. The appearance of lasers eliminated these limitations. Now, with the help of laser interferometers that generally include a minicomputer for numerical processing of results as one of their components, measurements of linear and angular dimensions and displacements can be made, and roughness profile maps with a maximal precision up to 5 nm can be made.

Interferometers can help in measuring deviations from rectilinearity up to ± 1 mm at distances up to 10 m with a precision of ± 3 μm. Using lasers with the interference method makes it possible to determine a distance up to 50 m with a precision up to 0.025 μm [7].

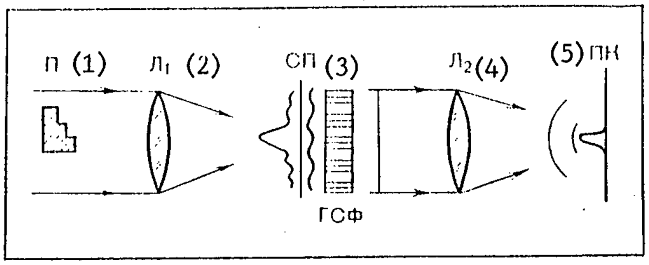

Figure 4. Optical train for determining the correspondence of the geometric form of an object being tested (1) to an etalon object, information about which is registered in a holographic matched filter

Key:

1. Object being tested
2. Lens
3. SP holographic matched filter
4. Lens
5. Plane of the output optical signal

Holographic interferometry, which has been rather widely used in industry in recent years, is based on recording information about two (or more) noncoincident states of the object being tested in the same hologram and afterwards organizing the interference of the images of these two states in the readout stage of the hologram. The difference between the two states of the object, which is manifest in the occurrence of interference bands in the restored image, is visualized. The precision of the method is tenths and hundredths of fractions of the wavelength of the radiation used when recording the hologram. This makes it possible to discover internal stresses occurring in a strained product. On the other hand, it is possible to determine the nature and location of internal defects by subjecting an object to mechanical stresses and analyzing its holographic interferogram [8]. Besides mechanical stress, it is also possible to use pulsed heating with the help of a rather high-power laser or the excitation by it of ultrasonic waves in a product, which results in a change in the state of an object during the recording of a second hologram.

Holography interferometry methods are used in industry to analyze objects vibrating with a frequency up to 400 kHz, mainly turbine vanes. Holographic systems equipped with special devices, derotators, make it possible to carry out the real-time testing of aircraft engine turbines rotating with a frequency up to 10,000 rpm and are also used to detect defects in aircraft and helicopter fuselages. In the quality control of motor vehicle tires, holographic interferometry makes it possible to discover sections of poor-quality adhesion at a depth of 20 layers from the surface.

The ever-increasing outfitting of interferometers with computer hardware and information output devices and displays is one of the main trends in the area of interferometry. According to American forecasts, in terms of cost, in 20 years the average interferometer will consist of 10 percent optical components, 10 percent mechanical devices, 20 percent electronic circuits, and 60 percent devices to output results.

The examples presented do not exhaust the areas in which lasers are used for diagnosis and measurement of industrial products. Abroad and in the USSR works are underway to create laser Doppler velocity meters, fiber optic endoscopes and interferometers, systems for holographic analysis of the characteristics of gas and liquid flows, etc.

Thus the appearance of lasers has led to a revolutionary change in the methods and means of remote industrial diagnosis and metrology. There is currently an observable increase in interest in optical diagnosis and, correspondingly, an expansion of works on this theme, as well as in connection with research on the creation of robotics systems, especially technical vision [9]: a robot closes an automatic line to produce and diagnose components, selecting and using them in the subassembly being created.

Problems in the Development of Laser Measurement Methods and Systems

We will examine ways of creating systems for laser remote diagnosis and testing. The operation of any such system may be divided into four stages: formation of the initial optical information, its transmission from the object to its image, registration of the image, and computations of the results.

The first stage is generally implemented with the help of the system's laser and optical stage. Above all, the further development of laser testing demands improving the lasers themselves, increasing their output (for holography of products with large overall dimensions), improving the quality of their radiation, and increasing their operating life.

Traditional optical systems, objectives and mirrors, are now used to shape and send an image. As a rule, objectives are developed and manufactured to work in incoherent white light, which leads to their significant cost. At the same time, laser testing systems generally operate at one wavelength, not using all the potential capabilities of the objectives. Therefore, using components of so-called diffraction optics, diffraction grating, Fresnel zone plates, holographically manufactured objectives, phase-only synthetic holograms, and digital holograms, is one of the more promising trends. Moreover, when creating completely automated systems it is frequently not necessary to obtain a classic type of image; therefore, it is possible to use systems with a synthesized aperture, etc.

The creation of coherent optical measurement systems requires a complex of fundamental research, from design of a theory of the operation of such systems to development of a technology for manufacturing them. The economic effectiveness of such systems is obvious: series manufacture of a diffraction objective is two to three orders of magnitude cheaper than an ordinary photographic objective.

In the development of optical measurement systems there is a striving to maximally reduce the effect of aberrations of the optical components, and the theoretical limit has already been attained in this respect. However, aberration phenomena that result in a loss of measurement information make it possible to conduct their preliminary processing. For example, it has been proposed that a defocused optical system be used to separate informationally significant components of an image, for example, it has been hypothesized that the significant chromatic aberration inherent in the eye is used to expand the range of its accommodation (focusing).

Provision of a high signal-to-noise ratio is an important task in the operation of diagnostic equipment. It is necessary to bear in mind that some threshold characteristic, the so-called tolerance field is always used for technical testing: a defect is recognized as a defect only when it exceeds certain geometric parameters. In this context, it is also desirable to use threshold optical systems that provide a sharp, stepwise change in the structure of the image during a continuous change in the parameter of a defect (for example, in its size). A raster system, with whose help a half-tone image is translated into a binary image with two brightness gradations, is an example of such a threshold system.

The possibility of the practical use of such promising areas of diagnosis and testing as fiber interferometers, iridescent holographic interferometry, incoherent optical information processing, and a number of others have been little researched to date.

In certain cases, the diagnosis of industrial products demands shifting the object, and then the contradiction between the precision provided by optical testing and the precision of the shifting that is connected with the mechanical actuating systems arises. This contradiction may be eliminated with the help of active optical components: deflectors, scanners, and spatiotemporal light modulators that make it possible to create an optical train with circular scanning of a stationary object. The investigation and development of such active optical components is now being conducted in photoelectronics; however, as a rule, these are geared toward use in rather specific devices of the holographic memory and optical processor type, and it is not always possible to use them in optical diagnosis systems. Using active optical components makes it possible to implement adaptive optical systems whose operating characteristics do not change under different operating conditions, during a change in operating temperature, in a turbulent atmosphere, etc.

The precision of modern optical measurement systems is primarily determined by the stage of the registration and readout of information, where registration media and photoconductors are used. Nearly all existing registration media have rigidly determined characteristics and properties, which do not make it possible to use them to process information in the recording process or to control them. Moreover, because of the nonidealness of modern light-sensitive materials, registering optical images on them leads to a loss in some, and sometimes a significant part of the information (although in some rare cases, for example, during intensification of the contrast of the image, this is necessary as a stage in processing optical information). Therefore, it is advisable to search for principles of the physical implementation of adaptive (self-organizing) registration media in the form of large autowave systems with distributed memory that implement the processing of the incoming optical information and store it in essentially revised form.

The wide use of holographic diagnostic systems will only be possible after the provision of their real-time operation, which demands a transition from photo-emulsion image registration to other methods, in particular with the help of reversible registration media. Holographic systems that contain thermoplast carriers operating in real-time are already being manufactured abroad. This material does not contain silver, which is in short supply, and has energy characteristics that are orders of magnitude better than those of photoemulsions; however, they do not make it possible to to record holograms with a diameter greater than 30 mm.

Television methods of receiving and processing measurement information have seemed not very suitable, primarily because of their insufficient resolution. Now, the main prospects for the development of photoelectron image registration systems are connected with CCD lines and matrices, which already detect image displacements with a precision of up to 0.3 to 0.5 μm.

It should be emphasized that development of photodetection systems must be undertaken with an allowance for the design features of the optical stage of the system and, conversely, the characteristic of photodetectors will necessitate an image-shaping circuit. The presently used circuits are based on visual perception criteria; therefore, photodetectors perceive all deviations of the energy, and geometric parameters of an image are perceived equally with measurement information. This problem may be solved only by the corresponding organization of the optical stage of the system.

The final stage in the measurement process is that of processing the electric signal received from the photodetectors and computing the results, on the basis of which the system decides about the products suitability. Basically, these tasks will be accomplished with the help of microprocessors and computers; however, in the context of the limited memory capacity and speed of computers at the present time, it is impossible to organize digital image processing in a real-time scale. Therefore a computer will calculate an image processed in analog form with the help of an optical processor.

It should be emphasized that it is frequently easier to process an image with the help of the system's optical stage; therefore, development of the digital stage must be unified with development of the optical stage. The task of interpreting interferograms when analyzing a product's internal stresses may serve as an example. The mixings of the object as a whole have a strong effect on the form of the interferogram and on the complexity of deciphering it, and solving the problem of eliminating this unnecessary mixing is complicated. It turned out that the method of obtaining interferograms (the multilayered hologram method) makes it possible to compensate this displacement and simplify the interferogram significantly.

A rather large number of digital image processing algorithms and systems currently exist; therefore, "mating" them with the optical stages of diagnostic systems remains the main task for the near future. Evidently, methods of extracting measurement information about the structure of an image rather than procedures based on the indication of changes in the light flux will receive preferential development.

Progress in computer tomography (a method of restoring an image according to its unidimensional projections) makes it possible to hope that laser systems for analyzing objects with a complex geometric shape, for example, turbine vanes, will be created in the near future. Practically speaking, this task will be accomplished by substituting the x-ray source in an x-ray computer tomograph with a laser beam with a minimal correction in its software.

Main Trends in the Development of Laser Diagnosis and Metrology

Proceeding from the experience of developing laser diagnostic and measurement systems and their requirements from the perspective of industrial enterprises, it is possible to formulate the main trends in the development of these devices.

Diagnostic systems with a modular organization which are multi-purpose by virtue of the interchangeability of the functional modules should be considered the most promising. Nevertheless, such a principle of organizing measurement systems should not exclude the creation of systems geared toward specialized areas of use.

The relative expensiveness of computers and lasers makes it advisable to use one computer and laser to service a whole series of measurement devices (installed for example, in the limits of one department) analogous to the use of one high-power laser by several production systems.

When directed toward creating unified measurement complexes in the framework of an entire enterprise, it is necessary when considering the experience of developing computer technology to organize the interaction of the system's components in the initial stage, bearing in mind the possibilities of changing them and adding to them. Here, on the example of the CAMAC standard in computer technology, it is necessary to use two approaches: rigid unification and standardization of the input and output stages of various types of systems and introduction of special interface devices. These approaches make it possible to provide the interaction of measurement devices testing, for example, different parameters of one and the same product and to implement the complex diagnosis of a product with the informational, optical, electrical, and design compatibility of different systems.

The necessity of interaction between different measurement systems follows from the fact that complex testing with one information transmission channel is connected with a number of complex design problems whose solution is more difficult than is introducing additional measurement devices. The complexity of electronic circuits in contactless diagnosis systems increases with an increase in the number of parameters being tested, and this may lead to a reduction in the reliability of the system's operation.

On the whole, analysis of the current situation connected with laser diagnosis and measurement of industrial products shows that, in practice, the use of these methods generally lags behind the results of scientific research. In particular, the measurement and testing operations are as a rule the end operations in the technical chain of product production, and the orders in which they are conducted are regulated by corresponding All-Union State Standards

[GOST]. Consequently, in order to introduce corresponding laser systems into production, it is necessary to first implement their metrologic certification, and for this it is necessary to have a specific, albeit experimental, prototype rather than a method or idea. It is difficult to prepare its scientific organization, and because of their insufficient interest in developing new technology, industrial enterprises do not strive toward this. In addition, strained planning quotas and insufficient labor forces do not as a rule permit plants to participate equally in the development of new hardware, especially that based on qualitatively new scientific results (and the laser undoubtedly belongs to this category). The process of introducing laser devices to a system for industrial technical testing and measurement requires the coordination of research and design operations and a keen estimate of the prospects of developing this area of science and technology.

Up until now, the Academy of Sciences has generally remained on the sidelines of works dealing with laser testing and diagnosis of industrial products (if one does not consider individual small groups working in this direction) inasmuch as it has been suggested that the corresponding devices for industry can be developed by branch scientific research institutes [NII]. The objective circumstances (absence in industry of personnel qualified in the area of quantum electronics, shortages of a material and technical base, lack of communication, etc.) have led, however, to a situation where the planned and purposeful introduction of laser systems in industry is now absent.

It is possible to say that a haphazard industrial experiment in using lasers for testing and measurement is underway in the country. It main task is to clarify the scale and feasibility of using laser diagnosis in various branches of industry. The haphazardness of the experiment and the lack of qualifications of those persons involved in it frequently results in the laser not being used where it is needed and not being used how it can be, which leads to disenchantment with laser measurement methods and to the discredit of a useful idea. These shortcomings may be overcome with the help of a center that is capable of coordinating and directing work in this area.

It is necessary that industry formulate "Think how to measure"-type questions for academic organizations, and this assumes the close joint work of industry and the Academy of Sciences as early as during the formulation of the task and the development of a methodology. Tests of methods and devices developed by scholars must be carried out in shops and with the direct participation of developers. In fact, the complexities of creating systems for laser remote diagnosis are aggravated even more by a whole complex of requirements set for them by real production conditions. These requirements include the accuracy of the information obtained and the reliability and the possibility of operation in conditions that are uncomfortable for optical devices (vibrations, dustiness, etc.).

Another circumstance necessitating the participation of the Academy of Sciences in this activity is the existence of a set of fundamental problems in the area of coherent optics that lie at the basis of laser remote diagnosis. The tasks of restoring the image of an object based on the distribution of radiation diffracted in it and the tasks of designing optical systems may be cited as examples. Moreover, even the theory of planar mirrors remains incomplete at the present time.

Inasmuch as optical diagnosis methods have existed hundreds of years and corresponding instruments are being series produced, it has been proposed that branch NII and industrial organizations can modify systems to use new light sources, lasers. However, the properties of laser radiation are so unusual and diverse that this has turned out to be a task that, for practical purposes, is too difficult for them.

Thus, the future of laser testing and measurement systems depends on both how soon the Academy of Sciences "turns to face" the problems of industry in this area and on how fast the proposition of "organization of such lines in the system of the Academy of Sciences that could provide the creation of experimental prototypes for their demonstration in industry" becomes a reality [10].

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12794
CSO 1861/522

OVERVIEW OF CONTEMPORARY REFRACTOMETER APPLICATIONS

Moscow SOTSIALISTICHESKAYA INDUSTRIYA in Russian 20 Feb 86 p 4

[Article by T. Aliyev, corresponding member of the AzSSR Academy of Sciences: "Monitoring From Behind the Mirror"]

[Text] Light rays have rendered long and sterling service to scientists and practical specialists seeking to study the more imponderable properties of a given medium. They provide information to chemists on molecular structure and inform geologists on the structure of minerals; physicians use them in clinical diagnosis and pharmaceutical chemists in the manufacture of drugs. This wide sphere of application is largely attributable to the fact that the interaction of light with the material under study does not affect the material in any damaging way. Another obvious reason is that the data acquired by this method is rooted in fundamental physical processes.

One of these processes is the refraction that occurs when light passes through a boundary surface between two heterogeneous media. An entire area of science and technology which deals exclusively with the development of methods for determining refractive indices--refractometry--has come into being. A great variety of refractometers, designed for several different sectors of the national economy, is now commercially available. Until recently, though, refractometers could only be used to study optically transparent items.

And yet it was Isaac Newton who discovered, while working on total reflection of light from a boundary surface separating two heterogeneous media, that some sort of light wave is propagated behind the reflecting surface, and that the intensity of that light wave is contingent upon the properties of those media, both their transparency and their absorptiveness. It was then possible, in principle at least, to study the properties of opaque materials, but this involved some exceedingly complex calculations, which only modern computers would prove capable of performing.

And so the phenomenon which Newton had discovered had to wait for over 250 years before being put to practical use. Of course, it took more than the wave of a magic wand--get a computer and the job's done--to produce the desired result. There is a method to it. It required a concatenation of basic and applied research projects and a lot of hard work in a whole host of institutes and enterprises across the country, coordinated by the State

Optical Institute imeni S.I. Vavilova. The outcome has been what is in essence a new scientific departure--reflective refractometry of absorptive media--and the development of a unique piece of apparatus which is challenged by no instrument built anywhere else in the world. These devices have thrown the study of such materials as chemical fibers, plastics and polymers, resins, various kinds of paint coatings, semiconductors and crystals, film-forming materials, petroleum and petroleum products wide open.

Optical verification methods were first used in selective oil cleaning equipment at the Baku Oil Refinery imeni 22d CPSU Congress. It used to take hours to gather information on multistage production procedures. Sampling was no easy matter either, and the operator was not able to keep tabs on the processing status and bring timely influence to bear on the production routine. This led to loss of output and reduced output quality. Now, in order to assess the "health" of the production process, all the operator has to do is glance at a specially designed television-sized monitor. The refractometer tracks changes in the optical characteristics of a luminous flux which interacts with the sample, and transmits vital information via telemetric channels to a microcomputer. Over 100 tons of furfural, which is expensive and in short suply, has been conserved by use of this apparatus. Potentially significant economies could be realized if similar equipment were to be brought into service in oil refineries, if nowhere else.

But one would suppose that the challenges set forth by the Party relative to the acceleration of scientific and technological progress call for intensive efforts to introduce batteries of refractometers into those sectors of the national economy where they could bring tangible benefits. It behooves us, in my view, to investigate the uses to which these instruments might be put in geochemical prospecting for oil and gas deposits and in quality control for raw materials and processed output in the petrochemical industry and in oil refining. This would make it possible to optimize processing procedures while according due consideration to output quality indices.

13185/13046
CSO: 1861/245

UDC 662.997:537.22(088.8)

EFFICACIOUS ARRANGEMENT OF INDIVIDUAL MIRROR ELEMENTS IN COMPOSITE PARABOLOCYLINDRICAL CONCENTRATORS OF RADIANT ENERGY

Tashkent GELIOTEKHNIKA in Russian No 2, Jan-Feb 86 (manuscript received 6 Dec 86) pp 24-38

[Article by O.Kh. Ataullayev, A.K. Ubaydullayev, M.B. Kagan, R.T. Rabbimov, and O.Yu. Sobirov, Tashkent Polytechnic Institute imeni Abu Raykhan Beruni, Navoi branch]

[Abstract] The design problem of a parabolocylindrical solar energy concentrator with a reflecting surface consisting of an array of paraboloidal mirrors is solved for maximum efficacy in terms of optical efficiency and surface utilization. The key geometrical parameters determining the average energy reflected by the mirrors onto the collector are the angle of radiation incidence at the collector and the angle subtended by the concentrator assembly, all depending on the inclination angles of the mirrors to the optical axis of their assembly and on the widths of these mirrors. Calculations based on these geometrical relations for a typical assembly of 20 mirrors indicate that efficacious arrangement of paraboloidal mirrors requires 30% less reflecting surface than plane mirrors. Figures 2; tables 1; references 5: all Russian.

2415/13046
CSO: 1861/425

UDC 535.8

INSTRUMENT FOR MEASURING CROSS-SECTIONAL DIMENSIONS OF OPTICAL CAPILLARIES

Leningrad IZVESTIYA VYSSHIKH UCHEBNYKH ZAVEDENIY: PRIBOROSTROYENIYE in Russian No 1, Jan 86 (manuscript received 12 Oct 84) pp 67-70

[Article by L.P. Lazarev, S.D. Mirovitskaya, and V.I. Tikhomirov, Moscow Institute of Radioengineering, Electronics and Automation

[Abstract] An optimal instrument for measuring the cross-section of capillaries and fiber optics employs a collimated light source to produce a beam that is split into three beams so as to illuminate the test sample from

three aspect angles (0°, 120°, 240° in the horizontal plane). The test object is immersed in a fluid with an index of refraction close to that of the object itself; the immersed portion is illuminated simultaneously with the portion above the fluid. Shadow patterns of the inside and outside diameters of the sample are produced in the near field and the boundaries of these patterns determine the inside and outside diameters (taking the magnification of the projection system into account) and the shape of the cross-section is also estimated from the difference in these pattern boundaries. The system can measure the inside and outside diameters as well as any axial misalignment in the cross-section of capillaries 600 to 2,500 micrometers, and can also test fiber optic blanks up to 10 mm in diameter. The block diagram and physical configuration of the system are shown along with a sample shadow pattern from a capillary. The cross-sectional shape of capillaries can be measured within 1.0 to 1.5% in a range of 600 to 2,500 micrometers. Figures 5.

8225/13046
CSO: 1861/290

UDC 533.6.011.72

GENERATING STRONG SHOCK WAVES IN AIR BY MEANS OF PULSE LASER

Leningrad VESTNIK LENINGRADSKOGO UNIVERSITETA, SERIYA 1: MATEMATIKA, MEKHANIKA, ASTRONOMIYA in Russian No 1, Jan 86 (manuscript received 1 Mar 84) pp 115-118

[Article by U. Daubayev, Yu.V. Sudyenkov, and B.V. Filippov]

[Abstract] The feasibility of generating a strong shock wave simulating detonation in atmospheric air has been demonstrated experimentally with the use of a pulse laser. A laboratory neodymium laser oscillator emitting pulses of 25 ns duration at the 1.06 μm wavelength with a maximum power density of the order of 10^{12} W/cm^2 was combined with four laser amplifier stages, three UIG-1M lasers and one GOR-300 laser. Ionization of air was initiated by a "laser spark" at a radiation power density of the order of 10^8 W/cm^2 and a temperature of several thousand degrees Kelvin, the laser radiation having been focused through a long-focus lens (f = 750 mm) into a beam 0.2 mm in diameter. The plasma filament produced as a result continued to absorb laser radiation, became approximately 50 mm long and wider. Acting as a "piston" on the ambient air, it generated a shock wave with a nearly cylindrical front. Velocity and pressure profiles were measured at various distances from the "spark" and at various instants of time, accurately within 10%, with the appropriate instrumentation. In order to generate a shock wave propagating at high velocities, with a Mach number N_M = 5.65-12.3, it was found necessary to use a copper wire 0.15 mm in diameter as pilot detonator broken down by a laser beam of approximately the same diameter. Figures 3; tables 1; references 4: all Russian.

2415/13046
CSO: 1861/270

UDC 621.373.826

EFFECTIVE HIGH FREQUENCY LASER LOSS MODULATOR WITH ACTIVE MODE SYNCHRONIZATION

Moscow PRIBORY I TEKHNIKA EKSPERIMENTA in Russian No 4, Jul-Aug 86 (manuscript received 19 Apr 84) pp 192-196

[Article by I.P. Angelov, G.V. Venkin, D.V. Kazantsev, and G.M. Mikheyev, Moscow State University]

[Abstract] A simple and reliable circuit is described for a high frequency laser loss modulator. The circuit features a triode and high-power transistor. The simplicity of the circuit provides good reliability and stability. Its high gain allows the use of a small matching resistor at the input, reducing the influence of pulse operation on the output of the master oscillator. The circuit allows operation of YAG laser with active mode synchronization producing single pulses of 0.7 mJ at a repetition frequency of 10 Hz and a pulse length of 0.1-1 ns. Figures 5, references 12: 11 Russian, 1 Western.

6508/13046
CSO: 1861/61

UDC 621.373.826

PULSED ELECTRIC POWER SOURCE FOR SEMICONDUCTOR LASER ARRAYS BASED ON HIGH POWER MOS SWITCHING TRANSISTORS

Moscow PRIBORY I TEKHNIKA EKSPERIMENTA in Russian No 4, Jul-Aug 85 (manuscript received 29 Apr 84) pp 102-104

[Article by V.P. Dyakonov and V.Yu. Smerdov, Smolensk Branch, Moscow Institute of Power Engineering]

[Abstract] Powerful MOS switching transistors with a vertical channel (VMOS transistors) allow the creation of sources of pulsed electric power for laser arrays. This article describes such a power supply, using type KP912 VMOS transistors with maximum voltage of 100 V and a current of 20 A. The device uses two separate channels operating into a common load, which improves the dynamic characteristics of the final stages, provides milder operating conditions for the preliminary amplification stages and increases the reliability of the system. Figures 2, references: 5 Russian.

6508/13046
CSO: 1861/61

UDC 531.43

AUTOMATIC ELASTIC RELAXATION SPECTROMETER

Moscow PRIBORY I TEKHNIKA EKSPERIMENTA in Russian No 4, Jul-Aug 85 (manuscript received 12 Apr 84) pp 201-203

[Article by V.V. Koshtoyev, Z.Sh. Mandzhavidze, M.V. Magradze, V.A. Melik-Shakhnazarov, and G.G. Sekhniaidze, Institute of Physics, Georgian Academy of Sciences, Tbilisi]

[Abstract] This article briefly reviews the contents of a preprint entitled 'Automatic Mechanical Oscillation Relaxation Spectrometer,' published by the authors' institute in 1983. The spectrometer was developed for measurement of the viscosity of rotating ^{3}He as a part of the Soviet-Finnish ROTA experiment. The spectrometer includes an exciter and oscillation stabilization unit, 8-stage frequency meter, 14-bit ADC, 24-bit binary counter, amplitude discriminator, program-controlled pulse generator and controller. The spectrometer also includes an Elektronika-60 microcomputer with a frequency deviation meter and an oscillator. The operation of the device is briefly described. Calibration measurements indicated a relative error of 0.01%. Figures 2, references 4: 3 Russian, 1 Western.

6508/13046
CSO: 1861/61

UDC 621.37/39:534

ACOUSTOOPTIC DEVICE FOR CONVERTING OPTICAL IMAGE INTO ELECTRICAL SIGNAL

Moscow KVANTOVAYA ELEKTRONIKA in Russian Vol 12, No 4, Apr 85 (manuscript received 8 May 84) pp 743-749

[Article by V.I. Balakshiy, A.G. Kukushkin, S.K. Mankevich, V.N. Parygin, B.V. Poletayev, and G.N. Stavrakov]

[Abstract] A new class of acoustooptic devices has been developed for light-to-signal conversion which can electrically record not only the amplitude but also the phase of an optical image. Such a device consists of an acousto-optic cell between a piezoelectric transducer which excites a short acoustic wave train in that cell and an absorber which ensures that the train becomes a traveling rather than standing wave. A space-modulated light wave from the object as source passes through this cell crossing the sound wave and some being diffracted by it. A collecting lens behind the cell projects all diffracted light onto a photoreceiver pad and all undiffracted light onto a screen next to it. The basic two performance characteristics of such a converter are the scan period equal to the cell aperture divided by the velocity of sound and the resolution equal to the cell aperture divided by the smallest dimension of a resolvable element. Determining this dimension exactly requires solving the corresponding problem of diffraction, which is done after

space Fourier transformation of the incident light beam into a sum of plane waves and analogous representation of the acoustic wave train as a superposition of monochromatic sound waves. Calculations are made first for the case of low diffraction efficiency, with independent interaction of each plane light wave and each monochromatic sound wave, for an object in the form of a sinusoidal amplitude grating. For maximum conversion efficiency is then considered incidence of light at the Bragg angle. The result indicates that the maximum number of resolvable elements increases but the conversion speed decreases as the cell aperture is increased. In an experimental study acoustic shear waves were excited in the [110] direction in a TeO_2 cell with standard cut, a paratellurite crystal being used on account of its optical activity and an $LiNbO_3$ crystal resonating at approximately 55 MHz being used as transducer. They were used for oscillographic recording of a Fraunhofer diffraction pattern, with the grating (period 35 μm) in the path of a collimated light beam. Figures 5; references: 6 Russian.

2415/13046
CSO: 1861/456

MECHANICS OF SOLIDS

UDC 534.833

SYNTHESIS OF ACTIVE VIBRATION PROTECTION SYSTEM CONTROL CHANNELS BY INVARIANT POINT METHOD

Moscow MASHINOVEDENIYE in Russian No 3, May-Jun 86 (signed to press 26 Dec 85) pp 22-27

[Article by S. V. Kravchenko, Moscow]

[Text] The application of active vibration protection systems which are automated vibration control systems [1], permits significant decrease in harmful vibration effects on different technical and biological subjects. When building wide-band active vibration protection systems [2] designed for installation on transport means, it has great significance to decrease the amplitudes of the resonant vibrations, increase the safety margins and expand the frequency ranges of effective vibration protection. These problems can be solved by introduction of controlled damping into the vibration protection system by the formation of control inputs within the defined frequency ranges in opposite phase to the vibration rate of the vibration active object [3].

In this article it is proposed that the invariant point method be used [4] to synthesize an active vibration protection system with controllable damping. The required assumptions connected with using this method are discussed, the appropriateness of which is checked by numerical optimization calculations and experimental results.

1. Let us consider an active vibration protection system for a vibrationally active object with controlled damping of the vibrations of an elastic object (Figure 1). Neglecting internal dissipation in the material of the object and passive vibration insulators compared to the introduced controlled damping, let us assume that a vibrationally active object with passive vibration protection means is a linear conservative system. Let us distinguish three types of characteristic points (Figure 1): the excitation point A at which the external disturbing force f^0 is applied, n observation points $B_1, B_2, \ldots, B_n$, two control points C and D. Sensors are installed at the points B_j ($j=1, n$), the signals from which, passing through n control panels with transfer functions $W_1, W_2, \ldots, W_n$, form the control input f^a. Let us represent the transfer functions of the control channels in the form of the ratio of polynomials as a function of the differentiation operator p: $W_j=H_j(p)/Q_j(p)$, ($j=1,n$). Whereas in an active vibration system, the principles of wide-band compensation or stabilization are realized [2], in a conservative vibrating system the control inputs are applied 0 or 180° out of phase with respect

to the external effect f^0. This means that the polynomials $Q_j(p)$ and $H_j(p)$ contain only the fourth powers of the operator p, that is, all W_j (j=1,n) are real functions of the frequency of the external disturbance ω. Let us consider the case where a term containing p to an odd power appears in the numerator or denominator of one of the transfer functions W_k. In this case W_k describes the channel in which the signal proportional to the vibration rate is formed to defined frequencies, and q_k is the coefficient which for an odd power of the operator p defines the parameters of the link insuring introduction of the controlled damping. Writing the equation of motion in operator form by the method of dynamic compliances, we find the ratio of the displacement of one of the characteristic points (for example, the point D) to the external disturbance amplitude f^0. Making the transition to the frequency region (by substitution of p=iω, where $i=\sqrt{-1}$, ω is the external disturbance frequency) and grouping all of the real and complex terms, it is possible to represent x_D/f^0 in the form of a piecewise linear function

$$x_D/f^0=(E+iFq_k)/(U+iVq_k), \tag{1}$$

where E, F, U, V are real functions of ω which cannot depend on q_k and which are determined by the dynamic compliance matrix elements at the characteristic points by the real transfer functions W_j j=1,n,j≠k) and the coefficients for even powers p of the polynomials H_k and Q_k. Under the condition

$$E/F=U/V \tag{2}$$

the values of expression (1) do not depend on q_k, which permits the use of the invariant point method for synthesis of the controlled damping channels [4]: the frequencies ω* corresponding to the invariant points, that is, the points that do not depend on the controlled damping, are determined, and the control parameters are found for which the vibration amplitudes are approximately the same on these frequencies. The tangents to the graph of the frequency amplitude characteristic of the vibrationally active object at invariant points must be horizontal.

When synthesizing the active vibration protection system control channels, the invariant point method permits approximate analytical relations to be obtained between the basic control parameters, on satisfaction of which the maximum reduction of resonant vibration amplitude level is insured. As will be demonstrated below, these analytical relations play a large role not only when calculating the efficiency, but also when investigating the stability of the active vibration protection system.

2. Let us consider the simplest diagram of a wide-band active vibration protection system with controlled damping [5] (Figure 2). The force gage in the base of a passive vibration insulator can be described by the transfer function W_1 of the first order upper frequency filter [2]. The wide-band compensation and controlled damping channels are described by the transfer functions W_2 and W_3. The simplest dynamic link, providing for the introduction of controlled damping and even in this case not distorting the amplitude-phase frequency characteristic of the basic wide-band compensation channel, is a second-order vibrational link, a low-frequency filter which at its resonance

frequency realizes a -90° phase shift relative to the input signal (the phase frequency-amplitude characteristics of this link are shown in Figure 3,a).

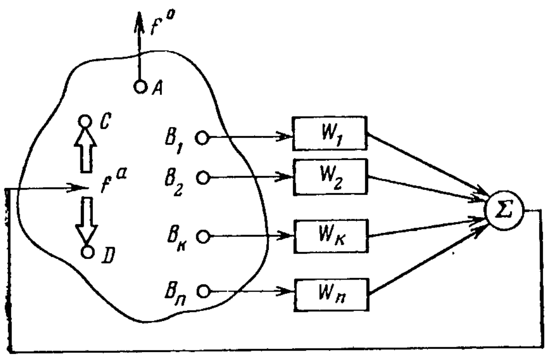

Figure 1

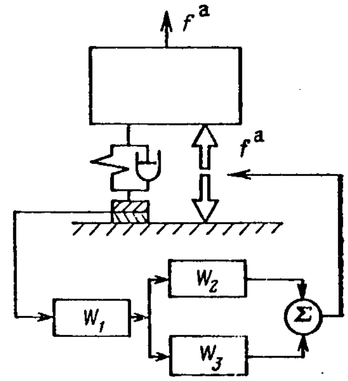

Figure 2

The dimensionless equations of the dynamics of an active vibration protection system in operator form have the form

$$x(p^2+\lambda p+1)=f^0+f^a, \quad f^a=W_1(W_2+W_3)(\lambda p+1)x, \tag{3}$$

where $W_1=p/(p+r_1)$; $W_2=k_2$; $W_3=k_3r_3{}^2/(p^2+pr_3/Q_3+r_3{}^2)$; λ is the damping in the passive shock absorber; k_2, k_3 are the gains of the compensation and controlled damping channel; r_1 is the conjugate frequency of the upper frequency filter; r_3,Q_3 are the resonance frequency and Q-factor of the lower frequency filter in the controlled damping channel. The frequencies r_1 and r_3 are expressed in fractions of the natural vibration frequency ω_0 of the vibrationally active object on a passive shock absorber.

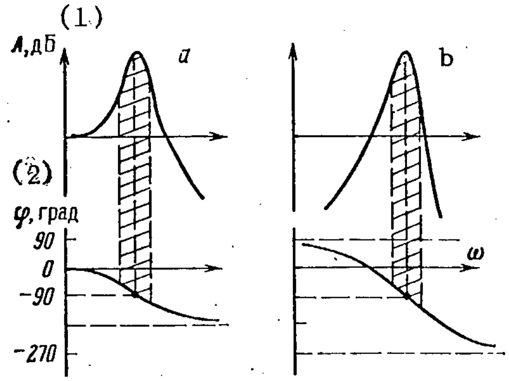

Figure 3

Key:
1. A, decibels
2. ϕ, degrees

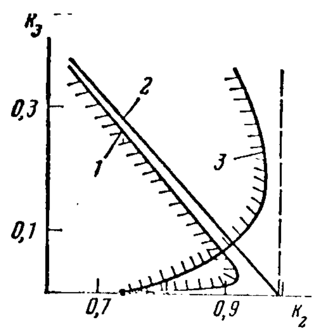

Figure 4

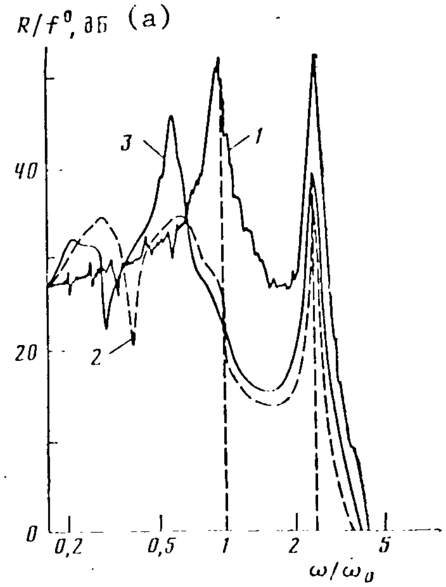

Figure 5

Key:
 a. decibels

In this example we show how the parameters r_3 and Q_3 of the controlled damping channel are optimally selected by the invariant point method. For this purpose, we set $\lambda=0$, $r_1 \ll r_3$ in (3) (that is, $W_1 \approx 1$), and we obtain the expression for the relative displacement analogous to (1) in the form of the piecewise linear function $x/f^0=(E+iFr_3/Q_3)/(U+iVr_3/Q_3)$, where $E=r_3{}^2-\omega^2$, $F=\omega$, $U=\omega^4-\omega^2(r_3{}^2+1-k_2)+r_3{}^2(1-k_2-k_3)$, $V=(1-k_2-\omega^2)\omega$.

From condition (2), the equations follow for determining the invariant point coordinates:

$$\omega^4-\omega^2(r_3^2+1-k_2)+r_3^2(1-k_2-k_3/2)=0, \quad |x/f^0|=\sqrt{F^2/V^2}=\sqrt{1/(1-k_2-\omega^2)}. \qquad (4)$$

Expressions (4) permit determination of the condition of optimal tuning of the filter W_3 in the controlled damping channel insuring equality of the vibration amplitudes at invariant points

$$r_{3\,opt}=\sqrt{1-k_2}. \qquad (5)$$

For $r_{3\ opt}$ the values of the x-axes of the invariant points are found from solution of the first equation of (4)

$$\omega_{1,2}^*=\sqrt{(1-k_2)\pm\sqrt{(1-k_2)\,k_3/2}}. \qquad (6)$$

From the condition $\partial(|x/f^0|)/\partial\omega=0$ for $\omega=\omega_{1,2}{}^*$, the optimal value of the Q-factor is determined

$$Q_{3\,opt}=\sqrt{2(1-k_2)/3k_3}. \quad (7)$$

In deriving equations (5) and (7), the damping in the passive shock absorber was not taken into account, and it was assumed that W_1 can be considered as a real transfer function. The series of numerical optimization calculations of the initial system of equations (3) without the above-indicated assumptions demonstrated that for the most important ratios of the parameters for practice ($\lambda \leq 0.25$; $r_1 \leq 0.1$) the formulas (5) and (7) obtained by the invariant point method with an error of 5 to 8 percent determine the optimal characteristics of the control channels.

The regions of stability of the active vibration protection system in the plane of the parameters k_2 and k_3 (Figure 4) were obtained by computer analysis of the location of the roots of the characteristic polynomial of the system of equations (3) on a complex plane for $\lambda=0.1$, $r_1=0.01$. In Figure 4, the stability regions are marked by hatch marks. The widest region of stability (curve 1 in Figure 4) was obtained for variable values of the controlled damping parameters corresponding to expressions (5) and (7). When constructing this region in each variation step of the coefficients k_2 and k_3, new values of the parameters r_3 and Q_3 were determined by expressions (5) and (7). The fact that the broadest region of stability corresponds to the optimal controlled damping parameters is explained by the phenomenon of the relation of stability to a decrease in resonant vibration amplitudes well-known in automatic control theory. This permits the assumption that the invariant point method can be used when synthesizing the correcting links in automatic control problems [6]. Setting $r_1 \ll r_3$ and using the Routh-Hurwitz criterion, a quite exact estimate was estimated for the upper bound of the region of stability (curve 2 in Figure 4)

$$k_2+k_3<1. \quad (8)$$

3. From stability condition (8), it follows that with the above-investigated simplest diagram of realization of the controlled damping channel, a contradiction arises between the simultaneous increase in k_2 (that is, increase in the wide-band compensation effect) and the increase in k_3 (that is, a reduction in resonant vibration amplitudes of the vibrationally active object). This is explained by the fact that on low frequencies the low-frequency filter has constant gain k_3, and its phase characteristic (Figure 3, a) $\phi(\omega)\approx 180°$ almost coincides with the frequency-phase characteristic of the wide-band compensation channel W_2. Therefore on the lower frequencies ($\omega \ll r_3$), the total gain for the entire system $k_\Sigma \approx k_2+k_3$. In [2], it was shown that for wide-band active vibration protection systems operating in the low-frequency band, $k_2 \leq 1$. This explains the estimates (9) obtained above for the upper bound of the region of stability and indicates that in the wide-band active vibration protection systems it is desirable to synthesize the controlled damping channels in the form of narrow-band filters having a drop in the frequency-amplitude characteristic on low frequencies, and a phase shift by ±90° with respect to the input signal on natural resonance frequencies. The required phase frequency-amplitude characteristics of the controlled damping channel can be realized on the basis of high-order (above second-order) filters.

The simplest method is joining two dynamic second-order links with identical Q-factors and resonance frequencies in series, for example, a narrow-band filter and low-frequency filter. In this case, the transfer function W_3' has the form

$$W_3'=pr_3^2/(p^2+pr_3/Q_3+r_3^2)^2. \quad (9)$$

In expression (10), terms with the operator p to an odd power appear simultaneously in the numerator and denominator; therefore it is impossible to use the above-described procedure for selecting the optimal parameters directly. However, the formulas (5) and (7) obtained by the invariant point method for the filter W_3' can be used for determining the parameters of the high-order narrow-band filter W_3'. From comparison of the amplitude and phase-frequency characteristics of the filters W_3 (Figure 3, a; second-order low-frequency filter) and W_3' (Figure 3, b; the fourth-order narrow-band filter) it follows that in the vicinity of natural resonances the characteristics of these links coincide in practice. On resonance frequencies of $\phi(\omega)=-90°$ introduction of controlled damping is insured. Therefore at resonance frequency the higher-order filter W_3' corresponds to a second-order equivalent filter, and then by expressions (3) and (7) and the conversion rules of the structural diagrams [6], formulas are obtained for the optimal narrow-band filter parameters (9)

$$r'_{3\,\mathrm{opt}}=\sqrt{1-k_2}, \quad Q'_{3\,\mathrm{opt}}=\sqrt{(1-k_2)\sqrt{2/(3k_3)}}. \quad (10)$$

Analysis of Figure 3 shows that in the preresonance region with a decrease in ω the link W_3' has a decreasing frequency-amplitude characteristic (Figure 3, b) in contrast to the amplitude of the link W_3 that is constant with respect to frequency (Figure 3, a). This fact permits use of the narrow-band filter W_3' to expand the boundary of the region of stability (curve 3 in Figure 4) and makes it possible to simultaneously increase k_2 and k_3. When investigating the stability of an active vibration protection system, in equations (3) the transfer function W_3 was replaced by expression (10). The numerical optimization calculations demonstrated that the widest region of stability (curve 3 in Figure 4) corresponds to the control parameters almost coinciding with the values obtained by formulas (10).

4. Experimentally obtained frequency-amplitude characteristics of the total force R transferred to the base by a controllable vibration insulator (Figure 2) are presented in Figure 5.* An elastic beam on vibration insulating supports with first natural vibration frequency ω_0 was used as the vibrationally active object. Curve 1 was obtained only during operation of a passive vibration insulation system (the active vibration protection system was switched off). The first peak ($\omega/\omega_0=1$) on curve 1 corresponds to the natural vibration frequency of the object as an absolutely rigid body on a passive vibration insulating support; the second resonance peak ($\omega/\omega_0\approx3.4$) corresponds to the first tone of the bending vibrations of the beam.

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*The experimental research was performed jointly with V. V. Yablonskiy, E. L. Rymalov and A. G. Chistyakov.

Curves 2 and 3 were obtained during operation of the wide-band active vibration protection system with differently tuned low-frequency filters in the controlled damping channel of the first natural resonance ($\omega=\omega_0$) of the vibrationally active object. The displacement of the first resonance peak to the low-frequency region and the effect of increasing the vibration insulation in the transresonance region ($\omega>\omega_0$) is explained by the effect of the wide-band compensation channel W_2 [2]. The characteristic splitting of the shifted resonance peak (Figure 5, curves 2, 3) is connected with introduction of controlled damping using the vibrational link W_3. Curve 2, which corresponds to maximum reduction of resonance vibrations was obtained for control parameters very close to the values found using expressions (4), (7). Both maxima of the split resonance peak have identical level and almost coincide with the invariant points defined by expression (6). The deviation from the optimal control parameters defined by formulas (4), (7) leads to a reduction in efficiency of the controlled damping (Figure 5, curve 3).

Comparison of the experimental and theoretical results shows that the invariant point method permits analytical expressions with sufficient accuracy for practice to be obtained for the characteristics of the control channels insuring maximum decrease in resonant vibration amplitudes and increase in the safety margins of the active vibration protection system.

In conclusion, let us note that the methods of simplifying complex dynamic models based on analysis of the connectedness of vibration of their individual subsystems [7, 8] permit the invariant point method to be extended to certain multidimensional active vibration protection systems [1] and use of it for synthesis of controlled resonance vibration amplitude damping channels on several natural vibration frequencies of a vibrationally active object.

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VIBRATION INSULATION OF MACHINES AT AUDIO FREQUENCIES

Minsk VESTSI AKADEMII NAVUK VSSR: SERYYA FIZIKA-TEKHNICHNYKH NAVUK in Russian No 2, Apr-Jun 86 (manuscript received 20 Feb 85) pp 63-68

[Article by V. I. Zaborov and M. I. Mogilevskiy, Institute of Construction and Architecture, BSSR Gosstroy]

[Text] The theory of vibration insulation of machines with regard to wave phenomena in vibration insulators was developed in [1, 2]. However, the frequency characteristics calculated from them are so irregular in nature that numerical evaluation of vibration insulation becomes difficult. At the same time, one should take into account that the operations of machines at audio frequencies are wideband random processes, while measurement and normalization of vibration occur in frequency bands. In this regard, one must use frequency-averaged values of vibration insulation in the calculations, which at the same time permits physical analysis of the process of vibration transmission in sufficiently general form.

Let the machine be initially installed rigidly on a base with impedance Z_0 and then be installed through vibration insulators on a base with impedance Z_{0B} (the impedance of the base can be varied by its attachment, installation of an additional mass and so on). A single harmonic force of frequency $f = \omega/2\pi$ is applied to the machine and all points of the machine and of the vibration insulators vibrate in the direction of the force. Regardless of the point of application of the force, the rate of vibration of the base at the point of attachment to the machine is

$$|v_1| = |v_0 Z_M/(Z_0 + Z_M)| \tag{1}$$

with rigid connection [3] and is

$$|v_2| = |v_0 Z_M|/|A(Z_M + Z_{0B}) + B + C Z_M Z_{0B}| \tag{2}$$

with vibration-insulated connection. Formula (2) can be found by a method similar to that presented in [3]. Here Z is the input impedance of the machine at the point of attachment, v is the rate of vibration of the machine at this point when it is disconnected from the base and the vibration insulators and A, B and C are the characteristic coefficients of a quadrupole, which represents the vibration insulators, and they are presented in [4].

Let us assume for frequencies less than the first wave resonant frequency f_1 of the vibration insulator a value of value of vibration insulation

$$V = 10 \lg |v_1/v_2|^2, \tag{3}$$

and in the range of wave resonances ($f \geq f_1$)

$$V = 10 \lg \left(\int_{f_{cp}-\Delta f}^{f_{cp}+\Delta f} |v_1|^2 \, df / \int_{f_{cp}-\Delta f}^{f_{cp}+\Delta f} |v_2|^2 \, df \right). \tag{4}$$

The average frequencies f_{cp} and the averaging bandwidth $2\Delta f$ are selected so that the correspond to the frequency bands in which the vibration is normalized, while function V(f) was varied rather smoothly. The resonant frequencies are $f_n = 2c/2h$, n = 1, 2, ... (h is the height of the vibration insulators) for the considered springs and rubber prismatic vibration insulators, which can be replaced by rods with effective wave impedance values of Z and speed of sound c [2, 5]. In this case formula (4) determines the mean vibration insulation in the octave bands at frequencies of $f \geq f_1$ and in one-third octave bands at frequencies of $f \geq f_4$.

Let us initially assume that the impedance of the base Z_0 did not vary after installation of the vibration insulators. The well-known relation follows from formulas (1)-(3) for frequencies at which no wave phenomena began in the vibration insulators

$$V = 20 \lg |Z_M Z_0 / (Z_M + Z_0) Z_B| \tag{5}$$

provided that $|Z_0/Z_B| > 6$, $|Z_M/Z_B| > 6$, which, as condition $|Z_0/Z_c| > 8$, $|Z_M/Z_c| > 8$, is assumed to be fulfilled (otherwise the vibration insulators are ineffective). Here $Z_0 = C^{-1}$ is the impedance of the vibration insulators, $Z_0 = K/i\omega$ for springs and rubber vibration insulators, K is their dynamic stiffness and $i = (-1)^{1/2}$.

Springs and rubber vibration insulators operate differently upon the occurrence of wave phenomena ($f \geq f_B$) due to the difference (by several orders of magnitude) of loss coefficients η. We find from formulas (1)-(4) for rubber vibration insulators

$$V = 10 \lg |Z_M^2 Z_0^2 \operatorname{ch}(kh\eta) / 2 (Z_0 + Z_M)^2 Z_c^2|; \tag{6}$$

and for springs

$$V = \begin{cases} 20 \lg |Z_M Z_0 \sin kh / (Z_0 + Z_M) Z_c|, & f_B \leq f \leq f_B' - f_1/\sqrt{2}, \\ 10 \lg \dfrac{Z_c [R_0 |Z_M|^2 + R_M |Z_0|^2] + |Z_0 Z_M|^2 kh\eta/2}{|Z_0 + Z_M|^2 Z_c^2}, & f \geq f_1, \end{cases} \tag{7}$$

where $k=\omega/c$; $R_0=\mathrm{Re}\,Z_0$; $R_M=\mathrm{Re}\,Z_M$. Vibration insulation for springs at $f'_B \leq f \leq f_1$ is determined by linear interpolation. Since $|Z_B| \sim \omega^1$, and Z_c = const, it follows from (5)-(7) that the wave phenomena in vibration insulators are accompanied by deceleration of the rate of increase or even by a reduction of vibration insulation. A reduction of vibration insulation, which is absent in rubber vibration insulators, also occurs for springs due to low energy losses ($\eta \sim 5 \cdot 10^{-4}$ and $kh\eta/2 << 1$) at frequencies of $f \geq f_1$.

The frequency characteristics of vibration insulation of a machine installed on a slab, calculated by formulas (5)-(7) for a typical case of the mass of the machine M = 500 kg, Z_0 = 0.41 MN·s/m, Z_c = 1 and 2.7 kNs/m, f_B = 25 and 117 Hz and f_1 = 75 and 350 Hz, respectively, when using springs and rubber vibration insulators are presented in Figure 1; the loss factor of rubber is η = 0.17.

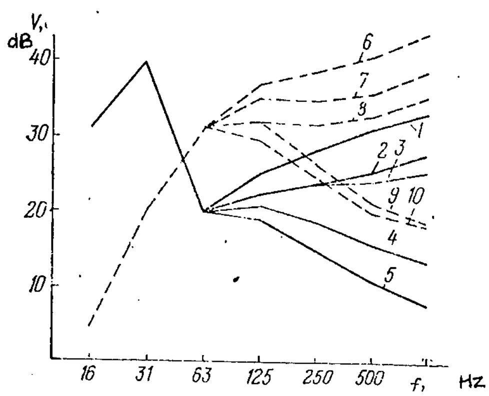

Figure 1. Vibration Insulation of Machine Installed on Slab: spring vibration insulators: curve 1 was plotted for machine with impedance for case 1zh; 2--for case 2m, 2u; 3--for case 2a; 4--for case 3a; 5--for case 3m, 3u; rubber vibration insulators: curve 6 was plotted for machine with impedance for case 1zh: 7--for case 2m, 2u; 8--for case 2a; 9--for case 3m, 3u; 10--for case 3a

Little is known with respect to the impedances Z of real machines. It was established experimentally in [3] and in other papers that machines, beginning at several tens of hertz, can no longer be regarded as rigid bodies, they are complex vibrational systems, the impedance of which can be active at resonant frequencies and reactive (massive or flexible) at other frequencies. In this case, $|Z_M| \sim$ const and $|Z_M| \sim f^{-1}$ on the average in different frequency bands. The following cases are considered in this regard: 1zh--the machine is rigid at all frequencies, 2m--the machine is rigid up to frequency of 80 Hz and the impedance Z_M is mass and constant at higher frequencies, 2u--the same as 2m, but Z_M changes sign at 80 Hz (it becomes elastic), 2a--the same as 2m and 2u, but Z_M is active beginning at 80 Hz, 3m, 3u and 3a--the same as 2m, 2u and 2a, respectively, but Z_M decreases according to the law f^{-1} at 80 Hz. Selection of a frequency of 80 Hz for analysis is unimportant.

Similar characteristics of vibration insulation were found when the machine was installed on a beam with $Z_o = 20(1 + i)f^{1/2}$ kN·s/m, the impedance of which, unlike that of a slab, has an imaginary part and increases with frequency.

It is obvious from Figure 1 that the pliancy of the machine leads to a decrease of vibration insulation to values of 10-20 dB and below at medium and high frequencies, which is also observed in the vibration insulation of real machines.

If the number of vibration insulators on which the machine is installed is increased, the vibration insulation decreases over the entire frequency band. It follows from (5)-(7) that if the number is increased s-fold and if the wave impedance and the impedance become $Z_c^* = sZ_c$, $Z_B^* = sZ_B$, the decrease of vibration insulation will comprise $\Delta V_B = 20 \lg s$ for rubber vibration insulators at all frequencies and for springs at $f \leq f'_B$. The decrease of vibration insulation is dependent on Z_0, Z_M and f for springs at frequencies of $f \geq f_1$, but, as calculations show, one can assume that $\Delta V_B = 20 \lg s$ with accuracy sufficient for practice.

Thus, the vibration insulation is small at frequencies of $f \geq f_1$ due to the non-stiffness of the machines, pliancy of the base and small energy losses in the springs (Figure 1).

Let us consider the possible methods of increasing the vibration insulation: by installation of a structure with large input impedance (a slab or frame) between the machine and the vibration insulators, by increasing the input impedance of the base to Z_{OB} and by installation of rubber spacers between the springs and base or by installation of viscous friction dampers in parallel with them.

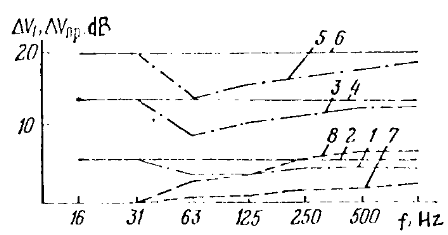

Figure 2. Increase of Vibration Insulation Upon Variation of Base Impedance--Slab--ΔV_1 and Upon Installation of Rubber Spacers Under Springs $\Delta V_{\text{пр}}$: 1, 3, 5--ΔV_1 upon installation of machine on springs at $\gamma = 2, 5, 10$, respectively; 2, 4, 6--ΔV_1 upon installation of machine on rubber vibration insulators at γ = 2, 5, 10, respectively; 7, 8--$\Delta V_{\text{пр}}$ upon installation of spacers 0.01 m thick ($K_{\text{пр}} = 1.1 \cdot 10^8$ N/m) and 0.02 m ($K_{\text{пр}} = 2.1 \cdot 10^7$ N/m), $\eta_{\text{пр}} = 0.17$

Let the first three of the indicated methods be implemented. Let us present the structure between the machine and vibration insulators in the form of concentrated mass m for simplicity. Since the mass of the vibration-insulated installation was increased, the required number of vibration insulators was also increased compared to the case of installing the machine without mass (Z_C, Z_B). Then

$$V = V(Z^*_{0B};\ Z^*_M;\ Z^*_c) + 20\lg|(Z^*_{0B} + Z^*_M)\, Z_{0B}/(Z_0 + Z_M)\, Z^*_{0B}|, \qquad (8)$$

where $V(Z_0;\ Z_M;\ Z_c)$ is the vibration insulation upon installation of a machine with impedance Z_M on base Z_0 through vibration insulators with wave impedance Z_C (with impedance Z_B), determined by formulas (5)-(7); $Z^*_{0B} = Z_{0B}Z_{\Pi p}/(Z_{0B}+Z_{\Pi p})$ is the impedance of the spacer, loaded on the base, $Z^*_M = Z_M + i\omega m$ is the impedance of the mass loaded onto the machine and $Z_{\Pi p}$ is the impedance of the spacers which are usually thin and wave phenomena cannot be taken into account in them.

Let us first use (8) to investigate the effect of variation of the impedance of the base and installation of mass m. Using formulas (5)-(7), we find that for rubber vibration insulators at all frequencies and for springs at $f \leq f'$

$$V = V(Z_0;\ Z_M;\ Z^*_c) + \Delta V_0 + \Delta V_m, \qquad (9)$$

where $\Delta V_0 = 20\lg|Z_{0B}/Z_0|$, $\Delta V_m = 20\lg|Z^*_M/Z_M|$. For springs at frequencies of $f \geq f_1$

$$V = V(Z_0;\ V_M;\ Z^*_c) + \Delta V_0 + \Delta V_m + 10\lg\left|1 - \left\{\frac{R_0 - R_{0B}|Z_0/Z_{0B}|^2}{|1 + Z_0/Z_M|^2 Z^*_c} + \frac{R_M(1 - |Z_M/Z^*_M|^2)}{|1 + Z_M/Z_0|^2 Z^*_c}\right\} 10^{-V(Z_0;\ Z_M;\ Z^*_c)/10}\right|, \qquad (10)$$

where $R_{0B} = \mathrm{Re}\, Z_{0B}$. The last term on the right side of formula (10) is negative for ordinary bases.

It follows from (9) that the total increase of vibration insulation consists of increasing it through installation of mass m with the base impedance fixed and by increasing the base impedance in the absence of mass m. This is not fulfilled precisely for springs at $f \geq f_1$ due to the last term on the right side of (10), but it does not play the main role.

If only the base impedance is varied, the increase of vibration insulation ΔV_1 for rubber vibration insulators is ΔV_0; the increase is also ΔV_0 for springs at $f \leq f'_B$ and at $f \geq f_1$

$$\Delta V_1 = \Delta V_0 + 10\lg\left|1 - \frac{R_0 - R_{0B}|Z_0/Z_{0B}|^2}{|1 + Z_0/Z_M|^2 Z_c} 10^{-V(Z_0;\ Z_M;\ Z_c)/10}\right|.$$

Calculation showed that ΔV_1 is essentially not dependent (ΔV_0 is independent) of the nature of Z_M (cases 1zh; 2m, 2u and 2a; 3m, 3u, 3a) and behaves identically with bases in the form of a slab and beam. The functions of an increase of vibration insulation $\Delta V_1(f)$ at $\gamma = Z_{0B}/Z_0 = 2, 5, 10$ are presented in

Figure 2. We note that the value $\Delta V_0 - \Delta V_1$ increases as γ increases for springs at $f \geq f_1$ (although ΔV_1 also increases as a whole) due to the fact that resonant vibrations in the springs are intensified.

Now let there be installed mass m, while the base impedance is not varied. The case when the number of vibration insulators increases in proportion to the increase of the mass of the vibration-insulated installation is of main interest: $Z_c^* = (1+\mu) Z_c$; $Z_B^* = (1+\mu) Z_B$, $\mu = m/M$. It follows in this case from formula (9) that an increase of vibration insulation, compared to the case of no mass m, is

$$\Delta V_2 = \Delta V_m = 20 \lg (1 + \mu) \tag{11}$$

and is independent of Z_0.

For spring vibration insulators at $f \geq f_1$

$$\Delta V_2 = V(Z_0;\ Z_M;\ Z_c^*) - V(Z_0;\ Z_M;\ Z_c) + \Delta V_m + \\ + 10 \lg \left| 1 - \frac{R_M (1 - |Z_M/Z_M^*|^2)}{Z_c^* |1 + Z_M/Z_0|^2} 10^{-V(Z_0;\ Z_M;\ Z_c^*)/10} \right|. \tag{12}$$

It follows from formulas (11) and (12) that the increase of vibration insulation ΔV_2 is determined mainly by the ratio $|Z_M^*/Z_M|$ and the nature of the impedance of the base and machine (mass, elastic, active), is of little significance. The increase of vibration insulation is $\Delta V_2 = 0$ in the case of a rigid machine, installed on rubber vibration insulators. This is also valid for springs at $f \leq f'_B$ and an increase of vibration insulation is observed at frequencies of $f \geq f_1$.

The vibration insulation of ΔV_2 increases mainly upon installation of mass m due to the fact that it is a vibration-inhibiting element; the value of ΔV_2 is higher, the greater the ratio $\omega m / |Z_M|$.

The frequency characteristics of vibration insulation of concentrated mass m upon installation between the machine and springs are presented as an example in Figure 3; the base of the machine is a slab. The frequency characteristics of the increase of vibration insulation ΔV_2 due to mass m is determined by the difference of the ordinates of the corresponding curves in Figure 3 at $\mu \neq 0$ and $\mu = 0$. The frequency characteristics ΔV_2 have a similar form upon installation of the machine on springs on a beam and upon installation of it on rubber vibration insulators.

Let us consider the effect of rubber spacers located under the vibration insulators. It follows from formulas (5)-(8) that vibration insulation in the case of rubber vibration insulators and also for springs does not vary at $f \leq f'_B$. Vibration insulation by springs increases only at frequencies of $f \geq f_1$ at

$$\Delta V_{\text{np}} = 10 \lg \left(1 + \frac{|Z_0|^2 \omega \eta_{\text{np}}}{|1 + Z_0/Z_M|^2 Z_c K_{\text{np}}} 10^{-V(Z_0;\ Z_M;\ Z_c)/10} \right)$$

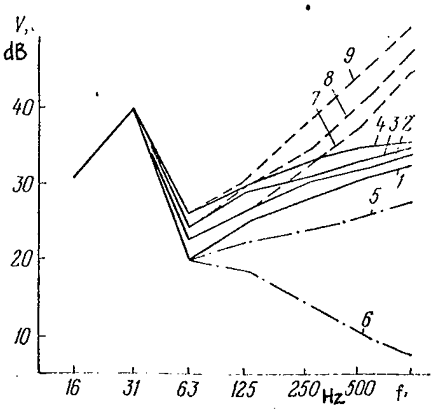

Figure 3. Vibration Insulation Upon Installation of Concentrated Mass m Between Machine and Springs; base--slab: 1, 2, 3, 4-- $\mu = m/M = 0, 1, 2, 4$, respectively, machine is rigid (case 1 zh); 5, 6-- $\mu = 0$, cases 2 m and 3 m, respectively; 7, 8, 9-- $\mu = 1, 2, 4$, respectively, case 2 m or 3 m (vibration insulation is essentially identical)

due to scattering of the energy in spacers in the vicinity of the resonant frequencies. Calculations showed that $\Delta V_{\text{пр}}$ is hardly dependent on Z_M and is determined mainly by the dynamic stiffness $K_{\text{пр}}$ and by the loss factor $\eta_{\text{пр}}$ of the spacers. Typical frequency characteristics of ΔV upon installation of a rigid machine on springs on a slab are presented in Figure 2; the values of $\Delta V_{\text{пр}}$ differ from those indicated in Figure 2 by no more than 1 dB for the cases indicated above, when the machine is not rigid (2m, 2u, 2a; 3m, 3u, 3a). The frequency characteristics $\Delta V_{\text{пр}}$ have similar form when the base of the machine is a beam.

Viscous friction dampers, installed in parallel with the springs, as is known, permit one to attenuate the resonance on the fundamental frequency of natural vibrations of a vibration-insulated machine $f_0 = (K/M)^{1/2}/2\pi$. In this case, the resonance is less marked than when the machines are installed on rubber vibration insulators. The problem of the possibility of attenuation using dampers and wave resonances is of interest. Since the type of impedance of the machine (active or reactive), as noted above, has a slight effect on vibration insulation, let us assume for simplicity that Z_M is imaginary. Let us regard the dampers as elements with lumped parameters and let us characterize them by the viscous friction coefficient $R_Д$. It is known that the vibration insulation decreases at frequencies of $2f_0 < f < f_в$ upon installation of dampers [1]. We find from (1)-(3) at frequencies $f_в \le f \le f'_в$ provided that $|Z_M| > 5R_Д$

$$V = 20 \lg \left| \frac{(Z_M/Z_c)(Z_0 + R_Д)\sin kh}{(1 + iR_Д \sin kh/Z_c)(Z_0 + Z_M)} \right|.$$

Since usually $|Z_0/R_д| \gg 1$, $R_д/Z_c = 2 \div 10$, dampers at these frequencies also have a negative effect on vibration insulation. For large frequencies from equations (1), (2) and (4) provided that $|Z_0| > 5R_д$, $|Z_м| > 5R_д$

$$V = 10 \lg \left\{ \frac{1}{|1 + Z_0/Z_м|^2} \left(\frac{R_0}{Z_c} + \frac{R_д}{Z_c} \left[\frac{R_д}{Z_c} + \left| \frac{Z_0}{Z_м} \right|^2 + 4 \frac{X_0}{|Z_м|} \right] + \frac{kh\eta}{2} \frac{(R_0 + R_д)^2 + X_0^2}{Z_c^2} \right) \right\},$$

$X_o = ImZ_o$. The calculations of vibration insulation were made by this formula at the values encountered in practice with respect to damping and at different values of Z_M, Z_O. The increase of vibration insulation is small and occurs only at very small values of $|Z_M|$. This result is explained by the fact that the support surfaces of the damper are located near the standing wave nodes in the vibration insulators in the vicinity of wave reasonant frequencies. Because of this, the difference of rates on the support surfaces of the dampers is small and they are essentially excluded from the paper.

The results are also naturally valid in the case when the source of vibrations is a base, while the machine is protected against vibrations (kinematic vibration insulation) and also not only for the considered rubber and spring vibration insulators, but for other insulators as well, the motion of which is subject to the wave equation, for example, to twisting or shear. To determine the vibration insulation, it is sufficient to substitute in the derived formulas the corresponding impedances, wave impedances and so on. The given formulas can be used directly in calculation of the vibration insulation of machines and equipment.

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ON ONE MODEL OF ROLLING FLEXIBLE WHEEL

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[Article by F.Sh. Yusupov, Tashkent Order of Peoples' Friendship Institute of Textiles and Light Industry imeni Yu. Akhunbabayev]

[Abstract] A deformable tire on a hard disk (wheel) is mounted on the offset strut of an undercarriage and rolls at a constant velocity in a straight line. All of the linkages are assumed to be holonomic and the equations of motion of the wheel systems are written in terms of the small transverse deviation and small angular deviation of the hard wheel disk from the assumed straight rolling line, the small elastic deformations of the tire with respect to the disk and the constant velocity of the wheel and carriage system. The wheel support strut and the wheel can rotate through a certain angle, independently of the elastic deformations of the tire. The final equations derived describe the motion of the disk and enable the analysis of the dynamic stability of such systems. No sample calculations or examples are adduced. References 2: 1 Russian, 1 Western in Russian translation.

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