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STRESS RELIEVING PROCEDURES FOR HELICAL COMPRESSION SPRINGS

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MAY 1974

FINAL REPORT

RESEARCH DIRECTORATE

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Various stress relieving procedures for the manufacture of cold wound helical compression springs were investigated to determine the effect that the time interval between the coiling and stress relieving operations has on spring life. Production springs with indexes of 3 to 13 were fabricated from various materials. The springs were stress relieved at varying times after the coiling operation. The effect of the time interval between the coiling

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and stress relieving operations was determined by visual observation for crack initiation and by laboratory endurance tests. Analysis of the test data showed that the time interval between the two operations has no effect on the endurance properties of the materials that were investigated.

CONTENTS

OBJECTIVES

The objectives of this program were to determine optimum stress relieving procedures for cold wound helical compression springs and to determine if it is necessary that the stress relieving operation be performed immediately after coiling.

INTRODUCTION

The purpose of the stress relieving operation of cold wound helical springs is to remove the induced stresses that are caused by the coiling operation and thereby increase the elastic properties of the spring material. The stress relieving operation is accomplished by subjecting the springs to a temperature of 400 - 900°F (depending on type of material) for approximately 30 minutes. It has been recommended by some investigators that the stress relieving operation should be done as soon as possible after coiling to minimize the possibility of crack initiation. It was pointed out that the elastic limit of most spring materials was 60 - 70% of the tensile strength. This results in a comparatively narrow range of stresses between the elastic limit and the tensile strength of the material within which the spring must be formed. Coiling stresses of necessity must exceed the elastic limit, but cannot exceed the ultimate strength. It was felt that under some conditions the coiling operation may produce trapped residual stresses that could initiate surface cracks if they were not removed promptly after coiling.

DISCUSSION

Material and Test Procedures

The helical compression springs that were used in this program were fabricated from the following spring tempered materials and given the specified stress relieving treatments. Wire diameter of .050 inch was used for all the material types.

MATERIAL	STRESS RELIEVING TREATMENT
Music wire, QQ-W-470	Heat at 450°F ± 10° for 30 minutes
Chrome vanadium, QQ-W-412, Comp. 1	Heat at 700°F ± 25° for 30 minutes
Stainless steel, QQ-W-423, Comp. FS302	Heat at 600°F ± 15° for 30 minutes
Nickel chromium, QQ-W-390, Cond C	Heat at 900°F ± 25° for 60 minutes

Six basic spring designs with indexes of 3, 5, 7, 9, 11 and 13 were prepared for this program. The spring index is defined as the ratio of the mean coil diameter to the wire diameter. Detailed specifications for these designs are given in the Appendix. Thirty springs of each design were fabricated from each material; a grand total of 720 springs were produced. Each group of 30 springs was divided into three sets of 10 springs each and the time to start the stress relieving operation varied as follows:

Set # 1 - Stress relieve immediately after coiling.

Set # 2 - Stress relieve one hour after coiling.

Set # 3 - Stress relieve 24 hours after coiling.

Prior to coiling, all material was examined thoroughly for surface defects with the aid of a binocular microsope. No cracks or surface defects were observed and the material was accepted for coiling. The material was re-examined after coiling and was found free of surface defects. After stress relieving, all springs were preset by compressing to solid height three times.

Test fixtures were designed and fabricated. The springs were endurance tested on a Krouse spring tester at a rate of 1000 cycles/minute. A photograph of a test spring assembled onto the fixture is included in the Appendix. Testing was performed between the stress levels of 100,000 psi and 170,000 psi for all springs. Measurements were taken on free heights and spring loads periodically during the tests. Approximately 80% of the testing was completed when it was decided to terminate the remaining scheduled endurance tests. The decision was based on the fact that the generated test data showed no apparent trend or consistent pattern from which to draw conclusions as to an optimum time to stress relieve springs. It was expected, based on recommendations by other investigators, that the springs that were stress relieved immediately after coiling would have longer life because of the fact that the induced coiling stresses which may be detrimental to the wire material were removed promptly; however, test data did not substantiate this supposition.

Test Results

The springs were endurance tested until breakage or 500,000 cycles were completed, whichever occured first. All of the music wire springs were tested and a graphical representation of the endurance life of each music wire spring is shown on the graphs in the Appendix. The following Table shows the number of broken springs in each sample group of 10 springs for the four materials.

BROKEN SPRINGS

Material	Spring Index	Stress Relieve 5 Min After Coiling	Stress Relieve 1 Hour After Coiling	Stress Relieve 24 Hours After Coiling
Music Wire	3	8	6	3
	5	6	5	5
	7	2	8	2
	9	1	3	2
	11	0	1	0
	13	1	0	0
Chrome Vanadium	3	4	6	2
	5	4	0	7
	7	1	7	7
	9	4	6	4
	11	0	4	4
	13	Not Tested	Not Tested	Not Tested
Stainless Steel	3	Not Tested	10	10
	5	10	9	10
	7	10	10	10
	9	10	10	9
	11	9	10	9
	13	Not Tested	Not Tested	Not Tested
Nickel Chromium	3	9	10	9
	5	10	10	10
	7	10	10	10
	9	Not Tested	Not Tested	Not Tested
	11	Not Tested	Not Tested	Not Tested
	13	Not Tested	Not Tested	Not Tested

STATISTICAL ANALYSIS

A statistical analysis was performed in an attempt to detect any significant differences in the widely dispersed data. A test, called the unbiased test[1], was made to statistically compare the sample means ($\overline{x}$). The test is based on the assumption that the data has a normal distribution with an unknown mean fatique life, μ. If μ_1 is the mean life for one heat treatment and μ_2 is the mean for another treatment whose life is believed to be longer because of the time at which it was heat treated, then the hypothesis that $\mu_1 = \mu_2$ or $\mu_2 - \mu_1 = 0$ is tested against the alternative $\mu_2 > \mu_1$ or $\mu_2 - \mu_1 > 0$.

By computing the value of t, derived in the reference, from the sample means and assuming $\mu_2 - \mu_1 = 0$ we can test our hypothesis. Choose a number (a) from the "student's" distribution tables with $n_1 + n_2 - 2$ degrees of freedom so that:

$$p_r\ (t>a) = \alpha$$

where α = level of confidence we have in saying that the life obtained with one delay before heat treatment is statistically longer than the life obtained by using a different time delay before heat treatment. The statistical comparison takes into account the sample size and variance.

If t is a larger value than a then we reject the hypothesis $\mu_2 = \mu_1$ in favor of $\mu_2>\mu_1$ with α level of confidence that $\overline{x}_2>\overline{x}_1$.

---

1. REF: H. D. Brunk, An Introduction to Mathematical Statistics, Page 258.

Example calculation:

From data on stainless steel spring with c = 7

n = sample size

x = sample life in thousands of cycles

$\overline{x}$ = mean life

S = variance

$$S^2 = \frac{1}{n} \Sigma_{i=1}^{n} x_i^2 - \overline{x}^2$$

$$S^2 \text{ (5 min)} = \frac{1}{10} (73^2 + 110^2 + 85^2 + 98^2 + 188^2 + 98^2 + 74^2 + 66^2 + 81^2 + 72^2) - 95^2 = 1053$$

$$S^2 \text{ (1 hr)} = 2533$$

$$t = \frac{(\overline{x}_2 - \overline{x}_1) - (\mu_2 - \mu_1)}{\sqrt{n_1 S_1^2 + n_2 S_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

$n_1 = n_2 = 10$ $\mu_2 - \mu_1 = 0$

$$t = \frac{(\overline{x}_2 - \overline{x}_1)}{\sqrt{10} \sqrt{S_1^2 + S_2^2}} \sqrt{\frac{(10)(10)(10 + 10 - 2)}{10 + 10}} = \frac{3 (\overline{x}_2 - \overline{x}_1)}{\sqrt{S_1^2 + S_2^2}}$$

$$t = \frac{3 (121 - 95)}{\sqrt{2533 + 1053}} = 1.303$$

The "student's" distribution table is used next.

n = 10 + 10 -2 = 18

F = .90 is chosen

a = 1.330 is found in the table

t = 1.303

In this case t is not larger than a, therefore, we can not reject the hypothesis $\mu_2 = \mu_1$. We have less than 90 percent confidence in saying that $\overline{x}_2 > \overline{x}_1$. In other words we can not say with 90 percent or greater confidence level that heat treat after a 5 minute delay is better than a 1 hour delay. When comparing the 24 hour delay to the 5 minute delay the confidence level would have to be lowered to 65 percent before the test hypothesis could be rejected.

The results of analyzing the data (see the following Tables) for stainless steel and nickel chromium do not support the contention that immediate heat treatment is necessary. In some cases the wait was detrimental and in other cases it was beneficial. Inspection of the breakage data for the music wire and chrome vanadium springs indicated that the timing of stress relief had no effect on spring life over a cycle life equivalent to 50 times the expected Army life usage.

STAINLESS STEEL

	n = 10 C = 5			n = 10 C = 7		
Time between coiling and stress relieving	5 Min	1 Hr	24 Hr	5 Min	1 Hr	24 Hr
	492	500	88	73	82	232
	84	115	95	110	86	93
(Cycles to breakage in thousands)	150	443	82	85	217	77
	84	151	159	98	81	98
	186	99	75	188	118	61
	120	262	70	98	80	77
	196	225	98	74	76	51
	87	195	128	66	121	161
	435	93	304	81	147	99
	142	97	114	72	204	93
Totals	1976	2180	1213	945	1212	1042
$\bar{x}$	198	218	121	95	121	104
S^2	19,101	19,219	4,429	1,053	2,533	2,646
S	138	138	67	32	50	51
		Comparing 5 min with 1 hr	Comparing 5 min with 24 hr		Comparing 5 min with 1 hr	Comparing 5 min with 24 hr
t		.307	1.502		1.303	.444
α		.60	.90		.85	.65

STAINLESS STEEL

Time between coiling and stress relieving	n = 10, C = 9: 5 Min	n = 10, C = 9: 1 Hr	n = 10, C = 9: 24 Hr	n = 10, C = 11: 5 Min	n = 10, C = 11: 1 Hr	n = 10, C = 11: 24 Hr
(Cycles to breakage in thousands)	229	194	85	500	98	62
	70	249	195	77	100	178
	237	75	252	73	164	72
	78	86	76	291	78	101
	59	85	98	89	152	108
	66	114	281	91	90	67
	72	186	226	134	82	107
	101	145	500	159	100	159
	96	98	89	455	207	94
	167	153	244	84	56	500
Totals	1175	1385	2046	1953	1127	1448
$\overline{X}$	118	139	205	195	113	145
S^2	4,068	2,830	15,138	23,920	1,881	15,238
S	64	53	123	155	43	123
		Comparing 5 min with 1 hr	Comparing 5 min with 24 hr		Comparing 5 min with 1 hr	Comparing 5 min with 24 hr
t		.397	1.277		1.531	.758
α		.65	.85		.90	.75

NICKEL CHROMIUM

Time between coiling and stress relieving	n = 10, C = 3			n = 10, C = 5		
	5 Min	1 Hr	24 Hr	5 Min	1 Hr	24 Hr
(Cycles to breakage in thousands)	405	341	300	134	164	144
	380	261	308	113	143	130
	332	250	303	120	127	105
	381	376	361	83	127	162
	500	232	425	53	131	180
	356	312	271	141	109	146
	370	330	273	151	186	97
	290	341	500	164	166	127
	291	337	430	156	151	137
	366	350	380	147	162	153
Totals	3671	3130	3551	1262	1466	1381
$\bar{x}$	367	313	355	126	147	138
S^2	3329	2101	5464	1159	375	590
S	58	46	74	34	19	24
		Comparing 5 min with 1 hr	Comparing 5 min with 24 hr		Comparing 5 min with 1 hr	Comparing 5 min with 24 hr
t		2.198	.384		1.609	.861
α		.975	.60		.90	.80

NICKEL CHROMIUM

Time between coiling and stress relieving	5 Min	1 Hr	24 Hr
	n = 10 C = 7		
(Cycles to breakage in thousands)	98	120	111
	124	130	124
	134	144	120
	117	137	121
	123	73	152
	111	135	124
	96	140	130
	95	140	119
	90	143	151
	127	106	108
Totals	1115	1268	1260
$\overline{x}$	112	127	126
S^2	111	395	198
S	11	20	14
		Comparing 5 min with 1 hr	Comparing 5 min with 24 hr
t		2.000	2.389
α		.95	.975

Time Between Coiling and Stress Relieving	No. of Tests That Were: Strongest	Weakest
5 Minutes	2	4
1 Hour	4	2
24 Hours	1	1

Average life for all springs with 5 minute delay - 173,000 cycles.
Average life for all springs with 1 hour delay - 168,000 cycles.
Average life for all springs with 24 hour delay - 171,000 cycles.

CONCLUSIONS

It is concluded from the analysis of the test data that the time interval between the coiling and stress relieving operations has no effect on the endurance properties of the four spring materials that were investigated. Therefore, it is not necessary for springs fabricated from these materials to be stress relieved immediately after coiling.

The large amount of spring breakage that occurred in this test program is attributed to the severe conditions of the cycling tests, particularly the maximum working stress level of 170,000 psi.

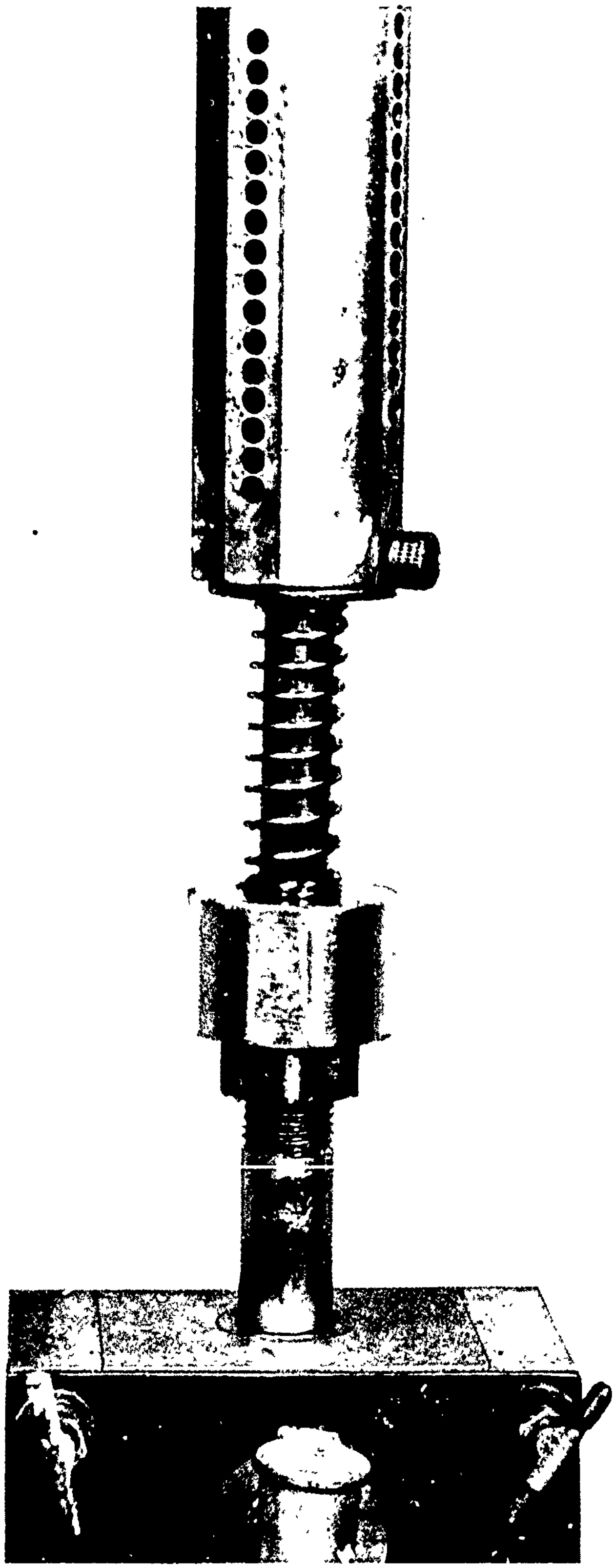
Analysis of the test results also indicates that there is more breakage with springs of smaller index than with springs of higher index, particularly for the music wire springs. One reason for this is that the stress concentration at the inner diameter of the coiled wire is inversely proportional to the spring index.

Another conclusion not directly related to the objective of the project is that music wire and chrome vanadium are superior materials to stainless steel and nickel chromium for spring applications where the operating stress levels are between 100,000 and 170,000 psi. This conclusion is based on the significantly larger amount of breakage for the latter two materials and agrees with most spring manuals which recommend music wire and chrome vanadium for high stress applications under repeated loading. Recommended design stress levels for these two materials are much higher than values given for stainless steel and nickel chromium.

RECOMMENDATIONS

It is recommended that no further effort be made to study the effect of the time interval between the coiling and stress relieving operations on the endurance properties of the four investigated spring materials.

APPENDIX



PRODUCTION SPRING INSTALLED ON ENDURANCE TESTER

STRESS RELIEVE PROGRAM

DESIGN # 1

SPRING INDEX - 3.0

WIRE SIZE (In.)................................	.050
OUTSIDE DIAMETER (In.).........................	.200 $\pm$ .003
TOTAL COILS....................................	37
TYPE OF ENDS...................................	Closed Ground
FREE HEIGHT, APPROX. (In.).....................	2.73
MEAN ASSEMBLED HEIGHT (In.)....................	2.300
LOAD AT ASSEMBLED HEIGHT (Lb.).................	32.7
MINIMUM OPERATING HEIGHT (In.).................	2.000
LOAD AT MINIMUM OPERATING HEIGHT (Lb.).........	55.5
LOAD-DEFLECTION RATE (Lb./In.).................	76
MAXIMUM SOLID HEIGHT (In.).....................	1.900
SPRING HELIX...................................	R.H.

STRESS RELIEVE PROGRAM

DESIGN # 2

SPRING INDEX - 5.0

WIRE SIZE (In.)................................	.050
OUTSIDE DIAMETER (In.).........................	.300 ± .005
TOTAL COILS....................................	30
TYPE OF ENDS...................................	Closed Ground
FREE HEIGHT, APPROX. (In.).....................	3.33
MEAN ASSEMBLED HEIGHT (In.)....................	2.369
LOAD AT ASSEMBLED HEIGHT (Lb.).................	19.6
MINIMUM OPERATING HEIGHT (In.).................	1.700
LOAD AT MINIMUM OPERATING HEIGHT (Lb.)........	33.3
LOAD-DEFLECTION RATE (Lb./In.).................	20.5
MAXIMUM SOLID HEIGHT (In.).....................	1.600
SPRING HELIX...................................	R.H.

STRESS RELIEVE PROGRAM

DESIGN # 3

SPRING INDEX = 7.0

WIRE SIZE (In.)................................	.050
OUTSIDE DIAMETER (In.).........................	.400 ± .005
TOTAL COILS....................................	27
TYPE OF ENDS...................................	Closed Ground
FREE HEIGHT, APPROX. (In.).....................	4.39
MEAN ASSEMBLED HEIGHT (In.)....................	2.721
LOAD AT ASSEMBLED HEIGHT (Lb.).................	14.0
MINIMUM OPERATING HEIGHT (In.).................	1.550
LOAD AT MINIMUM OPERATING HEIGHT (Lb.).........	23.8
LOAD-DEFLECTION RATE (Lb./In.).................	8.4
MAXIMUM SOLID HEIGHT (In.).....................	1.450
SPRING HELIX...................................	R.H.

STRESS RELIEVE PROGRAM

DESIGN # 4

SPRING INDEX = 9.0

WIRE SIZE (In.)..................................	.050
OUTSIDE DIAMETER (In.)...........................	.500 ± .005
TOTAL COILS......................................	20
TYPE OF ENDS.....................................	Closed Ground
FREE HEIGHT, APPROX. (In.).......................	4.59
MEAN ASSEMBLED HEIGHT (In.)......................	2.595
LOAD AT ASSEMBLED HEIGHT (Lb.)...................	10.9
MINIMUM OPERATING HEIGHT (In.)...................	1.200
LOAD AT MINIMUM OPERATING HEIGHT (Lb............	18.5
LOAD-DEFLECTION RATE (Lb./In.)...................	5.5
MAXIMUM SOLID HEIGHT (In.).......................	1.100
SPRING HELIX.....................................	R.H.

STRESS RELIEVE PROGRAM

DESIGN # 5

SPRING INDEX = 11.0

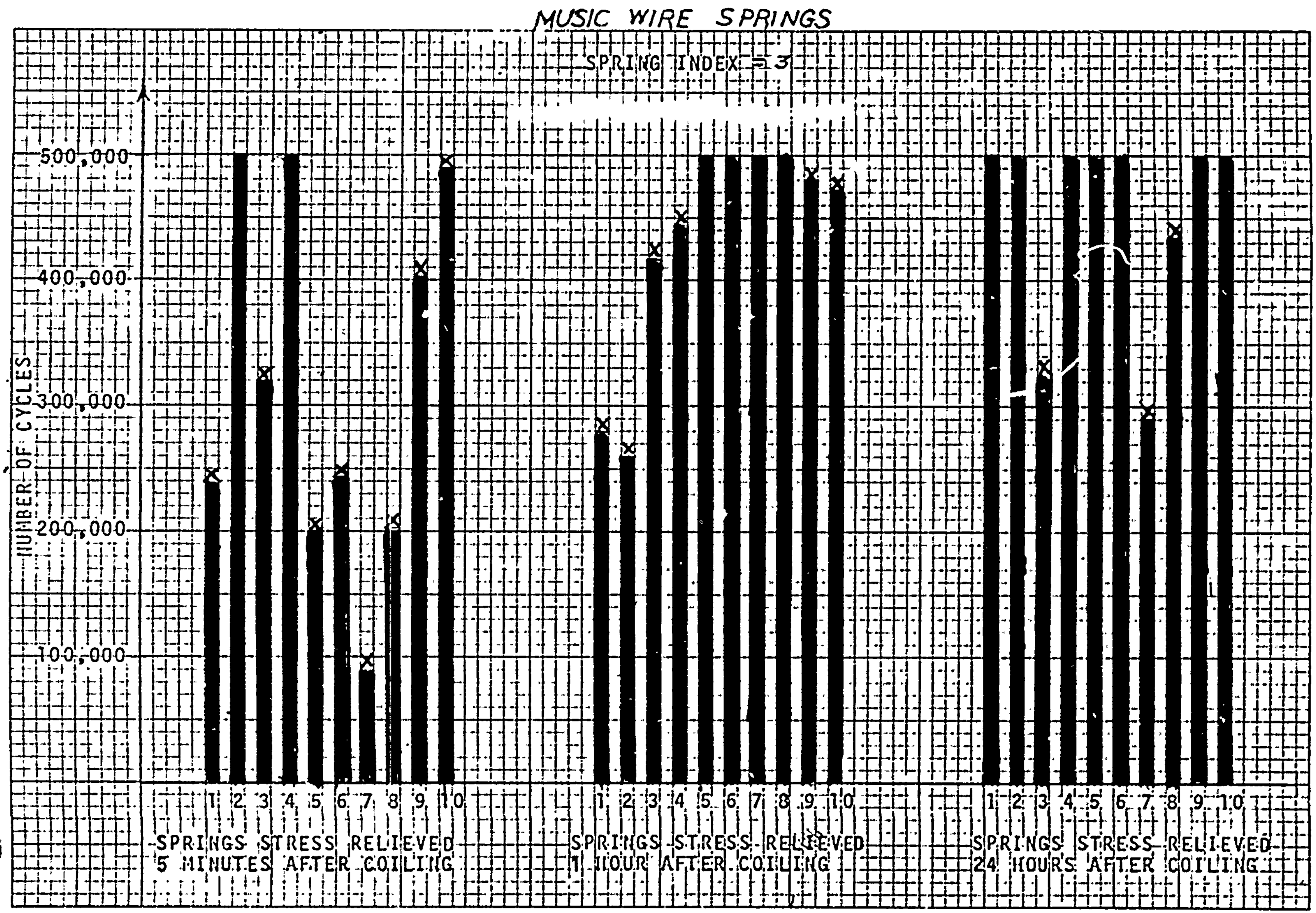
WIRE SIZE (In.)................................	.050
OUTSIDE DIAMETER (In.).........................	.600 ± .005
TOTAL COILS....................................	16
TYPE OF ENDS...................................	Closed Ground
FREE HEIGHT, APPROX. (In.).....................	4.93
MEAN ASSEMBLED HEIGHT (In.)....................	2.620
LOAD AT ASSEMBLED HEIGHT (Lb.).................	8.9
MINIMUM OPERATING HEIGHT (In.).................	1.000
LOAD AT MINIMUM OPERATING HEIGHT (Lb.).........	15.2
LOAD-DEFLECTION RATE (Lb./In.).................	3.9
MAXIMUM SOLID HEIGHT (In.).....................	.900
SPRING HELIX...................................	R.H.

STRESS RELIEVE PROGRAM

DESIGN # 6

SPRING INDEX = 13.0

WIRE SIZE (In.)................................	.050
OUTSIDE DIAMETER (In.)..........................	.700 ± .005
TOTAL COILS.....................................	14
TYPE OF ENDS....................................	Closed Ground
FREE HEIGHT, APPROX. (In.)......................	5.22
MEAN ASSEMBLED HEIGHT (In.).....................	2.677
LOAD AT ASSEMBLED HEIGHT (Lb.)..................	7.5
MINIMUM OPERATING HEIGHT (In.)..................	.900
LOAD AT MINIMUM OPERATING HEIGHT (Lb.)..........	12.8
LOAD-DEFLECTION RATE (Lb./In.)..................	3.0
MAXIMUM SOLID HEIGHT (In.)......................	.800
SPRING HELIX....................................	R.H.



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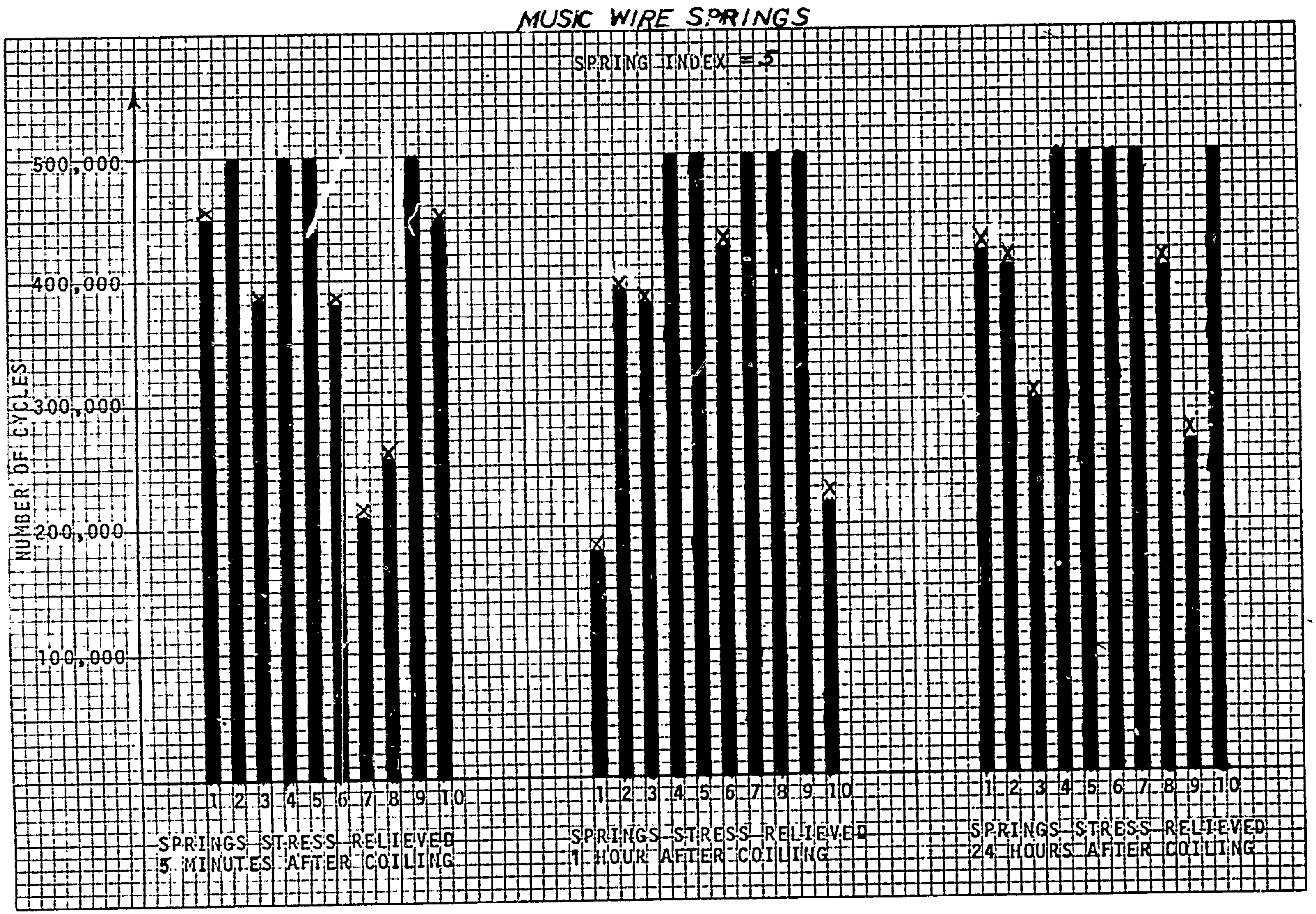

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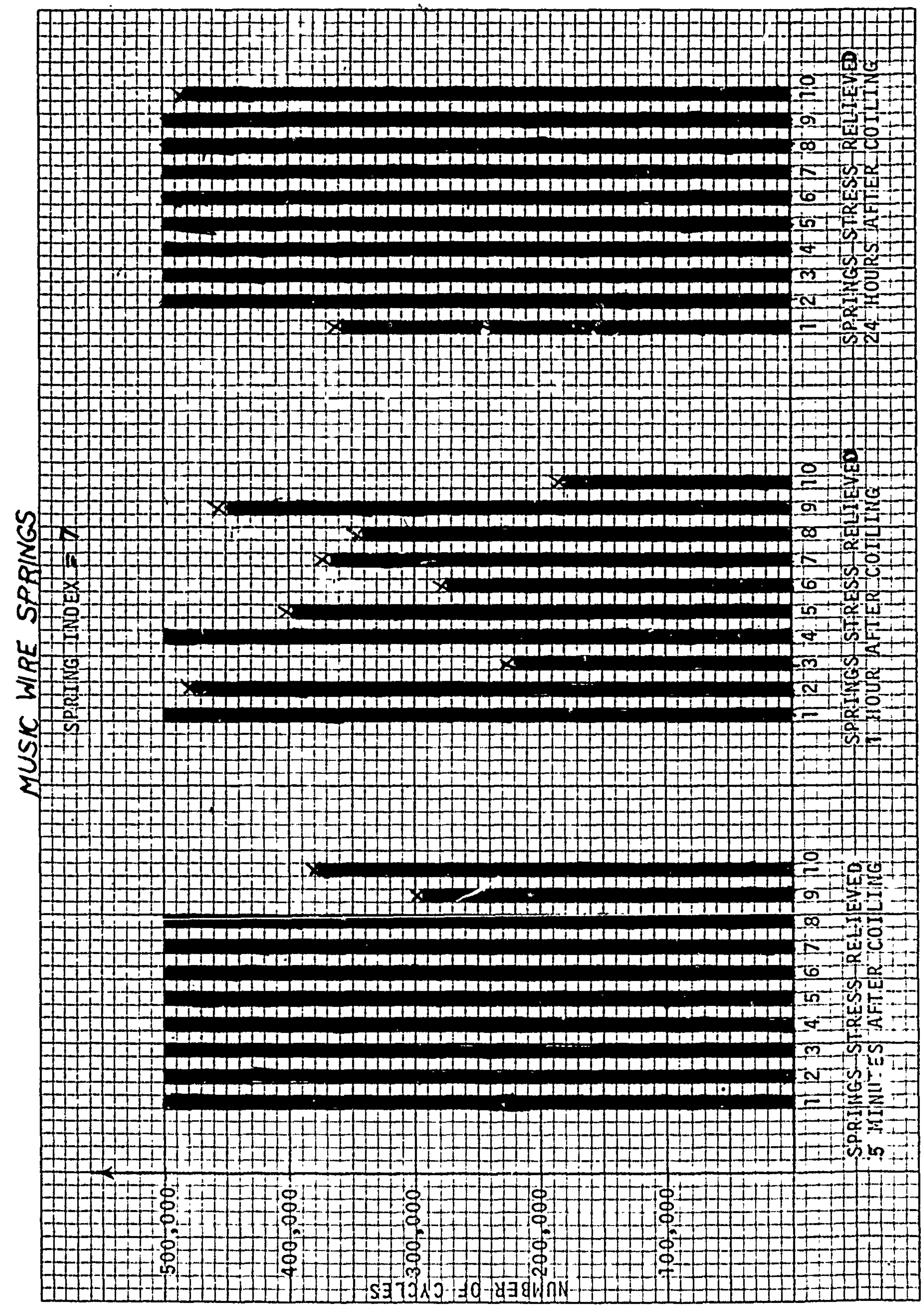

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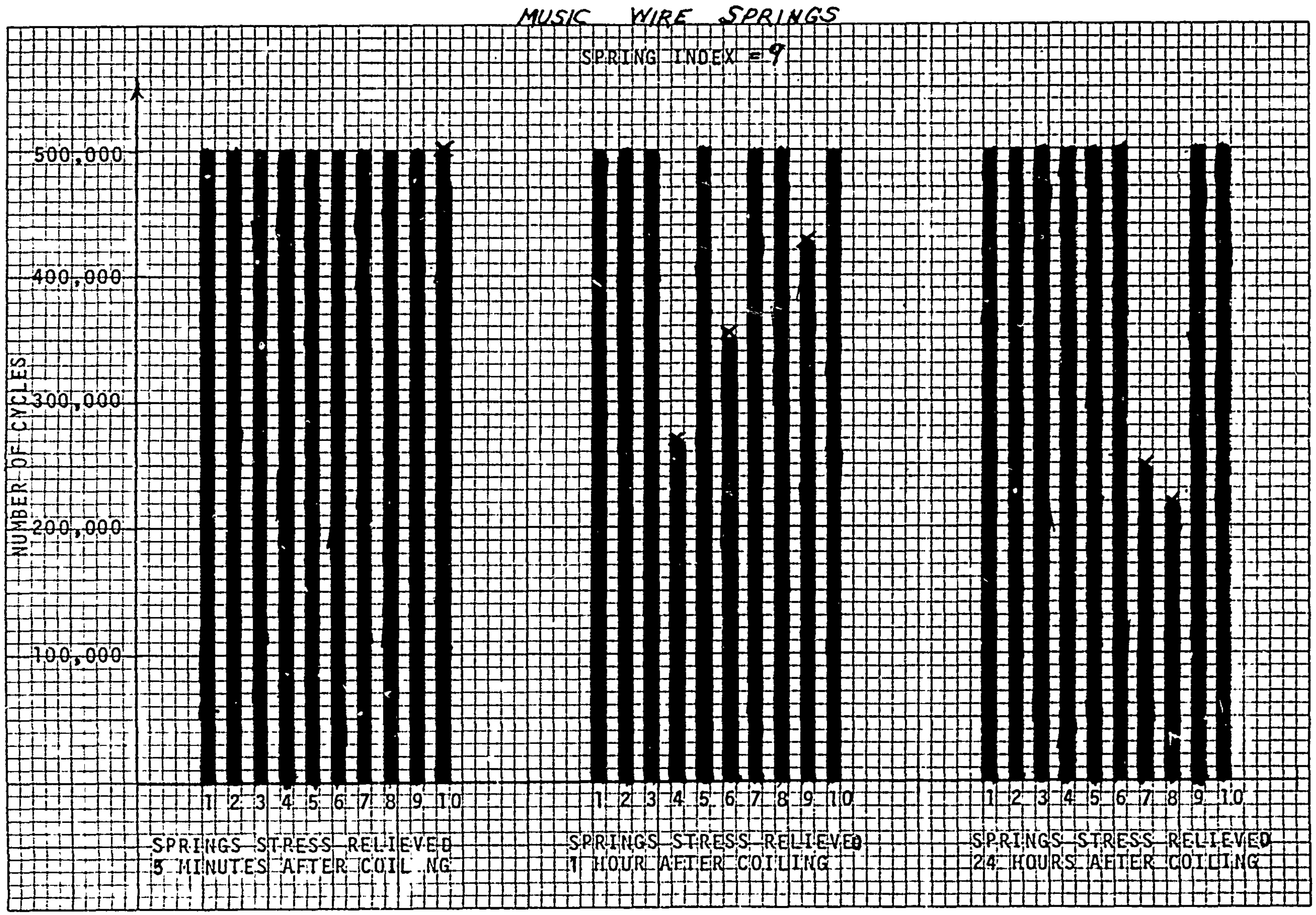

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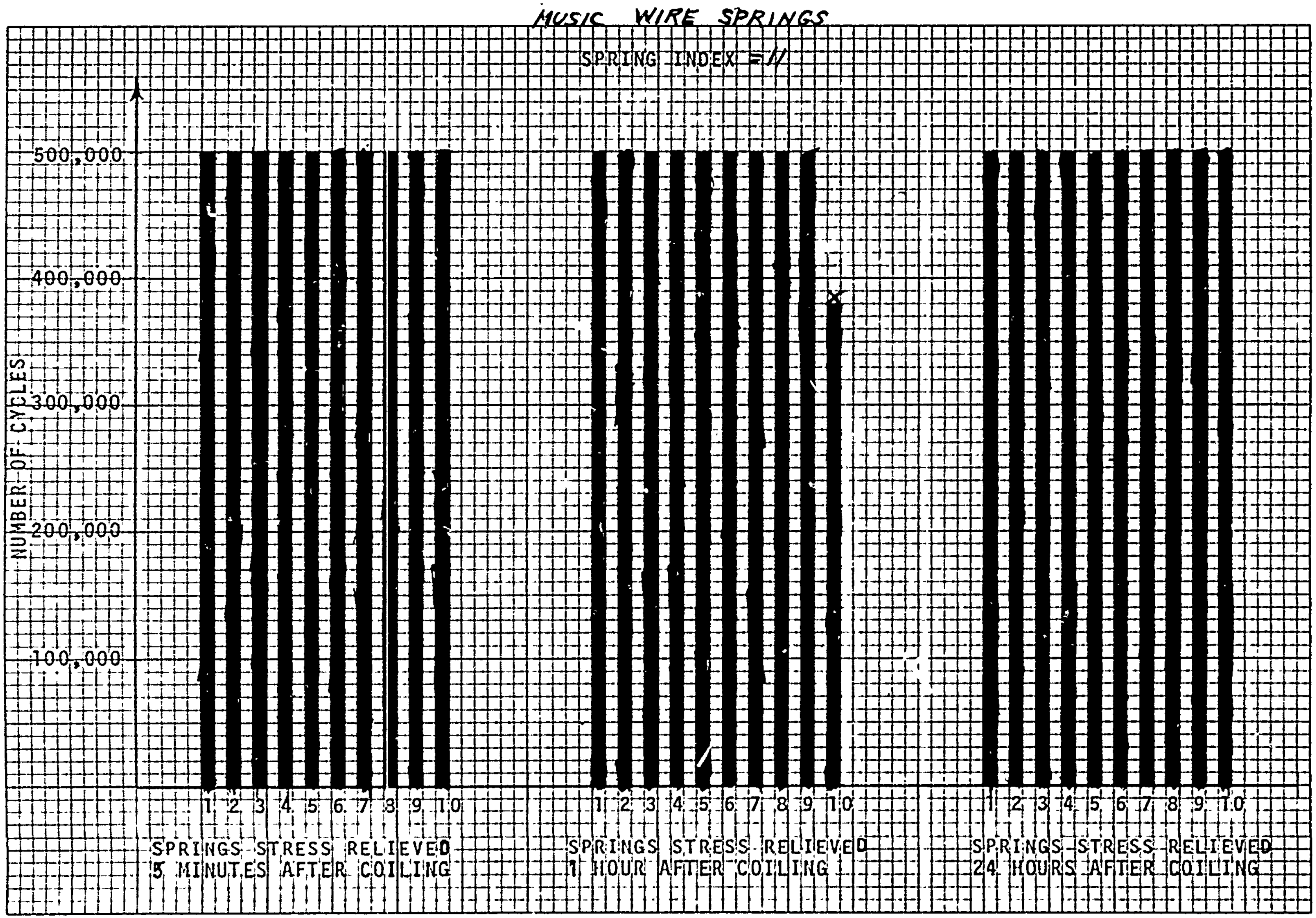

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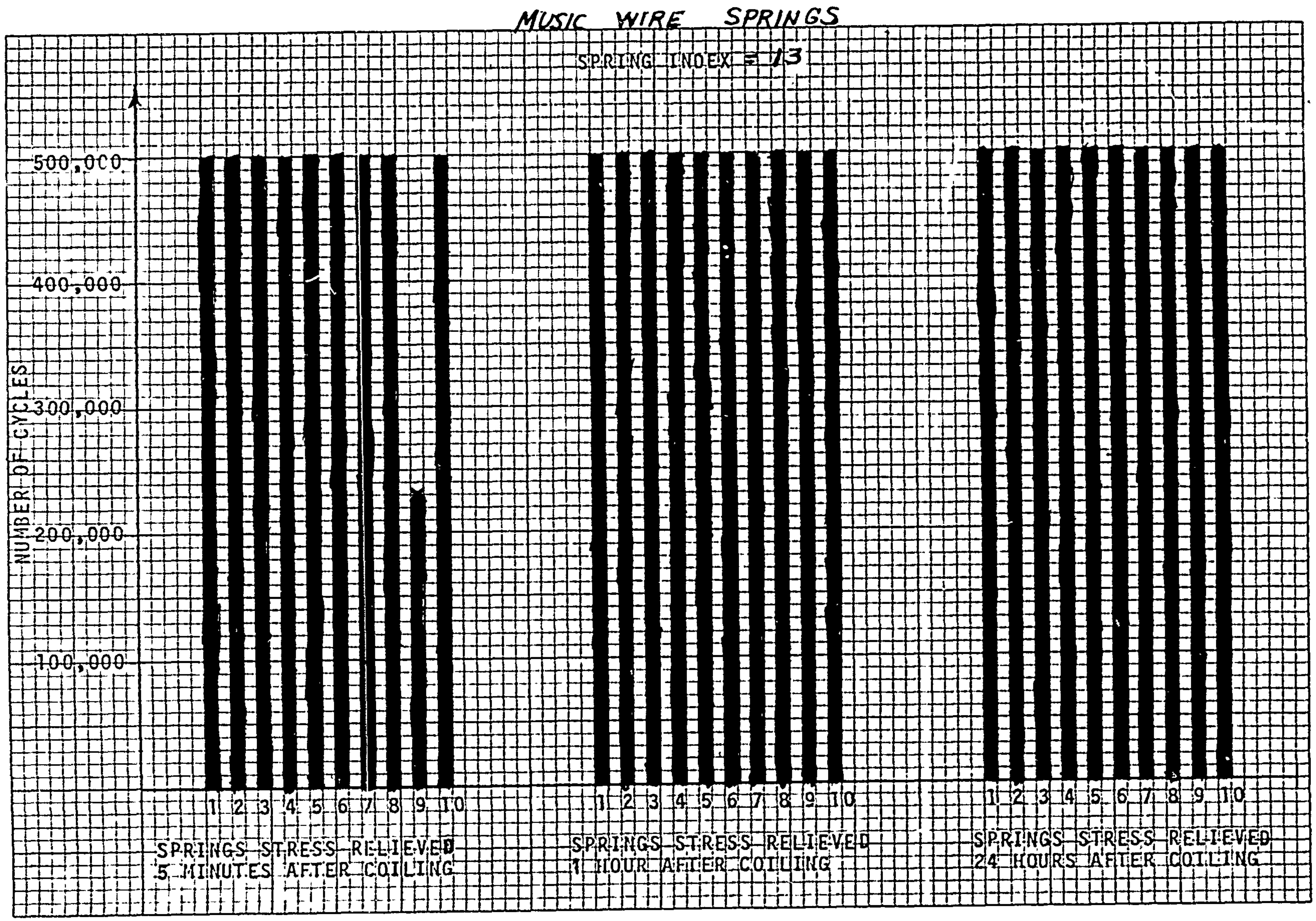

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STRESS RELIEVING PROCEDURES FOR HELICAL COMPRESSION SPRINGS

Prepared by: Henry P. Swieskowski

Technical Report No. R-TR-74-027

20 pages, Incl Figures & Tables

Various stress relieving procedures for the manufacture of cold wound helical compression springs were investigated to determine the effect that the time interval between the coiling and stress relieving operations has on spring life. Production springs with indexes of 3 to 13 were fabricated from various materials. The springs were stress relieved at varying times after the coiling operation. The effect of the time interval between the coiling and stress relieving operations was determined by visual observation for crack initiation and by laboratory endurance tests.

1. Stress Relieve
2. Manufacturing Methods
3. Cold Wound
4. Helical Springs
5. Endurance Tests

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