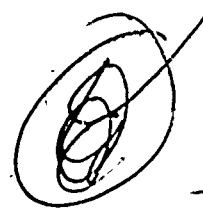


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STRESS RELIEVING PROCEDURES FOR HELICAL COMPRESSION SPRINGS

HENRY P. SWIESKOWSKI

MAY 1974

FINAL REPORT

RESEARCH DIRECTORATE

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-TR-74-027	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STRESS RELIEVING PROCEDURES FOR HELICAL COMPRESSION SPRINGS.		5. TYPE OF REPORT & PERIOD COVERED Final (Feb 72 - Dec 73)
7. AUTHOR(s) Henry P. Swieskowski		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Research Directorate, SARRI-LR GEN Thomas J. Rodman Laboratory Rock Island Arsenal, Rock Island IL 61201		8. CONTRACT OR GRANT NUMBER(s) 12-3
11. CONTROLLING OFFICE NAME AND ADDRESS CMDR, Rock Island Arsenal GEN Thomas J. Rodman Laboratory, SARRI-LR Rock Island, IL 61201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS 4497.06.6807
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE May 74
		13. NUMBER OF PAGES 28
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Final rept. Feb 72 - Dec 73,		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Stress Relieve Manufacturing Methods Cold Wound Helical Springs Endurance Tests		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) 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.



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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.

<u>MATERIAL</u>	<u>STRESS RELIEVING TREATMENT</u>
Music wire, QQ-W-470	Heat at 450°F $\pm$ 10° for 30 minutes
Chrome vanadium, QQ-W-412, Comp. 1	Heat at 700°F $\pm$ 25° for 30 minutes
Stainless steel, QQ-W-423, Comp. FS302	Heat at 600°F $\pm$ 15° for 30 minutes
Nickel chromium, QQ-W-390, Cond C	Heat at 900°F $\pm$ 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 microscope. 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 occurred 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 test¹, was made to statistically compare the sample means ($\bar{x}$). The test is based on the assumption that the data has a normal distribution with an unknown mean fatigue 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 (α) from the "student's" distribution tables with $n_1 + n_2 - 2$ degrees of freedom so that:

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

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 α then we reject the hypothesis $\mu_2 = \mu_1$ in favor of $\mu_2 > \mu_1$ with α level of confidence that $\bar{x}_2 > \bar{x}_1$.

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

$\bar{x}$ = mean life

S = variance

$$S^2 = \frac{1}{n} \sum_{i=1}^n x_i^2 - \bar{x}^2$$

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

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

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

$$n_1 = n_2 = 10$$

$$\mu_2 - \mu_1 = 0$$

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

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

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 $\bar{x}_2 > \bar{x}_1$. 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		
	5 Min	1 Hr	24 Hr	5 Min	1 Hr	24 Hr
Time between coiling and stress relieving						
(Cycles to breakage in thousands)	492 84 150 84 186 120 196 87 435 142 <u>1976</u>	500 115 443 151 99 262 225 195 93 97 <u>2180</u>	88 95 82 159 75 70 98 128 304 114 <u>1213</u>	73 110 85 98 188 98 74 66 81 72 <u>945</u>	82 86 217 81 118 80 76 121 147 204 <u>1212</u>	232 93 77 98 61 77 51 161 99 93 <u>1042</u>
Totals						
$\bar{x}$	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
t	Comparing 5 min with 1 hr			Comparing 5 min with 1 hr		
α	.307			1.303		
	.60			.85		
	Comparing 5 min with 24 hr			Comparing 5 min with 24 hr		
	1.502			.444		
	.90			.65		

STAINLESS STEEL

	n = 10 C = 9			n = 10 C = 11		
	5 Min	1 Hr	24 Hr	5 Min	1 Hr	24 Hr
Time between coiling and stress relieving						
(Cycles to breakage in thousands)	229 70 237 78 59 66 72 101 96 167 1175	194 249 75 86 85 114 186 145 98 153 1385	85 195 252 76 98 281 226 500 89 244 2046	500 77 73 291 89 91 134 159 455 84 1953	98 100 164 78 152 90 82 100 207 56 1127	62 178 72 101 108 67 107 159 94 500 1448
Totals						
$\bar{x}$	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
t	Comparing 5 min with 1 hr			Comparing 5 min with 1 hr		
α	.397			1.531		
	.65			.90		
	Comparing 5 min with 24 hr			Comparing 5 min with 24 hr		
	1.277			.758		
	.85			.75		

NICKEL CHROMIUM

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

NICKEL CHROMIUM

		n = 10 C = 7		
Time between coiling and stress relieving		5 Min	1 Hr	24 Hr
(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
	$\bar{x}$	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
		α		.95

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.

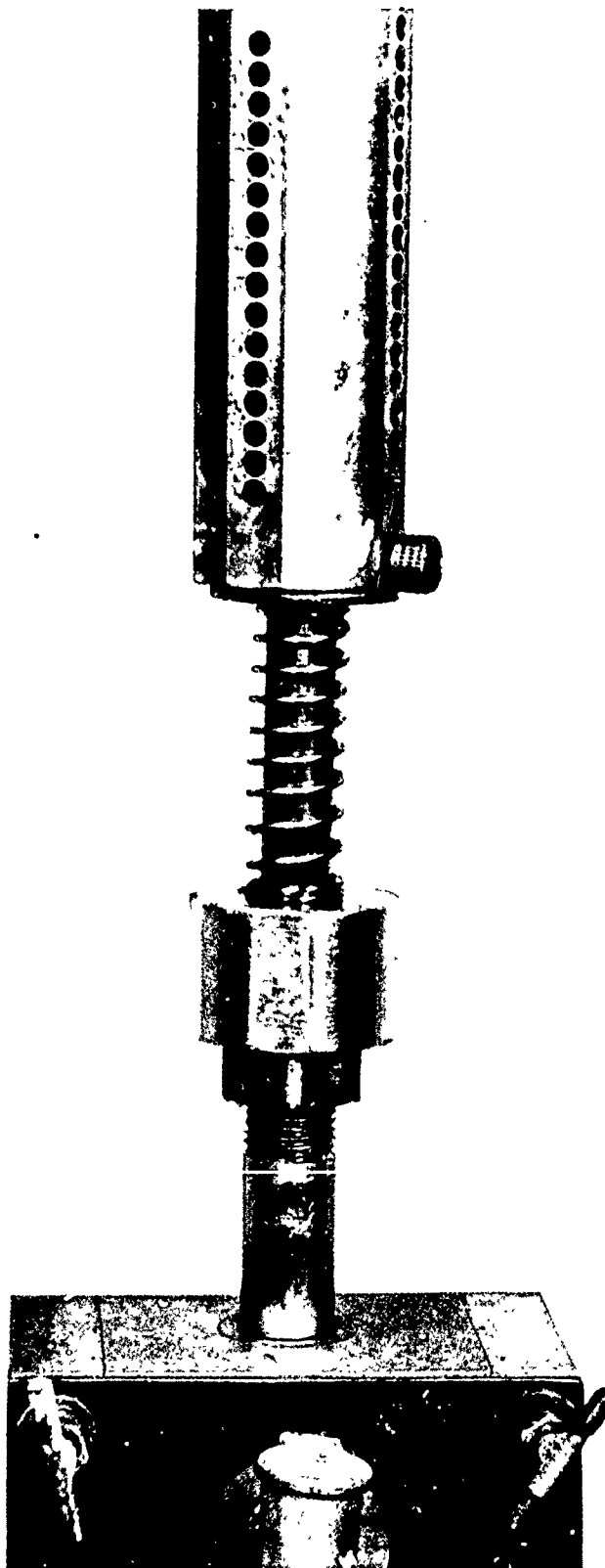
Another conclusion not directly related to the objective of the project is that music wire and chrome vanadium are superior materials to stainless steel and nickel chromium for spring applications where the operating stress levels are between 100,000 and 170,000 psi. This conclusion is based on the significantly 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

Photograph - Production Spring Installed on Endurance Tester
Specifications - Spring Design # 1
Specifications - Spring Design # 2
Specifications - Spring Design # 3
Specifications - Spring Design # 4
Specifications - Spring Design # 5
Specifications - Spring Design # 6
Graph - Music Wire - Spring Index = 3
Graph - Music Wire - Spring Index = 5
Graph - Music Wire - Spring Index = 7
Graph - Music Wire - Spring Index = 9
Graph - Music Wire - Spring Index = 11
Graph - Music Wire - Spring Index = 13



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 $\pm$.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 $\pm$.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 $\pm$.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 $\pm$.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

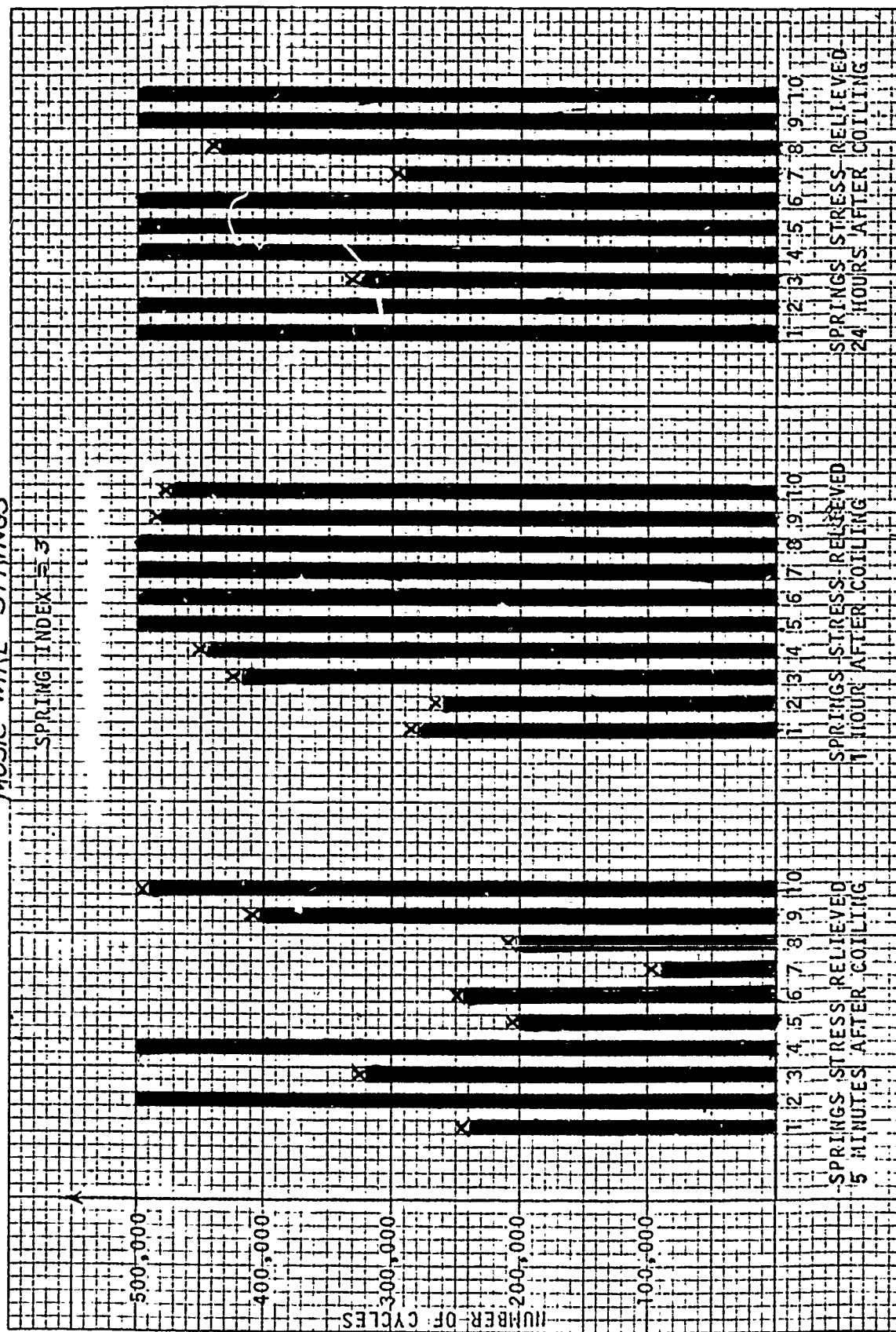
DESIGN # 6

SPRING INDEX = 13.0

WIRE SIZE (In.).....	.050
OUTSIDE DIAMETER (In.).....	.700 $\pm$.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.

MUSIC WIRE SPRINGS

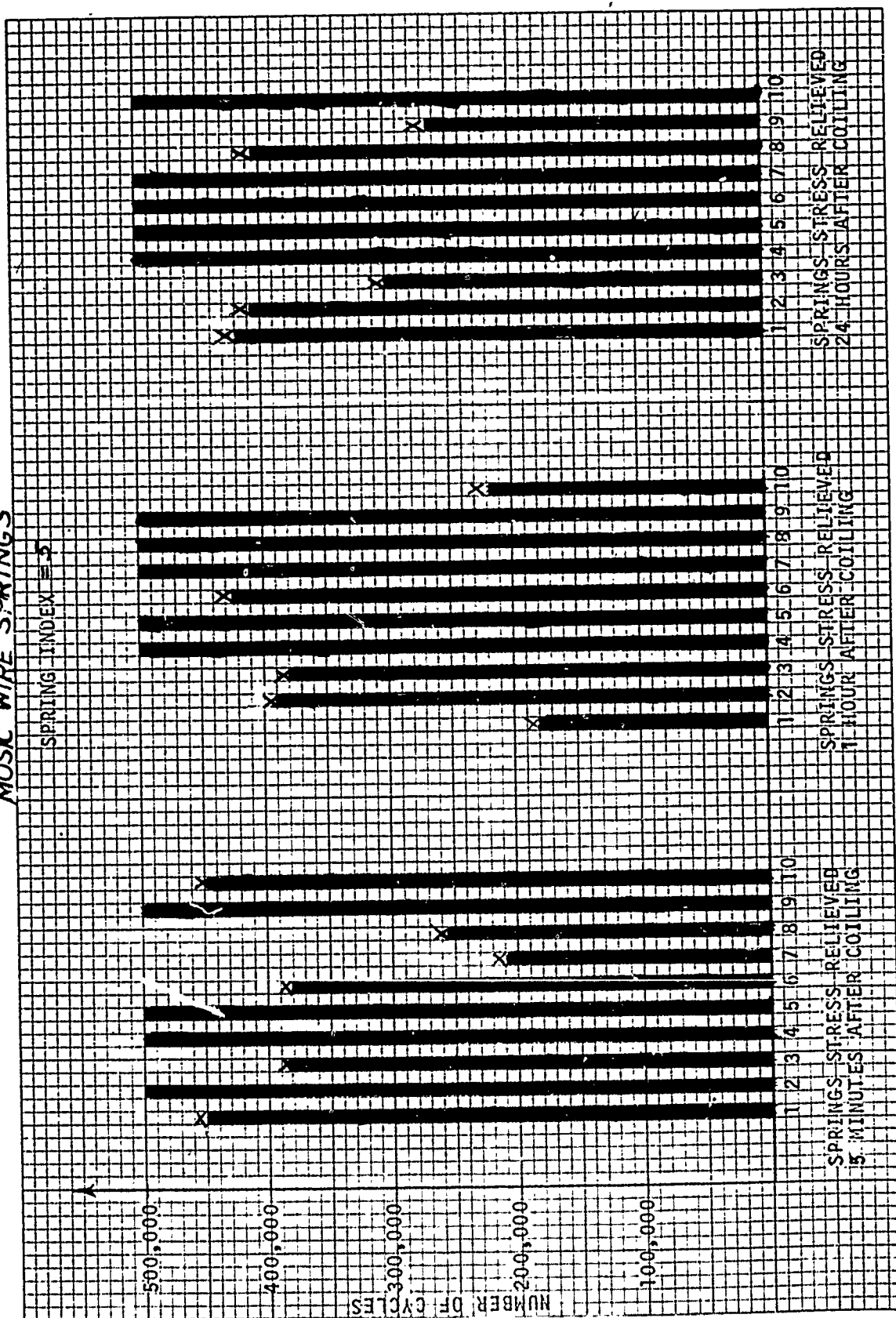
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x Denotes Spring Breakage

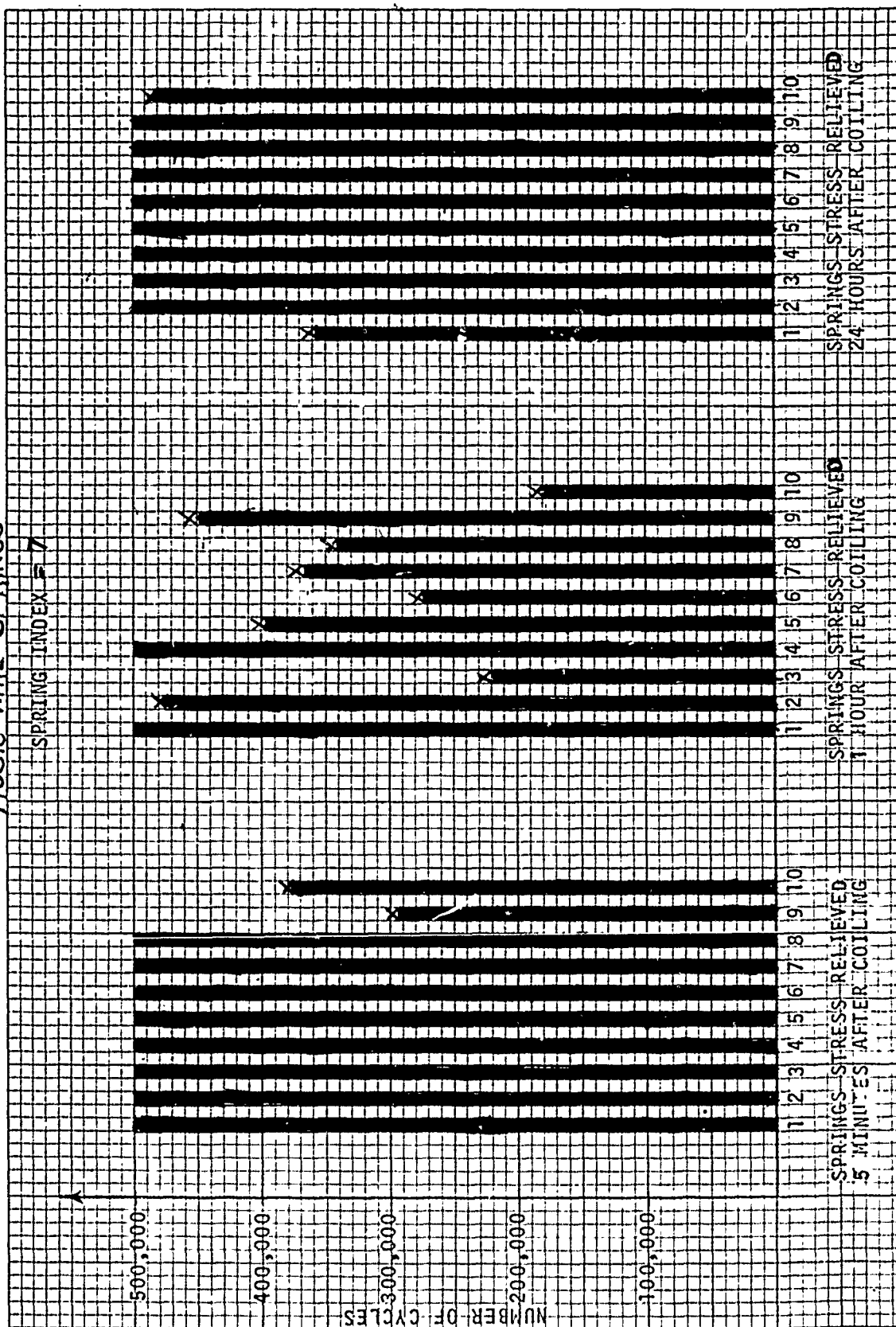
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SPRING INDEX = 5



X Denotes Spring Breakage

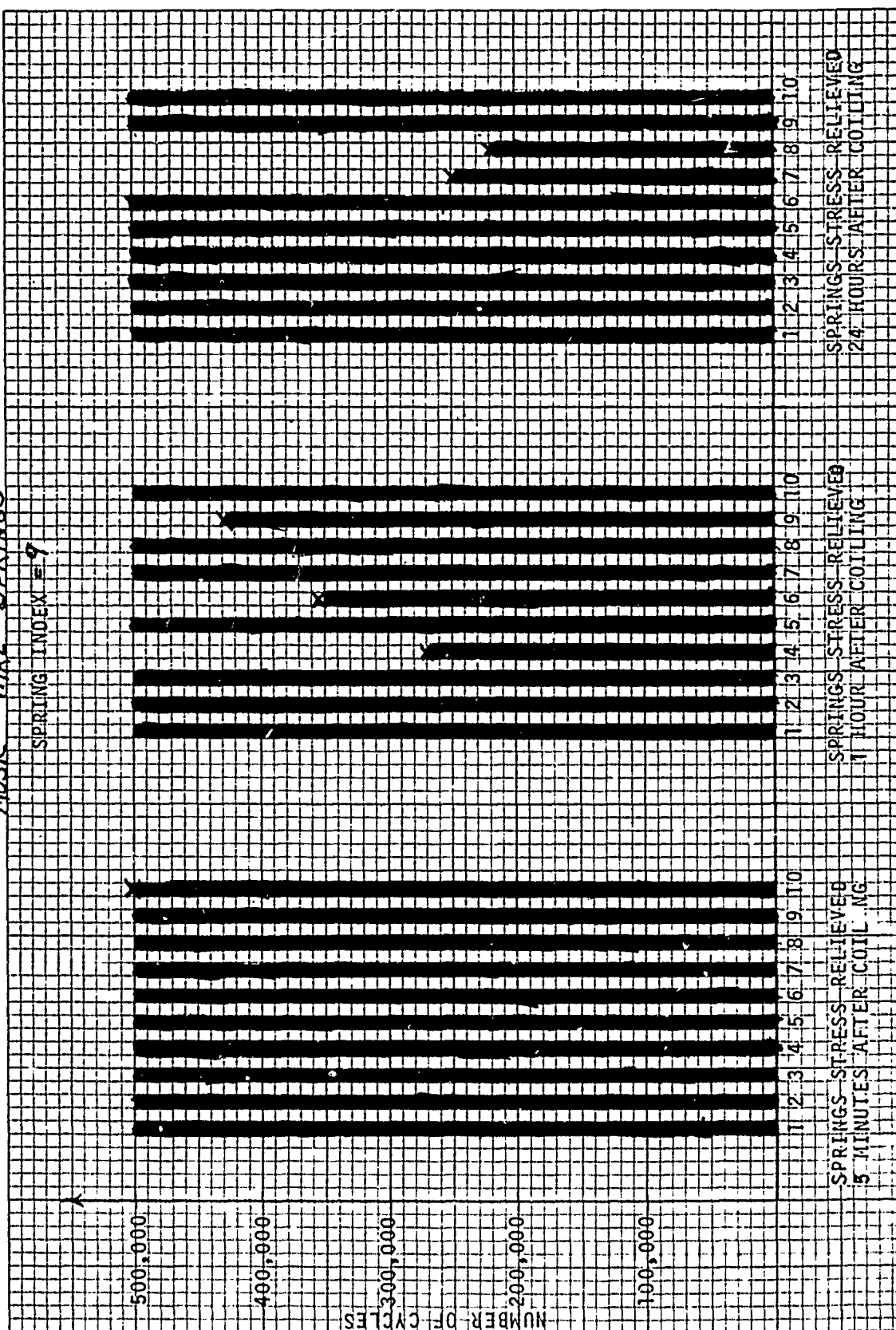
MUSIC WIRE SPRINGS



x Denotes Spring Breakage

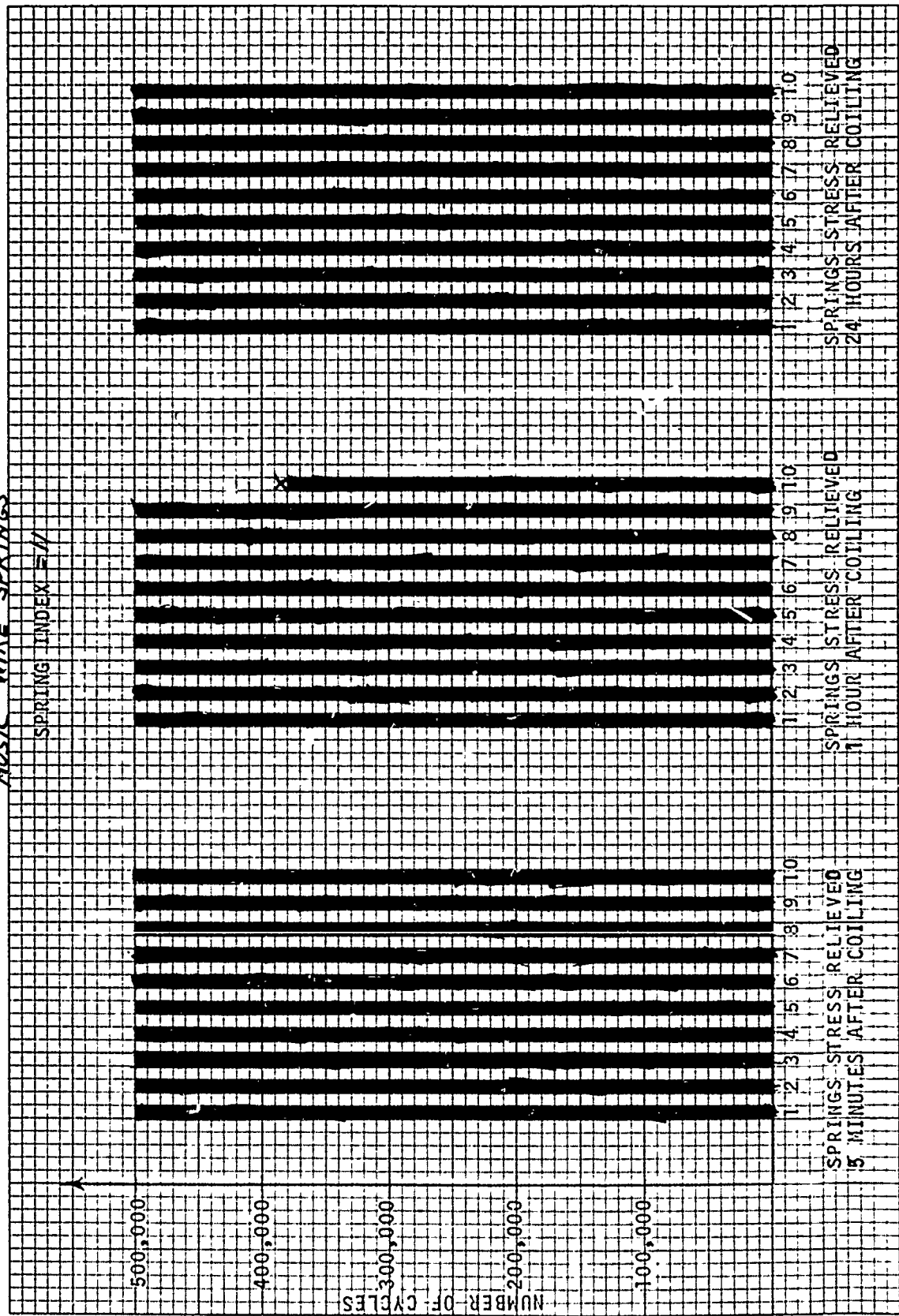
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SPRING INDEX = 9



x Denotes Spring Breakage

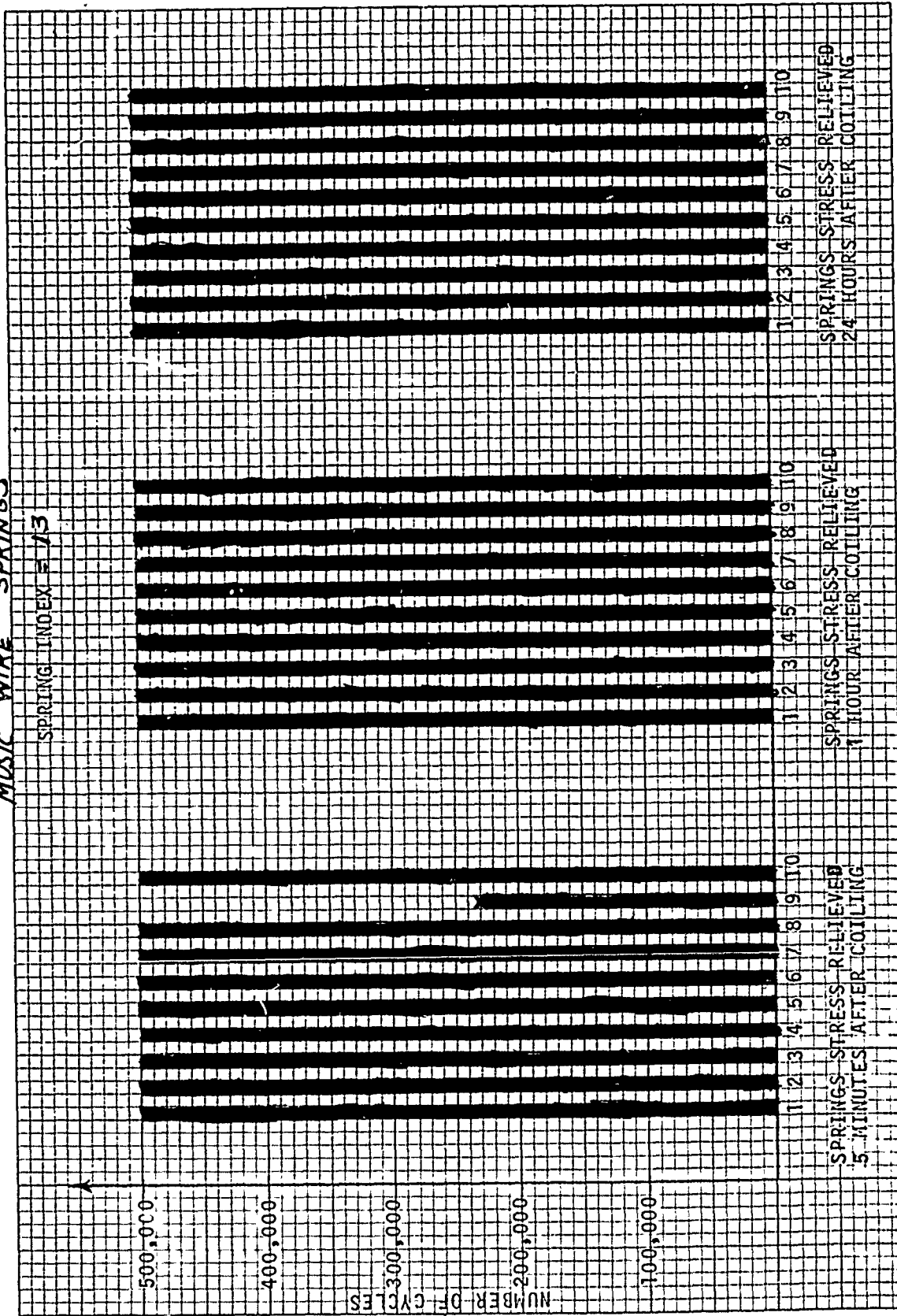
MUSIC WIRE SPRINGS



x Denotes Spring Breakage

MUSIC WIRE SPRINGS

SPRING INDEX = 13



x Denotes Spring Breakage

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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

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

I. Henry P. Swieskowski
II. Rock Island Arsenal
III. 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 and stress relieving operations was determined by visual observation for crack initiation and by laboratory endurance tests.

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