THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

A FURTHER STUDY OF THE EFFECTS OF WARM COILING USING ELECTRICAL RESISTANCE HEATING

by

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SUMMARY

This investigation was undertaken to verify and expand the findings of SRA Report No. 239, which dealt with the practical aspects of warm coiling.

A two point coiling machine was used and the wire heated by passing an electric current between the two coiling points.

The springs were coiled at 20°C (room temperature), 150°C, 175°C and 200°C. Tests were carried out on: their free length variation; wind up during low temperature heat treatment; reduction of solid stress during prestressing; relaxation at four stress levels; and fatigue life.

The results showed that heat treatment of the springs improves free length variability, wind up being reduced at the higher coiling temperatures but end coil variation becoming worse. Reduction in solid stress due to prestressing was not so great in the case of the warm coiled springs but their relaxation properties were poor compared with those of heat treated springs. Warm coiling and heat treating the spring did not appear to affect the fatigue properties of the springs.

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CONTENTS

CONTENTS (Cont.)

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1. INTRODUCTION

The previous work[1] carried out on warm coiling showed that the free length variation of the prestressed, warm coiled springs is reduced and the elastic properties of the material improved, so that in some cases normal low temperature heat treatment after coiling may not be required.

In this investigation a larger wire size was used and tests were carried out to evaluate the wind up, relaxation and fatigue performance of the coiled springs.

As in the previous work, the wire was heated by passing an electric current down one coiling point through the wire being coiled to the second point, thus completing the electric circuit. Different coiling temperatures could be obtained by adjusting the current.

The springs, which were of one design, were coiled at different temperatures and measured for free length variation before and after grinding, heat treatment and prestressing.

2. MATERIAL AND SPRING DESIGN

A patented, cold drawn spring steel wire to BS 1408C Range 3 was used and springs produced to the design shown below.

Wire diameter	2.65 mm (0.104 in)
Mean coil diameter	21.7 mm (0.854 in)
Total No. of coils	5.5
Active coils	3.5
Spring index	8.2

Free length	48.25 mm (1.90 in)
Free length after grinding	45.72 mm (1.80 in)
Free length tolerance (BS 1726)	$\pm$ 0.76 mm (0.030 in)
Ends closed and ground	

3. EXPERIMENTAL PROCEDURE

3.1 Equipment

The coiling machine, a Wafios UFM50 belonging to a Member Company of the Association was used for the experimental work. It was modified by fitting a micro-switch and a pair of adjustable cams, so that the electric current flowed only when the wire was being coiled and not when the machine was in the cut-off period.

Special coiling points were made in such a way that their tips were insulated from the main body of the tool and hence the machine. A 10KVA transformer was used for the power supply, the current being controlled by a Variac transformer on the mains side of the power transformer (Fig. 1). An ammeter and voltmeter were used to measure the power passing through the spring wire.

The temperatures of the springs were measured using heat sensitive crayons, which change colour at a predetermined rate when the appropriate temperature had been reached.

3.2 Coiling

The machine was set initially to produce springs of the correct dimension without any current passing through. It was found that when the power was switched on, the springs were coiled to a longer length and a smaller diameter. This was corrected at each temperature by suitable adjustment of the machine.

As a first trial, approximately 1500 springs were produced to determine the required adjustment to the machine and power supply.

A new set of coiling points was fitted and the machine was re-set as for ordinary coiling. Approximately 200 springs were produced to allow the tooling to settle. 1000 springs were then coiled, the last 10 of each 100 being collected for measurement and other tests.

For warm coiling, a new set of coiling points was used so that a comparison could be made of the wear occurring with warm and ordinary coiling. The machine was re-set and the springs collected after the first "settling in" run of 200 springs.

A check on the coiling temperature was taken before each sample was collected and necessary adjustments to the power were made if required. Springs were warm coiled at temperatures of 150°C, 175°C and 200°C being the maximum the equipment could sustain. A low coiling speed, 20 per minute, was selected to maximise the the temperature which could be achieved for a given power input. The run of 200°C had to be stopped after 800 springs had been coiled because of the excessive heat generated. The power requirement was a maximum of 0.65 kW whilst coiling at 200°C.

3.3 Test Procedures

Each spring collected was labelled and the free length measured in the as-coiled condition. The springs were then ground to a nominal length of 1.8in and their free lengths re-measured. The angular position was measured of the end coils of forty springs from each batch, which were given a low temperature heat treatment at 250°C for ½ an hour. The angular position of the end coils was re-measured and the wind up per coil calculated. The wind up can be used as a measure of the effectiveness of the heat treatment due to warm coiling. After heat treatment the free length of the springs was re-measured.

Twelve non-heat treated springs from each of the warm coiled samples and twelve heat treated springs from the cold coiled samples were prestressed and the loss in length of each was measured.

The load relaxation properties of the warm coiled springs were determined at stress levels of 300 N/mm^2, 500 N/mm^2 and 700 N/mm^2 by compressing them down on stainless steel bolts to the required stress levels, which were found by load testing. The springs were held at these stress levels for 72 hours at a temperature of 125°C. The load of each spring was then re-measured at the clamped length, so that the load relaxation of each spring could be found.

Fatigue testing was carried out on springs from each of the four non-heat treated samples, together with cold coiled springs that had been given a low temperature heat treatment, at stress levels of 700 N/mm^2, 800 N/mm^2 and 920 N/mm^2, with an initial stress of 100 N/mm^2. For both the relaxation and the fatigue tests, each spring was prestressed five times before testing.

4. RESULTS

4.1 Free Length Measurement

The free length of both the as-coiled and as-ground springs was measured and used to calculate the standard deviation of the samples.

The standard deviation was also calculated from a sample of pre-stressed springs with and without heat treatment.

The results of these measurements are shown in Table I below:

TABLE I THE EFFECT OF WARM COILING ON FREE LENGTH VARIATION

Coiling Temperature	20°C	150°C	175°C	200°C
Total Sample	(mm)	(mm)	(mm)	(mm)
As-coiled	0.307	0.257	0.39	0.496
As-ground	0.176	0.133	0.167	0.231
Sample I				
After prestressing	0.277	0.197	0.568	0.472
Sample II				
After LTHT	0.182	0.253	0.259	0.196
After LTHT + prestressing	0.108	0.195	0.181	0.035

4.2 Wind-Up

Wind-up of the springs after a stress relieving treatment of 250°C for half an hour was measured, using 40 springs from each batch of warm coiled springs.

The wind-up is defined as: $\frac{\text{No. degrees wind-up}}{\text{Total no. of turns}}$

The average of the four batches is shown in Table II:

TABLE II THE EFFECT OF WARM COILING ON WIND UP AFTER A LOW TEMPERATURE HEAT TREATMENT

Coiling Temperature	20°C	150°C	175°C	200°C
Wind-up/turn	3.63	3.18	2.87	2.72

4.3 Load Testing and Prestressing

Samples of non-prestressed springs from each of the different batches were load tested from free length to solid, in steps of 0.5 mm, to obtain an accurate load/deflection curve.* This enabled the rate and elastic limits of the springs to be determined; together with the theoretical solid stress of the spring before prestressing, using the equation,

$$q\ \text{solid} = S.(L_o - L_c).\ \frac{8.D.K.}{\pi d^3}$$

where q solid = Solid stress (N/mm^2)
S = Rate (N/mm)
L_o = Free length (mm)
L_c = Solid length (mm)
D = Mean coil diameter (mm)
d = Wire diameter (mm)
K = Sopwith correction factor

The springs were then prestressed to solid until stable, which required five operations. From the free length of the prestressed springs, the solid stress could again be calculated.

Samples of the cold coiled springs were given a low temperature heat treatment of 250°C for half an hour, and the same procedure was repeated on these springs.

Table III shows the test results in terms of solid stress and elastic limit.

TABLE III THE EFFECT OF COILING TEMPERATURE ON THE ELASTIC LIMIT AND SOLID STRESS OF THE SPRINGS

Coiling Temperature	20°C	150°C	175°C	200°C
Elastic limit (N/mm^2)				
As coiled	405	590	685	685
After LTHT	1150	-	-	-
Solid stress (N/mm^2)				
As coiled	1330	1370	1375	1380
As coiled after prestressing	1020	1085	1170	1145
After LTHT and prestressing	1250	-	-	-

4.4 Stress/Temperature Relaxation Test

The percentage relaxation was calculated at the four stress levels levels of 900, 700, 500, 300 N/mm^2; the results are given in Table IV.

The relaxation is defined as follows:

Percentage Relaxation =

$$\frac{\text{Load at length } x_1 - \text{Load at } x_1 \text{ after 72 hours}}{\text{Load at length } x_1} \times \frac{100}{1}\ \%$$

where x_1 is the compressed length of the spring at which the required stress level was attained.

TABLE IV THE RELAXATION BEHAVIOUR OF WARM AND COLD COILED SPRINGS

	% Relaxation of Load after 72h at 125°C				
Temperature	20°C	150°C	175°C	200°C	250°C (LTHT)
Stress level					
900 N/mm^2	35.9	34.3	30.8	34.5	14.5
700 N/mm^2	35.0	32.2	27.4	30.7	4.8
500 N/mm^2	32.5	29.5	23.8	25.5	4.8
300 N/mm^2	32.3	29.6	24.6	29.0	4.1

4.5 Fatigue Testing

Eight springs of each type were used for fatigue testing at each of these stress ranges: 100-700 N/mm^2, 100-800 N/mm^2 and 100-920 N/mm^2.

The cycles to failure of each spring can be seen in Figs. 4 - 6, the 250°C points being for springs coiled at 20°C and stress relieved at this temperature.

Additional fatigue tests were carried out at the middle stress range to measure any dynamic relaxation that occurred prior to failure. In this case, the springs were removed after 10^4, 5×10^4 and 10^5 cycles and were load tested again at the minimum compressed length. The load on all batches was found to vary less than 1% through the testing time.

4.6 Mechanical Properties of Wire

The tensile and torsional properties of the wire were determined in the 'as-received' condition and after a heat treatment of 250°C for half an hour. In addition, samples of wire were heated in a similar manner to that used for the springs during warm coiling and the mechanical properties of these were also determined. The results of these tests are shown in Table V.

TABLE V THE TENSILE AND TORSIONAL PROPERTIES OF THE WIRE AFTER RESISTANCE HEATING

Wire Condition	As-received	150°C warm coiled	175°C warm coiled	200°C warm coiled	250°C/½h stress relieved
Tensile properties (N/mm^2)					
0.1% Proof stress	1450	1550	1650	1750	1850
0.2% Proof stress	1600	1750	1800	1900	1900
Tensile strength	1950	1975	1950	2025	2000
Torsional properties (N/mm^2)					
Modulus of rigidity	76 000	78 500	79 700	78 500	81 000
0.1% Proof stress	905	975	1025	1025	1200
0.2% Proof stress	1000	1050	1125	1150	1275

5. DISCUSSION

The results in Table I show the effect of coiling, grinding, prestressing and low temperature heat treatment on the standard deviation of the free length. The free length tolerance, according to BS 1726, for this design of spring is $\pm$ 0.97 mm and it can be seen that the $\pm$ 2δ values for all the batches of as-coiled springs fell within this tolerance.

The effect of grinding the springs was to reduce the free length variability.

Samples I and II show the difference between prestressing with and without stress relieving treatment. In the former case (Sample I), variation in free length increased after prestressing in all batches, whilst after stress relieving the variation was reduced. This can be attributed to the variation occurring in the elastic limit of the warm coiled springs.

In general, the higher the coiling temperature, the worse the coiling tolerances; the general accuracy, however, is a reflection of the machine used.

The wind up results given in Table 2 show that the higher the coiling temperature, the lower the wind-up that occurred. This suggests that the higher coiling temperatures do have a stress relieving effect on the wire but are not sufficient to be fully effective.

The results showing the effect of the prestressing, given in Table 3 show that the increase in coiling temperature does have a beneficial effect in elevating the elastic properties of the metal.

The results for relaxation behaviour shown in Table 4 demonstrate that, even at the lowest stress levels, the relaxation of the warm coiled springs was about 26%, which is very poor compared with the performance of the heat treated springs. Thus it can be seen that warm coiled springs have a very poor relaxation performance at 125°C.

The fatigue tests carried out on the springs showed that the heat treatment and warm coiling have very little effect on the fatigue life of the springs, as can be seen in Figs. 2 - 4. At the two higher stress levels of 920 N/mm^2 and 800 N/mm^2, the scatter in the data was quite small and the mean lives of the batches were about 1.2×10^5 cycles and 2.5×10^5 cycles respectively. At the lowest stress, 700 N/mm^2, however, the scatter was much greater for all batches. Thus it would appear that the warm coiling has no detrimental effect on the fatigue life of the springs. It is also interesting to note that the normal stress relieving treatment after coiling does not significantly affect the fatigue performance.

In general the results tend to suggest that investigation of a much higher coiling temperature would be worthwhile.

Coiling point wear was not as severe as expected in the actual groove of the point but the rubbing of the formed coils on the outside of the first coiling point, along with small amounts of arcing, eroded the metal wall badly to such an extent that the groove wall was in danger of cracking away. The arcing that occurred aided the bedding-in of the points by wearing high spots away quickly.

6. CONCLUSIONS

1. The free length tolerances obtained with warm coiled springs were slightly worse than those for conventionally coiled springs, but were still within the limits specificed in BS 1726.

2. The fatigue properties of the springs were the same as those obtained using cold coiled springs.

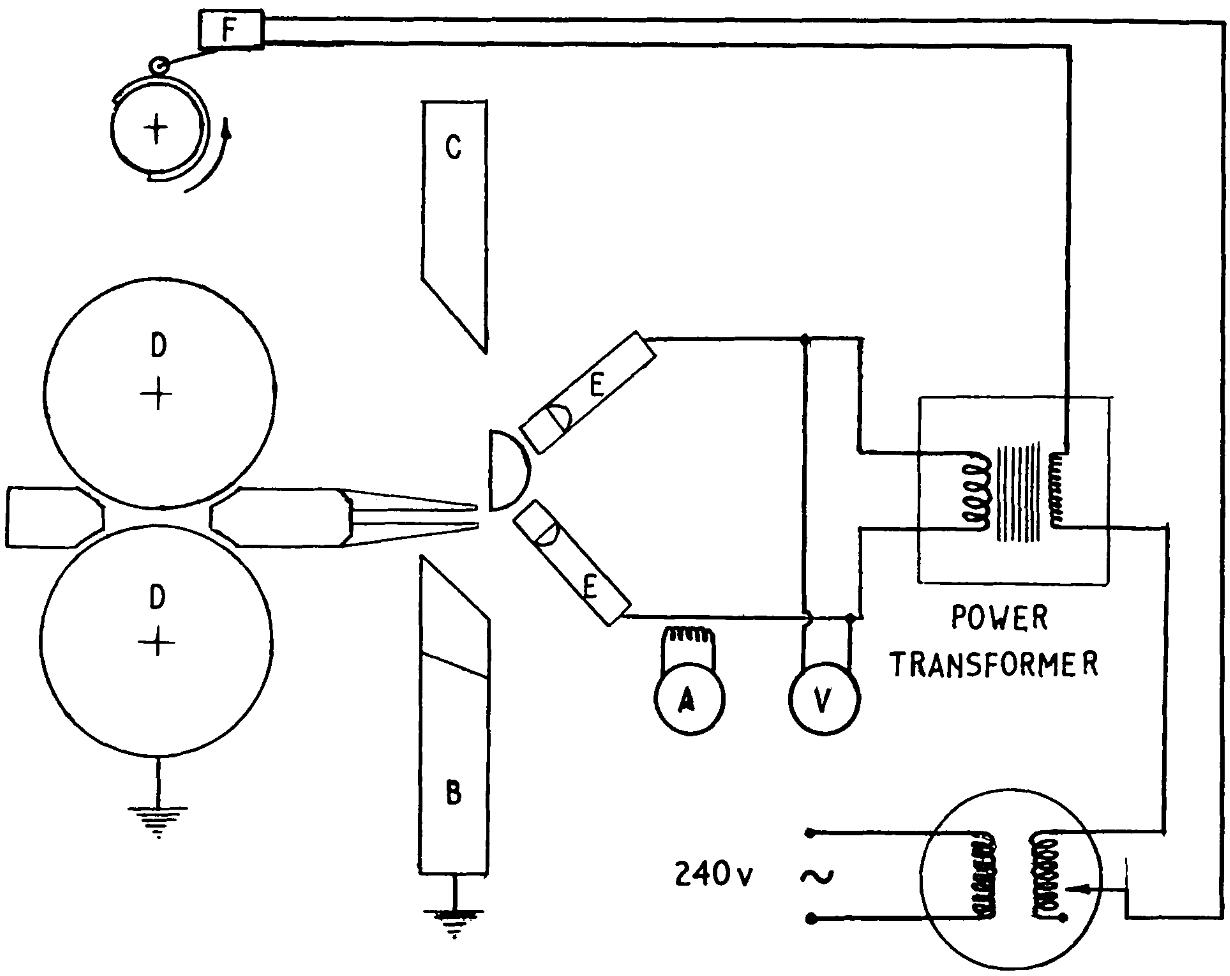
3. Load relaxation performance of the warm coiled springs at the elevated temperature of 125°C was very poor.

4. The reduction in solid stress due to prestressing of warm coiled springs was approximately half way between that of normally coiled springs in the Non-LTHT and LTHT conditions.

5. Wind up of the coils was approximately 25% less than the wind up of the normally coiled springs during LTHT.

7. REFERENCE

1. Southward, M.R., An investigation into the effect of warm coiling using electrical resistance heating. SRA Report No. 239.



A Ammeter
B Pitch Tool
C Cut Off Tool
D Drive Rolls
E Coiling Points
F Cam Operated Micro Switch
V Voltmeter

Fig.1 CIRCUIT DIAGRAM

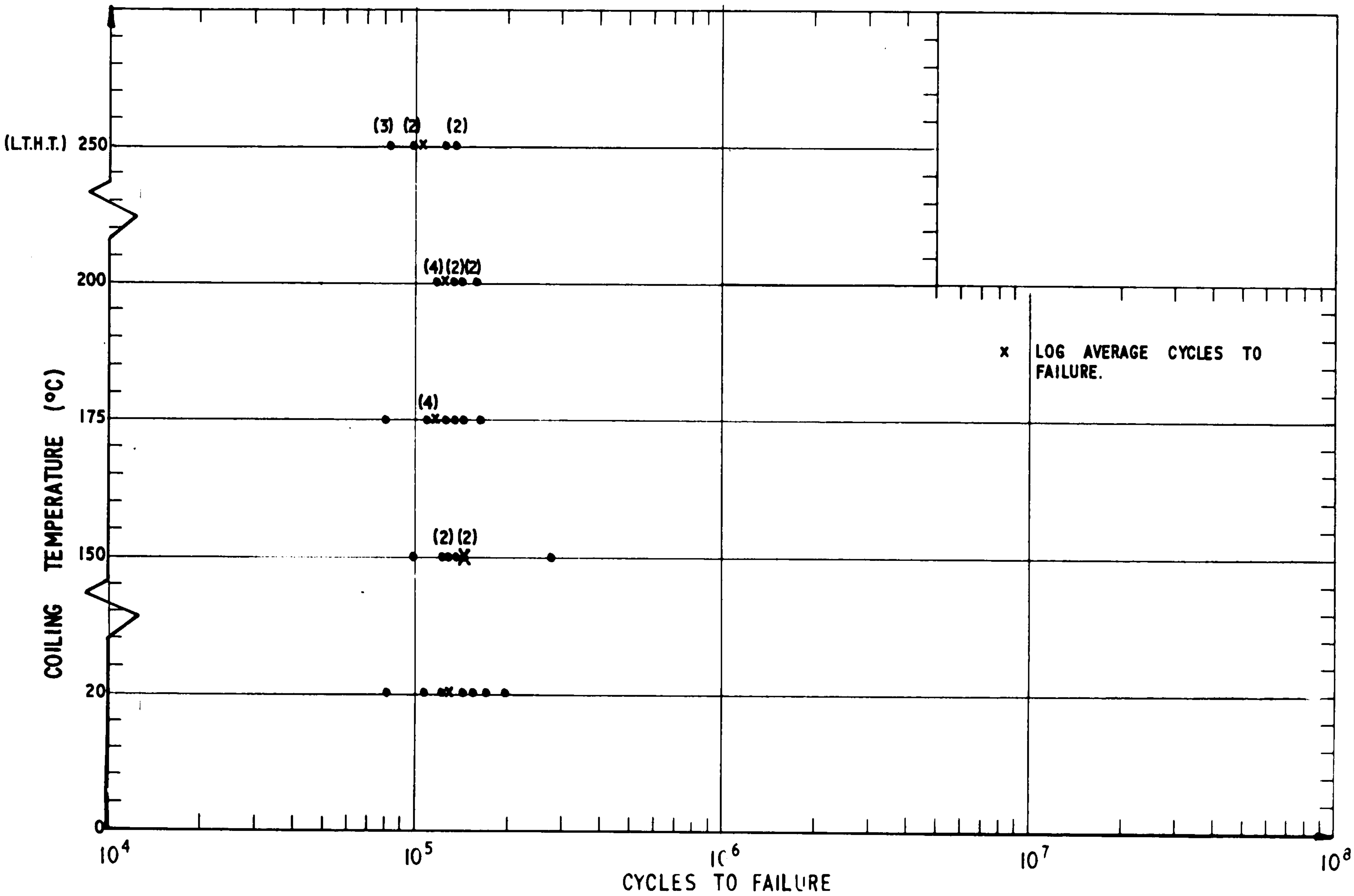


FIG. 2 TEMPERATURE v No. CYCLES TO FAILURE — STRESS RANGE 100 - 920 N/mm^2

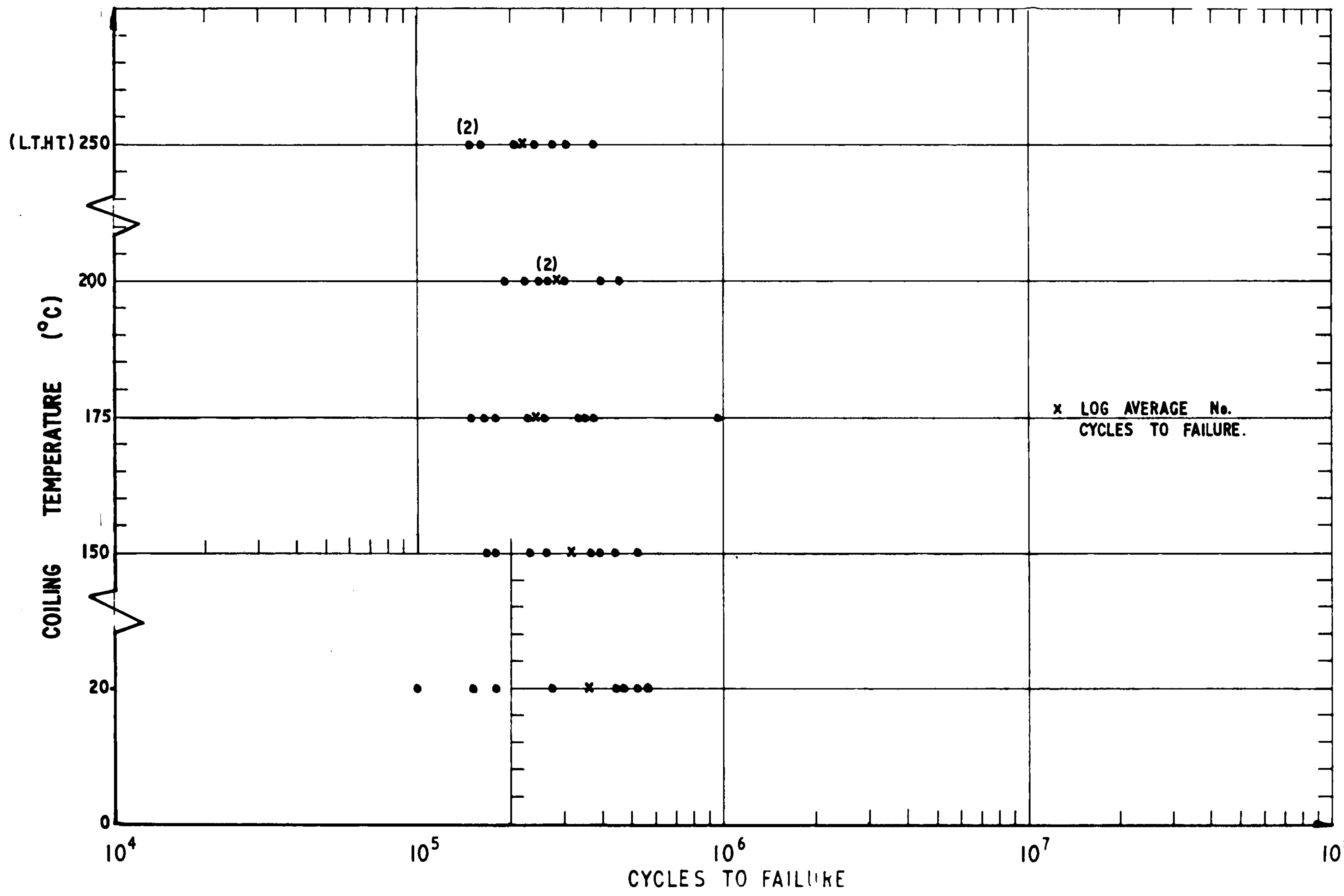


FIG. 3 TEMPERATURE v No. CYCLES TO FAILURE – STRESS RANGE 100 - 800 N/mm²

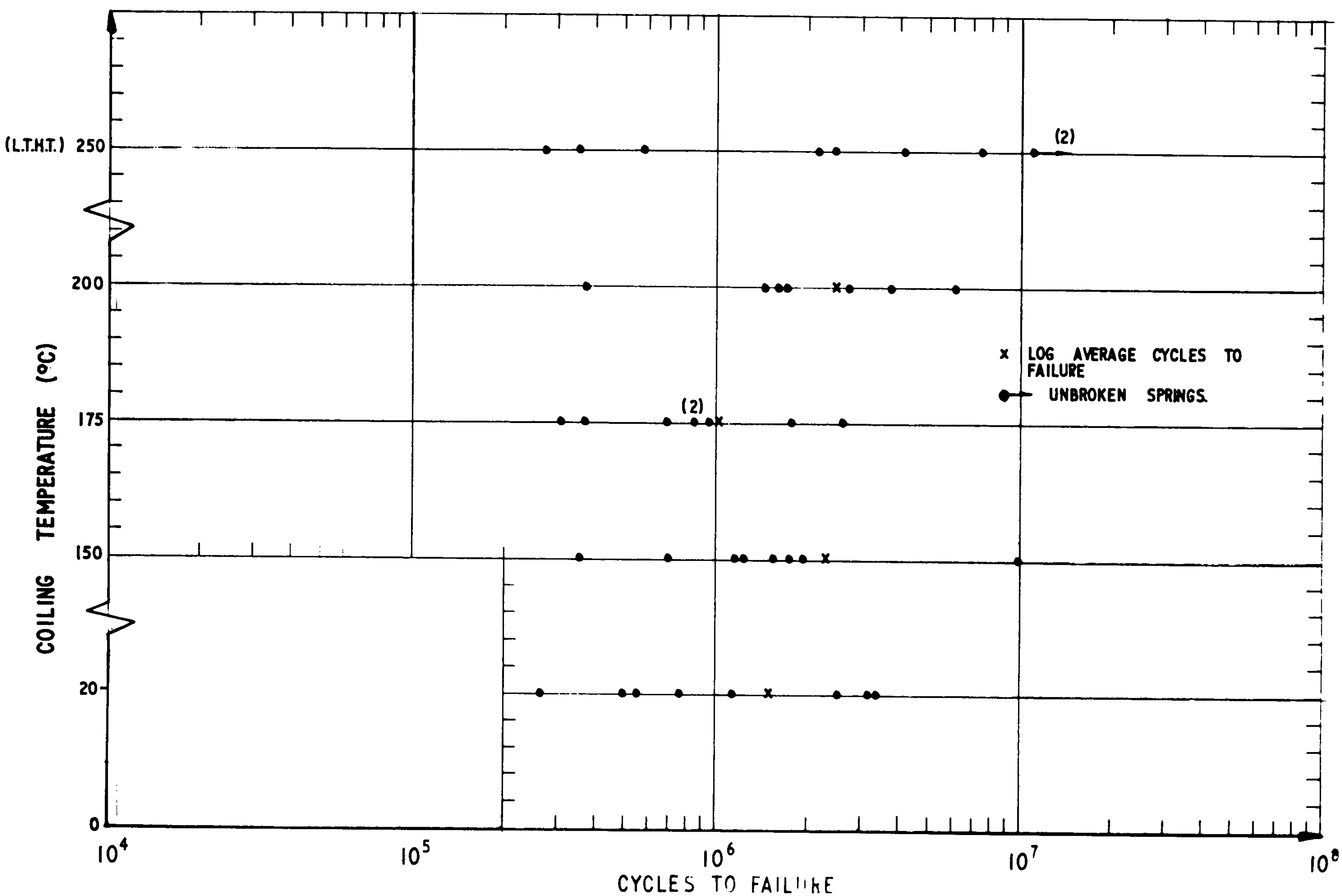


FIG. 4 TEMPERATURE v No. CYCLES TO FAILURE — STRESS RANGE 100— 700 N/mm^2