THE SPRING RESEARCH ASSOCIATION

Report No. 187

AN INVESTIGATION INTO THE EFFECT OF AN AGEING HEAT TREATMENT ON THE CONSISTENCY OF DIMENSIONS THAT CAN BE ACHIEVED WHEN COILING HIGH INDEX PHOSPHOR BRONZE SPRINGS

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SUMMARY

A series of experimental coiling trials was undertaken in order to compare the variability of spring dimensions when coiling 'as received' phosphor bronze and phosphor bronze artificially aged by heat treatment (100°C for two hours).

Statistical analysis of the data obtained from spring measurements showed that the ageing heat treatment caused a 26% reduction in the variability of free lengths, but no significant change in the variabilities of diameters.

A further experiment was undertaken to investigate the effect of a stress relieving operation (200°C for half an hour), after coiling, on the variability of spring dimensions.

This caused no significant change in the variability of spring dimensions. However, there were small but significant increases in diameters of approximately 0.2% and 0.3% for springs made from aged and 'as received' wire respectively.

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CONTENTS

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1. INTRODUCTION

Several manufacturers have for some time considered that aged phosphor bronze wire can hold better coiling tolerances than 'as received' phosphor bronze wire. In view of this, when coiling problems occur it is sometimes the practice to submit the wire to a low temperature heat treatment process before coiling in an attempt to bring about artificial ageing.

This report describes an experiment which was conducted in order to ascertain whether or not this procedure is worthwhile by examining the effects of a low temperature heat treatment before coiling and a stress relieving heat treatment after coiling on the variability of spring dimensions.

2. MATERIALS

Samples of wire were obtained from three independent suppliers. All wire used conformed to the following specification:-

Material:	Phosphor bronze (5% tin) to B.S. 384 - PB 102
Size:	0.048 in diameter
U.T.S:	45 - 55 $tonf/in^2$

3. SPRING DESIGN

One spring design was used throughout the experiment and was as follows:-

Nominal wire diameter	0.048 in
Nominal free length	2.0 in
Nominal outside diameter	1.2 in
Total no. of coils	$7\frac{1}{2}$
No. of active coils	5
Index	24
Each end closed but not ground	

A high index spring was chosen as this type of spring is generally difficult to coil.

4. EXPERIMENTAL PROCEDURE

4.1 Ageing Heat Treatment

The heat treatment chosen to artificially age the wire was 100°C for two hours. This was selected after consultation with spring manufacturers and was typical of procedure within the industry.

Before coiling trials were undertaken an investigation was carried out to determine whether or not this heat treatment affected the physical properties of the material. Accordingly, samples of wire from all three suppliers were heat treated at 100°C, 200°C and 300°C for two hours in a Wild Barfield air circulation furnace. The furnace had an internal diameter of 10 inches and was thermostatically controlled. An air circulation fan was situated at the base of the furnace. The wire coils, which varied in diameter from 8 in to 10 in, stood centrally in the furnace in an upright position. After heat treatment the wire was removed and allowed to air cool. The samples were then tested in tension to determine the U.T.S., elastic limit, and percentage elongation. These were compared and the results are shown graphically in Fig. 11.

From the results it is evident that the ageing heat treatment of 100°C for two hours did not significantly change these properties.

4.2 Stress Relieving Heat Treatment

The second part of the main experiment was to assess the effect of stress relieving after coiling on the variability of spring dimensions. The heat treatment was 200°C for half an hour. A Wild Barfield air circulating furnace was used.

4.3 Experiment Design

The experiment design was for 500 springs to be made from each batch of wire (as received from the suppliers), and then for the remaining wire to be heat treated as specified, before manufacturing a further 500 springs.

The experimental order was as follows:-

RUN NO.	CONDITION	SUPPLIER
1	NO HEAT TREATMENT	A
2	HEAT TREATMENT	A
3	NO HEAT TREATMENT	B
4	HEAT TREATMENT	B
5	NO HEAT TREATMENT	C
6	HEAT TREATMENT	C

The second part of the main experiment, which was to assess the effect of stress relieving after coiling, was carried out on springs from runs three and four.

4.4 Coiling

The spring design was produced on a Torrington 115A auto-coiling machine equipped with a high-speed steel coiling point.

Lubricants were not used on the coiling point or wire. Roller straighteners were used purely as a guide and did not effect any straightening of the wire.

Once the machine had been set to the operator's satisfaction, springs were coiled without further adjustment of the machine controls at a constant rate of 40 per minute. For each run a batch comprising 500 springs was coiled, and the last ten consecutive springs in every 50 were collected and identified in sequential order, thus giving ten sub-samples of ten springs each.

Having obtained the samples comprising 100 springs each, measurements of free length and outside diameter were made and the results analysed statistically.

4.5 Measurements

The free lengths were measured on a Nikon projector and the diameters were measured using a dial gauge as shown in Figs. 9 and 10. All measurements were made approximately 48 hours after coiling as it is known dimensions can change significantly during this period.

Because the free lengths were measured optically there was no distortion of the springs. In measuring the diameters of the springs, however, some distortion was inevitable, and to minimise this the tensator return spring was removed from the dial test indicator and the probe was replaced by a flat plate so as to span four of the coils during measurement.

5. STATISTICAL ANALYSIS

The variances were calculated for the analysis of the first set of experimental data, and the means and variances were calculated for data concerning the stress relieving (after coiling) experiment.

The experiment design allowed both the effect of ageing and the effect of different suppliers' wire to be analysed and compared. The F test was applied to the variances to determine whether or not the difference between the variabilities was significant.

To detect any drift due to the stress relieving operation, a comparison of means for free length and diameter, for the relevant samples (runs three and four, before and after stress relieving), was made using the Student's 't' test.

6. RESULTS

SUPPLIER	TOLERANCES (± 3σ in)			
	NO HEAT TREATMENT		AGEING HEAT TREATMENT	
	FREE LENGTHS	DIAMETERS	FREE LENGTHS	DIAMETERS
A	±0.1791	±0.0103	±0.1651	±0.0076
B	±0.1753	±0.0072	±0.0975	±0.0115
C	±0.1096	±0.0061	±0.0690	±0.0069
OVERALL TOLERANCES	±0.1580	±0.0081	±0.1176	±0.009

The data obtained from the investigation into the effect of ageing are given above

6.1 Effect of Ageing on Coilability

The overall effect of the ageing heat treatment used was to reduce the spring free length variability by 26%, that is, from ±0.1580 in to ±0.1176 in. This effect was significant at the 99.9% probability level.

There was no significant change in the variability of diameters.

6.2 Effect of Different Suppliers of Wire on Coilability

The wire had significant differences (97% probability) in coilability according to which supplier it had come from. The free length tolerances of springs produced from two of the suppliers' wire in the 'as received' condition were virtually the same. The third source of wire produced a 38% smaller free length tolerance of the springs.

Ageing effects varied according to wire supplier and reductions in the coiling tolerances after ageing for the three suppliers were 7%, 44% and 37%.

There were changes in diameter tolerances according to the supplier but these were small. The largest overall significant difference between the diameter tolerances of any two of the three suppliers was ±0.003 in.

6.3 Effect of Stress Relieving after Coiling

SPRINGS MADE FROM	TOLERANCE ($\pm$ 3σ in)			
	FREE LENGTHS		DIAMETERS	
	NOT STRESS RELIEVED	STRESS RELIEVED	NOT STRESS RELIEVED	STRESS RELIEVED
'AS RECEIVED' WIRE	±0.1752	±0.1728	±0.0072	±0.0060
AGED WIRE	±0.975	±0.1053	±0.0114	±0.0114

The stress relieving operation made no significant change in the variability of free lengths or diameters, nor was there any change in the mean of the free lengths. There was a small but significant increase in diameter of approximately 0.2% (0.002 in) and 0.3% (0.003 in) for springs made from aged and 'as received' wire respectively.

7. DISCUSSION OF RESULTS

Wire from different suppliers varies according to the method of manufacture, quality of production, and length of time the wire is kept in stock. Consequently, the 'as received' coilability necessarily varied according to the supplier and the effect of the ageing heat treatment on the coilability varied for the same reason.

In setting up the spring design on the autocoiler, a close coiled spring was produced before the pitch control was adjusted. Constant diameters were relatively easily formed but it was not possible to produce consistent close coiling. In all three cases, therefore, the wire was difficult to coil. This indicated that high variability in free length was to be expected and how improvement in coilability due to ageing might be made.

End coils were included in the overall free length measurements, thus increasing the free length variability because of their proneness to buckling and mal-formation.

The stress relieving treatment given to springs made no significant change in the variability of either the free lengths or diameters. This was true for springs made from both unaged ('as received') and aged wire.

It was thought that the springs might set down due to the stress relieving treatment but a Student's 't' test applied to the means of the results showed that only a minor (but significant) increase in diameter occurred; a slightly larger increase, in fact, occurred in the springs made from unaged wire.

8. CONCLUSIONS

1. Heat treatment before coiling gave rise to a significant reduction in free length variability from $\pm$0.158 in to $\pm$0.118 in (26%).

2. Heat treatment before coiling made no significant change in the variability of diameters.

3. The stress relieving after coiling made no significant change in the variability of either the free lengths or diameters.

4. The stress relieving after coiling made no significant change to the mean of free lengths.

5. The stress relieving after coiling produced a small increase in the mean diameter of 0.003 in (0.3% approx.)

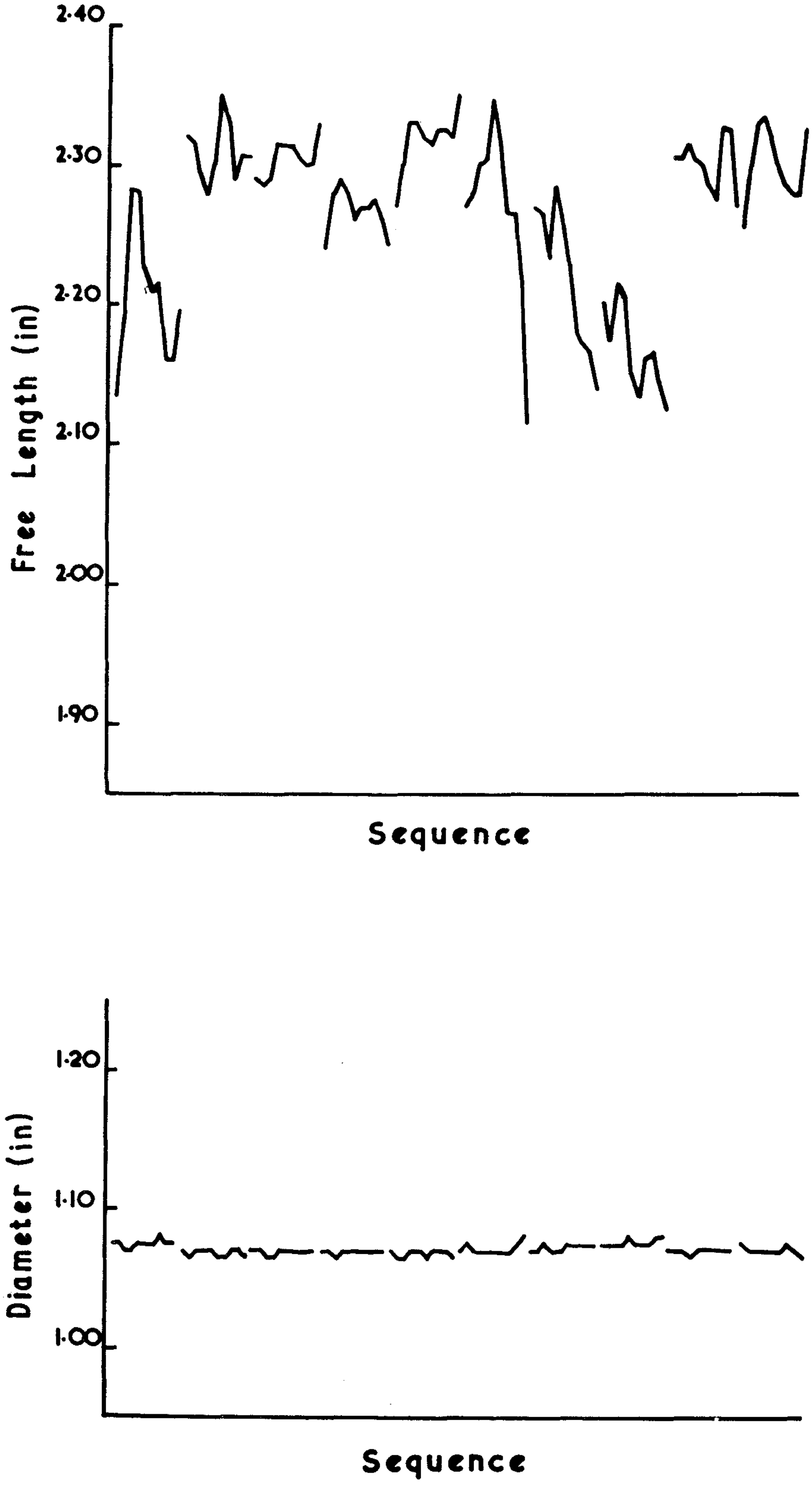


FIG. I SEQUENCE CURVES FOR RUN NO. I. SUPPLIER A 'AS RECEIVED'

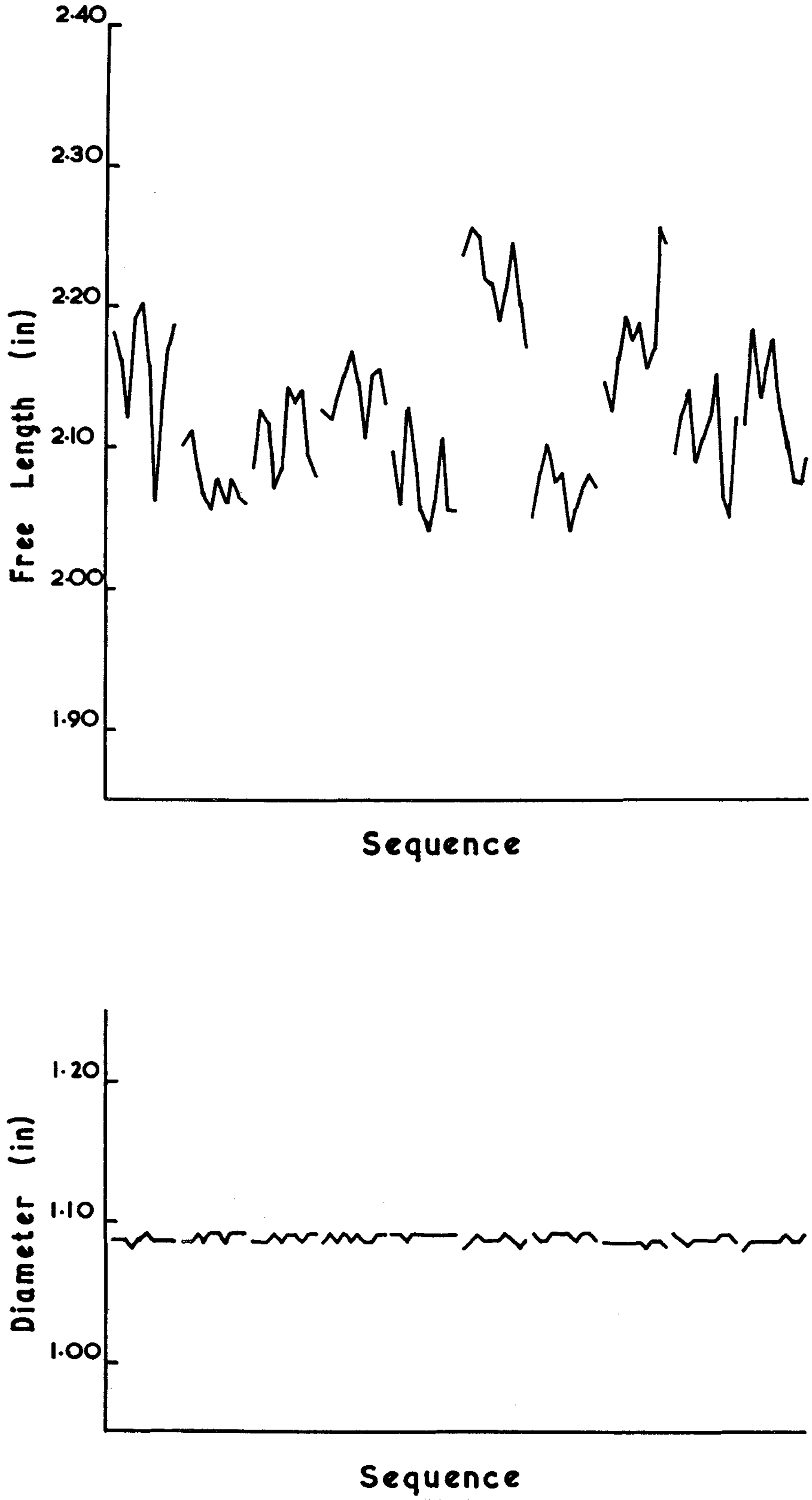


FIG. 2 SEQUENCE CURVES FOR RUN NO. 2.
SUPPLIER A AGED WIRE

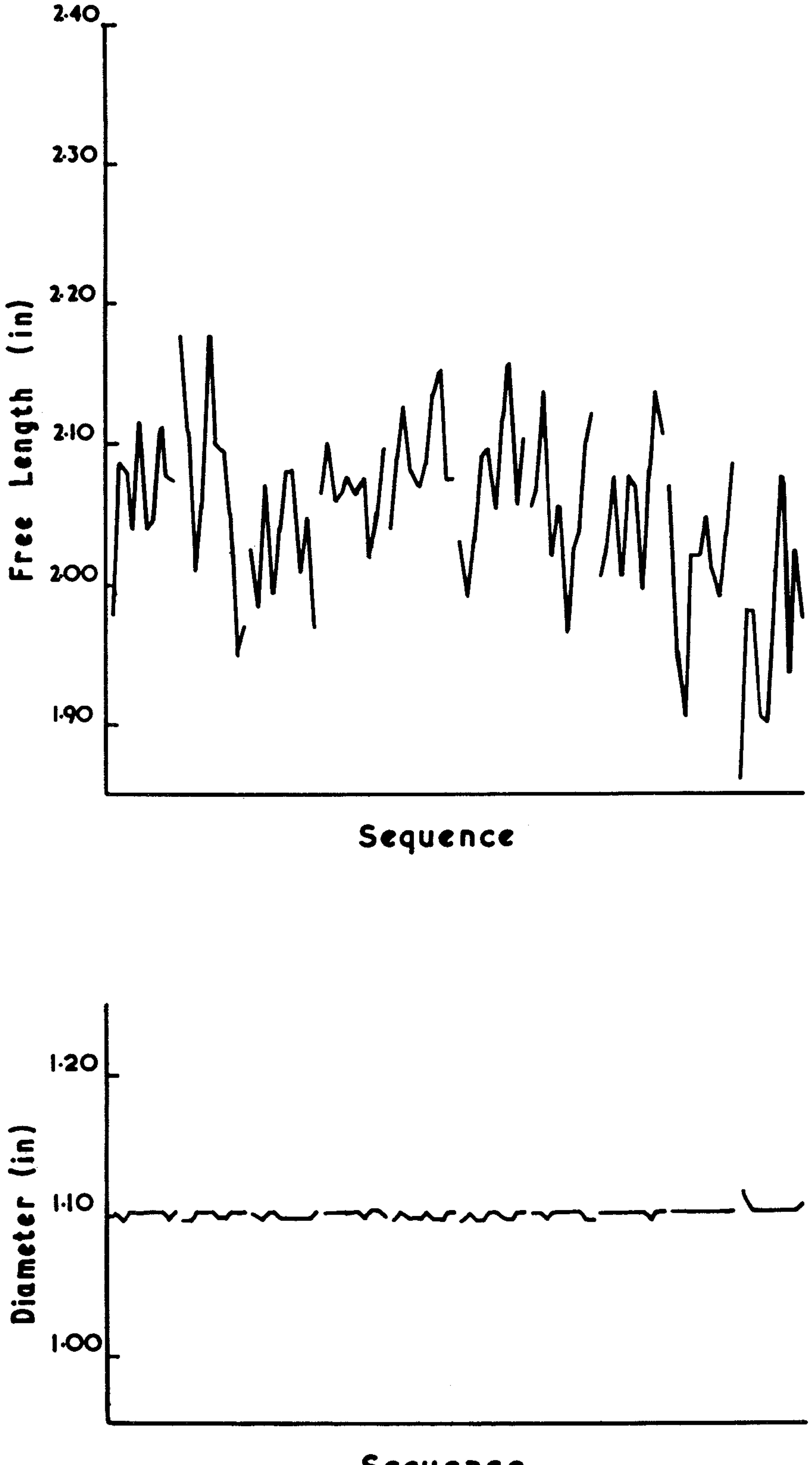
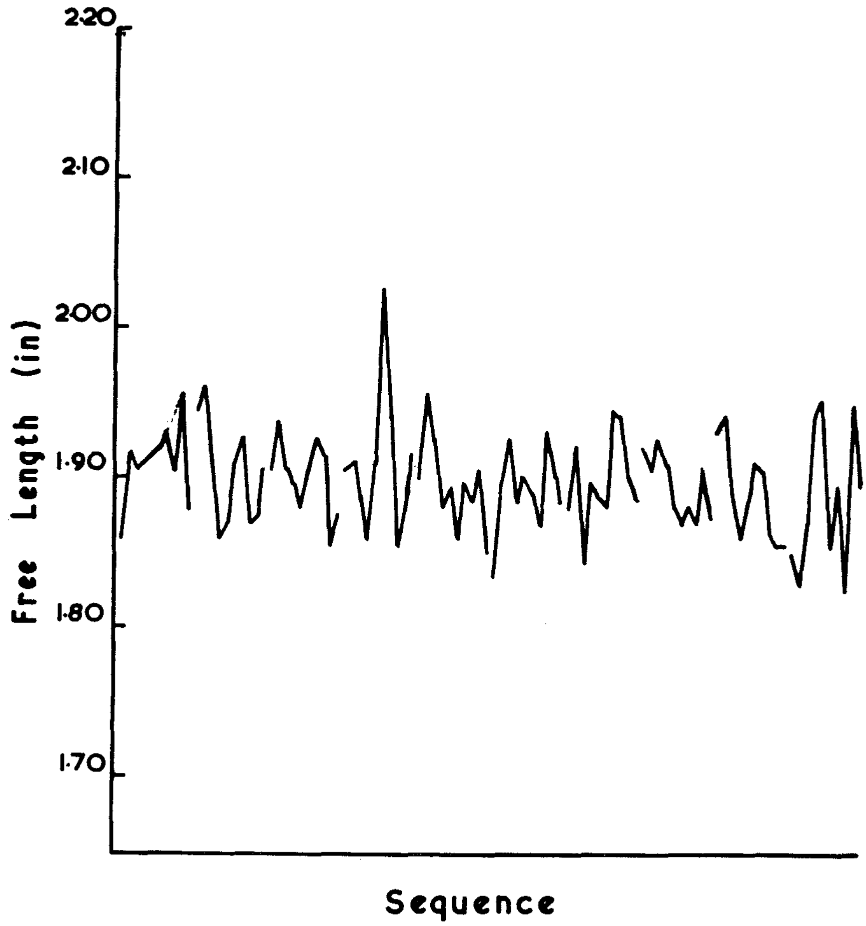


FIG. 3 SEQUENCE CURVES FOR RUN NO. 3.
SUPPLIER B 'AS RECEIVED'



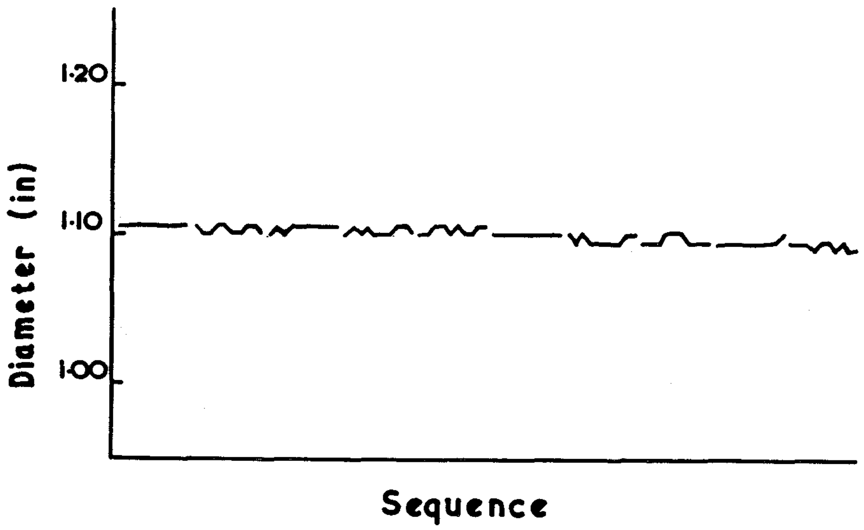


FIG. 4 SEQUENCE CURVES FOR RUN NO. 4.
SUPPLIER B AGED WIRE

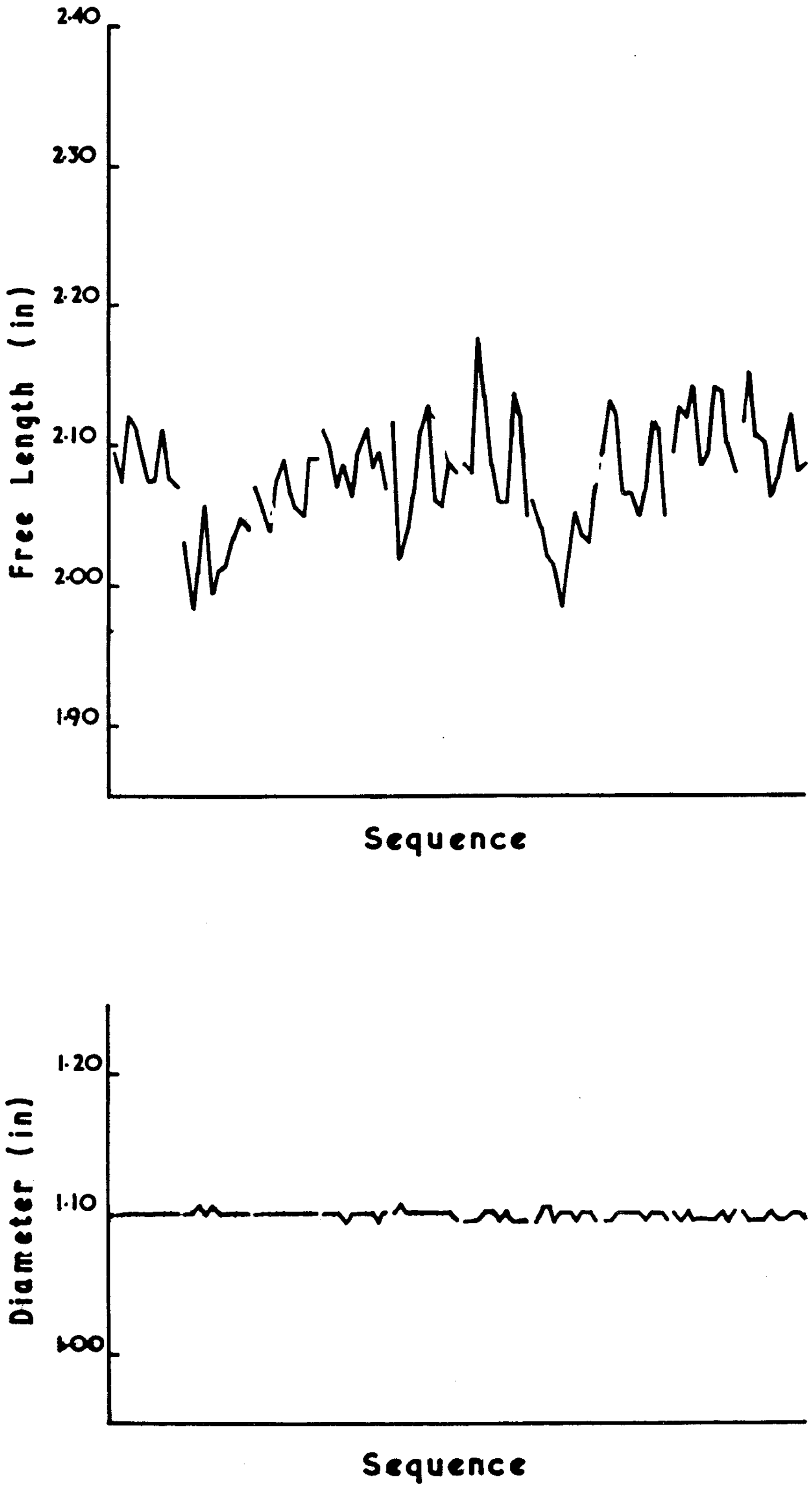


FIG. 5 SEQUENCE CURVES FOR RUN NO. 5. SUPPLIER C 'AS RECEIVED'

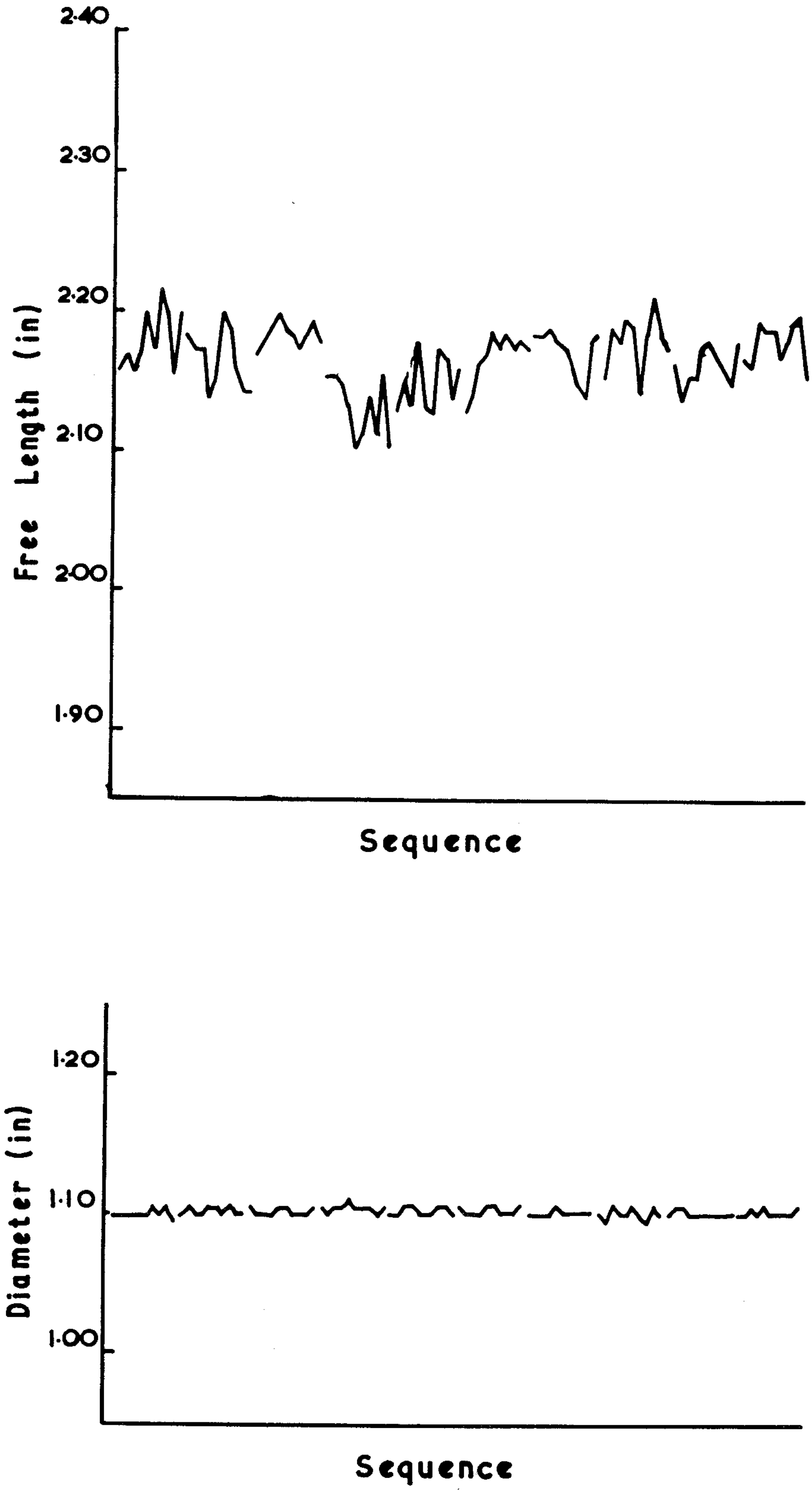


FIG. 6 SEQUENCE CURVES FOR RUN NO. 6.
SUPPLIER C AGED WIRE

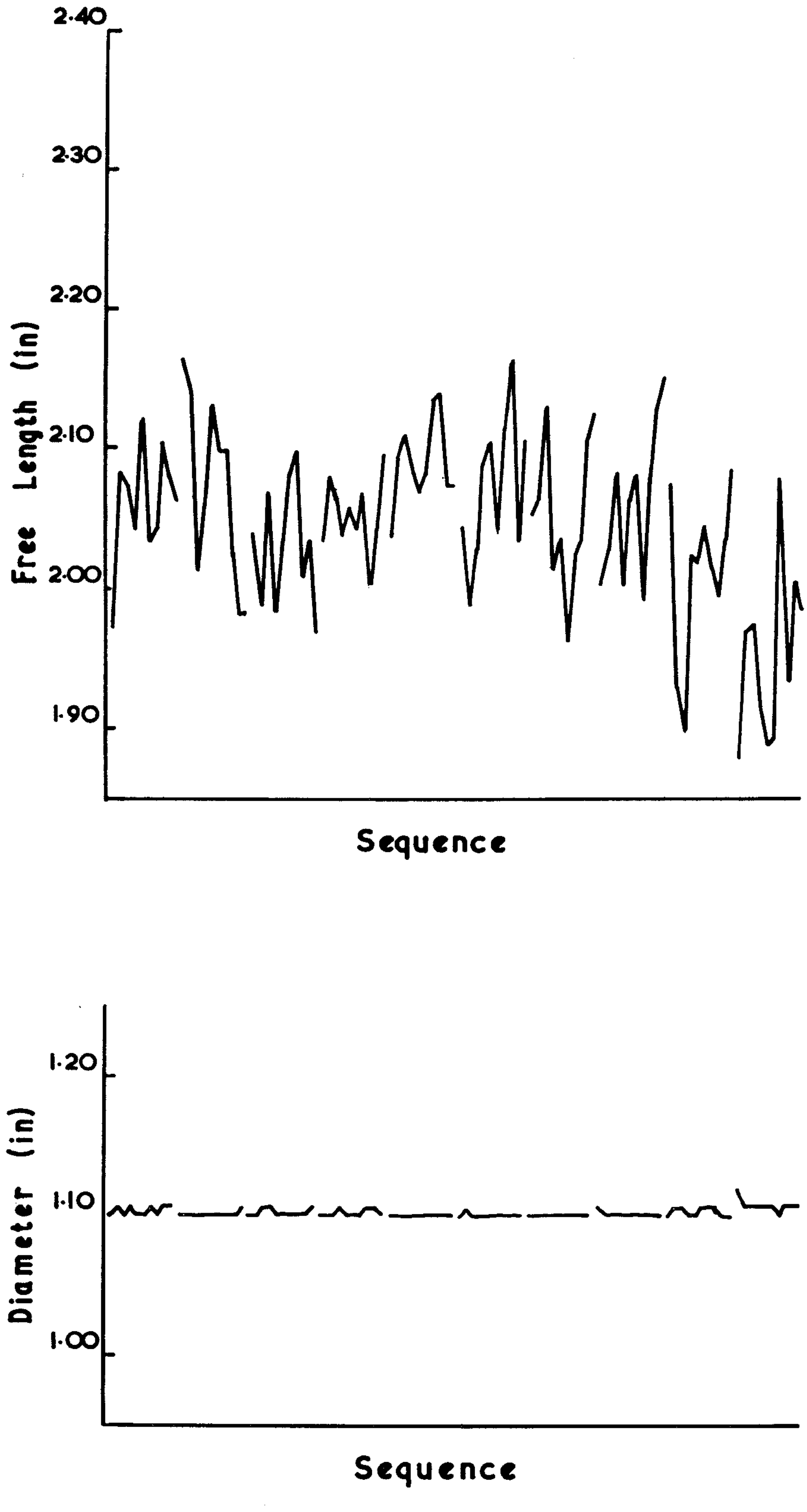
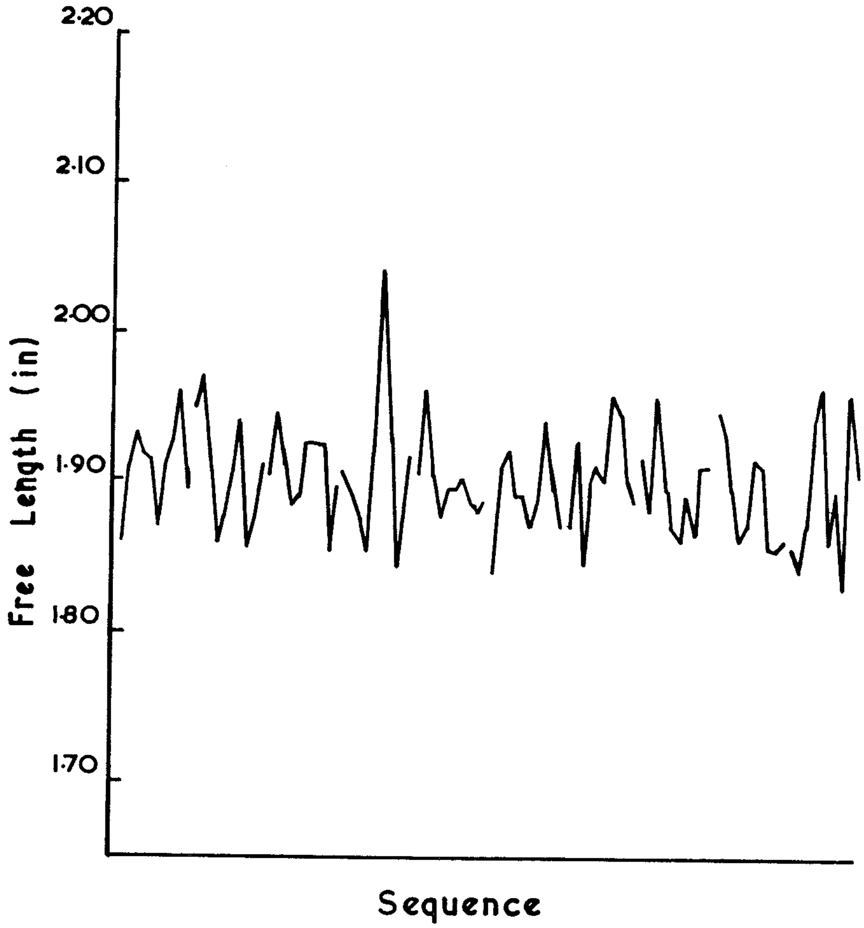


FIG. 7 REMEASUREMENT OF RUN NO. 3 AFTER STRESS RELIEVING



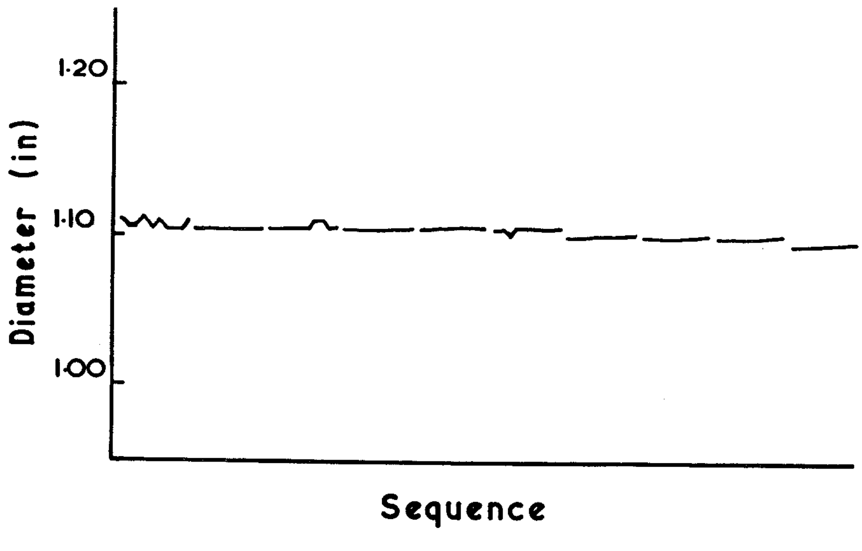


FIG. 8 REMEASUREMENT OF RUN NO. 4 AFTER STRESS RELIEVING

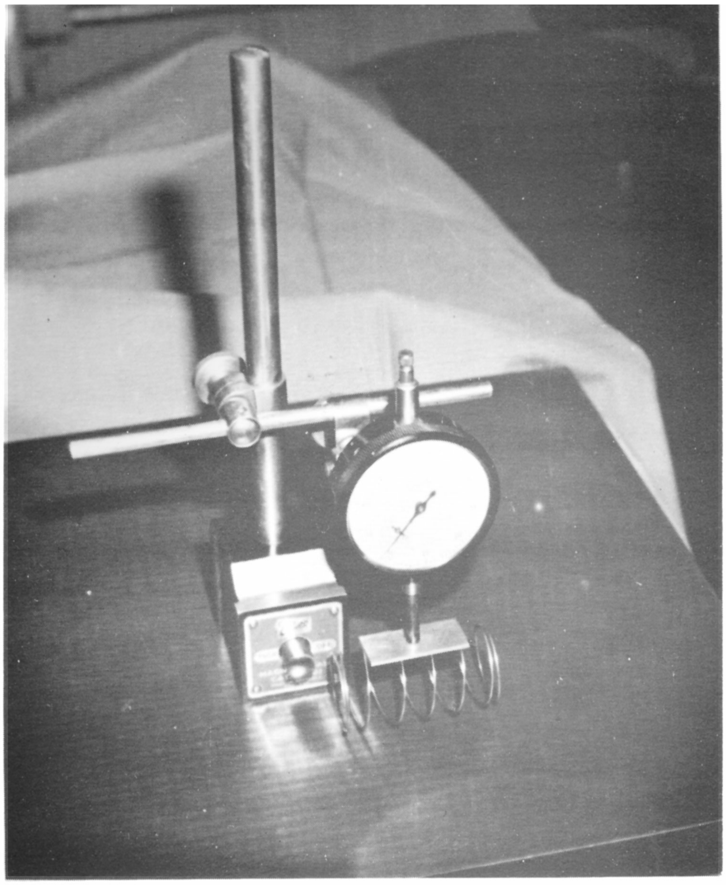


FIG. 9 DIAMETER MEASUREMENT

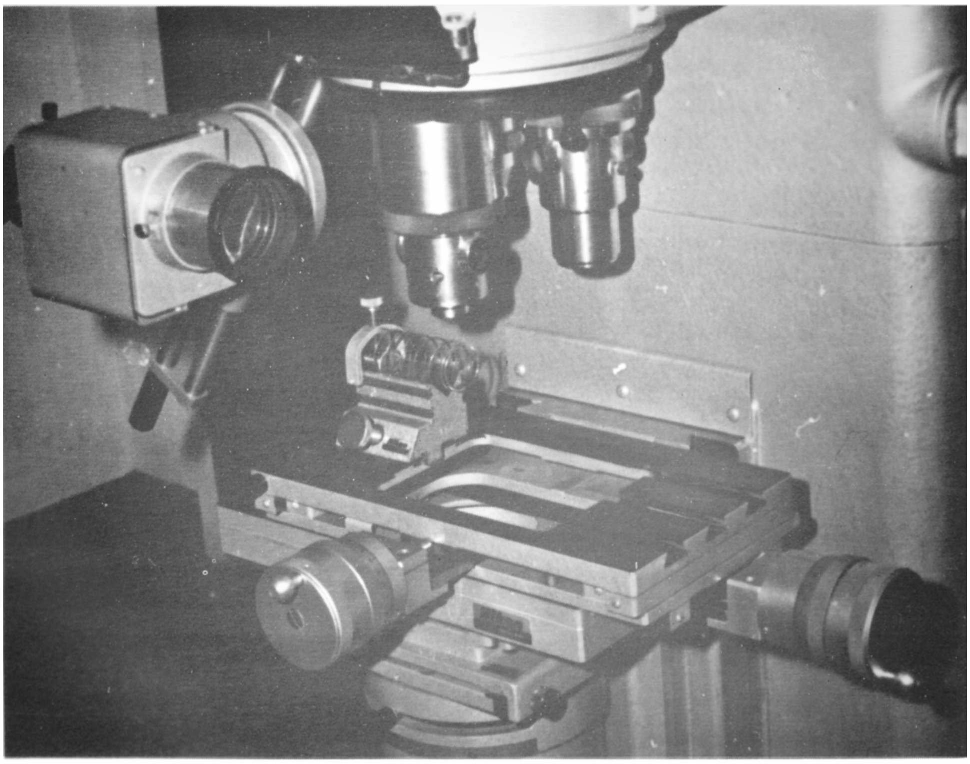


FIG. 10 FREE LENGTH MEASUREMENT

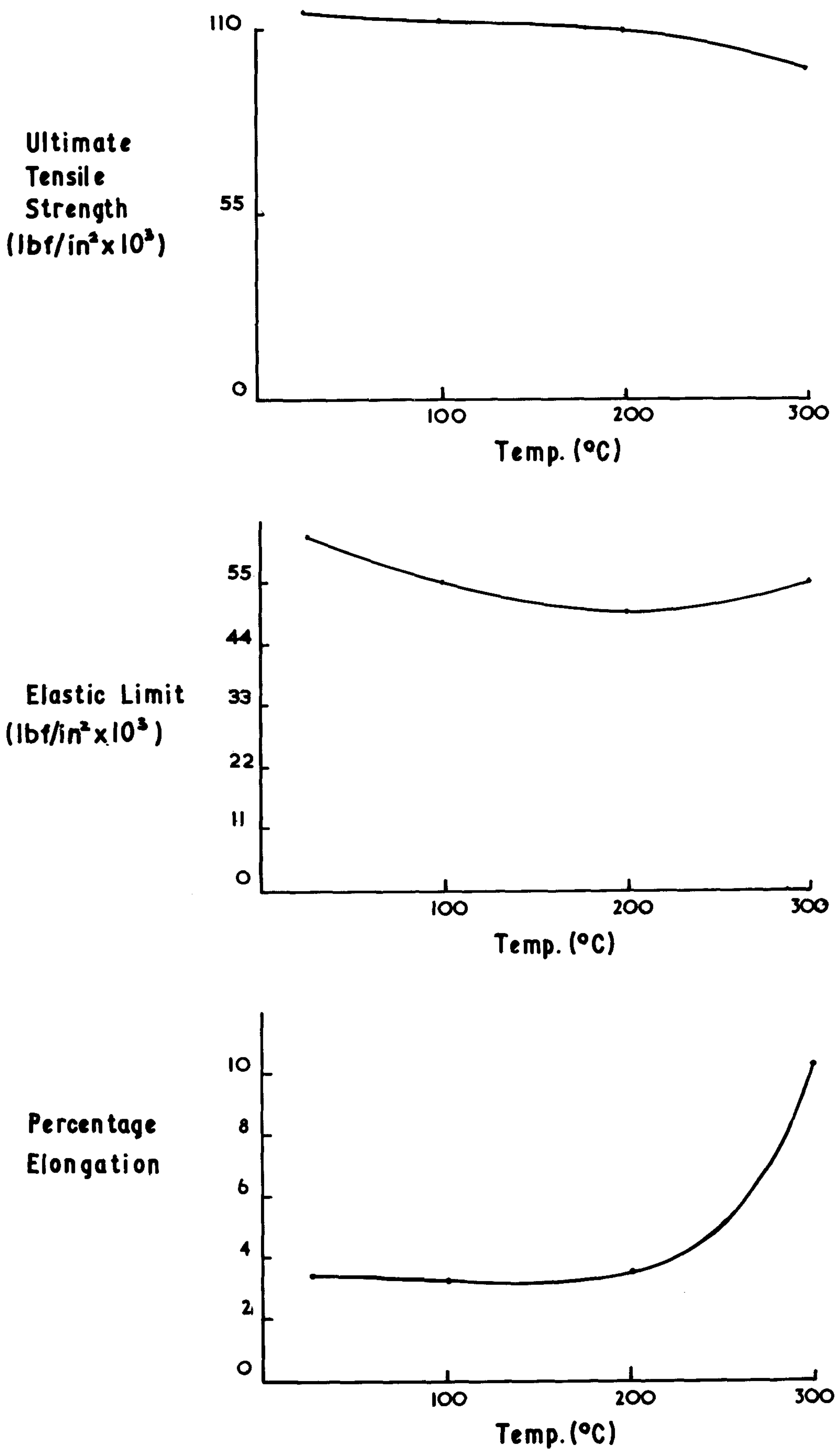


FIG. 11 EFFECT OF HEAT TREATMENT TEMPERATURE ON U.T.S., ELASTIC LIMIT AND PERCENTAGE ELONGATION