THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE COILABILITY OF PATENTED HARD DRAWN CARBON STEEL SPRING WIRE

SECOND PROGRESS REPORT

THE SEQUENTIAL ELASTIC PROPERTIES OF SPRING WIRES OF VARYING COILABILITY

by

L.F. Reynolds

Report No. 331

MAY 1980

THE COILABILITY OF PATENTED HARD DRAWN CARBON STEEL SPRING WIRE

SUMMARY

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Previous work at SRAMA has established that "poor" coilability of hard drawn carbon steel spring wires can be closely associated with a relatively high limit of proportionality in tension, and with a relatively low angle of springback in bending.

Sequential measurements of these two arbiters of elastic properties have now been made along the length of wires representative of both "good" and "poor" coilability. Whilst regular sequential variations in elastic properties were not consistently detected, the work has suggested that the random scatter of the springback results for the wire of "poor" coilability was consistently greater than that obtained for the equivalent wire of "good" coilability. Furthermore, the degree of random scatter associated with the results of the springback tests was considerably lower than that associated with the results of the analytical tensile tests.

The work has thus demonstrated that future investigations into variations of sequential elastic properties may require greater experimental precision, particularly with respect to the use of equipment which can maintain a constant rate of straining during testing.

It is concluded that the springback test offers the most promise in respect of a relatively simple technique for discrimination between wires of varying coilability within a particular wire grade and size range, and that the technique should now be subjected to more extensive investigations using wires of known coilability.

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1. INTRODUCTION

Previous work has suggested that "poor" coilability of patented, hard drawn carbon steel spring wire may be closely associated with relatively high values of the true proportional limit, σp, where the proportional limit is here defined as that true stress at which the first deviation from elastic linearity occurs[1]. This same work also established that "poor" coilability was associated with low values of elastic springback in bending, when the wires were bent through a 90^{o} angle over a mandrel such that the surface fibre strain exceeded an approximate value of 0.025.

The results of this previous work have led directly to the present investigation into a determination of the sequential variation, if any, of these two elastic parameters along the length of appropriate wires of "good" and "poor" coilability. Thus it was felt that marked sequential variations in the elastic properties could lead to equally marked variations in the free length, for example, of springs coiled from such wire.

In view of the relative ease with which the bend test could be executed, it was also considered desirable to improve the sensitivity of the test as presently used at SRAMA, with a view to possible future developments in the routine testing of spring wires.

. MATERIALS

Appropriate materials used for the previous investigation were also employed during this work, and the wires were therefore representative of materials conforming to BS 1408, R3, and BS 1408, M2.

The identification of the wires is shown in Table I, together with the spring makers assessment of their coilability.

. EXPERIMENTAL PROCEDURE

.1 Sequential True L. of P. ($_\sigma$p) in Tension

These tests were carried out at 28 cm intervals on unstraightened wires, using analytical techniques which have been fully described elsewhere[1].

Precise and reproducible measurements of the Limit of Proportionality require that the tests be carried out at a constant temperature and at a constant strain rate value throughout the tests, both increased temperature and decreased strain rates tending to give significantly lower values for the Limit of Proportionality.

The machine used for tensile testing at SRAMA was not equipped for constant strain rate experiments during the present work, however, and all the tests were therefore carried out in a constant time interval, in an attempt to maintain a suitably constant strain rate from test to test. It is estimated that the mean strain rate lay within the range 0.0003-0.0005 mm/mm/sec.

Although the ambient temperature of the laboratory varied between 8^{o}C and 15^{o}C over the year, the sequential tests on any one individual wire were essentially carried out at constant temperature.

The mathematical analysis of the true stress/true strain data was carried out using a Research Machines 380Z mini-computer, employing a program written at SRAMA.

3.2 Sequential Springback Tests

This test involved precise measurement of the wire springback after bending through 90^{o} over a mandrel of 25.4 mm diamater to fibre strains in excess of 0.025.

A general description of the testing technique has been given in an earlier report, where it was noted that differences in springback angle of approximately 6^{o} were obtained for wires of "good" and "poor" coilability respectively[1].

The previous work also revealed the main sources of error of the machine, namely the difficulty of establishing a reference point for measurement of the springback before and after the wire was bent over the mandrel.

This limitation to the precision of measurement would not normally be as prohibitive for differentiating between wires of "good" and "poor" coilability, but assumes greater significance where sequential differences of small magnitude may occur along the length of one particular wire.

In the event, the difficulties were avoided by the following means.

1. The electrical indicating technique used initially in the previous work employed a battery and bulb circuit which consumed approximately 300mA of current. This relatively high current caused some problems of arcing and intermittent contact at the brass contact/steel wire surface, although such problems were very substantially reduced by copper coating of the wire.

   A sensitive voltmeter was substituted for the indicating system, thus reducing the necessary current to 20 A, which was 15000 times smaller than that previously used.

2. Any remaining problems of intermittent contact were removed by gold plating both the brass reference contact and the test wires themselves. The brass reference contact was

gold electroplated. The wires were copper plated and were subsequently gold plated, in each case using the appropriate dip plating techniques outlined in the Appendix[2].

These two changes in test procedure completely eliminated the errors arising from poor or intermittent contact, thus permitting more precise measurement of the sequential springback of wires of "good" and "poor" coilability.

4. RESULTS AND DISCUSSION

The results for the analytical Limit of Proportionality are shown in Table II whilst the sequential values for this parameter are plotted in Figs. 1-5.

The results of the springback test are given in Table III, the sequential springback values being presented in Figs. 6-8.

In general, the results confirmed the findings of the previous work, in that the wires of "good" coilability were associated with relatively low values of the analytically determined Limit of Proportionality, and with relatively high values of the springback angle.

When the individual measurements were considered sequentially, however, the conclusions appeared to be less clear cut. The results of the limit of proportionality determinations could be interpreted as suggesting that the variations of this parameter along the length of "poor" coilability wire was less random that that exhibited along "good" coilability wire. The sensitivity of this parameter to variations in strain rate and ambient temperature have already been noted however, and it is therefore possible that sequential variations in the limit of proportionality were partly obscured by random variations generated as a result of fluctuations of temperature and, in particular, of strain rate during the tensile test. Indirect evidence of such random scatter can be seen in the relatively high values obtained for the coefficient of variation which is a dimensionless quantity defined by the relationship

$$(\%)\ \text{Coeff. of Var} = \frac{Sx}{\bar{x}} \times 100$$

Where Sx = Standard Deviation
$\bar{x}$ = Sample mean

This coefficient is an absolute measure of scatter, which can be useful in comparing the variations of distributions of the same type.

It can be seen that this parameter lies within the range 4.8 - 6.7% with a mean value of 6%, for the limit of proportionality determinations. It would therefore appear necessary for similar tests to be carried out at constant temperature and strain rate before a final conclusion can be reached on the sequential variation of the limit of proportionality.

The results of the sequential springback tests suggest that the wires of "poor" coilability consistently exhibited a degree of random scatter which was higher than that associated with the wires of "good" coilability. This feature of the work is demonstrated by the values quoted in Table III, the coefficient of variation (%) of the "poor" wires generally being 1.7-2.8 times greater than the equivalent values obtained for the "good" wires. It can also be noted that the coefficient of variation, for the springback results, generally lay within the range 0.6-2% with a mean value of 1.4%. The intrinsic scatter of the springback test would therefore appear to be significantly lower than that of the tensile determinations for the limit of proportionality, the coefficient of variation of the latter tests being 4-5 times greater than that obtained for the springback tests.

In general, however, it was once again not possible to establish systematic variations in springback along the length of the appropriate wires with any degree of confidence, although the observations of the previous work were confirmed, in that the springback of the "good" coilability wire was consistently greater than that of the "poor" coilability wire.

In terms of test techniques the work has confirmed the propriety of selecting the springback test for possible development to differentiate between the elastic properties of "good" and "poor" coilability wire within any one wire grade and diameter, this type of test apparently producing lower levels of random scatter as represented by the coefficient of variation, than the equivalent measurements of elastic properties obtained during tensile testing.

Calculations based on the springback data given in Table III suggest that, in the present case, approximately 10 tests per wire sample should discriminate between the wires of "good" and "poor" coilability tested in this work.

5. CONCLUSIONS

1. Regular fluctuations have not been detected, in either the true limit of proportionality or the angle of springback along the length of the wires tested.

   This may be a function of the equipment employed, however, in the sense that neither the tensile machine nor the springback tester could apply constant strain rates during the present work.

2. The springback tester has been improved to increase its precision, and the work has suggested that wires of "poor" coilability may exhibit a more pronounced scatter about the mean than wires of "good" coilability.

3. The work has confirmed the findings of previous investigations, in that the wires of "poor" coilability consistently exhibited true limits of proportionality and springback angles which were significantly higher and lower respectively than those obtained for the wires of "good" coilability.

4. In an industrial context, the springback test offers the best promise for development into a robust, portable and

sensitive instrument which may be capable of discriminating between those wires which will coil readily and those which will only coil with greater difficulty, for the particular wire grade and diameter in question.

6. RECOMMENDATIONS

1. Suitable springback tests should be carried out on a wide selection of patented hard drawn wires of known coilability characteristics. The validity of the test will thus be either confirmed or disproved in a wider context than that employed in the present work. It is suggested that the work be initially carried out using the equipment presently available at SRAMA although this will limit the maximum wire diameter to approximately 1.5 mm.

2. Further investigations into the sequential variation in elastic properties, along the length of appropriate wires, will require equipment which is capable of strain rate control. This is not currently available at SRAMA, and further work in this field will therefore necessitate either appropriate investment at SRAMA, or negotiation to pursue the work in laboratories already possessing these facilities. The work could be carried out under the auspices of an appropriate University study, for example.

7. REFERENCES

1. Reynolds, L.F. "The Coilability of Patented, Hard Drawn Carbon Steel Spring Wire." First Progress Report. "The Elastic Properties of Spring Wires and their Correlation with Coilability". SRAMA Report No. 323. March 1980.

2. Graham, A.K. (Ed). "Electroplating Engineering". Van Nostrand Reinhold, 1971.

8. APPENDIX A

Techniques for Dip Plating Steel Wires with Copper and Gold

Bright Copper Plating (From Ref. 2., P. 505)

Solutions

Two solutions are prepared when using this technique of copper plating.

Solution A: 50 gm of Copper Sulphate and 249 gm of 37-38% (w.w) Formaldehyde solution, dissolved together in 1 litre of distilled wate:

Solution B: 225 gm of Rochelle salt (Sodium Potassium Tartrate) and 67 gm of Sodium Hydroxide, dissolved together in 1 litre of distilled water.

Copper Plating Technique

After thorough cleaning of the wire surface, using both chemical and ultrasonic techniques if necessary, the sample is immersed in the plating bath, which consists of equal parts by volume of Solutions A and B, mixing of the two solutions having been carried out immediately prior to plating. Bright copper will be deposited slowly at room temperature, and more rapidly at temperatures of 30-40^{o}C. Higher temperatures than this will result in general precipitation of copper from solution within approximately 30 minutes.

Gold Plating Solution and Plating Technique (From Ref. 2., P . 476).

The following solution is prepared for gold plating.

Brown Gold Chloride:	0.85 gm
Potassium Bicarbonate:	40 gm
Distilled Water:	100 ml.

Appropriate quantities of solution (10 ml in the present work) are freshly prepared and boiled for 2 hours before the commencement of plating. (small quantities of a black precipitate may form during this time, but this does not affect the plating capability of the solution).

The copper plated steel wires are gold plated by immersion at 35^{o}C for approximately 30 seconds.

9. TABLES

TABLE I WIRES INVESTIGATED AND ASSESSMENT OF COILABILITY

Wire quality	Nominal wire size, mm	Sample No.	Springmakers assessment of coilability
BS 1408 R3	0.71 diam.	1	G = Good
		2	P = Poor (variable free length)
		3	P = Poor (" " ")
BS 1408 M2	0.76 diam.	4	G = Good
		5	P = Poor (variable free length)

TABLE II TRUE LIMIT OF PROPORTIONALITY, σ p, FOR PATENTED HARD DRAWN STEEL WIRES OF VARYING COILABILITY

Wire No.	Number of wires tested	L of P, σ p N/mm^2		Coefficient of Variation, %
		Mean	Standard Deviation	
1	30	1129.7	75.6	6.7
2	29	1218.6	78.0	6.4
3	20	1197.8	57.1	4.8
4	30	1208.1	79.0	6.5
5	31	1345.2	74.4	5.5

TABLE III SPRINGBACK ANGLE, θ^o, FOR PATENTED HARD DRAWN CARBON STEEL WIRES OF VARYING COILABILITY

Wire No.	Number of wires tested	Springback angle, θ^o		Coefficient of Variation, %
		Mean	Standard Deviation	
1	20	62.6	0.4	0.6
2	30	58.8	1.0	1.7
3	30	59.4	1.0	1.7
4	30	60.5	0.7	1.2
5	30	56.9	1.1	1.9

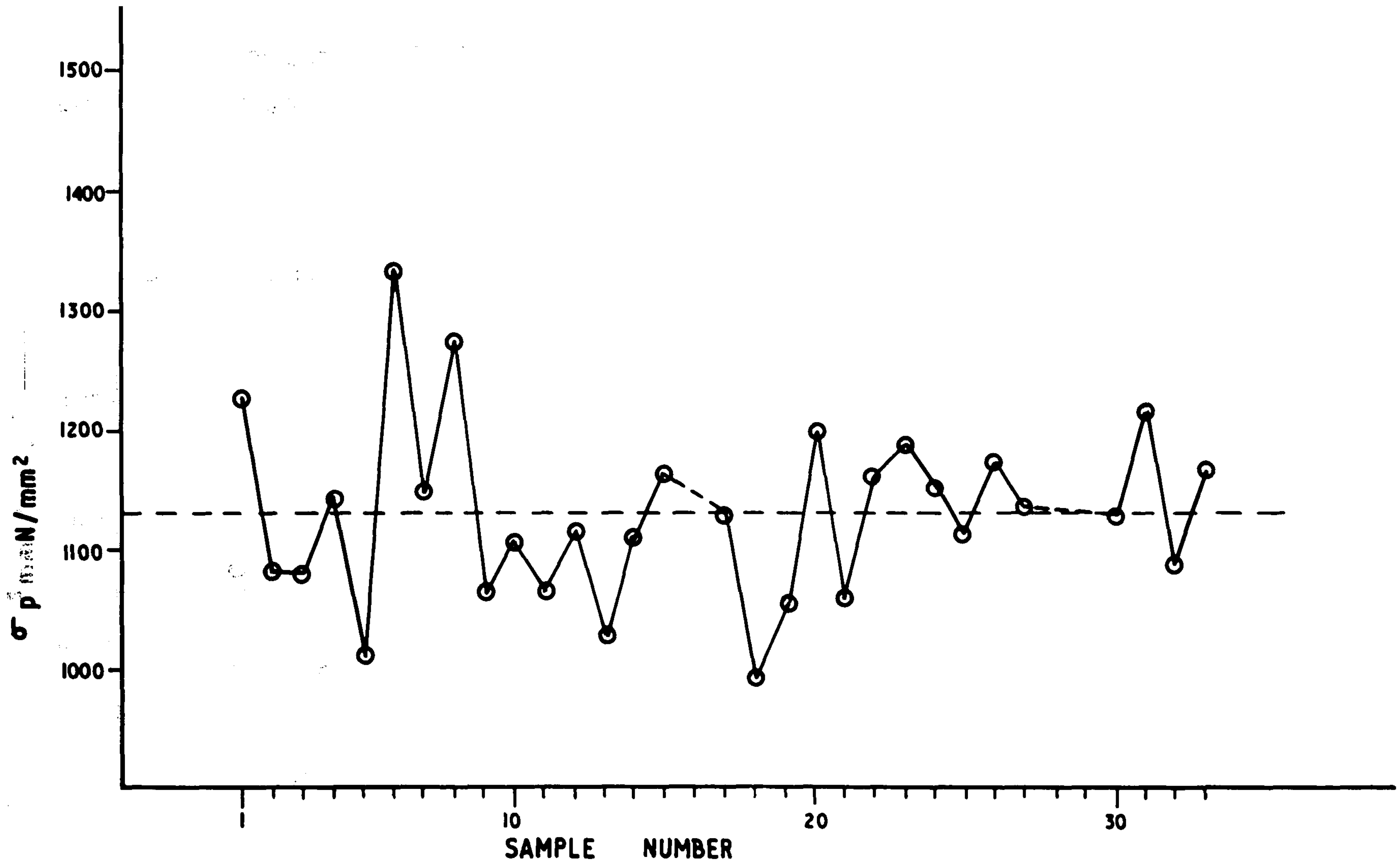

FIG.1. TRUE LIMIT OF PROPORTIONALITY, σ_p, FOR WIRE 1 (GOOD COIL'Y'), SAMPLED AT 28 cm INTERVALS.

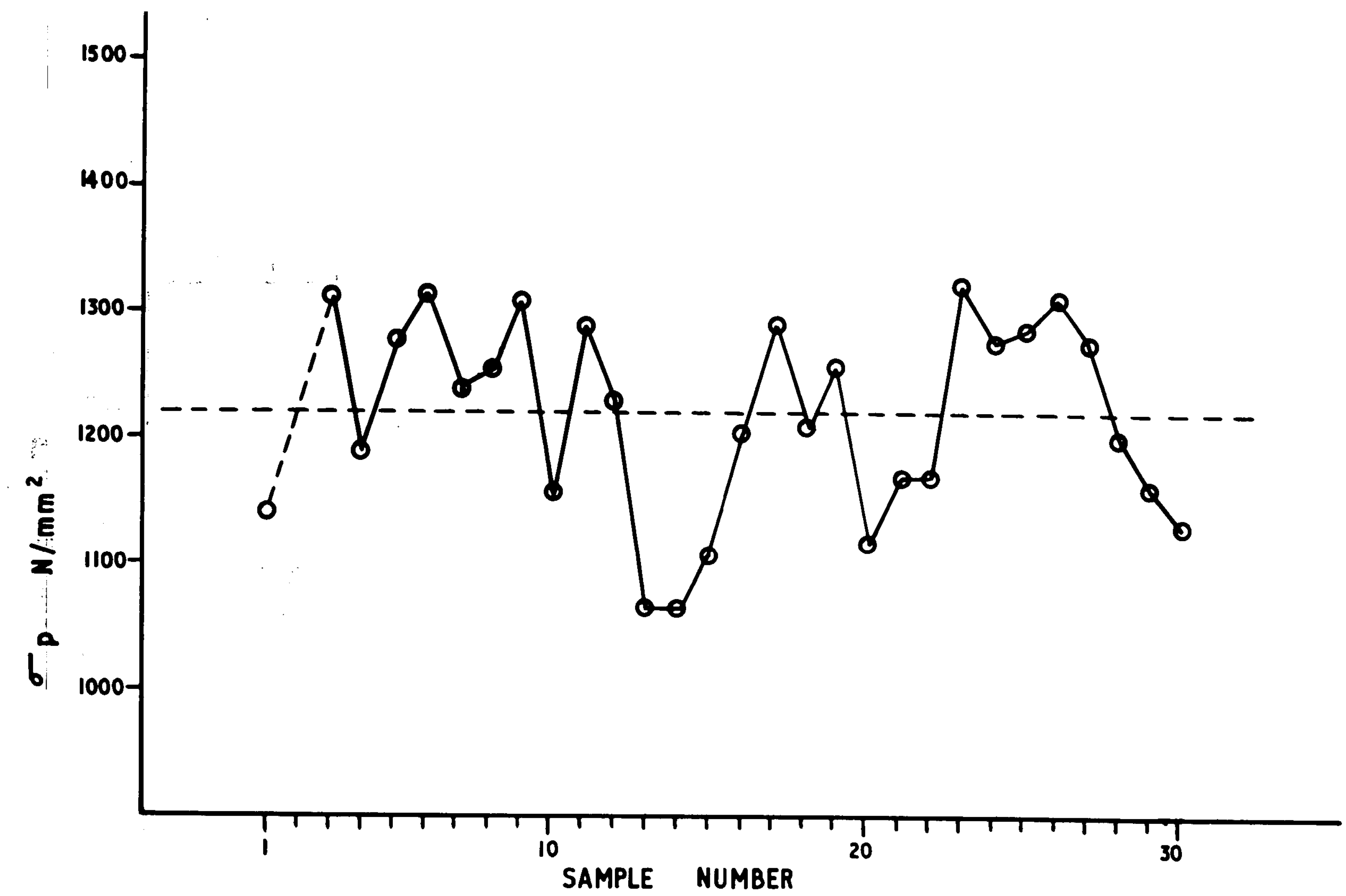

FIG. 2. TRUE LIMIT OF PROPORTIONALITY, σ_p, FOR WIRE 2 (POOR COIL Y), SAMPLED AT 28 cm INTERVALS.

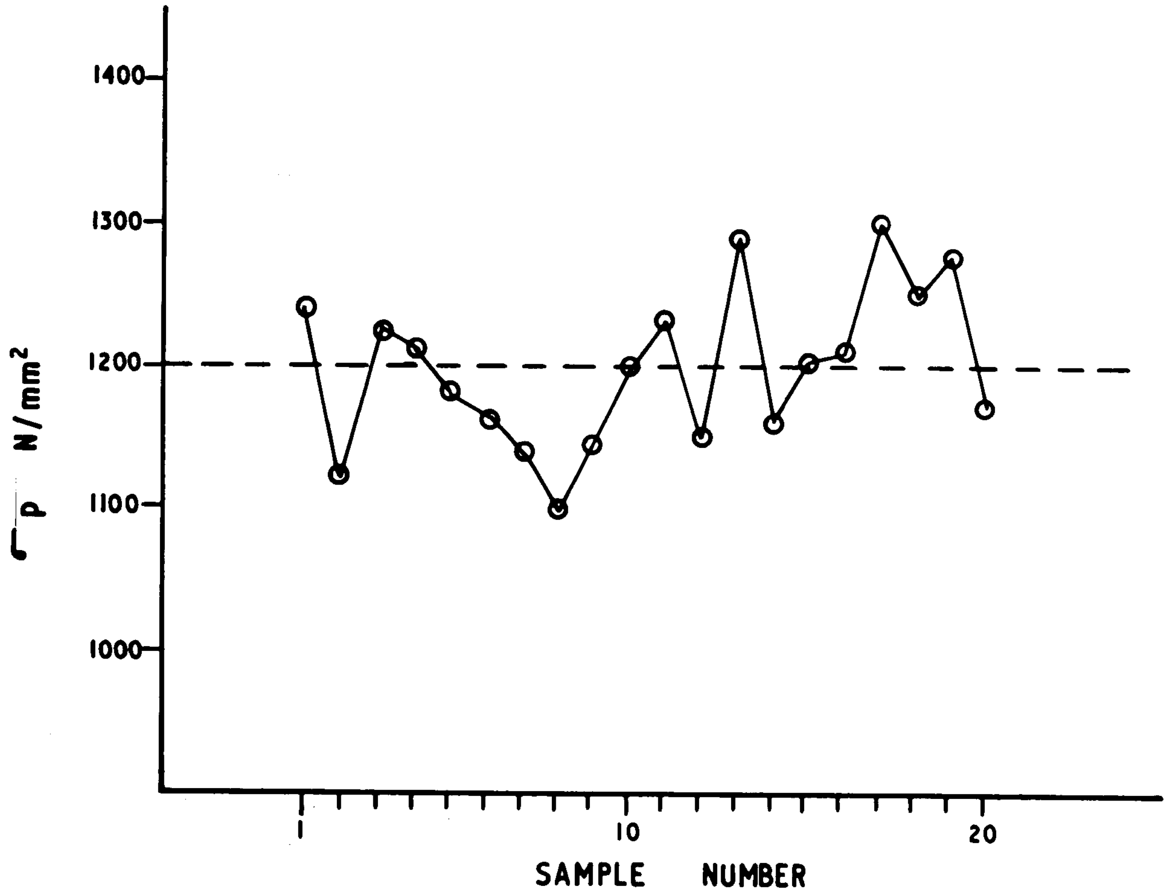

FIG. 3. TRUE LIMIT OF PROPORTIONALITY, σ_p, FOR WIRE 3 (POOR COIL γ) SAMPLED AT 28 cm INTERVALS.

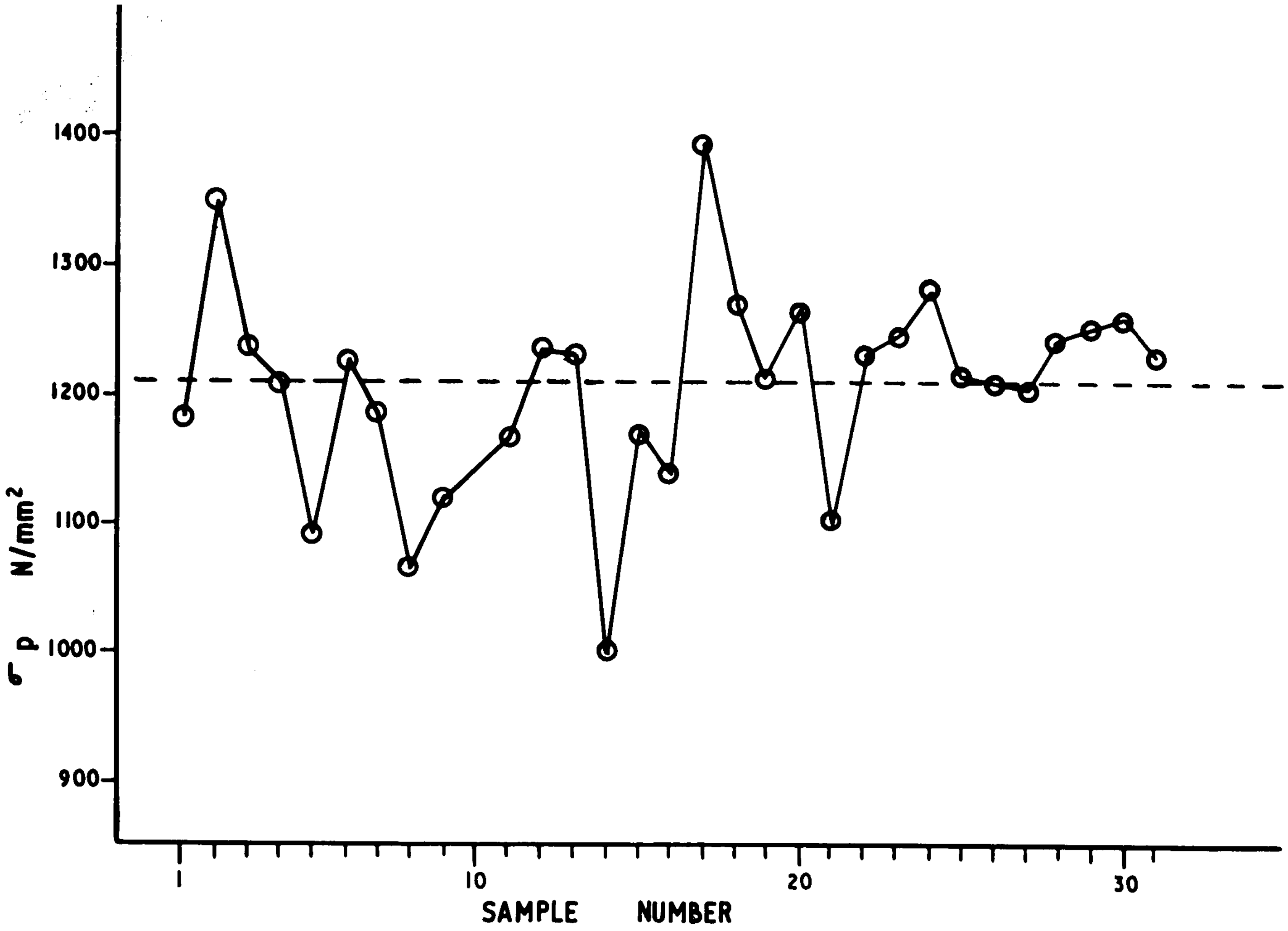

FIG. 4. TRUE LIMIT OF PROPORTIONALITY, σ_p, FOR WIRE 4 (GOOD COIL^{Y}), SAMPLED AT 28 cm. INTERVALS.

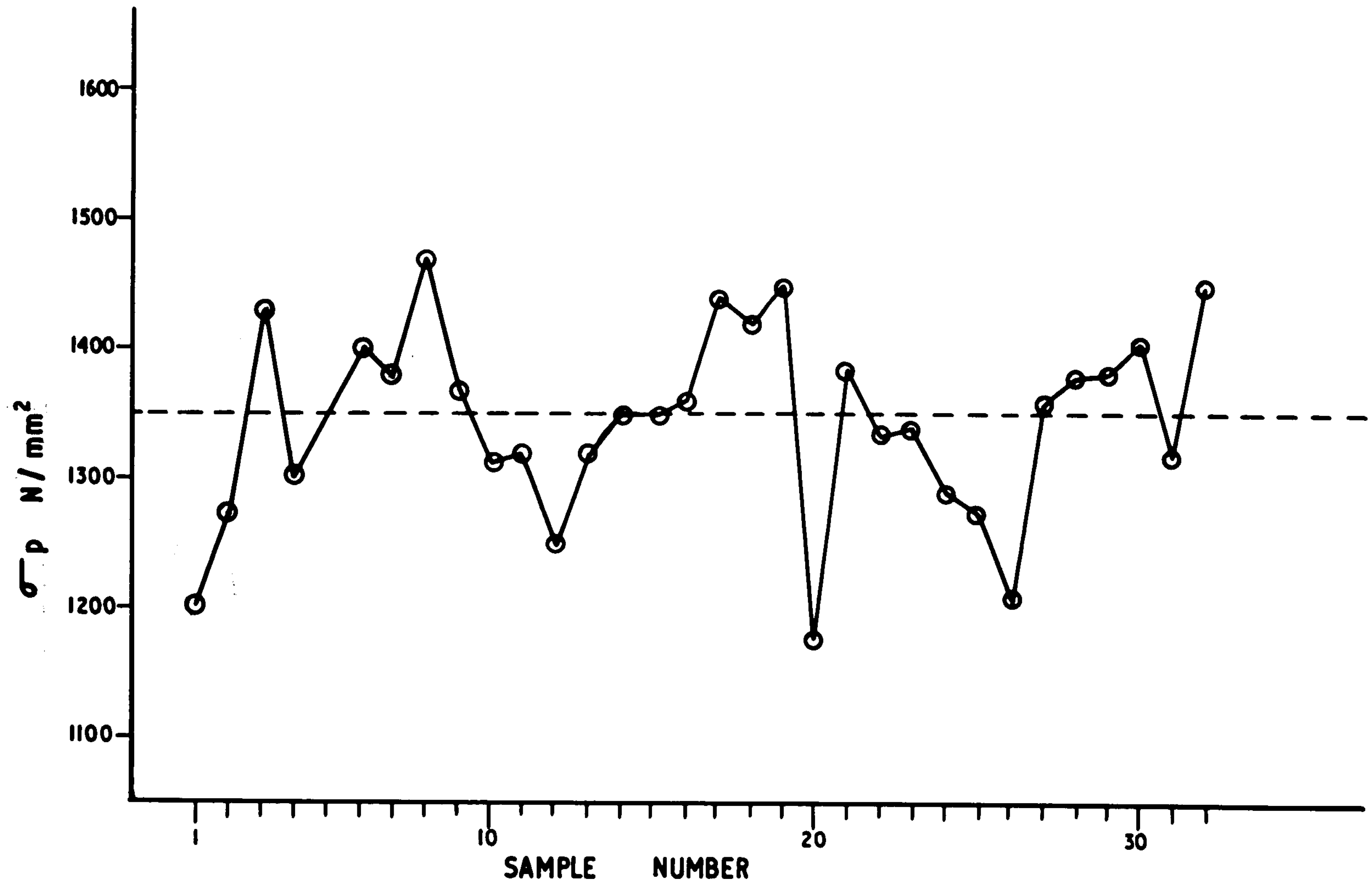

FIG. 5 TRUE LIMIT OF PROPORTIONALITY, σ_p, FOR WIRE 5 (POOR COILY), SAMPLED AT 28 cm. INTERVALS.

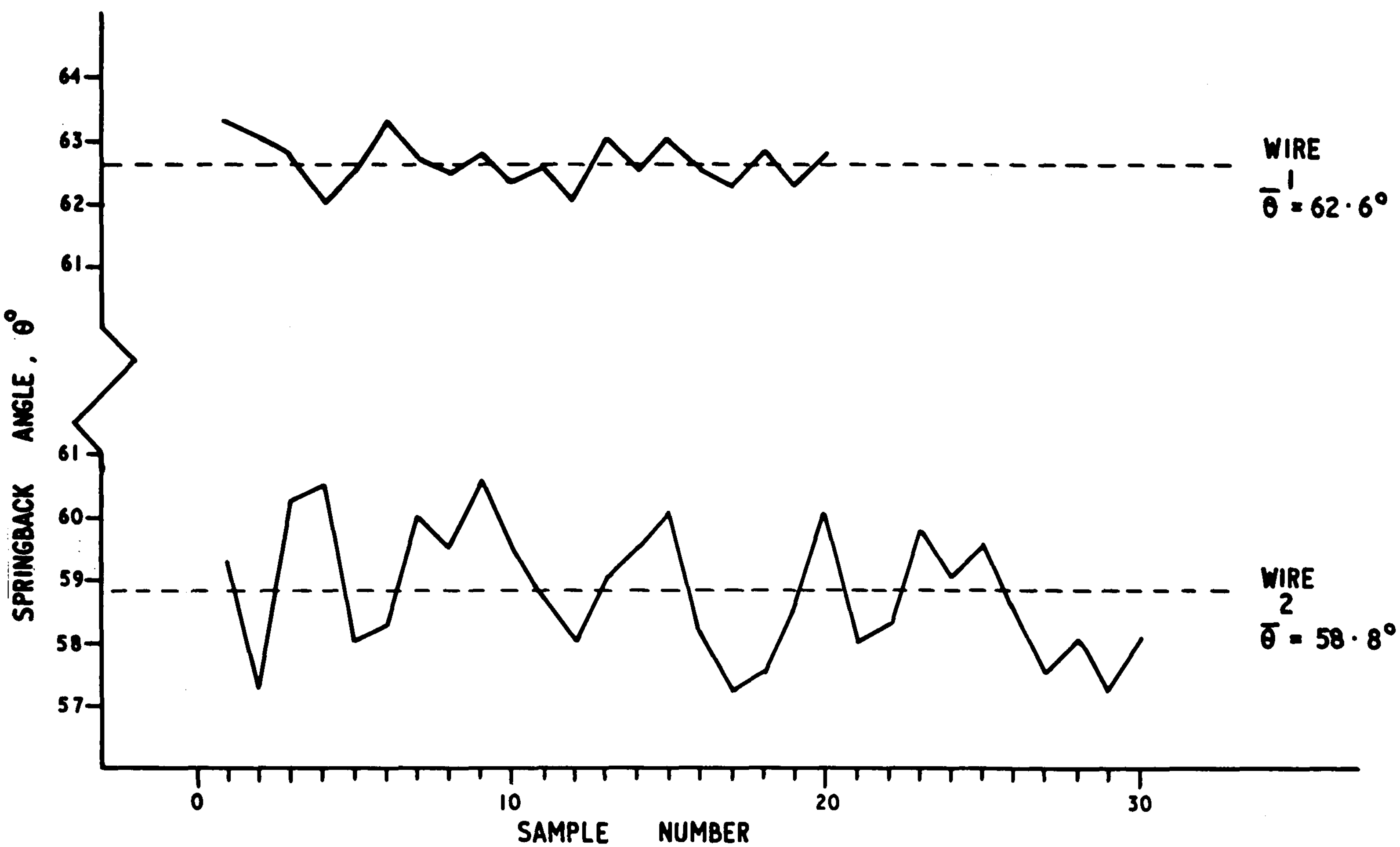

FIG. 6. SPRINGBACK ANGLE θ° FOR WIRES 1 (GOOD COIL γ) AND 2 (POOR COIL γ) SAMPLED AT 20 cm. INTERVALS.

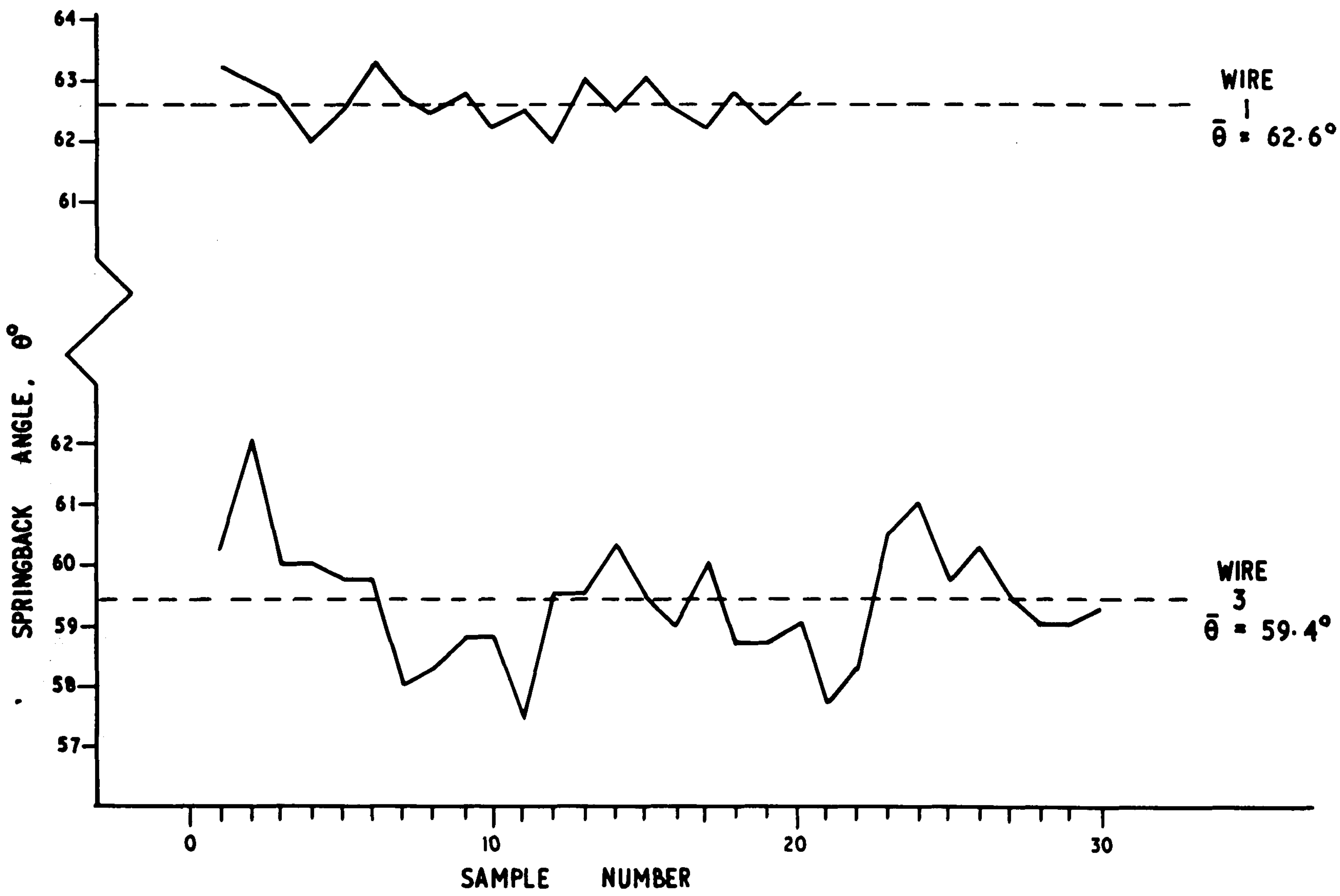

FIG. 7. SPRINGBACK ANGLE θ° FOR WIRES 1 (GOOD COIL^γ) AND 3 (POOR COIL^γ) SAMPLED AT 20 cm. INTERVALS.

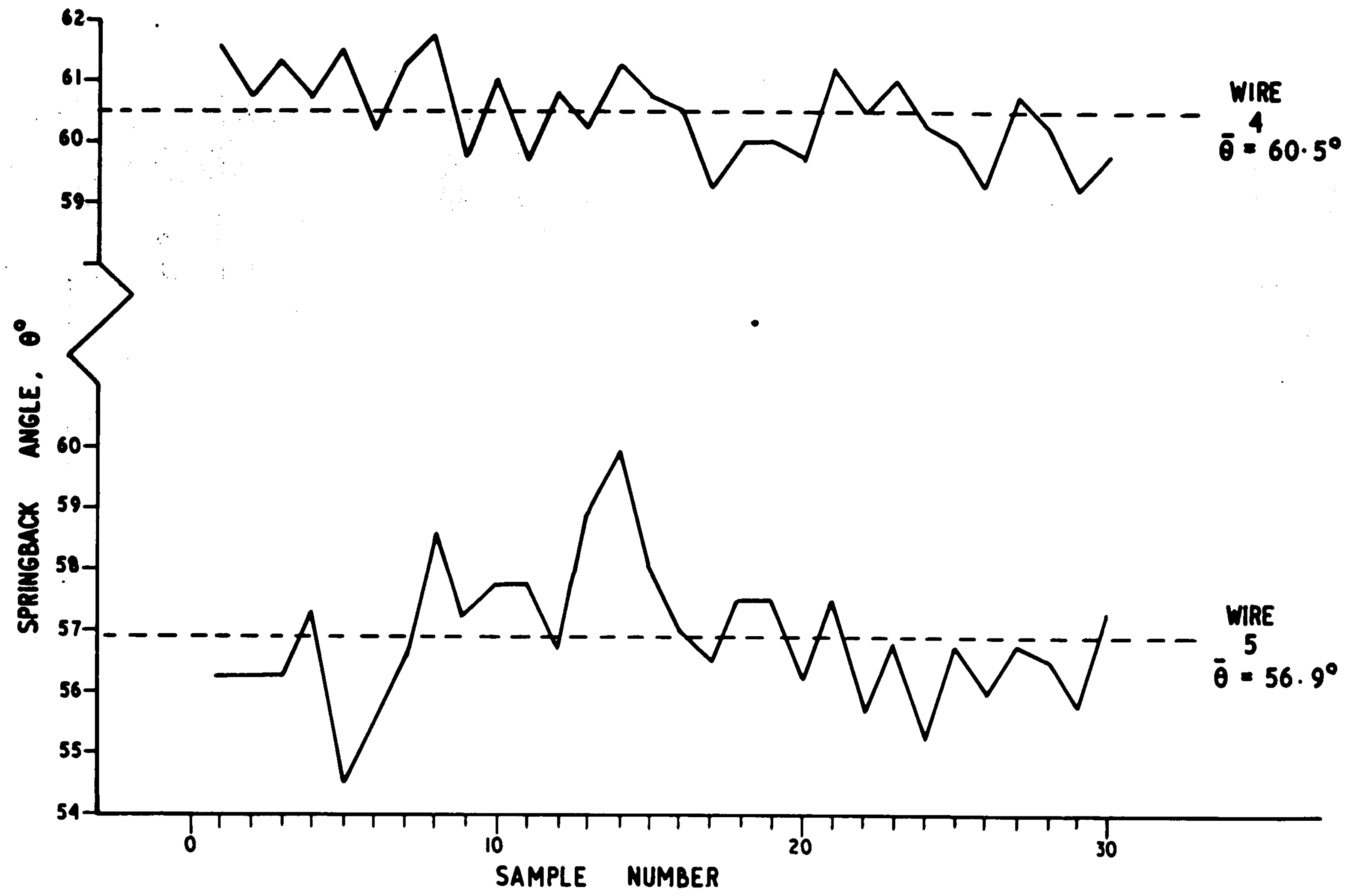

FIG. 8. SPRINGBACK ANGLE θ° FOR WIRES 4. (GOOD COIL γ) AND 5 (POOR COIL γ) SAMPLED AT 20 cm. INTERVALS.