THE SPRING RESEARCH ASSOCIATION

A Study of the Free Length Variability of Springs made from 'Coated' Stainless Steel Wire (En58A)

Report No. 177

by

J.M. Bowles

June 1970

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SUMMARY

This investigation was carried out to determine the effect of coatings of lead, zinc, cadmium, PTFE, and 'Superflo' on the free length variations of springs made from stainless steel wire. The tests were carried out in random fashion and five independent observations were made on each type of coating from each bundle of wire.

A statistical level of significance was only obtained in the case of the short term variance, giving the following order when considering the batches of 5 springs (short term):-

1.	Cadmium	± 0.005	
2.	Lead	± 0.005	
3.	PTFE	± 0.007	± 0.0015 in
4.	Superflo	± 0.008	
5.	Zinc	± 0.014	

During the experiment it was noted that the lead coated wire was far easier to use than any of the others and that the cadmium coated wire gave trouble in feeding from the swift because it unwound freely from the bundle and then tightened onto the centre of the swift. The 'Superflo' coated wire also gave trouble because the coating, being hydroscopic, had picked up moisture and this reduced the lubrication properties to a point where it was no longer possible to coil springs, but these properties were easily restored by heat treating the wire. A further environmental effect was observed when the temperature in the laboratories rose to 29°C and caused the PTFE coating to be deposited on the coiling pin.

The ease of coiling is however only one of the factors that must be considered when choosing a coating since the ease of removal and toxicity

must also be taken into account. Some advice is given in the report on the removal of the various coatings.

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1. INTRODUCTION

This investigation was carried out on a Torrington 115A coiling machine to determine the influence of various coatings on the variability of the free length dimension of the springs produced.

The coatings evaluated were:

1.	Zinc	-	metallic
2.	Lead	-	metallic
3.	'Superflo'	-	sodium stearate and borax
4.	Cadmium	-	metallic
5.	PTFE	-	plastic

2. SPRING DESIGN

Nominal free length	=	1.2 in
Outside diameter	=	0.3 in
Wire diameter	=	0.048 in
Total number of coils	=	16

One coil at each end closed
Coiled left handed
Material B.S. 2056 En58A

This spring design was purposely chosen as being difficult to coil in order to exaggerate dimensional changes. From a production point of view, however, the single point type coiling machine might not be the best for this particular job.

3. EQUIPMENT AND TOOLING

A Torrington 115A coiling machine was used with 'standard' high speed steel tooling as supplied by the machine manufacturer except for the coiling point which was lapped to provide a smoother finish.

The drive rolls were also of 'standard' pattern but the load was applied through a belleville washer and piezo-electric load cell in series. The latter gave a direct reading of the load, which in this experiment was 0. 1 tonf.

4. EXPERIMENTAL PROCEDURE

Each of the five coatings was tested five times, giving a total of twentyfive runs. The random sequence of carrying out the experiment was as follows:-

Coating	Experiment				
	1st	2nd	3rd	4th	5th
Zinc	1	4	2	1	5
Cadmium	4	3	1	3	4
PTFE	5	1	4	2	3
Lead	2	2	3	4	2
'Superflo'	3	5	5	5	1

The coiling machine was then set up to produce the required spring at a drive roll load of 0. 1 tonf, producing 40 springs per minute, and using a motorised swift.

Several hundred springs were coiled at this setting to allow the machine and tools to settle and to attain a working temperature. Five hundred springs were then produced with the machine running continuously; no adjustments whatsoever were made to the machine during this period. Sub-samples consisting of the last five springs of each sample of fifty were collected in sequential order and placed on peg boards for subsequent measurement.

The length data were then punched onto cards in order to compute the means, standard deviations and variances on the I B M 1130 computer. The variances were then analysed using a statistical technique developed and tested by BISRA

5. RESULTS

Table I gives the calculated values for both the long and short term variances. The quantitative measure of the effect of each coating on the 'long' and 'short term' variability, with the corresponding level of significance, is given in Tables II and III respectively. Table IV gives the tolerance on free length for each coating.

Sequence and frequency diagrams are plotted in Figures 1 to 5 and 6 to 10 respectively. A histogram of the free length range for each run is plotted in Figure 11.

6. DISCUSSION OF RESULTS

A statistical analysis was carried out on both the overall variances of the samples and the mean variances of the sub-samples; this gave a measure of the long and short term variations.

The statistical technique used gave a value for the effect of each coating on the free length variation and compared the values with the mean value of the variance estimates to determine the level of significance.

In the case of the long term variation none of the coatings proved to be significantly different from the mean, even with the calculated magnitude of effects given below.

1.	Lead	- .0000342	effect on mean variance 0.0000592
2.	PTFE	- .0000105	
3.	Cadmium	- .0000021	
4.	Zinc	.0000188	
5.	'Superflo'	.0000281	

However, the short term variations were shown to have a high degree of significance, the order being:-

1.	Cadmium	- .0000117	effect on mean variance 0.0000173
2.	Lead	- .0000108	
3.	PTFE	- .0000044	
4.	'Superflo'	- .0000015	
5.	Zinc	+ .0000284	

During the setting up and subsequent running of the coiling machine the operator made several observations. It was noted that the lead coated wire was far easier to use than any of the others. The cadmium coated wire gave trouble in feeding from the swift and this fact appears to be borne out by the results given above. The difficulty arose because the wire ran freely from the bundle until the waps had tightened onto the centre of the swift; this then increased the speed of the turntable until the wire returned to its original state, which resulted in the swift 'hunting' to maintain the wire feed. This type of problem has also been observed with carbon steel wires and with a conventional type of swift and could probably be eliminated by using reels of wire.

It was also noted, during the first run with 'Superflo' coated wire, that the coating, being hydroscopic, had absorbed moisture which reduced the lubrication properties to a point where it was no longer possible to coil the wire. After a discussion with the wire manufacturer the wire was heat treated at 100°C for 15 minutes, which restored the lubrication properties of the coating. It was necessary to repeat the treatment only before the fifth run, which took place several days later.

Since a large number of springs were produced during this experiment (12500 for actual tests) it was necessary to adjust the tooling to bring the spring dimensions back to the nominal design. The main source of wear was the coiling point and this was repolished or replaced before several of the runs. On one occasion during this experiment the temperature in the laboratories rose to 29°C with the result that some of the PTFE coating was deposited on the coiling point causing the end coils to open.

There are several factors which must be considered when choosing a coating since the ease of removal and toxicity must also be considered. For instance the food industry will not accept lead contaminated products, which rules out the use of lead coated wire for the production of springs in such an application.

Most of the coatings are readily removed in acid or alkaline dips but the plastic coatings may be difficult to remove and none of the present methods is 100% successful. If the springs are low temperature heat treated without first removing the coating a very unattractive appearance can result but this can be partially removed by an acid dip. Table V gives details of solutions for removing the coatings investigated

Further tests are required to provide statistical evidence and the total number of observations required would be about 60. This situation has arisen because the variation caused by the coatings was small compared with overall variation in free length due to all causes.

7. CONCLUSIONS

It is important to remember that these conclusions apply to a specific machine, of the single point type, and to one sample of wire in each case; other factors, such as ease of removal and toxicity, will also influence the choice of coating.

A statistical level of significance was not obtained for the long term effect of the five coatings and in order to determine whether statistical levels of confidence could be obtained, further experiments would be required. The different magnitudes of the effects in this investigation suggest that this would be worth while.

The short term variations however, were statistically highly significant, giving the following order:-

1.	Cadmium	± 0.005 in	± 0.0015 in
2.	Lead	± 0.005 in	
3.	PTFE	± 0.007 in	
4.	'Superflo'	± 0.008 in	
5.	Zinc	± 0.014 in	

TABLE I

FREE LENGTH VARIANCE AND MEAN VARIANCE RESULTS

Coating	Run	Variance x 10^{-3} 'Long Term' (in)	Mean Variance x 10^{-3} 'Short Term' (in)
Zinc	1	0.0473	0.0273
	2	0.1015	0.0524
	3	0.1013	0.0536
	4	0.0496	0.0242
	5	0.0903	0.0712
Lead	1	0.0438	0.0104
	2	0.0104	0.0061
	3	0.0199	0.0046
	4	0.0246	0.0073
	5	0.0264	0.0044
'Superflo'	1	0.2367	0.0460
	2	0.1162	0.0057
	3	0.0368	0.0049
	4	0.0137	0.0051
	5	0.0334	0.0177
Cadmium	1	0.0646	0.0072
	2	0.0105	0.0022
	3	0.0210	0.0052
	4	0.0128	0.0036
	5	0.1765	0.0100
PTFE	1	0.0513	0.0084
	2	0.0565	0.0146
	3	0.0318	0.0161
	4	0.0585	0.0142
	5	0.0454	0.0118

TABLE II

STATISTICAL RESULTS 'LONG TERM VARIATION'

Coating	Effect on Variability $x10^{-3}$	t-value	Probability*
Zinc	0.0188	0.78	52%
Lead	-0.0342	-1.42	76%
'Superflo'	0.0281	1.17	68%
Cadmium	-0.0021	-0.09	6.6%
PTFE	-0.0105	-0.44	30%

Mean variance of all observations= 0.0000592
F ratio value = 1.6 (Not significant)

TABLE III

STATISTICAL RESULTS 'SHORT TERM VARIATION'

Coating	Effect on Variability $x10^{-3}$	t-value	Probability*
Zinc	0.0284	5.26	98%
Lead	-0.0108	-2.01	88%
'Superflo'	-0.0015	-0.27	20%
Cadmium	-0.0117	-2.17	90%
PTFE	-0.0044	-0.81	52%

Mean variance of all observations = 0.0000173

F ratio value = 10 (Significant at 0.1% level)

* The probability value shows whether the effect has an influence on the mean value and a probability of 0.95 is normally accepted as the minimum for significance.

The F ratio value is the ratio of the variance of the effects to the residual variance and determines whether the effects are significantly contributing to the overall variance.

TABLE IV

CALCULATED FREE LENGTH TOLERANCES

'Long Term' **

Coating	Variance σ^2	Standard Deviation σ	95.4% Range $\pm 2\sigma$	99.7% Range $\pm 3\sigma$
Lead	.000025	.005	± .010	± .015
PTFE	.000049	.007	± .014	± .021
Cadmium	.000057	.008	± .015	± .023
Zinc	.000078	.009	± .018	± .026
'Superflo'	.000087	.009	± .019	± .028

'Short Term'

Coating	Variance σ^2	Standard Deviation σ	95.4% Range $\pm 2\sigma$	99.7% Range $\pm 3\sigma$
Cadmium	.0000056	.002	± .005	± .007
Lead	.0000065	.003	± .005	± .008
PTFE	.0000130	.004	± .007	± .011
'Superflo'	.000016	.004	± .008	± .012
Zinc	.000046	.007	± .014	± .020

Note: The confidence limits on the $\pm 2\sigma$ tolerances given above are ± 0.0015 in.

** The differences between these variances were not statistically significant and therefore the coatings cannot be accepted as appearing in this order.

TABLE V STRIPPING SOLUTIONS FOR REMOVAL OF COATINGS

Coating	Stripping Chemical	Dilution Aqueous solution	Additive
Cadmium	Hydrochloric Acid	50% v/v	33 ml/l Inhibitor
	Ammonium Nitrate	120g/l	
	Ammonium Persulphate	50g/l	100 ml/l Conc: Ammonia (30%)
Lead	Glacial acetic acid	330 ml/l	50 ml/l Hydrogen Peroxide
	Nitric Acid	15-20% v/v	
Zinc	Hydrochloric Acid	50% v/v	33 ml/l Inhibitor
	Caustic Soda (boiling)	10-20% w/w	
	Sulphuric Acid	2% v/v	2g/l Arsenic Acid
PTFE	Acetone agitation and fume extraction required 60°C.		
	Nitric Acid 60°C (suitable after low temperature heat treatment of wire)	20-50% v/v	
'Superflo'	Nitric Acid	15-20% v/v	

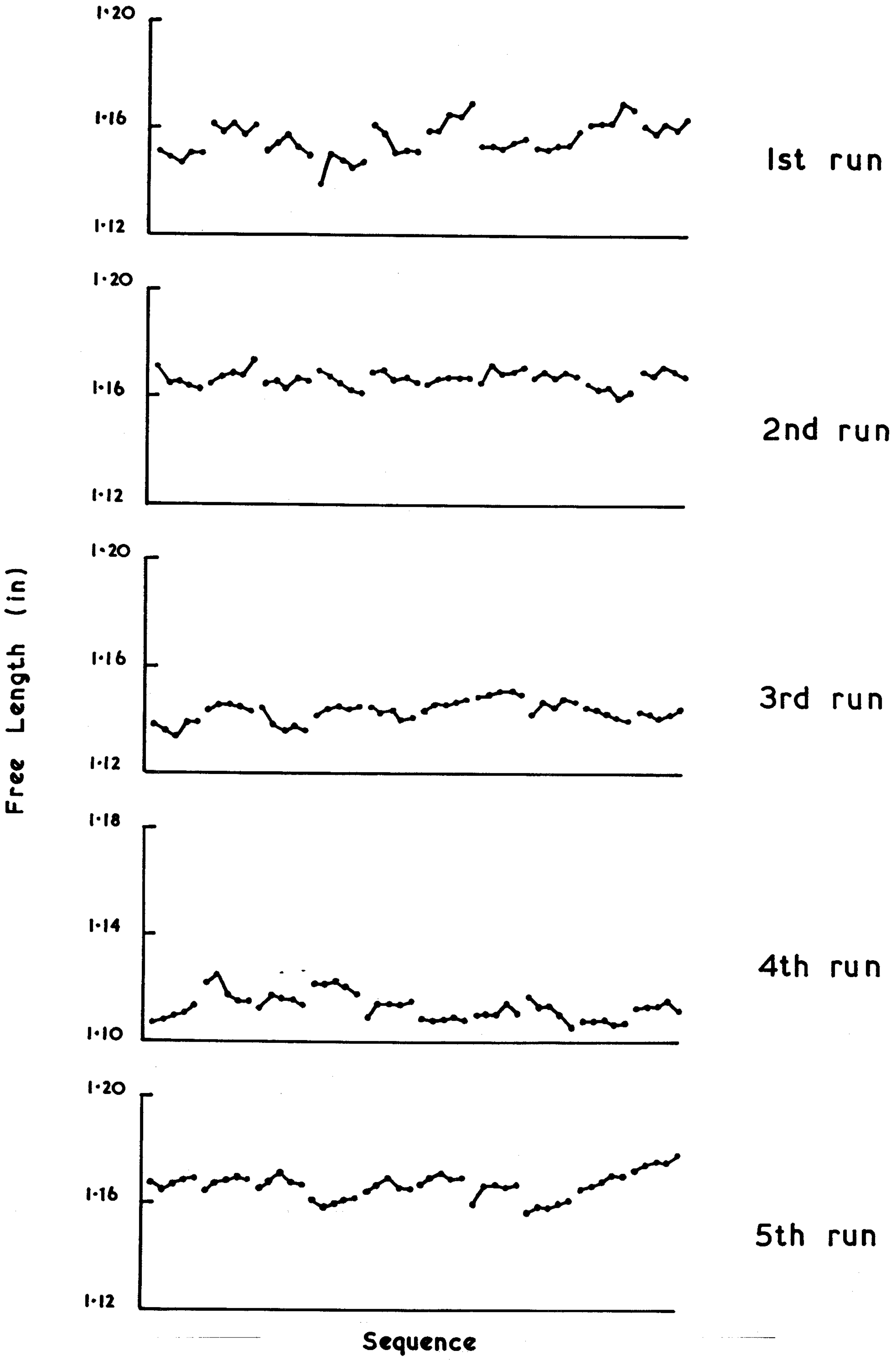

FIG. I. SEQUENCE DIAGRAMS FOR LEAD COATED WIRE

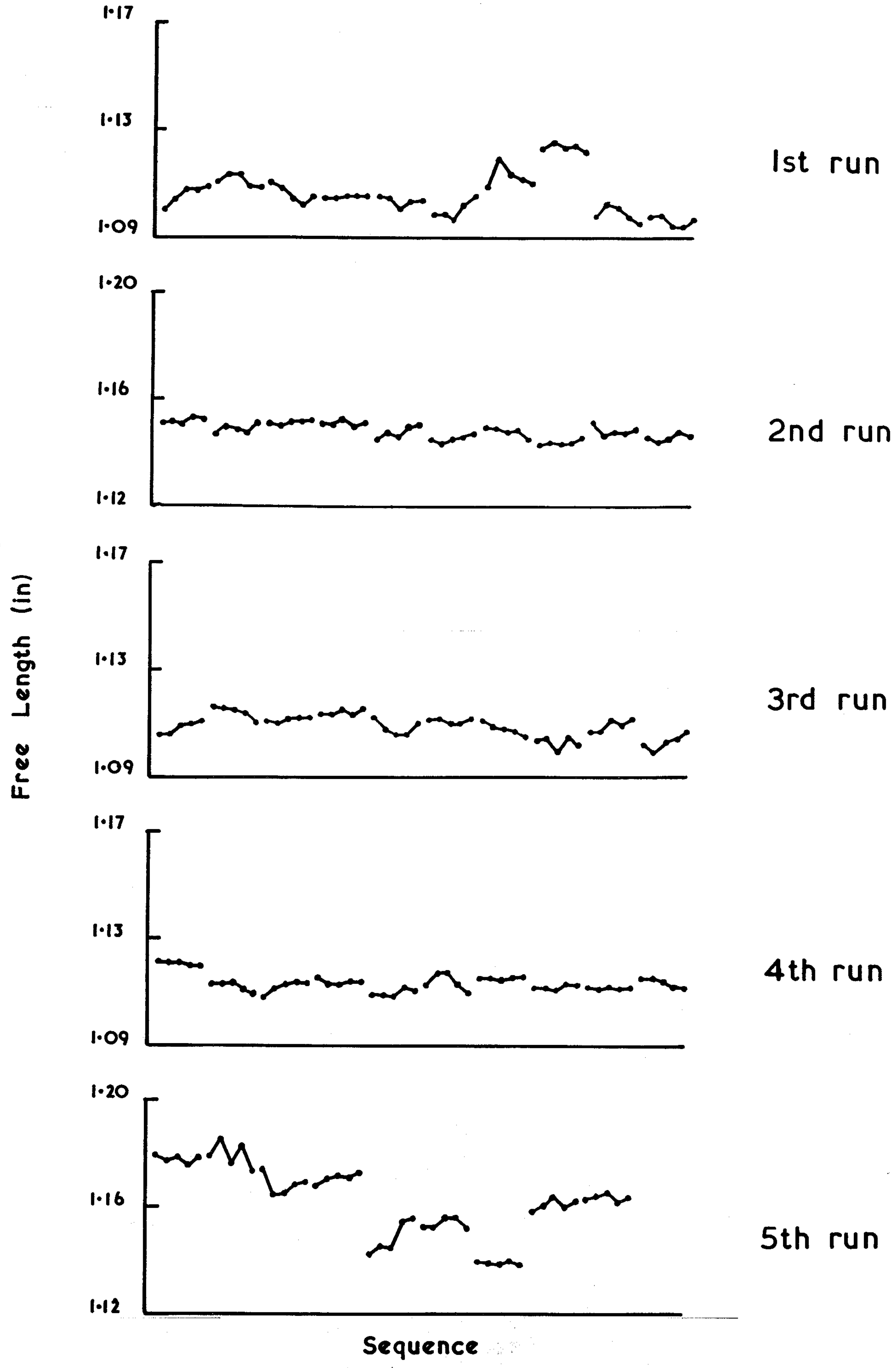

FIG. 2. SEQUENCE DIAGRAMS FOR CADMIUM COATED WIRE

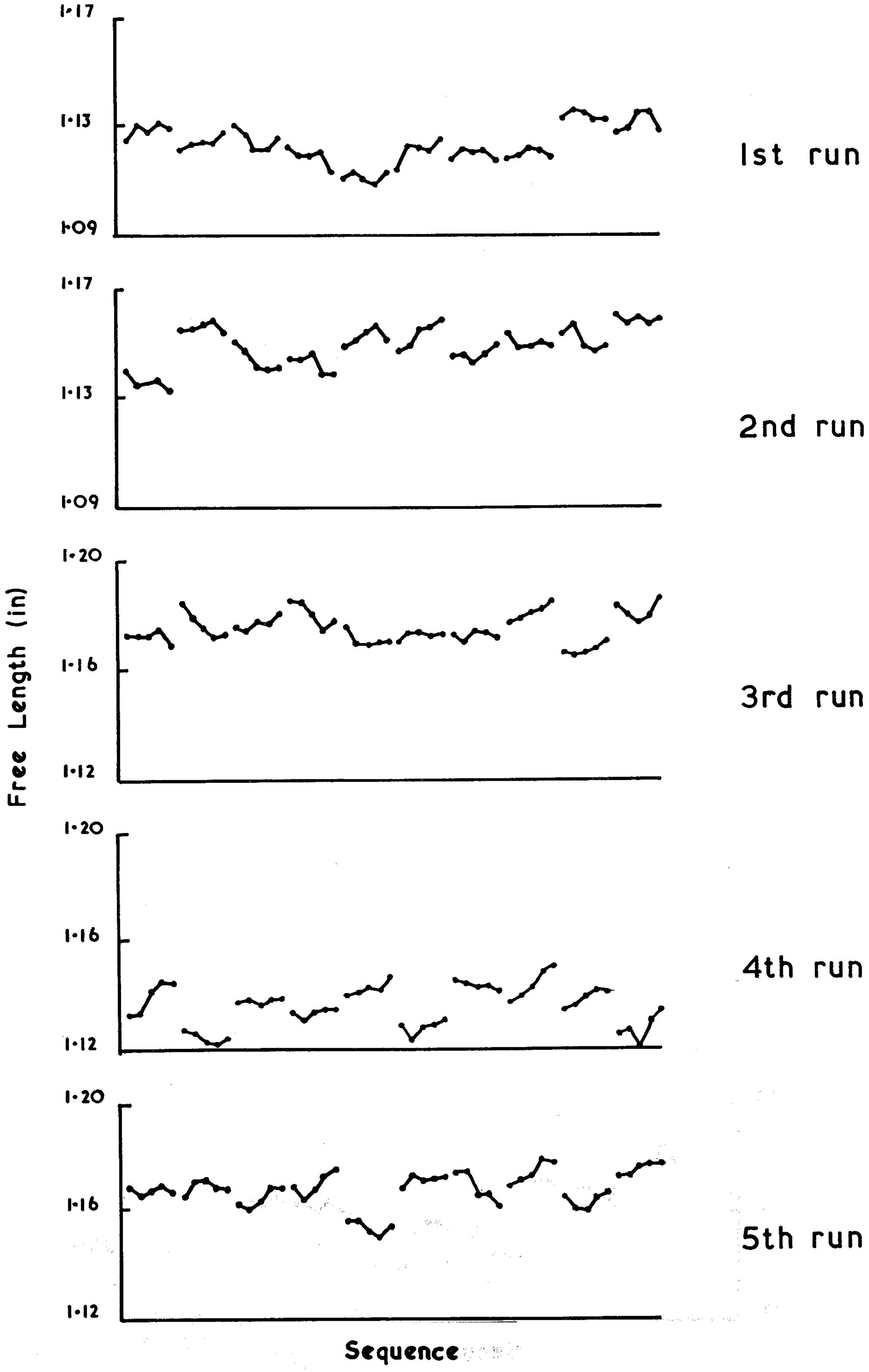

FIG. 3. SEQUENCE DIAGRAMS FOR P.T.F.E. COATED WIRE

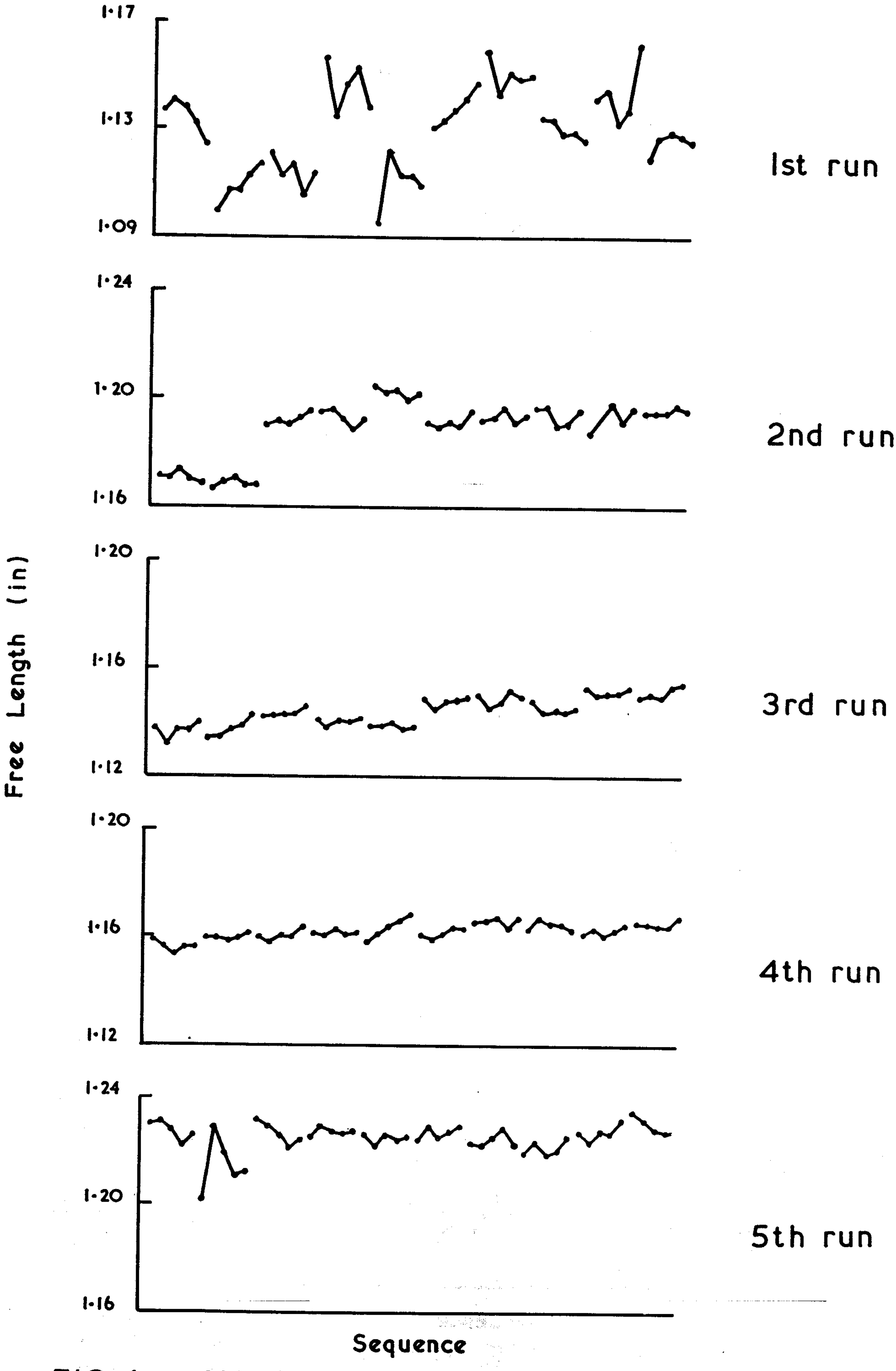

FIG. 4. SEQUENCE DIAGRAMS FOR 'SUPERFLO' COATED WIRE

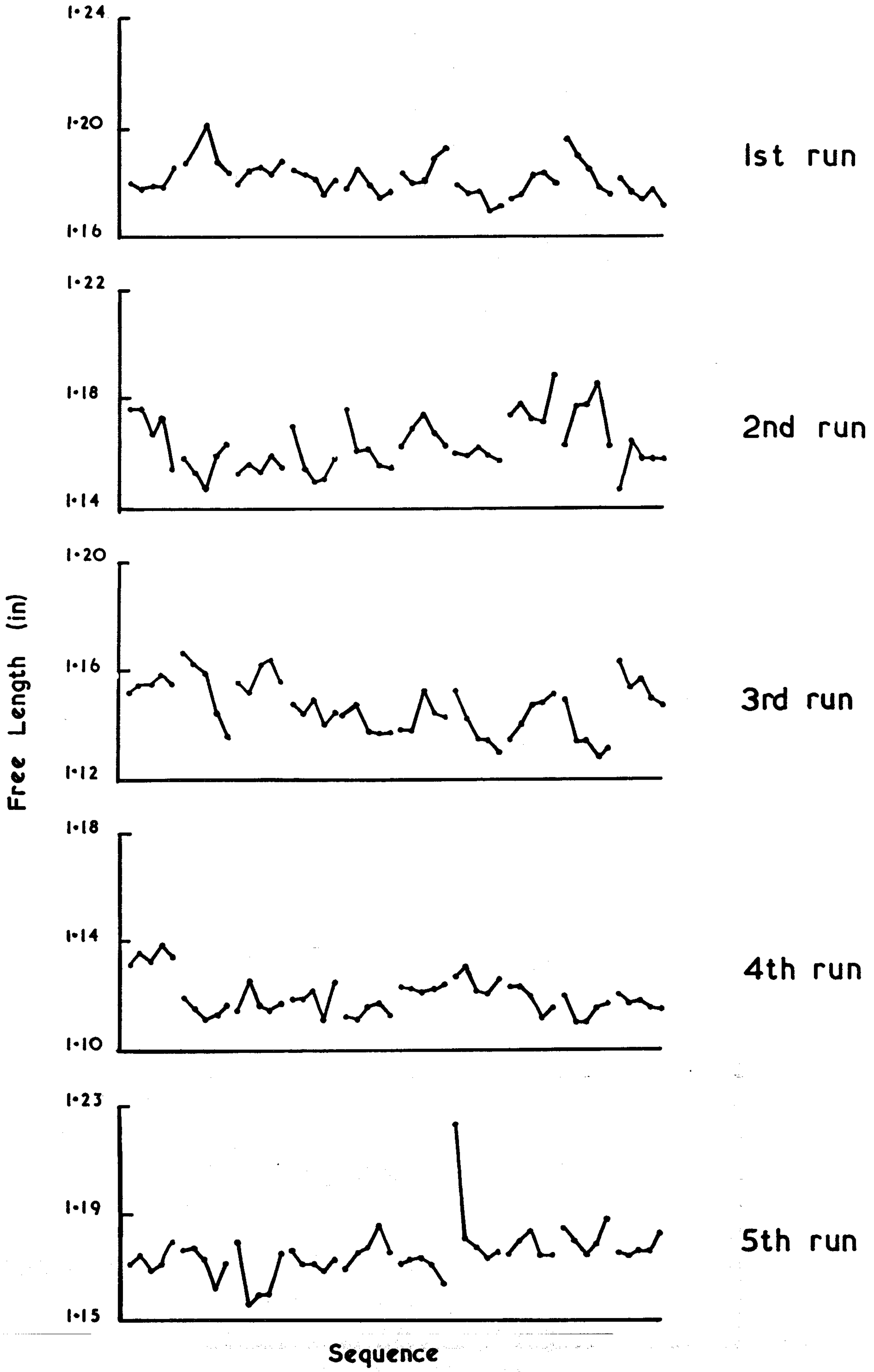

FIG. 5. SEQUENCE DIAGRAMS FOR ZINC COATED WIRE

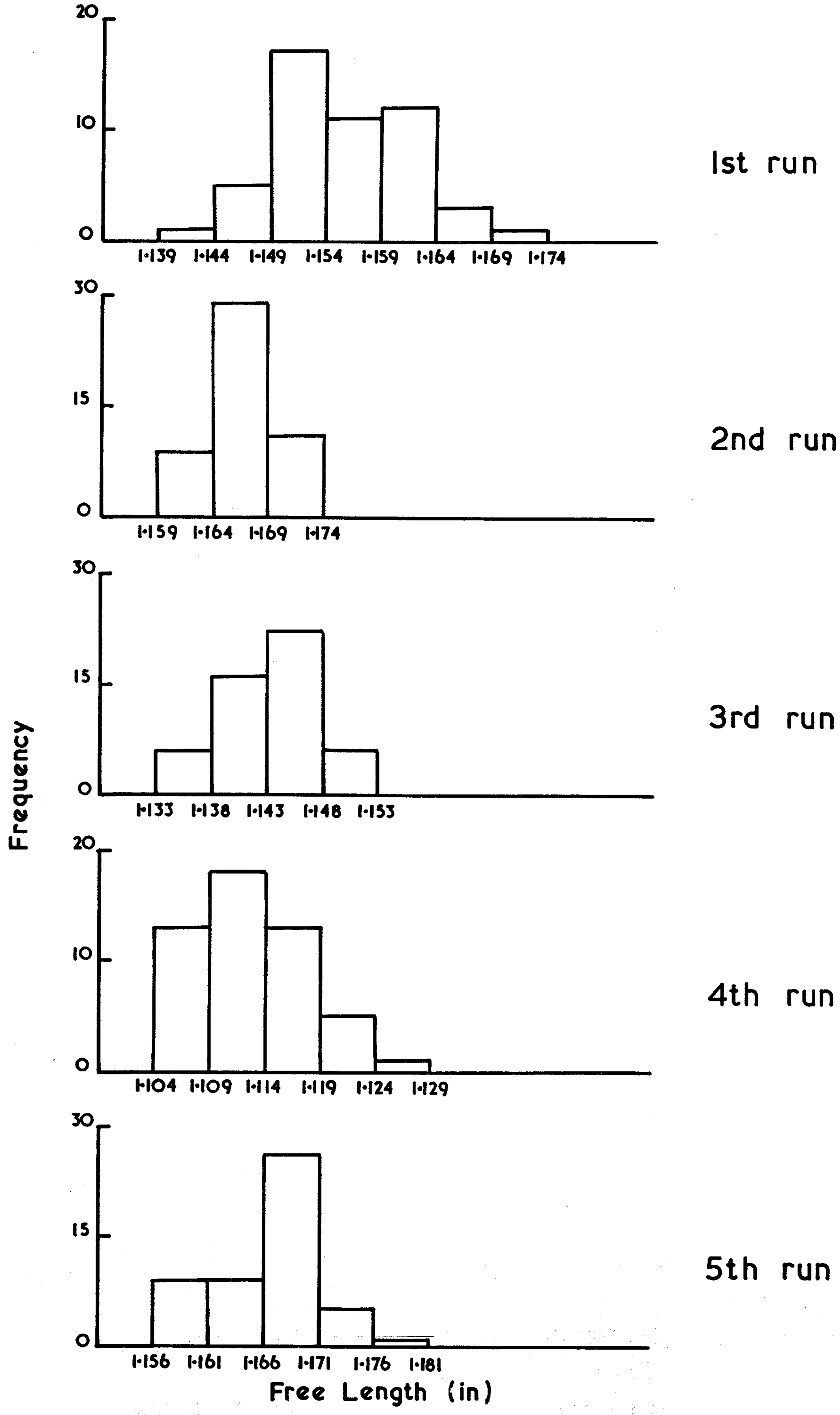

FIG. 6. FREQUENCY DIAGRAMS FOR LEAD COATED WIRE

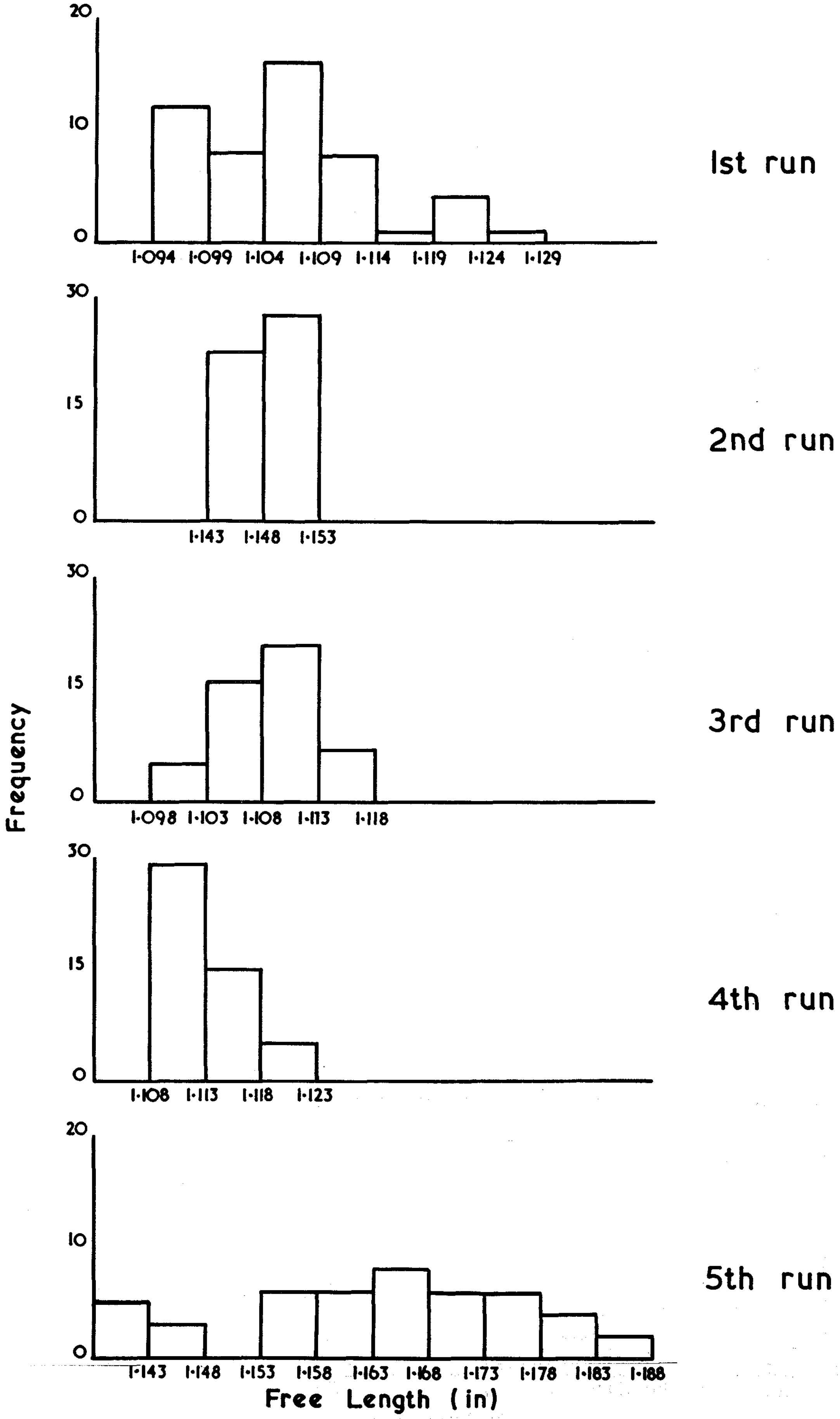

FIG. 7. FREQUENCY DIAGRAMS FOR CADMIUM COATED WIRE

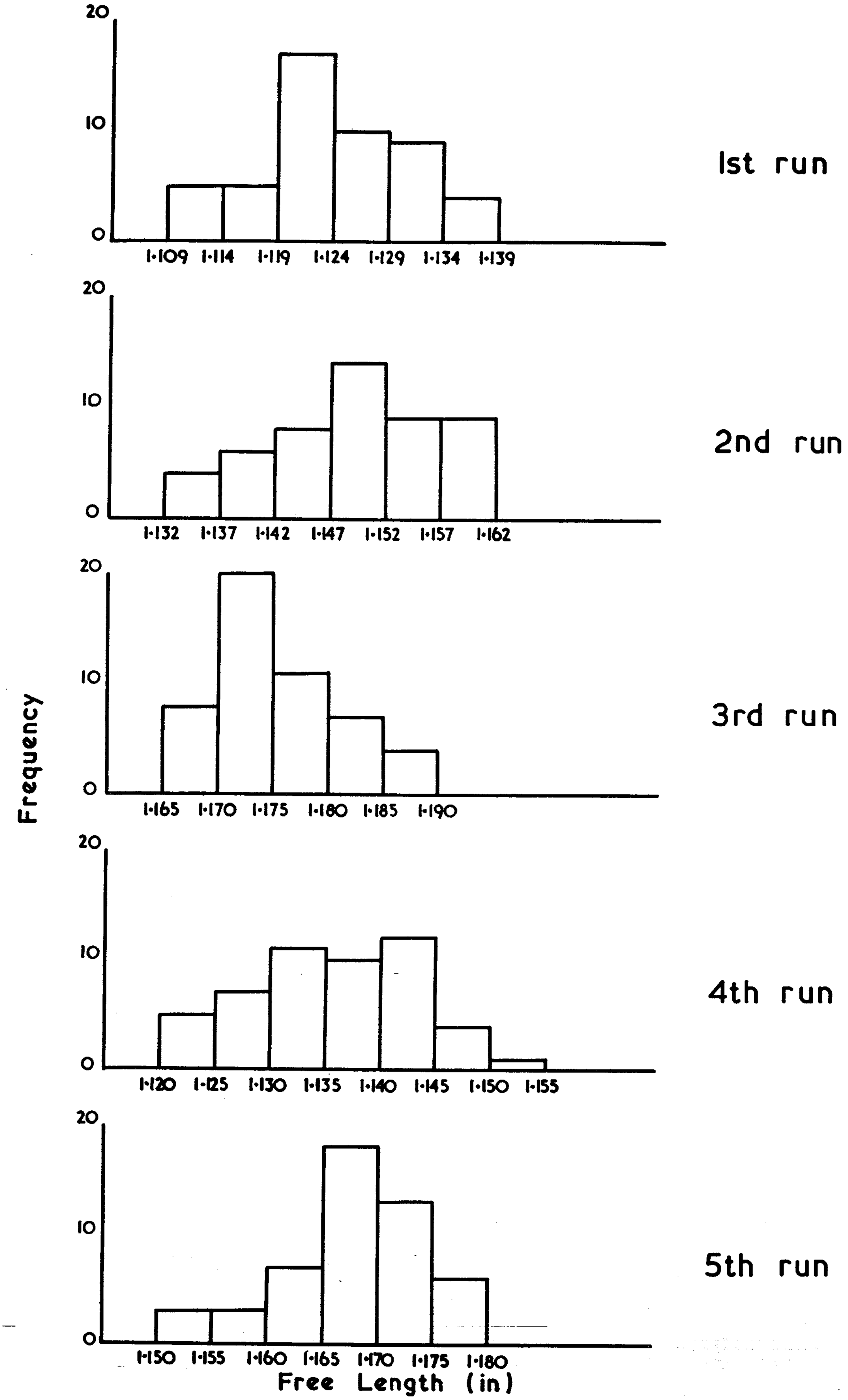

FIG. 8. FREQUENCY DIAGRAMS FOR P.T.F.E. COATED WIRE

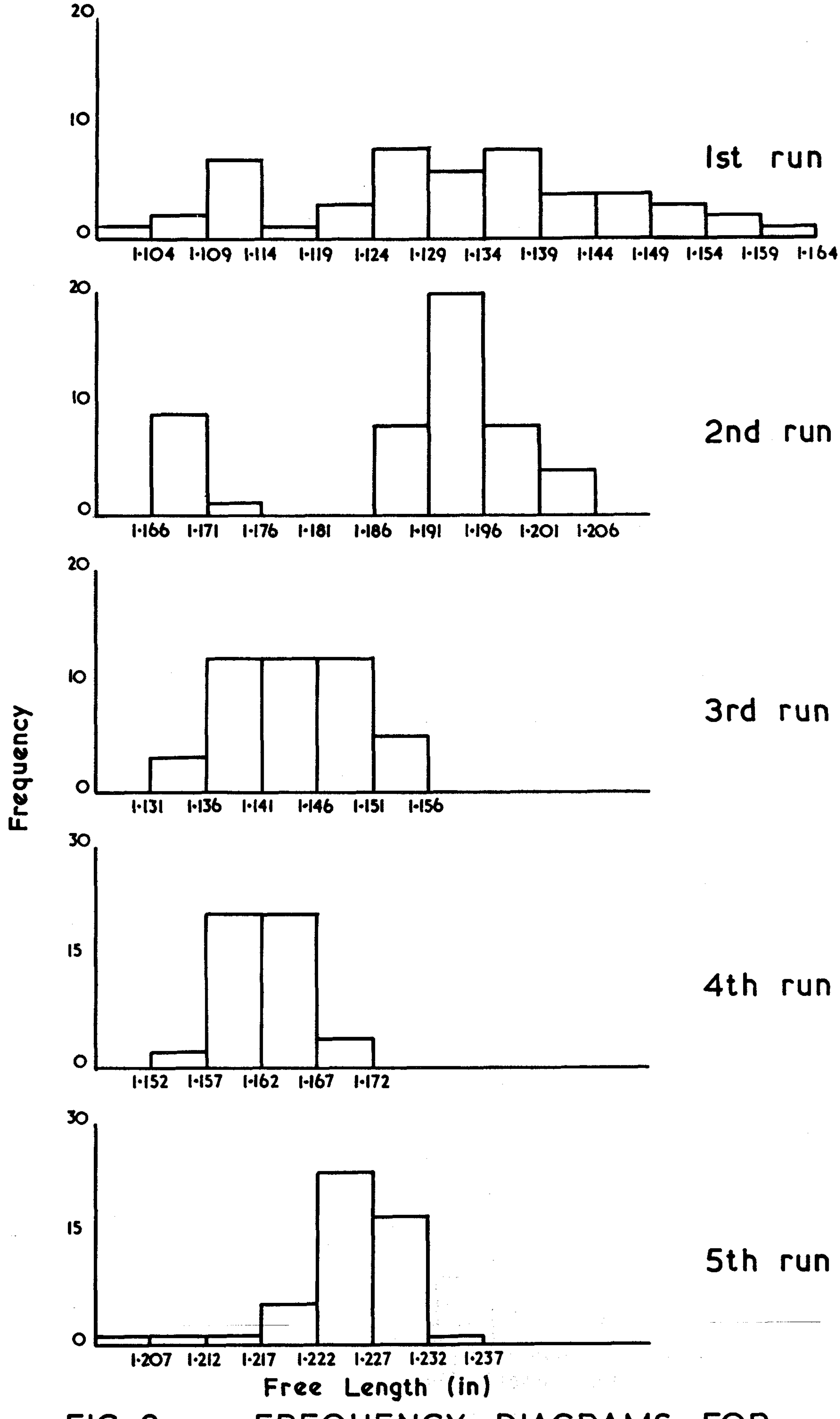

FIG. 9. FREQUENCY DIAGRAMS FOR 'SUPERFLO' COATED WIRE

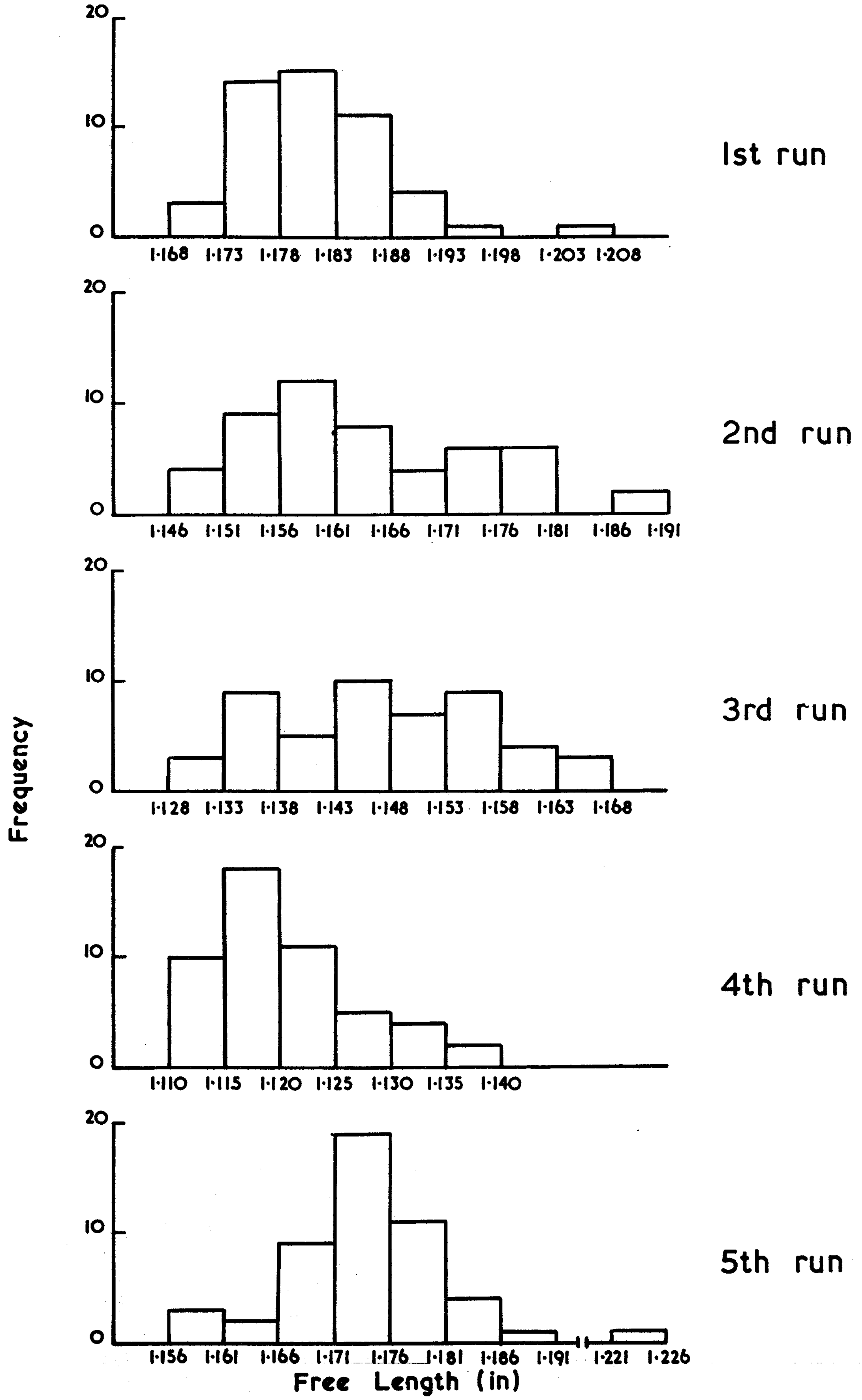

FIG. 10. FREQUENCY DIAGRAMS FOR ZINC COATED WIRE

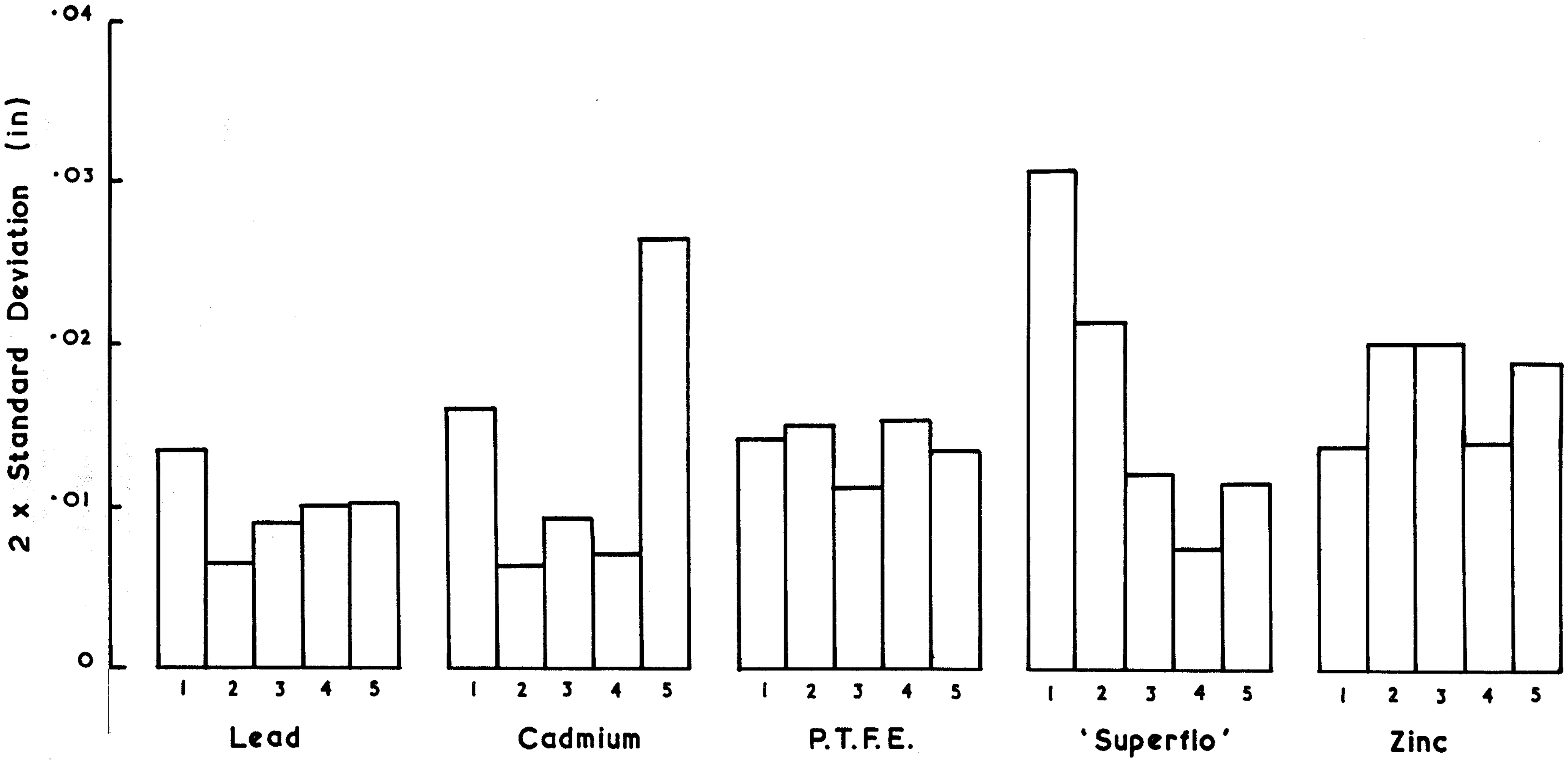

FIGURE 11. HISTOGRAM OF TOLERANCES OBTAINED FOR EACH SAMPLE