THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

MEASUREMENT OF SPRINGS

by

D. Saynor, B.Sc.

Report No. 309

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SUMMARY

An investigation has been carried out into the methods of measuring the free length, diameter, load/length, and squareness of springs. Commercial practices have been surveyed, and at SRAMA headquarters several methods have been analysed in detail to determine the most precise method for measuring each parameter.

In general, the spring industry was found to use methods which were fast and simple to use, with precision only a secondary consideration, and hence there was seen to be a need for standard, precise, measurement methods in case of disputes.

From the results of the analysis the following recommendations are made:

1. For measurement of free length and load/length an electronic load cell spring tester provides the most precise measurements whilst being reasonably quick and easy to use.

2. For diameter measurement, if the spring length is less than the platen diameter on the electronic load cell spring tester then this is the most precise method. However, the height gauge is recommended for springs in which this condition is not met.

3. For squareness measurement, ground tapered jigs on a surface plate give the greatest degree of precision combined with speed and simplicity.

4. For all methods at least 3 readings should be taken and averaged

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1. INTRODUCTION

In the current British Standard BS 1726 for the design and specification of coil springs, parameters such as free length, outside diameter, load/length and squareness are defined and toleranced. However, the methods used to measure these dimensions are not stipulated. This can lead to discrepancies in values obtained by customer and supplier, and also by inspectors using different equipment within the same company.

It would therefore seem logical to attempt to achieve method standardisation and to remove the use of different techniques as a source of error. This project was undertaken to evaluate the various current methods of measuring spring dimensions, and to put forward recommendations for a definitive method to determine each parameter.

To investigate normal commercial practice a questionnaire was sent to the quality control department of member companies. To analyse commercial methods of load testing, 3 springs were sent to several companies for load testing by various inspectors on different machines.

Finally, at SRAMA Headquarters three different sample springs were measured by several members of staff using six different methods. The results were analysed to determine which method was most precise and least subject to human error.

2. PARAMETERS SPECIFIED IN BS 1726

The following is a list of the spring parameters which are defined and toleranced by the current BS 1726, and which may therefore require measuring:-

Free length	-	defined in BS 1726 as "the distance between two parallel plates, perpendicular to the axis of the spring, and in contact with the end coils or part of the end coils".
Coil diameter	-	"The diameter of the helix (outer or inner surfaces) when the spring is unloaded. The diameter may be measured at any position along the spring".
Load/length	-	"the length of a spring under the steady application of a given axial load, or alternatively the load required to compress the spring to a given length".
Squareness	-	this is not defined in words by BS 1726 but is the maximum horizontal distance of the outside diameter from a vertical line perpendicular to the end coil.
Solid length	-	"the length at which a reasonable increase of load produces no perceptible decrease in length when the spring is slowly compressed (i.e. in principle when metal to metal contact occurs)".

The rate of a spring is toleranced by the standard, but since this factor is based upon measurements of load/lengths, only the methods of determining load/length were considered in this report.

Similarly, the solid length is measured using load procedures and the best load/length measurement method would also be the best method for measuring solid length.

Wire diameter is an important dimension also, however, wire diameter cannot be accurately measured after the spring has been coiled, and since the tolerances and measurement are related to the appropriate wire standards, this dimension is not usefully considered by the project.

For the determination of the squareness of a spring BS 1726 does outline a method using a flat plate and set square. However, the gap between the square and the spring is only specified as being measured by "a suitable measuring device" which leaves the method of measurement rather ill defined.

From consideration of the foregoing it was decided that the parameters which were of primary importance and therefore whose appropriate measurement methods required study were free length, diameter, load/length and squareness.

3. SURVEY OF COMMERCIAL MEASUREMENT METHODS

A questionnaire was sent to member companies which sought information on all methods used by a company to measure the free length, diameter, squareness, and load/length of springs which they manufactured. The survey was not intended to be comprehensive, but to act as a general indication of the most commonly used measurement techniques within the spring manufacturing industry. Table I is a summary of the methods used by companies.

Free length measurements were usually taken as being the maximum free length, although certain companies measured free length at ¼ turn into the helix on the basis that this gave an indication of the mean free length. The common free length measurements on extension springs were overall length and length inside the loops. Table I also outlines the method used to support springs whilst the measurements were being made. For flimsy springs in methods where 'hand holding' was normally used the spring was often placed on a supporting peg and measurements made in the horizontal position. For diameter measurements the outside diameter was usually the maximum diameter taken from overall measurements of the spring. However, some manufacturers measured the end coils only, probably assuming that this was the position of maximum outside diameter. If inside diameter was measured it was always the minimum diameter which was taken. This generally was assumed to occur in the centre of the spring.

4. SURVEY OF COMMERCIAL ACCURACY OF LOAD/LENGTH MEASUREMENTS

In order to assess the accuracy to which commercial load/length measurements are made, 3 springs were submitted to various manufacturers for load/length testing in accordance with the procedure given in Appendix A. Each of the companies involved were asked to measure each of the 3 springs using separate combinations of a machine with various operators and/or an individual operator with various machines. Each machine/operator combination produced 16 readings for each spring. The results are shown in Table II (i), (ii), (iii) for each of the three springs.

In the Table II; A, B, C, D and E are the companies involved and the numbered columns are the different machine/operator combinations within each company. The vertical numbers 1-8 relate to the 8 different positions of the spring at which the load at 1" height was taken. The + and - signs relate to measurements taken on compression and release respectively. For each operator/machine combination the mean of the 16 readings was calculated, and then the average of all the mean values taken with the tolerance of the highest and lowest mean value expressed as a percentage. The values gave a variation of approximately $\pm 2\frac{1}{2}\%$ for this. The calculation was repeated for the highest and lowest individual readings and gave a variation of approximately $\pm 3\frac{1}{2}\%$.

The springs used were light with 10 coils, hence according to BS 1726 the load tolerance was $\pm 5\%$ (if the springs were required to be of Class A standard). It does not seem consistent to specify a spring with a load tolerance of $\pm 5\%$ when commercial methods give a variation of approximately $\pm 3\frac{1}{2}\%$ in measured load. A spring could actually be only within $\pm 8\frac{1}{2}\%$ of the required load and yet be accepted as within the specified tolerance by certain companies. This clearly shows the need for a standard, more precise method of load measurement so that the tolerances given in the BS 1726 become meaningful. The results of Table II also indicate the necessity of taking several readings of the load in order to reduce the measured load tolerance (in this case from $\pm 3\frac{1}{2}\%$ to $\pm 2\frac{1}{2}\%$).

5. ANALYSIS OF MEASUREMENT METHODS AT SRAMA

As discussed in section 2 the important parameters which require measuring are free length, outside diameter, load/length and squareness. For each parameter an assessment was carried out into possible measurement methods which existed at SRAMA Headquarters. Each measurement method was then carried out by 7 operators on 3 different compression springs, the designs of which are given in Table III. (The springs used were not those used for the commercial survey of load/length measurement). For each method on each spring, individual operators took 5 separate readings.

5.1 Methods Used

For the measurement of free length and outside diameter 6 different methods were used.

(i) Vernier:

The vernier used was graduated in 0.001 in. divisions. The range of measurement was from 0 to 190 mm and the jaws were 45 mm long by 4 mm thick. The spring was held in the hand whilst being measured.

(ii) Dial Gauge:

The dial gauge used was graduated in 0.01 mm divisions and was fitted with a ball end. The spring was stood on a surface plate and the dial gauge rigidly supported on the plate via a magnetic block. The zero position on the dial gauge was set to the nominal value of the dimension being measured using slip gauges. The dial gauge was not used on spring C free length measurement because the spring was too flimsy for relevant measurements to be made.

(iii) Profile Projector:

The profile projector used was graduated in 0.001 mm divisions and was fitted with lenses for 10X, 20X and 50X magnification. The table measured 140 mm x 120 mm and the cross wires on the screen were 300 mm long corresponding to distances on the springs of 30 mm, 15 mm and 6 mm at 10X, 20X and 50X magnification respectively. The springs were held in position horizontally on the table by bringing one end of the spring up to a magnetic block.

(iv) Conventional Mechanical Spring Load Tester:

The load tester was fitted with a dial gauge graduated in 0.001 in. divisions. The platen was 50 mm diameter, and the maximum distance between top and bottom platen was 110 mm. The dimension was measured by placing the spring on the bottom platen and bringing the top platen down to the spring until contact was made, which was indicated by the balance scale just registering a load. The dial gauge was zeroed to the nominal value of the dimension being measured using slip gauges.

(v) Height gauge:

The height gauge was graduated in 0.01 mm divisions and had a range of 0-300 mm. It was used on a surface plate with the spring free standing.

(vi) Electronic Load Cell Spring Tester:

The load cell tester was fitted with a dial gauge graduated in 0.01 mm divisions. The platen was 45 mm diameter, and the maximum distance between the top and bottom platen was 100 mm. It was used in a similar manner to the mechanical tester except that the load was registered on a digital readout.

For the measurement of load/length, three methods were used.

(i) Avery Load Tester:

Two Avery machines were used. The larger, having a capacity of 220 lbs, was used for springs A and B, and the smaller, having a capacity of 20 lbs, was used for spring C. The load length was set using slip gauges.

(ii) Comaco Load Tester:

Two sizes of Comaco machines were used. The larger (200 lbs capacity) used for springs A and B, the smaller (25 lbs capacity) for spring C.

(iii) Electronic Load Cell:

This machine was only used for spring C since the capacity of the load cell was only 22.5 lbs (100N). The digital load readout was in stages of 0.01N.

For the measurement of squareness the following three methods were used:

(i) Square and Feelers:

The spring was rotated next to a square on a surface plate and the gap between the square and the spring measured using feeler gauges.

(ii) Profile Projector:

The spring was located horizontally against a magnetic block on the projector table, and the screen rotated until the cross wires lay along the outer line of the coils. The angular rotation of the cross wires was noted and this was then converted back into units of in/in length.

(iii) Taper Gauges:

The springs were rotated next to taper gauges stood on a surface plate. Only 2 gauges were available corresponding to Class A and Class B squareness tolerances for light springs from BS 1726 (i.e. 0.02 in/in length for Class A and 0.04 in/in length for Class B).

5.2 Results and Discussion

(a) Free Length and Diameter Measurement

No real purpose would be served by listing the 1215 individual measurements made, and so this is omitted from the report. For both the free length and diameter measurements an Analysis of Variance was conducted to determine which factors had the greatest effect on the measurements obtained. (For a full description of this statistical method see chapter 19 of M.J. Moroney's 'Facts from Figures' Pelican). The factors considered in the analysis were the operator conducting the measurements, the method used, and the spring being measured. The results of the Variance ratio significance analysis are summarised in Table IV.

From Table IV it can be seen that the method used for measuring both the free length and diameter of a spring is highly significant (i.e. the measurement taken is highly dependent upon the method used). The probability that the signficance obtained from the measurements made in these tests could have occurred by chance, is less than a thousand to one. This emphasises the need for standardisation of a single method of measuring spring dimensions.

It can also be seen from Table IV that for the free length measurement the operator is a highly significant factor, whilst for the diameter measurement this is only of possible significance (probability is one in twenty that the significance obtained was due to chance alone). The significance reflects a lack of consistency between operators which is due to different operators applying different value judgements when taking a measurement (e.g. different 'feels' on a vernier and height gauge, different zeros on a profile projector etc.) The measurement method can only reduce this human factor if it reduces the amount of 'value judgement' in a method (e.g. digital instead of analogue readouts etc.). Probably the best way to reduce the variation introduced by this factor is to define as closely as possible the processes all operators must undertake when using a particular method of measurement, and training the operators in their use. The spring being measured is probably a significant factor also. Little can be done in this respect except possibly to alter the standard method of measurement to suit a particular type of spring.

To summarise, the method of measurement had proven to be the single most important factor producing varation in the measurements obtained. In the light of this it was decided that the best method would be that which consistently gave the lowest standard deviation (i.e. least scatter) for the different springs when all the readings taken by different operators using that method were pooled. This is summarised in Table V where the standard deviation and mean are given for each method on each spring. From consideration of Table V it is clear that the electronic load cell tester was the method which consistently gave least scatter in the readings taken, irrespective of the operator taking the readings and the spring being measured. This was probably due to the fact that there was very little value judgement involved in the method, and hence the human error was minimised. The load readout was digital and hence the point at which the readout changed from 0.00 to 0.01N was precise. The only judgement required by the operator was to decide upon the dial gauge reading and even this could be removed by fitting the tester with a digital readout of length. There were also very few initial 'setting up' errors introduced by the operator since the dial gauge was zeroed using slip gauges set to the nominal value of the dimension taken.

In comparison with the load cell method, the profile projector was seen as a very poor method because setting up the spring on the table with its end coils aligned with the cross wires was an involved and lengthy procedure requiring much patience. Also, very important value judgements were required in order to decide when the image of the spring was in focus and when the cross wires of the screen were touching the image. The poor performance of this instrument was a disappointment since with a 50X magnification and 0.001 mm graduations there was a great potential for very accurate measurements. Since the work in this project has been carried out, much effort has been directed into obtaining more consistent measurements from this instrument and a large degree of success has been achieved. Perspex jigs consisting of vee blocks and mandrels have been manufactured to hold springs on the table and eliminate almost all setting up errors. However, value judgements still play an important role and the equipment is relatively slow in use requiring a high degree of meticulousness on the part of the operator.

Consideration has been given to inaccuracies introduced into the electronic load cell method because the spring was free standing and the springs own mass would cause a compression of the spring. Also, the fact that a load of 0.01N had to be applied to a spring before the contact point was registered introduced an error in the measurement taken. The calculation of the discrepancies introduced is given in Appendix B, but the calculations show that the compression of the spring caused by both the mass of the spring and the applied 0.01N load was very small (max. of 0.02 mm, i.e. 0.08% for the light spring C). However, in cases where this could mean the difference between acceptance and rejection, the value of the error is easily calculated, and can be added to the reading for the free length.

However, before recommending the electronic load cell method for the measurement of diameter (on the basis that it produces least variation in the measurement obtained) consideration must be given to what a manufacturer requires when making a diameter measurement. Almost invariably the diameter required is the maximum outside diameter of the spring, and this usually occurs at the end coils. In many cases the diameter of the platens on the load cell device will be less than the length of the spring, and therefore the end coils will not be included in the diameter measurement. The reading taken will therefore be less than the maximum diameter. For this reason the diameter measurement taken using the load cell device is invalid if the spring length is greater than the platen diameter, and a different method must be used, even though the second method may be subject to greater scatter in the results.

From consideration of the methods used and Table V the method which gave the least scatter and yet did include measurement of the end coil diameter was the height gauge, and this is therefore recommended in situations where the load cell method is invalid.

(b) Load Length Measurement

As with the free length and diameter measurements, the most precise method was that which gave the lowest standard deviation when the different operator measurements were pooled. The results are given in Table VI, and it can be seen from the results that there is little difference between the two mechanical spring testers with regard to precision. The Avery gave least variation for spring B whilst the Comaco was better for springs A and C. However, for spring C which was light enough for the electronic load cell to be used, both the mechanical testers proved inferior to the load cell tester. This was considered to be due to the lack of value judgement required from the operators using the digital load readout of the electronic tester.

From consideration of speed and simplicity the Comaco was the poorest machine, with little difference between the Avery and electronic load cell, although again the digital readout of the latter tended to speed up the operation.

(c) Squareness Measurement

A statistical examination of the results was not possible since the tapered gauges method did not give an exact measurement for the squareness, but only indicated whether the squareness was of Class A or B standard. Precise measurements could have been made using this method if a large range of tapered gauges had been available. In practice, the tapered gauge method clearly proved to be the best method. It was very quick and simple to use and all operators could determine whether the spring was Class A or B. In comparison, the profile projector and square and feeler methods proved very cumbersome and tedious and did not give very precise results. The profile projector method was particularly awkward to set up and the square and feeler method was subject to very important value judgments on the part of the operator with regard to the 'feel' of contact, this difficulty was more pronounced when measuring light springs.

6. GENERAL DISCUSSION

The methods assessed in this report were not chosen to give an exhaustive coverage of all the possible methods which might exist, but were taken as an average sample of the common methods employed by the spring manufacturing industry.

In recommending specific methods for determining any spring parameter, as this report does, the commercial implications for manufacturers of spring testing and measuring equipment must be considered. Therefore, it should be clearly understood that the recommendation in this report of a particular method for measuring a particular spring parameter does not imply that any other method should be discarded. The suggestions made in this report are based on methods which proved the most precise, and in many situations such precision may be unwarranted and other methods would then be perfectly acceptable.

For example, the recommendation of electronic load cell spring testers as opposed to mechanical spring load testers for measurement of load/length relates to a situation in which narrow tolerances on load/length may be specified, and obviously in this case an electronic load cell with a typical tolerance range of 0.05% would be much superior to a mechanical tester. Of vital importance, however, is that the tolerance on a particular measurement method must be negligibly small in comparison with the tolerance band stipulated on the measurement, otherwise incorrect rejections or acceptances will occur.

7. CONCLUSIONS

From the work done in this project the following conclusions have been drawn:-

(a) Common commercial methods of measuring the diameter and free length of springs are generally not the most precise possible but are usually methods which are quick and simple.

(b) Commercial methods of measuring load/length are subject to gross variation which make the application of tolerances of ±5% meaningless.

(c) The electronic load cell tester is the most precise method for measuring free length, diameter, and load/length; being least subject to variation in the readings given, and this method is recommended for measurement of these parameters.

(d) In situations where the length of the spring is greater than the diameter of the platen on the cell device, the height gauge is recommended for measurement of diameter.

(e) The method for determining squareness using a set square and suitable measuring device which is stipulated in BS 1726 does not in practice prove to be the best method. It is recommended that taper gauges be used for reasons of speed, ease of operation, and accuracy.

(f) To reduce inconsistency in readings obtained by different operators using the same method of measurement it is recommended that the measurement process should be stipulated as closely as possible and demonstrated to the operators. With this in mind, for the recommended methods put forward in this report, the exact steps followed are given in Appendix C.

TABLE I COMMERCIAL METHODS OF MEASURING SPRINGS

(i) Free Length

Method	Method of Support Whilst Measuring Spring	No. of Companies Using Method	
		Compression	Extension
Vernier	Hand held	7	5
Micrometer	Hand held	6	4
Shadowgraph+	Not specified	3	
Dial gauge	Free standing on surface plate	3	
Go/NoGo gauge	Hand held	3	
Height gauge	Free standing on surface plate	2	
Rule*	Free standing on surface plate	1	
Calipers*	Hand held	1	1

(ii) Diameter

Method	Method of Support Whilst Measuring Spring	No. of Companies Using Method
Vernier	Hand held	6
Go/NoGo gauge	Hand held	6
Micrometer	Hand held	4
Shadowgraph+	Not specified	2
Dial gauge	Free standing on surface plate	2

(iii) Squareness

Method	Method of Support Whilst Measuring Spring	No. of Companies Using Method
Square and slip gauges or feelers.	Free standing on surface plate	7
Adjustable square.	Free standing on surface plate	4
Shadowgraph+	Not specified	1
Tapered gauges	Free standing on surface plate	1

(iv) Load/length

Method	No. of Companies Using Method
Conventional Mechanical Spring Testers	8
Electronic Load Cell	3
Dead Weights	2

+This method is generally reserved for 'precision' springs

*These methods are generally reserved for large stiff springs

TABLE II COMMERCIAL LOAD/LENGTH MEASUREMENT

(i) SPRING 1: Load (oz) at 1" height

Company		A		B					C	D			E	
M/c-Operator Combination		1†	2	1	2	3	4	5*	1†	1	2	3	1	2
1	+	$33\frac{1}{4}$	33	34	$32\frac{1}{4}$	$33\frac{1}{2}$	$33\frac{1}{2}$	$32\frac{25}{32}$	$33\frac{13}{16}$	33	$33\frac{1}{2}$	33	32	$32\frac{1}{4}$
	-	$33\frac{3}{16}$	"	"	"	33	"	"	$33\frac{3}{4}$	"	"	"	$31\frac{1}{2}$	$31\frac{3}{4}$
2	+	$33\frac{1}{4}$	"	33	"	34	"	$32\frac{13}{16}$	$33\frac{13}{16}$	"	$33\frac{1}{4}$	"	$32\frac{1}{2}$	$32\frac{1}{2}$
	-	$33\frac{3}{16}$	"	$33\frac{1}{2}$	$32\frac{1}{2}$	$33\frac{1}{2}$	"	"	$33\frac{3}{4}$	"	"	"	$31\frac{1}{2}$	$31\frac{1}{2}$
3	+	$33\frac{1}{4}$	"	34	"	"	"	$32\frac{3}{4}$	$33\frac{7}{8}$	"	"	"	$32\frac{1}{4}$	32
	-	"	"	$33\frac{1}{2}$	$32\frac{1}{4}$	"	"	"	$33\frac{3}{4}$	"	"	"	$31\frac{1}{2}$	$31\frac{1}{2}$
4	+	"	"	"	"	"	"	"	$33\frac{13}{16}$	"	"	"	32	$31\frac{3}{4}$
	-	$33\frac{3}{16}$	"	"	$32\frac{1}{2}$	$33\frac{1}{4}$	"	"	$33\frac{3}{4}$	"	"	"	$31\frac{1}{2}$	$31\frac{1}{4}$
5	+	$33\frac{1}{4}$	"	34	"	$33\frac{1}{2}$	"	"	$33\frac{13}{16}$	"	"	$33\frac{1}{4}$	$32\frac{1}{4}$	32
	-	$33\frac{3}{16}$	"	$33\frac{1}{2}$	$32\frac{1}{4}$	$33\frac{1}{4}$	"	"	$33\frac{3}{4}$	"	"	"	32	"
6	+	$33\frac{1}{4}$	"	34	$32\frac{1}{2}$	"	"	"	"	"	"	33	$32\frac{3}{4}$	$32\frac{1}{2}$
	-	$33\frac{3}{16}$	"	"	"	"	"	$32\frac{25}{32}$	$33\frac{11}{16}$	"	"	"	32	$31\frac{3}{4}$
7	+	$33\frac{1}{4}$	"	"	$32\frac{1}{4}$	$33\frac{1}{2}$	"	"	$33\frac{3}{4}$	"	"	"	$32\frac{1}{2}$	$32\frac{3}{4}$
	-	$33\frac{3}{16}$	"	"	"	"	"	"	"	"	"	"	32	32
8	+	$33\frac{1}{4}$	"	$33\frac{1}{2}$	$32\frac{1}{2}$	"	33	$32\frac{13}{16}$	$33\frac{13}{16}$	"	"	"	"	$32\frac{1}{4}$
	-	"	"	"	"	"	"	"	$33\frac{3}{4}$	"	"	"	$32\frac{1}{4}$	32
Mean		$33\frac{7}{32}$	33	$33\frac{23}{32}$	$32\frac{3}{8}$	$33\frac{7}{16}$	$33\frac{7}{16}$	$32\frac{25}{32}$	$33\frac{25}{32}$	33	$33\frac{9}{32}$	$33\frac{1}{32}$	$32\frac{1}{32}$	32

All loads to nearest $\frac{1}{4}$ oz except: †to nearest $\frac{1}{16}$ oz

*to nearest $\frac{1}{32}$ oz (0.01 N)

Average of mean loads = $33\frac{3}{32}$ oz $+\frac{11}{16}$ oz (+2.1%) $-1\frac{3}{32}$ oz (-3.3%)

Average of individual loads = $33\frac{3}{32}$ oz $+\frac{25}{32}$ oz (+2.4%) $-1\frac{27}{32}$ oz (-5.6%)

(ii) SPRING 2: Load (oz) at 1" height

Company		A		B					C	D			E	
M/c-Operator Combination		1†	2	1	2	3	4	5*	1†	1	2	3	1	2
1	+	$40\frac{3}{4}$	$40\frac{1}{2}$	41	$39\frac{3}{4}$	$40\frac{1}{2}$	40	$39\frac{23}{32}$	$41\frac{5}{16}$	40	40	$40\frac{1}{4}$	$39\frac{1}{2}$	$39\frac{1}{2}$
	-	$40\frac{5}{8}$	"	"	"	"	"	$39\frac{11}{16}$	$41\frac{1}{4}$	"	"	"	$39\frac{1}{4}$	$39\frac{1}{4}$
2	+	$40\frac{11}{16}$	"	"	40	"	$39\frac{1}{2}$	"	$41\frac{5}{16}$	"	"	"	$39\frac{1}{2}$	$39\frac{3}{4}$
	-	$40\frac{5}{8}$	"	"	"	"	"	$39\frac{3}{4}$	"	"	"	"	"	$39\frac{1}{2}$
3	+	$40\frac{3}{4}$	"	"	$39\frac{1}{2}$	"	40	"	$41\frac{1}{4}$	"	"	"	$39\frac{1}{4}$	$39\frac{1}{4}$
	-	$40\frac{11}{16}$	"	$40\frac{1}{2}$	$39\frac{3}{4}$	$40\frac{1}{4}$	"	$39\frac{23}{32}$	"	"	"	"	39	"
4	+	$40\frac{3}{4}$	"	41	$39\frac{1}{2}$	$40\frac{1}{2}$	"	$39\frac{3}{4}$	"	"	$40\frac{1}{2}$	"	"	"
	-	$40\frac{11}{16}$	"	$40\frac{1}{2}$	$39\frac{3}{4}$	$40\frac{3}{4}$	"	$39\frac{23}{32}$	"	"	"	"	"	$39\frac{1}{2}$
5	+	"	"	41	"	$40\frac{1}{2}$	$39\frac{1}{2}$	$39\frac{25}{32}$	$41\frac{5}{16}$	"	40	"	$39\frac{1}{4}$	"
	-	"	"	"	"	$40\frac{3}{4}$	"	$39\frac{3}{4}$	$41\frac{3}{8}$	"	"	"	39	$39\frac{1}{4}$
6	+	"	"	"	$39\frac{1}{2}$	"	"	$39\frac{23}{32}$	$41\frac{5}{16}$	"	$40\frac{1}{4}$	"	$39\frac{1}{2}$	$39\frac{3}{4}$
	-	$40\frac{5}{8}$	"	$40\frac{1}{2}$	"	$40\frac{1}{2}$	"	$39\frac{25}{32}$	"	"	"	"	"	$39\frac{1}{2}$
7	+	$40\frac{3}{4}$	"	41	$39\frac{3}{4}$	$40\frac{3}{4}$	"	$39\frac{23}{32}$	$41\frac{1}{4}$	"	"	"	39	$39\frac{1}{4}$
	-	$40\frac{11}{16}$	"	"	40	$40\frac{1}{2}$	"	$39\frac{25}{32}$	$41\frac{3}{16}$	"	"	"	"	39
8	+	"	"	$41\frac{1}{2}$	$39\frac{3}{4}$	"	"	$39\frac{3}{4}$	$41\frac{1}{4}$	"	"	"	$39\frac{1}{4}$	$39\frac{1}{2}$
	-	"	"	"	$39\frac{1}{2}$	"	"	$39\frac{13}{16}$	$41\frac{3}{16}$	"	"	"	$39\frac{1}{2}$	"
Mean		$40\frac{11}{16}$	$40\frac{1}{2}$	$40\frac{31}{32}$	$39\frac{23}{32}$	$40\frac{9}{16}$	$39\frac{11}{16}$	$39\frac{3}{4}$	$41\frac{9}{32}$	40	$40\frac{5}{32}$	$40\frac{1}{4}$	$39\frac{1}{4}$	$39\frac{13}{32}$

All loads to nearest $\frac{1}{4}$ oz except: †to nearest $\frac{1}{16}$ oz
*to nearest $\frac{1}{32}$ oz (0.01N)

Average of mean loads = $40\frac{5}{32}$ $+ 1\frac{1}{8}$ oz (+2.8%) $- \frac{29}{32}$ oz (−2.3%)

Average of individual loads = $40\frac{5}{32}$ oz $+ 1\frac{7}{32}$ oz (+3.0%) $- 1\frac{5}{32}$ oz (−2.9%)

(iii) <u>SPRING 3:</u> Load (oz) at 1" height

Company		A		B					C	D			E	
M/c-Operator Combination		1†	2	1	2	3	4	5*	1†	1	2	3	1	2
1	+	$40\frac{5}{8}$	$40\frac{1}{2}$	41	$39\frac{1}{2}$	$40\frac{1}{2}$	$40\frac{1}{2}$	$39\frac{9}{32}$	$41\frac{3}{16}$	40	$40\frac{1}{4}$	40	39	40
	−	$40\frac{1}{2}$	"	"	"	"	"	$39\frac{5}{16}$	$41\frac{1}{8}$	"	"	"	"	$39\frac{1}{2}$
2	+	$40\frac{5}{8}$	"	$40\frac{1}{2}$	"	"	"	$39\frac{13}{32}$	$41\frac{1}{4}$	"	"	"	$39\frac{3}{4}$	$39\frac{3}{4}$
	−	$40\frac{9}{16}$	"	"	"	"	"	"	$41\frac{3}{16}$	"	"	"	$39\frac{1}{2}$	$39\frac{1}{2}$
3	+	"	"	41	$39\frac{1}{4}$	"	"	$39\frac{11}{32}$	$41\frac{1}{4}$	"	40	"	"	"
	−	$40\frac{1}{2}$	"	"	$39\frac{1}{2}$	"	"	"	$41\frac{3}{16}$	"	"	"	$39\frac{1}{4}$	39
4	+	$40\frac{5}{8}$	"	$40\frac{1}{2}$	$39\frac{1}{4}$	"	"	$39\frac{7}{16}$	"		"	"	$39\frac{1}{2}$	$39\frac{1}{4}$
	−	$40\frac{9}{16}$	"	"	"	$40\frac{3}{4}$	"	$39\frac{11}{32}$	$41\frac{1}{8}$	"	"	"	$38\frac{3}{4}$	$38\frac{3}{4}$
5	+	"	"	41	$39\frac{1}{2}$	"	"	$39\frac{5}{16}$	$41\frac{3}{16}$	"	$40\frac{1}{4}$	"	$39\frac{3}{4}$	39
	−	$40\frac{7}{16}$	"	$40\frac{1}{2}$	"	41	"	$39\frac{11}{32}$	$41\frac{1}{8}$	"	"	"	39	"
6	+	$40\frac{5}{8}$	"	"	$39\frac{1}{4}$	$40\frac{3}{4}$	"	$39\frac{13}{32}$	$41\frac{3}{16}$	"	"	"	$39\frac{1}{2}$	$39\frac{1}{2}$
	−	$40\frac{1}{2}$	"	"	"	"	"	$39\frac{7}{16}$	$41\frac{1}{8}$	"	"	"	$39\frac{1}{4}$	"
7	+	$40\frac{5}{8}$	"	"	$39\frac{1}{2}$	41	"	$39\frac{13}{32}$	$41\frac{3}{16}$	"	40	"	$39\frac{1}{2}$	$39\frac{3}{4}$
	−	$40\frac{9}{16}$	"	"	$39\frac{1}{4}$	$40\frac{1}{2}$	"	"	$41\frac{1}{8}$	"	"	"	39	$39\frac{1}{4}$
8	+	$40\frac{5}{8}$	"	41	"	"	"	$39\frac{9}{32}$	"	"	$40\frac{1}{4}$	"	"	"
	−	$40\frac{9}{16}$	"	"	$39\frac{1}{2}$	"	"	$39\frac{11}{32}$	"	"	"	"	$38\frac{1}{2}$	$38\frac{3}{4}$
Mean		$40\frac{15}{32}$	$40\frac{1}{2}$	$40\frac{23}{32}$	$39\frac{3}{8}$	$40\frac{5}{8}$	$40\frac{1}{2}$	$39\frac{3}{8}$	$41\frac{5}{32}$	40	$40\frac{5}{32}$	40	$39\frac{1}{4}$	$39\frac{5}{16}$

All loads to nearest $\frac{1}{4}$ oz except:
† to nearest $\frac{1}{16}$ oz
* to nearest $\frac{1}{32}$ oz (0.01 N)

Average of mean loads = $40\frac{1}{8}$ oz $+1\frac{1}{32}$ oz (+2.6%) $-\frac{7}{8}$ oz (−2.2%)

Average of individual loads = $40\frac{1}{8}$ oz $+1\frac{1}{8}$ oz (+2.8%) $-1\frac{5}{8}$ oz (−4.0%)

TABLE III SPRING DESIGN DETAILS

	Spring A		Spring B		Spring C	
Nom. free length (mm)	77		26		25	
Nom. outside dia. (mm)	38		20		12	
Nom. wire dia. (mm)	5		4		1	
Coil dia. (mm)	33		16		11	
Spring index	6.6		4		11	
No. total coils	8¼		5½		9½	
No. working coils	6¼		3½		7½	
Load/length (mm)	50		21		15	
Wire tolerance (in)	±0.0015		±0.001		±0.00005	
Free length tolerance (mm)	±1.38		±0.52		±0.63	
Outside dia. tolerance (mm)	±0.50		±0.20		±0.28	
Class	A	B	A	B	A	B
Load/length tolerance (%)	±5	±10	±7½	±15	±5	±10
Squareness tolerance (in/in length)	0.02	0.04	0.02	0.04	0.02	0.04

TABLE IV RESULTS OF VARIANCE RATIO SIGNIFICANCE ANALYSIS

(i) Free Length

Degrees of Freedom of Residual = 576

Source	Variance Ratio	Degrees of Freedom	Significance
Operator	17.64	6	>99.9% i.e. highly significant
Method	127.49	5	>99.9% i.e. highly significant
Spring	36.45	2	>95.0% i.e. possibly significant

(ii) Diameter

Degrees of Freedom of Residual = 611

Source	Variance Ratio	Degrees of Freedom	Significance
Operator	4.13	6	>95.0% i.e. possibly significant
Method	49.57	5	>99.9% i.e. highly significant
Spring	96.26	2	>97.5% i.e. probably significant

TABLE V STANDARD DEVIATION AND MEAN OF FREE LENGTH AND DIAMETER MEASUREMENTS

		Vernier		Dial Gauge		Profile Projector		Mechanical Load Tester		Height Gauge		Electronic Load Tester	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Free length (mm)	Spring A	77.45	0.0995	77.41	0.1135	77.63	0.2573	77.50	0.0488	77.47	0.0982	77.53	0.0549
	Spring B	26.25	0.1019	26.27	0.0711	26.36	0.1717	26.33	0.0850	26.29	0.1012	26.31	0.0527
	Spring C	25.62	0.1505			25.95	0.2015	25.78	0.1164	25.73	0.1693	25.81	0.0751
Diameter (mm)	Spring A	38.08	0.2188	38.05	0.0745	38.07	0.1363	38.08	0.0780	38.10	0.0561	38.02	0.0355
	Spring B	20.17	0.0598	20.15	0.0732	20.16	0.0699	20.15	0.0394	20.22	0.0637	20.18	0.0338
	Spring C	12.10	0.0339	12.07	0.0307	12.11	0.0487	12.11	0.0407	12.14	0.0243	12.11	0.0288

TABLE VI STANDARD DEVIATION AND MEAN OF LOAD/LENGTH MEASUREMENTS

		Avery	Comaco	Electronic Load Cell
Spring A	Mean (N)	657.9	655.6	
	St. Dev.	2.193	2.003	
Spring B	Mean (N)	666.3	671.5	
	St. Dev.	9.305	12.913	
Spring C	Mean (N)	10.97	11.14	11.06
	St. Dev.	0.305	0.101	0.050

APPENDIX A

Test Procedure for Commercial Load/Length Measurement Survey

Each company/inspector/machine combination was required to measure each spring 16 times using the following procedure.

1. Compress the spring to 1" height and record load reading.
2. Compress the spring to its solid height.
3. Release the spring to 1" height (Do not release to free height).
4. Record load reading.
5. Completely release spring.
6. Rotate spring through 90°.
7. Repeat steps 1-6 three more times.
8. After 8 readings are obtained turn the spring end for end and repeat steps 1-7.

APPENDIX B

Calculation of Errors in Electronic Load Cell Method of Measuring Free Length

(i) Due to spring compression under its own weight.

To determine the compression of a spring under its own weight calculate the deflection which would occur if approximately 35% of the mass of the spring acted as an axial load at one end of the spring.

The springs were weighed, and were as follows:-

Spring A = 1.185 N
Spring B = 0.221 N
Spring C = 0.020 N

The spring rates were calculated and the results were as follows:-

Spring A = 27.6 N/mm
Spring B = 177.0 N/mm
Spring C = 0.993 N/mm

The spring deflections under their own weight were therefore:-

Deflection of A = $\frac{1.185 \times 0.35}{27.6}$ = 0.015 mm

Deflection of B = $\frac{0.221 \times 0.35}{177}$ = 0.0004 mm

Deflection of C = $\frac{0.020 \times 0.35}{0.993}$ = 0.007 mm

(ii) Due to axial load of 0.01 N

Deflection of A = $\frac{0.01}{27.6}$ = 0.0004 mm

Deflection of B = $\frac{0.01}{177}$ = 0.00006 mm

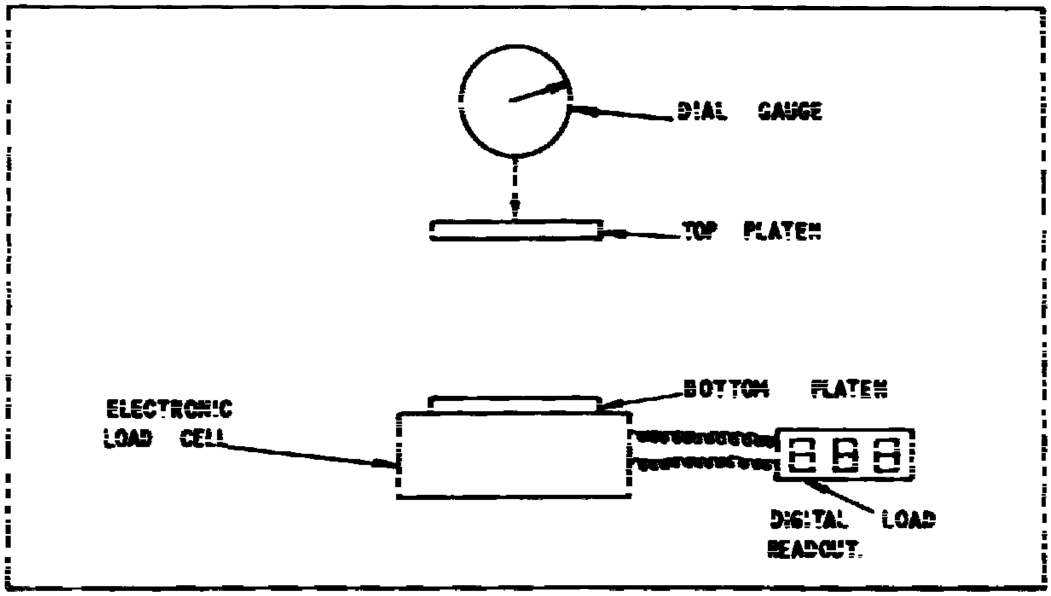
Deflection of C = $\frac{0.01}{0.993}$ = 0.010 mm

Hence, the maximum total errors were as follows:-

Spring A = 0.02 mm
Spring B = 0.00 mm
Spring C = 0.02 mm

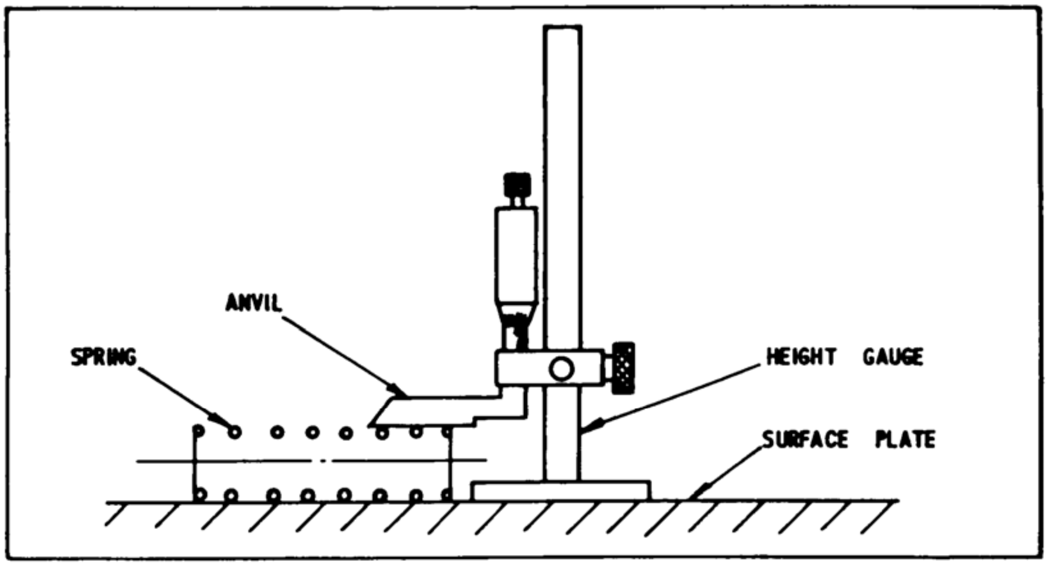
APPENDIX C

a. Procedure for use of Electronic Load Cell Method to Measure Free Length and Diameter



1. Set slip gauges to nominal dimension being measured.
2. Place slip gauges on bottom platen and zero digital load readout for weight of gauges.
3. Bring top platen down onto slip gauges.
4. Zero dial gauge when contact made with gauges. This is when digital load readout increases with no change in dial gauge reading.
5. Release top platen and remove slip gauges.
6. Place spring on bottom platen and zero digital load readout for weight of spring.
7. Bring top platen down onto spring until contact is made registered by load readout changing to 0.01 N.
8. Note dial gauge reading at this position.
9. Subtract or add dial gauge reading to nominal dimension set by slip gauges at step 1.
10. Release top platen and remove spring then repeat from step 6 at least twice more.

b. <u>Procedure for use of Height Gauge to Measure Diameter</u>



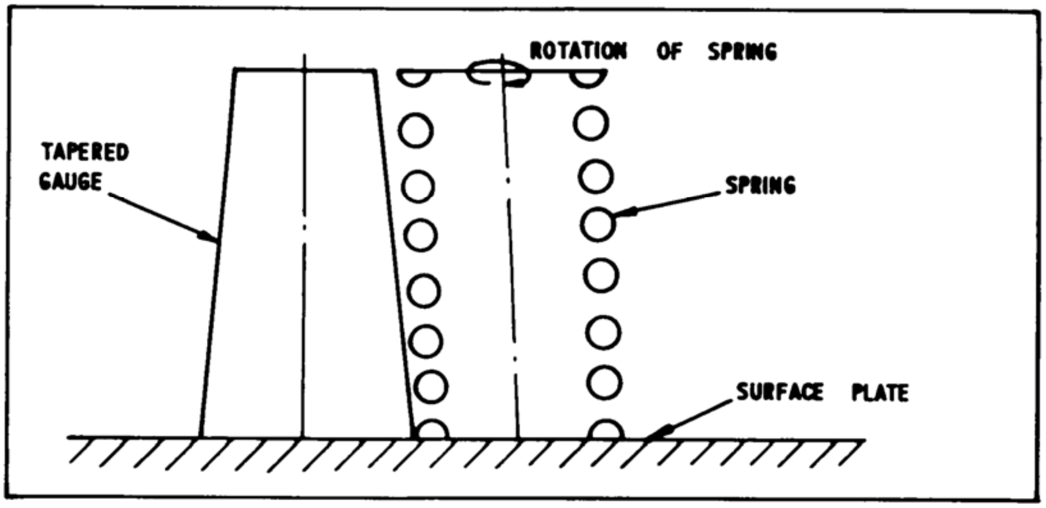
1. Place one end of spring under the anvil of the height gauge as shown above.
2. Rotate spring underneath the anvil and gradually lower the anvil until contact is made as adjudged by the 'feel' as the spring is rotated.
3. Note the reading of diameter.
4. Insert other end under anvil and repeat steps 2 and 3.
5. Take the maximum of the two readings taken.
6. Repeat steps 1 to 5 at least twice more.

c. <u>Procedure for use of Electronic Load Cell Method to Measure Load/Length</u>

Repeat steps 1-6 of (a) above with the nominal dimension of step 1 being the length at which the load measurement is required.

7. Bring top platen down onto spring until the zero dial gauge position is reached.
8. Note digital load readout at this position.
9. Repeat step 10 of (a) above.

d. Procedure for use of Tapered Gauges to Measure Squareness



1. Select the tapered gauge corresponding to the Class of Spring.
2. Stand the gauge on a surface plate with the spring alongside.
3. Rotate the spring next to the gauge and in contact with it.
4. If a gap appears between the spring and gauge at the base of the spring then the spring is outside of tolerance. If a gap is maintained at the top then the spring is within tolerance for the end the spring is stood on. The spring is then turned upside down and the process repeated from step 2.