THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

STANDARD INSPECTION TECHNIQUES FOR SPRINGS

Report No 409

by

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APRIL 1987

STANDARD INSPECTION TECHNIQUES FOR SPRINGS

SUMMARY

A programme of work has been undertaken to establish standard inspection techniques for springs and these will be considered for inclusion in the section of BS 1726 dealing with 'Methods of Testing'.

In Phase I of the work standard techniques were developed, which gave the most accurate and repeatable measured values, by means of comparison of practical measurements.

In Phase II of the work, these standard techniques were compared, again by statistical analysis of practical measurements, with those techniques currently in general use by a number of springmaking and spring using companies. The claimed improvements in measurement repeatability when using the standard techniques was conclusively demonstrated.

The adoption of the standard techniques established herein should reduce the numbers of springs incorrectly rejected as out of tolerance and should help the resolving of disputes between supplier and customer.

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STANDARD INSPECTION TECHNIQUES FOR SPRINGS

INTRODUCTION

The British standard for the specification of springs, BS 1726, is currently nearing the end of a major revision by a BSI committee, GME/15. The revised standard will upon completion comprise parts I, II and III covering compression, extension, and torsion springs.

The revised standard has been extensively updated and amended. A major new inclusion within each part is a section dealing with Methods of Testing. This section has been included because it is an established fact that the result of the measurement of any spring dimension or property is dependent upon the method of test used, and can in certain instances lead to extremely variable results, making the application of tolerances meaningless.

Currently however, the number of different techniques in use for determining spring dimensions and properties is extremely large as a survey carried out by SRAMA (1) has already shown. In addition it is recognised within the spring industry that the measurement of spring dimensions and properties for both production and quality control purposes presents considerable practical difficulties.

These problems exist for two main reasons:-

i) A spring has a highly complex overall profile with few, if any, regular surfaces. Consequently, it often proves very difficult to establish a reliable datum from which accurate measurements can be made.

ii) A spring is not a rigid body, hence considerable care has to be taken to ensure that the measuring procedure does not cause a change in dimensions during measurement. This is particulary important when measuring light (low stiffness) springs.

These two factors therefore make the measurement of springs difficult and subject to error which can in turn lead to customer rejections and disputes between customer and supplier.

As a result, and in order to make meaningful and reliable recommendations within the next BS1726 revision document, this programme of work has been undertaken to establish clearly the most appropriate standard method of of measurement to be used in case of dispute between customer and supplier.

The work was divided into two parts. In phase I inspection techniques which can be applied to springs across a wide range of designs have been surveyed and the most appropriate were developed into standard test procedures. In phase II a comparison was undertaken between the standard test procedures developed in phase I and those currently used withing the industry to show the effect of using the standard methods on measurement variation and therefore on spring rejections.

SCOPE

Standard methods for measurement were developed for those parameters which the BS1726 working party included in the 'Methods of Testing' section of parts I, II and III. The parameters included are as follows:-

a) Compression springs:-

Outside coil diameter

Inside coil diameter

Free length

Total number of coils

Angle of Grind

Tip thickness

Chamfer

Squareness

Parallelism

Bow

Load at length

Spring rate

Solid length

b) Extension springs:-

Outside coil diameter

Free length

Total number of coils

End loop opening

Relative end loop position

Load at length

Spring rate

Initial tension

c) Torsion springs:-

Outside coil diameter
Inside coil diameter
Body length
Total number of coils
Relative leg position
Torque at angle
Spring rate

Certain of these parameters are not affected by spring type (for example outside coil diameter of extension and torsion springs), and the standard technique developed is applicable to more than one spring type.

PHASE I - ESTABLISHING STANDARD TECHNIQUES

(i) Method

Initially a literature survey of all previously published information concerned with spring measurement was carried out to determine the extent of any work already undertaken. A major finding at this stage was that there existed no published information concerned with the measurement of extension and torsion springs. In addition, of the documented information concerned with compression spring measurement, only one limited programme of work (1) had been undertaken to assess measurement repeatability with a view to establishing the most suitable technique for a given parameter.

Once aware of the published information regarding spring measurement, and with consideration of the spring's inherent flexibility, a survey of SRAMA members and staff was undertaken to determine the items of equipment that would be most likely to give consistent results for the parameters under consideration. This allowed possible methods to be proposed which could then be investigated by means of practical measurements on suitable springs.

The possible methods investigated fell into three general categories. These were dimensional measurements (eg free length, outside diameter, etc), angular measurements (e.g. angle of grind, relative leg position) and property measurements.

It was clear from the outset that non-contact dimensional measurement techniques were likely to be the most accurate and repeatable for low rate and/or small springs. The non-contact method generally used in the spring industry involves use of a shadowgraph profile projector of the vertically illuminated type, hereinafter referred to simply as a shadowgraph. This method was assessed in conjunction with perspex jigs, which provided a reliable measurement datum. Dimensional measurements may be made using hand held contact measurement equipment such as micrometers and verniers for higher rate and larger springs.

For angular measurements, it was necessary to manufacture suitable fixturing to ensure the spring axis was normal to the angle measuring device. For larger springs this necessitated the building of a special purpose jig.

Property measurements were invariably carried out on electronic measuring equipment, since this equipment is very much more accurate than any other type of property measuring device.

ii) Measurements

Having considered the posible methods for spring measurement and decided which techniques were to be used, it was necessary to evaluate measurement repeatability by means of practical measurements and therefore confirm the suitability or otherwise of a specific technique. In particular the division between small/large springs and low rate/high rate springs, described in BS 1726, is rather vague and needed to be clarified to enable the most appropriate technique to be recommended for all spring types. There were, however, several parameters where it was considered no accurate measurements could possibly be taken, and therefore nothing to be gained by attempting such measurements. In these instances the technique to be recommended would be that most commonly accepted within the industry.

Spring measurements were undertaken on quantities of springs obtained via various springmakers' stock catalogues. All equipment used was covered by current BCS calibration certificates to ensure that measurement accuracy would be unaffected by equipment condition. Measurement repeatability was assessed by statistical analysis of the measured values obtained on a specific parameter. In order that the statistical analysis carried out accounted for all possible sources of variation, for a specific technique each parameter was measured five times by three operators on each of three nominally identical springs. Carrying out this matrix of measurements ensured that, as well as measurement variation due to technique errors, the effect of a number of operators applying various value judgements, and different spring seating conditions, were assessed.

The primary statistical quantity which was used in analysing the results was the standard deviation. The standard deviation (σ) is a calculated value which quantifies the measurement variation. Calculating the value of three standard deviations (3σ) gives the measurement variation to be expected from 99.73% of all measurements taken on the parameter in question. The 3σ values obtained can be taken to be representative of the overall measurement variation since they are each based on 45 individual measurements. It was decided that the ideal criterion for acceptance or rejection of a technique should be that the 3σ value be less than 10% of the BS 1726 revision grade A tolerance figure. If this were so then the technique would be capable of measuring to a level of precision at least one order of magnitude greater than that which the parameter is required to achieve.

This then allowed the measurement variation for each parameter to be quantified, and compared to the relevant BS 1726 tolerance figure for assessment. In instances where a parameter was measured by two different techniques, the 3σ values obtained for each technique were compared by means of an 'F' test. This determined whether or not the observed difference in variation was significant and therefore whether one technique could be confidently recommended over another as the standard for inclusion in BS 1726.

iii) Results and Discussion

Spring measurements were undertaken as described previously. The spring designs used are listed in Table I. An example set of measured values, along with the subsequent analysis, is given in Appendix I. For all other measurements only relevant values from the analysis are given. Each parameter is analysed in turn with consideration being given to the reasoning behind the choice of possible techniques along with results of the analysis where applicable. Only brief details of the techniques used were included at this point, the actual techniques recommended being set out in full in Appendix II.

a) Compression Springs

Outside Coil Diameter

The measurements undertaken concentrated on measurement of maximum outside diameter whether this occurred on the body or end coil of the spring. The two techniques considered best suited to repeatable diameter measurements involved using a shadowgraph, and a vernier height gauge and surface plate.

Measurements undertaken on the shadowgraph would be non-contact and therefore not affected by spring deformation during the measurement process. Measurements undertaken using the height gauge offered the advantage over other hand held items of equipment that both spring and height gauge would stand on the same datum surface, the spring requiring only to be located and not hand held.

A range of springs were measured and the results analysed. The relevant details are given in Table II. It can be seen that overall measurement variation, denoted by the 3σ values in the table, is less for the height gauge than for the shadowgraph, and in addition that, taken overall, the difference between techniques is, according to the 'F' test values, highly significant (significance level of at least 99%).

It can also be seen that, as the outside diameter is decreased, the 3σ values tend to increase, particularly for the height gauge which relies on hand location of the springs on the surface plate. Looking at the trend followed by the 3σ values suggests that all springs with an outside diameter of 10 mm or less should be measured using a shadowgraph since these springs are in practice extremely difficult to measure using the height gauge with any greater precision than that achievable with the shadowgraph. The shadowgraph is itself not particularly precise for these small springs due to differences in value judgement between operators, as evidenced by the 3σ values as a percentage of the BS 1726 tolerance value, but is the only known device which can be used for measurement of smallsprings.

It was noted that springs with a free length of less than 20 mm could not be readily supported by the operator for measurement using the height gauge. It is also noted from the 3σ values that springs with a rate down to 2 N/mm could be measured using a contact method, ie the height-gauge, with improved repeatability over the non-contact method.

It is therefore recommended that springs with a rate of less than 2 N/mm, and/or an outside diameter of less than 10 mm, and/or a free length of less than 20 mm, be measured using a shadowgraph. Springs which lie outside this category should be measured using a height gauge and surface plate.

Inside Coil Diameter

Only the minimum inside coil diameter is of interest since it is this which affects the spring's ability to function on a rod or locate on a boss correctly. The inaccessibility of the inner body coils precludes the use of any item of adjustable measuring equipment. No measurements were therefore undertaken on this parameter since it is only possible to obtain an indication of the dimension using plug gauges. It is still possible to make recommendations for this parameter, in line with practice in industry.

It is possible to obtain an indication of the inside diameter measurement if a range of plug gauges are available. For body coil inside diameter the length of these gauges should be equal to or greater than the spring

1.5 times the wire diameter. The increment between the gauges will of course have a direct effect on measurement precision. The springs are required to pass over the gauge under their own weight.

It is more usual in industry for inside diameter to be checked using go-no go plug gauges sized to the tolerance limits required since this is sufficient to ensure that the spring will locate and operate as required.

Free Length

A number of techniques were considered for free length measurement: for small and/or low rate springs a shadowgraph, for other springs up to 600 mm in length with ground ends, the height gauge and surface plate. Springs larger than 600 mm could be measured using a ruler graduated in 0.5 mm increments.

A range of springs were measured and the results analysed, details of which are included in Table III. Initial trials with the height gauge determined that springs with an outside diameter of less than 10 mm and/or a free length of less than 10 mm were not sufficiently stable for a measurement to be made. As can be seen from Table III, all springs measured with the height gauge have a 3σ value, i.e. an overall measurement variation which is within 10% of the calculated tolerance value. It can also be seen that measurement variation when using the shadowgraph is significantly greater than that of the height gauge for stiff springs such as designs 2 and 14. Investigation of the effect of spring rate on 3σ values has not shown the height gauge to be adversely affected for rates down to less than 2 N/mm.

It is again apparent that the smaller springs which require to be measured by a shadowgraph are subject to measurement variation which exceeds 10% of the allowable tolerance figure.

Only one spring design was measured (number 20) which had a free length greater than 600 mm. This was measured using a precision steel rule and has demonstrated that it is possible to measure free length by this method on long springs with overall measurement repeatability, an order of magnitude less than the allowable tolerance value.

Although no unground springs were measured it is recommended that unground springs which are of a size within the measurement range of a shadowgraph be measured by this means. The measurement range of a typical shadowgraph should be at least 100 mm. As can be seen later in the results of measurements performed on extension springs, the shadowgraph is less subject to variation in measured values when the spring's high point is readily identifiable - for ground compression springs it is necessary to rotate the spring, a process which lends itself to increased measurement variation, to bring the high point on the end coil uppermost and into focus. For unground compression springs and extension springs the high point is readily identifiable as being the wire cut off or top of the end loop. Larger unground compression springs should be located on a mandrel, the diameter of which should be at least 95% of the spring's inside diameter, stood on a surface plate and measured using a height gauge. This ensures that the spring axis is perpendicular to the measuring datum and therefore that true axial length is measured.

To summarize, the following recommendations are made in respect of free length measurement:-

A shadowgraph should be used for ground springs which have either a free length of less than 10 mm, an outside diameter of less than 10 mm, or a spring rate of less than 2 N/mm. It should also be used for unground springs which are within its measuring range. Other ground springs should be measured using a height gauge, or alternatively a precision steel rule for springs over 600 mm in length if a height gauge is not available (height gauges are available up to 1000 mm range but are very expensive). Unground springs too large for a shadowgraph should be measured using a height gauge while located on a mandrel.

Total Coils

No British standard tolerance is specified on total coils as this parameter is not of critical importance in its own right and is often varied during spring manufacture to achieve the required spring rate. For this reason it is generally sufficient to count the number of whole coils and estimate the fraction to the nearest eighth.

If for some reason it is necessary to know accurately the fraction of a coil, then a shadowgraph with suitable fixturing or a purpose built jig should be used to ensure that the centre of the protractor is located accurately on the axis of the spring. A jig was designed and built (Fig 1) to enable accurate measurement of the fraction of a coil for both compression and extension springs. The jig is universal for a range of springs, for compression spring inside diameters of 25 mm and upwards and extension spring outside diameters of 20 mm upwards, and can also be used for measurement of angle of grind on compression springs.

The analysis of measurements undertaken is summarized in Table IV. It can be seen that for all four spring designs, overall measurement variation is less than 3°, ie less than one hundredth of a turn. This level of measurement variation is acceptable, especially in relation to the usual accuracy of estimation of the fraction of a coil. It is therefore recommended that the two techniques evaluated be used in those cases where it is necessary to estimate accurately the fraction of a coil.

Angle of Grind

To accurately measure angle of grind it is necessary that the centre of the protractor must be located accurately on the axis of the spring. Measurements were undertaken on a range of springs, the shadowgraph being used for springs with outside coil diameters up to 25 mm and the SRAMA jig for diameters greater than this. The results of the analysis on these measurements are given in Table V.

As can be seen, for all six designs, the overall measurement variation represents less than 10% of the allowable tolerance value. Both of these techniques can therefore be recommended for angle of grind measurement.

Tip Thickness

A number of techniques are currently in use for tip thickness measurement. These include use of a shadowgraph, vernier depth gauge, dial gauge with knife edge attachment and vernier calipers. It was considered that the shadowgraph should be used for axial wire dimensions of up to 5 mm, and one of the other techniques for larger wire sizes, since the actual tip thickness for this size would then be sufficiently large to enable accurate measurement by a contact method.

The results of measurements made are given in Table VI. No 'F' values are given for comparison of the 3σ values obtained for springs 5 and 21 since these only show that there is no statistically significant difference between them. No tolerance exists in BS 1726 for this parameter, the actual value for which is to be agreed between customer and supplier. It is therefore considered that the shadowgraph is suitable for measuring tip thicknesses of springs with axial wire sizes up to 5 mm since at worst its overall measurement variation is less than 0.1 mm. For material sizes of 5 mm and above, the dial gauge appears the least subject to measurement variation and is therefore recommended.

Chamfer

Investigation into commercial methods used for chamfer measurement have indicated that chamfers are always checked against a gauge made to correspond with the part with which the spring will mate in service. No British standard tolerance exists on chamfer since these are only specified in order that the spring clears radii on adjacent components.

It may be possible to measure external chamfers using a shadowgraph, but certainly not internal chamfer. In view of this it is recommended that chamfer be checked against suitable gauges, in line with the initial recommendations made by the BS 1726 revision working party.

Squareness

Three main methods for undertaking squareness measurement were considered. These involved use of shadowgraph, angle plate and feeler gauges, and a jig designed and manufactured by SRAMA (see Fig 2). The measurements undertaken and analysed are set out in Table VII.

Carrying out an 'F' test on the 3σ values obtained for springs 26 and 14 shows there to be a significant difference in measurement variations between the feeler gauge method and the shadowgraph method, the latter being subject to the least overall measurement variation. From the measurements undertaken on springs 3 and 10, nothing conclusive can be established by 'F' test, but the overall measurement variation of both the feeler gauge method and SRAMA jig is well within 10% of the tolerance allowed. Feedback from the operators who undertook these squareness measurements has indicated the SRAMA jig to be much less tedious to use.

In an attempt to improve the SRAMA jig still further it was modified for electrical contact detection such that a light would glow when contact was made with the spring, rather than relying on visual judgement. This was not, however, reliable because any dirt, grease or paint on the spring under measurements could lead to false values being obtained.

Based on the results obtained, and operator feedback, it is recommended that the shadowgraph be used for squareness measurement of springs with a free length of less than 30 mm. It is also recommended that springs with a free length greater than 30 mm should be measured using the SRAMA jig or one which operates on the same principle, although use of feeler gauges and an angle plate would not be subject to an unacceptable level of measurement variation.

Parallelism

The technique recommended by the draft revision of BS 1726 at present involves standing the spring on a surface plate, lowering a second plate onto it until it just touches the high point on the upper end coil, and measuring the maximum gap between that coil and the upper plate with feeler gauges. In addition, this is only recommended for springs with a rate greater than 15 N/mm. It is generally agreed that this method is difficult to undertake.

The measurements undertaken here, the analysis of which is given in Table VIII, were carried out using a lever type dial gauge, which is the method preferred by a number of springmaking companies. Use of a lever type dial gauge, as opposed to a conventional dial gauge, allowed parallelism measurement on lower rate springs by virtue of the reduced lower pressure and therefore spring deflection.

As can be seen from the table, the 3σ values obtained all represent an overall measurement variation of less than 0.1 mm. In addition, as rate is reduced, 3σ as a percentage of the allowed tolerance does not appreciably alter, although for the small wire sizes of the springs used here, it is greater than 10% of the tolerance value.

Use of the dial gauge is recommended here as it is favoured in industry, and does not suffer an unreasonable level of measurement variation. In addition springs can be measured which have a rate down to 2 N/mm.

Bow

Measurements were undertaken using feeler gauges and a surface plate. The results obtained (Table IX) show acceptable measured variation in relation to the BS 1726 tolerance value allowed.

Attempts to carry out measurements using the shadowgraph were not successful as it was not possible to focus on the small gap between the spring and datum face due to the short focal lenth of the lenses used in the shadowgraph.

Use of feeler gauges and surface plate is the method generally used in industry and is appropriate for this parameter.

Load at Length

For this parameter only the use of electronic load testing equipment was advocated, based on the recommendations of a previous SRAMA report (1) in which a comparison between mechanical and electronic load testing machines was undertaken. A number of measurements were undertaken using two different electronic load testing machines. The results of the analysis are included in Table X.

In all cases the overall measurement variation was well within 10% of the allowable tolerance value. In addition, these machines proved extremely simple to use since they have digital readouts for both load and length and therefore require no value judgements from the operator.

Spring Rate

Spring rate is not in itself a measured quantity, but rather a calculated quantity based on two load at length measurements. These measurements should be carried out in the range of 20% to 80% of the safe deflection at two agreed lengths, and spring rate calculated using the formula:-

$$\text{Spring rate} = \frac{\text{change in force}}{\text{change in length}}$$

For this reason no measurements of spring rate have been undertaken but it is recommended that the necessary load at length measurements be undertaken using electronic load testing equipment, in line with the findings of work undertaken on that parameter.

Solid Length

The procedure for solid length measurement is based on load at length measurement. A length value is recorded after the spring has been compressed to a load which is generally agreed to be 1 to 1.5 times the theoretical solid load.

b) Extension Springs

Outside Coil Diameter

The measurement of outside diameter on extension springs differs from that of compression springs in that the end loop often protrudes outside the body diameter. This makes measurement by similar techniques prone to greater variation.

A number of measurements were undertaken, the results of which are given in Table XI. As can be seen, a micrometer has been used with less measurement variation than the height gauge and surface plate, the difference in variation being highly significant by 'F' test. Even spring 24, which has an extremely low rate value, has been measured with acceptable variation using a micrometer.

It is recommended that all close coiled extension springs with a wire diameter less, and a body length greater, than the anvil diameter of a micrometer be measured using a micrometer which should ideally be clamped in a micrometer stand. Other extension springs, including open-coiled ones, should be measured using those techniques recommended for compression springs. Due to the additional difficulties the end loops on these springs create, extreme care is necessary when measuring outside diameter using either the shadowgraph or height gauge method.

Free Length

Free length measurements were undertaken using the shadowgraph, the results of which are shown in Table XII, which shows that the measurement variation on extension springs is less than 10% of the tolerance allowed, except for very small springs, such as design 25. Extension spring free length can be measured more accurately than compression spring free length because the maximum free length is readily identifiable. For small springs, such as design 25, the shadowgraph is the only instrument capable of being used due to the difficulty of holding such a small spring without causing deformation.

It is therefore recommended that a shadowgraph be used for free length measurement on all extension springs which are within its range. To gain an indication of measurement variation to be expected from larger springs, design 26 was measured using vernier calipers since this is the favoured method in industry. The variation experienced was within 10% of the tolerance and so vernier calipers are to be recommended for these larger springs.

Total Coils/Relative Loop Position

Measurement of these two parameters involves exactly the same techniques since the start and finish of the body coils are defined by the plane through the end loops. As for angular measurements on compression springs, the shadowgraph and the purpose built SRAMA jig are advocated. Measurements were therefore undertaken using these two techniques, the results of which are given in Table XIII.

As can be seen, other than for design 24 measurement variation is less than 10% of the tolerance. Spring 24 is of very low rate and has a large number of coils, making it prone to being wound up and therefore accounting for the increased variation. There is however no doubt that both of these techniques are eminently suited to accurate total coils and relative loop position measurement and are to be recommended, the SRAMA jig being used on springs with an outside diameter of greater than 20 mm.

End Loop Opening

This parameter is not subject to a British standard tolerance. It is also generally a relatively small dimension which, though tending to be inaccessible to contact type measuring equipment, can be measured by projection using a shadowgraph. The main reason for dimensioning this parameter is to ensure that the spring will fit over a rod for location purposes.

It is therefore recommended that this parameter be checked using rod gauges in a go-no go manner. An indication of the dimension can be obtained if a range of rod gauges are available.

Load at Length

For the same reasons as for compression spring measurement, extension spring load at length measurement is to be carried out using electronic load testing equipment. Measurement repeatability should be better for extension springs since these load up axially whereas compression springs have a non-axial loading characteristic.

Spring Rate

Spring rate is determined by calculation from two load at length measurements, these loads being measured at two positions within the range of 20% to 80% of the safe deflection.

Initial Tension

Initial tension cannot be measured directly, but must be calculated from two load at length measurements and the free length measurements. These measurements are to be undertaken as detailed previously.

c) Torsion Springs

Outside Coil Diameter

The measurement of outside coil diameter on torsion springs can be likened to that of extension springs since these springs are often close coiled and have legs which protrude outside the spring's body diameter. For this reason, the recommendations made in respect of extension spring measurement also apply to torsion springs.

Inside Coil Diameter

Those techniques recommended for compression spring measurement will apply also to torsion springs.

Body Length

This parameter is only toleranced for springs which do not require to be torque tested. Body length should be measured axial to the spring and include fractions of a coil. This makes this measurement prone to large inaccuracies when attempting to use hand held equipment due to operators misaligning the measuring and spring axis. Further inaccuracies occur due to the many different leg forms which these springs can have.

It is recommended that this dimension be checked using go-no go gap gauges suited to the type of leg form the springs have. Making the gap of these gauges adjustable would provide a means for carrying out measurements on this parameter.

Total Coils/Relative Leg Position

Measurement of these two parameters involves exactly the same techniques since the start and finish of the body coils are defined by a plane through the legs. Again, due to the requirements for accuracy, either a shadowgraph or a purpose built jig should be used.

Two designs of tangential leg torsion spring were measured using a shadowgraph. The results are given in Table XIV. As can be seen, overall measurement variation for both designs is within 10% of the allowed tolerance, despite the fact that one of the designs was extremely small, consequently creating locational difficulties during measurement. It is therefore recommended that the shadowgraph be used for total coils and relative leg angle measurement on springs which can be displayed on its screen, and a purpose built jig used for larger springs.

Torque at Angle

Torque at angle measurements are probably subject to more sources of variation than any other measured parameter. Even measurements taken on a single spring on one machine are known to be subject to large variations due to differences in mandrel size, lubrication, direction of loading and method of loading of legs. In addition, different levels of friction between coils, and differences in material surface condition, will have an effect on overall measurement variation.

For these reasons the method of measuring torque at angle must be agreed between customer and supplier, and the specific details of the test method closely followed if meaningful results are to be obtained. In addition, it is recommended that electronic torque measuring equipment is used since the digital readouts of torque and angle are an aid to reducing measurement variaton by virtue of the fact that the operator does not have to make value judgements in respect of these quantities. It is also recommended that the torque is measured using the mandrel on which the spring will operate in service.

Spring Rate

To enable calculation of the spring rate, it is necessary for two torque measurements to be carried out at agreed positions within the range of 20% to 80% of the safe deflection. As stated previously, the method for carrying out these torque at angle measurements must be agreed between customer and supplier.

PHASE I CONCLUSIONS

The methods available for measuring a spring parameter are numerous, any of which may be used. The recommended techniques, which are set out in detail in Appendix II are those which have been shown to be the most accurate and precise, and which should be used in cases of dispute between customer and supplier. These standard techniques are not necessarily the quickest to use and may well require increased time and effort which other less accurate techniques would not.

A number of instances have occurred where the overall measurement variation is in excess of 10% of the BS 1726 Grade A tolerance, particularly where small springs are concerned. This must raise some doubt as to the suitability of tolerances which are so tight that it is not possible to measure the parameter in question to an order of magnitude greater. However, the advent of video inspection techniques using cameras and automatic edge detection may well circumvent this problem.

PHASE II INDUSTRIAL COMPARISON OF STANDARD TECHNIQUES

i) Method

A number of springmaking and spring using companies were approached and each was requested to supply springs for which any of the parameters relevant to this project had been measured by their own inspection departments. Upon receipt at SRAMA these springs were measured by means of the relevant standard technique, established in Phase I and set out in detail in Appendix II.

This would enable the improved measurement repeatability of the standard techniques, demonstrated in Phase I on selected spring designs measured under laboratory conditions, to be ratified on springs randomly selected by the industry itself. In addition, any other effect of the use of a standard technique, such as change in the mean measured value, could be observed and assessed.

ii) Measurements

The specific request made to springmakers and users was that, for each design submitted, they should send six springs. In addition, to permit analysis of repeatability, each parameter that the company measured was to be measured five times per spring by a single operator. When received at SRAMA, an identical matrix of measurements was undertaken using the standard technique.

As in Phase I, values of overall standard deviation, σ, were calculated for both the technique used by the participating company and the standard technique. These standard deviations were then compared by means of an 'F' test to establish the significance if any of the difference in these calculated values. This then determined whether or not the standard technique measurement repeatability was better than that achieved by the industry. In addition, by means of a simple non-parametric technique (2), an assessment of the measured values was carried out to determine whether or not a shift of the mean measured value had occurred, when comparing the results of the two measurement techniques.

iii) Results and Discussion

Springs and associated measurements were received from a number of companies. The measurements received concentrated on a few spring parameters, being those which spring users most frequently require to be measured by springmakers. A summary of the spring designs measured in this Phase is given in Table XV, and an example set of measured values along with the subsequent analysis is given in Appendix III. Each parameter is analysed in turn:-

Outside Coil Diameter

The results and analysis of measurements undertaken are given in Table XVI for all the compression, extension and torsion springs received. It can be seen that the overall standard deviation, and therefore measurement variation, is reduced when using the standard technique for all those springs received, except for designs 55 and 69. Comparing the overall values by means of an 'F' test shows them to be generally significant. For designs 55 and 69, the ones for which the standard technique did not improve measurement repeatability, the detected difference in overall standard deviation was not highly significant. It can be concluded, therefore, that use of the standard technique for outside coil diameter measurement will, taken overall, improve measurement repeatability.

Examination of the mean of measurements taken has shown that, for the four compression spring designs, the standard technique will cause a significant increase in the mean of the measured values. For the extension and torsion springs measured, the direction of mean shift encountered is not consistent, even though the shift is significant for three of the designs. In those cases where the mean value has decreased, the amount of this decrease is much less than the level of increase experienced on other designs. Considering all the results indicates that a slight increase of up to 1% in outside diameter is to be expected when using the standard technique.

Use of the standard technique as opposed to that more normally used could alter the number of acceptable springs in a batch by reducing measurement variation and therefore the number of measured values outside the tolerance limits. If the mean of the measured value was, however, on the upper tolerance limit, then use of the standard technique may reduce the number of springs in tolerance by moving the mean of the measurement values outside the tolerance band.

Free Length

The results of the analysis of measurements undertaken on the compression and extension springs received are given in Table XVII. It can be seen from the 'F' test results that the reduction in overall standard deviation, or measurement variation, experienced when using the standard technique as opposed to the industrial method is highly significant for all springs measured other than design 64. For this spring there is no detectable difference in measurement variation.

It can also be seen that use of the standard technique creates a significant positive change, ie an increase, generally between .1 and .5 mm in the mean of the measured values, for six of the eight spring designs measured. For the other two designs the mean values do not change significantly in either direction.

To summarise, it can be expected that adoption of the standard technique will decrease measurement variation and cause an increase in the mean of the measured values. This may lead to more springs in a given batch being 'in tolerance' unless use of the standard technique causes the mean value to be shifted outside the tolerance band.

Load at Length

The results of the analysis of measurements undertaken is given in Table XVIII. The results show that use of the standard technique can reduce measurement variation. For design 53 the apparent improvement in repeatability when using a mechanical load tester as opposed to the electronic type advocated by the standard technique is due to its poor measurement resolution of 0.28 N which is nearly three times that of the electronic machine used (resolution 0.1 N). Indeed, for design 66, which was measured in industry using a similar mechanical load testing machine, the standard technique is more repeatable. It can be seen that, for designs 62 and 63, measured in industry using electronic machines, there is no significant difference in measurement repeatability when compared to the use of the electronic machine as proposed by the standard technique. For design 51, also measured in industry using an electronic machine, the results are less repeatable than those obtained by the standard technique. This confirms that use of any electronic machine does not guarantee good repeatability.

This is because some of the different types of electronic machine available either use load and length measurement systems which are in themselves subjected to high levels of measurement variation, or are mounted in loading frames which are not sufficiently rigid and can lead to poor measurement repeatability.

It can be seen that the mean shifts experienced are not consistent in direction. This emphasises the importance of establishing true length and load zero positions prior to test, and accounting for frame deflection in the test machine.

Overall the results demonstrate that use of electronic machines, which are capable of a higher level of measurement resolution than other types, in conjunction with standard procedures, should reduce overall measurement variation and increase accuracy of measured values. This should in turn result in fewer springs being rejected as 'out of tolerance'.

Tip Thickness

The results of the analysis of measurements undertaken are detailed in Table XIX. Two sets of results are given for both spring designs since measurements were undertaken on tip thickness at both ends of the spring.

It can be seen that in all cases the improvement in measurement variation experienced at SRAMA using the standard technique is highly significant. It is also indicated that a negative change, ie a decrease, in the mean of the measured values is to be expected when using the standard technique.

Squareness

The results of the analysis of measurements undertaken are detailed in Table XX. Two sets of results are given for spring design 53 since measurements were undertaken on both ends of this spring.

It can be seen that in all cases a highly significant improvement in overall measurement variation occurs when using the standard technique at SRAMA. The results also indicate a tendency for the mean of the measured value to increase.

Solid Length

The results of the analysis of measurements undertaken are detailed in Table XXI. It can be seen that using the standard technique causes a highly significant improvement in measurement repeatability. No conclusions can be reached regarding change in mean values from the results obtained. However, the importance of using a standard technique for solid length measurement cannot be overstated, for the same reasons as are stated for load at length measurement.

Other Parameters

Only one set of measurements was received for each of angle of grind (design 58), relative loop position (design 68), and relative leg position (design 69). In addition only a single measurement had been carried out for each of the six springs of each design. Since there was no possibility of statistically analysing these results, a single measurement only was undertaken by the standard technique. The results obtained are detailed in Tables XXII, XXIII and XXIV. It is immediately obvious that the measurement resolution achievable by the standard technique is greater than that used in industry, which also varies between different companies, and will therefore improve accuracy of measured values. This is particularly important for relative leg angle of torsion springs which is of critical importance in defining the spring's operating capability.

No measurements were received for inside diameter, total number of coils, chamfer, parallelism, bow, end loop opening, or body length. This is a reflection of the fact that these parameters rarely require to be measured. No torque at angle measurements were received probably due to the fact that, as explained previously, measurements on this parameter are subject to such a high level of variation and very few companies have accurate torque measuring equipment available.

PHASE II CONCLUSIONS

The improvement in measurement repeatability claimed for the standard techniques developed in Phase I under laboratory conditions has, by means of statistical comparison of measurements undertaken on springs supplied by participating companies, been confirmed.

A major effect of this improved repeatability is that the number of springs rejected as out of tolerance in a given batch may be reduced.

It has also been shown that use of the standard techniques does tend to alter the mean of the measured values. A springmaker needs to be aware of this since, in a case of dispute, use of the standard technique may increase rejections by shifting the measurement mean outside the tolerance limits.

REFERENCES

1. Measurement of Springs by D Saynor, SRAMA Report No 309.

2. Statistical Design of Experimental Work by W E Duckworth, 'The Metallurgist', April 1966, Pages 28-32.

TABLE I SPRING DESIGNS USED IN PHASE I

Design No.	Spring Type	Wire Diameter (mm)	Free length (mm)	Outside diameter (mm)	Spring rate (N/mm)	Total no. of coils
1	C	1.12	44.4	9.1	1.90	17.75
2	C	1.80	19.1	11.1	22.76	8
3	C	2.00	88.9	22.2	2.06	12
4	C	4.00	88.9	25.4	23.15	14
5	C	4.87	152.4	50.8	6.47	11
6	C	4.87	76.2	50.8	11.67	7
7	C	0.51	9.5	4.6	1.71	7.75
8	C	0.56	25.4	4.6	0.89	18.75
9	C	1.12	25.4	7.6	5.24	12.75
10	C	1.42	25.4	9.1	9.53	11.25
11	C	1.60	25.4	9.5	15.79	10.5
12	C	2.00	25.4	12.7	27.66	7
13	C	4.75	76.2	37.6	20.18	9
14	C	4.00	76.2	25.4	28.00	12
15	C	0.90	19.0	9.5	1.96	8
16	C	1.40	63.5	11.1	2.55	20
17	C	1.80	76.2	11.1	7.75	20
18	C	1.30	76.1	12.2	1.33	18.5
19	C	4.47	250.0	34.1	4.00	23.5
20	C	30.00	875.0	240.0	280.00	12
21	C	9.50	130.0	90.0	32.58	5.5
22	C	7.15	26.0	33.0	668.00	4
23	E	2.06	50.0	12.5	9.32	11
24	E	0.37	25.0	4.0	0.14	45
25	E	0.35	9.0	2.0	1.03	15
26	E	2.65	101.6	25.4	2.00	15
27	E	3.25	177.8	25.4	2.55	40
28	T	1.23	15.0	11.5	—	12
29	T	0.26	2.8	2.6	—	8.75

C = Compression, E = Extension, T = Torsion

TABLE II COMPRESSION SPRING OUTSIDE DIAMETER RESULTS

Spring No	Nominal O/D (mm)	Nominal Free length (mm)	Nominal Rate (N/mm)	BS1726 tolerance ± (mm)	Overall 3σ (mm)		'F' Test	
					Shadowgraph	Height Gauge	'F'	Significance Level (%)
7	4.6	9.5	1.71	0.134	.076 (56%)	—	—	—
8	4.6	25.4	0.89	0.133	.090 (68%)	—	—	—
10	9.1	25.4	9.53	0.140	.120 (86%)	.082 (58%)	2.15	99
1	9.1	44.4	1.90	0.143	.324 (225%)	.035 (25%)	85.36	99.9
12	12.7	25.4	27.66	0.161	.057 (35%)	.046 (29%)	1.53	90
3	22.2	88.9	2.06	0.303	.070 (23%)	.012 (4%)	32.30	99.9
4	25.4	88.9	23.15	0.321	.033 (10%)	.012 (4%)	7.43	99.9
6	50.8	76.2	11.67	0.689	.083 (12%)	.025 (4%)	11.22	99.9

Note:- Figures in brackets are the percentage of the tolerance value which the 3σ value represents

TABLE III COMPERESSION SPRING FREE LENGTH RESULTS

Spring No	Nominal free Length (mm)	Nominal O/D (mm)	Nominal Rate (N/mm)	BS1726 tolerance ± (mm)	Overall 3σ (mm)		'F' Test	
					Shadowgraph	Height Gauge	'F'	Significance Level (%)
7	9.5	4.6	1.71	0.322	.042 (13%)	—	—	—
2	19.1	11.1	22.76	0.438	.076 (17%)	.025 (6%)	9.44	99.9
8	25.4	4.6	2.06	0.569	.108 (19%)	—	—	—
16	63.5	11.1	2.55	1.173	—	.080 (7%)	—	—
17	76.2	11.1	7.75	1.300	—	.003 (2%)	—	—
18	76.2	12.2	1.33	1.439	—	.017 (1%)	—	—
14	76.2	25.4	28.04	1.308	.056 (4%)	.011 (1%)	25.92	99.9
3	88.9	22.2	2.06	1.736	.038 (2%)	.039 (2%)	1.06	—
19	250.0	34.1	4.00	4.240	—	.082 (2%)	—	—
20	875.0	240.0	280.0	13.65	—	1.09 (8%)	—	—

Note:- Spring number 20 was measured using a ruler, graduated in 0.5mm increments.
Figures in brackets are the percentage of the tolerance value which the 3σ value represents.

TABLE IV COMPRESSION SPRING TOTAL COILS RESULTS

Spring No	Nominal O/D (mm)	Overall 3σ (degrees)	
		Shadowgraph	Jig
11	9.5	2.9	——
4	25.4	2.3	——
5	50.8	——	1.3
21	90.0	——	0.4

TABLE V COMPRESSION SPRING ANGLE OF GRIND RESULTS

Spring No	Nominal O/D (mm)	Overall 3σ (degrees)		BS1726 tolerance
		Shadowgraph	Jig	
8	4.6	6.39 (8%)	——	260°-340°
11	9.5	1.55 (2%)	——	"
3	22.2	1.87 (2%)	——	"
4	25.4	0.95 (1%)	——	"
5	50.8	——	1.03 (1%)	"
21	90.0	——	0.50 (.6%)	"

TABLE VI COMPRESSION SPRING TIP THICKNESS RESULTS

Spring No	Wire diameter (mm)	3σ (mm)			
		shadowgraph	depth gauge	dial gauge	vernier
11	1.60	.079	——	——	——
13	4.75	.096	——	——	——
5	4.87	——	.093	.077	.110
21	9.50	——	.178	.159	.167

TABLE VII COMPRESSION SPRING SQUARENESS RESULTS

Spring No	nominal free length (mm)	BS1726 tolerance (mm)	3σ (mm)		
			shadowgraph	feeler gauges	SRAMA jig
15	19.0	0.57	.075 (13%)	.123 (22%)	—
9	25.4	0.76	.098 (13%)	.148 (19%)	—
3	88.9	2.67	.267 (10%)	.093 (3%)	.117 (4%)
5	152.4	4.57	—	.308 (7%)	.217 (5%)

TABLE VIII COMPRESSION SPRING PARALLELISM MEASUREMENTS

Spring No	Wire diameter (mm)	Outside diameter (mm)	Rate (N/mm)	BS1726 tolerance (mm)	3σ (mm) lever type dial gauge
15	0.90	9.5	1.96	0.48	.075 (15%)
9	1.12	7.6	5.24	0.38	.059 (16%)
2	1.80	11.1	22.76	0.56	.084 (15%)
3	2.00	22.2	2.06	1.11	.059 (5%)

TABLE IX COMPRESSION SPRING BOW MEASUREMENTS

Spring No	Free length (mm)	Rate (N/mm)	BS1726 tolerance (mm)	3σ (mm) Feeler gauges
3	88.9	2.06	2.23	.072 (3%)
14	76.2	28.0	1.90	.113 (6%)

TABLE X COMPRESSION SPRING LOAD AT LENGTH RESULTS

Spring No	nominal load at length		BS1726 tolerance ± (N)	3σ (mm)			
	(N)	(mm)		Probat SF 100EL (0-20N)	Probat SF 100EL (0-100N)	SRAMA 2000N m/c (0-200N)	SRAMA 2000N m/c (0-2000N)
11	14	25.00	8.5	.117(1%)	—	—	—
2	76	15.50	11.6	—	.373(3%)	.326(3%)	—
22	1700	24.00	580.0	—	—	—	8.62(2%)

TABLE XI EXTENSION SPRING OUTSIDE DIAMETER RESULTS

Spring No	nominal O/D (mm)	nominal length (mm)	Rate (N/mm)	BS1726 tolerance ± (mm)	3σ (mm)		
					shadowgraph	micrometer	height gauge
24	4.0	25.0	0.14	0.135	.018 (13%)	.009 (7%)	—
23	12.5	50.0	9.32	0.146	—	.011 (7%)	—
27	25.4	101.6	2.55	0.332	—	.047 (14%)	.115 (35%)
26	25.4	177.8	2.00	0.241	—	.073 (21%)	.119 (35%)

TABLE XII EXTENSION SPRING FREE LENGTH RESULTS

Spring No	nominal free length (mm)	Rate (N/mm)	BS1726 tolerance ± (mm)	3σ (mm)	
				shadowgraph	vernier calipers
25	9.0	1.03	0.39	.076 (19%)	—
24	25.0	0.14	1.09	.077 (7%)	—
23	50.0	9.32	1.30	.039 (3%)	—
26	101.6	2.00	2.54	—	.067 (3%)

TABLE XIII EXTENSION SPRING RELATIVE LOOP POSITION RESULTS

Spring No	Rate (N/mm)	Total number of coils	BS1726 tolerance $\pm^{o}$	3σ (mm) shadowgraph	SRAMA Jig
23	9.32	11	37	1.67 (4%)	—
26	2.00	15	42	2.42 (6%)	3.24 (8%)
27	2.55	40	67	—	2.58 (4%)
24	0.14	45	70	8.54 (12%)	—

TABLE XIV TORSION SPRING RELATIVE LEG ANGLE RESULTS

Spring No	nominal O/D (mm)	nominal total no of coils	BS1726 tolerance $\pm(^{o})$	3σ $(^{o})$ shadowgraph
28	2.8	8.75	20.40	1.17 (6%)
29	11.5	12	24.65	2.11 (9%)

TABLE XV SPRING DESIGNS USED IN PHASE II

Design No	Spring type	Wire diameter (mm)	Free length (mm)	Outside diameter (mm)	Spring rate (N/mm)	Total no of coils
51	C	1.85	12.3	22.5	5.27	2.5
52	C	2.40	30.0	28.5	4.11	4.5
53	C	1.60	25.6	12.3	8.16	6.5
54	C	0.36	65.5	5.9	0.03	31
55	C	0.48	18.8	2.8	2.72	15.5
56	C	3.25	30.4	21.5	6.86	6
57	C	0.48	10.0	3.3	2.35	10
58	C	4.86	47.9	31.2	46.56	6.5
59	C	3.72	32.2	54.9	6.29	2.25
60	C	3.20	98.0	32.0	4.25	10.25
61	C	4.30	25.7	20.3	165.47	5
62	C	2.50	73.2	19.9	6.13	12
63	C	2.52	73.8	22.9	4.29	11
64	E	0.70	28.0	5.1	1.86	15
65	E	1.60	72.0	9.5	3.76	35
66	E	2.95	180.0	20.2	4.80	30.5
67	E	0.60	45.5	6.9	0.40	13
68	E	2.06	50.0	12.5	9.32	11
69	T	1.02	8.5	11.0	—	4.75
70	T	0.50	10.3	5.2	—	6

C = Compression, E = Extension, T = Torsion

TABLE XVI OUTSIDE COIL DIAMETER RESULTS

Spring No	Nominal O/D (mm)	Nominal free length (mm)	Nominal rate (N/mm)	Technique		Overall σ (mm)		'F' test		Mean shift	
				SRAMA	Industry	SRAMA	Industry	'F'	Sig level (%)	Range	Sig (%)
55	2.8	18.8	2.72	A	B	.005	.004	1.40	—	.02/.04	95
57	3.3	10.0	2.35	A	B	.007	.010	1.91	95	0/.03	95
56	21.5	30.4	6.86	C	D	.004	.023	31.74	99.9	.05/.13	95
52	28.5	30.0	4.11	C	D	.004	.022	25.00	99.9	.06/.17	95
67	6.9	45.5	0.40	B	D	.003	.004	1.81	90	-.01/.01	—
65	9.5	72.0	3.76	B	B	0	.010	∞	99.9	0/.05	95
70	5.2	10.3	—	A	D	.009	.013	2.12	95	0/.04	95
69	11.0	8.5	—	A	B	.007	.005	1.73	90	-.01/-.02	95

A - shadowgraph
B - micrometer
C - height gauge
D - vernier caliper

TABLE XVII FREE LENGTH RESULTS

Spring No	Nominal free length (mm)	Nominal O/D (mm)	Nominal rate (N/mm)	Technique		Overall σ (mm)		'F' test		Mean shift	
				SRAMA	Industry	SRAMA	Industry	'F'	Sig level (%)	Range	Sig (%)
57	10.0	3.3	2.35	A	B	.004	.008	3.71	99.9	-.01/.02	—
55	18.8	2.8	2.72	A	B	.006	.042	51.69	99.9	.10/.17	95
53	25.6	12.3	8.16	C	D	.003	.022	57.03	99.9	.07/.18	95
52	30.0	28.5	4.11	C	D	.005	.038	51.14	99.9	.18/.46	95
56	30.4	21.5	6.86	C	D	.003	.035	116.24	99.9	.06/.20	95
54	65.5	5.9	0.03	A	D	.012	.137	139.69	99.9	.12/.36	95
64	28.0	5.1	1.86	A	D	.009	.009	1.07	—	.04/.51	95
67	45.5	6.9	0.40	A	D	.007	.025	14.91	99.9	-.01/.03	—

A - shadowgraph
B - micrometer
C - height gauge
D - vernier caliper

TABLE XVIII LOAD AT LENGTH RESULTS

Spring No	Nominal load at length (N)	(mm)	Technique SRAMA	Industry	Overall σ (N) SRAMA	Industry	'F' test 'F'	Sig level (%)	Mean shift Range	Sig (%)
63	78	58.00	A	A	.056	.054	1.04	—	-.1/.1	—
62	85	60.00	A	A	.046	.050	1.20	—	-.1/0	—
53	88	19.30	A	B	.116	0	∞	99.9	.3/.9	95
51	110	5.64	A	A	.194	.913	22.15	99.9	-1.3/-4.6	95
60	168	63.50	A	B	.115	.338	8.68	99.9	2.5/3.1	95
66	185	196.98	A	B	0	.432	∞	99.9	-1.8/-2.5	95

A - Electronic load testing machine
B - Mechanical load testing machine

TABLE XIX TIP THICKNESS RESULTS

Spring No	Wire diameter (mm)	Technique		Overall σ (mm)		'F' test		Mean shift	
		SRAMA	Industry	SRAMA	Industry	'F'	Sig level (%)	Range	Sig (%)
61	4.30	A	B	.030	.072	5.99	99.9	-.05/-.28	95
				.034	.078	5.13	99.9	-.01/-.16	95
58	4.86	A	B	.043	.123	7.97	99.9	-.26/.02	95
				.035	.099	8.09	99.9	-.17/.25	—

A - shadowgraph
B - vernier calipers

TABLE XX SQUARENESS RESULTS

Spring No	Nominal free length (mm)	Technique		Overall σ (mm)		'F' test		Mean Shift	
		SRAMA	Industry	SRAMA	Industry	'F'	Sig level (%)	Range	Sig (%)
53	25.6	A	B	.016	.032	3.93	99.9	.18/.25	95
		A	B	.020	.050	6.39	99.9	.19/.34	95
60	98.0	C	B	.013	.031	5.21	99.9	-.20/.29	—

A - shadowgraph, B - feeler gauge, C - SRAMA jig

TABLE XXI SOLID LENGTH RESULTS

Spring No	Calculated solid load at nominal length		Technique		Overall σ (mm)		'F' test		Mean Shift	
	(N)	(mm)	SRAMA	Industry	SRAMA	Industry	'F'	Sig level (%)	Range	Sig (%)
59	345	12	A	B	.008	.137	307.60	99.9	-.06/-.20	95
58	1598	30	A	B	.007	.108	230.95	99.9	-.10/.04	—

A - Electronic load testing machine
B - Spring compressed solid between flat plates and gap measured with vernier calipers

TABLE XXII ANGLE OF GRIND RESULTS FOR SPRING DESIGN 58

Spring No	Technique		Measured values (degrees)			
			End A		End B	
	SRAMA	Industry	SRAMA	Industry	SRAMA	Industry
1	A	B	280.92	260	291.22	300
2	A	B	296.95	300	314.65	310
3	A	B	280.33	270	286.13	280
4	A	B	282.03	280	286.18	290
5	A	B	286.80	290	300.00	290
6	A	B	290.92	280	300.55	290

A - Shadowgraph
B - Protractor

TABLE XXIII RELATIVE LOOP POSITION RESULTS FOR SPRING DESIGN 68

Spring No	Technique		Measured values (degrees)	
	SRAMA	Industry	SRAMA	Industry
1	A	B	72.00	74
2	A	B	76.33	75
3	A	B	83.50	82
4	A	B	82.53	85
5	A	B	93.00	91
6	A	B	82.33	79

TABLE XXIV RELATIVE LEG ANGLE RESULTS FOR SPRING DESIGN 69

Spring No	Technique		Measured Values	
	SRAMA	Industry	SRAMA	Industry
1	A	B	93.83	95
2	A	B	94.88	95
3	A	B	92.88	90
4	A	B	94.37	95
5	A	B	94.98	95
6	A	B	94.67	95

A - Shadowgraph
B - Protractor

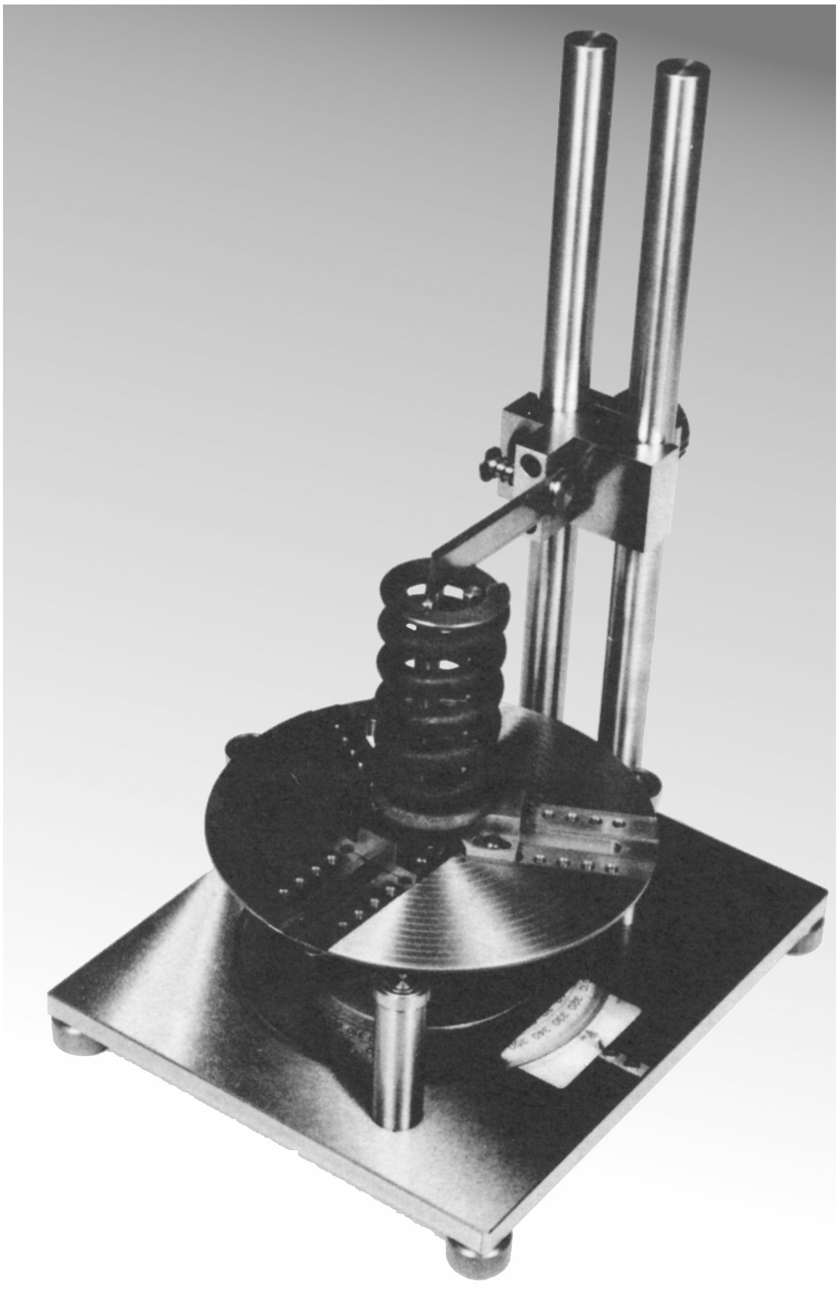

FIG 1 - TOTAL COILS/ANGLE OF GRIND JIG

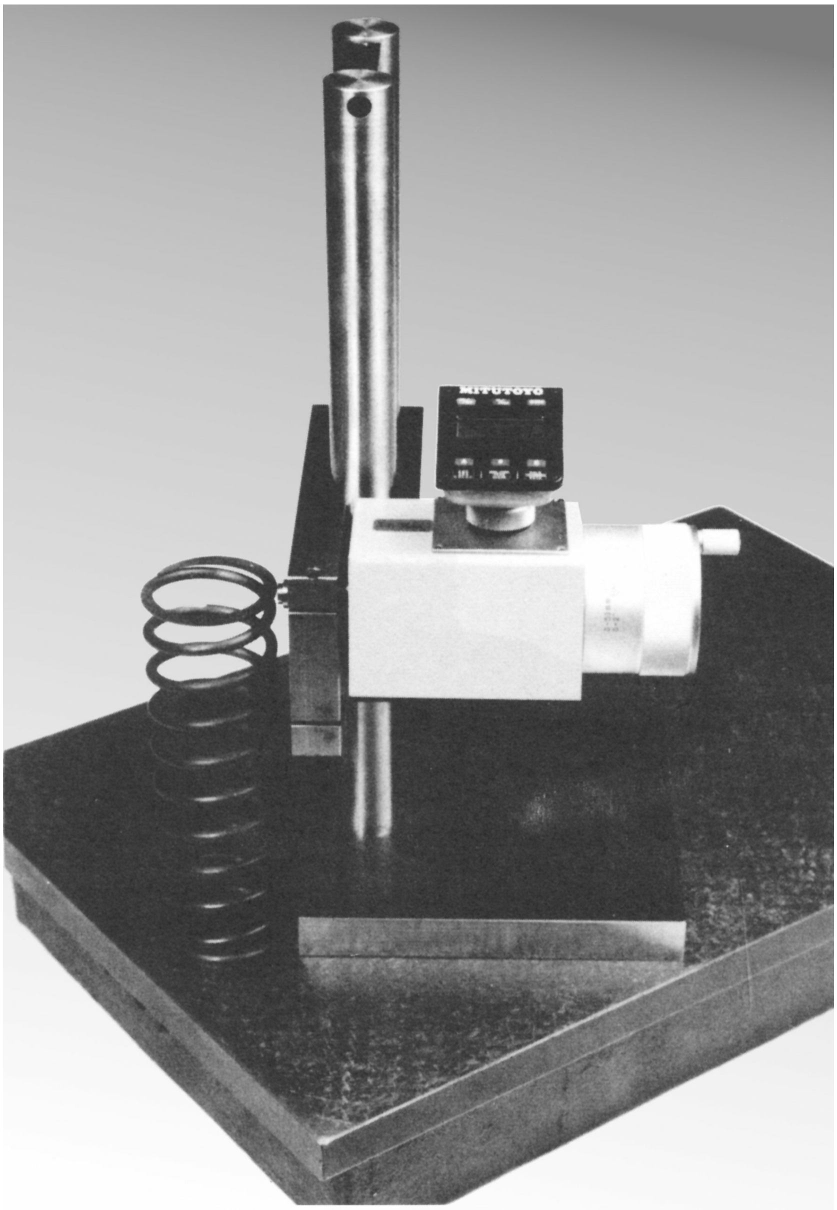

FIG 2 — SQUARENESS JIG

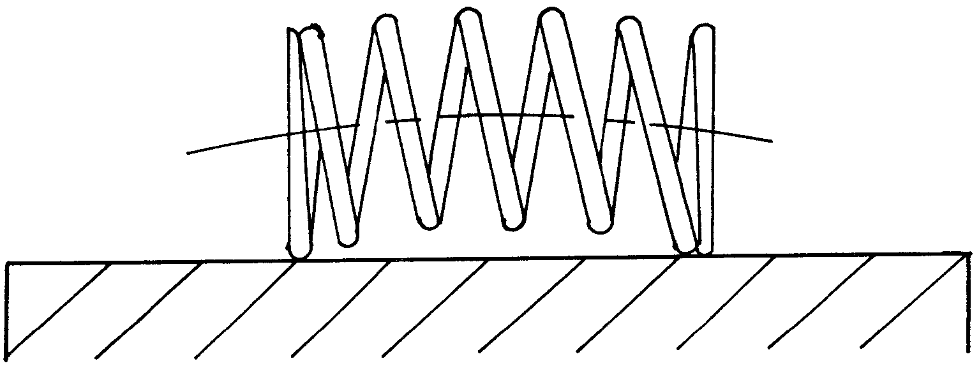

FIG 3 - HOGBACKED SPRING

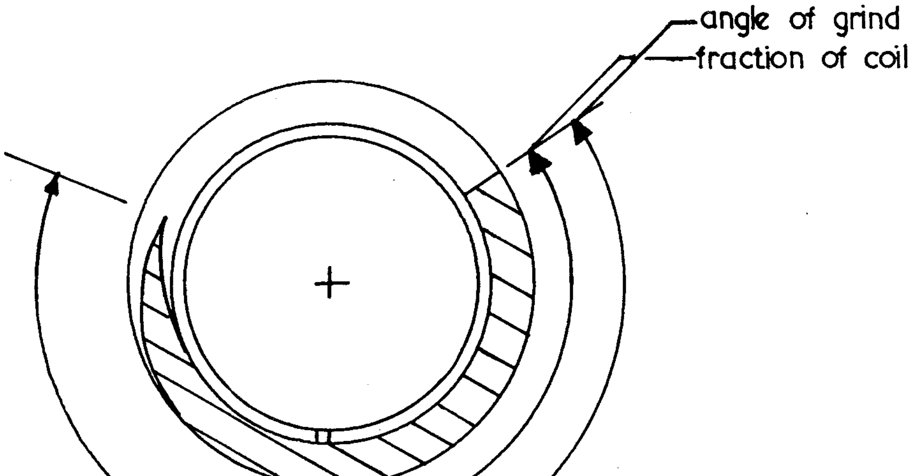

FIG 4 - TOTAL COILS/ANGLE OF GRIND

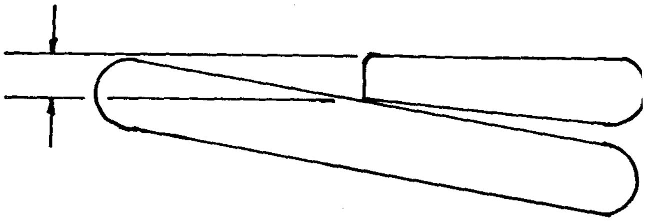

FIG 5 – CLOSED TIP THICKNESS

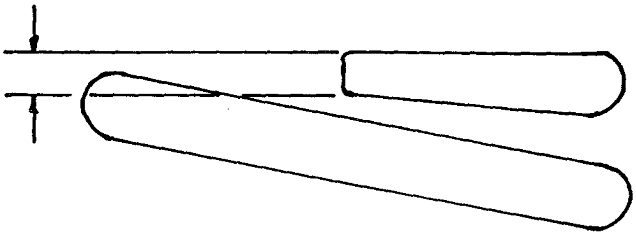

FIG 6 – OPEN TIP THICKNESS

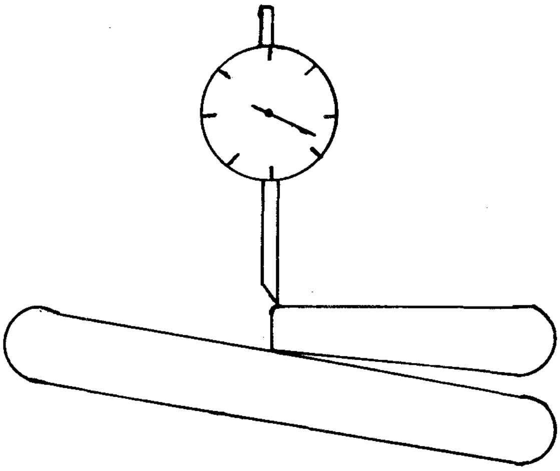

FIG 7 – TIP THICKNESS MEASUREMENT USING DIAL GAUGE

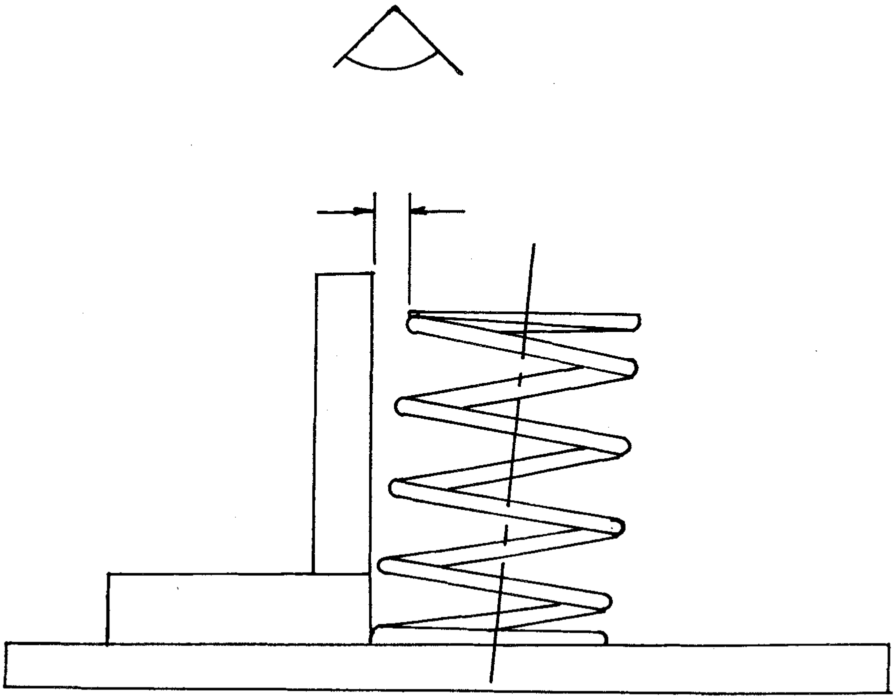

FIG 8 – SQUARENESS MEASUREMENT

APPENDIX I: ANALYSIS OF AN EXAMPLE SET OF PHASE I MEASUREMENTS

Free length measurement on spring design number 14.
a) Using Nikon shadowgraph

Measurement No	Operator 1			Operator 2			Operator 3		
	22a	22b	22c	22a	22b	22c	22a	22b	22c
1	76.72	76.17	76.55	76.73	76.13	76.52	76.73	76.19	76.60
2	76.72	76.09	76.56	76.69	76.13	76.54	76.73	76.22	76.60
3	76.72	76.17	76.55	76.73	76.14	76.53	76.71	76.23	76.60
4	76.72	76.18	76.55	76.72	76.13	76.53	76.73	76.20	76.56
5	76.71	76.16	76.56	76.71	76.14	76.54	76.73	76.22	76.58

b) Using vernier height gauge on surface plate.

Measurement No	Operator 1			Operator 2			Operator 3		
	22a	22b	22c	22a	22b	22c	22a	22b	22c
1	76.60	76.15	76.45	76.60	76.16	76.45	76.60	76.16	76.44
2	76.60	76.17	76.45	76.60	76.14	76.45	76.60	76.16	76.44
3	76.60	76.16	76.44	76.60	76.15	76.45	76.60	76.15	76.44
4	76.60	76.16	76.44	76.59	76.15	76.45	76.60	76.15	76.45
5	76.60	76.16	76.44	76.60	76.15	76.44	76.60	76.15	76.45

All measured values are in mm.

The standard deviation of measurement for each spring is:-

Spring No	Standard Deviation	
	Nikon	Height gauge
22a	.011	.003
22b	.041	.007
22c	.026	.005

An overall standard deviation or 'pooled estimate of standard deviation' is then calculated for each technique using the following formula:-

Overall standard deviation

$$= \sqrt{\frac{(5 \times \sigma_1^2) + (5 \times \sigma_2^2) + (5 \times \sigma_3^2)}{(5 \times 9) - 9}}$$

The following values were obtained when multiplied by 3:-

Nikon - .056

Height Gauge - .011

The BS 1726 free length tolerance for this spring is ± 1.736 mm

It can be seen that the overall 3σ values for each technique, representative of 99.73% of all measurements made by that technique, are both less than .174 mm (or 10% of the tolerance figure) therefore indicating that both measurement techniques can measure to an order of magnitude greater than that which the parameter must achieve on this spring.

On inspection it can also be seen that the 3σ value and therefore the measurement variation obtained by the height gauge is less than that by the shadowgraph. The difference can be confirmed as signficant by means of an 'F' test. The 'F' value is:-

$$F = \frac{.056^2}{.011^2} = 25.92$$

Upon reference to standard F tables it can be seen that the difference in 3σ values is 99.9% significant and can be attributed to actual differences in technique repeatability rather than to chance.

The vernier height gauge and surface plate would therefore be recommended for free length measurement on a spring of this design.

APPENDIX II - Standard Measurement Techniques

General Guidelines to be Observed When Following Standard Techniques

1. All equipment should have current BCS traceable certification.
2. Operators should be trained in the use of equipment and standard techniques.
3. All measurements should be undertaken in a suitable environment, such that external influences such as noise, vibration and poor lighting will not distract the operator and therefore affect the measured values obtained.
4. Each measurement should be repeated, and preferably be undertaken five times to give an average value.

a) Compression Springs

Outside Coil Diameter

i) Small springs with an outside diameter of less than 10 mm and/or a free length of less than 20 mm and/or a spring rate of less than 2 N/mm should be measured using a shadowgraph profile projector, of the vertically illuminated type, as follows:-

1. Attach a transparent (eg perspex) vee block to the shadowgraph worktable.
2. Align the vee block axis with the screen crosswires (after ensuring crosswires are locked in their own zero datum position) and lock in position.

3. Lay spring to be measured in the vee block and focus on one side of the spring. Note micrometer reading.

4. Traverse the shadowgraph table and focus on the other side of the spring. Note micrometer reading.

5. The outside diameter is the difference between the micrometer readings.

6. Rotate spring about its axis in increments to 180° and repeat steps 3 to 5 to obtain a maximum outside diameter value.

7. Repeat measurements about the position of maximum outside diameter previously found.

ii) Other springs should be measured using a height gauge and surface plate as follows:-

1. Ensure surface plate is clean and lightly oiled. Also clean height gauge base and measuring arm.

2. Check the height gauge zero against the surface plate.

3. Lay the spring on the surface plate and roll until hogbacked (Fig 3). Offer light support by hand, to ensure spring remains in position, without causing any spring deformation.

4. Increment the height gauge down while gently sliding the height gauge on the surface plate, passing the measuring arm over the spring.

5. The spring's maximum outside diameter is established as the height at which contact is just felt between the height gauge arm and spring.

6. Read and note the vernier scale value.

Inside Coil Diameter

1. Plug gauges should be machined up to the required diameter limits. Where overall inside diameter is of interest these gauges should be at least 1.5 times the spring's free length. Where end coil inside diameter is of interest, the gauge length should be at least 1.5 times the wire diameter.

2. If the spring will pass over or onto the minimum inside diameter gauge under its own weight but not the maximum inside diameter gauge then it is in tolerance.

3. To obtain an indication of the actual inside diameter measurement a range of gauges should be machined, the minimum practical machining increment being 0.05 mm. The spring's inside diameter is that of the largest plug gauge which it will pass over under its own weight.

Free Length

i) Small ground springs with a free length of less than 10 mm and/or an outside diameter of less than 10 mm and/or a spring rate of less than 2 N/mm, and all unground springs within its range, should be measured using a shadowgraph as follows:-

1. Attach a perspex vee block to the shadowgraph worktable. For free length measurement the vee block should have one end blanked off by a piece of perspex, to act as a datum.

2. Align end datum face with the screen crosswires (which must have been locked in their own zero position) and lock the vee block in position.

3. Align crosswire with the end datum face, ensuring focus is correct, and note micrometer reading. Re-focus and re-align crosswires a further 4 times to enable an average datum value to be obtained.

4. Place the spring in the vee block, ensuring that one end is in contact with the datum face.

5. Focus on the other end of the spring. Rotate the spring, while ensuring it remains in contact with the datum face, to ensure the high point on the spring's end is uppermost. Align crosswires with high point and note micrometer reading.

6. The spring's free length is the difference between the noted reading and the average datum value.

ii) Larger and stiffer springs, and unground springs outside the measuring range of the shadowgraph, should be measured using a height gauge and surface plate.

1. Ensure surface plate is clean and lightly oiled. Also clean height gauge base and measuring arm.

2. Check height gauge zero against surface plate.

3. Ground springs should be placed free standing on the surface plate. Unground springs should be located by a mandrel with a diameter at least 95% of the spring's inside diameter and stood on the surface plate.

4. Increment the height gauge down while gently sliding on the surface plate to pass measuring arm over spring.

5. The spring's maximum free length is the height at which contact is just felt, heard or seen between the height gauge arm and spring. In the case of ground springs ensure that the height gauge arm passes over all of the top coil so that the actual maximum free length is measured.

6. Read and note the vernier scale value.

7. In the case of ground springs, replace springs on surface plate the other way up and repeat steps 3 to 6, as free length may differ due to differences in out of squareness of the spring ends.

iii) Very large springs with a free length in excess of 600 mm (or 1000 mm if a height gauge is available with a 1000 mm range) should be measured using a surface plate and calibrated steel rule which is graduated in 0.5 mm divisions.

Total Coils

i) Where an accurate measure of total number of coils is required, and the spring is of a size which allows an image of the end coil to be obtained on its screen, the shadowgraph should be used.

1. A jig should be attached to the shadowgraph worktable, which comprises a mandrel with a diameter of at least 95% of the spring's inside diameter and length just less than the spring's free length and a knife edge for the spring's lower and tip to seat against (Fig 4).

2. Align the centre of the crosswires with the mandrel centre by direct sighting on a marked centre.

3. Align the shadowgraph crosswires with the knife edge set in the jig base and note the angular scale reading.

4. Locate the spring on the mandrel with its lower end tip against the knife edge.

5. Focus on the spring's upper end coil, rotate crosswires and re-align on the upper end tip.

6. Note the angular scale reading. The fraction of a turn is then the difference between scale readings. The whole number of turns can be counted manually.

ii) For larger springs the fraction of a coil can only be accurately measured if a jig is constructed, such as the SRAMA jig (Fig 1). This has the same features as the jig used in conjunction with the shadowgraph, ie a mandrel to locate the spring axis with the protractor centre, and a knife edge for the lower end tip to locate against. Use of such a jig will vary between specific designs, but the following basic steps should be followed:-

   1. Align the measurement face with the lower knife edge and note protractor reading.

   2. Ensure mandrel size is at least 95% of spring's inside diameter.

   3. Place the spring on the jig with its lower end tip located against the lower knife edge.

   4. Align measurement face with the upper end coil tip.

   5. Fraction of a turn is the difference in readings taken at 1 and 4.

Angle of Grind

Measurement of angle of grind (Fig 4) utilises exactly the same procedures as measurement of the fraction of a coil, which is given above under 'Total Coils', with the following exceptions:-

1. No knife edge is necessary for the spring's lower end tip to locate against.

2. The crosswires (shadowgraph) or measurement face (jig) are aligned with the start and finish of the continuous grind on the spring's upper end coil; the differences in scale readings being the angle of grind.

3. Both ends of the spring should be measured.

Tip Thickness

i) For axial wire sizes of up to 5 mm a shadowgraph should be used as follows:-

    1. Attach a perspex vee block to the shadowgraph worktable.

    2. Align the vee block axis with crosswires on the screen (after ensuring crosswires are locked in their own zero datum position) and lock in position.

    3. Lay the spring in the vee block with the end tip under consideration uppermost.

    4. Focus on the end tip.

    5. Align the crosswire with the ground surface and note micrometer reading. Re-align crosswire with the point where the end coil and the adjacent coil make contact (Fig 5) and note micrometer reading.

6. For springs which have a gap between the end tip and adjacent coil, the crosswires are focussed in turn with the ground surface and the point where the end coil and the adjacent coil would make contact when the spring is compressed (Fig 6).

7. For either closed or open end tips, the thickness is the difference in measurements made at the two alignment positions.

ii) For axial wire sizes greater than 5 mm, a dial gauge with knife edge attachment is used as follows:-

1. Stand the spring on the surface plate with end tip to be measured uppermost.

2. Set up the dial gauge so that its knife edge is on the ground surface of the spring just adjacent to the end tip (Fig 7), ensuring that direction of travel of the dial gauge is perpendicular to the surface plate. Note reading.

3. Lift the dial gauge knife edge off the spring, rotate the spring slightly and allow the knife edge to drop into the root where the end tip and adjacent coil meet. Note reading.

4. Tip thickness is the difference in readings taken.

5. Springs with a gap under the end coil tip should have this gap removed by means of suitable shims.

Chamfer

This is to be checked using gauges corresponding to the components the spring will have to seat against. Suitability of the spring is determined by offering the gauge to the spring while sighting against a white screen to see if the spring locates as it should.

Squareness

i) Springs with a free length of 30 mm or less should be measured using a shadowgraph as follows:-

1. Attach a perspex angle plate to the shadowgraph worktable.

2. Align the end datum face with the crosswires on the screen (which must have been locked in their own zero position) and lock in position.

3. Align the crosswire with the end datum face, ensuring focus is correct, and note the micrometer reading. Re-focus and re-align crosswires a further 4 times to enable an average datum value to be obtained.

4. Stand the spring on the worktable with its lower end coil against the datum face and rotate the spring to obtain the maximum gap between the upper end coil and the datum face (Fig 8).

5. Focus on the upper end coil and align the crosswire with its inner edge. Note the micrometer reading.

6. Divide the measured value by the nominal free length to obtain the value of out of squareness for comparison against the British Standard tolerance.

7. Invert the spring and check out of squareness of its other end.

ii) Springs with a free length greater than 30 mm should be measured using a jig such as that built at SRAMA (Fig 2) as follows:-

1. Check micrometer zero.

2. Adjust the micrometer's vertical position so that its anvil is at the same level as the upper end coil.

3. Stand the spring against the jig base and rotate to obtain maximum gap between the datum face and the upper end coil.

4. Measure gap using micrometer sighted against a white backdrop.

5. Divide the measured value by the nominal free length to obtain the out of squareness value.

6. Invert spring and check the out of squareness of the other end of the spring.

Parallelism

Springs with a rate down to 2 N/mm should be measured using a lever type dial gauge as follows:-

1. Stand the spring on a surface plate with the end to be measured uppermost.

2. Place the dial gauge arm on the ground face of the spring, ensuring that the arm is as close to horizontal as possible.

3. Lift the arm, rotate the spring slightly, and replace the arm on the ground surface.

4. Repeat 3 in increments around the upper end coil, noting the maximum and minimum values. Calculate difference between these and divide by the nominal outside diameter to obtain a value for comparison against the British Standard tolerance.

5. Invert spring and repeat steps 2 to 4 for the other end coil.

Bow

All springs should be measured using a surface plate and feeler gauges as follows:-

1. Lay spring on a surface plate and roll until hogbacked (Fig 3).

2. Measure the maximum deviation between any coil and the surface plate using feeler gauges.

Load at Length

i) Springs which have ground ends and are not liable to buckle, as defined in section 4.5 of the British Standard, should be measured using electronic load testing equipment as follows:-

    1. Select the appropriate load range.

    2. Zero load readout with the plattens apart.

3. Clean the plattens and bring together until a load approximating to that to be measured is displayed.

4. Zero the length display.

5. Open the plattens and stand the spring to be measured on the lower platten ensuring it is positioned centrally. Zero the load readout to ensure spring's own weight does not affect the measured value.

6. Bring the top platten down until the required length is displayed.

7. Record load.

ii) Springs without ground ends or springs which may buckle should be tested on a rod, which allows free working of the spring, using electronic load test equipment as described above.

Spring Rate

It is necessary that load measurements be undertaken at two agreed lengths within 20% to 80% of the spring's safe deflection range, using the procedures described for load at length measurement. Spring rate is then calculated from the following formula:-

$$\text{Spring rate} = \frac{\text{Change in load}}{\text{Change in length}}$$

Solid Length

The length measurement is undertaken at an agreed load which does not exceed 1.5 times the theoretical solid load of the spring. The procedure to be followed is identical to that described for load at length, except for steps 6 and 7 which are as follows:-

6. Bring top platten down until required load is displayed.

7. Record length.

b) Extension Springs

Outside Coil Diameter

i) A micrometer should be used for close coiled springs which have an axial wire dimension less than, and a body length greater than, the anvil diameter as follows:-

   1. Clean micrometer anvils and check zero.

   2. Extend spring just enough for it to become open coiled, and release.

   3. Measure outside diameter using just sufficient force for the micrometer to grip the spring. Measure up and down the body to ensure maximum dimension is measured.

   4. Read micrometer.

ii) Open coiled springs and others not covered in i) above are measured as for compression spring outside diameter using the procedures set out in that section, with the following additions:-

1. Close coiled springs should be pulled open coiled and released prior to measurement.

2. Ensure that the end loop does not affect the measured value.

Free Length

i) A shadowgraph should be used for all springs which are within its measurement range. The procedure is identical to that to be followed for compression spring free length measurement using a shadowgraph, details of which are given in the relevant section. It is then necessary to subtract two wire diameters from the measured value to obtain a value for free length under the loops.

ii) Larger springs are to be measured using vernier calipers as follows:-

1. Clean caliper measuring faces and check zero.

2. Incrementally close the measuring faces over the spring, checking that the spring will still pass through the jaws. Care must be taken to ensure that the spring is held with its axis perpendicular to the measuring face.

3. When contact is just felt between the measuring faces and the spring end loops, note the vernier reading.

4. Subtract two wire diameters from the measured value to obtain the free length under the loops.

Total Coils/Relative Loop Position

i) Springs with an outside diameter of up to 20 mm should be measured on a shadowgraph as follows:-

   1. Align a crosswire on the datum face to which the end loop is to be clamped. Note the angular scale reading.
   2. Extend close coiled springs and release.
   3. Clamp the lower end coil against the datum face with the spring axis vertical, taking care not to distort spring.
   4. Focus on the upper end loop and rotate the crosswire to re-align on the upper end loop. Note the angular scale reading.
   5. The difference in scale readings is the relative loop angle. This is also the fraction of a turn since the start and finish of the body coils are defined by a plane through the end loops. Count the whole number of turns manually if total of coils is required to be known.

ii) Larger springs should be measured by a similar procedure to that above on a jig such as the SRAMA jig (Fig 2) which fulfills the following requirements:-

   1. The measurement face must be capable of being zeroed against the face which locates the lower end loop.

2. The spring must be clamped axially and centrally to the measuring protractor.

End Loop Opening

This is to be checked on all springs using rod gauges as follows:-

1. Rod gauges should be available at the required gap limits.
2. The end loop should slide over the lower limit gauge but not the upper limit gauge for it to be in tolerance.
3. To obtain an indication of the actual loop opening a range of rod gauges would have to be machined, the minimum practical machining increment being 0.05 mm. The end loop opening would be that of the largest gauge it would slide over.

Load at Length

All springs should be measured on electronic load testing equipment as follows:-

1. Select appropriate load range.
2. Zero load readout with loading hooks apart.
3. Bring loading hooks together and hook on one another. Load up to the expected spring load and zero the length display. If the loading hooks cannot be hooked together, a setting rig of known dimension should be used to establish a datum position.
4. Hook spring onto loading hooks and extend to required length.

5. Record displayed load.

Spring Rate

Load measurements should be undertaken at two agreed lengths within 20% and 80% of the spring's safe deflection range using the procedures described for load at length measurement of compression springs. Spring rate is then calculated from the following formula:-

$$\text{Spring rate} = \frac{\text{Change in load}}{\text{Change in length}}$$

Initial Tension

The initial tension is obtained by calculation from two load at length measurements and a free length measurement, using the relevant procedures.

c) Torsion Springs

Outside Coil Diameter

Measurement of a torsion spring's outside diameter is to be undertaken by exactly the same procedures as are specified for extension springs.

Inside Coil Diameter

Measurement of a torsion spring's inside diameter is to be undertaken using exactly the same procedures as are specified for compression springs.

Body Length

All springs should be checked against go-no go gap gauges, suited to the type of leg form the springs have, as follows:-

1. If the spring will pass into the 'go' section but not into the 'no go' section of the gauge under its own weight then it is in tolerance.

2. If the gap is adjustable, it should be altered in increments to find the smallest gap into which the spring will pass under its own weight. This gap should then be measured using either a vernier caliper or internal micrometer.

Total Coils/Relative Leg Position

All springs are to be measured either using a shadowgraph and suitable jig for those springs which can be displayed on its screen, or a purpose built jig for larger springs. In either case the jig must have a mandrel, diameter at least 95% of the spring's inside diameter, to locate the spring axis onto the protractor centre, and a lower datum point against which the lower leg can be located. The following basic procedure should be followed:-

1. Align the crosswire/measurement face with the lower datum point.

2. Place the spring on the mandrel, and locate lower leg against the datum.

3. Align the crosswire/measurement face with the upper leg.

4. The fraction of a turn/relative leg position is the difference in angular measurements made at steps 1 and 3.

5. If total coils measurement is required, count manually the number of whole coils and add to the fraction measured above.

Torque at Angle

All springs should be measured on electronic torque testing equipment. Prior to test, the exact test conditions, ie mandrel size and type, direction and method of loading and any lubrication need to be agreed between customer and supplier. The basic test procedure is then as follows:-

1. Zero torque readout.

2. If torque at a relative leg angle is required, align the datum marks on the driven and static side of the jig, to provide a known zero position, and zero deflection readout.

3. Locate the spring in the jig and take up the free play.

4. If torque at a deflection from the spring's free leg angle is required, increment driven side of jig until smallest measurable torque is recorded. Zero deflection readout.

5. Load spring up to required deflection position and note torque readout. If torque on unloading is required, the spring should be deflected by an agreed amount past required position, and then unloaded back to this position prior to noting torque value displayed.

Spring Rate

Torque measurements should be undertaken at two agreed deflection positions within 20% to 80% of the spring's safe deflection range, using the procedure described for torque at angle measurement. Spring rate is then calculated from the following formula:-

$$\text{Spring rate} = \frac{\text{Change in torque}}{\text{Change in angle}}$$

APPENDIX III ANALYSIS OF AN EXAMPLE SET OF PHASE II MEASUREMENTS

Free length measurement on spring design number 56.

a) Measurements received from participating company, undertaken using vernier calipers.

Measurement No	Spring No. 1	2	3	4	5	6
1	30.48	30.48	30.73	30.48	30.51	30.84
2	30.51	30.51	30.71	30.45	30.56	30.86
3	30.45	30.43	30.76	30.51	30.48	30.91
4	30.51	30.51	30.78	30.48	30.51	30.84
5	30.45	30.48	30.78	30.45	30.56	30.84

b) Measurements undertaken at SRAMA using a height gauge and surface plate as per the standard technique.

Measurement No	Spring No. 1	2	3	4	5	6
1	30.63	30.62	30.85	30.53	30.64	31.06
2	30.64	30.62	30.85	30.53	30.64	31.06
3	30.64	30.62	30.85	30.53	30.64	31.06
4	30.63	30.61	30.85	30.53	30.64	31.06
5	30.63	30.62	30.85	30.53	30.64	31.06

All measured values are in mm.

The standard deviation of measurement for each spring is:-

Standard Deviation	Spring No. 1	2	3	4	5	6
Industry	.030	.033	.031	.025	.035	.030
SRAMA	.006	.005	0	0	0	0

An overall standard deviation or 'pooled estimate of standard deviation' is then calculated for each technique using the following formula:-

$$\text{Overall standard deviation} = \sqrt{\frac{(5 \times \sigma_1^2 + \ldots\ldots + (5 \times \sigma_6^2)}{(5 \times 6) - 6}}$$

The following values were obtained:-

Industry - .035

SRAMA - .003

On inspection it can be seen that the overall measurement variation achieved by the standard technique is less than that achieved by the industrial technique. This can be confirmed by the carrying out of an 'F' test. The 'F' value is:-

$$F = \frac{.035^2}{.003^2} = 136.11$$

Upon reference to standard F tables it can be seen that the difference in values is 99.9% significant and can be attributed to actual differences in technique repeatability rather than to chance.

It is possible to make an assessment of the change in the mean measured values by the following technique, explained in greater detail in 'The Metallurgist' (2).

	Spring No					
	1	2	3	4	5	6
Mean Value - Industry	30.48	30.48	30.75	30.47	30.52	30.86
Mean Value - SRAMA	30.63	30.62	30.85	30.53	30.64	31.06
Change in Mean	+.15	+.14	+.10	+.06	+.12	+.20

The basic reasoning used to determine whether or not a significant change in the mean has occurred is that if

$(A - B)$ is greater than $2\sqrt{A + B}$

Where A = number of positive changes in mean value

and B = number of negative changes in mean value

then the observed change in mean values is significant at the 95% level of confidence and can be taken to be representative of the effect of using the standard technique.

For the spring design in question, here it can be seen that use of the standard method causes an increase in the mean value for all six springs measured. Therefore:-

$A - B = 6 - 0 = 6$

$2\sqrt{A + B} = 2\sqrt{6 + 0} = 4.9$

Since $A - B$ is greater than $2\sqrt{A + B}$ then the observed change in mean values is significant and it is to be expected that use of the standard technique will cause an increase in the mean of the measured values, demonstrated for this spring design to be between 0.06 mm and 0.20 mm.