THE SPRING RESEARCH ASSOCIATION

THE PRODUCTION OF SPRING FATIGUE DATA WITH STATISTICAL LEVELS OF CONFIDENCE

Part 6 of 7 parts

CONCLUSIONS AND DISCUSSION

by

G. C. Bird, B.Sc.

Report No. 228

February, 1974

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1. INTRODUCTION

Part one of this report dealt with the methods of fatigue testing and of analysing the data obtained. The results obtained from the individual materials tested are presented in parts two to five. In this part, it is the intention to look at the difficulties encountered in the fatigue testing programme and also to examine the results obtained for each material to discover whether there are any general trends in the programme as a whole.

2. MATERIAL

The materials used in the research programme, together with the specified range of tensile strength, are given below.

Material	Tensile strength (N/mm^2)
BS 1408 C and D Range 1	1230 - 1390
BS 1408 C and D Range 2	1390 - 1550
BS 1408 C and D Range 3	1550 - 1690
BS 2803 Grades I and II	1460 - 1620
BS 1429, En 47 Grade I	1550 - 1670 *
BS 2056, En 58A and En 58J	1230 - 1550

* Approximate value, hardness specified as 500/550 HV.

The variation in the fatigue resistance of springs from different suppliers was substantially affected by the quality of the wire. Variation in the quality of the wire would be expected if the material had been obtained from different sources, as appears to be the case here.

Each manufacturer was asked to send a length of wire for static testing with the springs, but only in some cases was it received. Thus comparison between different batches had to be carried out be checking the hardness and microstructure of sample springs.

Previous work (1) has shown that the wire properties can noticeably influence the fatigue performance of a spring. In the case of BS 1408 wire, it was found that the variation in tensile strength over the permitted range of 150 N/mm^2 caused a difference of 20 N/mm^2 in the fatigue limit of the springs.

3. SPRING DESIGN

The spring design used was the same for all the materials tested. This could have two major consequences. One is that in theory, if all the springs are coiled with the same solid stress (as was specified), then different materials would have experienced different amounts of prestressing which would affect the fatigue properties of the springs. This is because springs made from a material with a low tensile strength would generally have a low elastic limit, and therefore if coiled to give the same solid stress as springs from a higher tensile strength material, would receive more plastic deformation and would have a better residual stress pattern. From the results of the research programme it would indeed appear that, in general, springs which have a higher solid stress have a better fatigue resistance, although this distinction may be masked by metallurgical differences in the springs.

The second consequence was a practical one, namely for some materials it was impossible for the manufacturers to coil the springs to achieve the solid stress required without excessive distortion. For example, for BS 1408 Range 1, which has a specified tensile strength of 1230 - 1390 N/mm^2, the solid stresses of the springs from the four suppliers was only between 925 and 1050 N/mm^2.

For BS 1408 Range 3 wire with a tensile strength of 1550-1690, solid stresses of 1120 - 1180 N/mm^2 were achieved. It is clear that the higher the tensile strength of the material, the higher the solid stress with which the springs can be made. Work carried out by the Association(2) has shown that for BS 1408, cold drawn wire, there is a solid stress above which springs cannot be made. This value of solid stress depends on the tensile strength of the wire and was found in all cases to be approximately 80% of tensile strength. This figure has also been borne out by the data obtained from this project.

These two effects have made it very difficult to compare the results of different materials, especially for the six types of BS 1408 where the different tensile strengths and different solid stresses have made it difficult to produce the Goodman diagrams which are given in part 7 of this report.

4. MANUFACTURING PROCESSES

One of the principal points shown by the tests arises from the fact that very few of the springs received from the four manufacturers conformed to the dimension and rate specification issued by SRA. The reason why the free length of the springs varied has been discussed in section 3. The variation in rate, both within the springs from one manufacturer, and also from supplier to supplier caused difficulty with the production of the finite life fatigue data.

The actual method of manufacture of the springs would not vary a great deal from supplier to supplier since all the springs were produced on automatic coiling machines. The low temperature heat treatment of the springs after coiling serves to eliminate the detrimental stresses put into the spring during coiling and in addition, for the cold drawn material, raises the elastic properties of the wire. Details of the stress relieving temperatures for each material are given in the appropriate part of this report. There was however, no way to determine whether the heat treatment had been carried out correctly.

The variation observed in the fatigue properties of springs in the unpeened condition must be caused mainly by the variations in the properties of the wire of which the springs had been made. With the shot peened springs, another parameter has been introduced which affects the fatigue behaviour, that of the shot peening process. The specification issued by SRA called for springs to be shot peened with S330 shot to a Almen arc rise of 0.018/0.022 A2, followed by a low temperature heat treatment of 220°C for half an hour. Each spring manufacturer shot peened the springs in his own plant and there is little doubt that the greater variation of fatigue properties in the shot peened springs reflect the effect of the efficiency of the supplier's peening process.

Although the manufacturers were asked to send a sample Almen strip with the springs, only one in fact did so. Even springs peened to the same arc rise in different machines could well have different fatigue properties. Again there was no way to determine whether the springs had been heat-treated correctly after peening, except it appears that springs which might not have been heat-treated correctly have a greater tendency to relax during fatigue testing.

The most noticeable trend in the shot peened springs was that, in general, the springs from supplier 2 had the poorest fatigue resistance for all materials. The greatest amount of dynamic relaxation usually occurred with shot peened springs of suppliers 3 and 4 where the fatigue limit at 300 N/mm^2 initial stress was very close to the solid stress of the springs.

Overall, the work carried out has shown that there can be quite distinct differences between the fatigue behaviour of springs of one material, but that because of both the wide variations permitted in material specification and the process variations generally accepted in manufacturing it was not possible to identify the prime causes of the differences. Apart from one or two exceptions, there was no evidence to suggest that any of the springs were in any way "defective" either regarding conformity with material specification or manufacture, and it must be assumed that the springs are representative of those which are industrially available and that the results obtained should be accepted as valid.

5. FATIGUE TESTING

The difficulties encountered in the fatigue programme have been discussed in part 1 of this report and stem mainly from the variation in spring dimensions (rate and free length) from batch to batch. The result of the variations was that it was necessary to load test and to adjust each spring individually on the fatigue testing machines, and in some cases it was not possible to test springs of the same material but obtained from different suppliers, at the same time. To some extent these problems were overcome by altering the methods used to produce and analyse the data.

The work has shown that the variation in the wire properties and the manufacturing processes have a greater effect on the fatigue properties for the finite life than for infinite life performance.

Experience with the testing programme has shown that the machine specifically designed for the project could produce fatigue data with confidence levels only for limited life, that is for 10^5 cycles for unpeened springs and for 10^5 and 10^6 cycles for shot peened springs. To produce the infinite life data the springs had to be tested on a different machine, which because of the insufficient number of springs, could not produce the fatigue data with full statistical levels of confidence.

All results obtained from the fatigue testing programme are summarised below in general terms.

The line of maximum working stress can be represented by an equation of the form.

$$MS = MS_o + P \times IS$$

where MS = maximum stress

MS_o = maximum stress at zero initial stress, constant for a particular diagram

IS = value of initial stress

P = constant, equal to the slope of the line of maximum stress

This equation is represented graphically in Fig.1.

For all the materials investigated the shape of the Goodman diagrams for both finite and infinite life data differ between the unpeened and shot peened springs. For any particular material, the slope of line of maximum stress for the shot peened springs was less than the slope of the line for the unpeened springs. This means in effect that as the initial stress of the spring is increased so the superiority in the fatigue resistance of the shot peened springs decreases. This is particularly noticeable for short life applications involving high working stress where the benefits of shot peening are only marginal.

For the Goodman diagrams for infinite life, the values of MS_o and P have been calculated for each material in the unpeened and shot-peened conditions and the results are presented in Table 1. It can be seen that for three materials, En 47, En 58A and En 58J in the unpeened condition, the values of P are approximately equal to unity. This means that the working stress range (maximum stress - initial stress) does not depend on the initial stress in the spring.

From the values in Table 1, the percentage increase in working stress at zero initial stress due to shot-peening can be calculated. For BS 1408 and BS 2803, the increase is about 25-35%, for En 47 the increase is about 85%, whilst for the stainless steel materials, En 58A and En 58J, the increase is over 150%. As explained above, however, this improvement in fatigue properties diminishes as the initial stress in the spring is increased.

6. CONCLUSIONS

(i) The variation in the fatigue resistance of springs of one material from different suppliers was substantially affected by both the manufacturing processes and the quality of the wire.

(ii) The use of the same design solid stress for all materials meant that some springs received a greater amount of prestressing than others.

(iii) For some materials it was impossible for the manufacturers to coil the springs to achieve the solid stress required without excessive distortion.

(iv) In general, springs which have a higher solid stress have a better fatigue performance.

(v) The greater variation in fatigue properties of shot-peened over unpeened springs reflects the effect of the efficiency of the supplier's peening processes.

(vi) The improvement in fatigue properties on shot peening was much greater on the stainless steel materials than on the carbon steel materials.

(vii) As the initial working stress in the spring is increased, the superiority in fatigue resistance of the shot peened springs is decreased.

(viii) For high working stresses and short endurances there is little advantage in shot peening springs.

(ix) The work has indicated the desirability of tightening permissible tolerances in material specifications. Indeed, since this work was undertaken, the specifications of BS 1408 have been revised, those of BS 2803 and BS 1429 are under revision, and where possible these specifications have been tightened up.

7. REFERENCES

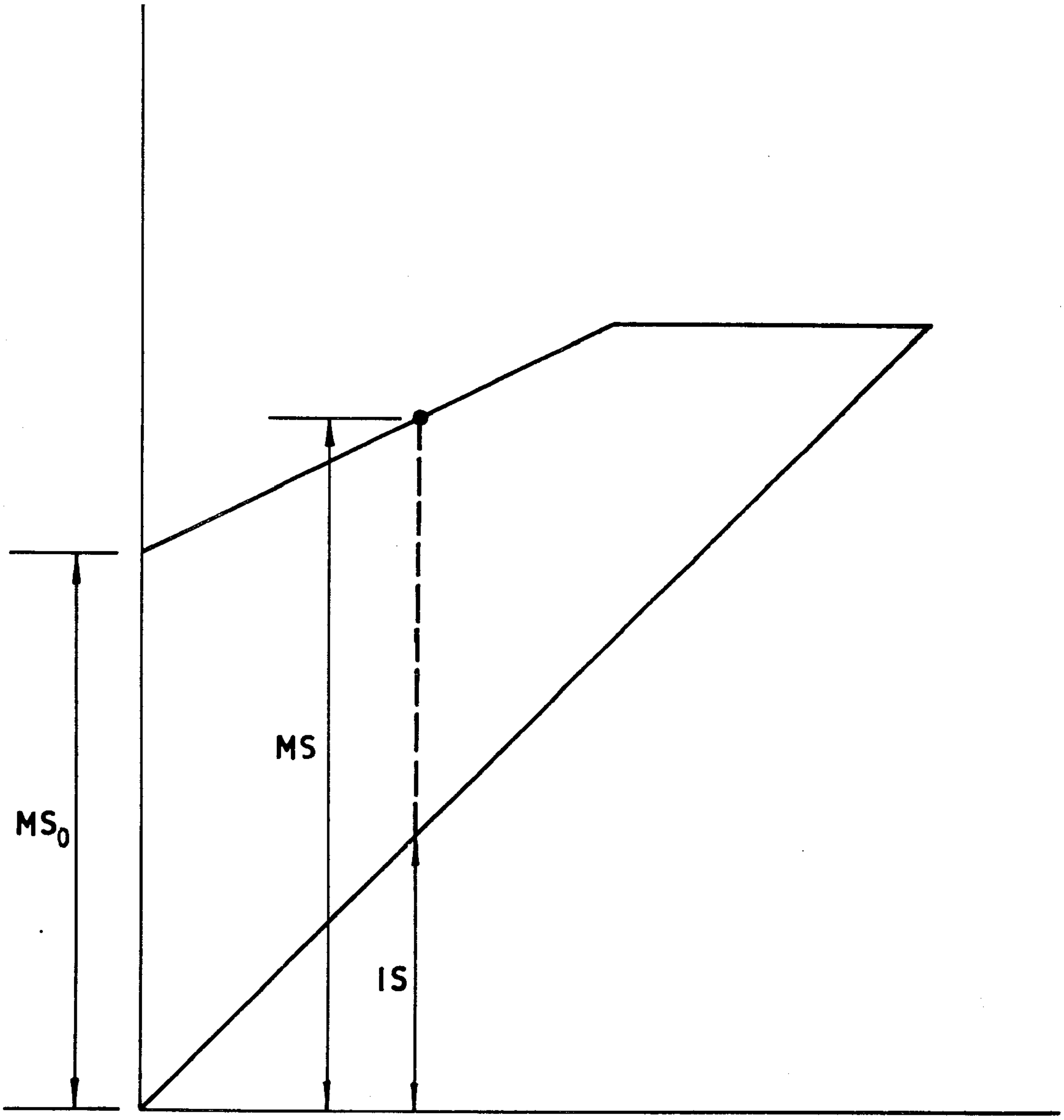
(1) J. W. Mee 'Fatigue Properties of Springs made from Patented Cold Drawn Wire to BS 1408 C and BS 1408 D in three Ranges of Tensile Strength' SRA Report No. 164 June 1967.

(2) G. C. Bird 'An Investigation into the Effect of Solid Stress on the Prestressing of Compression Springs' SRA Report No. 208 October 1972.

TABLE 1

VALUES OF GOODMAN DIAGRAM CONSTANTS

MATERIAL	UNPEENED		SHOT-PEENED	
	MS_o	P	MS_o	P
	(N/mm^2)		(N/mm^2)	
1408C Range 1	420	0.725	570	0.475
1408C Range 2	480	0.667	640	0.225
1408C Range 3	540	0.617	710	0.484
1408D Range 1	460	0.750	590	0.575
1408D Range 2	520	0.750	660	0.650
1408D Range 3	580	0.725	730	0.575
BS2803 Grade I	550	0.717	760	0.425
BS2803 Grade II	540	0.700	690	0.375
BS1429 (En 47)	350	0.900	650	0.542
BS2056 (En 58A)	140	1.000	450	0.800
BS2056 (En 58J)	170	0.925	430	0.440



$$MS = MS_0 + P \times IS$$

FIG. 1. EQUATION REPRESENTING GOODMAN DIAGRAM