THE SPRING RESEARCH AND MANUFACTURERS´ ASSOCIATION

ON THE FATIGUE PERFORMANCE OF DISC SPRINGS

Report No. 411

by

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SUMMARY

The fatigue performance of disc springs manufactured by stamping from carbon steel has been compared with that of the disc springs manufactured with machined edges from chrome vanadium steel. The results of the research indicated that the material from which the disc springs are made may be a greater influence on fatigue performance than the manufacturing method employed.

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CONTENTS

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1. INTRODUCTION

Cold formed disc springs can be manufactured by several different process routes, but the two most frequently used yield springs with stamped or machined edges. The purpose of this study was to compare the fatigue performance of disc springs made by these two process routes, and in particular to establish whether disc springs made by the more expensive machining route had a superior fatigue performance.

2. SPRINGS USED

Initially, two small batches of disc springs were obtained. One batch was stamped from CS70 steel, the other was machined from 1% chrome vanadium steel, and both batches were austempered to approximately 500 Hv. Both were manufactured to a nominal design of 50 mm outside diameter, 25.4 mm inside diameter 1.25 mm thick (50 x 25.4 x 1.25) and with a cone height 1.6 mm.

Exploratory fatigue tests on these disc springs revealed that both batches had a very good fatigue performance, and springs to this design, irrespective of manufacturing process, could not be fatigue tested to destruction. A disc spring design was therefore sought which would enable a higher stress to be applied. Existing test equipment at SRAMA dictated a 2000N maximum load, a 70 mm maximum outside diameter, and it was also desirable to maximise the cone height and hence the stroke on the fatigue test, in order to minimise the setting error. The optimum disc spring design available from stock catalogues fulfilling all these requirements had 45mm outside diameter, 22.4 mm inside diameter, 1.25 mm thickness and a cone height of 1.6 mm, and two batches of this configuration were obtained.

The first batch had been manufactured by stamping a coned washer shape from cold rolled CS70 steel, austempering to 43-52 HRC, barrelling to round edges and removing stamping burrs, and phosphating. The second batch had been manufactured by stamping cold rolled 1% CrV (50 CrV4) steel to a coned washer shape, machining the inside and outside diameters of the disc, austempering to 43-52 HRC, barrelling to round edges, phosphating and prestressing to solid three times. The use of the low alloy steel for the machined discs is required by DIN 2093 at all material thicknesses greater than 1 mm.

3. EXPLORATORY TEST RESULTS

Fatigue testing of individual 50 x 25.4 x 1.25 mm disc springs on SRAMA´s forced motion single station fatigue testing machines revealed one important aspect of the fatigue behaviour of disc springs-that considerable wear takes place. The relative motion of the disc spring against the plattens of the fatigue test machine caused fretting wear of both the spring and the platten.

This fretting limits the speed of the fatigue test to 500 cycles per minute, because at higher speeds appreciable heat is generated. The wear pattern on the plattens necessitated the use of hardened steel to keep the wear to a minimum and to ensure that the set heights on the fatigue test did not alter significantly during the test. It was necessary to regrind the plattens between tests.

On the disc spring, a flat area is worn on the two faces in contact with the plattens. The wear is progressive, and causes a change in the spring characteristics during the test, inasmuch as both the free height and the effective outside diameter/inside diameter ratio are reduced.

The lower stress on the fatigue test has to be relatively large initially because the wear and relaxation of the spring will have the effect of greatly reducing this minimum stress during the test. This effect is exacerbated by the non-linear load deflection characteristics of disc springs (Fig 1).

These exploratory tests also revealed that, in the unlikely event of a fatigue crack propagating, the spring will continue to operate without falling out from between the plattens of the fatigue test machine. It was therefore necessary to stop the fatigue test at frequent intervals in order to inspect the spring for a crack. Disc springs fail by the propagation of a single radial crack and, in the designs tested here, the crack propagated from the outside towards the centre of the disc.

4. FATIGUE TEST METHOD

The 45 x 22.4 x 1.25 mm disc springs were prestressed five times to solid and tested individually between freshly ground, hardened and tempered silver steel plattens. All tests, on both stamped and machined disc springs of nominally identical design, were carried out between test heights of 1.65 mm and 2.61 mm. Each spring was load tested before fatigue testing, and each was inspected for cracks after every fifty thousand cycles up to 200,000, every hundred thousand cycles to 500,000, and every two hundred thousand to 1,000,000 cycles. If the springs survived 1,000,000 cycles they were load tested again.

5. RESULTS

The fatigue performance of eight stamped springs was compared with that of eight machined springs and the results are shown in Table I. All springs were tested to failure or to one million cycles, except those stamped springs which wore and set down to such an extent that they would no longer support a significant load at 2.61 mm.

In order to gain a fuller understanding of the results in Table I, a test was undertaken in which the progressive change in load at the two set heights was measured during the fatigue test. The results are contained in Table II. Another set of load tests was carried out to establish the load deflection characteristics of the stamped and machined discs before and after fatigue testing to one million cycles. These results are illustrated in Fig 1, which shows that the shape of the load deflection curve is altered at spring deflections greater than 0.4 mm for both spring types after fatigue testing . Also shown is the fact that wear and set down of the stamped springs is slightly greater than that for the machined disc springs. This result is confirmed by measurement of the width of the wear zones created on the two types of spring during the fatigue testing. The stamped discs had wear zones created during the fatigue test of 1.1 - 1.25 mm wide, and the machined discs had wear zones of 1.0 - 1.20 mm wide on average. Wear zones reduce the lever length (the effective outside diameter/inside diameter ratio) of the discs and account for the substantially increased spring rate during the fatigue test of the springs at deflections of greater than 0.4 mm.

6. METALLOGRAPHY

Metallographic checks were made on both unused disc springs and ones that had failed on fatigue test, in order to check that the springs were metallurgically satisfactory. Two springs were also examined on the scanning electron microscope to check the extent and origin of the fatigue region on the fracture surfaces.

The structure of both stamped and machined disc springs was found to consist of fine carbides in a matrix of lower bainite, with hardnesses of 514 Hv10 and 500 Hv10 respectively. Both types of spring were free from significant surface defects, although the machined discs had a layer of complete decarburisation on the long faces to a maximum depth of 0.013 mm (ie 1% of their thickness).

The metallographic examination of sections taken parallel to a fracture surface revealed no structural or physical abnormality in the broken springs of either type. It did, however, reveal a fatigue crack in the machined disc 2.8 mm from the outside edge of the disc to a depth of .33 mm (26% of the material thickness). This fatigue crack appeared to be a circumferential one, but there was no evidence from any of the broken springs that a circumferential crack had caused the fatigue failure of any disc - all failure cracks being radial in direction.

Examination of one fracture surface, from both types of spring, each of which failed after 750,000 cycles, revealed similar appearances. The fatigue portion extended to approximately one quarter of the whole fracture surface, and the origins of the fatigue region were multiple from the wear zone on the outside of the disc, as shown in Fig. 2.

7. DISCUSSION

The original objective was to establish any marked effect of manufacturing method on the fatigue performance of disc springs. During the course of this work, insufficient springs have broken to come to any firm conclusions, but the evidence presented by the fatigue results, and the mechanism of fatigue failure that exists in disc springs, would suggest that manufacturing method is unlikely to have a substantial influence on disc spring fatigue performance.

However, there is evidence of the effect of the steel used on the fatigue performance because the machined disc springs, which are made of a low alloy CrV type steel, appear to have suffered a little less wear, and to have relaxed or set down to a smaller extent, than the carbon steel stamped disc springs. From these observations, it could be argued that disc springs made from CrV steel would give similar performance whether stamped out or machined. However, to confirm this theory, it would be necessary to have disc springs especially manufactured with a very high solid stress in order that fatigue peformance may be studied effectively.

It is a little surprising that fatigue failures occurred in only a small proportion of the disc springs tested. The Schnorr Handbook of Disc Spring Graphs indicates that 45 x 22.4 x 1.25 mm machined CrV springs may start failing after 10^5cyles. In fact, one of the eight machined springs tested failed before 5×10^4 cycles, but five survived 10^6 cycles. Clearly the spread of lives when fatigue testing is at least as great as that for compression springs.

8. CONCLUSIONS

1. The load deflection characteristics of disc springs are altered considerably during the course of fatigue testing

due to the effects of wear.

2. There is evidence to suggest that manufacturing method has little effect on the fatigue performance of disc springs.

3. Use of low alloy CrV steel in preference to carbon steel is likely to result in less spring wear and less relaxation of disc springs in fatigue applications.

9. REFERENCES

1. DIN 2093 - Disc springs; dimensions, material, properties.

2. "Schnorr handbook for disc springs". Adolf Schnorr Gmbh

TABLE I FATIGUE TEST RESULTS

Spring type	Load test result before fatigue test 2.61mm	1.65mm	Life on fatigue test	Load test result after fatigue test 2.61mm	1.65mm
Machined	740	1780	Failed after 200,000 cycles		
	700	1740	Survived 1,000,000 cycles	237	2060
	644	1723	Failed before 50,000 cycles		
	620	1710	Survived 1,000,000 cycles	207	1885
	704	1762	" " "	87	2050
	734	1802	" " "	348	2011
	582	1767	" " "	348	1955
	388	1722	Failed after 750,000 cycles		
Stamped	980	1905	Failed after 50,000 cycles		
	610	1730	Failed after 150,000 cycles		
	452	1712	Failed after 750,000 cycles		
	662	1786	Survived 1,000,000 cycles	40	2050
	394	1700	Survived 600,000 cycles	89	1948
	439	1770	Survived 1,000,000 cycles	6	2060
	525	1772	Survived 500,000 cycles	0	2040
	312	1666	Survived 500,000 cycles	1	1930

TABLE II LOAD TEST RESULTS DURING A FATIGUE TEST OF A MACHINED DISC SPRING

No. of cycles/thousands	Load/N at 2.61mm	Load/N at 1.65mm
0	700	1740
50	580	1902
100	548	1932
150	508	1980
200	506	2002
300	487	1968
400	406	2032
500	334	1990
750	339	1997
1000	328	2014

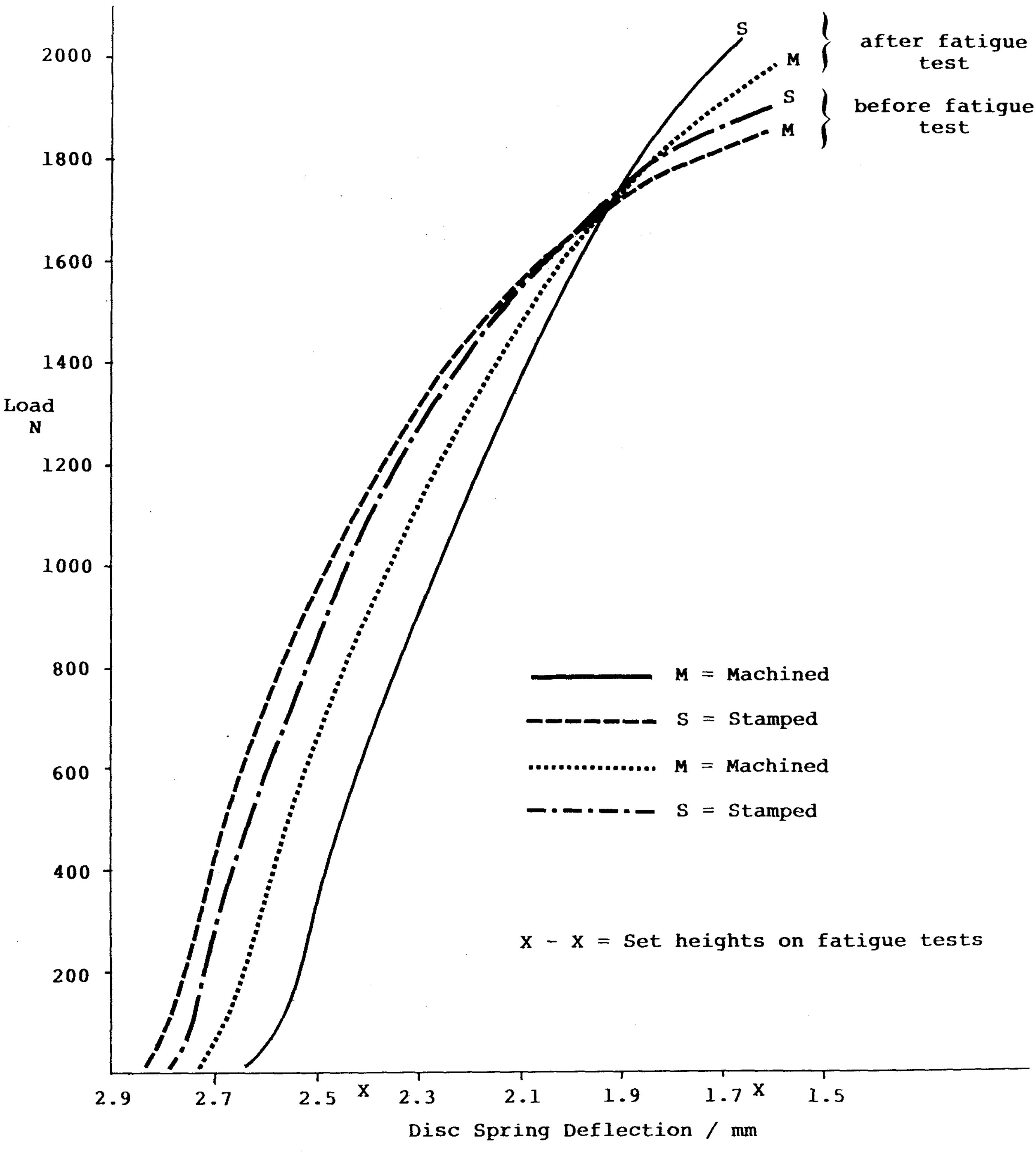

Fig 1: LOAD / DEFLECTION CURVES

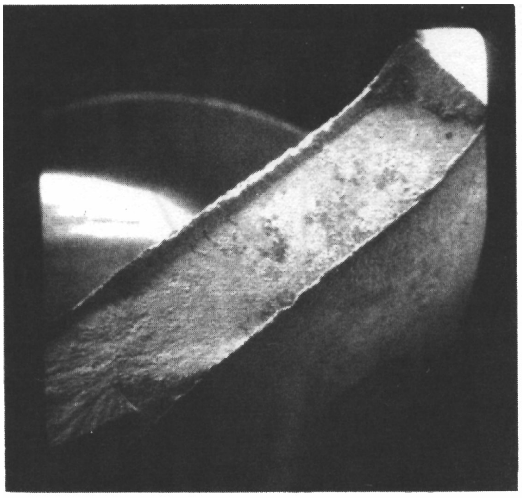

Fig 2 x16
Scanning electron micrograph showing the fatigue portion of a disc spring fracture surface, with multiple fracture origins from the wear zone.