IMPROVED METHOD OF SHOT-PEENING CONTROL EXAMINES VARIABLES IN PRODUCTION PROCESS

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ABSTRACT

In commercial practice, helical coil springs such as automobile valve springs are shot peened in bulk. (Typically 4/5000 springs per charge). The accepted method of control being the inclusion of Al men test pieces. This type of test piece is not representative of the components and in some cases the test results have been proved to be misleading. A new concept of control test piece was designed in the form of a helical coil of wire. By fatigue testing at resonant frequency, rapid results were obtained which could be used to establish a measure of shot-peening efficiency. The test coil can be of the same specification and may be subjected to the same low temperature stress relieving treatments as the components it represents. This paper describes the basic features of the test equipment and gives the results of a large scale experiment which examines the effect of varying the operating conditions of a production shot-peening plant.

KEYWORDS

Shot-peening control; Fatigue life coil springs, Resonant frequency fatigue testing; Peening process parameters.

INTRODUCTION

The modern automobile valve spring and similar components are the result of considerable design, material and process development. The stress levels at which they are expected to perform are amongst the greatest used in engineering. Their reliability has been achieved by research in three major areas. Firstly, by careful selection of materials and wire production methods. The cold drawn or pre-hardened and tempered valve spring wires must be free from decarburisation and surface defects. In fact, continuous eddy-current flaw detection is in regular application. Secondly, the low temperature stress relieving treatments which are applied at certain stages of production must be optimised for the particular type of material and service conditions. The final vital requirement is the optimisation of the shot-peening process and a satisfactory technique of quality control. It is a well established fact that even with the optimum levels of material quality and heat-treatments, high performance springs will fail under dynamic fatigue conditions if the fatigue limit of the material is not elevated by inducing compressive stress into the surface layers by a suitable peening treatment with hard steel shot. The area on the surface of a helical compression spring which particularly requires this treatment is the inside diameter of the coils, where the torsional stress is greatest.

Two types of shot have become established for the majority of commercial shot-peening of steel springs. The first of these is cast carbon steel shot which is subsequently hardened and tempered to a controlled hardness level. This method of manufacture may result in inherent cracks of variable depth with the constant risk of fracture when used as the impact media. The sharp edges of broken shot may produce a 'notch' in the spring wire which is obviously detrimental to fatigue life.

The alternative shot is the type known as 'cut wire', which is made by cutting high tensile steel wire into pellets of length equal to the diameter. These cut lengths must be 'pre-conditioned' to produce a roughly spherical form before being used for the peening process. The cut-wire type is preferred by the authors because it wears down with no risk of fracture and although more expensive than hardened and tempered shot, experience has indicated that when all factors are considered the true running cost of the two materials shows no significant difference.

The established method of control in the application of shot-peening to springs is the Almen test. This is described in S.A.E. Standard J 442. If we consider these hardened and tempered steel strip test pieces mounted on the standard holder and compare them with the springs which they are supposed to represent, it will be clear that the relative shape and density are quite dis-similar. In commercial processing these test pieces included in a mass of springs in a Wheelabrator type machine will not tumble and be distributed in the same manner as the general mass of work. They are more likely to sink to the bottom of the charge of work and therefore, be shielded from the shot stream for a disporportionate time. It has been found that there can be considerable variation in the results of several test pieces processed in the same batch of springs. Averaging results is not entirely satisfactory. The poor correlation between Almen test and fatigue results is illustrated by Fig. 1.

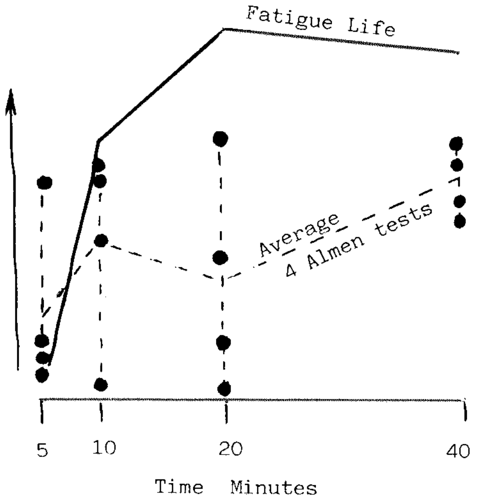

Fig. 1.

We therefore searched for an alternative to the Almen test and concluded that the ideal test specimen must be of similar shape and of the same type of material as the springs which it is to represent, also, it should respond to the heat-treatments which are applied in practice, before and after shot-peening. The method of measuring the effects of these treatments on the test specimen must, of necessity, be the fatigue life of the material. For this to be a practicable control method, the results of fatigue testing must be obtained rapidly and confidence must be obtainable with a small number of duplications of test.

HIGH SPEED TEST METHOD

The method which was chosen is to vibrate a test piece in the form of a helical coil of spring wire, with a low forcing signal power. If this forcing signal is tuned to the natural frequency of the test piece a high amplitude of vibration can be generated in the coils of the test piece, causing a significantly high stress range so as to obtain fatigue failure at a relatively low number of stress cycles. (Typically 200,000 cycles at 310 Hz. (Approx. eleven minutes).

The amplitude of movement is measured by using a travelling microscope to observe a 'marker' fixed to the centre point of the test coils.

By testing at resonant frequency, the initiation of a fatigue crack in the specimen is very easily detected by a sudden drop in the frequency needed to hold resonance. In practice the equipment is capable of detecting crack initiation and will stop the test before the specimen actually breaks.

The design of the test specimen was based on a wire which was in regular supply for a particular valve spring. The details are given below.

Wire diameter 0.152" (3.861 mm)
Mean coil diameter 1.500" (38.10 mm)
Pitch of coils 0.700" (17.78 mm)
Total number of coils 5¾. Left hand and with open ends.

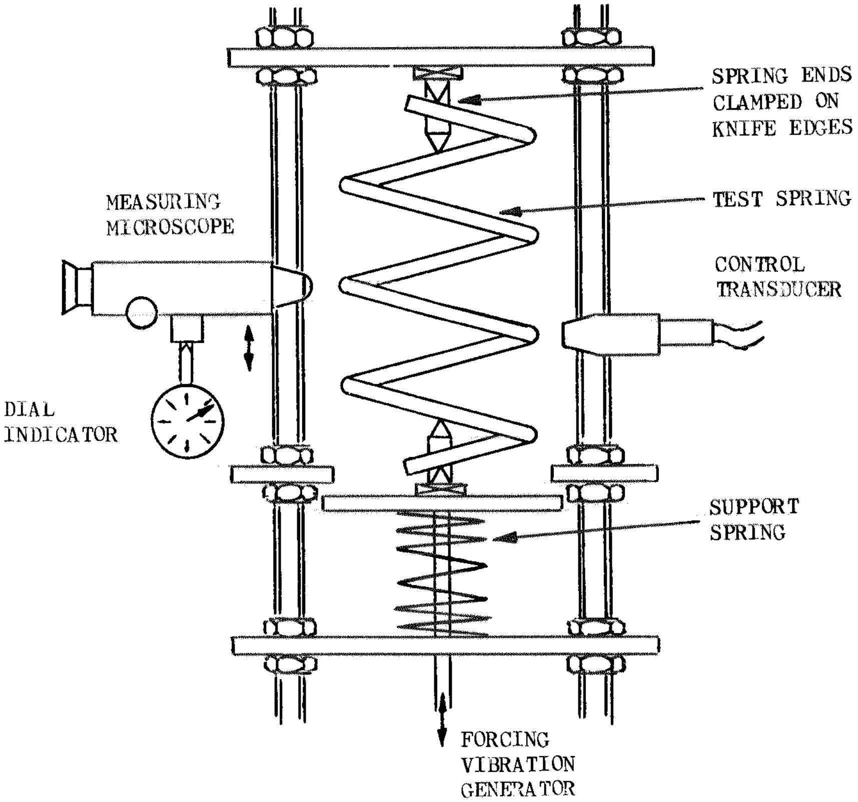

Fig. 2. General Arrangement of Resonant Frequency Test Rig.

The test specimen is mounted in clamping plates at each end which support the end coils on carbide 'knife edges'. A pre-stress is applied to the specimen when it is in the test rig in order to prevent the end coils leaving their bearings when the specimen is under vibration. The general arrangement is shown by Fig. 2. A guard plate is fitted to prevent damage to the suspension of the vibrator unit when the specimen breaks and a supplementary spring, designed to have a different resonant frequency to that of the test specimen is used to balance the load applied to the armature.

The test rig can be operated under manual control but it was found in practice that minor shift of the bearing points and changes in temperature of the test specimen were sufficient to cause a change in resonant frequency, necessitating constant survailence of amplitude and frequent adjustment of the controls. This disadvantage was overcome by obtaining a system of 'feed-back'[1] to continuously monitor the vibration amplitude of the test specimen. This was originally done by using a microphone as the sensor and later by using a distance transducer. The signal is fed into a microprocessor which implements the control alogrithims and also terminates the cycle count when fracture is detected. In practice the test is set-up under manual control, the system is then calibrated by a 'set-point' controller and the test unit is switched into automatic control.

The test rig and microprocessor unit is shown in Fig. 3.

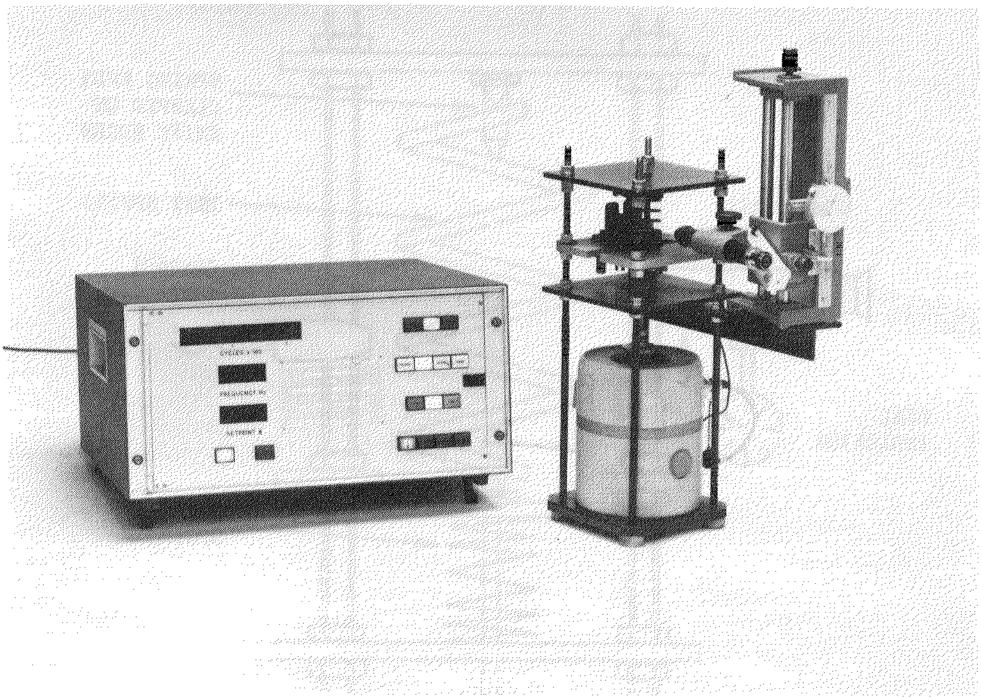

Fig. 3.

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[1] Barker H.A., Noble A.E. and Mills V.O. Control of Resonant vibration in a spring fatigue testing instrument. Proc. I.E.E. Vol. 125 No.9 Oct. 1978

ANALYSIS OF RESULTS

Experience with the test rig has indicated that control charts can be constructed to show 'average' and 'range' of test in triplicate so that warning and action situations can be defined. The system is now in regular use for the control of the shot-peening operation,

For a more detailed study of material and process variables a statistical analysis of the results of eleven repeated tests is the standard procedure. Because we are naturally interested in the probable minimun life conditions, all the test results which are above the median are ignored. The median and the five results are used to construct a synthetic normal distribution and the standard deviations are then calculated. By this technique we arrive at something approaching a true confidence level for the calculated minimun fatigue life. The comparisons of results are made on the basis of the values of the Median minus three standard deviations. The 'life values' quoted in this paper are the log of the number of cycles to failure, modified to take into consideration varying amplitudes and frequencies, log cycles + (frequency (Hz) x amplitude (mm) x F.) F. has been determined for varying metallurgical structure i.e. cold worked or hardened and tempered wires. A typical experimental result for optimisation of low temperature heat-treatment is shown by Fig. 4.

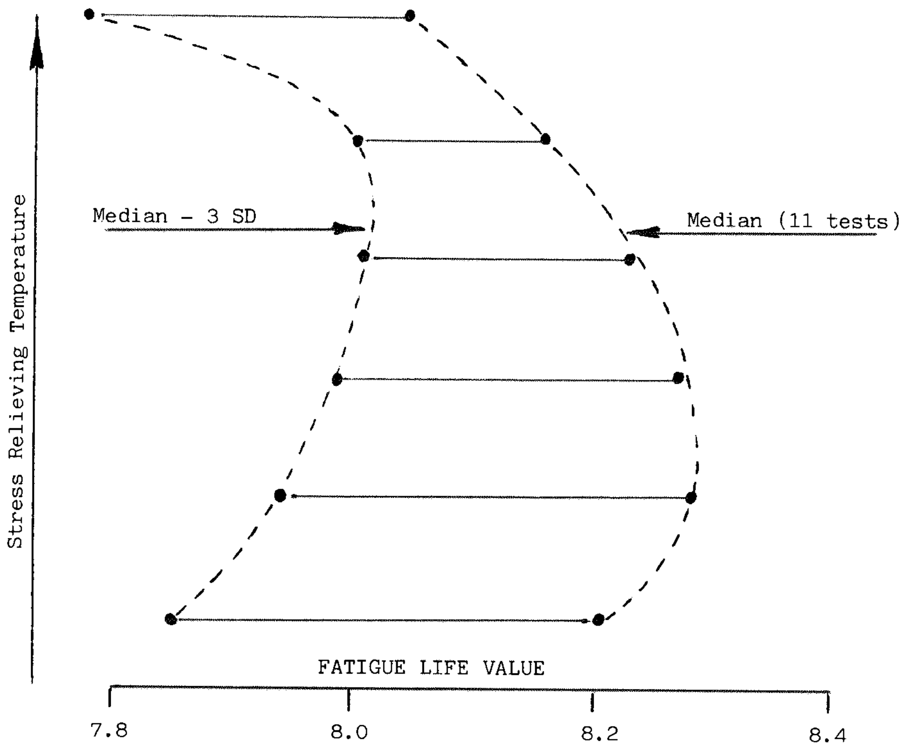


Fig. 4. Effect of low temperature heat - treatment on the fatigue life of a low alloy valve spring wire.

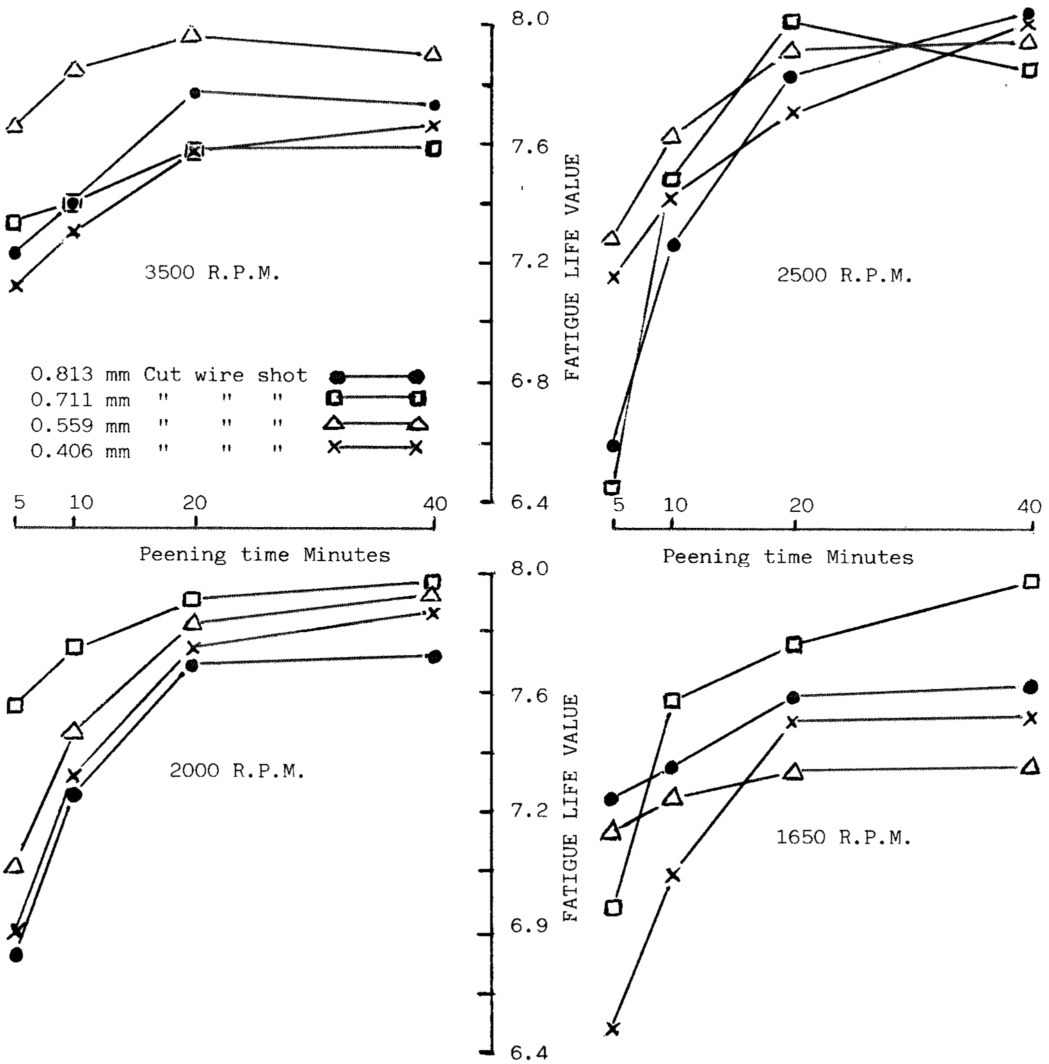
EXPERIMENTS TO EXAMINE THE EFFECTS OF VARIABLES IN THE SHOT PEENING OF SPRINGS

These tests were carried out in the Tilghman WTBOA Wheelabrator, using cut wire shot. The material used for the test specimens was AVOT 2 Valve Spring Wire. (Oil hardened and Tempered Chrome - Vanadium alloy). All of the test specimens were given the first low temperature stress relieving treatment as a single batch. For each experiment forty-four specimens were charged into the shot-peening machine together with a 'dummy batch' of typical helical coil springs to simulate the turnover of the work charge which would take place in practise. At each of the shot sizes and impeller speeds chosen for the experiment, eleven springs were taken out of the machine at intervals of 5, 10, 20 and 40 minutes. Shot sizes were 0.813 mm/0.711/0.559 mm/0.406 mm and impeller speeds were 3500/2500/2000/1650 R.P.M. All of these specimens were given a second low temperature stress relieving treatment at the same temperature as commercial practise. The results of the tests and the statistical analysis are given in Figs 5 to 8.

SHOT SIZE (m.m.)	WHEEL SPEED (R.P.M.)	PEENING TIME (Minutes)	ALMEN ARC RISE (m.m.)	FATIGUE LIFE VALUES		
				MEDIAN	STANDARD DEVIATION	MEDIAN -3 STANDARD DEVIATIONS
0.813	3500	5	0.222	8.081	0.287	7.220
		10	0.343	8.096	0.231	7.403
		20	0.381	8.118	0.112	7.782
		40	0.337	8.080	0.107	7.759
0.813	2500	5	0.184	8.142	0.518	6.588
		10	0.203	8.134	0.287	7.273
		20	0.248	8.127	0.091	7.854
		40	0.394	8.294	0.089	8.027
0.813	2000	5	0.095	7.746	0.343	6.717
		10	0.089	8.103	0.278	7.269
		20	0.197	8.074	0.125	7.699
		40	0.292	8.275	0.186	7.717
0.813	1650	5	0.025	7.775	0.179	7.238
		10	0.057	7.704	0.126	7.326
		20	0.089	7.938	0.120	7.578
		40	0.102	8.076	0.154	7.614
0.711	3500	5	0.210	7.919	0.170	7.409
		10	0.337	8.008	0.220	7.348
		20	0.406	8.265	0.225	7.590
		40	0.425	8,331	0.252	7.575
0.711	2500	5	0.102	8.121	0.554	6.459
		10	0.165	8.134	0.216	7.486
		20	0.140	8.328	0.101	8.025
		40	0.210	8.214	0.126	7.836

0.711	2000	5	0.159	7.866	0.105	7.551
		10	0.216	8.207	0.103	7.898
		20	0.229	8.275	0.176	7.747
		40	0.229	8.388	0.148	7.924
0.711	1650	5	0.108	8.076	0.404	6.864
		10	0.127	8.192	0.208	7.568
		20	0.140	8.287	0.181	7.744
		40	0.108	8.347	0.125	7.967
0.559	3500	5	0.191	8.223	0.185	7.668
		10	0.248	8.130	0.087	7.868
		20	0.311	8.113	0.049	7.967
		40	0.311	8.231	0.110	7.900
0.559	2500	5	0.140	8.133	0.285	7.277
		10	0.140	8.399	0.257	7.627
		20	0.171	8.185	0.090	7.916
		40	0.171	8.285	0.111	7.952
0.559	2000	5	0.044	8.033	0.333	7.034
		10	0.108	8.344	0.292	7.469
		20	0.095	8.439	0.207	7.818
		40	0 152	8.319	0.134	7.918
0.559	1650	5	0.076	7.718	0.195	7.134
		10	0.064	7.780	0.178	7.247
		20	0.076	8.159	0.279	7.323
		40	0.127	8.329	0.354	7.329
0.406	3500	5	0.025	8.159	0.343	7.131
		10	0.064	8.176	0.284	7.323
		20	0.089	8.555	0.355	7.489
		40	0.159	8.315	0.219	7.658
0.406	2500	5	0.032	8.089	0.306	7.171
		10	0.076	8.377	0.314	7.435
		20	0.089	8.290	0.192	7.714
		40	0.133	8.387	0.124	8.014
0.406	2000	5	0.076	7.941	0.380	6.801
		10	0.051	8.222	0.310	7.292
		20	0.108	8.439	0.237	7.728
		40	0.089	8.417	0.185	7.862
0.406	1650	5	0.044	8.536	0.689	6.469
		10	0.044	8.162	0.398	6.968
		20	0.108	8.554	0.354	7.491
		40	0.095	8.310	0.252	7.510

Table of results from a 4 x 4 x 4 experiment giving the statistical analysis of 704 fatigue tests.



Figs. 5.- 8. Median - 3 SD Values.

OBSERVATIONS

There are clear indications that the fatigue life of springs shot-peened by the method used in the experiment is dependant upon the time of processing. Also an indication, but of lower significance, that there is an optimum impeller speed. Shot size, within the range examined, is not significant but there are indications that size below those used would result in a reduction of peening efficiency. The results are applicable to the particular machine and work load but the experiment indicates that the technique could be used to optimise the variables of the process for similar production equipment. The results have clearly shown that there is no correlation between Almen are rise and fatigue life.