THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE DYNAMIC RELAXATION BEHAVIOUR OF HELICAL COMPRESSION SPRINGS

Report No 394

by

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SUMMARY

Tests have been conducted to determine the dynamic relaxation behaviour of shot peened springs made from BS5216 HD3, BS2803 carbon, chrome vanadium chrome silicon quality wires at a temperature of 120°C ie corresponding to the conditions encountered in internal combustion engines.

Although it was not possible to establish a relationship between static and dynamic relaxation, it was generally found that the dynamic level was lower than the static level under similar stressing conditions. The exception to this was the chrome vanadium material where similar relaxation levels were experienced under both static and dynamic conditions.

The behaviour of the patented hard drawn carbon steel was better than anticipated, with this material exhibiting similar dynamic relaxation levels to the chrome silicon material.

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1. INTRODUCTION

For springs operating in dynamic applications, the major cause of failure will be through fatigue; however, in certain applications, dynamic relaxation or load loss can be a problem particularly where elevated temperatures are encountered, for example in engine valve springs etc. Processes which improve the fatigue resistance of springs (such as shot peening) are known to have a deleterious effect on relaxation performance.

Very little data on dynamic relaxation are currently available to the spring designer compared with the large data bank available for static relaxation. In fact only one previous SRAMA report[1] has examined dynamic relaxation, and that involved unpeened springs. Due to this lack of information, it has always been the practice in predicting dynamic relaxation levels to assume that the level experienced would be less than the static relaxation under similar temperature and stress conditions. The reason for this assumption is that, under dynamic conditions, the stress level on the spring in continuously increasing and decreasing and so the spring is only maintained at the maximum stress level for less than half of each cycle.

The objective of this program of work was to test this assumption, and if possible to establish a relationship between dynamic and static relaxation so that the existing relaxation data bank could be drawn on.

2. MATERIALS AND SPRING DESIGN

The work was carried out on springs made from 4 grades of spring wire. These were patented cold drawn carbon steel to BS 5216 HD3 and three prehardened and tempered grades to BS 2803 i.e. a carbon steel 094A65, a chrome vanadium steel 735A50 and a chrome silicon steel 685A55. The details of the spring designs are given in table 1. Due to complications during the course of testing (see below), two sets of BS 5216 HD3 and BS 2803 735A50 springs were used.

The springs were given appropriate heat treatments i.e 375°C for 30 minutes for the carbon steel grades and 400°C for 30 minutes for the alloy steel grades, they were then shot peened using S230 shot to an arc rise on Grade A Almen strips of 0.4mm minimum and were then stress relieved at 220°C for 30 minutes.

3. TESTING PROCEDURE

As any dynamic relaxation data generated would be most widely used for engine valve springs, testing was conducted under similar conditions to those encountered in this type of service i.e at an elevated temperature of 120°C.

3.1 Dynamic Relaxation Testing

Dynamic relaxation tests were conducted at three maximum stress levels for each set of springs to a life of 10^7 cycles using the Association's eight station forced motion fatigue testing machine fitted with thermostatically controlled hot boxes. Test speed was kept constant throughout these tests at 1500 rpm.

Prior to commencement of testing, a series of temperature checks were conducted on the hot boxes using an independent thermocouple and digital thermometer to ensure that the correct temperature conditions were achieved.

The maximum stress levels chosen for the testing (900, 800 and 700 N/mm^2) were based on the results of previous fatigue testing of these grades of wire[2]. The minimum stress level used throughout the course of testing was 100 N/mm^2. The loads necessary to produce the required stress levels in the springs were calculated from the standard design formula, and the springs were load tested both prior to and after testing using the Association's electronic 2000 N spring load tester. From the data obtained the dynamic relaxation was calculated.

Problems were encountered with the BS 2803 094A65 material in that the springs were experiencing fatigue failures at the two highest stress levels of 900 and 800 N/mm^2, so further tests were carried out at lower stress levels i.e 600 and 500 N/mm^2 so that some springs remained unbroken.

The results for all four materials are given in table II and are presented graphically in Figures 1 to 4.

A limited amount of testing was carried out on each material to assess whether there was any relationship between dynamic relaxation and the duration of the fatigue test. This testing involved the dynamic relaxation testing of 2 springs of each material at the lowest stress level for each material i.e. 700 N/mm^2 for the BS 5216 HD3 and the two low alloy grades, and 500 N/mm^2 for the BS 2803 094A65 material. Load tests were carried out after lives of 10^6, 10^7, 3×10^7, and 5×10^7 cycles, and the results of this testing are presented in Table III.

3.2 Static Relaxation Testing

Static relaxation tests were conducted on each of the four materials at the same stress levels used for the dynamic testing, using standard nut and bolt techniques. The springs were bolted up and subjected to a temperature of 120°C for a period of 111 hours i.e equivalent to a test to 10^7 cycles during dynamic testing. The results of this testing are presented in Table IV and are presented graphically in Figures 1 to 4.

4. DISCUSSION OF RESULTS

The data obtained were analysed using standard statistical techniques to assess the relationship between static and dynamic relaxation, and to determine the possible relationship between dynamic relaxation with test duration.

The dynamic relaxation results obtained for the BS 5216 HD3 material were lower than those obtained for the BS 2083 735A50 grade, and so retests were carried out which confirmed these results using different sets of springs. The results for the retests are presented in Table II.

For the springs of the two carbon steel grades and for the chrome silicon grade, the level of dynamic relaxation was lower than the level of static relaxation under similar conditions. For the cold-drawn patented material the dynamic relaxation level was between a third and half of the static level, for the prehardened and tempered carbon steel grade was approximately half of the static level and for the chrome silicon grade it was approximately two thirds of the static level.

The results of the chrome vanadium grade of material were very different from those obtained from the other materials, in that at the two lower stress levels similar levels of dynamic and static relaxation were experienced, while at the higher stress level the level of dynamic relaxation was nearly half as much again as the static relaxation level.

It was found that, although there was a general trend for the dynamic relaxation level to increase as the test duration increased, the data were insufficient to produce statistically meaningful results.

No logical explanation for the apparent lack of a consistent relationship between dynamic and static relaxation has been proposed, but the results clearly show a need for further research in this important area, especially since motor manufacturers specify maximum dynamic relaxation levels in some recent specifications. Also further work needs to be undertaken to determine the relationship between test duration and dynamic relaxation.

5. CONCLUSIONS

1. The likely dynamic relaxation level for springs in the shot peened condition has been established at 120^{o}C for cold-drawn patented carbon steel to BS 5216 HD3 grade, prehardened and tempered carbon steel BS 2803 094A65, prehardened and tempered chrome vanadium steel to BS 2803 735A50 and prehardened and tempered chrome silicon steel to BS 2803 685A55.

2. No obvious relationship appears to exist between dynamic and static relaxation, although generally the dynamic level is lower than that of the static level under similar stressing conditions. The exception to this appears to be the chrome vanadium material where similar levels of dynamic and static relaxation are encountered.

3. With increasing life the level of relaxation increases.

6. RECOMMENDATION

Further testing should be conducted in order to provide sufficient data to enable a relationship between life and dynamic relaxation to be determined. Tests should also be conducted on hot prestressed springs as this process is widely used on engine valve springs to reduce relaxation levels.

In a real life situation, engine valve springs do not operate in a dynamic manner continuously, but alternate between dynamic and static operations; ie while the engine is running the springs will operate dynamically at temperature, and then when the engine is stopped the springs will be compressed statically with the temperature gradually reducing down to ambient. It can be seen that under this manner of operation springs could experience both static and dynamic relaxation and a series of tests to establish whether this relaxation is accumulative would be beneficial.

7. REFERENCES

1. Gray, S.D. "The relationship between static and dynamic relaxation of three spring materials." SRAMA report no. 218, Sept 1973.

2. Hayes M.P. "Decarburisation/Defects and their effect on dynamic properties of springs made from spring wire." SRAMA report no. 377, Jan 1985.

TABLE I SPRING DESIGNS

	BS 5216 HD3	BS 5216 HD3 Retest Springs	BS 2803 094A65	BS 2803 735A50	BS 2803 735A50 Retest Springs	BS 2803 685A55
Wire Diameter (mm)	2.93	4.00	2.80	2.50	3.80	2.64
Mean Coil Diameter (mm)	20.92	28.24	22.65	19.74	24.46	18.77
Spring Index	7.14	7.06	8.09	7.90	6.44	7.11
Total Coils	5.50	5.50	5.50	5.50	5.50	5.50
Free Length after End Grinding & Prestressing (mm)	36.50	47.50	38.80	36.20	41.30	33.00
Solid Stress after End Grinding & Prestressing (N/mm2)	1175.00	1105.00	1075.00	1220.00	1140.00	1195.00

TABLE II DYNAMIC RELAXATION OF SHOT PEENED SPRINGS AFTER 10^7 CYCLES AT 120°C

BS 5216 HD3		BS 2803 094A65		BS 2803 735A50		BS 2803 685A55	
Stress (N/mm^2)	%R	Stress (N/mm^2)	%R	Stress (N/mm^2)	%R	Stress (N/mm^2)	%R
900	5.6	700	4.8	900	11.8	900	5.7
	5.6		3.5		11.4		6.1
	7.3		5.3		11.0		4.4
	7.8		6.1		11.8		5.9
	4.5		3.5		11.4		4.9
	6.9		4.4		11.8		6.3
	7.8		4.0		11.2		5.0
	5.3		4.4		10.7		5.9
$\bar{x}$	6.4	$\bar{x}$	4.5	$\bar{x}$	11.4	$\bar{x}$	5.5
800	4.2	600	2.1	800	7.1	800	3.5
	5.9		2.1		6.1		4.4
	4.2		2.0		6.2		3.5
	3.4		2.6		7.7		4.4
	2.9		3.6		8.7		3.5
	5.1		3.1		7.7		3.5
	3.6		3.6		7.7		3.5
	4.1		2.6		7.2		3.5
$\bar{x}$	4.2	$\bar{x}$	2.7	$\bar{x}$	7.3	$\bar{x}$	3.7
700	2.5	500	3.1	700	3.5	700	2.0
	2.2		2.5		5.9		2.0
	2.2		2.5		4.1		2.0
	2.5		1.9		4.7		3.0
	2.5		3.1		4.7		2.0
	3.3		3.1		3.5		2.0
	3.2		2.5		6.4		3.0
	1.1		1.8		5.1		2.0
$\bar{x}$	2.4	$\bar{x}$	2.6	$\bar{x}$	4.7	$\bar{x}$	2.3
800 retests	5.3			800	8.2		
	2.9				7.6		
	4.5				7.3		
	3.7				8.0		
	4.3				7.3		
	3.5				6.8		
	3.2				7.3		
	4.6				7.6		
$\bar{x}$	4.0			$\bar{x}$	7.5		

TABLE III LIFE Vs DYNAMIC RELAXATION RESULTS (Duplicate Results)

Life (cycles)	% Relaxation			
	BS5216 HD3	BS2803 094A65	BS2803 735A50	BS2803 685A55
10^6	3.9 2.0	3.1 1.8	3.4 2.6	1.8 1.8
10^7	5.1 2.0	3.1 1.8	4.0 2.6	2.4 2.4
3×10^7	5.1 3.4	4.9 1.8	5.0 2.6	3.0 2.4
5×10^7	6.4 4.2	4.9 3.7	5.0 3.6	4.2 4.3

TABLE IV STATIC RELAXATION RESULTS

BS 5216 HD3		BS 2803 094A65		BS 2803 735A50		BS 2803 685A55	
Stress (N/mm^2)	%R	Stress (N/mm^2)	%R	Stress (N/mm^2)	%R	Stress (N/mm^2)	%R
900	13.4	700	7.5	900	5.4	900	7.5
	13.0		7.5		7.2		9.6
	12.1		6.6		8.0		10.1
	12.4		7.5		7.5		8.5
	13.7		8.8		9.1		9.0
$\bar{x}$	12.9	$\bar{x}$	7.6	$\bar{x}$	7.4	$\bar{x}$	8.9
800	10.2	600	5.6	800	6.6	800	4.2
	11.9		4.6		6.6		4.8
	10.7		5.1		5.9		4.8
	10.0		6.2		6.9		4.2
	10.7		6.2		5.9		4.8
$\bar{x}$	10.7	$\bar{x}$	5.5	$\bar{x}$	6.4	$\bar{x}$	4.6
700	6.2	500	4.9	700	5.2	700	3.4
	7.0		4.9		5.4		4.1
	7.8		4.3		5.4		4.1
	6.6		4.9		5.0		3.4
	8.0		3.1		5.2		3.4
$\bar{x}$	7.1	$\bar{x}$	4.4	$\bar{x}$	5.2	$\bar{x}$	3.7

TABLE V RATIOS OF MEAN DYNAMIC RELAXATION LEVEL TO MEAN STATIC RELAXATION LEVEL

BS 5216 HD3		BS 2803 094A65		BS 2803 735A50		BS 2803 685A55	
Stress (N/mm^2)	Ratio	Stress (N/mm^2)	Ratio	Stress (N/mm^2)	Ratio	Stress (N/mm^2)	Ratio
900	0.49	700	0.59	900	1.53	900	0.62
800	0.38	600	0.49	800	1.16	800	0.82
700	0.34	500	0.58	700	0.90	700	0.61

Figure 1.   Relaxation results for BS 5216 HD3 Springs

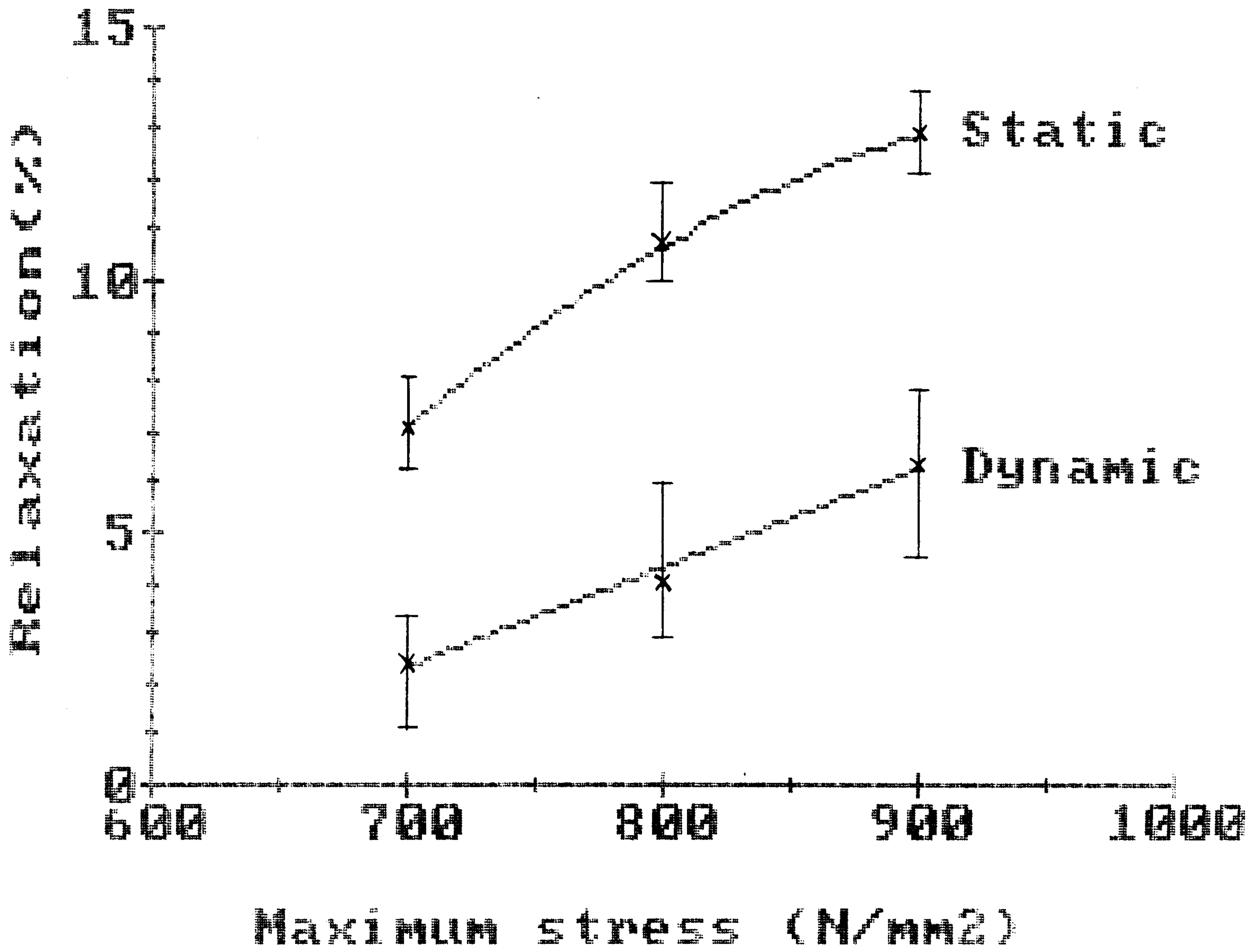

Figure 2. Relaxation results for BS 2803 094A65 Springs

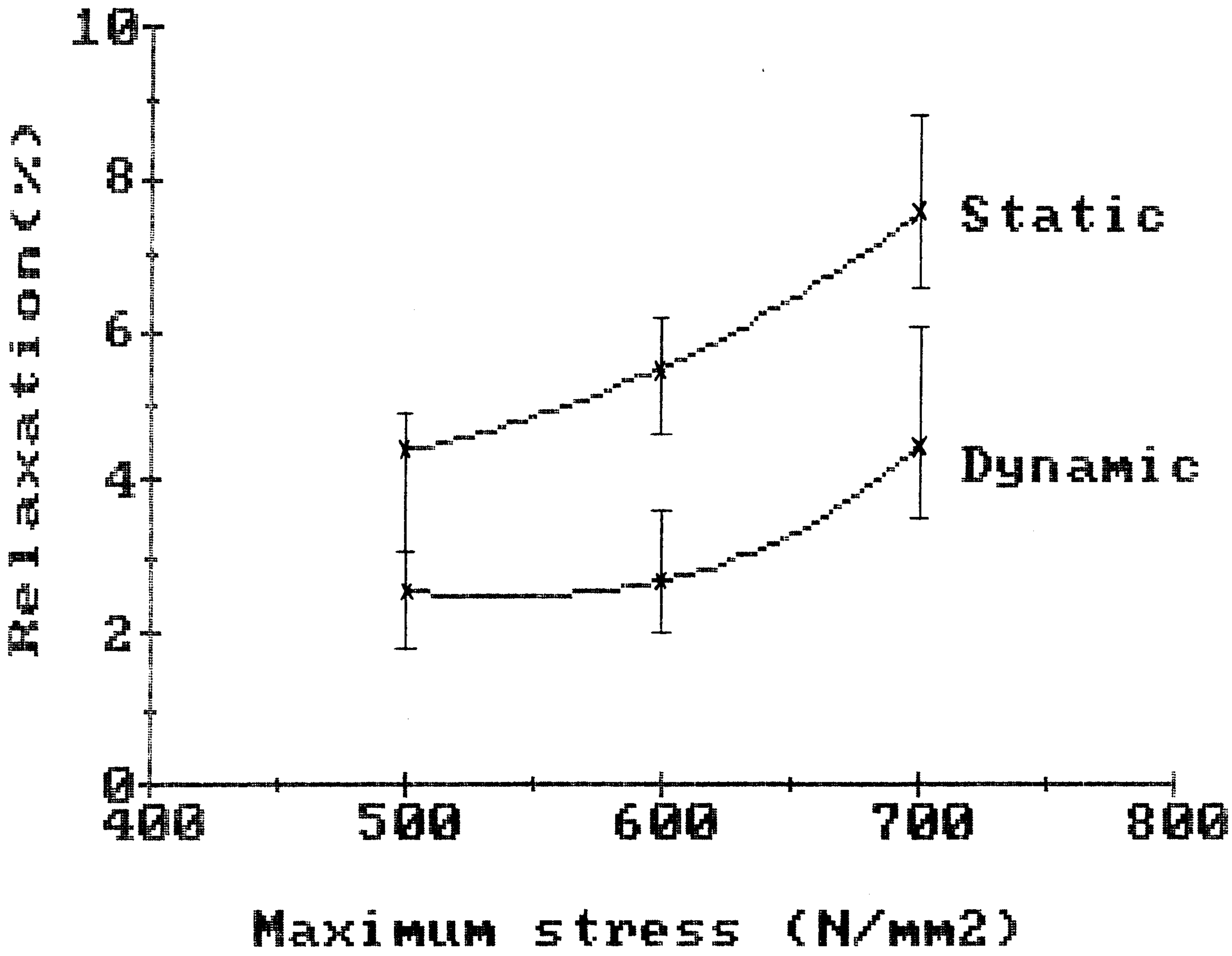

Figure 3. Relaxation results for BS 2803 735A50 Springs

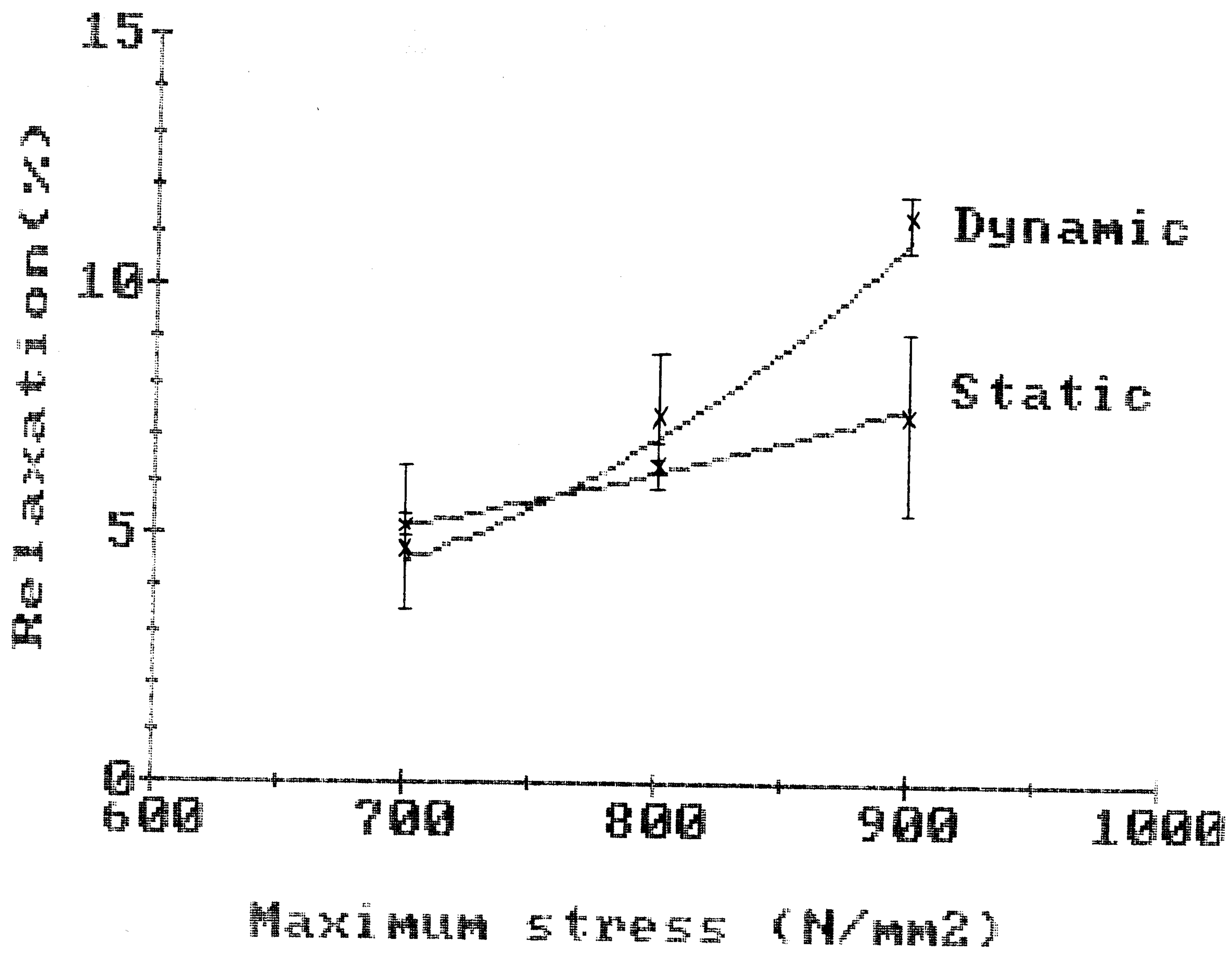

Figure 4.   Relaxation results for BS 2803 685A55 Springs