THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE FATIGUE PERFORMANCE OF HELICAL EXTENSION SPRINGS

by

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SUMMARY

An investigation has been conducted to evaluate the fatigue performance of extension springs with German end hooks, made from cold drawn patented carbon steel wire. This type of material is the most widely used for extension springs, accounting for approximately 80% of all production.

The results of the testing indicated that, with an initial stress level of 200 N/mm^2 the fatigue limit stress for 95% survival was approximately 650 N/mm^2. This is approximately 25% lower than the fatigue limit stress range for compression springs of the same material operating under similar initial stress conditions. It was also found that the fatigue limit appeared to be independent of spring index.

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1. INTRODUCTION

When the need arises for an extension spring to be used in a dynamic application, the spring designer finds very limited data available regarding maximum allowable stresses in comparison with the vast wealth of data available for compression springs. In determining allowable stress levels, the general practice is to use compression spring fatigue data reduced by a suitable percentage. However, a brief examination recently carried out by the Association[1] of the limited amount of published literature giving data on extension springs, revealed a considerable variation in the recommended levels of stress reduction. Carlson[2] recommends reducing the allowable maximum working stress levels as generated from compression springs by 10 - 15%, Wahl[3] suggests 20 - 25%, while Meyers and Albright[4] are even more conservative in recommending a 30% reduction. The German DIN specification 2089 goes so far as to recommend avoiding using tension springs in fatigue wherever possible. Previous work by SRAMA[5,6] has concluded that, for extension springs, the reduction in maximum allowable stress for fatigue applications should be approximately 20%, but it is acknowledged that this tentative conclusion is based on insufficient data.

The main recommendation of the Association's recent work[1], was that the general fatigue performance of extension springs should be established to verify or otherwise the general stress reduction proposed relative to compression spring fatigue data. Thus, the aim of this work is to aid the spring designer by providing reliable design data for fatigue of extension springs.

2. SPRING DESIGNS AND TESTING PROCEDURES

Springs having indices of approximately 4, 8 and 12 were made from 1.0 mm diameter cold drawn, patented carbon steel wire to BS 5216 HD 3 grade; the full design details of the springs are given in Table I. For consistency of design, the radius of the bend between the spring body and the German end hook was made the same size as the mean coil radius (see Figure 1). The springs were used in the as-coiled condition, ie they did not receive either a low temperature heat treatment or a prestressing treatment.

Metallographic checks on the wire found it to have a satisfactory micro-structure of cold drawn pearlite. The material was free from wire defects and decarburization, had a hardness level of 575-580 Hv_{20} and a tensile strength of 2100 N/mm^2.

Prior to commencement of fatigue testing, 5 springs of each design were load tested to determine initial tension levels and thereby establish a suitable initial stress level for subsequent fatigue testing. The mean initial tension level for each design is given in Table I. 200N/mm^2 was chosen as the initial stress level for the fatigue testing, being greater than the maximum initial tension stress level in the springs.

Fatigue tests were performed using the Association's forced motion fatigue testing machines which had been suitably modified to accommodate extension springs. The springs were tested to various maximum stresses to establish the approximate maximum stress level, at which half the springs tested survived 10^7 cycles. Further testing was then conducted in order that a Probit analysis could be carried out about this approximate median, in accordance with the procedure laid out in BS 3518: Part 5: 1966. The number of springs (group size) tested at each stress increment was varied in accordance with the British Standard in order to simplify the subsequent analysis, and the increments of stress were chosen in such a way that the percentage survival at each maximum stress level most nearly fitted the ideal of the Probit distribution, ie:

% Survival	Relative Group Size
25 to 75	1
15 to 20 or 80 to 85	1½
10 or 90	2
5 or 95	3
2 or 98	5

The stress increments that gave results which came nearest to this ideal were 50 N/mm^2 for the index 4 and 8 springs, and 25 N/mm^2 for the index 12 springs.

It was noticed during the course of testing that all the failures occurred below 10^6 cycles. It was decided, therefore, to adopt $3x10^6$ cycles as the criterion for survival in the fatigue testing.

3. RESULTS AND DISCUSSION

The results of the fatigue tests are presented in graphical form in Figures 2, 3 and 4 for the index 4, 8 and 12 springs respectively. From these fatigue test results Probit analyses were performed, the results of which are given in Table II.

For all three spring indices the failures occurred in the end hook within the region indicated on Figure 1, ie within the region of maximum stress in the end hook. This siting of the failures may, in part, be due to the presence of a detrimental residual stress system within the end hook occurring as a result of the hook forming process.

The results of the Probit analyses revealed that there was no significant difference for the three sets of springs in either the fatigue limit for 50% survival ($\sigma 50$) or in that for 95% survival ($\sigma 95$), indicating that spring index has little influence on the fatigue properties of extension springs with German end hooks. This confirms the findings of previous work by SRAMA[5].

From the results it will be seen that the $\sigma 95$ fatigue limit occurs at a maximum stress level of approximately 650 N/mm². By comparison, the maximum allowable stress level for BS 5216 HD3 compression springs operating from an initial stress level of 200 N/mm² is 800 N/mm²[7]. Thus the maximum allowable stress range in fatigue for extension springs is approximately 75% of that for compression springs under similar initial stress conditions.

4 CONCLUSIONS

1 The fatigue limit for 95% survival for extension springs with German end hooks made from BS 5216 HD3 wire operating from an initial stress of 200 N/mm² has been determined as approximately 650 N/mm².

2 The fatigue limit stress range of 450 N/mm² equates to approximately 75% of the fatigue limit stress range for compression springs tested under similar initial stress conditions.

3 Spring index does not significantly affect the fatigue limit in extension springs with German end hooks.

4 Under fatigue conditions, extension springs with German end hooks are unlikely to fail above a life of 10^6 cycles.

5 All the fatigue failures occurred in the end hooks at the region of maximum stress.

5. RECOMMENDATIONS

Further testing should be conducted to assess the influence of screwed - in and tapered ends on the fatigue limit of extension springs, as elimination of end hook failures should improve the reliability of this type of spring. Also, the effects of heat treatment on fatigue performance should be examined as many extension springs are heat treated in order to stabilise them prior to service. Production of sufficient data to enable the construction of Goodman diagrams for both heat treated and as-coiled springs would be of benefit to the spring designer.

6. REFERENCES

1 Saynor, D. "A survey of the fatigue performance of extension springs", The Spring Journal, 154, August 1986, pp 53-57.

2 Carlson, H. "Spring designer's handbook," 1978 (Marcel Dekker, Inc).

3 Wahl, A.M. "Mechanical springs", 1963 (McGraw - Hill).

4 Meyers, O.G. and Albright, S.L. "Precision extension spring design", Electromech. Design, Nov/Dec, 1957.

5 Bird, G.C. "The effect of end loop configuration on the static and dynamic properties of tension springs", SRAMA Report 231, May 1974.

6 Southward, M.R. "An investigation into the stresses encountered in two types of end loop formation in extension springs, "SRAMA Report 272, February 1977.

7 "Spring Materials Selector", 1984 (SRAMA).

TABLE I SPRING DESIGNS

	1	2	3
Wire size (mm)	1.00	1.00	1.0
Outside diameter (mm)	5.10	9.02	12.99
Spring index	4.10	8.02	11.99
Free length - pull to pull (mm)	28.33	25.68	26.04
Total Coils	20.00	10.00	5.00
Spring rate (N/mm)	7.19	1.92	1.15
Initial tension load (N)	12.96	7.13	3.62
Initial tension stress (N/mm^2)	187.80	170.50	122.60
Loop type	German	German	German
Radius between body and loop (mm)	2.00	4.00	6.00

TABLE II RESULTS OF PROBIT ANALYSES

Spring Index	Y = a + bX		Correlation Coefficient	Level of Significance	Fatigue limit % Survival	
	a	b			$\sigma 50$	$\sigma 90$
4.10	-10.14	0.013	0.93	99%	646± 7	646± 18
8.02	-10.70	0.014	0.96	99%	793± 12	671± 19
11.99	-12.48	0.016	0.80	95%	763± 10	662± 20

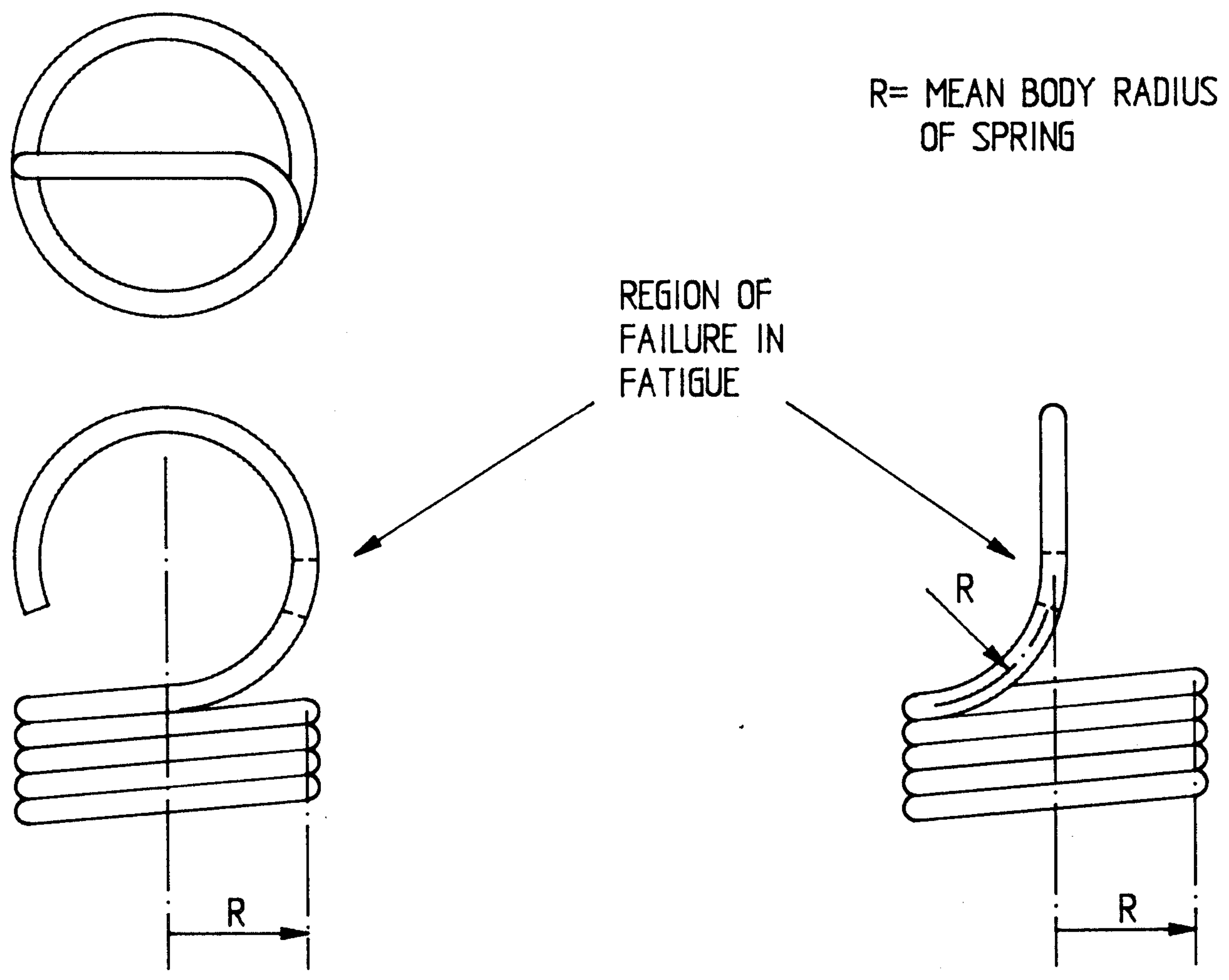

Fig 1 END LOOP FORMATION

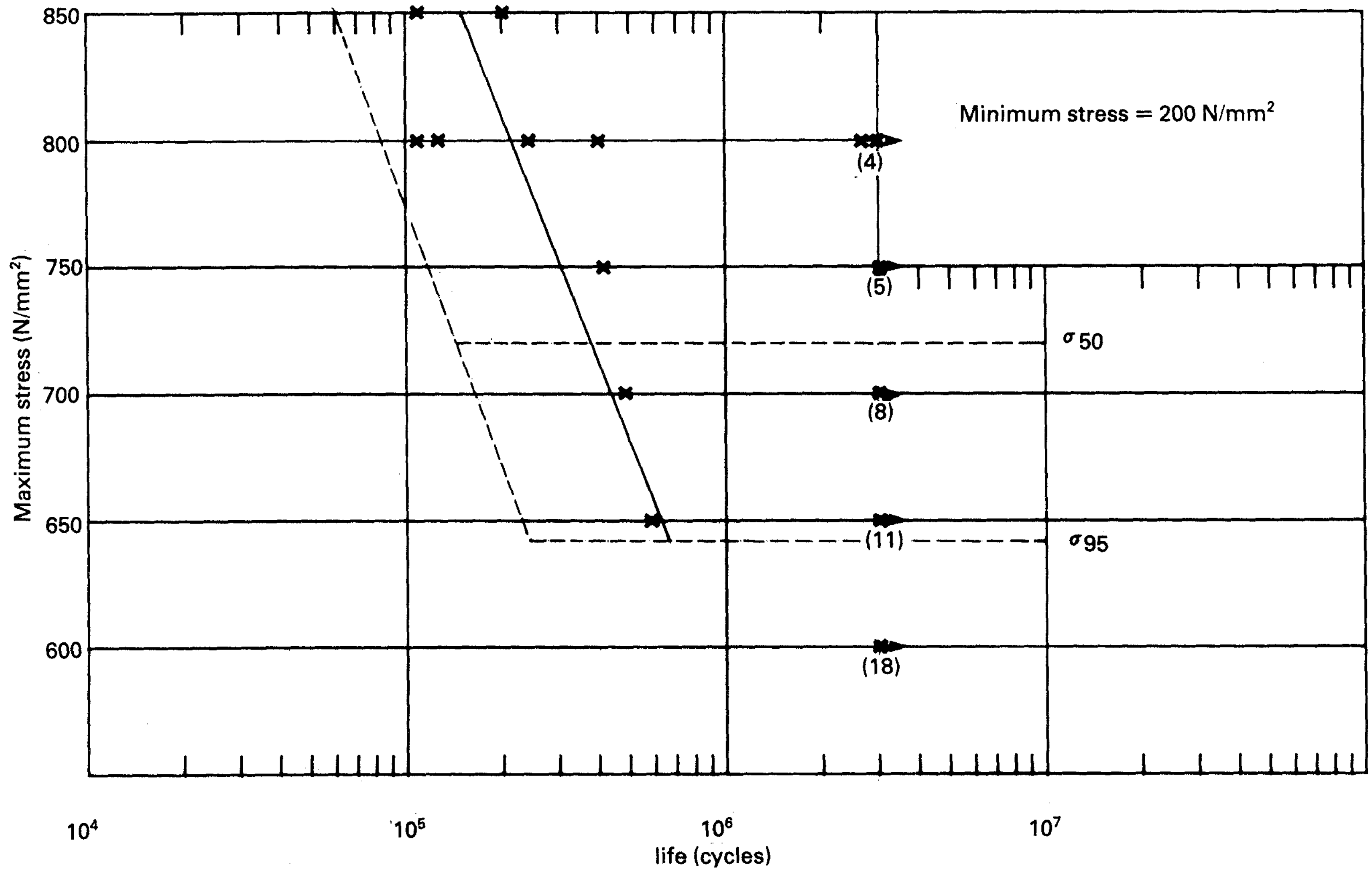

Fig 2: S/N CURVE FOR INDEX 4 EXTENSION SPRINGS

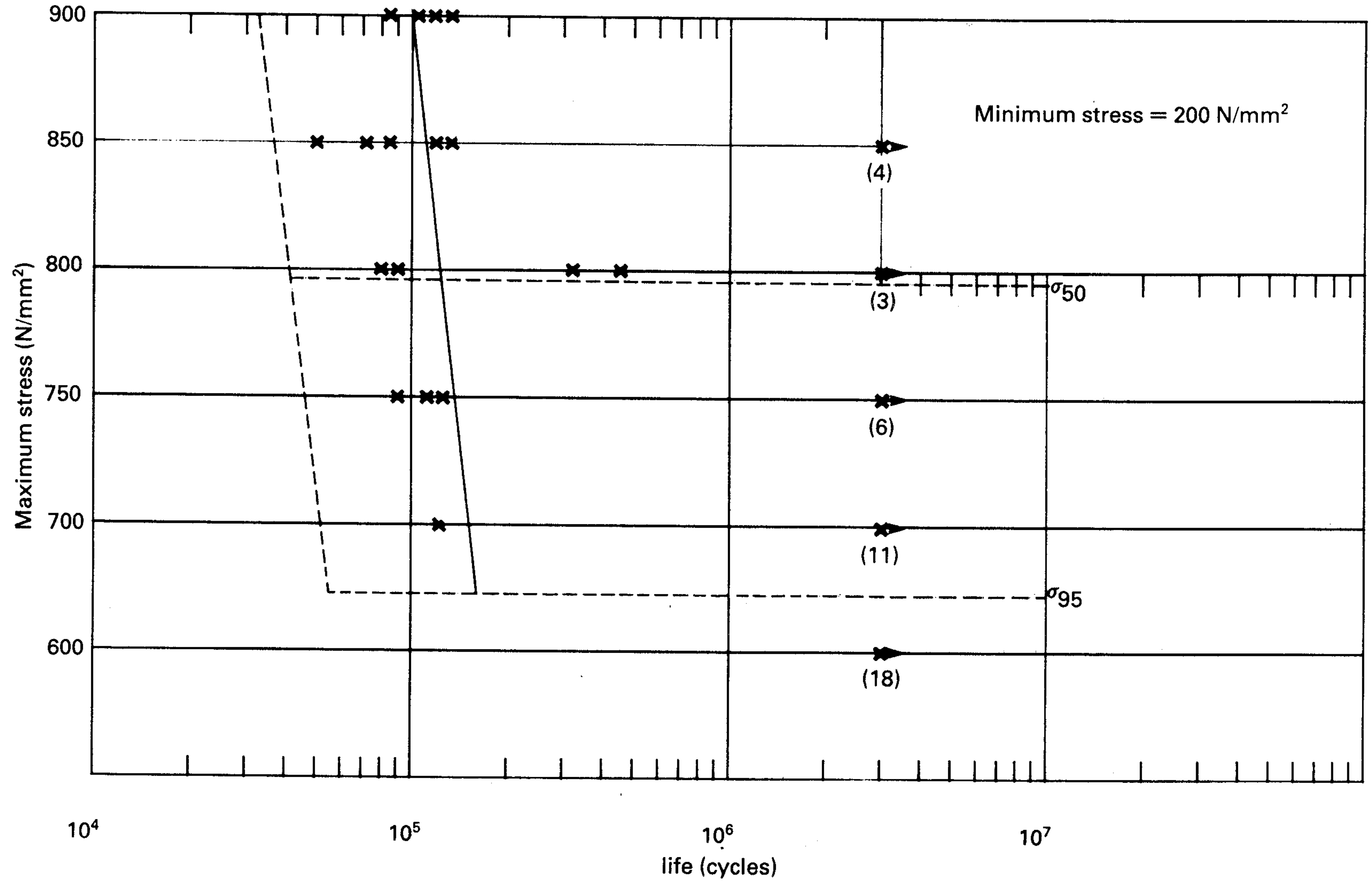

Fig 3: S/N CURVE FOR INDEX 8 EXTENSION SPRINGS

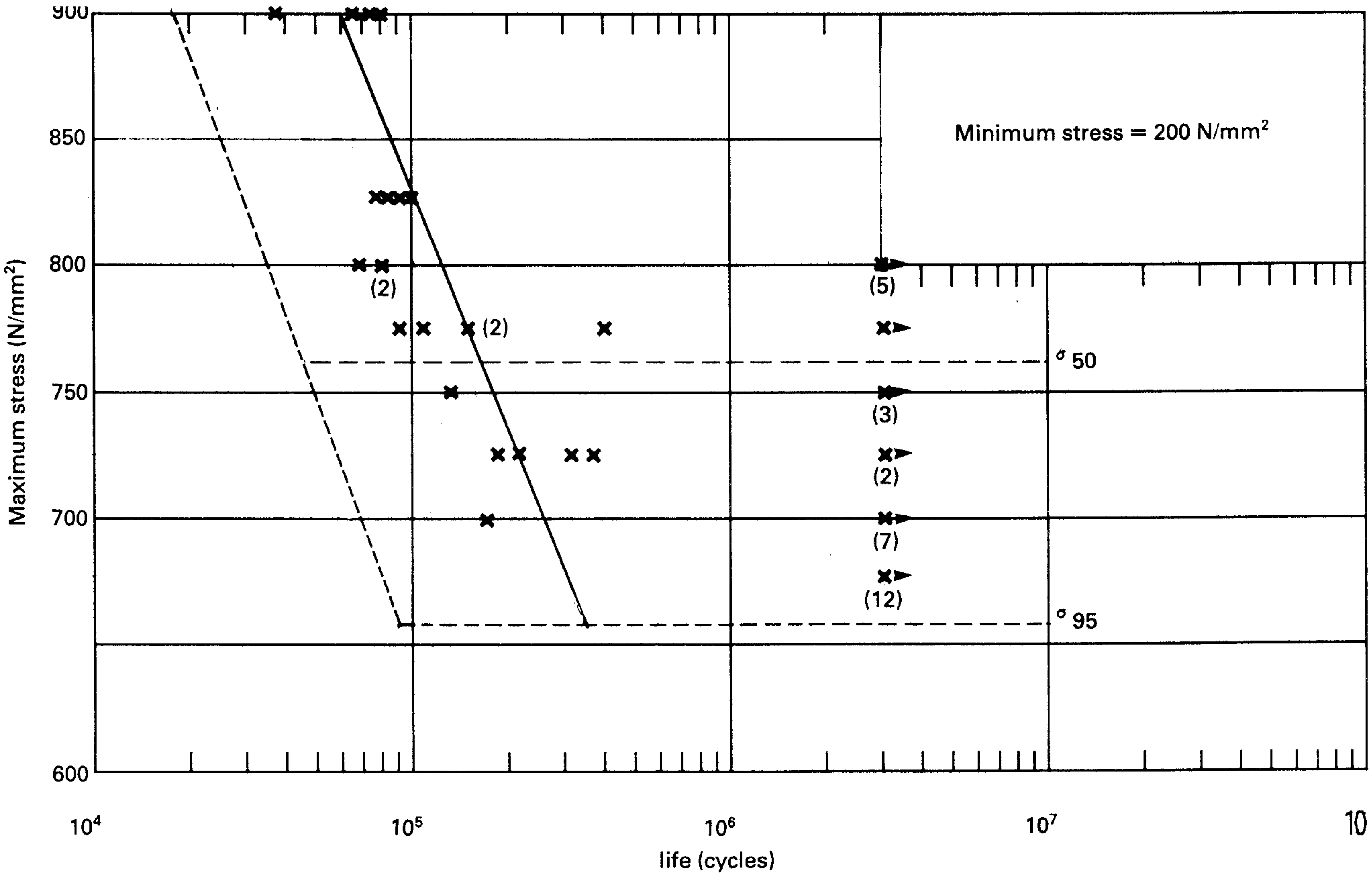

Fig 4: S/N CURVE FOR INDEX 12 EXTENSION SPRINGS