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NBS TECHNICAL NOTE

480

Misalinement Detector for Axial Loading Fatigue Machines

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NBS TECHNICAL NOTE 480

ISSUED APRIL 1969

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by Donald C. Robinson

ABSTRACT

A strain gage device for measuring changes in alinement between the test fixtures of axial loading fatigue machines is described. Variations in fixture orientation are determined by measurement of the bending induced in a compliant beam clamped in parallel mounts attached to the test fixtures. Changes in bending with applied tension loads are an indication of alterations in the alinement between the load transmitting members of a machine. An approximately linear relationship was found to exist between changes in bending determined by the detector and the fatigue life of high strength fasteners for various levels of misalinement induced in a fatigue machine.

Key words: Axial loading, fatigue machine, misalinement, test fixtures.

1. Introduction

In order for a fatigue testing machine to give significant results, it must produce the desired stress distribution within the specimen. Fatigue lives of high strength metal fasteners, for example, have shown large variations in tension-tension tests due to the presence of undesired bending loads*. For the quality control of such products, it is necessary to detect undesired stresses due to misalinement of the testing machine in order to determine when variations in the test results are due to an inferior lot rather than due to the machine. This note describes the development of a device for detecting such misalinement.

Various methods have been used by other investigators for minimizing misalinement in a fatigue machine. Some require precision machining of specimens and the machine test fixtures[1]**. Other

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* Personal Communications with the Engineering Staff of the Precision Fastener Division, Standard Pressed Steel Company, Jenkintown, Pennsylvania.

** Numbers in brackets indicate the literature references at the end of this paper.

alining procedures have been developed in which a misalinement indicating device is installed in a machine in place of, or in series with, a specimen . This technique allows the possibility of a change in alinement when the device is removed. The device described in this report is able to detect misalinement of the load transmitting members of an axial-loading machine for the range of loads applied during a tension-tension test while a specimen remains in place. Changes in the alinement of the machine are indicated by bending induced in the detector which is attached to the machine test fixtures.

2. Misalinement Detector Design

A schematic of the misalinement detector is shown in Figure 1. Its principal components are a beam, a flexure, and fittings for attaching the detector to fatigue test fixtures. The beam was constructed from an 11 in. (279.4 mm) x 1 in. (25.4 mm) x 3/16 in. (4.8 mm) aluminum bar. The center portion of this member was reduced to approximately 0.625 x 0.016 in. (15.9 x 0.4 mm). A four-arm, temperature compensated bridge circuit constructed of foil-type, resistance strain gages was bonded to the reduced section. It was connected to measure bending and to cancel axial strain components.

The purpose of the flexure was to transmit the effects of bending due to misalined test fixtures to the gaged section of the beam. It was required that the flexure have a low resistance to axial motion and also provide for a connection to the test fixture surfaces having high stiffness in the horizontal direction. A leaf flexure, whose basic operating principle is given by Jones and Young[2], was employed. A cross section through the flexure is shown in Figure 1. The flexure leaves were constructed from 0.005 in. (0.13 mm) brass shims arranged to provide parallel motion of a rectangular element having a 0.281 in.^{2} (7.1 mm^2) surface area which was in contact with the surface of the beam. Polytetrafluoroethylene tape was applied to each of these surfaces and to the end of the beam to minimize the friction due to sliding.

The flexure was used to clamp the upper end of the beam to a steel fitting, and the lower end of the beam was bolted to another fitting. Both fittings were clamped to the circumference of the test fixtures by means of an adjustable metal clamp. In order to minimize the misalinement between the pair of fittings themselves, they were fabricated from one piece of material and cut along a plane perpendicular to the mounting surfaces during the last machining operation. Although these fittings were designed for cylindrical test fixtures, fittings for attaching to other fixtures are feasible.

In order to protect the compliant gaged section of the beam from being damaged during assembly, cover plates which attach to the beam by screws completely enclosed the reduction section. It was necessary to loosen these plates when the detector was being used in order for bending of the beam due to misalinement between its mounting surfaces to be effectively transmitted to the strain gages.

In order to obtain an absolute determination of misalinement, the test fixtures could be compared to a precision alined surface external to a testing machine. Due to the beam configuration and gage arrangement, it is difficult to prevent the beam from transmitting undesired torsional strains to the compliant gaged section which would be misinterpreted as due to bending. This device measures bending in only one plane. In this investigation, care was taken to aline this plane with the plane of bending.

3. Installation

To minimize any misalinement between the fittings which attach the beam to the machine test fixtures, a uniform steel fitting alinement bar, having the same nominal size as the gaged beam, is first clamped to the fittings. The adjustable clamps which fasten the fittings to the test fixtures are then tightened, the alinement bar is removed and the gaged beam is installed.

One end of the beam is fastened to the upper fitting by means of the flexure, and its other end is fastened to the lower fitting by screws, as shown in Figure 1. To insure that the bearing surface of the flexure is in uniform contact with the beam, the upper end of the beam is first connected, the screws attaching the plates covering the gaged section are loosened and the lower end of the member is then tightened.

4. Measurement Procedure

The bending determined by the detector, which is an indication of the bending transmitted between the fatigue test fixtures to the specimen, is measured using a strain indicator. The procedure for estimating the change in alinement between test fixtures over the range of loads applied during a tension-tension fatigue test is as follows:

1. Apply a static tension load to a specimen corresponding to the mean cyclic load.

2. Balance the strain gage bridge.

3. Reduce the load to a value corresponding to the minimum cyclic load, rebalance the bridge, and record the indicated strain.

4. Remove the misalinement detector before beginning a fatigue test.

5. Sensitivity

A calibration of the misalinement detector which was used to estimate its sensitivity was determined by recording the bending at its gaged section induced by various size shims placed under one of the attachment fittings while the detector was clamped to a uniform cylindrical surface. The calibration curve shown in Figure 2 was determined by placing shims under one fitting located approximately 5.0 in. (127 mm) from the gaged section while the other end of the beam was clamped. From these data, it is estimated that the detector is capable of determining bending less than one percent of the axial strain experienced by a 1/4 in. (6 mm) diameter specimen when subjected to a tension load. When the detector is attached to the test fixtures of a machine, its sensitivity is also influenced by the rigidity of the machine.

6. Results and Discussion

In order to verify that the bending determined by the detector was representative of the bending experienced by a specimen, a strain gage bridge circuit for measuring bending was bonded to the surface of a 1/4 in. (6 mm) diameter bolt. A comparison of the bending in a bolt with the bending determined by the misalinement detector, shown in Figure 3, was found by attaching the detector to 3 in. (76 mm) diameter test fixtures installed in a 5,000 lbf (22,000 N) capacity, hydraulic, axial loading fatigue machine. The data plotted in Figure 3 shows two regions, represented by dashed and solid lines. The portion of the curves which are dashed indicates a region where the detector measured bending before the bolt was tightly seated in the test fixtures. After the fastener was seated, the region represented by solid lines, the coefficient of correlation for the two sets of data was 0.95. This indicates that the bending experienced by the two correlate linearly.

Another investigation was made in which misalinement was induced in a fatigue machine with beveled washers. The washers, whose flat surfaces were ground non-parallel, were placed under the bolt heads of 1/4 in. (6 mm) diameter steel fasteners. A 24,000 lbf (107,000 N) capacity, electromechanical, axial loading machine was used. The test fixtures were 2 1/2 in. (64 mm) in diameter.

The values of bending induced by washers with various angles at tension loads of 2,000 lbf (8,900 N), 1,000 lbf (4,450 N) and 200 lbf (890 N) are given in Table 1. The results of fatigue tests on the same bolts are given in Table 2. These fasteners have an assembly minimum tensile strength of 260,000 lbf/in.^{2} (1,790 MN/m^2), and were known to be particularly sensitive to bending loads when subjected to tension-tension fatigue tests. The curves in Figure 4 give the comparison of the data from Table 1 for a tension load of 200 lbf (890 N) and the average fatigue life of the bolts. The bending was measured at 200 lbf (890 N) to determine whether the test fixture alinement changed significantly below the minimum load applied during the fatigue tests. The data did not indicate any large changes in fixture alinement for the two loads within the range of the fatigue test and the alinement for the load below the test range. The data for a tension load of 200 lbf (890 N) was used for comparison with the average fatigue life of the bolts since the larger scatter in the measurements at 2,000 lbf (8,900 N) and 1,000 lbf (4,450 N) suggests that the orientation of the larger washers below the bolt heads was more critical at the larger loads and this orientation was not closely controlled. The questionable data are identified in Table 1.

The values for the fatigue life of the 1/4 in. (6 mm) diameter bolts and the bending determined by the misalinement detector when the fixtures were alined (0 degree washer) were most affected by the smallest angularity induced by the beveled washers, 0.18 degree, with relatively smaller changes being observed for larger angularities up to 1.1 degrees. The magnitude of the coefficient of correlation[3] between the bending determined at 200 lbf (890 N) and the fatigue life for various washers was approximately 0.9; in Figure 5 is shown a direct comparison of the bending at this load and the average fatigue life of the bolts.

7. Conclusions

The device described in this report utilizes bending induced in a compliant beam to detect changes in the alinement of the test fixtures of an axial loading fatigue machine for a range of loads applied during a tension-tension test. The changes in bending with applied load are an indication of alterations in the alinement of the load transmitting members, which should be kept to a minimum to prevent excessive bending loads from being applied to a specimen.

Based on the experimental measurements, the relationship between the bending determined by the detector due to misalined test fixtures and bending experienced by a specimen installed in the fixtures was linear. An approximately linear relationship was found to exist between the bending determined by the detector and the fatigue life of high strength bolts for various levels of misalinement induced in a fatigue machine.

Mr. R. Snyder assisted in the construction of the misalinement detector. Mr. T. Baumgartner, Engineering Manager of the Precision Fastener Division, Standard Pressed Steel Company, Jenkintown, Pennsylvania, arranged for tests to be conducted on fatigue equipment at the Jenkintown plant.

The project which led to this report was conducted under the sponsorship and with the financial assistance of the Naval Air Systems Command, Department of the Navy.

8. References

1. Weibull, W., Fatigue Testing and Analysis of Results, Pergamon Press (1961).

2. Jones, R. V. and Young, I. R., Some Parasitic Deflexions in Parallel Spring Movements, J. Sci. Instr., 33, p. 11-15 (Jan. 1956).

3. Li, J. C. R., Statistical Inference, Vol. I, p. 301, Edwards Brothers, Inc., (1964).

Table 1 - Strain Indicated by the Misalinement Detector Due To Beveled Washers Installed in an Electromechanical Testing Machine (a)

Angle of beveled washer	Applied tension loads 2000 lbf (8900 N)	1000 lbf (4450 N)	200 lbf (890 N)
deg	in./in.	in./in.	in./in.
0	58×10^{-6}	69×10^{-6}	85×10^{-6}
0.18	144	160	166
0.41	176	175	177
0.62	149 (b)	162 (b)	176
0.93	228 (b)	223 (b)	180
1.08	238 (b)	242 (b)	215

(a) These values represent changes in bending found at a load of 2500 lbf (11,120 N) and the indicated load.

(b) Questionable data due to orientation of beveled washers.

Table 2 - Effect of Angularity of Bolt Head Seat on the Fatigue Life of 1/4 inch (6 mm) Diameter Fasteners. Tension-Tension Load Cycles of 505 to 5050 lbf (2250 to 22,500 N)(a)

Angle of beveled washer	Cycles to failure	Average fatigue life	Average reduction in fatigue life
deg		cycles	percent
0	126,000	102,000	0
	78,000		
0.18	53,000	62,500	39
	39,000		
	85,000		
	73,000		
0.41	66,000	42,750	58
	34,000		
	28,000		
	43,000		
0.62	45,000	42,250	59
	46,000		
	36,000		
	42,000		
0.93	56,000	49,000	52
	42,000		
1.08	44,000	38,000	63
	32,000		

(a) Axial stress levels corresponding to this loading were 10,300 to 103,000 lbf/in.^{2} (71 to 710 MN/m^2).

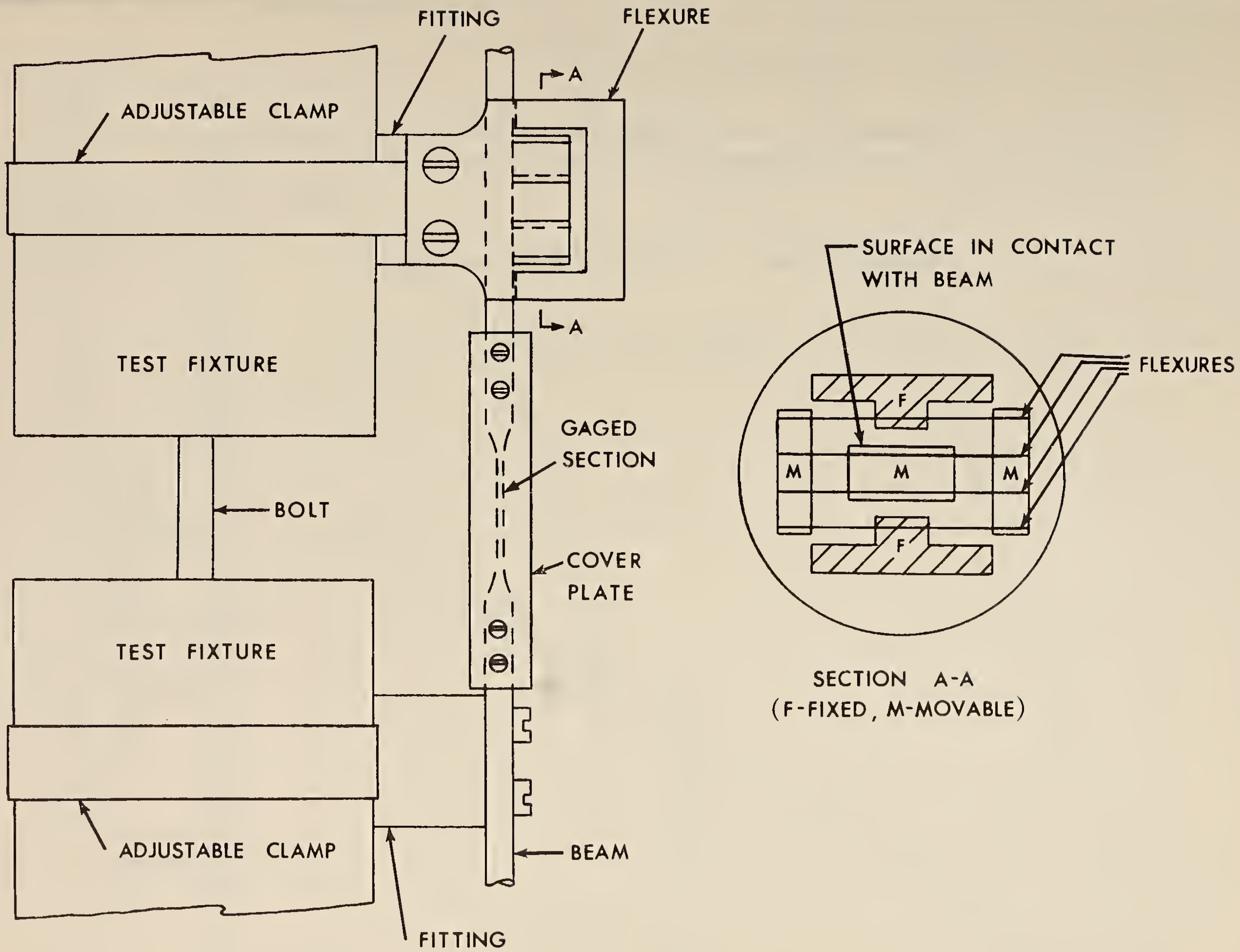

Figure 1 - Schematic of Misalinement Detector

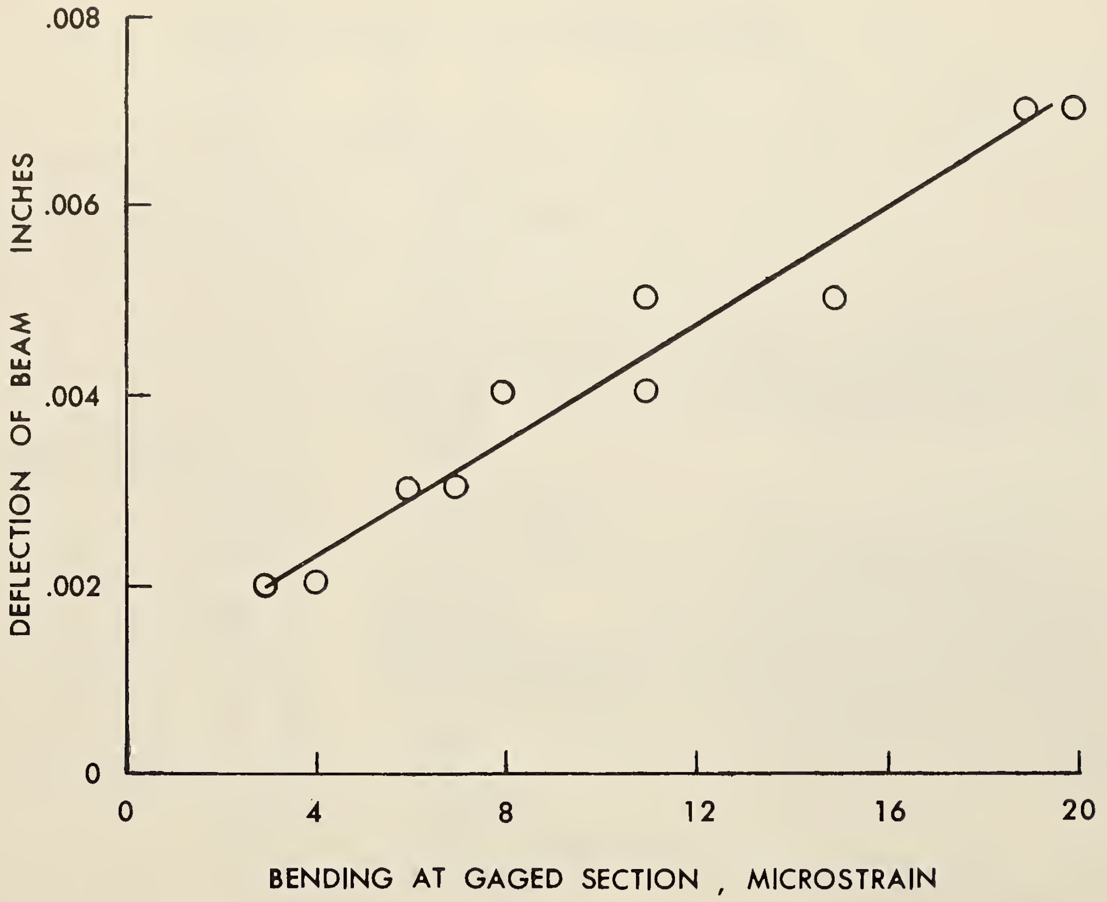

Figure 2 - Calibration Curve of Misalinement Detector for Deflection of Beam 5.0 in. (127 mm) from Gaged Section

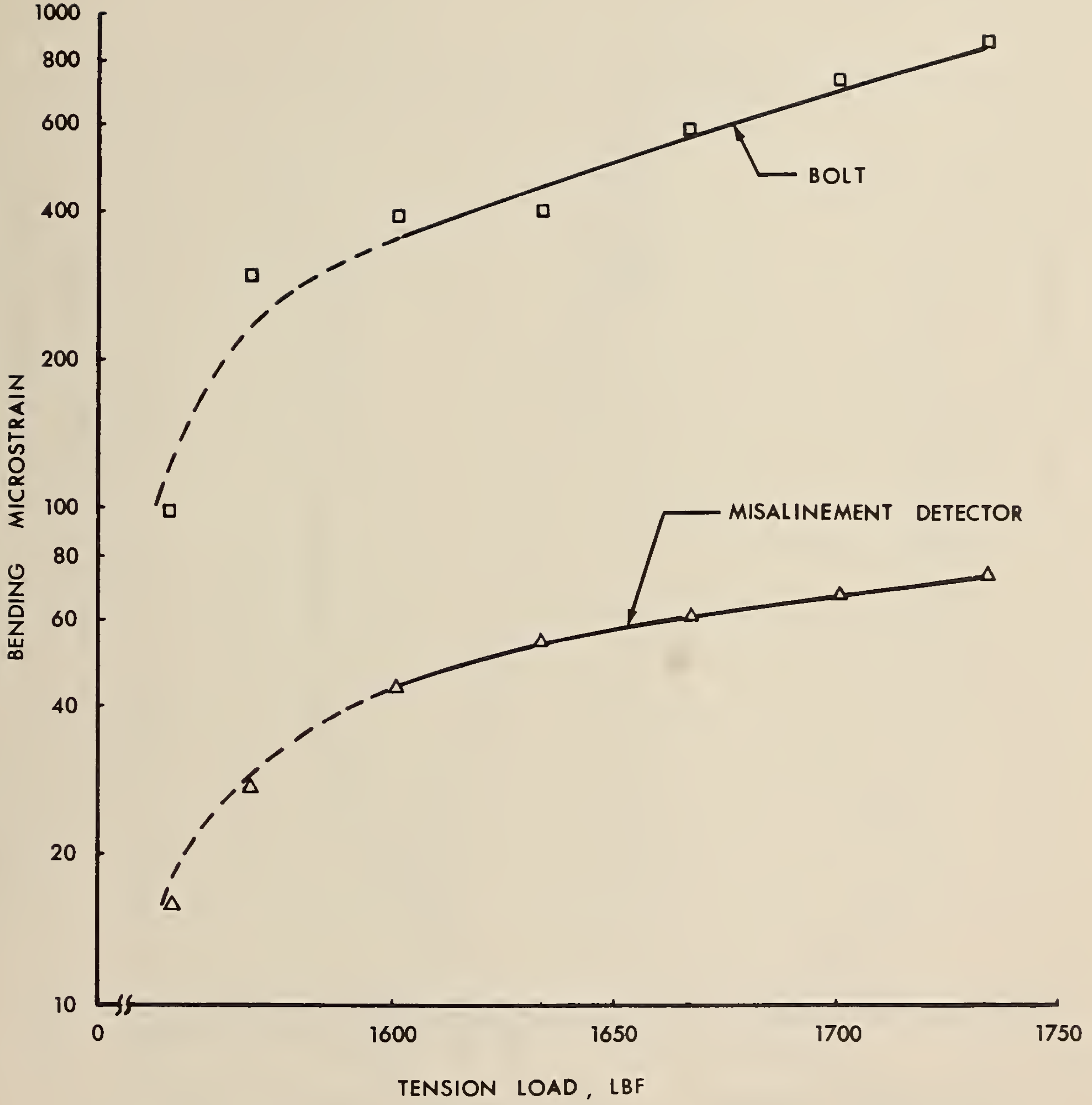

Figure 8 - Comparison of Bending in a Bolt with Bending Determined by Misalinement Detector.

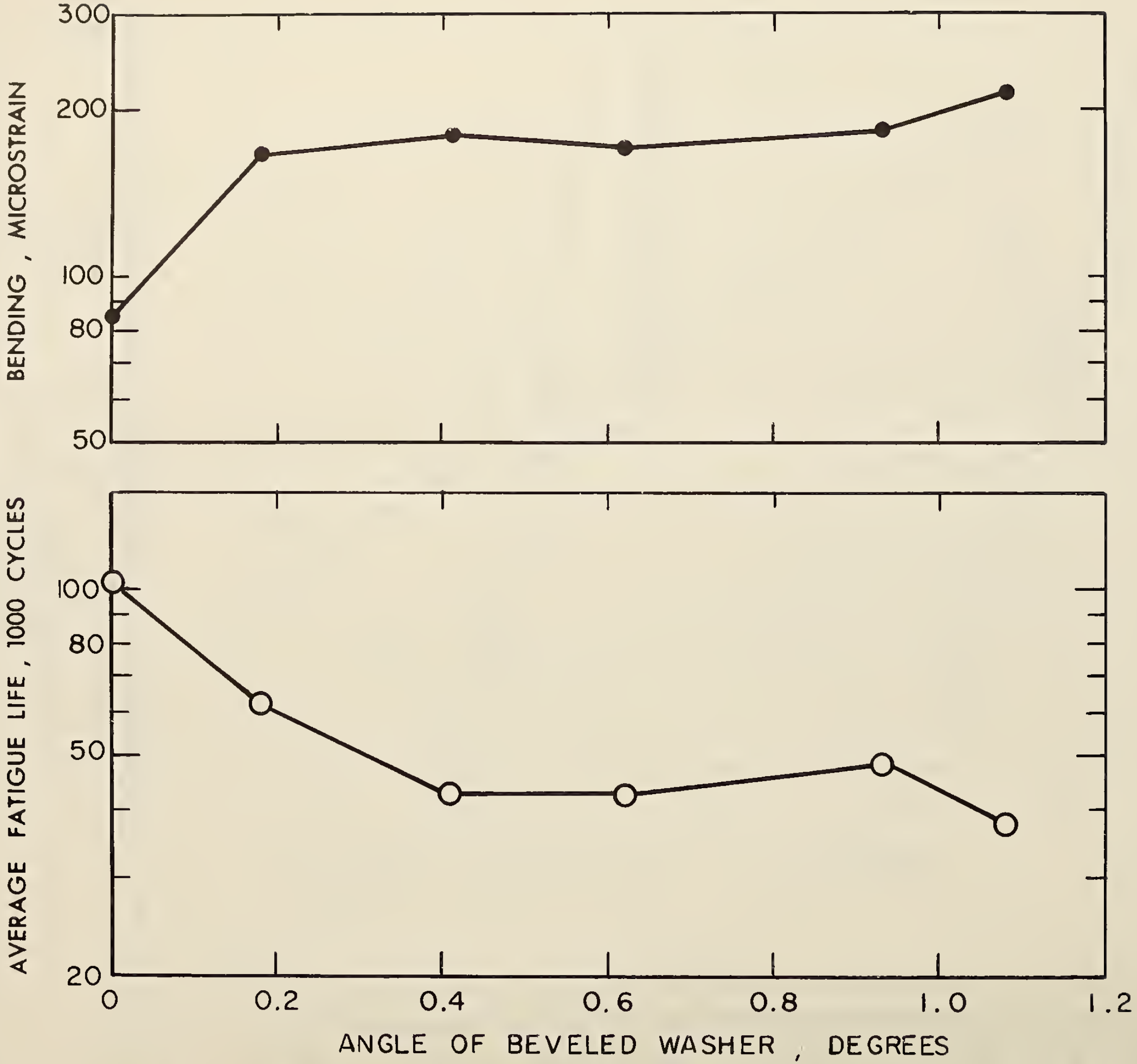

Figure 4 - Comparison of Bending Induced by Beveled Washers and Bolt Fatigue Life.

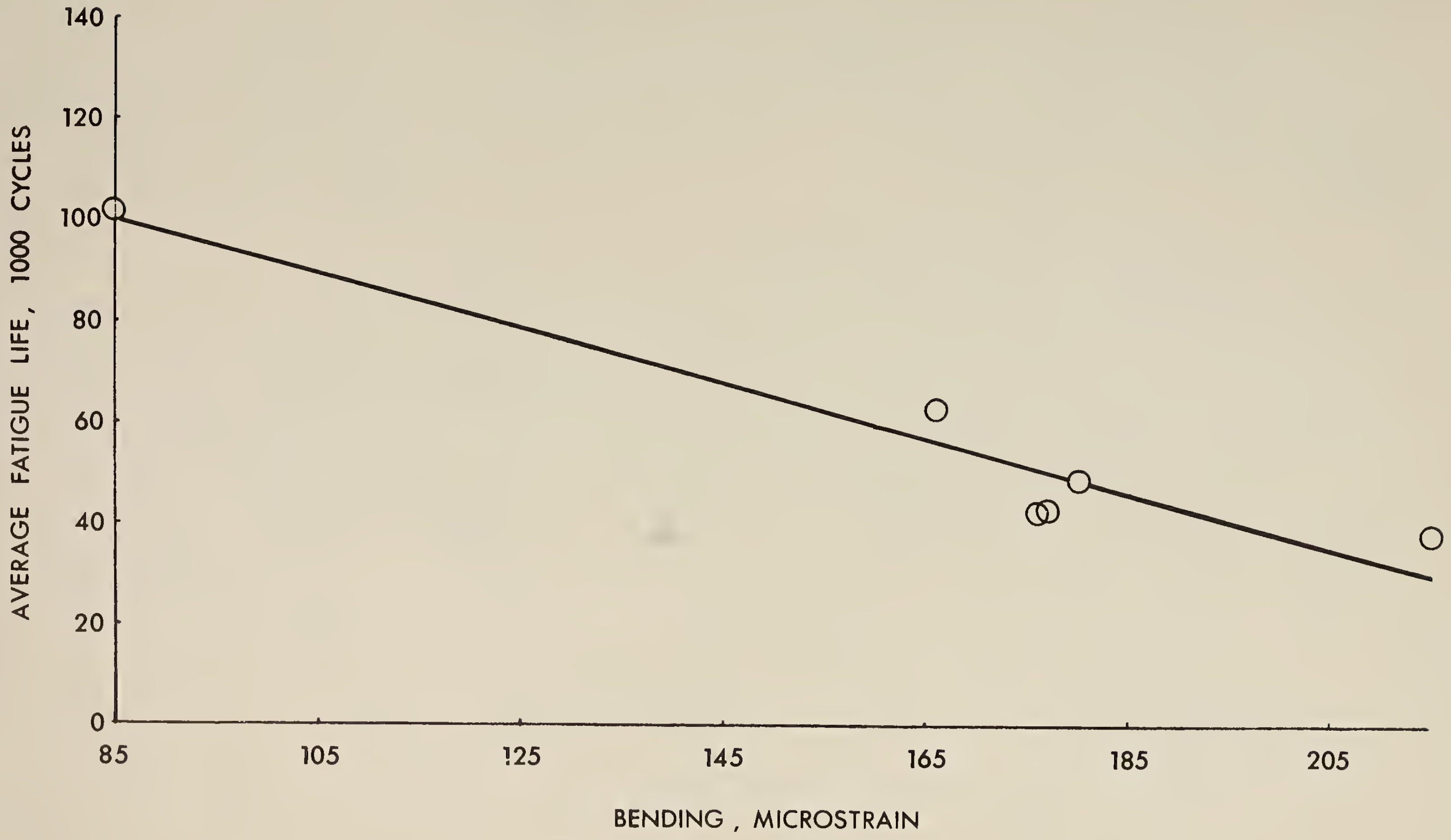

Figure 5 - Comparison of Bending Recorded by Misalinement Detector and Bolt Fatigue Life

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