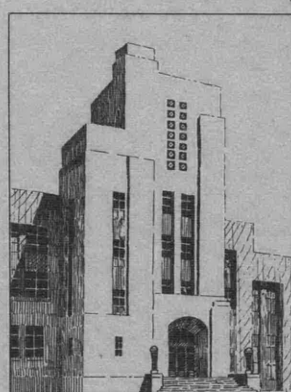
THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

FATIGUE TESTS OF DIESEL ENGINE PISTON RODS WITH AND WITHOUT SPRAYED METAL COATING

BY J. V. COOMBE



AUGUST 1942 RESTRICTED REPORT 493

THE DAVID W. TAYLOR MODEL BASIN

BUREAU OF SHIPS

NAVY DEPARTMENT

WASHINGTON, D.C.

RESTRICTED

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REPORT 493

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PERSONNEL

The tests were conducted and reported by J.V. Coombe, assisted by E.O. Berdahl.

DIGEST

The piston rods of the double-acting diesel engines of certain U.S. submarines have been found to require frequent replacement because of the wear and erosion resulting from friction in the stuffing boxes and corrosive action of the products of combustion.

A method of repairing the worn rods by turning them down and metal-spraying the surface with high-carbon steel has been developed and successfully used but there has been some apprehension that this treatment might adversely affect the fatigue strength of the rod.

A group of new piston rods of 0.35 carbon steel and heat-treated chrome-nickel steel, three uncoated and five metal-coated with 0.80 carbon steel, were tested to failure in the alternating-load testing machine at the David Taylor Model Basin. Figure 1 illustrates the shape and dimensions of the uncoated rod and Figure 20 shows the method of preparing the surface preparatory to metal-spraying the rod.

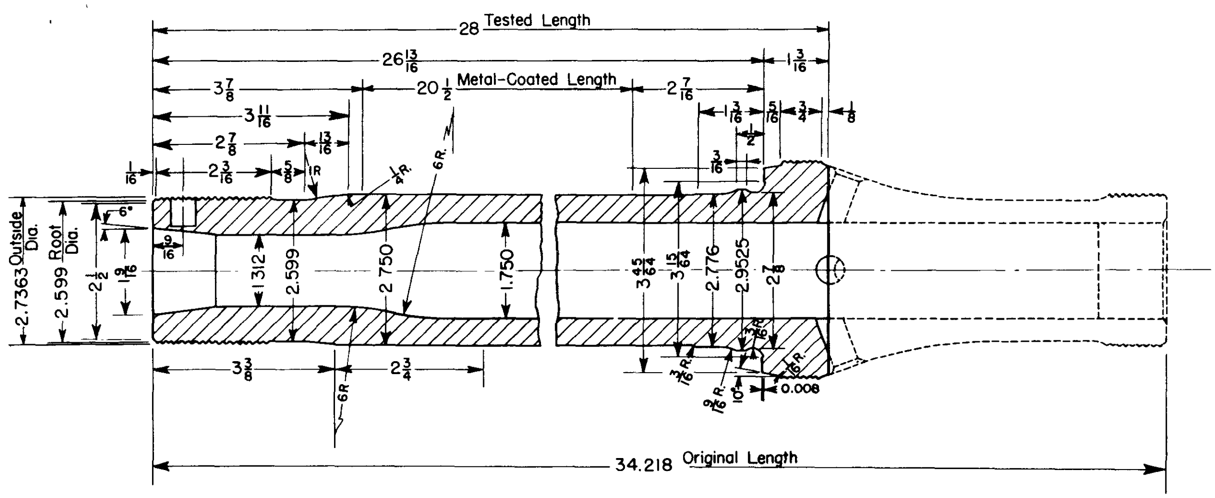

Figure 1 - Details of Specimen

The complete rod is outlined. The portion to the right, shown in broken lines, was removed before testing to facilitate gripping in the alternating-load machine.

The specified physical characteristics and chemical composition of the rods are given in Tables 1 and 2 on pages 2 and 3 of the report.

To facilitate holding the piston rods in the testing machine, the piston ends were cut off as shown in Figure 1. Two piston ends were then clamped together by a pair of bolted plates, as shown in Figure 8, and two rods were tested at once. The crosshead ends of the rods were attached to crossheads of the type used in the engines, and the forces from the testing machine were delivered through the wrist pins.

The rods were loaded alternately in tension and compression at a rate of 250 cycles per minute with stresses in each direction from 25 to 50 per cent in excess of the designed maximum operating stresses.

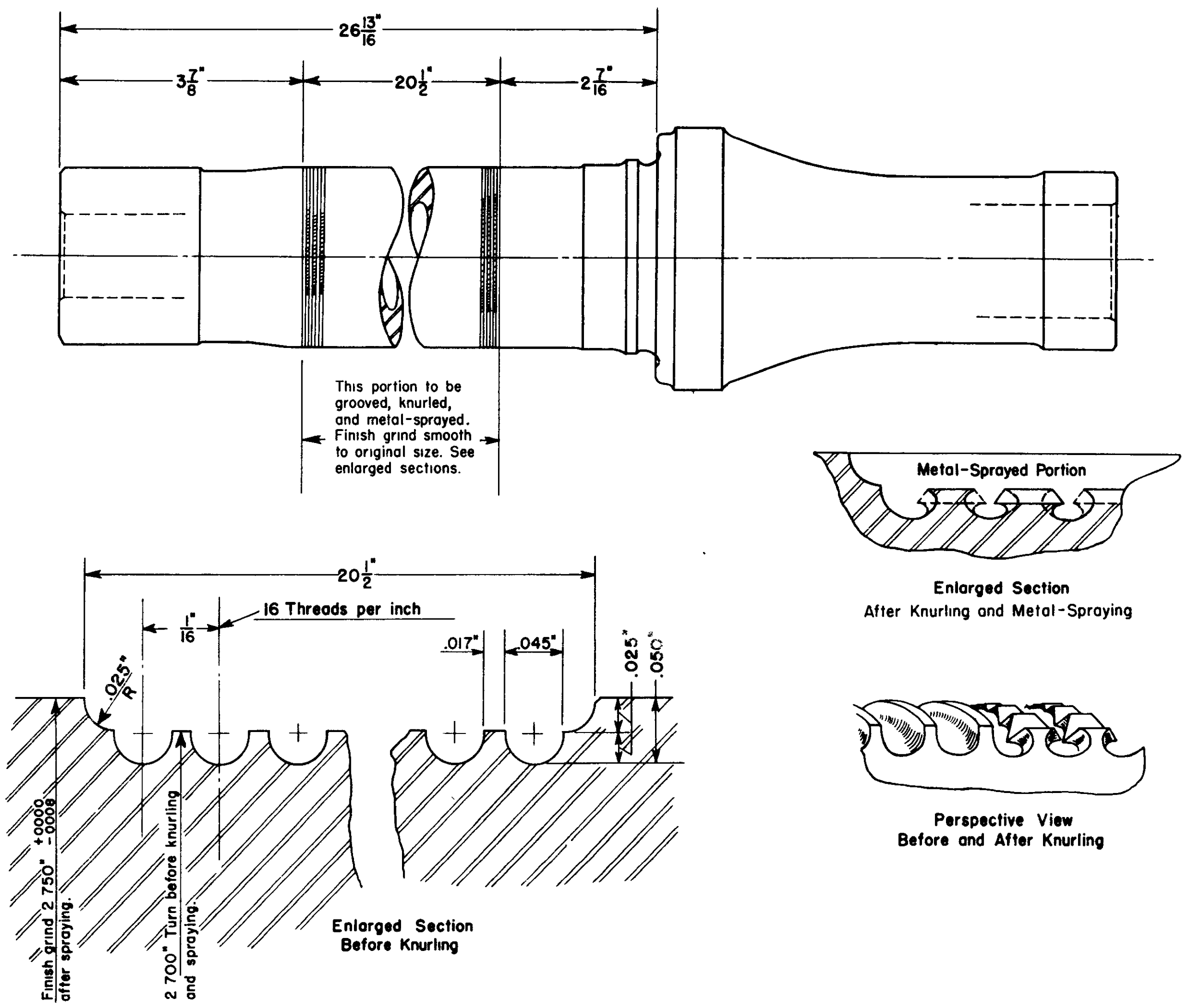

Figure 20 - Sketch showing Preparation and Details of Metal-Coated Rods

The section of the rod to be metal-coated was first turned to a diameter of 2.700 inches. It was then prepared for bonding the metal coat by cutting 16 threads to the inch with a round-nosed tool. The threads were then knurled to increase the bonding effect.

Strain measurements taken on the rods near the piston ends showed that there was little or no eccentric loading but the method of clamping the piston ends caused fractures in all rods but one to occur in a fillet normally inside the lower piston head, instead of in the metal-coated region as was expected. See Figure 15.

The tests, while not as conclusive as had been hoped, at least demonstrated that the rods would not fail in the metal-coated sections under the alternate tension and compression overloads applied, and justified a recommendation that used piston rods for double-acting diesel engines be reclaimed by the metal-coating process.

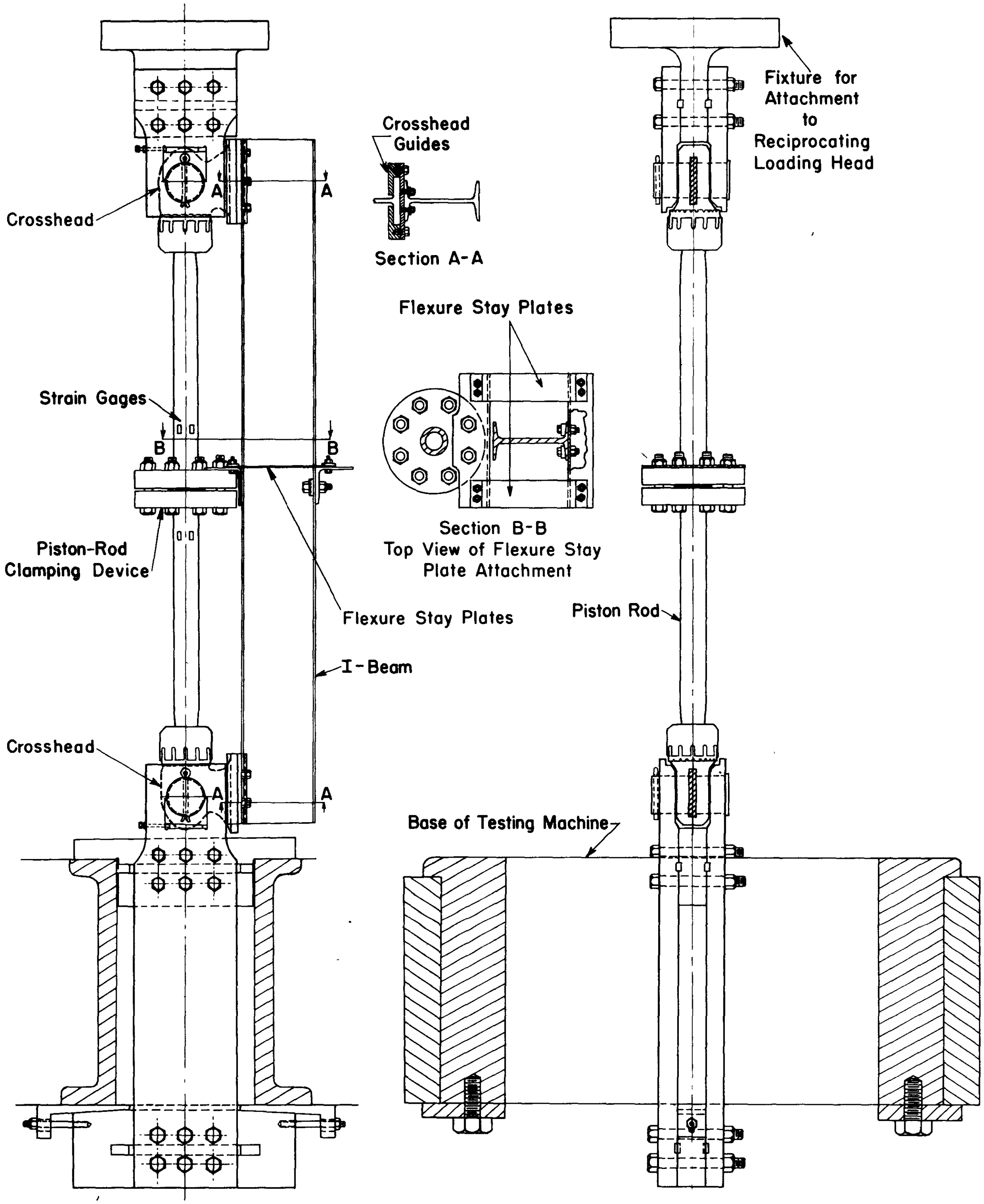

Figure 8 - Sketch of Rig for Testing Rods in Alternating-Load Testing Machine

Two rods were clamped together at the piston ends and were tested at the same time. Details of the clamping are shown in Figure 11 of the report. The crossheads were constrained to move in a straight line by having the slippers move in guides bolted to an 8-inch I-beam. The rods were attached to this beam at the center through flexure stay plates which provided support against column buckling.

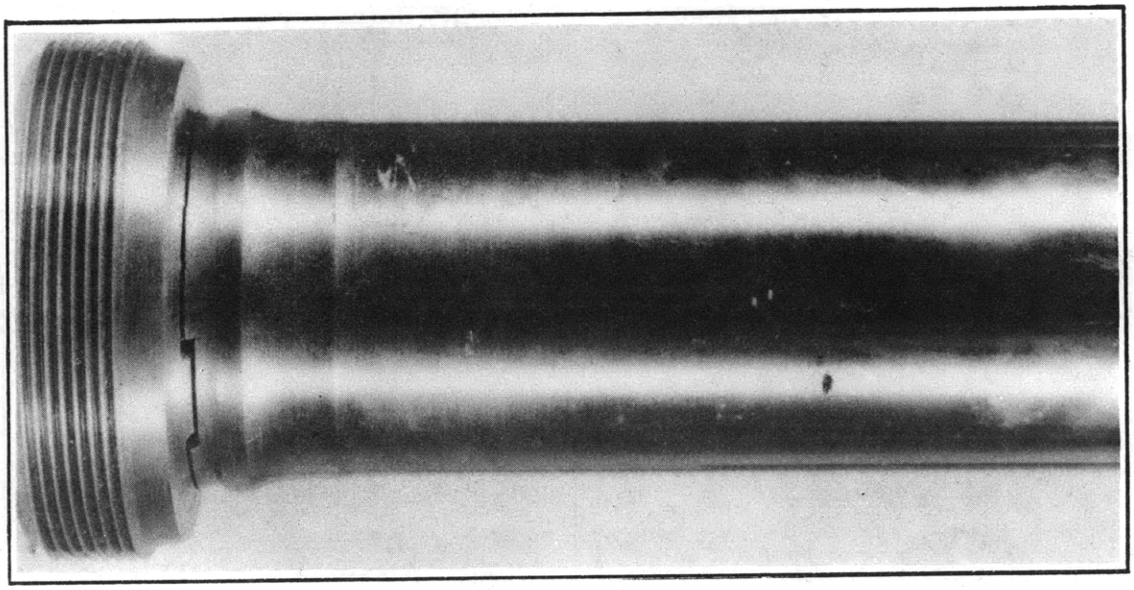

Figure 15 - Specimen N2 after Failure

Failure occurred after 243,232 cycles at a nominal stress range from 22,000 pounds per square inch tension to an equal compression. This failure is typical of most of the rods tested. In general the fatigue cracks followed circumferential tool marks visible before the fatigue tests began.

FATIGUE TESTS OF DIESEL ENGINE PISTON RODS WITH AND WITHOUT SPRAYED METAL COATING

ABSTRACT

Fatigue tests were made on eight diesel engine piston rods, three of which were unused rods of heat-treated 0.35 per cent carbon steel without metal coating, three were unused rods of the same steel with a metal coating of high-carbon steel, and two were used rods of heat-treated chrome-nickel steel with a metal coating of high-carbon steel.

The specimens were loaded axially, as they would be in service, with end connections corresponding to those in the engines. Static strain measurements were taken to determine the distribution of stress.

Since in no case did failure occur in the metal-coated portion of the rod, it is concluded that the endurance strength of the specimen was governed by the stress-raising effect of the fillet rather than by any stress raising due to the grooving and metal-spraying.

INTRODUCTION

In certain classes of U.S. submarines, including the SALMON, SEAL, and SKIPJACK, double-acting diesel engines are installed. The piston rods of these engines slide back and forth in the stuffing box through the head of the lower combustion chamber for a distance of about 20 1/2 inches. This service subjects the rod both to wear from friction and to corrosion from the products of combustion, and the rods require frequent replacement. The worn surface of the rods removed was sometimes repaired by spraying with high-carbon steel, and while tests showed that repairs made in this manner produced good wearing qualities, there was some apprehension that this treatment might adversely affect the fatigue strength of the rod.

The present investigation was authorized by the Bureau of Ships (1)* to determine whether or not this treatment reduces the fatigue strength of the rods.

Fatigue tests were conducted on eight rods, each of which was subjected to an axial stress which varied from a specified tension to an equal compression. All tests were carried to failure.

DESCRIPTION OF SPECIMENS AND TESTS

The details of the specimens used in the tests are shown in Figure 1. The rods which were submitted were completely finished, but since the part to be tested was that portion to the left of the large diameter, the section shown in broken lines at the right in Figure 1 was carefully removed and the end surface was ground normal to the axis of the rod.

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* Numbers in parentheses indicate references on page 18 of this report.

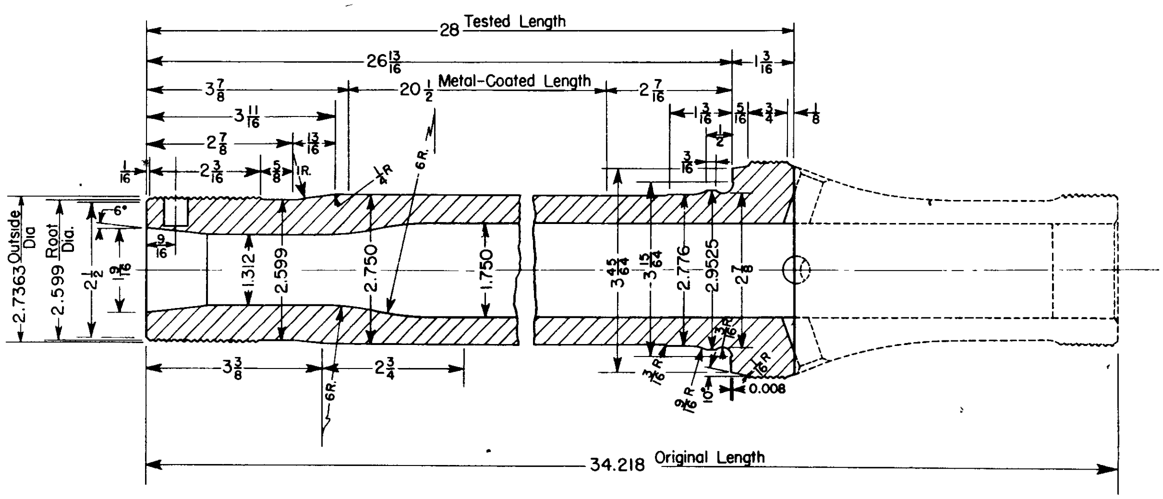

Figure 1 - Details of Specimen

The complete rod is outlined. The portion to the right, shown in broken lines, was removed before testing to facilitate gripping in the alternating load machine.

TABLE 1

Specified Physical Properties of Piston Rods

CARBON STEEL RODS - Specimens N1, N2, N3 and NMC1, NMC2, NMC3*	
Ultimate Strength	80,000 pounds per square inch
Yield Point	55,000 pounds per square inch
Elongation	25 per cent in 2 inches (minimum)
Reduction of Area	55 per cent (minimum)
Brinell Hardness Number	190-230

Forging and Heat-Treatment:

Use 6-inch billet. Hammer to 4 7/8-inch diameter on head and 3 5/8-inch diameter on stem. Heat-treat to give physical characteristics specified on Bureau of Engineering Drawing SS253-S41-45 Alt. 2.

CHROME-NICKEL STEEL RODS - Specimens UMC1 and UMC2	
Ultimate Strength	95,000-110,000 pounds per square inch
Yield Point	60,000-80,000 pounds per square inch
Elongation	26 per cent in 2 inches
Reduction of Area	55 per cent
Brinell Hardness Number	200-240
Izod Impact	70 foot-pounds (minimum)

Forging and Heat-Treatment:

Electric furnace steel. Use 6-inch billet. Hammer to 4 7/8-inch diameter on head and 3 5/8-inch diameter on stem. Heat to 1550° F, quench in oil, draw to 1325° F then rough-turn and draw at 1100° F, Bureau of Engineering Drawing SS182-S41-010 Alt. 0.

* The symbol N designates a rod not coated; NMC a new rod that has been metal-coated; and UMC a used rod that has been coated.

TABLE 2

Chemical Composition of Piston Rods

All numerical values indicate per cent.

CARBON STEEL RODS - Specimens N1, N2, N3 and NMC1, NMC2, NMC3		
	Specified	Actual*
Carbon	0.30 to 0.40	0.32
Manganese	0.60 to 0.90	0.89
Phosphorus	0.04 maximum	0.046
Sulphur	0.035 maximum	0.025
Silicon	0.15 to 0.30	0.15
CHROME-NICKEL STEEL RODS - Specimens UMC1 and UMC2		
	Specified	Actual*
Carbon	0.37 to 0.42	0.42
Nickel	1.50 to 2.00	1.73
Chromium	0.50 to 0.80	0.89
Manganese	0.50 to 0.80	0.91
Silicon	0.35 maximum	0.15
Sulphur	0.035 maximum	0.022
Phosphorus	0.04 maximum	0.021
Molybdenum	0.20 to 0.40	0.27

* The actual chemical properties were determined by analysis made at the Washington Navy Yard (2).

The physical and chemical properties of the rods are given in Tables 1 and 2.

The rods were finished to a smooth surface, but close inspection revealed tool marks near the ends as shown in Figures 2, 3, and 4, despite the note on the shop drawing calling for a polish on the large-angle 3/16-inch-radius fillet. The metal-coated rods usually had a rough junction where the metal coating joined the bare surface, as shown in Figures 3, 4, 5, and 6. Figure 7 shows two complete specimens as altered for testing.

The chrome-nickel steel rods, reclaimed and metal-coated and designated as UMC1 and UMC2, were subjected to the same metal-coating treatment as described for Specimens NMC1, NMC2, and NMC3 in Appendix 1.

The rods were tested in the 150,000-pound alternating-load testing machine at the David W. Taylor Model Basin.* It was necessary to design and build a special rig for these tests, as shown in Figures 8 and 9. The clear distance between the yokes was sufficient to test two specimens at one time.

* See Appendix 2, page 21, for description of the machine.

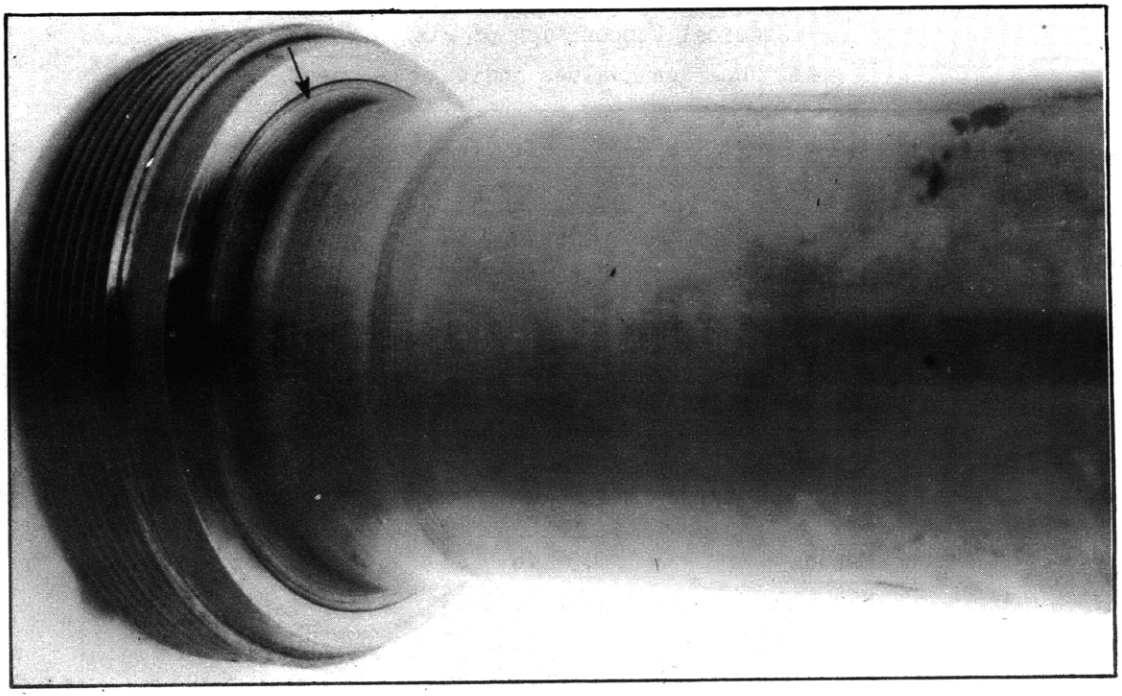

Figure 2 - Piston End of Specimen without Metal Coating before Testing

Note the deep tool marks, especially in the bottom of the radius where the rod flares out. These tool marks are perpendicular to the direction of loading and probably cause local regions of high stress.

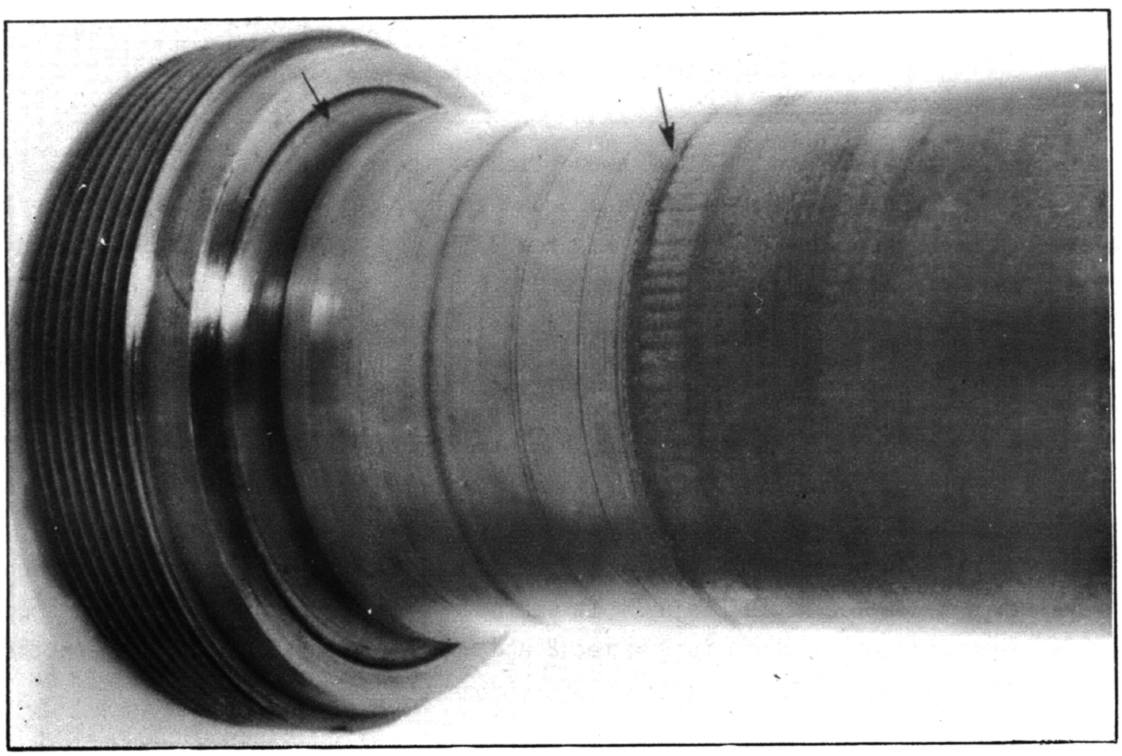

Figure 3 - Piston End of Metal-Coated Specimen before Testing

Note the tool marks as in Figure 2; also the gouge in the metal coating at the top.

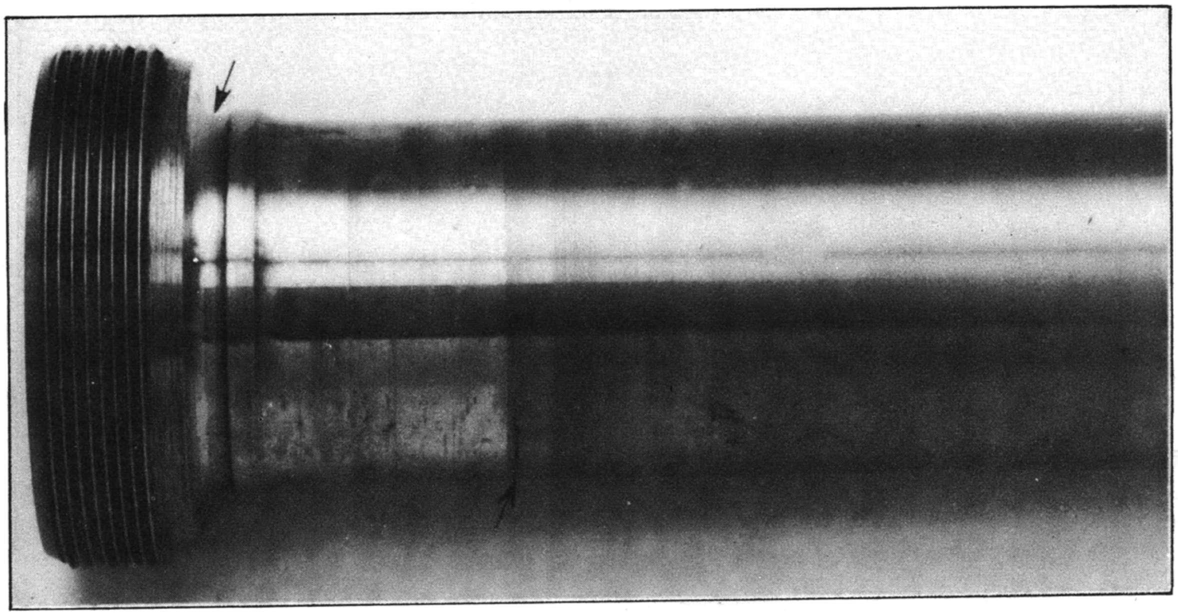

Figure 4 - Piston End of Metal-Coated Rod before Testing

Note the gouge in the metal coated surface. The first fatigue crack developed in the fillet, however, rather than in the gouge.

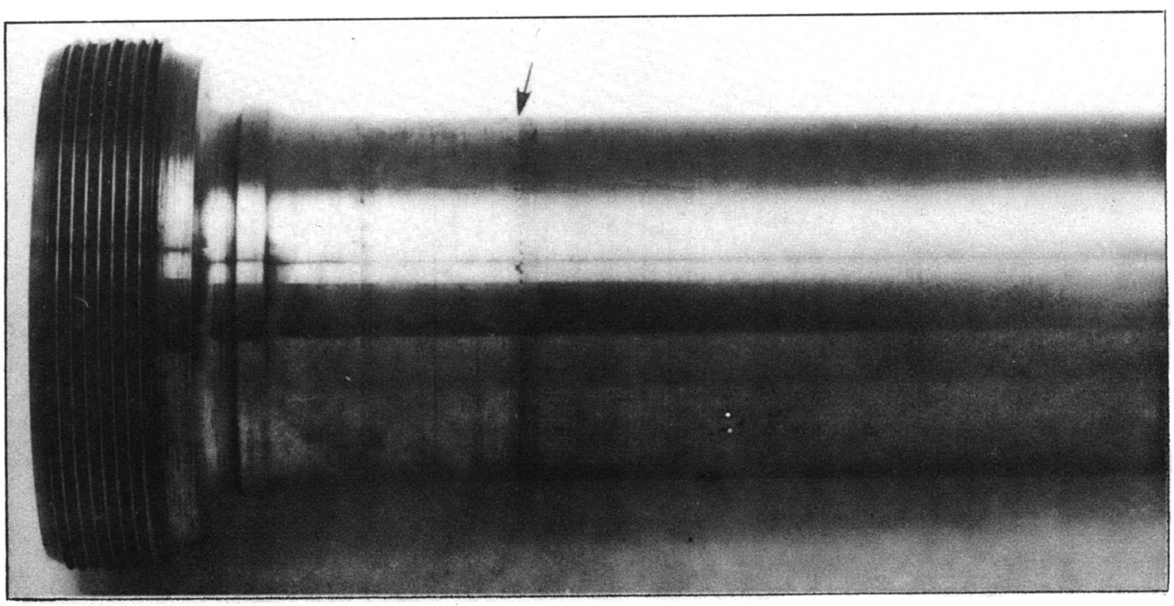

Figure 5 - Piston End of Metal-Coated Rod before Testing

Note the improper finish at the junction of the metal coating and the bare rod.

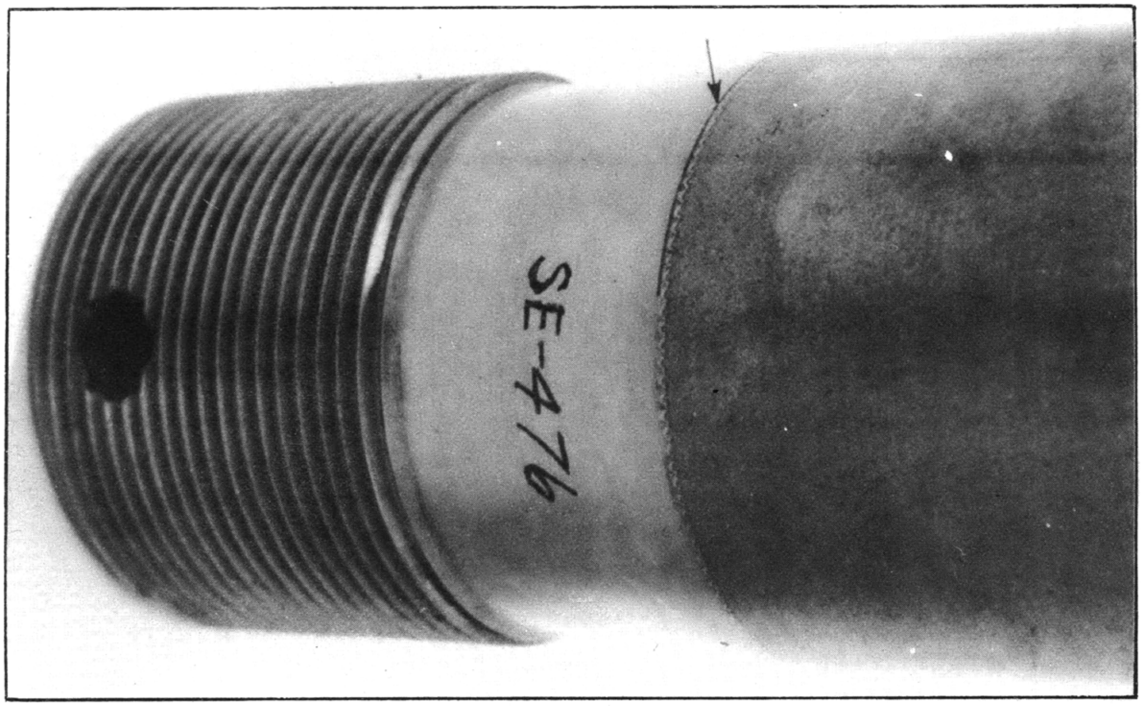

Figure 6 - Crosshead End of Metal-Coated Rod

Note the gouge, knurling, and tool marks. This rod actually failed at the root of the thread as shown in Figure 16.

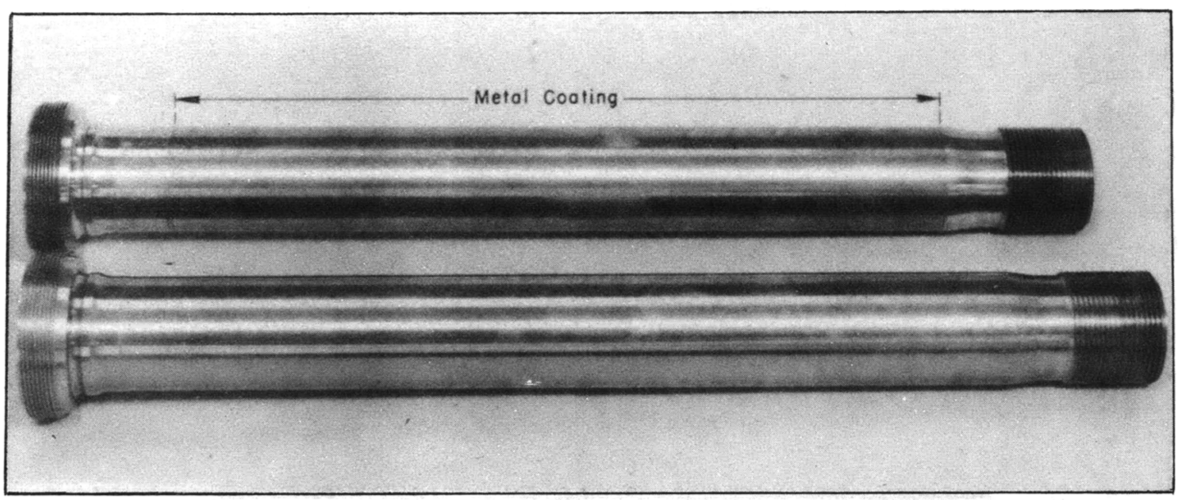

Figure 7 - Specimens as Altered for Testing

The specimen at the bottom is a new rod of the N series without metal coating. The one at the top is a new metal-coated rod of the NMC series. The metal coating is easily distinguishable by its darkened color.

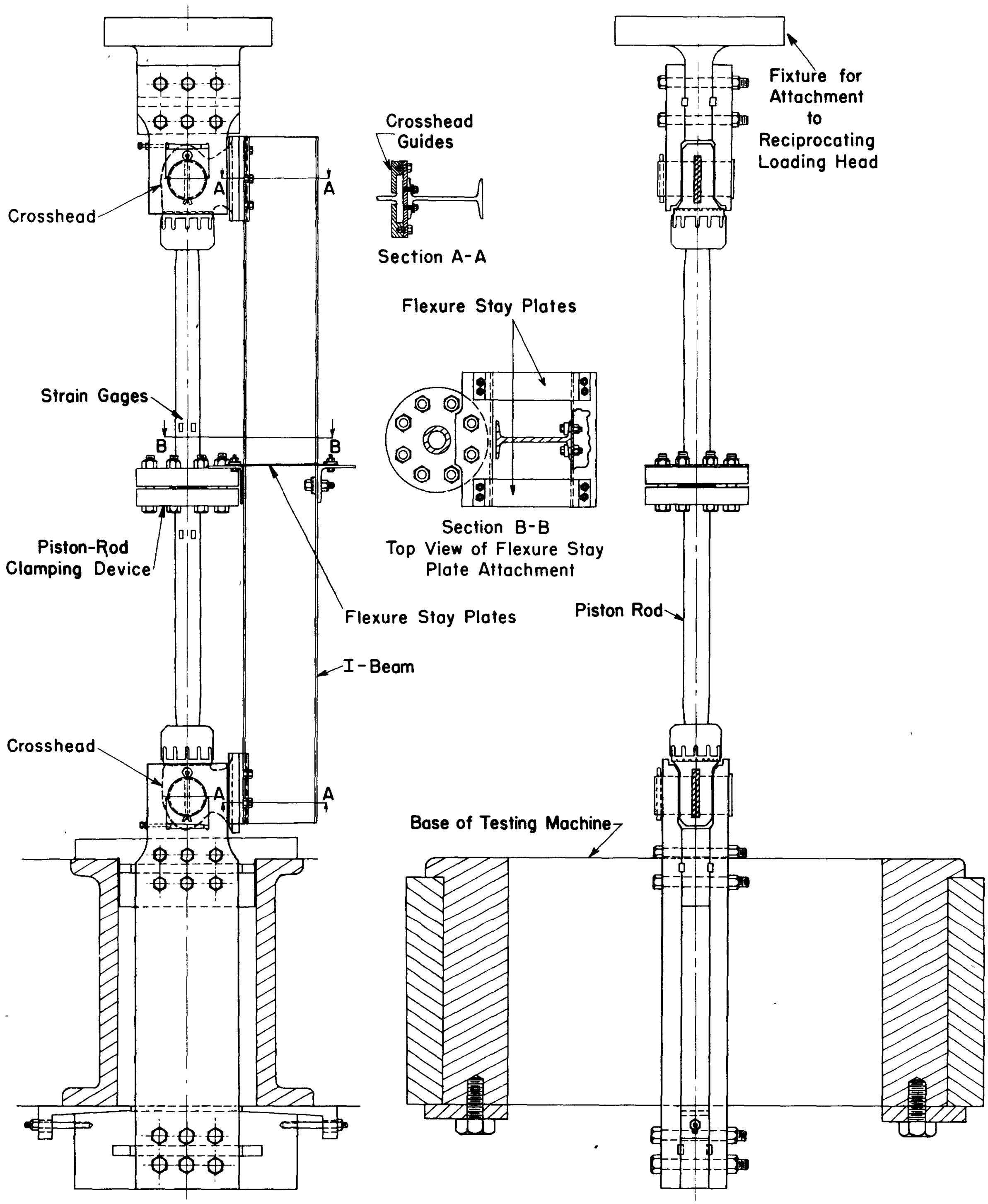

Figure 8 - Sketch of Rig for Testing Rods in Alternating-Load Testing Machine

Two rods were clamped together at the piston ends and were tested at the same time. Details of the clamping are shown in Figure 11. The crossheads were constrained to move in a straight line by having the slippers move in guides bolted to an 8-inch I-beam. The rods were attached to this beam at the center through flexure stay plates which provided support against column buckling.

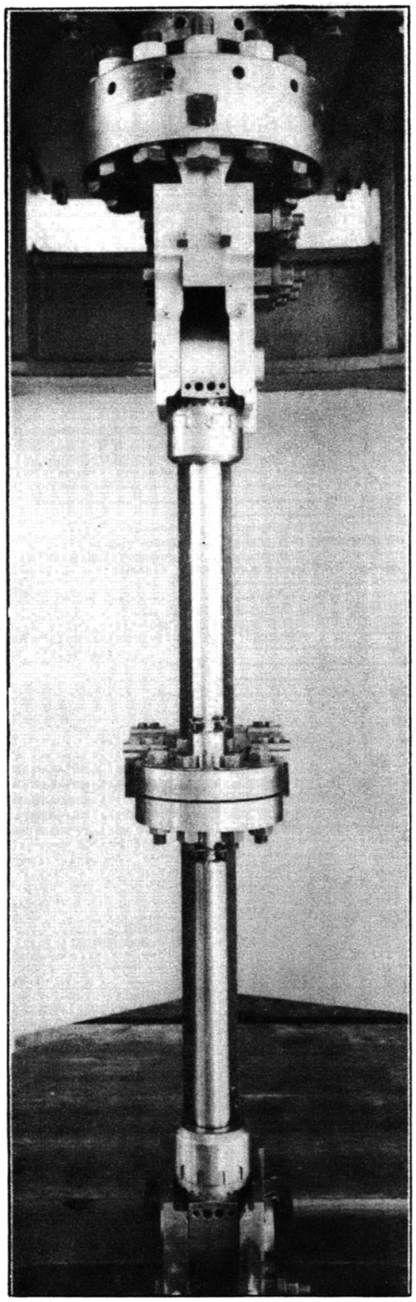

Figure 9 - Photograph showing Two Rods set up in Alternating-Load Testing Machine ready for Test

The I-beam support is behind the rods. Note the flexure stay plates on each side connecting the I-beam to the heavy disks at the center. The four small dark objects, two above and two below the heavy disks, are Tuckerman optical strain gages.

The crosshead ends of the rods were held exactly as they would be in the engine, in order that working conditions might be duplicated as nearly as possible. Crossheads were procured from the manufacturer for this purpose. The crossheads were held in place by wrist pins through the yokes, and were free to turn slightly on the pins. The crossheads were designed by the engine builder so that moment due to rocking of the crosshead would not be transmitted into the rod, by building a spherical seat into the crosshead. A spherical brass nut was screwed onto the piston rod and was fitted into the seat. A large cover nut held the assembly together. The disassembled crosshead, nut, and rod are shown in Figure 10.

Unfortunately, the great pains taken to duplicate service conditions at the crosshead end of the piston rods were not maintained sufficiently at the piston end of the rods.

The Bureau of Ships directive (1) on this project stated that "If it is so desired the excess length at the right (piston) end may be cut off." Taking advantage of the available space between the loading heads of the testing machine, and of the Bureau authorization, the Model Basin cut off the rod inside the piston as shown in Figure 1, carefully squared and ground the ends, and clamped the piston ends of two rods together by the heavy disks shown in Figure 11.

To prevent the adjacent rod ends from separating and hammering during the test, it was necessary to apply an initial compressive load on the rod ends, by the disks and bolts, greater than the maximum tension load expected during any part of the test. This load was applied wholly on the flat end of the enlarged portion, and it resulted in an initial compressive stress in the metal under this surface greater than the stress would have been if the two rod ends had not been clamped together and the assembly had been put under tension.

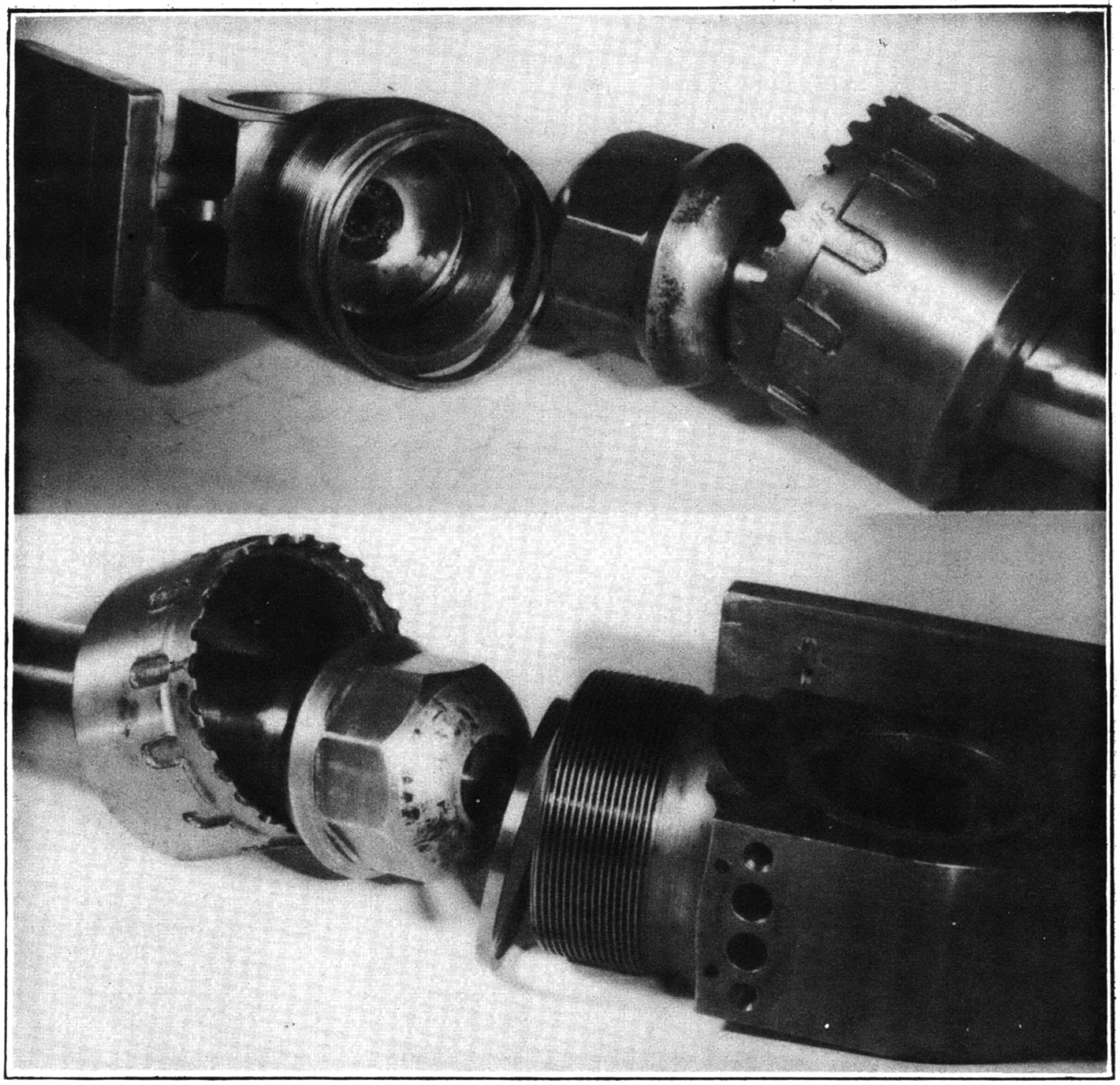

Figure 10 - Photographs of Disassembled Crosshead and Crosshead End of Rod showing Spherical Nut and Seat

This arrangement permits rotation of the rod with reference to the crosshead without imposing a bending moment on the rod.

A glance at Figure 12 will show that the holding arrangement at the right, corresponding to Figure 11, departed in several essential respects from the arrangement in the engine, shown at the left.

In the first place, the piston of the engine bears against the rod not only on the flat surface at the bottom of the enlarged section but against a tapered neck and an enlarged section just below the large fillet. As the load on the lower head of the piston is practically always upward, the metal inside the threads is subjected only to the compression developed by screwing the piston on the rod. The upward

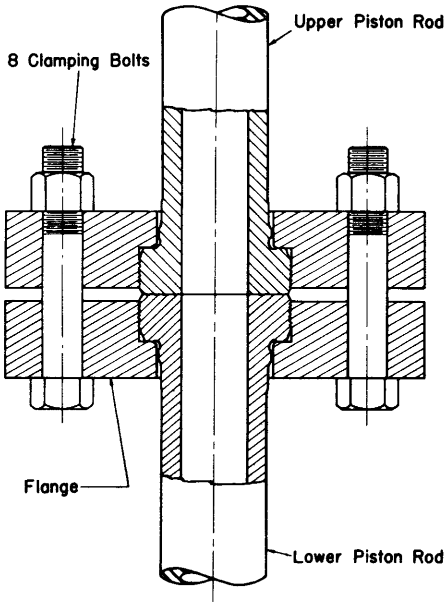

Figure 11 - Section showing the Piston Ends of the Rods clamped together during a Test

The large ends of the rods were threaded into the counterbored recesses in the plates.

thrust of the piston is transferred to the rod partly through the tapered neck and partly through the flat portion above it; these parts were undoubtedly designed to prevent any appreciable deformation between them.

However, in the test assembly of Figure 12b, all the upward load exerted by the disk is taken by the flat face alone. Despite the relatively large radius of the fillet there must be excessive deformation in this region, especially in view of the great disparity in section areas above and below the fillet.

The test arrangement of Figure 12b was approved by the Bureau of Ships before the tests began. After fracture of the first rod in the bottom of the large fillet, a conference was held with Bureau representatives, at which time it developed that the

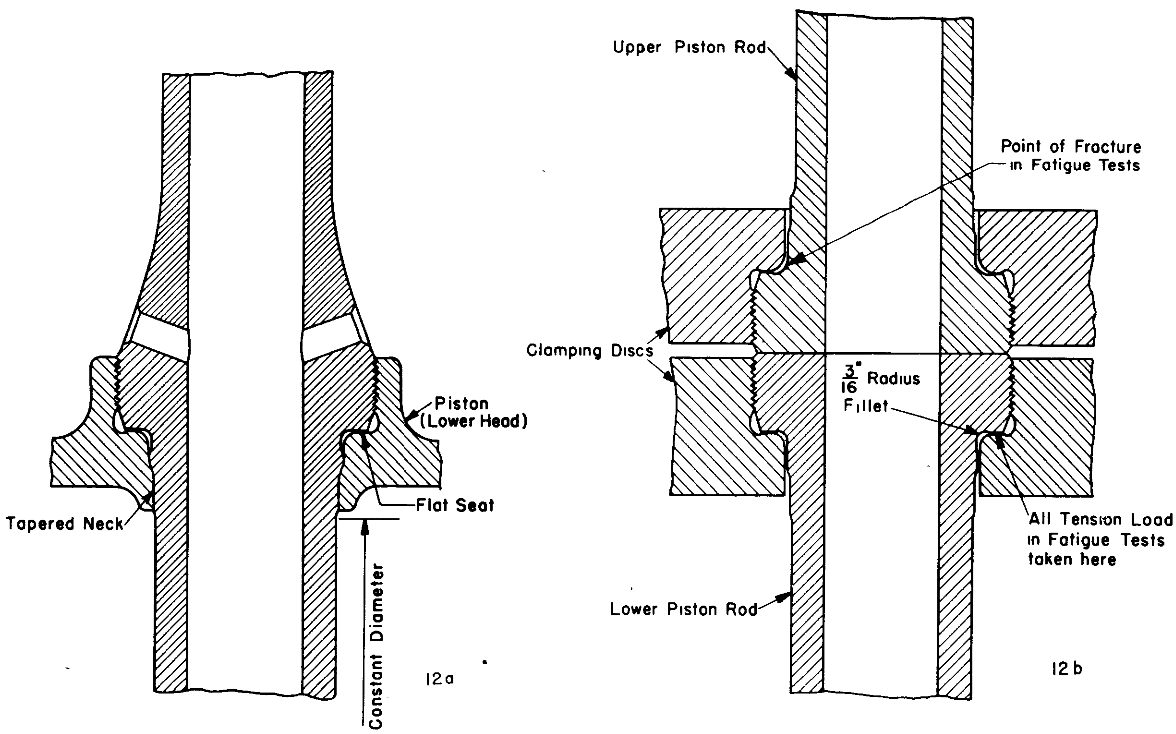

Figure 12 - Methods of Clamping Piston End of Rod in Engine and in Test

The method of attaching the lower piston head to the rod is shown at the left; the head bears against a tapered neck as well as against a flat seat.

engine conditions were not being accurately represented, as outlined in the paragraphs preceding. It was decided, however, to continue the tests with the apparatus already built.

STRAIN MEASUREMENTS

To check the uniformity of strain distribution in the section, Tuckerman gages were mounted 90 degrees apart as shown in Figures 8 and 13; these can also be seen in Figure 9 near the disks. Static load was applied to the specimens by turning the testing machine over manually, and strain readings were then taken for upper and lower peak loads.

After the stress distribution had been measured statically, the specimens were subjected to alternate tension and compression loads applied at the rate of 250 cycles per minute. Tests were interrupted only to shut down for the night or to inspect and repair the testing machine. All tests were carried to failure of the specimen.

In service the maximum pressure against the piston, as obtained from indicator cards, produces an average calculated stress in the rod of about 18,000 pounds per square inch. Since there was no record of fatigue failures in service even after many millions of load cycles had taken place, it was decided to test the first rods at a stress considerably above normal working stress. Specimens N1 and NMC1 were accordingly placed in the machine and the machine was adjusted to produce an alternating tension and compression stress of 27,500 pounds per square inch in the uncoated rod, Specimen N1. It was suspected, and later confirmed by strain data, that the metal coating does not carry any appreciable stress. Consequently the stress in Specimen NMC1 should be computed on the actual diameter of the rod, 2.65 inches, at the bottom of the recess machined to receive the coating and the metal in the coating should be neglected. Thus the maximum stress in the body of the coated rod is about 13 per cent greater than the stress in the uncoated rod for the same load. In service, the same load is applied to all rods, regardless of their condition. To make the present tests comparable with service conditions, the stresses are therefore calculated on nominal outside diameters.

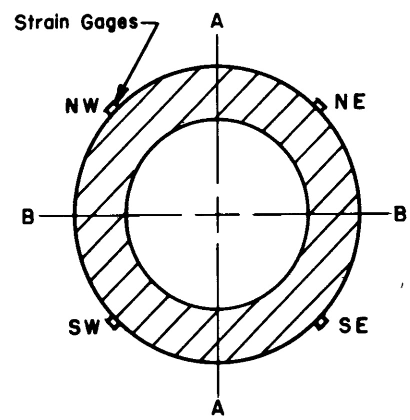

Figure 13 - Cross-Section of Rod with Tuckerman Strain Gage Stations and Principal Bending Axes

Axis A-A would be the neutral axis of any bending which might be introduced by the slight linear displacement due to rocking of the loading head of the testing machine about its pivot.

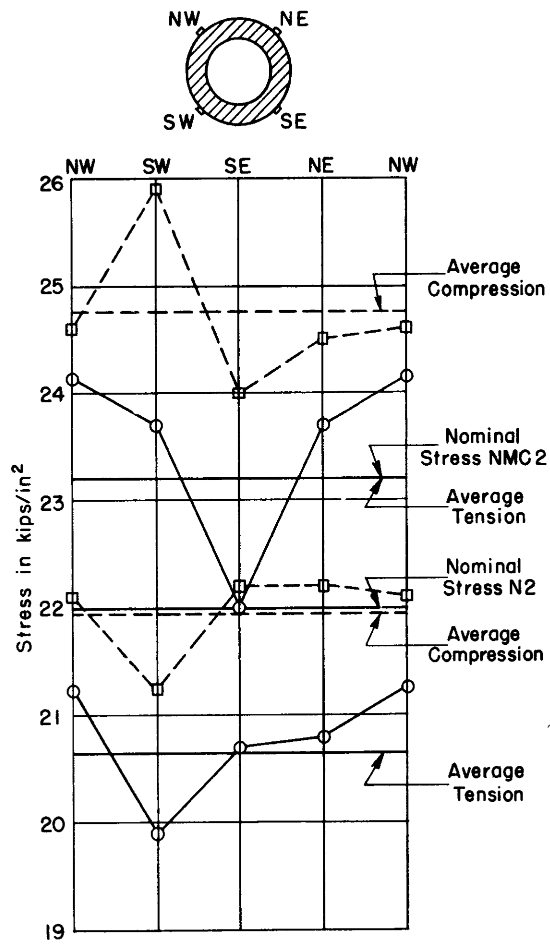

Figure 14 - Distribution of Stresses around the Circumference of Specimens N2 and NMC2

The stresses are derived from Tuckerman strain gage data. An elastic modulus of 30 x 10^6 pounds per square inch was assumed.

TEST RESULTS

STATIC TESTS

The results of the static measurements of distribution of stress about the circumference of the rods are given in Table 3; these results are shown graphically in Figure 14. The accuracy of the strain measurements taken on the metal-coated rods is open to question since the coating itself does not carry an appreciable stress. The variation is somewhat greater on the coated rod than on the uncoated one and is not in the same direction at corresponding points. This deviation is small in comparison with measurements made on other testing machines used for similar tests (3). The maximum deviation from the average, however, does not in any case exceed 5 per cent.

FATIGUE TESTS

Specimens N1 and NMC1 were subjected to an alternating load which produced a nominal stress varying from 27,500 pounds per square inch tension to the same stress in compression. Both specimens failed in the radius at the piston end of the rod, in the location indicated in Figure 15. N1 failed at

TABLE 3

Stress Distribution under Static Load
Stresses are expressed in kips per square inch*

Specimen	Average Stress			NE		NW		SW		SE	
	P/A		Measured	Measured	Departure from average per cent	Measured	Departure from average per cent	Measured	Departure from average per cent	Measured	Departure from average per cent
N2	Tension	22.00	20.66	20.8	0.7	21.25	2.85	19.9	3.66	20.7	0.2
	Compression	22.00	21.94	22.2	1.18	22.1	0.73	21.25	3.14	22.2	1.18
NMC2	Tension	23.400	23.39	23.7	0.9	24.15	2.9	23.7	0.9	22.0	5.95
	Compression	23.400	24.75	24.5	1.0	24.6	0.6	25.9	4.65	24.0	3.16

* Measured stresses were derived from Tuckerman strain gage data.
An elastic modulus of 30 x 10^6 pounds per square inch was assumed.

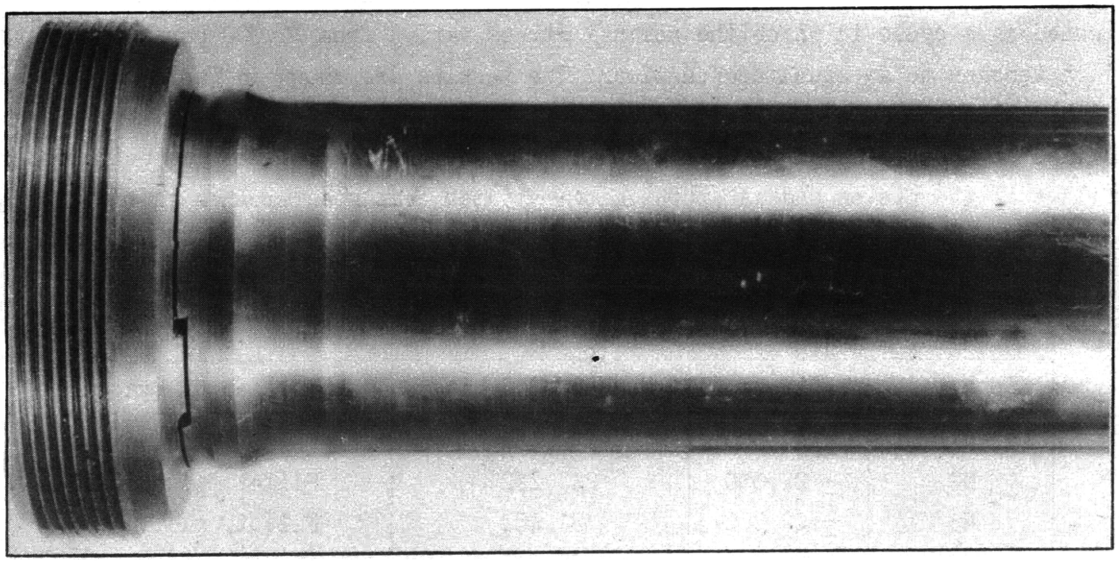

Figure 15 - Specimen N2 after Failure

Failure occurred after 243,232 cycles at a nominal stress range from 22,000 pounds per square inch tension to an equal compression. This failure is typical of most of the rods tested. In general the fatigue cracks followed circumferential tool marks visible before the fatigue tests began.

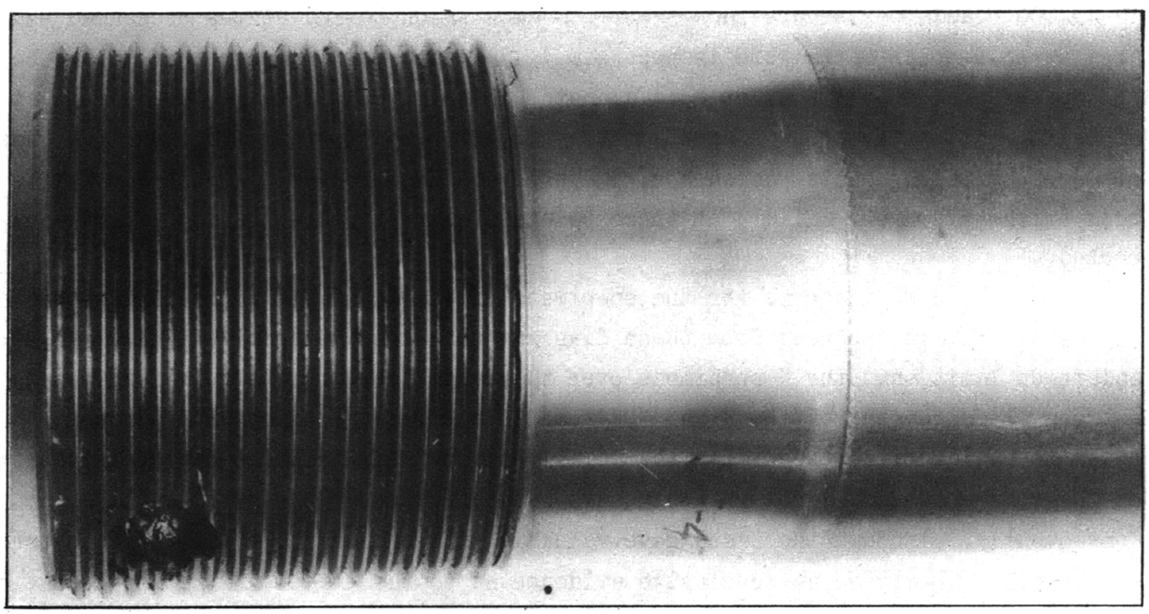

Figure 16 - Specimen NMC2 after Failure

Note that the fatigue crack developed at the base of the last thread at the crosshead end of the rod. All of the other specimens tested failed at the piston end as shown in Figures 15, 18, and 19.

39,562 cycles and NMC1 failed at 92,545 cycles. All of the remaining specimens were tested in a cycle in which the nominal stress varied from 22,000 pounds per square inch tension to an equal compression. The results are shown in Table 4. All specimens failed at the piston end, as shown in Figure 15, excepting Specimen NMC2 which failed at the crosshead end, as shown in Figure 16. The area at the bottom of the fillet at the piston end is approximately 15 per cent greater than in the straight

TABLE 4
Results of Fatigue Tests

Specimen	Stress	Number of Cycles	Location of Fracture
N1	± 27,500	39,562	Fillet, piston end
N2	± 22,000	243,232	Fillet, piston end
N3	± 22,000	181,484	Fillet, piston end
NMC1	± 27,500	92,545	Fillet, piston end
NMC2	± 22,000	665,089	Crosshead end
NMC3	± 22,000	342,167	Fillet, piston end
UMC1	± 22,000	699,366	Fillet, piston end
UMC2	± 22,000	159,462	Fillet, piston end

portion of the rod; hence the average stress at this point of failure was approximately 19,000 pounds per square inch. For rod NMC2 which failed at the crosshead end, the area at this point of failure is approximately 21 per cent greater than in the body of the rod because of the smaller bore diameter in this region; hence the average stress at this point of failure was approximately 18,000 pounds per square inch. The maximum stresses at these points, because of the short-radius grooves, is probably far in excess of the average. Failure at these points of stress concentration is not unexpected.

The S-N* diagrams for the specimens of the N and NMC series are shown in Figure 17. It is apparent from these diagrams that the NMC specimens had a higher endurance limit than the N specimens over the range tested. The marked difference between the strengths of the N and NMC rods is surprising, since the rods were supposed to be identical except for the metal coating. All failures occurred in parts of the rods which could not possibly have been affected by the metal-coating process. Consequently, although the tests gave valuable information about the fatigue strength of the rods, they gave no conclusive evidence as to the effect of the metal coating.

* The S-N diagram is obtained by plotting the number of cycles of stress at failure as abscissa and the stress during the cycle as ordinate. Each point on this diagram represents the test of one specimen. Such diagrams usually are plotted to a semi-log scale.

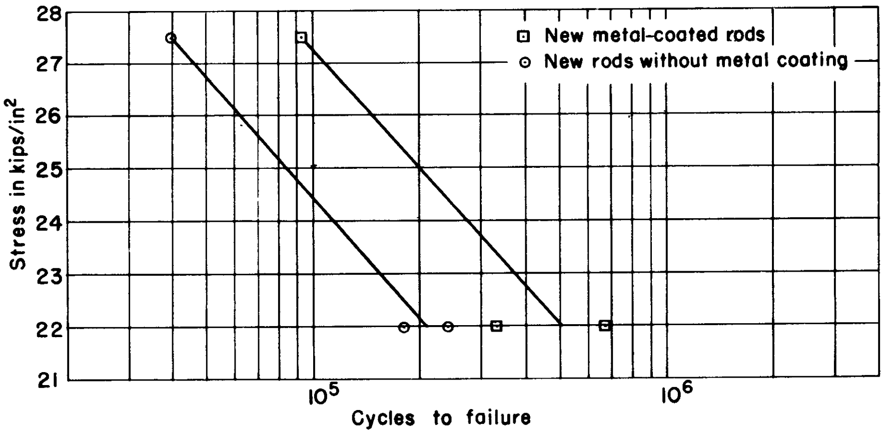

Figure 17 - Partial S-N Diagrams for N and NMC Specimens

USED METAL-COATED RODS

One of the used metal-coated rods, UMC2, failed at a relatively low number of cycles, 159,462. This is explained by the excessive corrosion on this rod, as shown in Figure 18.

DISCUSSION

The question of the effect of metal-coating on the fatigue strength of diesel engine piston rods was not answered by this test. Evidence from tests conducted by other experimenters is meager and conflicting. For example, Thum and Lange (3) conclude from tests on light-metal bars with a sprayed-steel surface layer that the endurance limit is decreased about 14 per cent. This might be due to a difference in surface finish in the two cases. On the other hand, Horger and Buckwalter (5) found that the endurance limit of car axles was increased more than 50 per cent by metal coating. In these tests the axle was pressed in a wheel, and the maximum stress in the axle was at the wheel. The metal coating was on that part of the axle which was within the bore of the wheel.

The fatigue strength of the metal-coated portion of diesel engine piston rods would appear not to be important if, as the present tests indicate, all the failures may be expected to occur in other sections. However, it is understood that service failures have not occurred in the piston ends of the rods and raises the question whether the test conditions employed did or did not properly duplicate the service conditions. There seems to be little question about the loading of the crosshead end of the rod as it was loaded by the same crosshead assembly used in service. However, as previously discussed, the piston ends of the rods were cut off and clamped together by heavy rings as shown in Figure 11. Although the clamped ends of the rods were ground perpendicular to the axis, it is entirely possible that the clamping introduced appreciable bending stresses in the radius near the clamped flanges. It may be that the clamping action alone would be sufficient to induce appreciable stresses in the

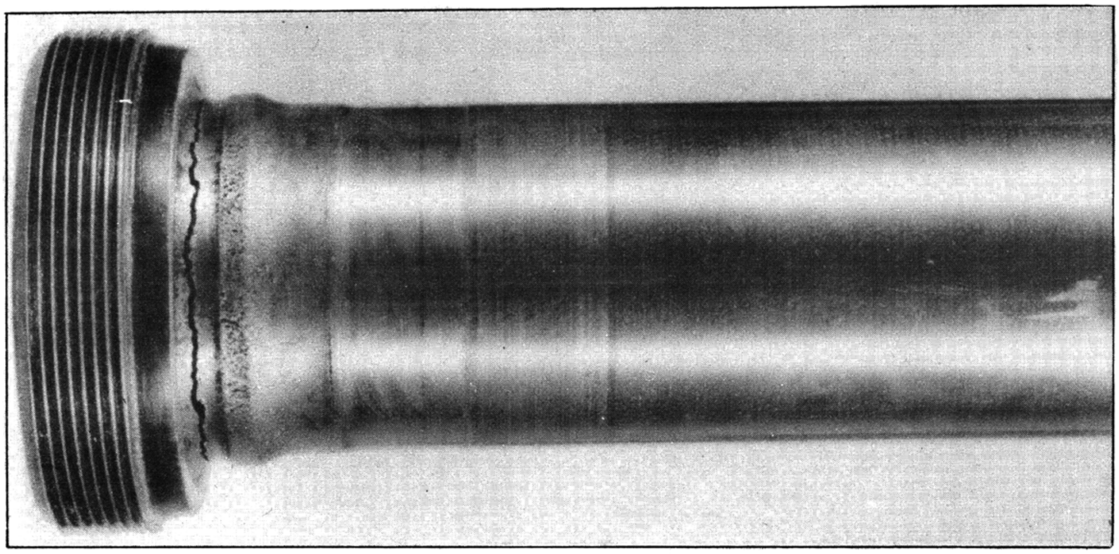

Figure 18 - Specimen UMC2 after Failure

This is the piston end of a reclaimed rod. Note the pitting at the left end of the rod, on the enlarged neck and in the large fillet. Whether this is due to the corrosive effects of the products of combustion which leaked under the piston seat, to corrosion fatigue, or to both, has not been determined. This rod is to be compared with the reclaimed rod UMC1 shown in Figure 19. Rod UMC2 withstood only 159,462 cycles whereas UMC1 withstood 699,366 cycles at the same stress of 22,000 pounds per square inch.

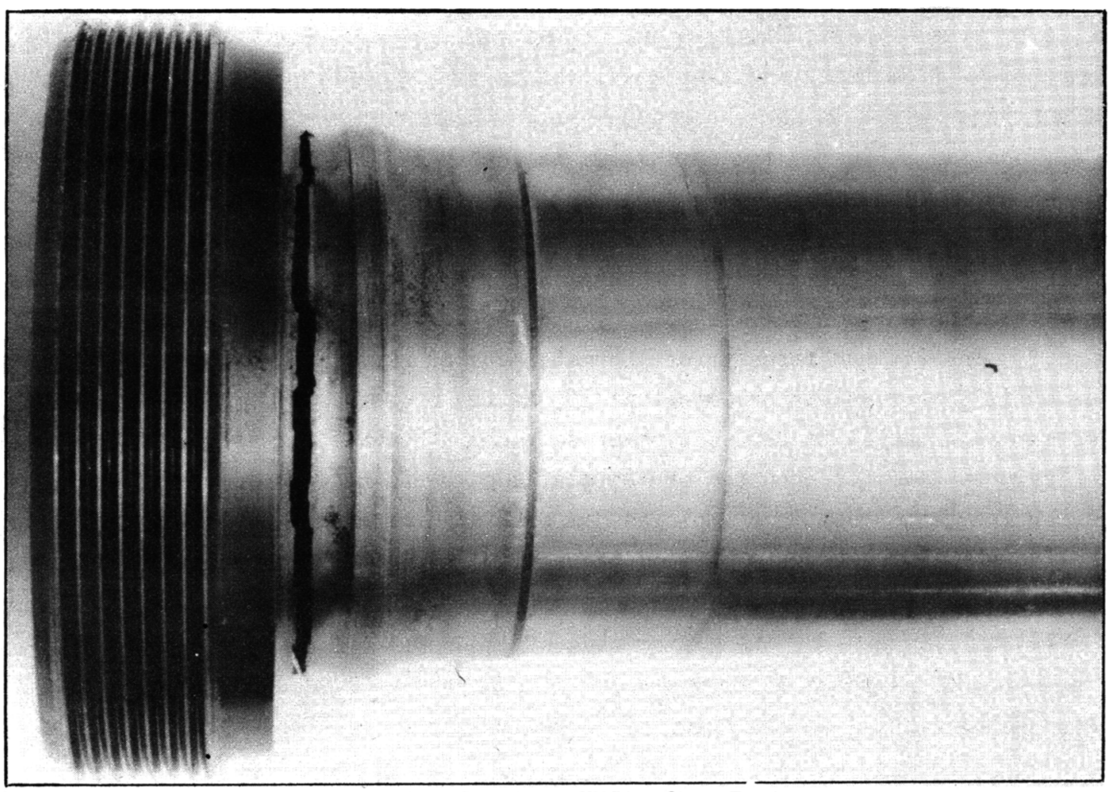

Figure 19 - Specimen UMC1 after Test

This is the piston end of a reclaimed rod. Note that the condition of the surface in way of the tapered neck and the large fillet is better than that of the reclaimed rod shown in Figure 18.

radius even though the ends were perfectly plane and perpendicular to the axis. A photoelastic investigation might throw some light on the probable magnitude of these stresses.

Rod UMC2 shown in Figure 18 was badly pitted by corrosion; the corrosion pitting in Rod UMC1 of Figure 19 was less pronounced. Rod UMC2 endured only about one quarter the number of cycles endured by Rod UMC1 before failure. Corrosion pitting evidently greatly reduces the endurance strength of diesel engine piston rods.

The broken ends of Rods N2 and UMC2 were sent to the Metallurgical Laboratory at the Washington Navy Yard for metallographic tests and chemical analyses; the results of the chemical analyses of these rods are given in Table 2 on page 3. They showed compliance with the values specified. Hardness surveys on longitudinal sections of the rods indicated very uniform properties. In no case did the hardness vary more than 3 per cent from the average. The hardness immediately below the metal coating for Rod UMC2 was not different from that at other points in the section, indicating that the application of the metal coating did not affect the hardness. Photomicrographs showed that Rod UMC2 had a fine-grained sorbitic structure whereas Rod N2 was of a much coarser pearlitic structure with some free ferrites.

CONCLUSIONS

1. The test is inconclusive with respect to possible damage caused by grooving and metal-spraying, since failure occurred in an untreated part of the rod in all cases.

2. Damage caused by grooving and metal-spraying, if it exists, is not enough to cause failure under the conditions of the test.

3. Though eccentric loading was not present, failure appears to have been caused by the method of clamping the piston end, except in rod NMC2. This exception suggests that the piston and the crosshead ends had approximately equal endurance.

4. Reduced endurance is observed in the case of severe pitting, as on Rod NMC2.

RECOMMENDATIONS

It is recommended:

1. That used piston rods of double-acting diesel engines be reclaimed by metal-coating provided the corrosion is not too severe. Corrosion-pitted metal should be removed and replaced during the repair operations.

2. That all tested specimens not already inspected be examined by magnaflux survey of the metal-coated area, by micrographs of the sections at either end and in the middle of the rod, and by hardness survey at the same points. The David Taylor Model Basin is not equipped to do this work.

3. That photo-elastic studies be made to determine the stress conditions caused by the special method of clamping the piston ends together.

REFERENCES

(1) BuShips letter S14-5(341), SS/S41-5 to Director TMB of 5 July 1941.

(2) Navy Yard, Washington, letter N8-5(291) to Director TMB of 5 March 1942.

(3) "Strain Distribution in a Fatigue Test," TMB Report 474, March 1941.

(4) "Fatigue Tests of Light-Metal Bars with a Sprayed Steel Surface Layer," A. Thum and S. Lange, VDI, vol. 84, No. 38, September 21, 1940, pp. 718-720.

(5) "Fatigue Strength of 2-Inch Diameter Axles with Surfaces Metal-Coated and Flame-Hardened," A.J. Horger and T.V. Buckwalter, Proceedings of the American Society for Testing Materials, vol. 40, 1940, p. 733.

APPENDIX 1

The metal-coated rods designated as Specimens NMC1, NMC2, and NMC3 were manufactured from the same material and in the same manner as Specimens N1, N2, and N3. After completion, however, the piston rods were turned to a diameter of 2.700 inches. To assure adequate bonding of the metal coat with the rod a 16-pitch thread was cut with a special round-nosed tool which produced a round-bottom groove as shown in the section of Figure 20. The threads were then knurled, after which the metal was sprayed on in one pass, building the diameter up to 1/16 inch over the desired finished diameter. The wire used for metal-spraying was 1/8 inch in diameter and contained 0.80 per cent carbon.

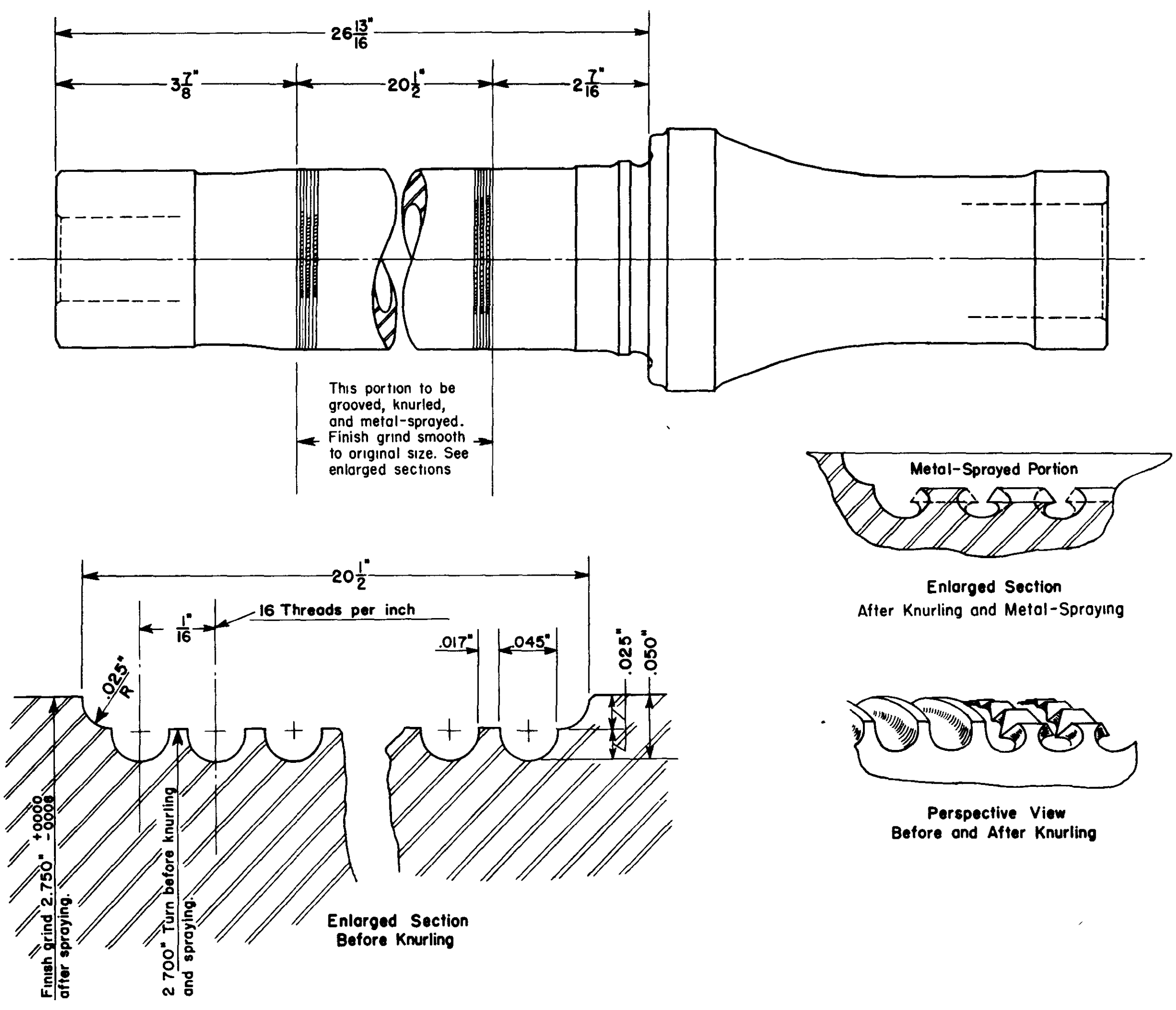

Figure 20 - Sketch showing Preparation and Details of Metal-Coated Rods

The section of the rod to be metal-coated was first turned to a diameter of 2.700 inches. It was then prepared for bonding the metal coat by cutting 16 threads to the inch with a round-nosed tool. The threads were then knurled to increase the bonding effect.

In the metal-spraying process it is of utmost importance that the correct spraying technique be used so that a fine-grained deposit is obtained without lamination. The long, uninterrupted surface of 20 1/2 inches must be sprayed in one continuous operation.

Since the sprayed metal was so hard it could not be turned with a high-speed tool, it was roughed off with a carbide tool, leaving about 0.020 inch to be removed by grinding. The grinding was done with a precision grinder using a grinding wheel of the same grit and grade as is used for grinding cast iron. Sprayed metal cannot be polished or superfinished. Its inherent porosity will harbor lubrication, which may be advantageous.

APPENDIX 2

The tests were conducted in the alternating-load testing machine shown in Figure 21. This machine is, so far as known, the only one of its particular type in existence. It is capable of exerting a load of 150,000 pounds either upward or downward on beam-type or column-type specimens. Deflections of 1/2 inch in either direction can be applied at loads up to 50,000 pounds and of 1/8 inch for loads of 150,000 pounds. The machine can be operated at any speed from 10 cycles to 250 cycles per minute.

Column-type specimens about 14 feet in length can be accommodated, with the use of a suitable adapting rig. Beam specimens of any length up to 12 feet 6 inches can be tested.

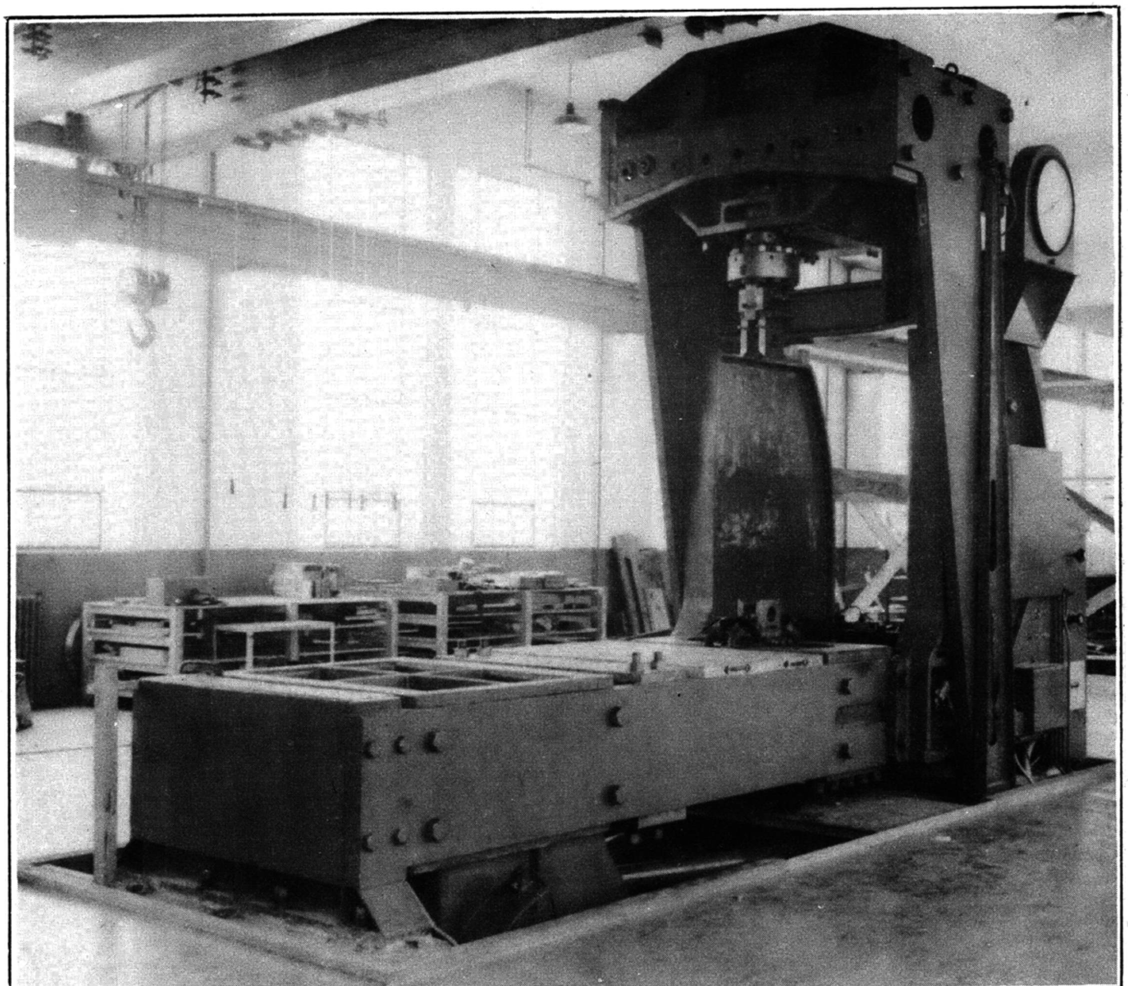

Figure 21 - Alternating-Load Testing Machine of 150,000 Pounds Capacity at the David Taylor Model Basin

The loading head at the top with the upper testing fixture hanging from it moves up and down, while the lower testing fixture is attached to the frame of the machine and remains stationary.

APPENDIX 3

O.J. Horger and T.V. Buckwalter (5) of the Timken Roller Bearing Company have found that metal-coating greatly increases the fatigue strength of car axles. Their conclusions, from data obtained since the results were published, are tabulated here. This table is taken from a letter from Mr. Buckwalter to J.V. Coombe, dated 26 August 1941.

	Endurance Limit of Wheel Seat to Prevent			
	Initiation of Fatigue Cracks		Breaking off of Axle	
	lb/in²	per cent	lb/in²	per cent
a. Without metal spray	9000	100	11000	100
b. Axle metal-sprayed at wheel fit with 0.25 per cent carbon wire	13500	150	17000	155
c. Axle metal-sprayed at wheel fit with 1.20 per cent carbon wire	17500	195	18000	164