Report No. ACNP-6107

PATHFINDER ATOMIC POWER PLANT

NOZZLE GALLING TEST, FINAL REPORT

DECEMBER 29, 1961

Submitted to

U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY
NUCLEAR POWER DIVISION
Milwaukee 1, Wisconsin

Ref: AEC Contract No. AT(11-1)-589

DISCLAIMER

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Under
Agreement dated 2nd Day of May 1957, as Amended
between
Allis-Chalmers Mfg. Co. & Northern States Power Co.
under
AEC Contract No. AT(11-1)-589

December 29, 1961

Classification – UNCLASSIFIED
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PATHFINDER ATOMIC POWER PLANT

NOZZLE GALLING TEST

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FOREWORD

A galling test was conducted to provide a basis for selecting a material for the Pathfinder boiler fuel element nozzle so that galling of the nozzle or reactor grid plate is precluded. The test and evaluation of results are described in the following report.

The test was undertaken as part of the research and development program for the Pathfinder Atomic Power Plant, which is a 66-mwe plant that will be owned and operated by Northern States Power Company of Minneapolis. The plant will be built near Sioux Falls, South Dakota and is scheduled to become critical in mid-1962.

Contributing to the research and development program are the U. S. Atomic Energy Commission and Central Utilities Atomic Power Associates, a group of ten midwestern private utility companies. CUAPA members include the following: Central Electric and Gas Company, Interstate Power Company, Iowa Power and Light Company, Iowa Southern Utilities Company, Madison Gas and Electric Company, Northern States Power Company, Northwestern Public Service Company, Otter-Tail Power Company, St. Joseph Light and Power Company, and Wisconsin Public Service Corporation.

Allis-Chalmers Manufacturing Company is prime contractor for design and construction of the plant. The plant will incorporate the Controlled Recirculation Boiling Reactor with Integral Nuclear Superheater.

ABSTRACT

Galling tests of 304, 17-4PH, and chrome-plated 304 stainless-steel nozzles with 304 stainless-steel sleeves were conducted at Pathfinder reactor conditions of 489 F, 600 psig. A horizontal force was imposed on the sleeve with the nozzle inserted; and the nozzle was moved axially to determine galling tendencies. Galling was produced on both the 304 and 17-4PH stainless-steel nozzles. The chrome-plated 304-stainless-steel nozzles were cycled numerous times without galling. On the basis of these tests, chrome-plated 304L-stainless-steel is the material selected for the Pathfinder boiler fuel-element nozzle.

CONTENTS

1. INTRODUCTION

The Pathfinder boiler fuel-element nozzle consists of a hollow cylinder with two lands which fits into a 304L stainless steel sleeve in the reactor grid plate. Due to fluctuations in temperature and flow during reactor operation, the nozzle may move up and down with respect to the sleeve. The vertical movement may be accompanied by a horizontal load due to tilting of the nozzle. Therefore, galling of sleeve and nozzle material is possible.

Three materials otherwise suitable for the nozzle are 304, 17-4PH, and chrome-plated 304 stainless steels. In order to ensure that galling does not become a problem in the operating reactor, a test is necessary.

2. OBJECTIVE

Tests were conducted of nozzles made of 304, 17-4PH, and chrome-plated 304 stainless steels to determine the material and surface finish which would result in minimum galling when used with a 304L stainless steel grid plate at Pathfinder operating conditions.

3. CONCLUSION

Of the three materials tested, chrome-plated 304 stainless steel yielded the best results, and was therefore specified for use in the Pathfinder boiler fuel elements. It was found that in chrome-plating the 304 stainless steel, it was necessary to have a smooth, blended transition from the chrome-plated portions to the unplated portions. Without the blends, the chrome plate had a tendency to chip and peel from the base metal.

In tests 4 and 5, there were no obvious differences in wear that could be attributed to improvement of the surface finish from 16 microinch rms to 8 microinch rms. In test 3 (18-25 microinch rms nozzle surface finish), scratches appeared on the sleeve before any horizontal load had been applied; a condition which did not occur in tests 4 and 5. Therefore, the conclusion was made that surface finishes above 16 microinch rms had a noticeable effect on the wear characteristics, and that surface finishes better than 16 microinch rms would yield only negligible improvement.

Although 304L stainless steel is used for the sleeves in the Pathfinder, it was assumed that its tendency to gall is not significantly different than the 304 stainless steel used in the test and, therefore, that the test is entirely pertinent to the Pathfinder fuel element nozzles.

The test of a 304 stainless steel nozzle (test 1) was not considered conclusive, since there were many unknown parameters. However, the galling obtained in test 1 was so severe that further tests did not seem warranted.

4. APPARATUS

The test apparatus (Figure 1 and 2) consists of an 8-in pipe with welded neck flanges and with blind flanges bolted to each end. On one end and on one side, 5-in dia. air cylinders are attached with shafts extending into the housing. The nozzle is attached to the shaft of the vertical cylinder, which moves the nozzle up and down, simulating motion due to temperature and flow fluctuations in the reactor. The sleeve is attached to the lower blind flange by means of a clevis bracket. The horizontal cylinder provides a horizontal load on the sleeve simulating the condition where the nozzle and sleeve are not aligned.

Gages on the air supply lines and on the side of the test housing indicate pressure in the air cylinders and pressure vessel. The test is heated to reactor temperature and pressure by six 900-watt electrical band heaters. The test housing is surrounded by 2-1/2-in thick insulation, which is not shown. The interior of the carbon steel housing is coated with sprayed aluminum to reduce corrosion at high temperatures.

5. TEST PROCEDURE

The following test procedure was used for all tests.

1) The nozzle and sleeve are installed, and the test is assumbled.

2) The test housing is filled with water.

3) The heaters are operated to obtain reactor conditions of 489 F, 600 psig.

4) The vertical cylinder is actuated. The number of cycles, vertical cylinder pressure, and vessel pressure are recorded.

5) The test is disassembled, and the nozzle and sleeve are inspected.

6) Steps 1, 2, 3, and 4 are repeated.

7) The horizontal cylinder is pressurized to place a specified horizontal load on the sleeve.

8) The vertical cylinder is operated for ten cycles. The pressures in the vertical and horizontal cylinders and in the test vessel are recorded.

9) Steps 4 and 5 are repeated.

Before tests were begun, the test housing was hydrostatically tested at 900 psig, cold. The approximate frictional resistances of the packing on the shafts was determined in a test run without the nozzle and sleeve. These forces were found to be about 30 lb for the vertical shaft and 60 lb for the horizontal shaft.

The net force on the nozzle and sleeve consists of the cylinder force due to the pressure in the cylinders minus the frictional resistance of packing on the shafts and the outward force on the shafts exerted by the vessel pressure.

Since the packing rings were tightened from time to time during the heating-up period, and since the packing was changed several times between tests without redetermining the frictional resistances, the values may have varied from those given. A second source of inaccuracy arose because the actuating cylinder pressure was difficult to read with the pressure varying throughout the stroke. Since small changes in pressure produce relatively large changes in applied force, some error in determining the force required to move the nozzle is possible. However, since the increase in vertical load resulting from galling is large compared to the combined inaccuracy, which is less than 100 lb, the inaccuracy is not significant.

Under ideal conditions, the horizontal load applied in each test would have been the same. However, due to the difficulty in controlling the pressure to the horizontal cylinder by means of the four-way control valve, there were variations in horizontal loads in this series of tests.

6. RESULTS

A total of six nozzles were tested. Each test is discussed in the following paragraphs. A summary of test data is given in Table I.

Test 1 - 304 Stainless Steel Nozzle. A test with 304 stainless steel was made primarily to shake-down the test setup. No measurement of hardness, surface finish, or diameters were made on the nozzle or sleeve. The test was run at 540 psi, 477 F due to a leak.

With no horizontal load and with 55 psi in the vertical cylinder, the nozzle moved approximately 1/8 in, which compares to a full stroke of 1.25 in. No further movement resulted when the pressure in the vertical cylinder was increased to 96 psi. The pressures of 55 and 96 psi correspond to net downward forces of 488 and 1228 lb, respectively.

After the test apparatus was cooled to room temperature, the nozzle was moved through a full stroke by 50 to 55 psi in the vertical cylinder. This pressure is equivalent to a net downward force of about 1000 lb. The nozzle was operated through four strokes in this manner.

Severe galling was noted on both nozzle and sleeve (Figure 3) when the test was disassembled. Although the test had been intended only as a test of the test apparatus, the galling was so severe that no further test of 304 stainless steel was made.

Test 2 - 17-4PH Stainless Steel Nozzle. The second test was conducted with a nozzle made of 17-4PH stainless steel having a hardness of BHN 404 and a surface finish of 20×10^{-6} in. rms. The 304 stainless steel sleeve had a hardness of BHN 153 and a surface finish of 20 to 32 10^{-6}-in. rms. The diametral clearance between nozzle and sleeve was 0.014 in.

The first test run consisted of 50 cycles with no horizontal force and with 595 psi and 488 F in the housing. Initially, approximately 500 lb net vertical force was required to move the nozzle. The actuating pressure leveled off to about 45 psi with 578 psi in the housing, which yields a net downward force of 144 lb. The high initial force required is attributable to new packing in the packing gland.

When the test was disassembled, the nozzle and sleeve were both slightly marred. The marring appeared to consist of scratches rather than galling in that no metal was picked up by either nozzle or sleeve (Figure 4).

The nozzle and sleeve were then tested at 620 psi, 492 F. The nozzle was cycled 100 times with no horizontal force. The operating force leveled off to about 33 lb net downward force. A 165 lb net horizontal load was applied and the net force required to move the nozzle increased to 482 lb net on the third stroke and to 978 lb net on the fourth. The horizontal load was then reduced to 70 lb net and the operating force decreased to 592 lb net for the next six cycles. The horizontal load was removed entirely, and the nozzle was operated for ten cycles. The force required to operate the nozzle decreased to 425 lb net. The increase in force required to move the nozzle, (33 to 425 lb net), was attributed to galling.

When the test was disassembled, considerable galling of both the nozzle and sleeve was evident (Figure 5).

Test 3 - Chrome-Plated 304 Stainless Steel. The third nozzle tested was of chrome-plated 304 stainless steel having a hardness of approximately BHN 1200 and a surface finish of 18×10^{-6} in. rms. The 304 stainless steel sleeve had a hardness of BHN 153 with a surface finish of about 25×10^{-6} in. rms. The diametral clearance between nozzle and sleeve was 0.012 in. The test was conducted at 615 psi.

The first test run consisted of 100 cycles without any horizontal force applied. The pressure required to operate the vertical air cylinder quickly leveled off at 43 psi, a net downward force of 60 lb.

The test was disassembled for inspection. The nozzle was not marred, and the sleeve had only minute scratches.

The second test run consisted first of 50 cycles with no horizontal load during which the operating force leveled off at 60 lb net. A 155 lb net horizontal load was then applied. On the first stroke, the operating load increased to 575 lb net downward. On the second and third strokes, the required force increased to 673 lb net downward. From the fourth through tenth cycles, the horizontal load was decreased to 82 lb net. The corresponding vertical force required decreased to 60 lb net downward, which was the same force required at the beginning of the test.

When the test was disassembled, the nozzle was not marred but the sleeve was badly scratched. No galling was evident (Figure 6).

Test 4 - Chrome-Plated 304 Stainless Steel. The fourth nozzle tested was chrome-plated 304 stainless steel having a hardness of approximately BHN 1200 and a surface finish of 16×10^{-6} in. rms. The 304 stainless steel sleeve had a hardness of BHN 119 and a surface finish of 20 x 10^{-6} in. rms. The diametral clearance between nozzle and sleeve was 0.012 in.

The nozzle was first operated for 100 cycles with no horizontal load. At a housing pressure of 570 psi, a net vertical force of 20 lb was required to move the nozzle. The test was disassembled, but neither the nozzle nor sleeve showed any signs of wear.

The test was reassembled, and the nozzle was again operated with no horizontal load for 50 cycles. The vertical force required was 20 lb net with a housing pressure of 600 psi. Upon the application of a 290 lb net horizontal load for ten cycles, the vertical force required increased to 960 lb net. When the horizontal load was removed, the vertical force required decreased to 70 lb net.

When the test was disassembled, the sleeve was severely scratched but no galling was evident. The metal from the scratches in the sleeve was deposited at the end of the stroke (Figure 7).

<u>Test 5 - Chrome-Plated 304-Stainless-Steel.</u> The fifth nozzle test was the same as the fourth except for nozzle surface finish. This nozzle had a surface finish of 8 x 10^{-6} in. rms. The test pressure was 615 psi. The nozzle was first run for 100 cycles with no horizontal load. The net vertical load required was 20 lb. When the test was disassembled, no galling was evident.

After reassembly, the nozzle was again operated with no horizontal load for 50 cycles with a vertical force of 20 lb net required. When a 268 lb net horizontal load was applied, the required vertical force increased to 930 lb net. After the horizontal load was removed, the vertical force required decreased to 65 lb net.

No galling was found on either the nozzle or the sleeve after disassembly. Severe wear in the form of scratches were found on the sleeve, and metal from the scratches formed a ridge at the end of the stroke (Figure 8).

Test 6 - 17-4PH Stainless Steel. The sixth and last test was conducted with a nozzle made of 17-4PH stainless steel. The hardness was BHN 393. The surface finish was 20 x 10^{-6} in. rms. The 304 stainless steel sleeve had a hardness of BHN 119 and a surface finish of 28 x 10^{-6} in. rms. The diametral clearance between nozzle and sleeve was 0.012 to 0.014 in.

The nozzle differed from any of the others tested in that a Inconel X spring was mounted on the upper portion, as it would be in the reactor. Although the spring constant was known at room temperature, its rate at test temperature could not be calculated because it was improperly wound. However an estimate of its loading was made, and considered in determining the net vertical load.

The nozzle was tested for 100 cycles with no horizontal load. The required vertical load was 20 lb net with the housing at 620 psi. The test was disassembled, and some wear on both nozzle and sleeve was evident. (Figure 9)

The nozzle was then tested for ten cycles with 300 lb. net horizontal load. The required net vertical load was 1108 lb at a housing pressure of 540 psi. After removing the horizontal load, the required vertical load decreased to 140 lb. net.

Severe wear and galling were noted on both nozzle and sleeve after the test was disassembled (Figure 10). The spring had no discernible effect on the performance of the nozzle.

TABULATION OF RESULTS

NOZZLE GALLING TEST

Test No.	Material: Nozzle	Material: Sleeve	Surface Hardness (BHN): Nozzle	Surface Hardness (BHN): Sleeve	Surface Finish (10^{-6} in. rms.): Nozzle	Surface Finish (10^{-6} in. rms.): Sleeve	Net Vert. load (lb)	Net Horiz. load (lb)	Results (Fig. No.)
1	304 SS	304 SS					1000	0	3
2	17-4PH	304 SS	404	153	20	20 to 32	144	0	4
							33	0	
							482	165	
							780	165	
							978	165	
							592	70	
							425	0	5
3	Chrome Plated 304 SS	304 SS	Approx. 1200	153	18 to 25	20 to 32	60	0	
							575	155	
							673	155	
							575	82	
							60	0	6
4	Chrome Plated 304 SS	304 SS	Approx. 1200	119	16	20	20	0	
							960	290	
							70	0	7
5	Chrome Plated 304 SS	304 SS	Approx. 1200	130	8	20	20	0	
							950	268	
							65	0	8
6	17-4PH	304 SS	393	119	20	28	20	0	9
							1110	300	
							150	0	10

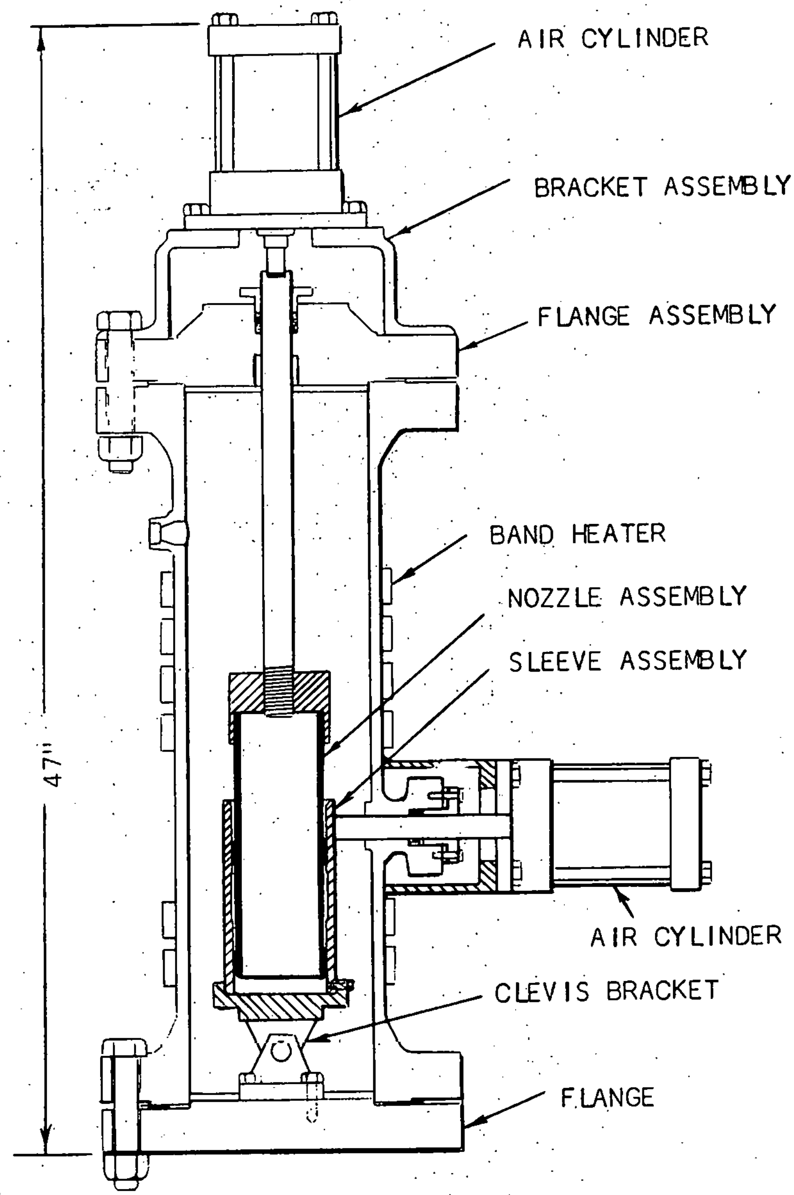

Figure 1. Nozzle-Galling Test Assembly.

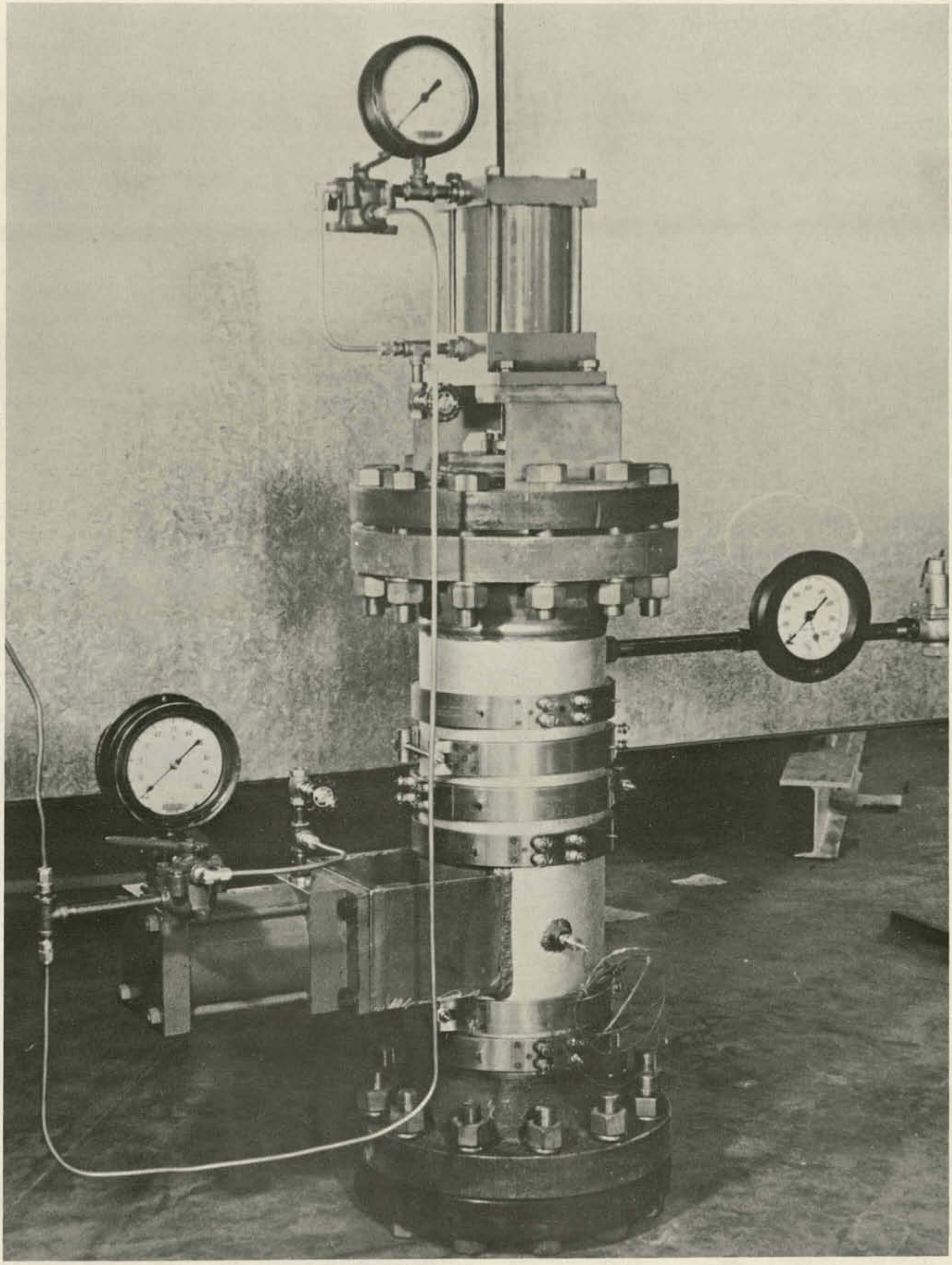

Figure 2. Nozzle-galling test assembly.

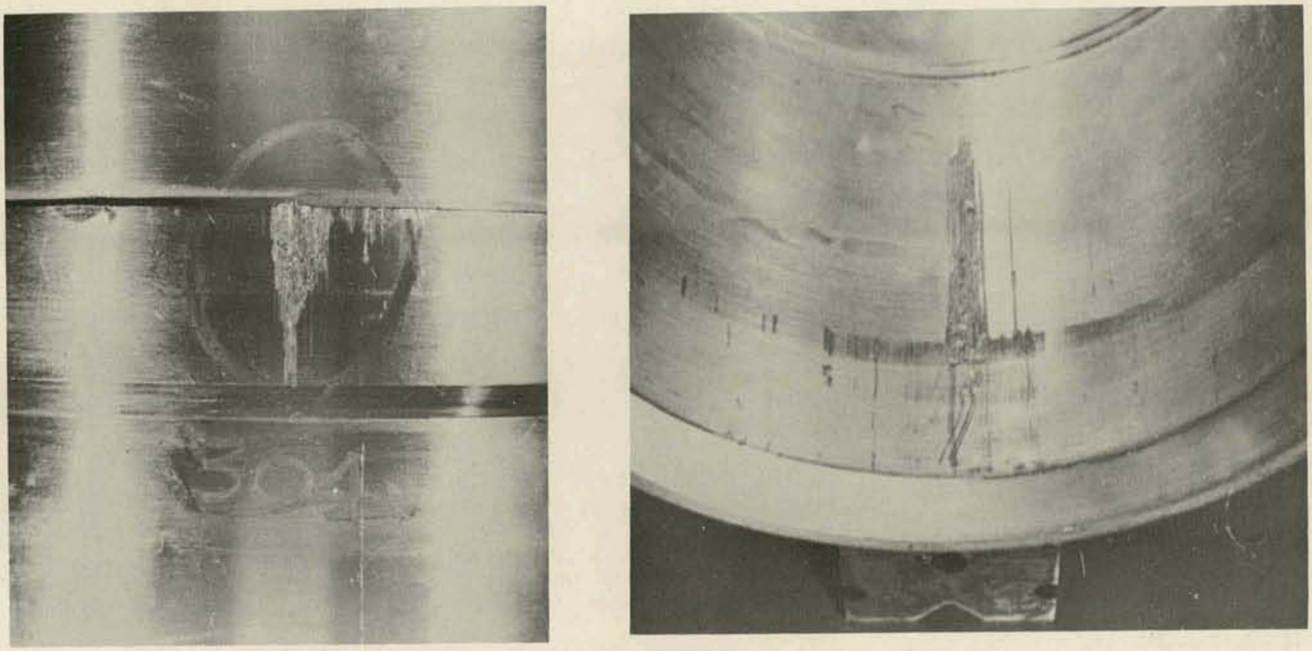

Figure 3. Test 1 - 304 stainless steel nozzle (left) and 304 stainless steel sleeve (right) after galling test with no horizontal load. (NP Photo 18A-5, -10)

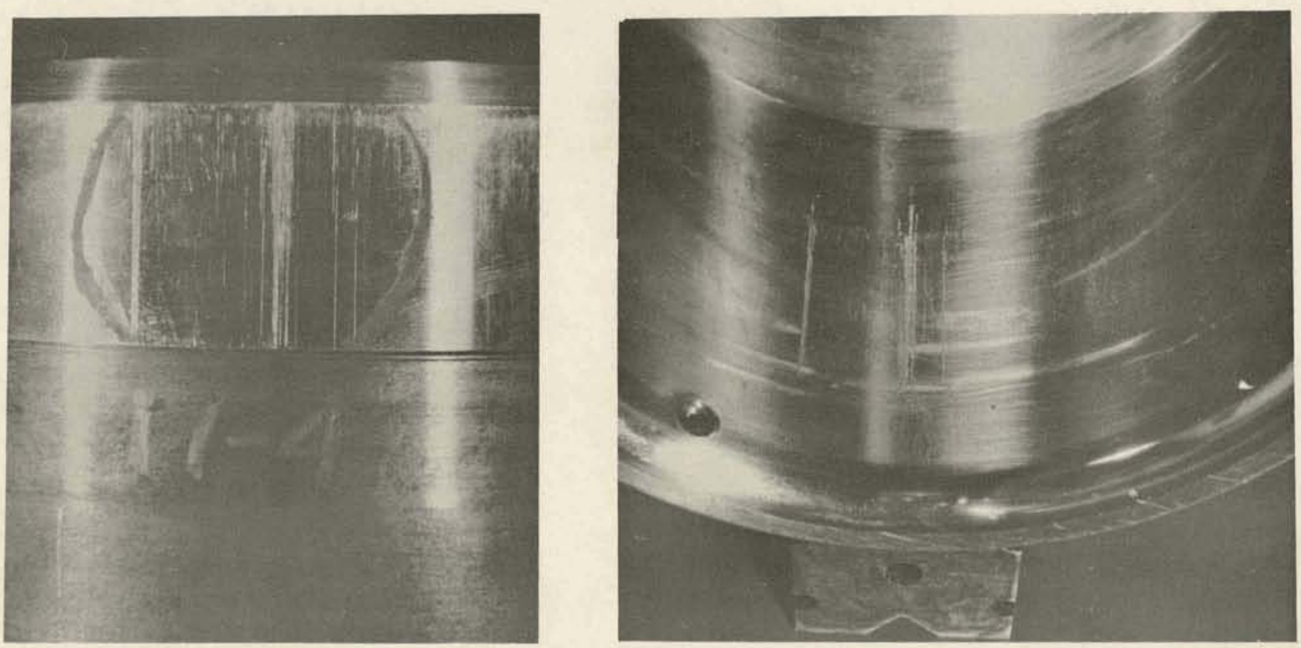

Figure 4. Test 2 - 17-4PH stainless steel nozzle (left) and 304 stainless steel sleeve (right) after galling test with no horizontal load. (NP Photo 18A-7, -9)

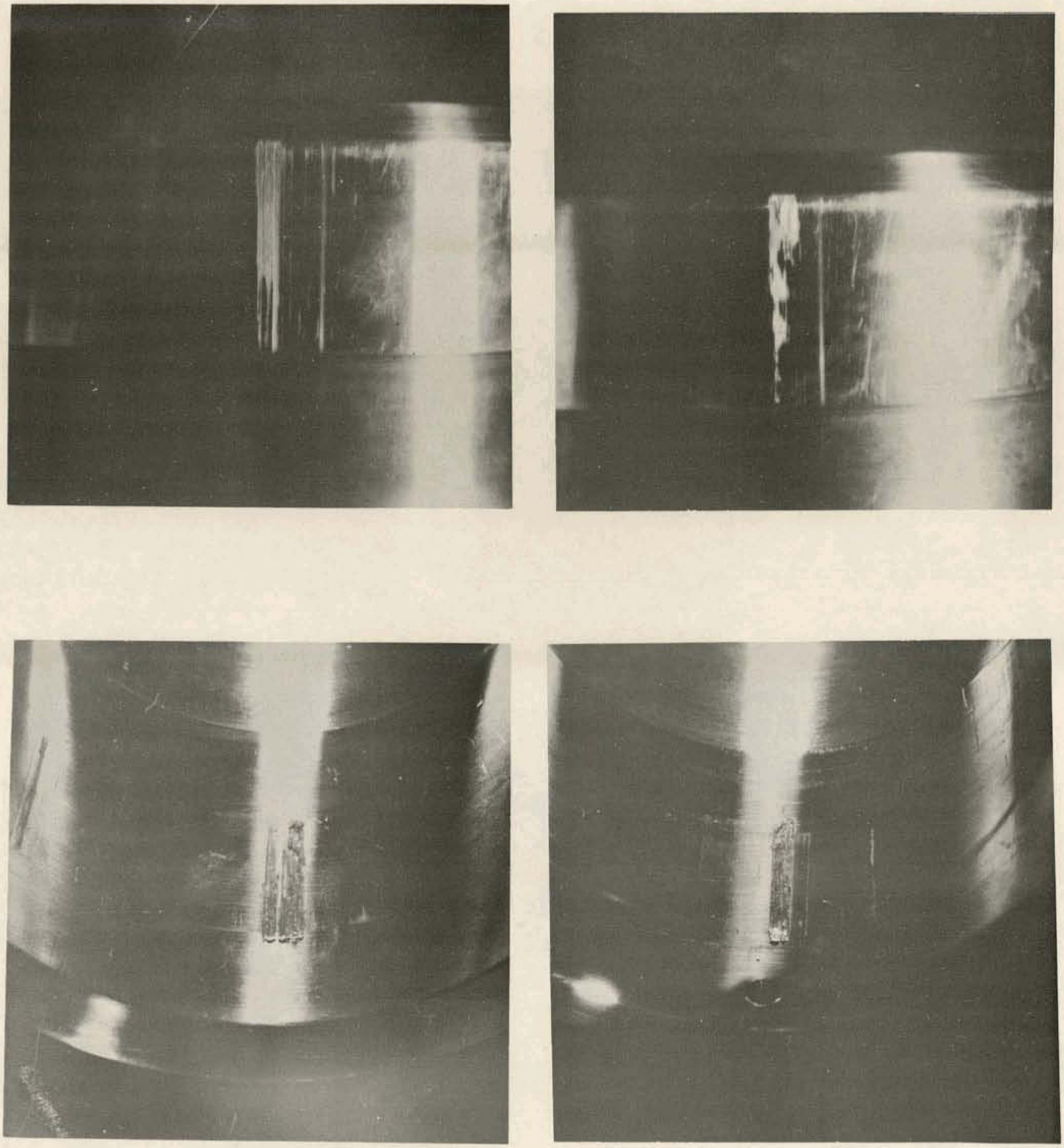

Figure 5. Test 2 - 17-4PH stainless steel nozzle (top) and 304 stainless steel sleeve (bottom) after galling test with 165-lb horizontal load. (NP Photo 18A-12, -13, -15, -16)

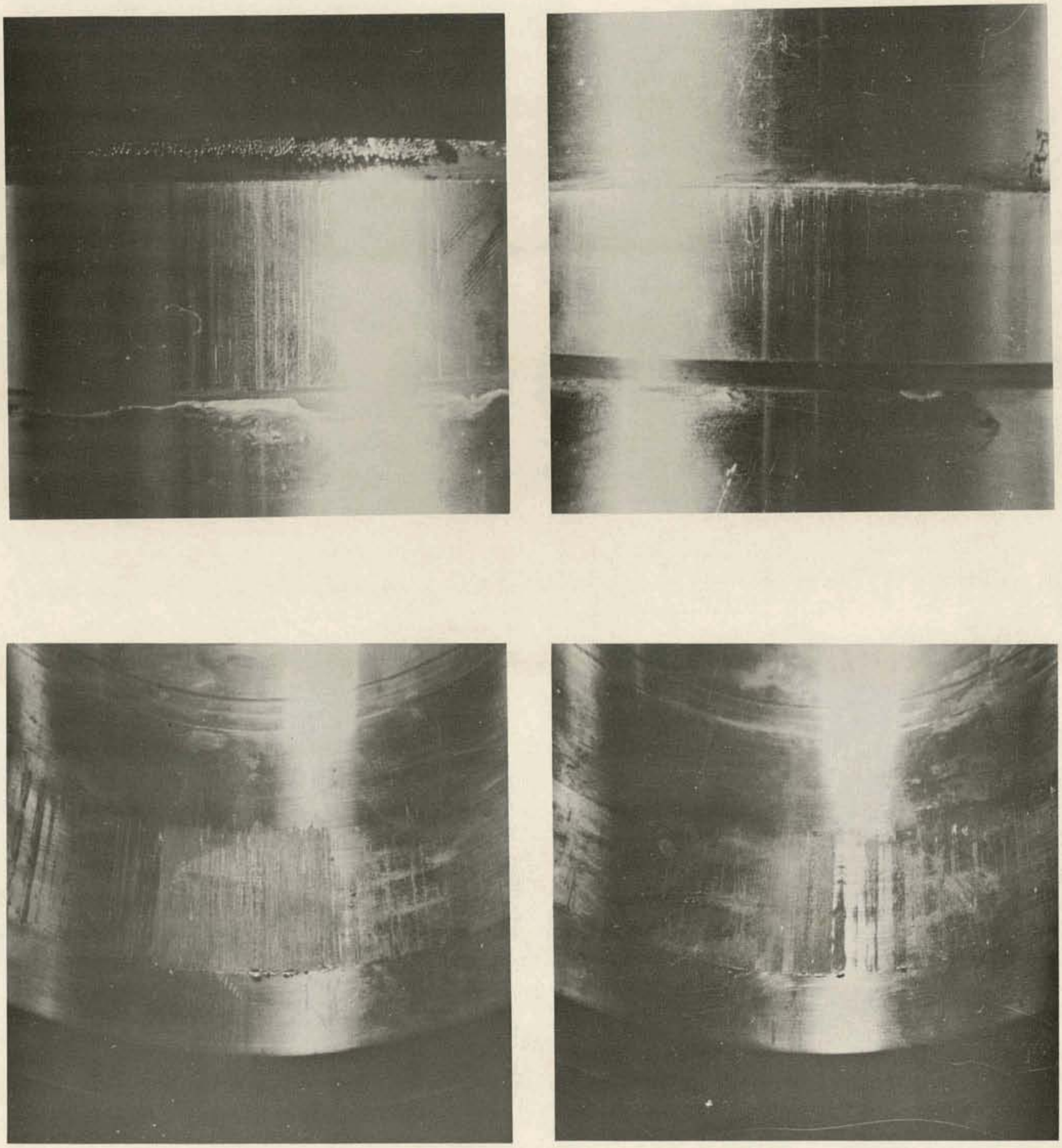

Figure 6. Test 3 - Chrome-plated 304 stainless steel nozzle (top) and 304 stainless steel sleeve (bottom) after galling test with 155-lb horizontal load. (NP Photo 18A-18, -19, -23, -25)

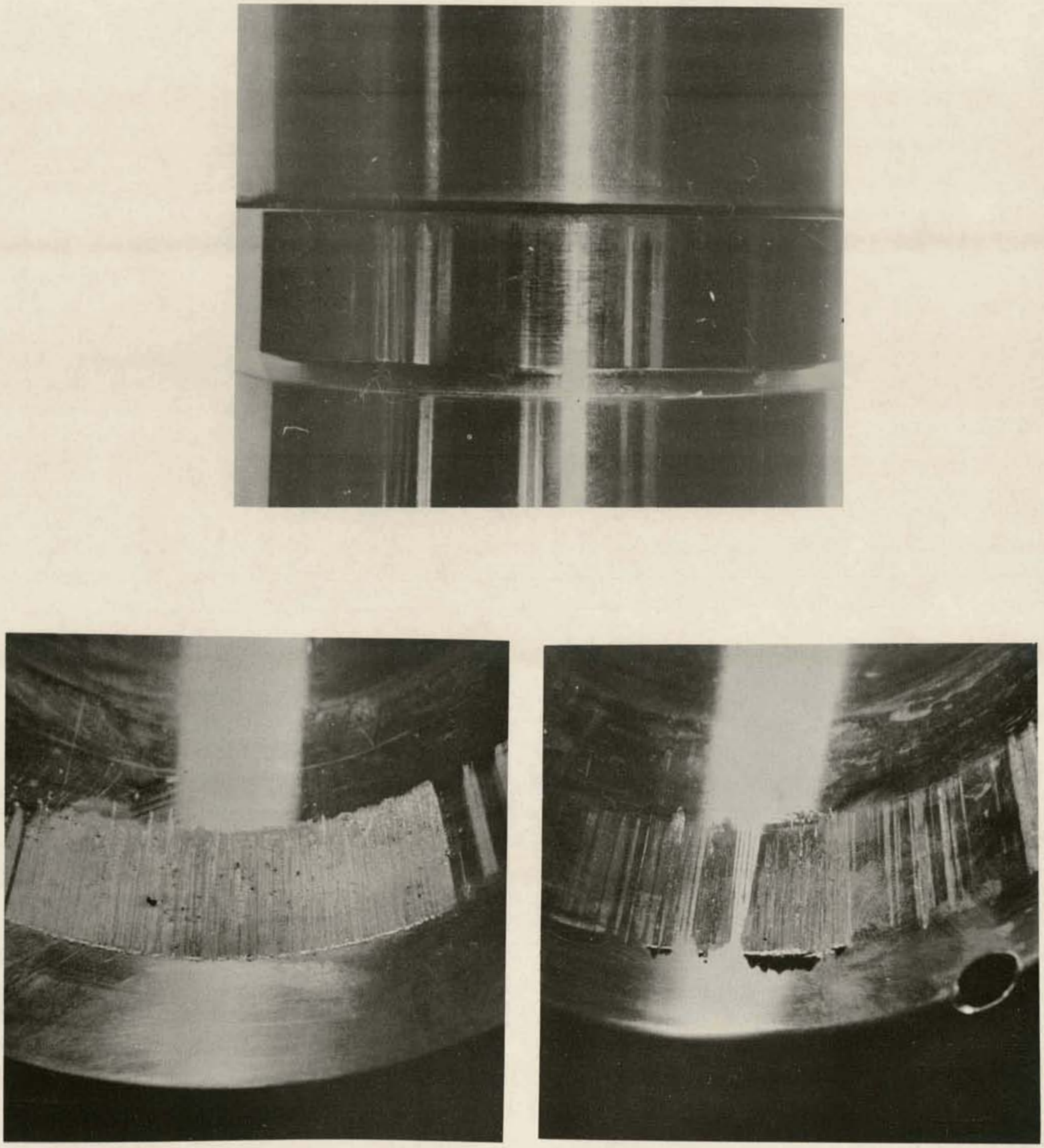

Figure 7. Test 4 - Chrome-plated 304 stainless steel nozzle (top) and 304 stainless steel sleeve (bottom) after galling test with 290-lb horizontal load. (NP Photo 18A-0-26, -28, -29)

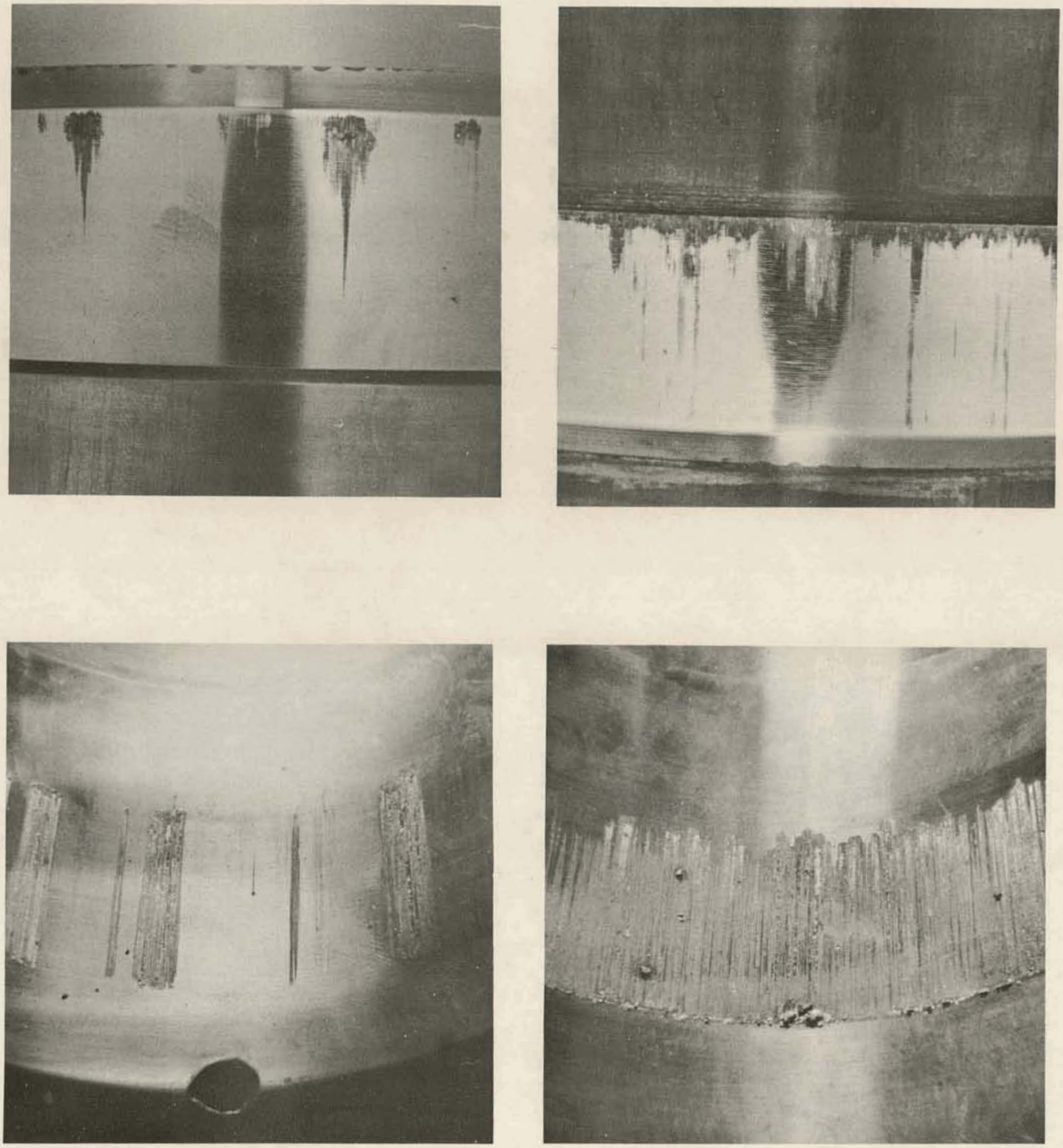

Figure 8. Test 5 - Chrome-plated 304 stainless steel nozzle (top) and 304 stainless steel sleeve (bottom) after galling test with 268-lb horizontal load. (NP Photo 18A-0-33,-34,-39, -40)

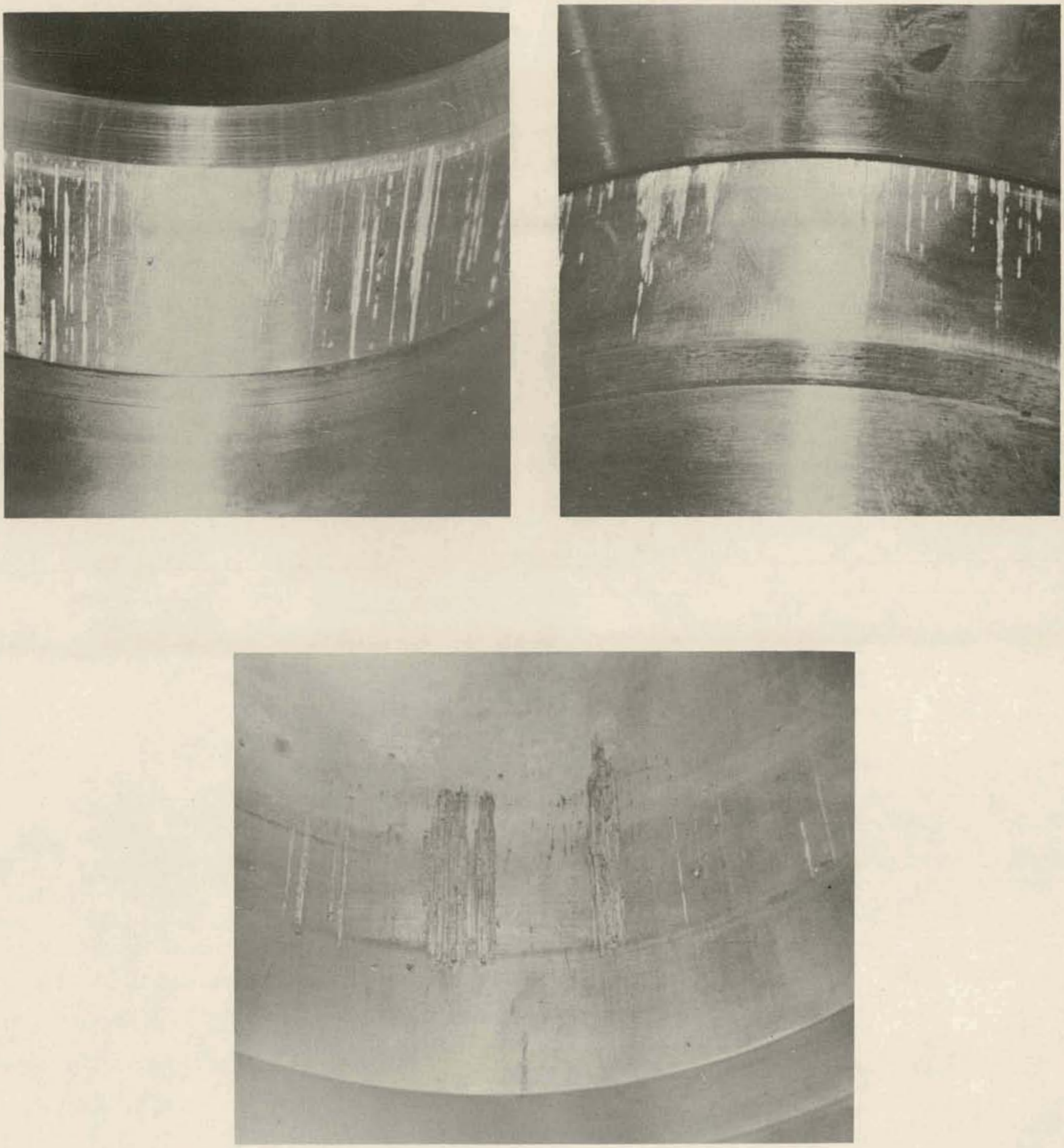

Figure 9. Test 6 - 17-4PH stainless steel nozzle (top) and 304 stainless steel sleeve (bottom) after galling test with no horizontal load. (NP Photo 18A-0-30, -31, -32)

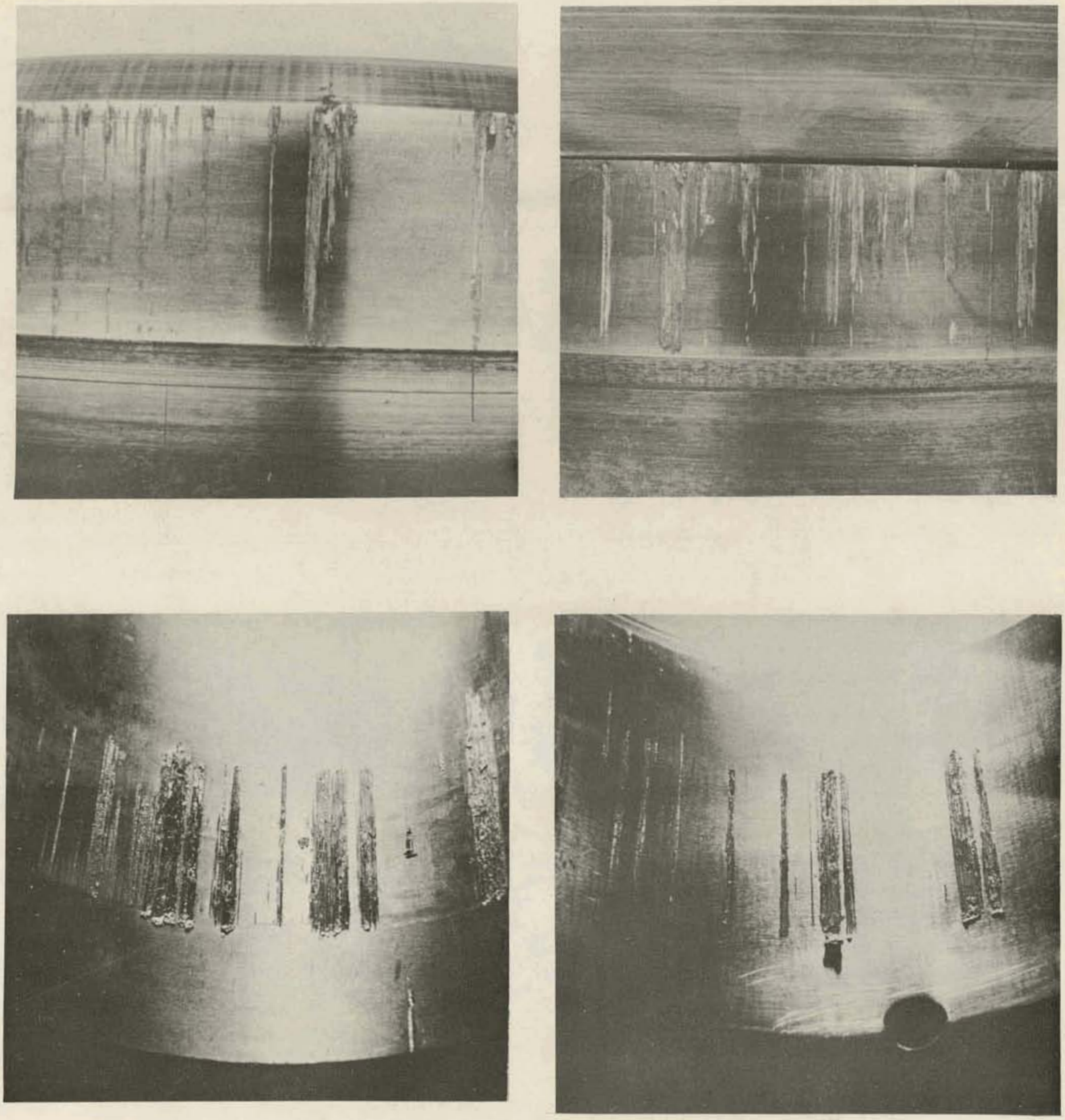

Figure 10. Test 6 - 17-4PH stainless steel nozzle (top) and 304 stainless steel sleeve (bottom) after galling test with 300-lb horizontal load. (NP Photo 18A-0-35, -36, -37, -38)