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INVESTIGATION OF CAVITATION DAMAGE OF A MECHANICAL PUMP IMPELLER IN HIGH TEMPERATURE POTASSIUM

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prepared for

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INVESTIGATION OF CAVITATION DAMAGE OF A MECHANICAL PUMP IMPELLER IN HIGH TEMPERATURE POTASSIUM

by

R. S. Kulp and J. V. Altieri

I. ABSTRACT

28876

This is the second and final quarterly progress report prepared under NASA Contract NAS3-6468 and covers the period March 1, 1965 to July 2, 1965. This contract was terminated as of July 2, 1965, due to closing of CANEL by the Atomic Energy Commission. This report and Quarterly Progress Report No. 1 (NASA CR-54383) completely describe all work accomplished during this program.

During this quarter water calibration of the RI-7B3 impeller has been completed. The results check closely with data obtained from the RI-7A3 impeller tests.

Design work on the KP-1 turbopump and the Liquid Metal Pump Test Stand has been completed. Fabrication of parts for the turbopump has been completed, and the pump has been assembled.

A water test of the turbopump in the Liquid Metal Pump Test Stand has been completed. Radial forces on the impeller have been determined to exist and their magnitude calculated. A two hour acrylic lacquer test run has been completed.

Author

II. PROGRESS DURING THE QUARTER

The results of the RI-7A3 acrylic lacquer tests in water were discussed at NASA-Lewis Research Center with NASA personnel on March 16, 1965. At that meeting P&WA suggested a water test be run in the Liquid Metal Pump Test Stand. The purpose of this water test would be to evaluate the stand inlet conditions and to determine if radial side loads existed on the impeller in cavitation. The KP-1 turbopump required minor changes to incorporate instrumentation to detect the impeller side loads.

A more detailed discussion of these points is given in the following paragraphs:

A. RI-7A3 Data Discussion with the NASA

At the March meeting the results of the RI-7A3 water test were discussed (see Reference 1). Two possible values of NPSH at a variable vane tip clearance of 0.035 inch inlet to 0.025 inch discharge were recommended as most likely to produce minimum cavitation damage in 1000 hours in the liquid metal test. A value of NPSH of 22 feet was recommended as being an optimistic point at a suction specific speed of 16,500. A more conservative value suggested was an NPSH of 30 feet at the same clearance values, which is a suction specific speed of 13,100. However, before deciding on an NPSH value, a water test run in the Liquid Metal Pump Test Stand was recommended. This test would provide data for :

1. determination of any change of lacquer removal patterns due to the different inlet conditions of the impeller and pump stands
2. determination of performance characteristics at room temperature from which any changes in vane tip clearance due to thermal expansion could be noted
3. determination, by suitable instrumentation, of radial forces on the impeller imposed by cavitation.

The recent report by Rosenmann (Reference 2) of radial loads caused by cavitation enhanced the desirability of conducting this test. His report described work on a three bladed rocket pump inducer stage whose inlet configuration is strikingly similar to the three bladed RI-7 impeller. The diameter of the inducer was six inches with an inlet blade angle of nine degrees. The RI-7 impeller inlet diameter is five inches with an inlet blade angle of eight degrees. Flow rates of the two machines were very close, but the RI-7 impeller produced a head rise at the test shaft speed of 6375 rpm that was three times that of the inducer run at a shaft speed of 6500 rpm.

Using strain gages mounted on the shaft, Rosenmann determined radial forces of about 150 pounds existed on the inducer and were unidirectional with respect to the inducer. As NPSH was decreased, these loads began to appear at an NPSH value of about 40 feet. They increased to a maximum then dropped to zero as the knee of the cavitation curve was reached.

B. Design Changes to KP-1 Turbopump

Redesign of the turbopump shaft was considered necessary to strengthen the area most subject to high stress levels anticipated from radial forces on the impeller during operation in cavitation. The shaft to be used for this test was partially machined, and changes could be incorporated easily with no increase in costs or delay in time.

The specific changes to the shaft design are in the impeller attachment and dynamic seal area (see Fig. 1 and compare to Fig. 8 of Reference 1). The impeller end of the shaft was lengthened approximately two inches, and diameters in this area were increased. In place of an attachment bolt, as used in the earlier design, the shaft end was threaded and the impeller screwed on and locked by a small bolt. The increased diameter was carried through the dynamic seal area necessitating changes in the dimensions of these seals.

The instrumentation installed in the pump to detect dynamic shaft bending consists of four inductance type distance detectors placed 90 degrees apart (Fig. 1). The signal generated by the distance detectors sensing position of the rotating shaft was displayed on an oscilloscope and calibrated to give shaft movement in inches. Information on shaft displacement gained through this method was used to calculate the magnitude of the radial forces. It is presently considered that all causes of the rubbing contact of impeller and scroll experienced in the previous liquid metal test have been taken into account.

Assembly of the KP-1 turbopump and installation in the Liquid Metal Test Stand was completed. Assembly procedures have indicated a more rigid unit has been obtained by the design changes which incorporate the NP-1 pump bearing housing into the KP-1 turbopump.

C. Water Tests of RI-7B3 Impeller

The RI-7B3 impeller was finish machined by cutting the vane tip arc to provide the recommended tip clearance of 0.035 inch inlet to 0.025 inch discharge. However, due to an error in the machining, the position of the arc center was shifted 0.018 inch toward the impeller discharge This resulted in more material being removed from the vane tips at the impeller discharge than desired.

After machining the vane tip contour, water calibration of the RI-7B3 impeller was done. The hydraulic and cavitation data are shown in Figs. 2 and 3, respectively. The data for the RI-7A3 impeller is also shown for comparison. Removal of the additional material on the vane tips at the discharge did not affect the hydraulic performance of the RI-7B3 impeller.

Photographs of the RI-7A3 and RI-7B3 impellers in cavitation at the same conditions and vane tip clearance are shown in Figures 4 and 5. The cavitation formations are identical. Figs. 6 and 7 show the paint removal patterns of the RI-7A3 and RI-7B3 impellers for the same conditions. The similarity of these patterns is quite evident.

D. Liquid Metal Pump Test Stand

The Liquid Metal Pump Test Stand was easily adapted to perform the water test of the turbopump. Deaerated and demineralized water was used.

In place of the hot trap of the liquid metal test, a water-to-water heat exchanger was installed, as shown in Fig. 8. A control valve was located in the line to the heat exchanger to allow some flexibility in system throttling and thus investigate a small portion of the performance curve.

Flow measurement in the water test was done by two pitot-static probes located 90 degrees apart in the position of the electromagnetic flowmeter. The fluid velocity profile was established by traversing the pipe with the two probes, and flow rate was calculated from these data. Accuracy of this measurement system, based on flow profile, is estimated to be within two percent.

E. Water Test of KP-1 Turbopump

The KP-1 turbopump with the RI-7B3 impeller and distance detectors was installed in the Liquid Metal Pump Test Stand as shown in Fig. 9. The pump was dry run to seat the oil seals and to obtain a base line for the distance detectors. The patterns obtained on the oscilloscope are shown in Fig. 10.

The test loop was then filled with demineralized water which was degassed in the loop. Initial shakedown and check-out of the system proceeded, including calibration of the flow measurement method. Cavitation and some hydraulic data were obtained and are shown in Figs. 2 and 3.

Upon completion of this work, the flow rate was set at 700 gpm at a constant shaft speed of 6375 rpm, and data were recorded from the distance detectors. Photographs of the oscilloscope screen are given in Figs. 11, 12, and 13. These photographs were obtained in orderly steps of decreasing NPSH.

The oscilloscope traces of Fig. 12 show instabilities of the shaft position which are attributed to a relatively small, randomly applied hydraulic load at an NPSH value of 22 feet. When the NPSH value was decreased to 18 feet, oscillations occurred causing the trace to shift between Fig. 12B and Fig. 12C. These oscillations appeared to have approximately six seconds duration at each point. After about one minute, the trace stabilized to that of Fig. 12C and remained so for the duration of the time at this point. Fig. 12D is the same as Fig. 12C but with scale factor changed. Further decreases in NPSH values yielded the traces as shown in Figs. 12E and 12F.

Calculations based on the oscilloscope traces (and taking into account initial eccentricities and centrifugal forces due to imbalance) indicate radially applied hydraulic loads of about 150 pounds. Forces of this magnitude are quite capable of having caused the rubbing contact experienced during the liquid metal test described in Reference 3 (Final Report Under NASA Contract NAS3-2541).

The KP-1 turbopump was removed from the test stand far enough to permit painting the impeller with gold colored acrylic lacquer. After the paint was thoroughly dry, the pump was reinstalled. Test conditions were set at a shaft speed of 6375 rpm, flow rate of 700 gpm and an NPSH value of 30 feet. After a two hour run at these conditions, the pump was removed and the impeller examined for paint removal patterns. These patterns, shown in Figs. 13 and 14, are very similar to those of the RI-7A3 impeller under the same conditions in the Impeller Water Test Stand (Reference 1, Figs. 57 and 58). It is concluded from this test that the cavitation pattern in the turbopump is slightly less intense than the impeller test but located in the same areas.

IV. REFERENCES

1. Kulp, R. S. and Altieri, J. V., Jr. "Investigation of Cavitation Damage of a Mechanical Pump Impeller in High Temperature Potassium", Quarterly Progress Report No. 1, NASA CR-54383, (P&WA CNLM-6028), April 1965.

2. W. Rosenmann, "Experimental Investigations of Hydrodynamically Induced Shaft Forces With a Three Bladed Inducer", Rocketdyne TAMM-4115-34, May, 1964.

3. Kulp, R. S. and Altieri, J. V. Jr., "Cavitation Damage of Mechanical Pump Impellers Operating in Liquid Metal Space Power Loops", NASA CR-165, December, 1964.

FIG I

KP-I TURBOPUMP DESIGN (FINAL)

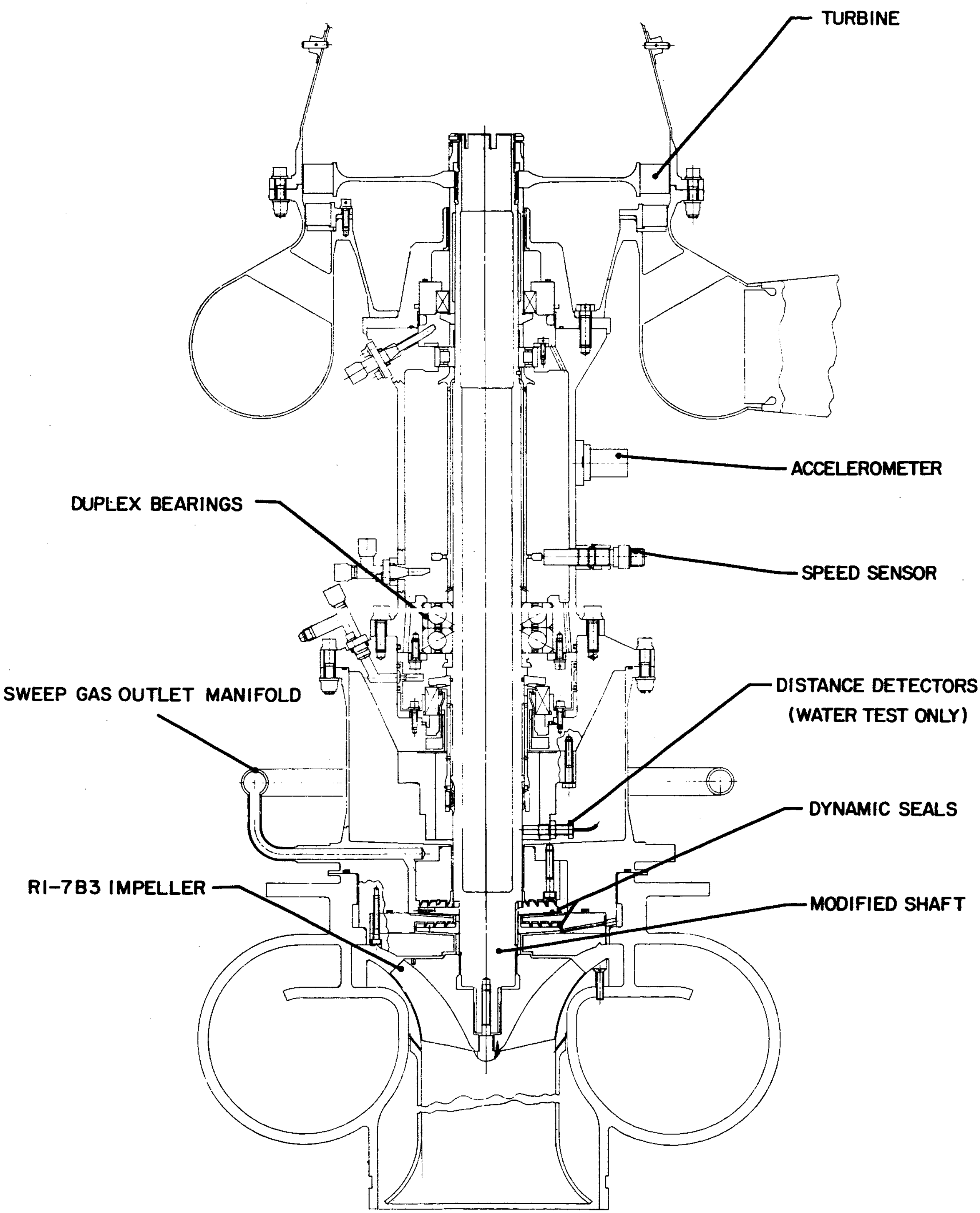


FIG 2

HYDRAULIC PERFORMANCE COMPARED FOR ALL WATER TESTS

SPEED - 6375 RPM

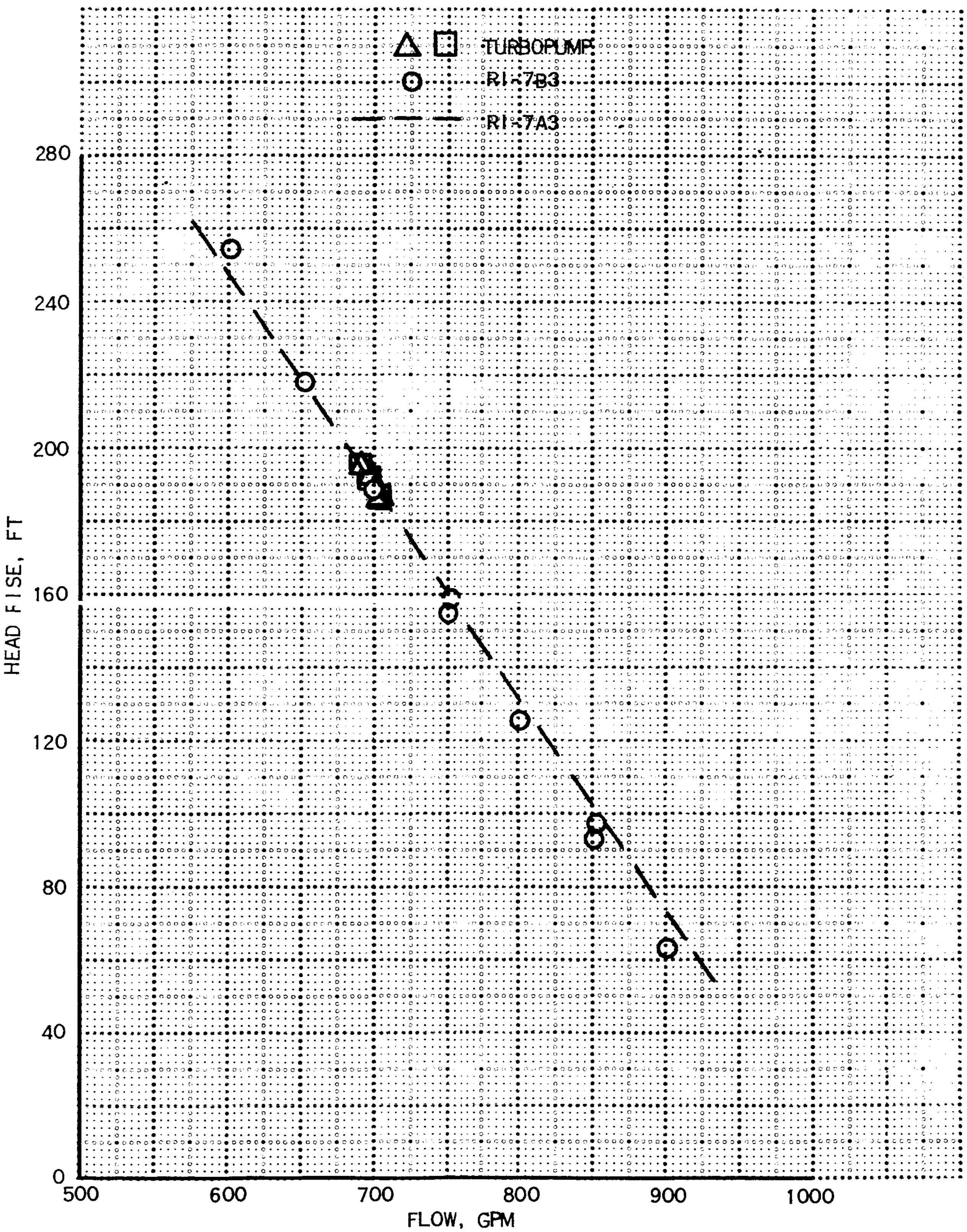


FIG 3

CAVITATION PERFORMANCE COMPARED FOR ALL WATER TESTS

SPEED - 6375 RPM
FLOW - 700 GPM

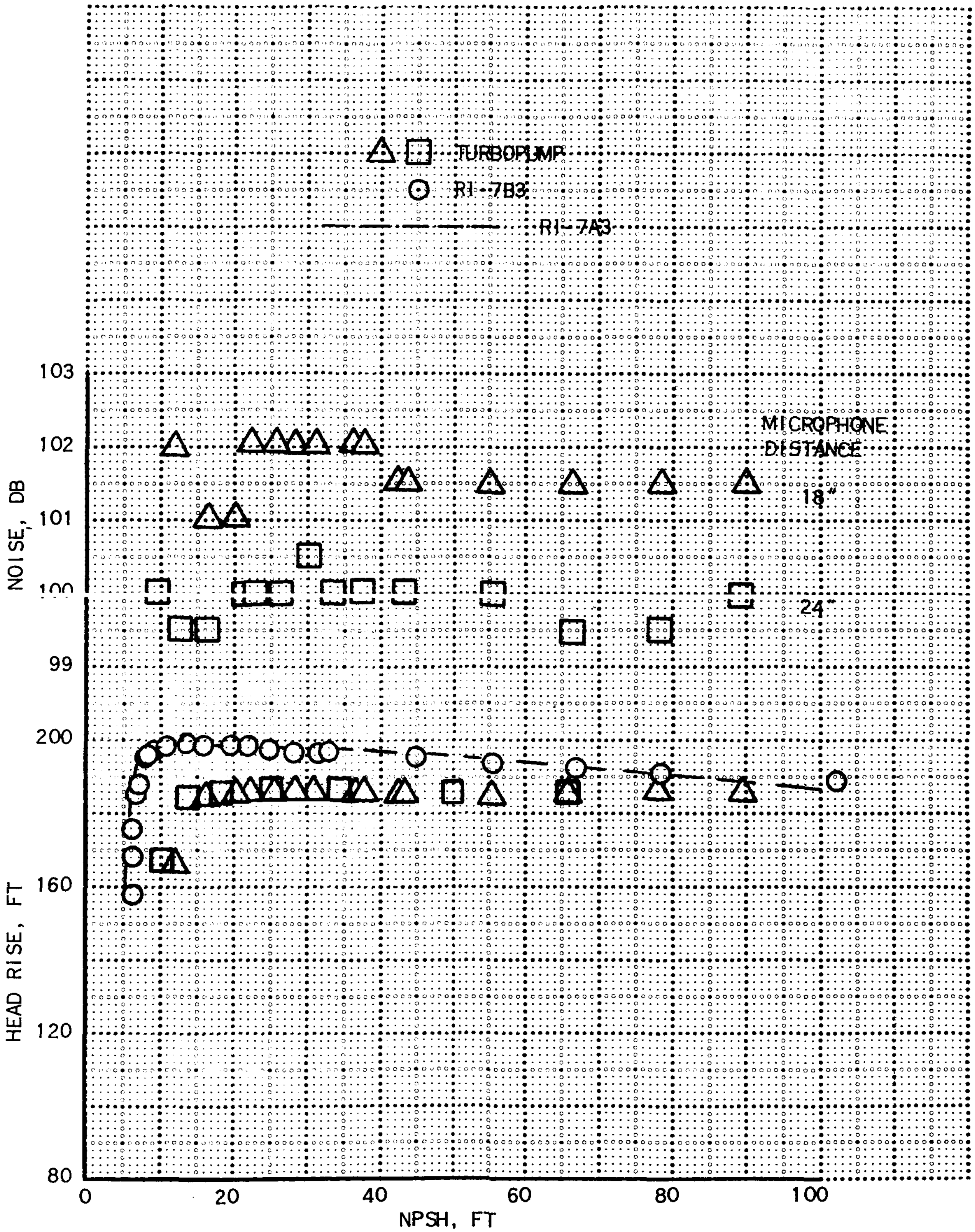


FIG 4

CAVITATION ON THE RI-7A3 IMPELLER AT AN NPSH OF 30 FEET AND 0.035-0.025 INCH VANE TIP CLEARANCE

SPEED: 6375 RPM N_{SV}: 13,100 FLOW: 700 GPM
VANE 3

FIG 5

CAVITATION ON THE RI-7B3 IMPELLER AT AN NPSH OF 30 FEET AND 0.035 INCH INLET AND 0.025 INCH DISCHARGE VANE TIP CLEARANCE

SHAFT SPEED: 6375 RPM N_{SV}: 13,100 FLOW RATE: 700 GPM

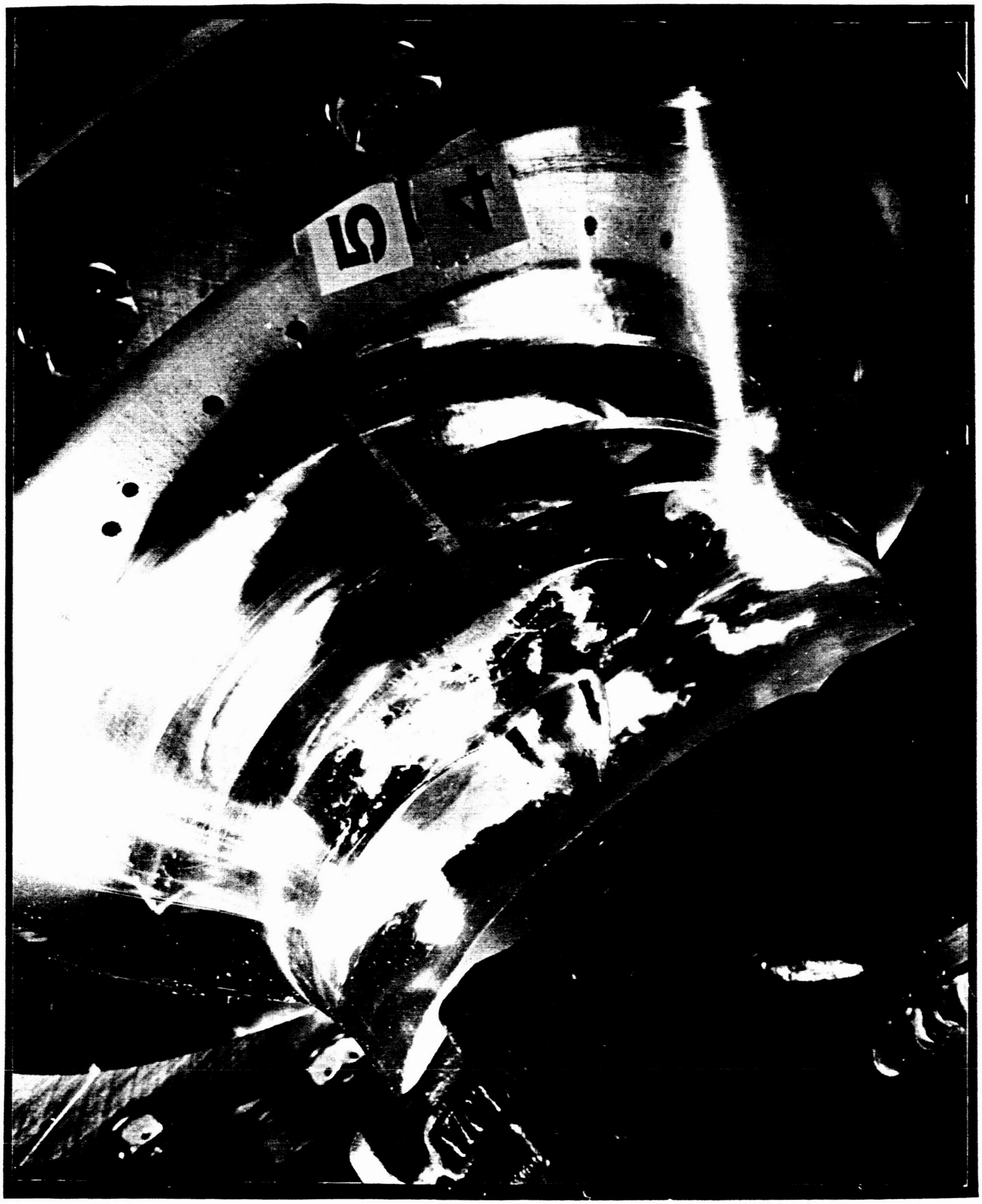


FIG 6

C-14457

RI-7A3 IMPELLER COATING DAMAGE PATTERNS AFTER 2 HOURS AT AN NPSH OF 30 FEET AND 0.035-0.025 INCH VANE TIP CLEARANCE (SUCTION SURFACES)

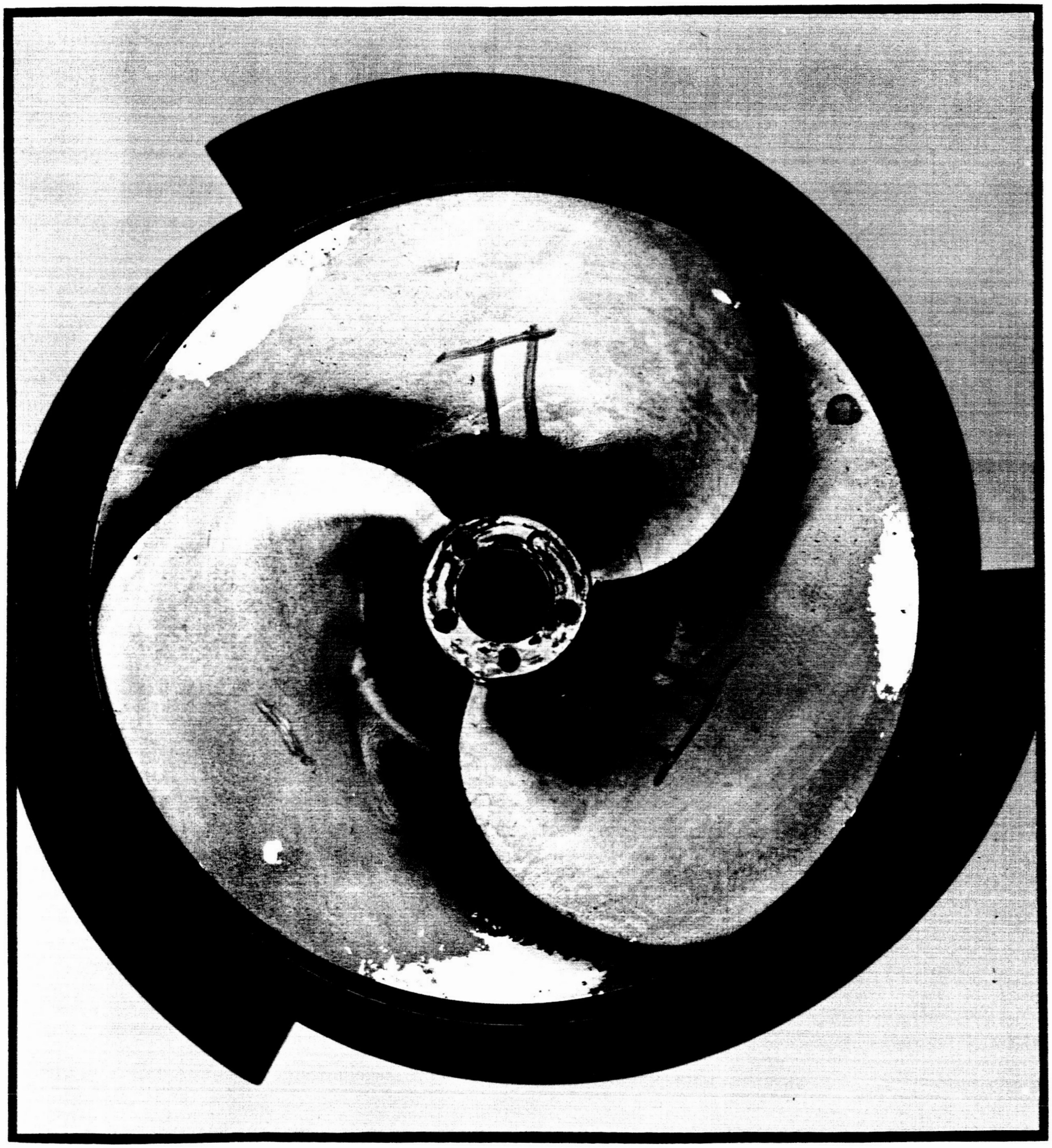
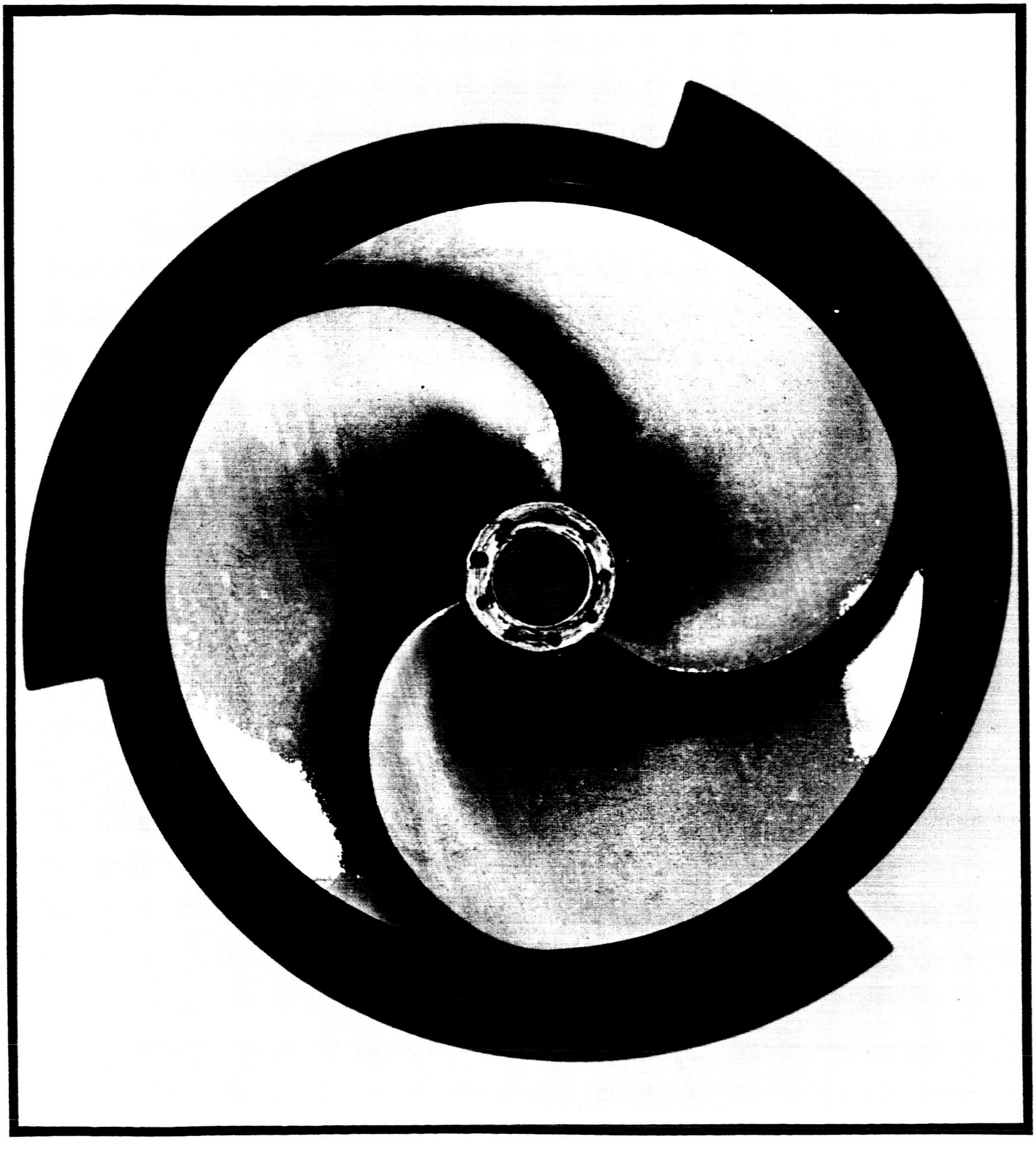


FIG 7

C-14641

RI -7B3 IMPELLER COATING DAMAGE PATTERNS AFTER 2 HOURS AT AN NPSH OF 30 FEET AND 0.035-0.025 INCH VANE TIP CLEARANCE



F-14754

FIG 8

LIQUID METAL PUMP TEST STAND MODIFIED FOR WATER TEST

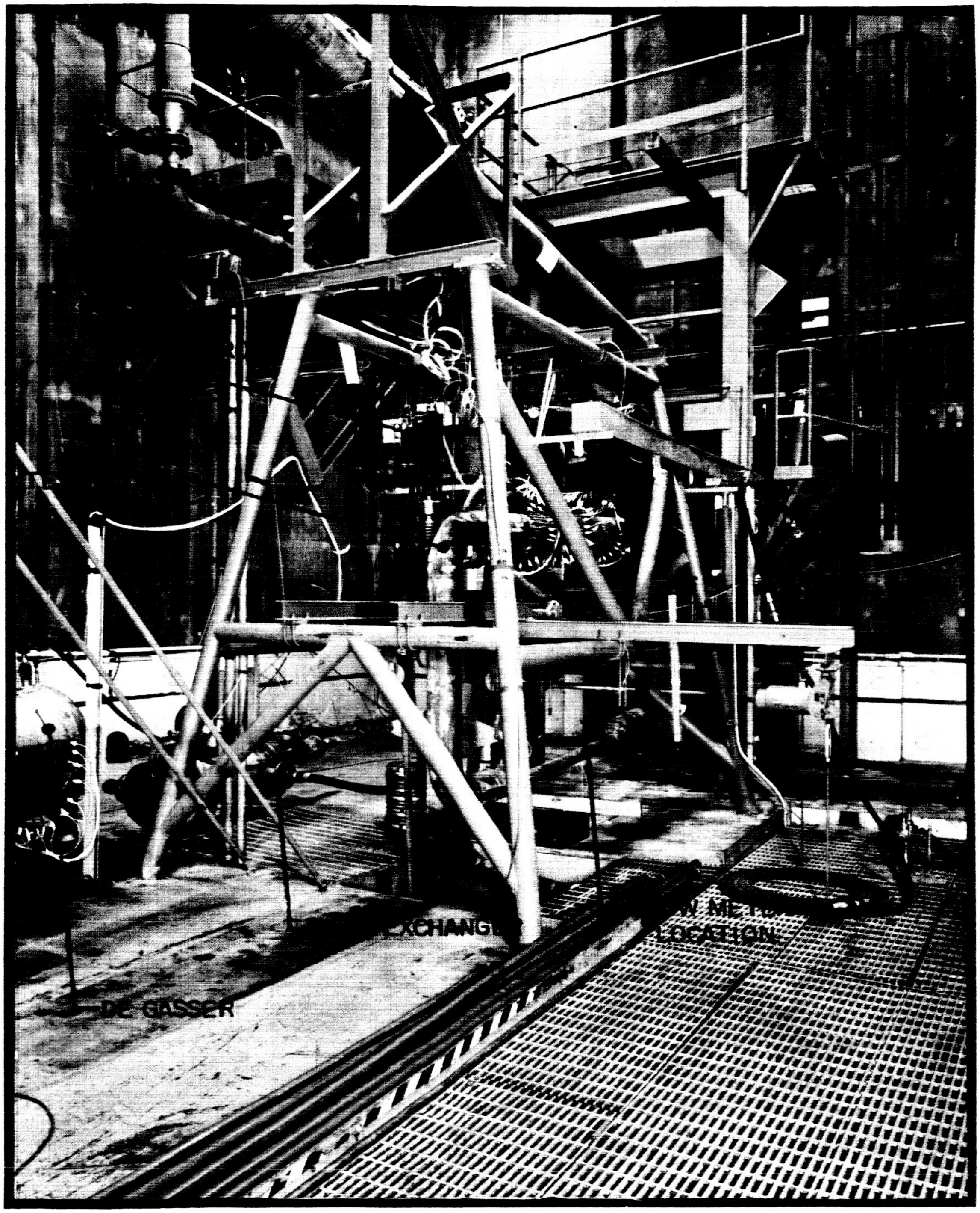


FIG 9

KP-1 TURBOPUMP INSTALLED IN LIQUID METAL PUMP TEST STAND

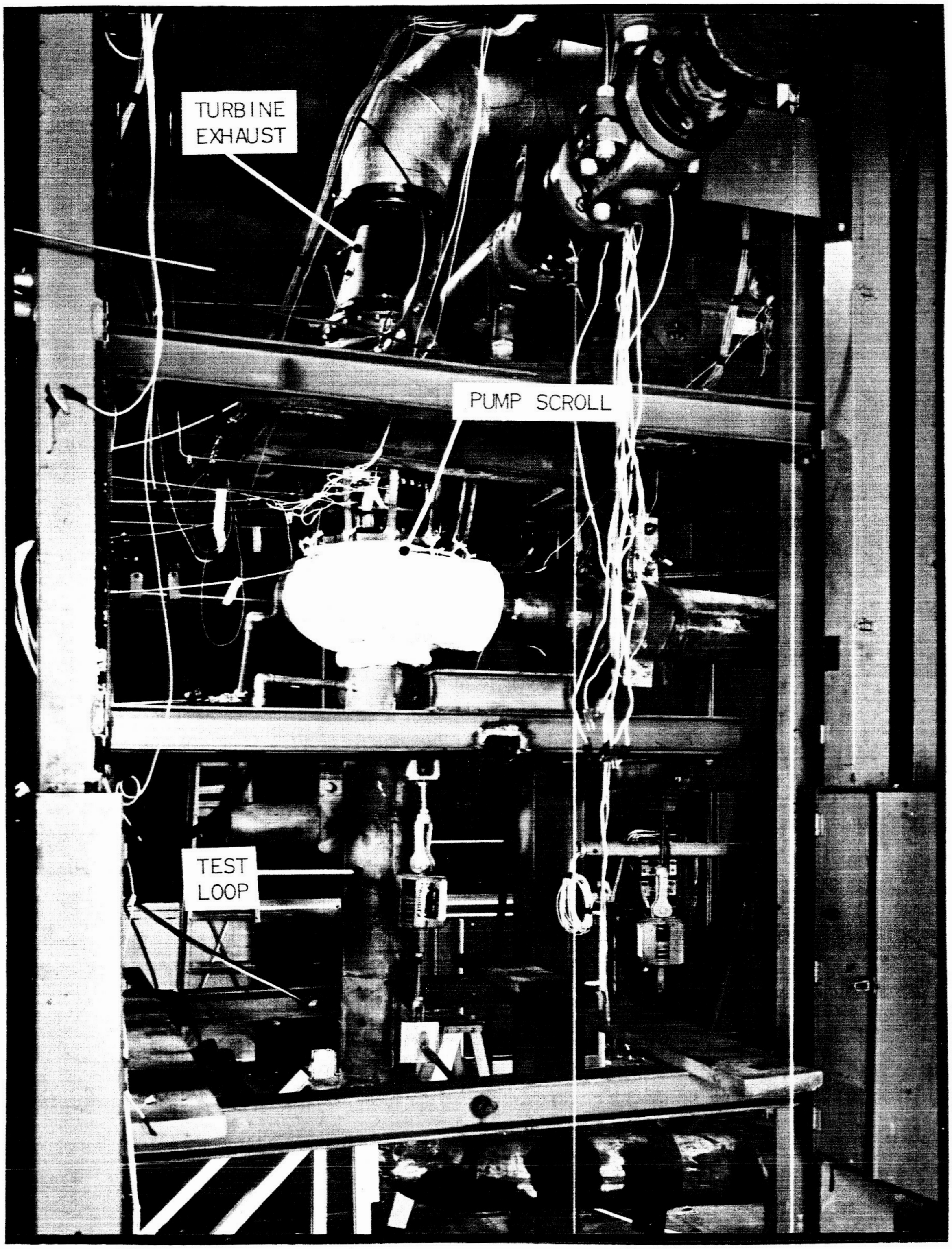


FIG 10

BASE LINE CALIBRATION OF DISTANCE DETECTORS

CONDITIONS: SCALE 1-1/2 SQUARES/0.001 INCH. NO WATER IN PUMP
SPEED: 6375 RPM INITIAL ECCENTRICITY: 0.0007 INCH

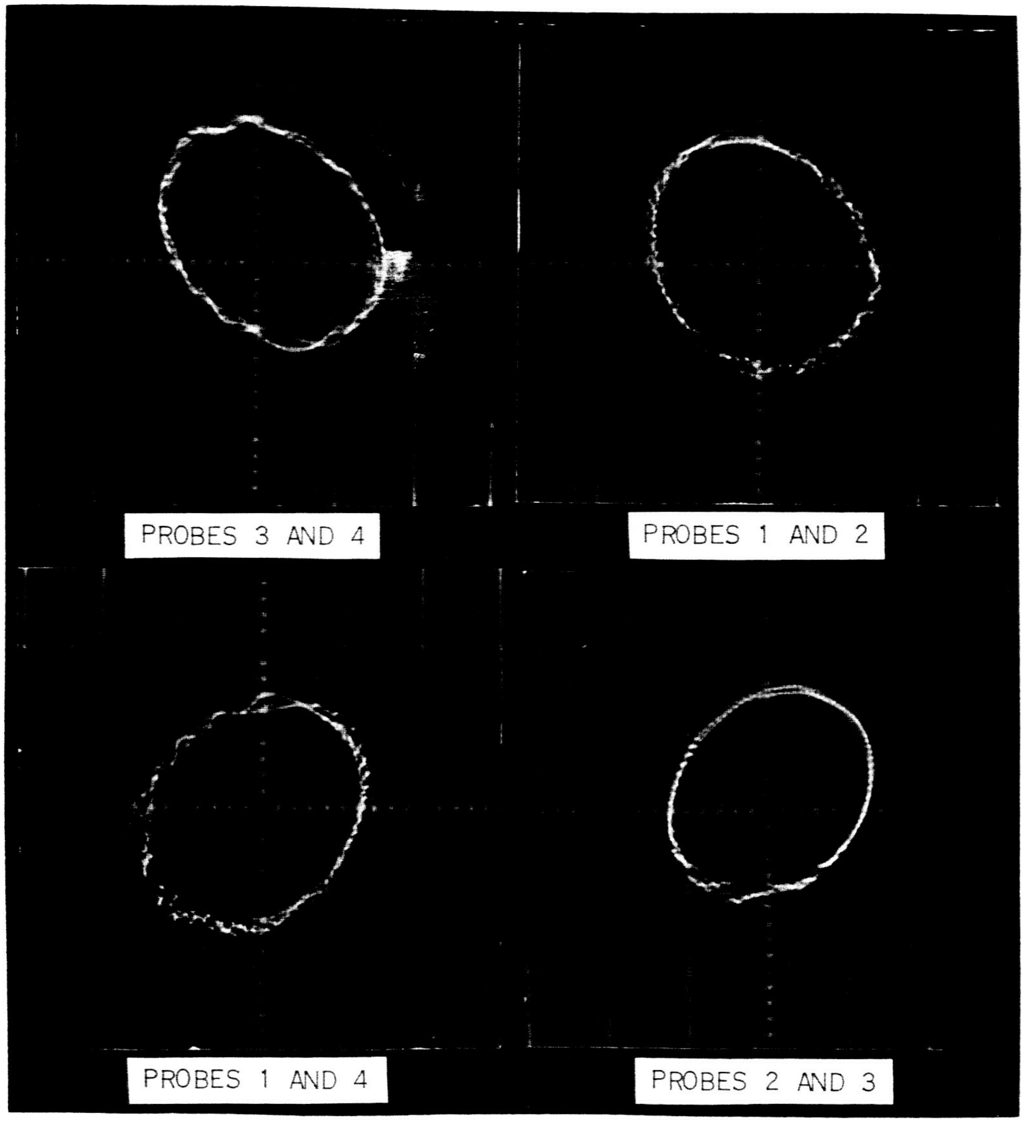


FIG 11

OSCILLOSCOPE TRACES AT HIGH NPSH VALUES

SCALE: 1-1/2 SQUARES/0.001 INCH SPEED: 6375 RPM

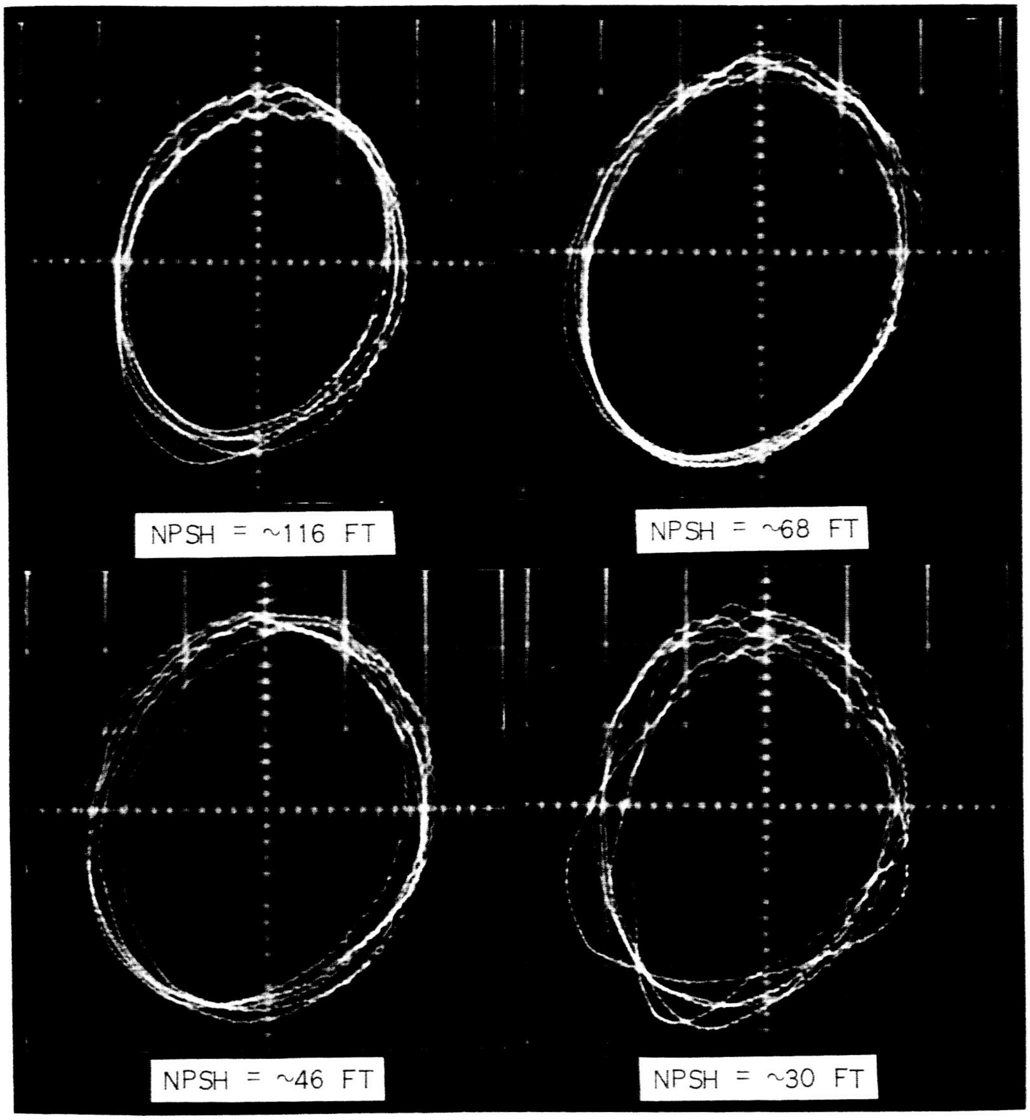
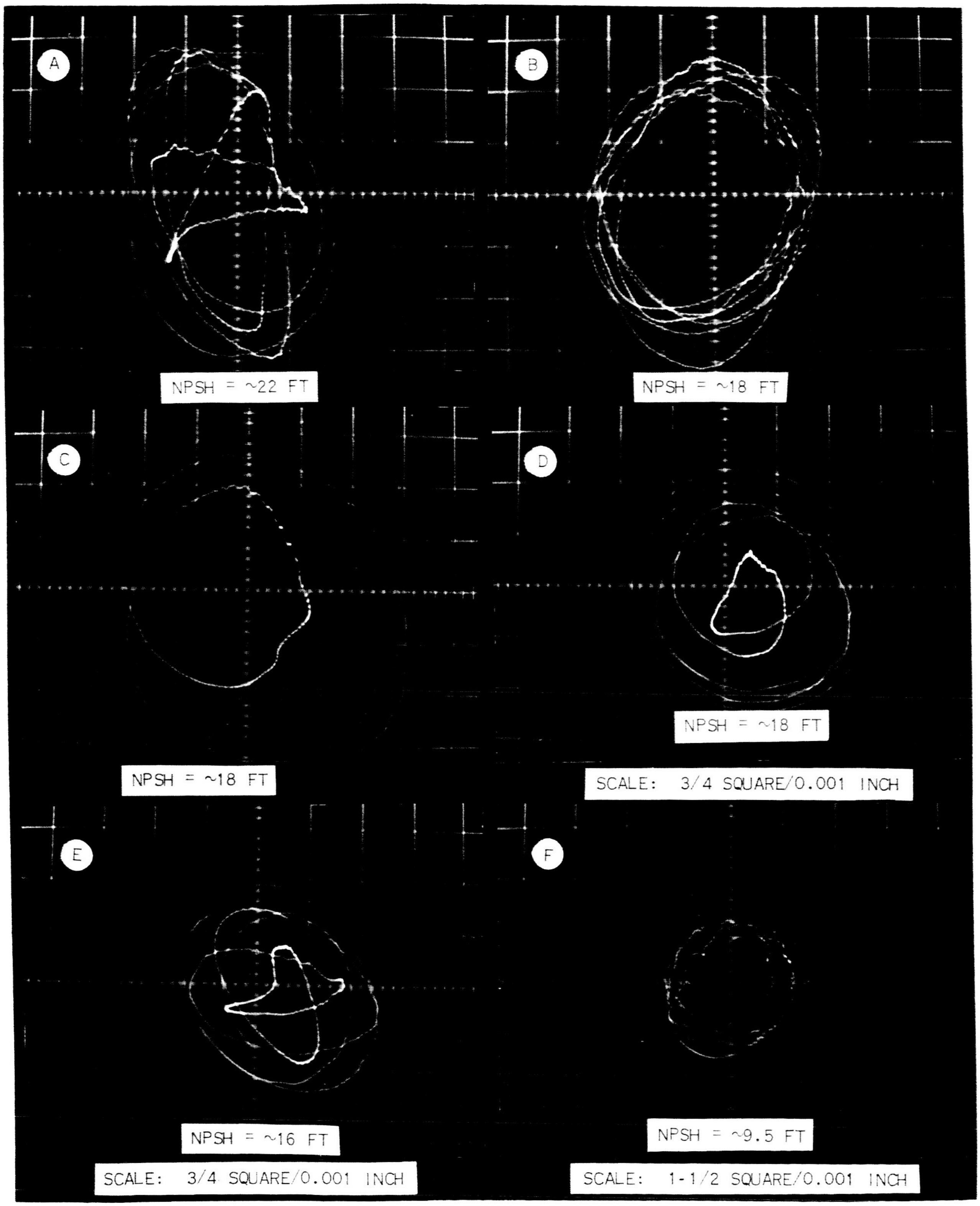


FIG 12

OSCILLOSCOPE TRACES FROM DISTANCE DETECTORS

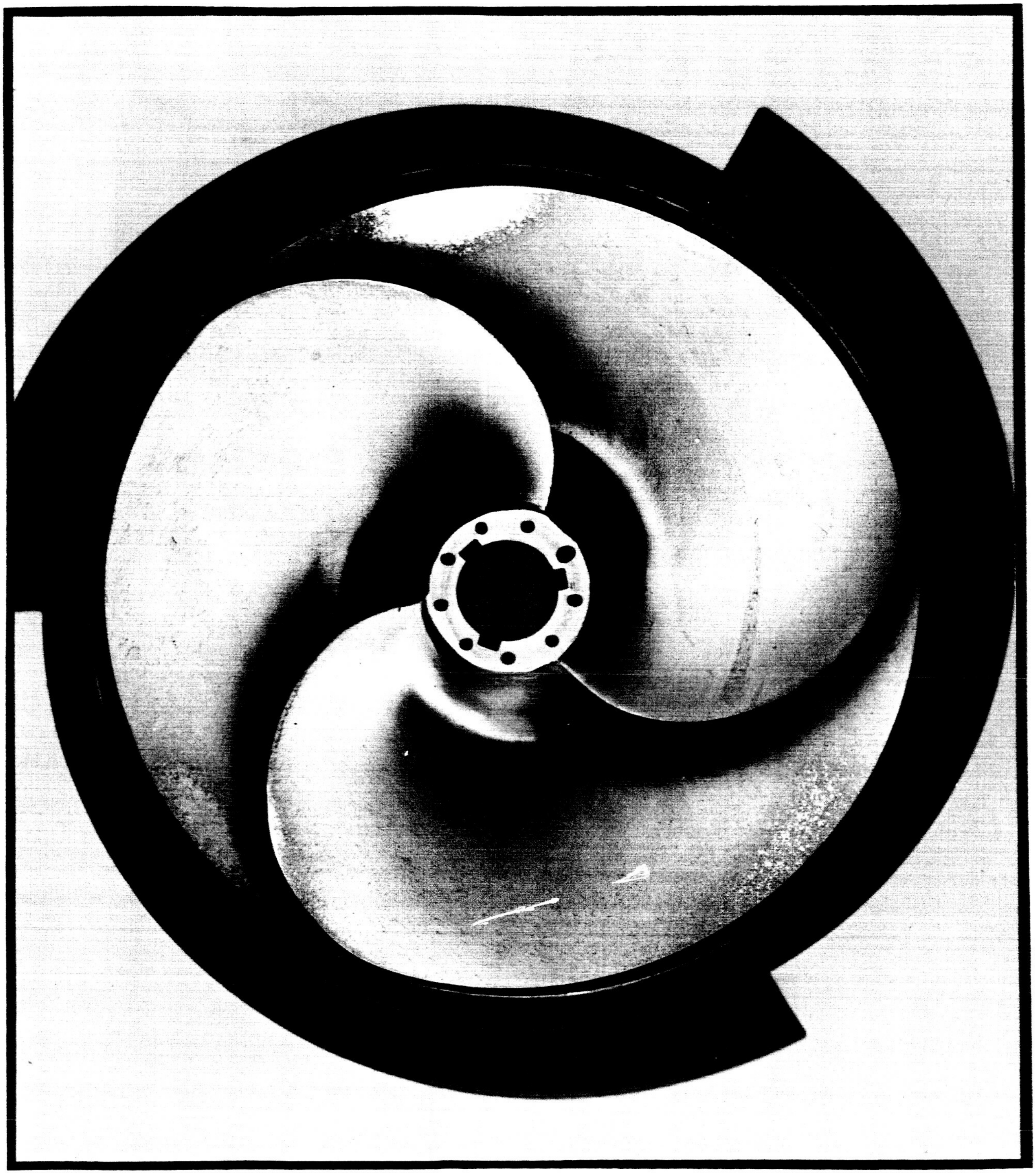
SCALE: 1-1/2 SQUARES/0.001 INCH SPEED: 6375 RPM



C-15042

FIG 13

PAINT REMOVAL PATTERNS ON IMPELLER INLET



C-15041

FIG 14

PRESSURE SURFACE PAINT REMOVAL PATTERNS

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