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OTV Bearing Deflection Investigation

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The primary goal of the Bearing Deflectometer Investigation was to gain experience in the use of fiber optic displacement probe technology for bearing health monitoring in a liquid hydrogen trubopump. The work specified in this Task Order was conducted in conjunction with Air Force Rocket Propulsion Laboratory Contract F04611-86-C-0010. APD conducted the analysis and design coordination to provide a displacement probe design compatible with the XLR-134 liquid hydrogen turbopump assembly (TPA). Specifications and requirements of the bearing deflectometer were established working with Mechanical technology Instruments, Inc. (MTI). The TPA design accommodated positioning of the probe to measure outer race cyclic deflections of the pump inlet bearing. The fiber optic sensor was installed as required in the TPA and sensor output was recorded during the TPA testing. Data review indicated that no bearing deflection signature could be differentiated from the inherent system noise. Alternate sensor installations were not investigated, but might yield different results.

1.0 INTRODUCTION/SUMMARY

Many space transportation propulsion system designs utilize turbomachinery with rolling element bearings. Extreme radial and axial load demands placed upon the bearings often result in their being the key system life determinator. Providing improved means of monitoring bearing life is essential to the establishment of propulsion system performance, reliability and maintainence requirements. In the interest of the aforementioned goal, the NASA LeRC developed the Bearing Deflectometer Investigation as Task Order E.5 of the Orbit Transfer Rocket Engine Technology Program. The task order called for the use of an MTI Fotonic sensor, a fiber optics proximity monitoring instrument. The instrument would be installed in a liquid hydrogen turbopump to better understand it's potential for bearing health monitoring in a cryogenic environment..

Subtask 1 (Design), of the investigation task order called for incorporating the MTI 1000 Fotonic sensor into the design of the XLR-134 liquid hydrogen turbopump developed under the Air Force Rocket Propulsion Laboratory contract F04611-86-C-0010. The turbopump housing design was made to accommodate the sensor probe such that it would monitor the outside diameter of the outer bearing race of the single pump inlet bearing. MTI sensors had some history of use in monitoring outer bearing race deflections in turbomachinery and the Task E.5 investigation design intent was to further the study by monitoring bearing deflection patterns in the cryogenic environment of the XLR-134 hydrogen turbopump.

Subtask 2 (Test) of the task order called for installation of the probe into the turbopump for check-out, monitoring and recording of the displacement probe output during the turbopump test. Subsequent to the test, the resulting data would be reduced for evaluation and reporting.

The displacement probe installed for testing was the MTI model 3812, selected for it's high sensitivity. The installation gap and respective output voltage were set for the displacement probe response to be on the forward slope of the probe calibration curve. It was determined that once the system reached the cryogenic operating temperature that the probe to outer race gap would increase but that the resulting operating output would still correspond to the desired front slope portion of the calibration curve.

1.0, Introduction/Summary (cont.)

Analysis of the test data indicated that while the sensor output was within the desire range for optimum displacement sensitivity, it was not possible to establish the expected bearing trace or signature. The ambient probe gap was altered between tests in order to acquire data over a slightly wider operating range. The bearing signatures which are vital to the establishment of a bearing health trend could not be differentiated from the inherent system noise.

The test plan for the XLR-134 fuel turbopump called for extensive testing at nominal speed (74K RPM) to verify it's long life design. In fact, the test program was terminated short of it's intended goals due to lack of follow-on contract support. As a result, there was not sufficient test run time available to to alter the set-up of the MTI 1000 Fotonic sensor and test system to achieve more positive results.

2.0 EXPERIMENT DESIGN DETAILS

2.1 BEARING DEFLECTOMETER

The NASA LeRC provided the instrument based on previous experience with the design and a desire to gain further knowledge of it's range of application. The Model 1000 Fotonic sensor is manufactured by Mechanical Technology Inc. (MTI) and utilizes a fiber optic probe system which is designed to perform non-contact displacement/vibration and surface condition measurements. The system utilizes probe tip designs incorporating optical fibers with various combinations and orientations of sending and receiving fibers depending on the application, wide range or high sensitivity.

Two different probe tip designs were ordered for the test series. Each of the probes had an outer tip diameter of 1/8 in. and utilized a specially designed safety barrier in the cable sheath to keep hydrogen gas from finding it's way from the inner turbopump housing area to the sensor signal conditioner. One of the probes designs (MTI-3812) utilizes a random pattern of sending and receiving fibers for high sensitivity. The other probe (MTI-3814) is a hemispherical design and was acquired for the purposes of providing a broader range option. The probe tip length requirement was based on that which would allow the tip to penetrate through the turbopump housing and accommodate the special fitting to hold the probe in place. Figure 1 shows the sketch that was used for design definition and fabrication.

2.2 TURBOPUMP AND PROBE

Special design considerations were required to incorporate the MTI probe into the XLR-134 turbopump. Figure 2 shows a cross section of the turbopump with the probe installed. Modifications to the baseline pump design included adding a raised boss to the outside of the housing at the location of the single pump inlet bearing. Machined into the boss, an MS 33649 port provided for acceptance of a fitting which incorporates a standard AN style union on the boss side and a 1/8 in. Swagelok tube fitting on the probe entrance end. The outer and inner pump housings were match machined to accept the probe tip. The clearance between the inner housing and probe tip end was minimal to restrict internal flow losses in the pump.

3.0 TEST DETAILS

3.1 HARDWARE SET-UP

Figure 3 shows the XLR-134 turbopump on the test stand with the MTI displacement probe installed. In order to avoid damage to the probe optical fibers, the swage fitting utilized a composition TFE and glass fiber ferrel.

Throughout the testing, the ferrel provided a positive means for holding the probe tip while effectively sealing the pump housing at the interface. Figure 4 shows the MTI 1000 signal conditioning unit installed in the test bay. The unit was installed in a fire safety box during testing due to the proximity of hydrogen in the area of the test stand.

3.2 TEST SET-UP

The probe with the random fiber pattern (MTI-3812) was selected for use based on it's high sensitivity and the feeling that any outer race deformation resulting from ball bearing passing loads would be slight. Two different probe tip gaps and their resulting voltage output were utilized during the course of the testing. Due to the

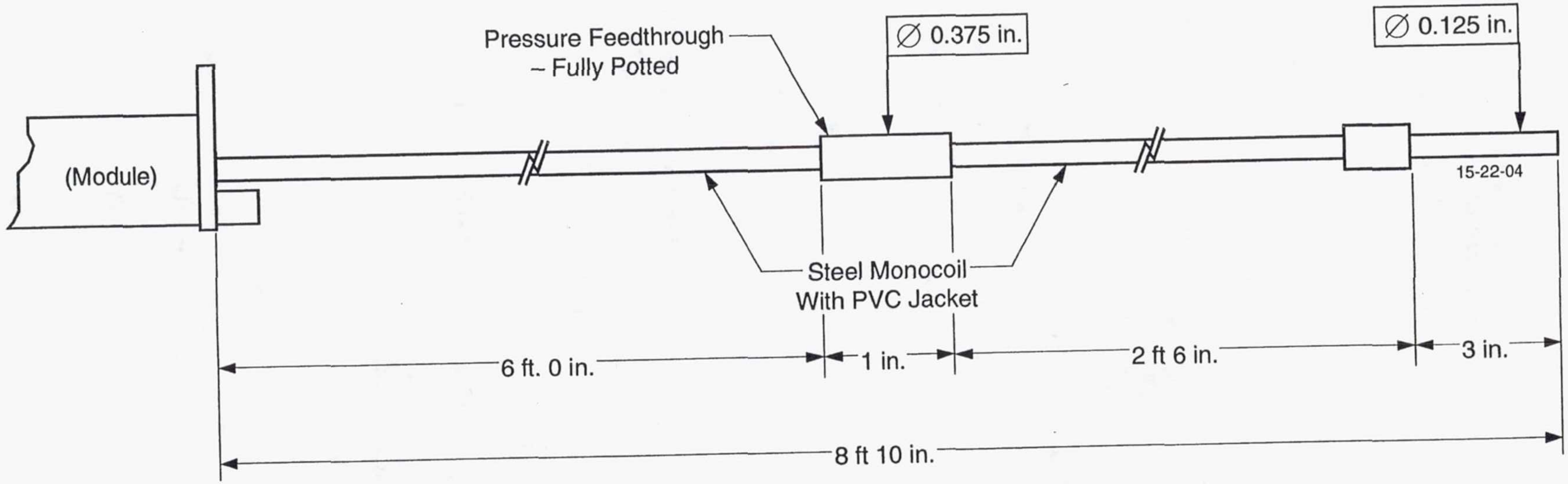

Figure 1. MTI Fotonic Sensor Design Dimensions

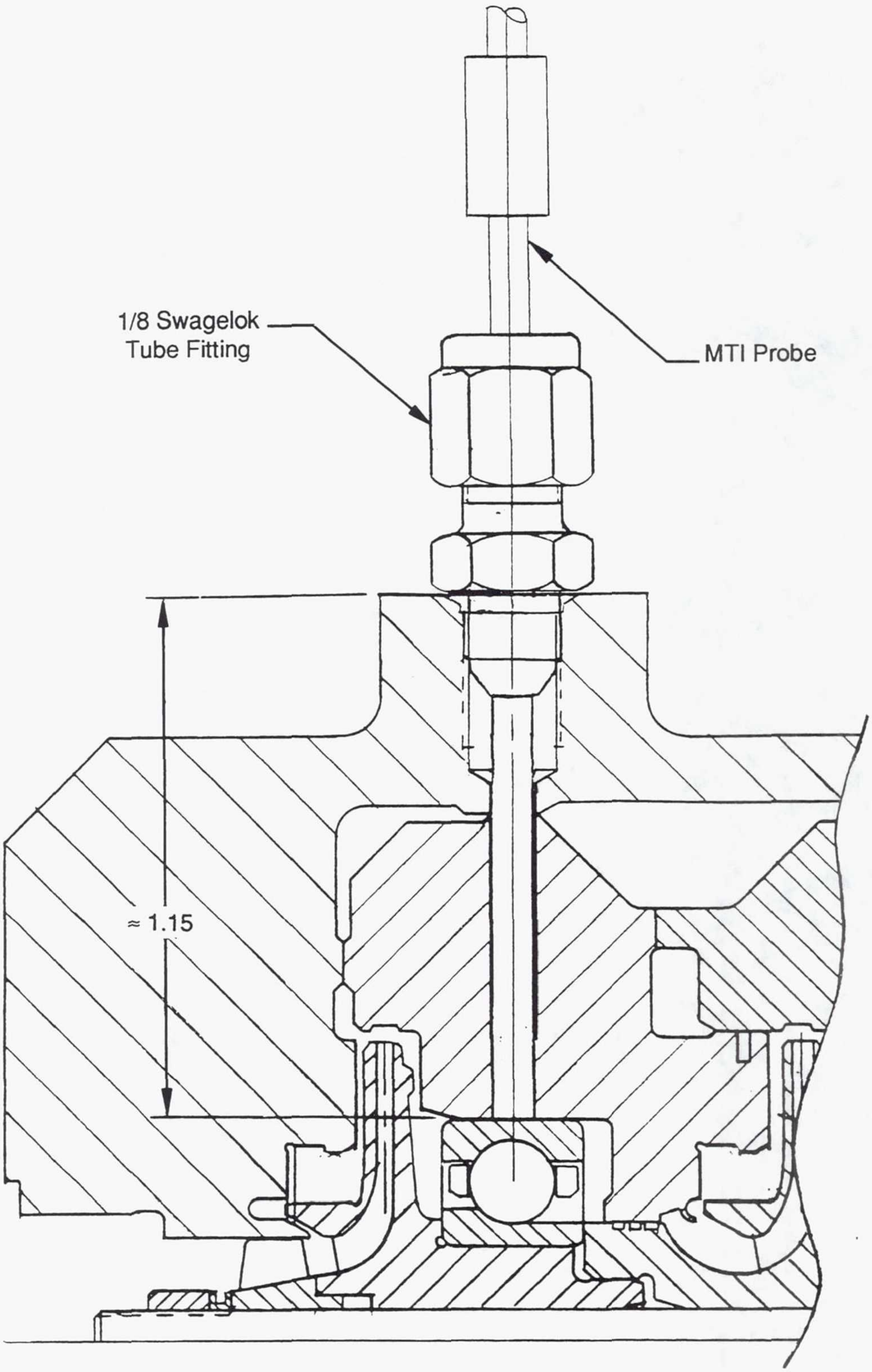

Figure 2 XLR-134 Fuel Turbopump/MTI Probe Assembly

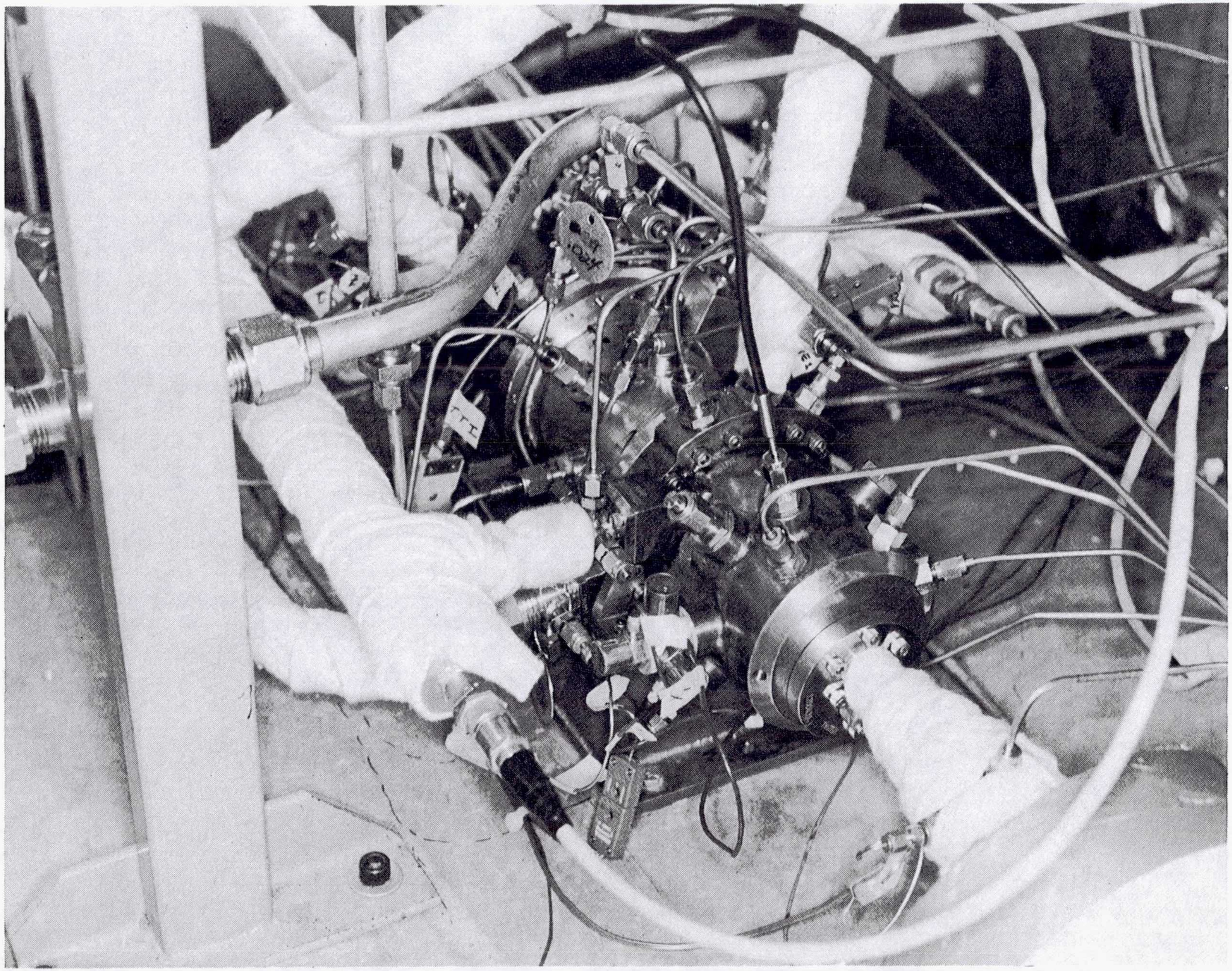

Figure 3 XLR-134 Turbopump With MTI Probe Installed

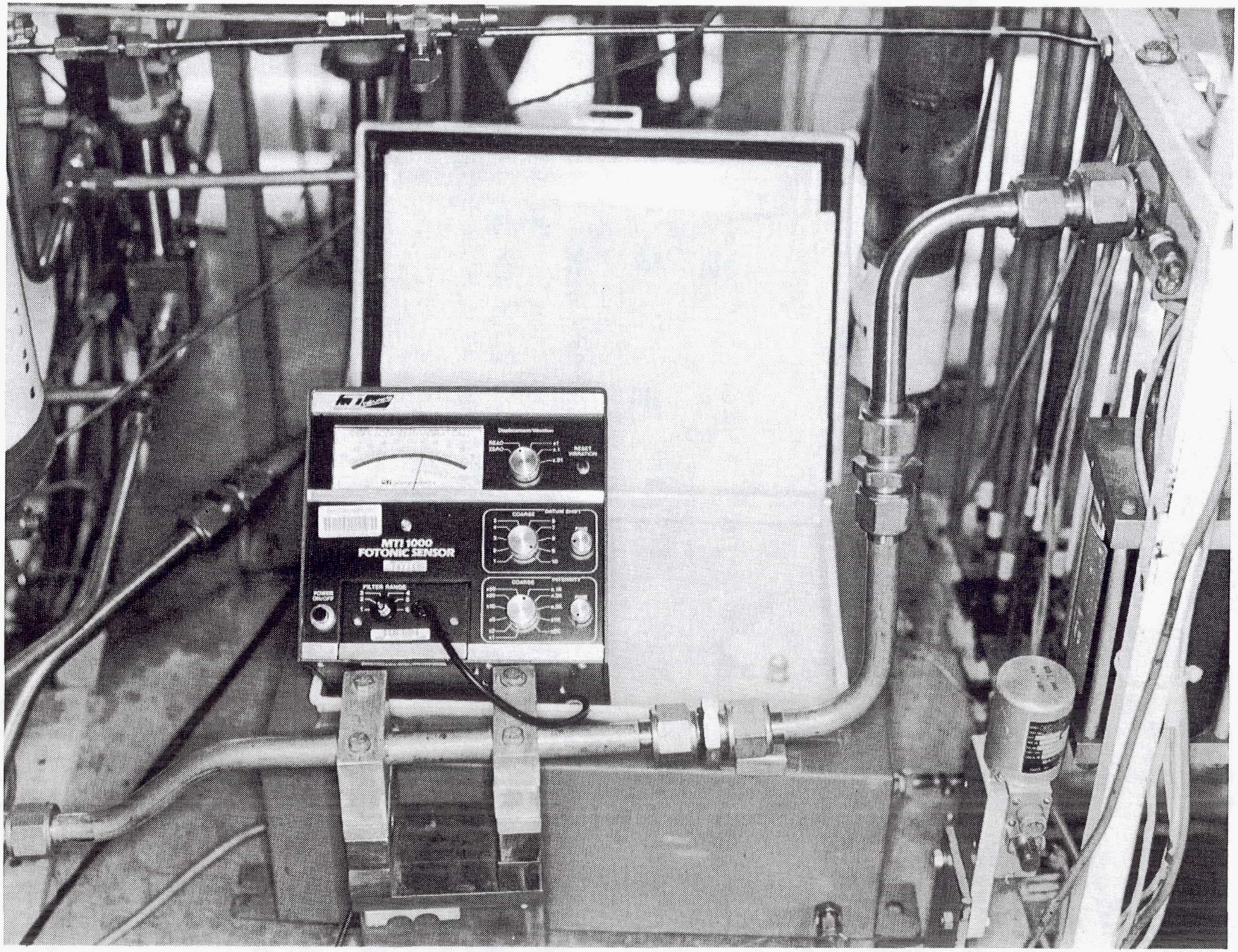

Figure 4 MTI 1000 Signal Conditioning Unit in the Test Bay

nature of the hardware, it was not possible to physically measure the probe tip to bearing race gap. In each case the gap was simply established by using the probe calibration curve and correlating the output voltage to the indicated gap. Frequency response was based upon the expected 1233 Hz signal for rotating assembly unbalance and radial play and 3.7K to 6.2K Hz ball passing frequency. Ball passing frequency is a function of the bearing axial load. The expected frequency response was based upon a planned turbopump nominal speed of 74K RPM. Calibration and frequency response curves were furnished with each of the probe tip fiber configurations and are included in Appendix A along with probe specifications.. The following table indicates the set-up conditions for the probe and signal conditioner:

Voltage Ambient	Voltage Cryo	Filter Setting	Datum Shift	Intensity Setting	Displacement/ Vibration
2.1	.73	2	10	X.1K	Read
4.4	2.0	2	10	X1K	Read

As with all of the turbopump test instrumentation, the output from the probe was remotely monitored from the test control room. A visual reading of the output voltage was available at all times and signal was recorded on FM tape. Due to the nature of the test it was not possible to alter the set-up while the pump was "chilled in" or running.

4.0 DATA ANALYSIS

The test data which was recorded on FM tape was given to the Dynamics Analysis group. They were directed to look at specific channels of the tape to establish a period during which the turbopump was operating at it's nominal rotational speed after which they could look at the displacement sensor data. They were told to look for any signal in the 1.2K to 6.2 Hz frequency domain. They utilized a dynamic signal analyzer to analyze at the data. The results of their analysis indicated that there was no recorded data representative of shaft unbalance, axial play or outer race deformation due to ball passing loads.

5.0 CONCLUSION

The XLR-134 turbopump test plan was established to demonstrate long life operation of the pump assembly. The actual turbopump test time achieved was only a fraction of that which was planned due to limited funding.. As a result, there was not sufficient time available to iterate between reconfiguration of the MTI displacement probe set-up and dynamics analysis until more positive results were achieved.

APPENDIX A

PROBE DATA

TABLE A-1

MTI FOTONIC PROBE SPECIFICATIONS

	MTI-3812	MTI-3814
• Probe tip diameter	0.125 in.	0.125 in.
• Frequency response	70 KHz (-3 db)	70 KHz (-3db)
• Output signal ripple	20 mV p-p	20 mV p-p
• Resolution (% of range)	0.2 dynamic	0.3 dynamic
• Resolution (% of range)	0.05 static	0.1 static
• Sensitivity	0.6 μ in./mV	7.0 μ in./mV
• Linear range	0.004 in.	0.030 in.
• Standoff	0.0025 in.	0.25 in.

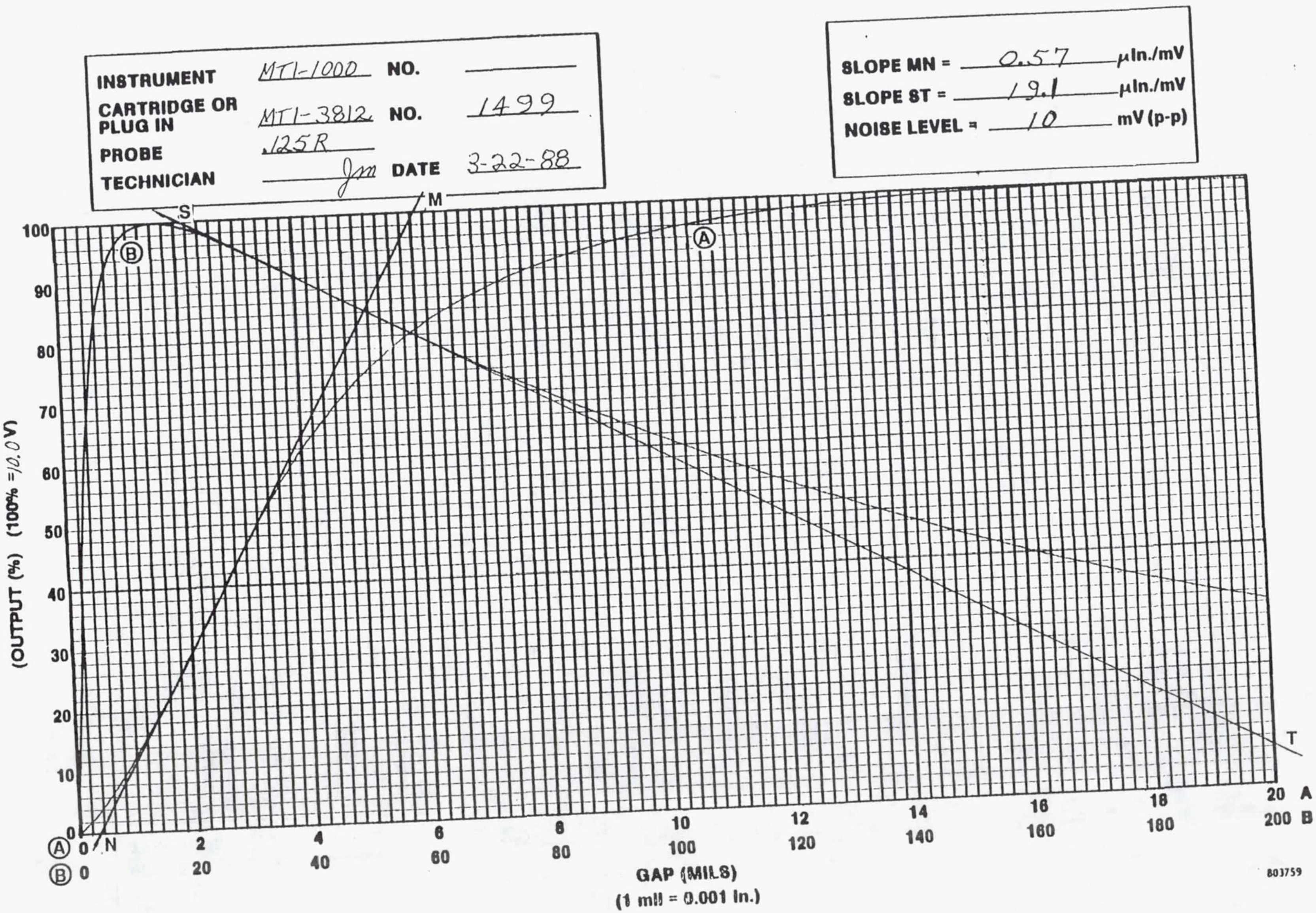

Figure A-1 MTI-3812 Probe Gap Calibration

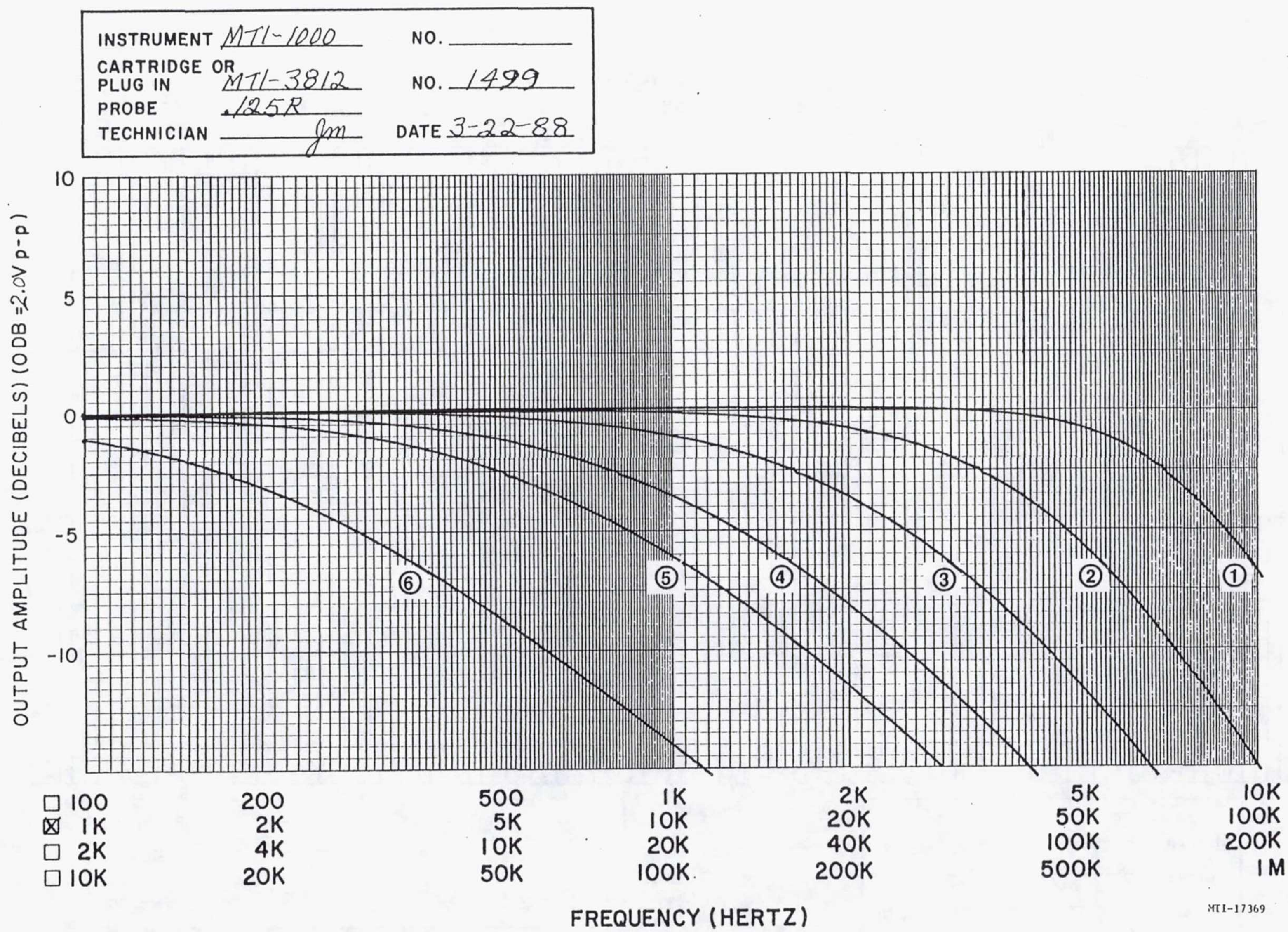

Figure A-2 MTI-3812 Probe Frequency Response

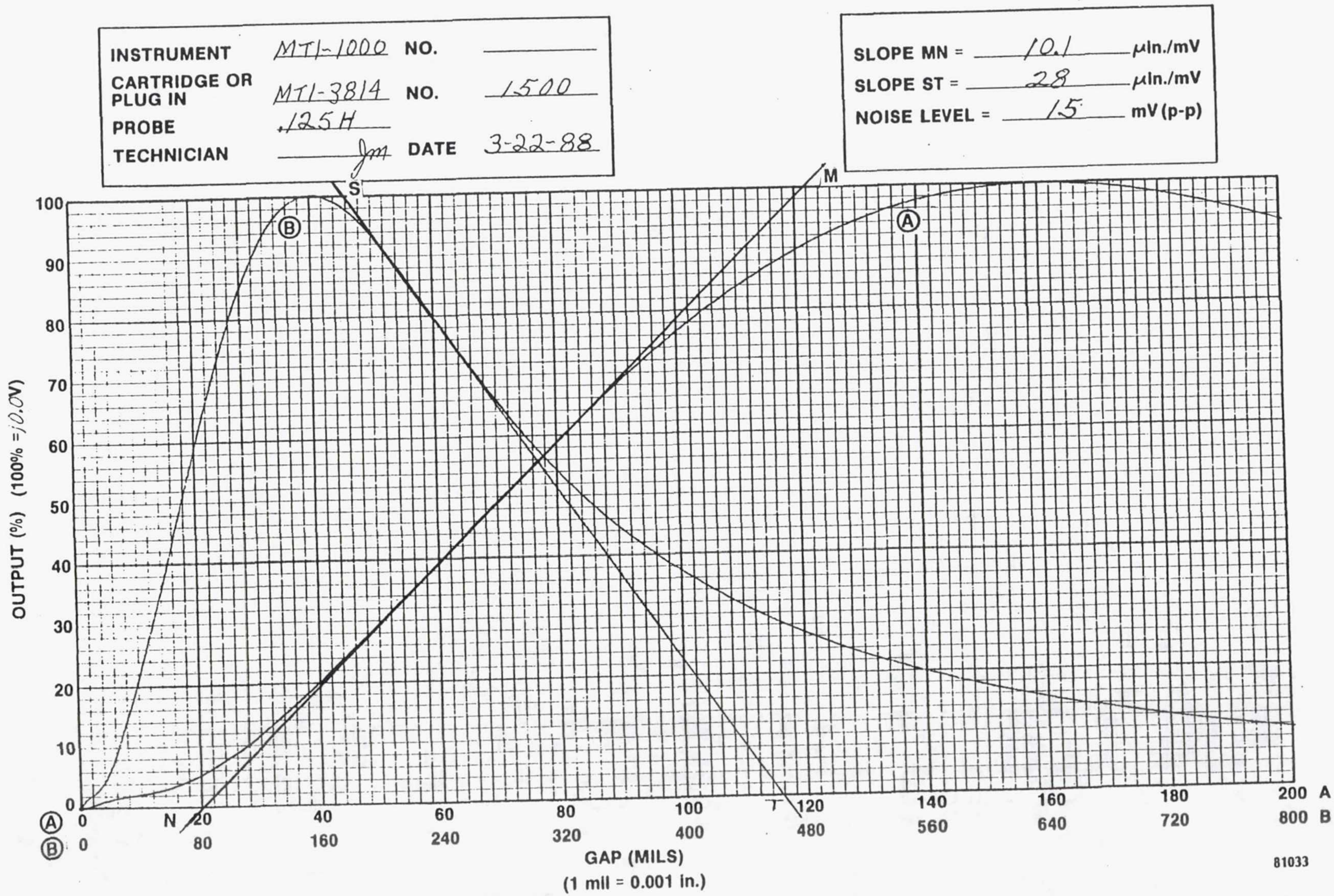

Figure A-3 MTI-3812 Probe Gap Calibration

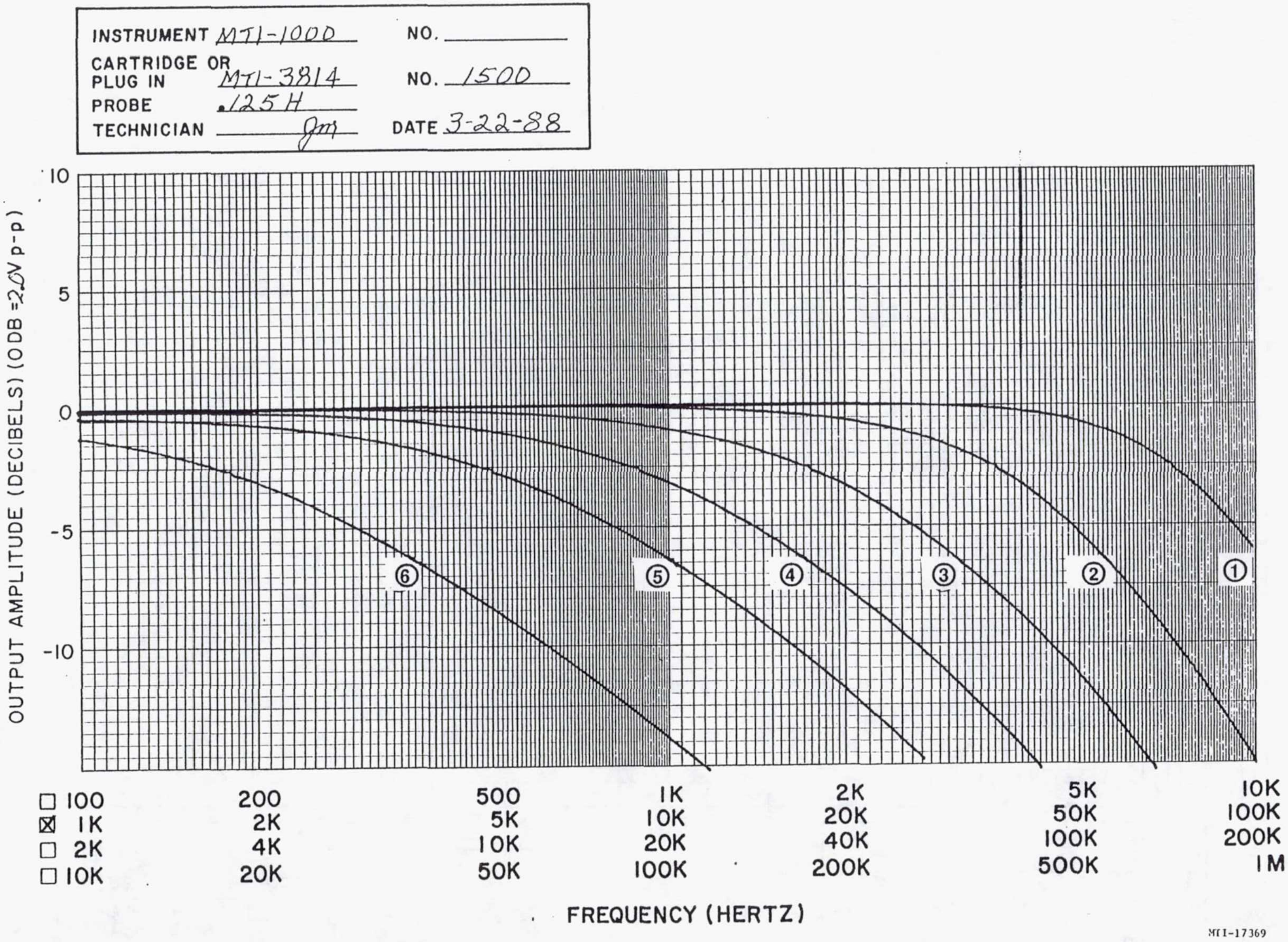

Figure A-4 MTI-3812 Probe Frequency Response

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