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FINAL TECHNICAL REPORT

NASA GRANT NAG1-989

Title

The Study of Pressure Measurement Techniques and Devices in the Range of 10^{-1} to 10^{-5} torr (2 millipsi to 0.2 micropsi)

submitted to

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by

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(NASA-CR-186926) THE STUDY OF PRESSURE MEASUREMENT TECHNIQUES AND DEVICES IN THE RANGE OF 10(EXP -1) TO 10(EXP -5) TORR (2 MILLIPSI TO 0.2 MICROPSI) Final Report, 1 Dec. 1989 - 9 Jun. 1990 (Texas Univ. at

N91-11667

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I. SUMMARY

This is the final technical report on the research conducted under NASA grant NAG1-989 entitled "Study of Pressure Measurement Techniques and Devices in the Range of 10^{-1} to 10^{-5} torr." The atmospheric pressure range being studied lies in a region where conventional pressure sensing devices do not provide meaningful measurements. However, a hot filament gauge has been developed and miniaturized which will measure the pressure in the 10^{-1} to 10^{-5} torr (2 millipsi to 0.2 μpsi) region, hence the name Micropsi gauge. Laboratory studies have been made comparing the currently available devices with the newly developed miniature low power "Micropsi" pressure sensor.

II. BACKGROUND

This research studied the development of a pressure gauge suitable for measuring the pressure in the baseflow region of a hypervelocity vehicle as it enters the upper atmosphere of the earth in the region from somewhat above 100 km down to 80 km or below. The flow around the vehicle is expected to be highly turbulent with predicted pressures in the range of 10^{-1} to 10^{-4} torr or lower. Other pressure gauges on such a vehicle are of the variable reluctance monometer type that are capable of measuring pressures in the range of 20 to 0.01 psi (full scale). These are not suitable for the baseflow region as they do not have sufficient sensitivity.

In order to measure the pressure distribution over the backside of the vehicle, a light weight pressure gauge having a fairly rapid response time has been developed and tested over the required pressure range. If this gauge were to be flown on a hyper-velocity vehicle, data would be available to provide a baseline for validating nonequilibrium flow field computer models and for correlating with radiative heat transfer models. The distribution of gas pressures on the back side of the aeroshell is important in determining the degree of turbulence around the vehicle which in turn affects the heat budget. By having baseline data that would place flow field models of such vehicles on a firmly established basis, the design of the future Aeroassist Orbital Transfer Vehicles (AOTV) would be greatly enhanced.

III. THE PROBLEM

In order to study the pressure distribution around the baseflow region of a hypervelocity vehicle, it will be necessary to mount a number (upwards of 10) pressure gauges around the vehicle's perimeter, on the rocket motor housing and on its rear side. See Figure 4 for possible location of the gauges. The anticipated pressure range in these regions during entry into the atmosphere is from 10^{-1} to 10^{-4} torr. This range of pressure is a somewhat awkward one for making accurate measurements since it is below the sensitivity range of mechanical type gauges and above the range of standard ionization gauges. The aneroid type, a sealed container with a movable diaphragm whose position is sensed by a mechanical linkage or by a variable capacitance or reluctance, is not accurate below about

10^{-3} torr, and therefore does not cover the required range. Baritron gauges that operate on the principle of a capacitance monometer also do not cover the entire range required and are bulky and sensitive to temperature changes and acoustic noise.

Another type of gauge is the cold cathode gauge that operates on the Penning discharge principle. These contain two unheated electrodes, a cathode and an anode, between which the so-called cold discharge is excited and maintained by means of a d.c. voltage (of about 5 kV) so that the discharge still continues at very low pressures. This is accomplished by the use of a magnetic field to make the paths of the electrons so long that their collision probability with gas molecules is sufficiently large to maintain the discharge through the formation of the required number of charge carriers. The positive and negative charge carriers produced by collision ionization move to the corresponding electrodes and form the pressure-dependent discharge current which is also dependent on the nature of the gas. The upper limit of the measuring range is determined by the fact that above 10^{-2} torr the Penning discharge changes to a flow discharge with intense light output in which the current - at constant voltage - depends only to a small extent on the pressure and is, therefore, not suitable for measurement purposes.

Hot cathode ionization gauges which consist of three electrodes (cathode, anode, and ion collector) contain a hot filament cathode that emits copious quantities of electrons. These are accelerated by an electronic field between cathode and anode and form positive ions by collision with the gas molecules. The ions are collected by the collector electrode, usually a fine wire to minimize x-ray generated current (Bayard-Alpert type). The positive ion current is proportional to the gas density, but is also species dependent, and so, must be calibrated for the type of gases whose pressure is to be measured. Again, the upper limit of pressure measurement is 10^{-2} to 10^{-3} torr because uncontrolled glow or arc discharges can occur between the electrodes at higher pressures. Hence, the pressure region required for the required measurements lies between the standard sets of pressure gauges. Thermocouple or pirani gauges do cover at least part of this range, from 1 torr to about 10^{-3} torr but become highly non-linear at both ends. Owing to poor accuracy and slow response time, these devices are deemed not suitable for use on a hypervelocity vehicle.

IV. THE SOLUTION

A certain type of hot filament gauge, known as a "high pressure" ionization gauge, has a range from 1 torr to 10^{-5} torr. Typically, this device is a triode gauge having a large filament and an anode surrounded by a grid. By making the electrode spacings very small, a cathode to anode current may be maintained by a regulated power supply. Positive ions formed by electron bombardment are collected by the grid, the magnitude of the current being a measure of the number density of the gas molecules. In order to be operated at high pressures the filaments must be made of a non-burnout material, such as iridium. There are commercially available gauges in this pressure range called Millitorr (Varian) or Ionivac (Leybold). The filaments of these require a large power consumption and the ion current is gas species dependent - as are all ionization type gauges. The latter problem can be solved by calibration of the gauge response to known gas mixtures.

A "high pressure" laboratory model ionization gauge, called the Micropsi gauge, was designed, fabricated and tested in a vacuum chamber pumped by a turbomolecular pump. Various gases could be fed into the chamber containing the gauge and the pressure controlled by inflow rate of the gases and by throttling the pump port to the turbomolecular pump. Figure 1 details the test configuration.

A small filament of thoria coated iridium was developed. It required .6 watts of power and had an average lifetime of 20 hours. The gauge elements were made of stainless steel with stainless steel wires welded in place to form the grid. Figure 2 is a drawing of the gauge. The limited life seemed to result from a loss of the thoria coating by vaporization. Since vacuum tube thoria coated filaments last thousands of hours, the limited life of the test gauge is probably due to faulty laboratory formation processes.

Tests were run on this gauge using a Baratron and an ionization gauge as standards. The two were calibrated against each other in their overlapping range. The gas used was air. It was slowly bled into the vacuum chamber to gradually raise the pressure to 1×10^{-1} torr while readings on both the standard gauges and the Micropsi gauge were recorded. A plot of these two readings against each other yielded curves like that of Figure 5. The straightness of the curve gives a measure of the linearity of the gauges with respect to each other. It can be seen that over the desired pressure range that the micropsi gauge is linear to within about 10% of the standard gauges. Good calibration data can be developed using this method that will result in the micropsi gauge being able to measure pressures around the reentry vehicle to an accuracy of $\pm 5\%$.

These tests provided that a thoria coated iridium filament was a much more efficient source of electrons since the filament consumed only .5 watts. The ion current varied linearly with pressure over the range 10^{-1} to 10^{-5} torr. Next the header assembly was miniaturized by building the filament, grid, and anode onto a .75 inch diameter hermetically sealed pin header. The miniature header sensor was tested over the required pressure range with good results. These tests up to this point used laboratory power supplies to drive the filaments and generate the cathode grid, and anode voltages needed to operate the sensor. Breadboard electronics have been built from which the sensor has been operated. The pressure versus current cures taken using the breadboard electronics compare closely to that data taken using the laboratory electronics. Total power consumption of the gauge assembly using the breadboard electronics is 2.5 watts.

V. RESEARCH RESULTS

Figure 1 is an outline of the test configuration which has been assembled to gather data and provide the required operating environment for this research activity. The pressure in the test chamber can be adjusted by varying the turbomolecular pump's speed setting, the leak rate of the leak valve, and the setting of the gate valve. Test data plots have been provided as Appendix A. The concepts of the sensor package, and the electronics package are presented in Figure 2 and Figure 3. Specification of the proposed sensor are as follows:

Micropsi Vacuum Pressure Gauge Assembly.

A. Sensor Unit

Weight:	.3 lbs (computed estimate)
Volume:	.4 cubic inches (computed estimate)
Range:	10^{-1} to 10^{-5} torr
Shield Voltage:	0 Vdc
Grid Voltage:	+130 Vdc
Anode Voltage:	0 Vdc
Filament Voltage:	+30 Vdc
Emission Current:	10 microAmpers
Construction:	Stainless Steel, Viton Seal

B. Electronics Unit

Weight:	1.0 lbs (computed estimate)
Volume:	3.0 cubic inches (computed estimate)
Power:	28 Vdc, 90 mA (2.5 watts)
Amplifier Output:	Log scale, 0 to 5 Vde (1 V/pressure decade)

VI. APPLICATIONS

The Micropsi gauge is suited for several applications in the 90 to 150 km altitude range. The tether satellite, TSS-2, the atmospheric tether, is planned for a mid-1990's flight. It will be carried by the shuttle and deployed down to an altitude of 130 km. The pressure gauge, which is very compact and light weight, can be effectively used to measure pressures around the vehicle, including the ram pressure. Several gauges could be mounted around the vehicle, all powered by a common electronics.

Other applications include the Tethered Atmospheric Research Probes (TARP). This is a proposed set of probes to fly on Delta launch vehicles. They would be deployed to altitudes as low as 90 km to explore this region before the tethered satellites are flown down to these low altitudes. The Micropsi gauge would be well suited to measure gas pressure down to 90 km. Another planned mission is called the Atmospheric Verification Mission that would include an expendable pathfinder probe capable of acquiring critical aerothermal data prior to the flight of TSS-2. The probe would be instrumented with very simple instruments to quantitatively assess the aerodynamic forces, heating and controllability of the probe. The Micropsi gauge meets the requirements of the AVM mission.

Four Micropsi gauges can be coupled in a configuration that will determine the attitude of the vehicle. By measuring the pressure behind four orifices all oriented in the ram direction, the attitude (pitch and yaw) of the vehicle can be determined to within the order of 0.1 degree or so relative to the ram direction. This device would supply the information necessary to determine the controllability of the probe as well as the aerodynamic forces acting on it.

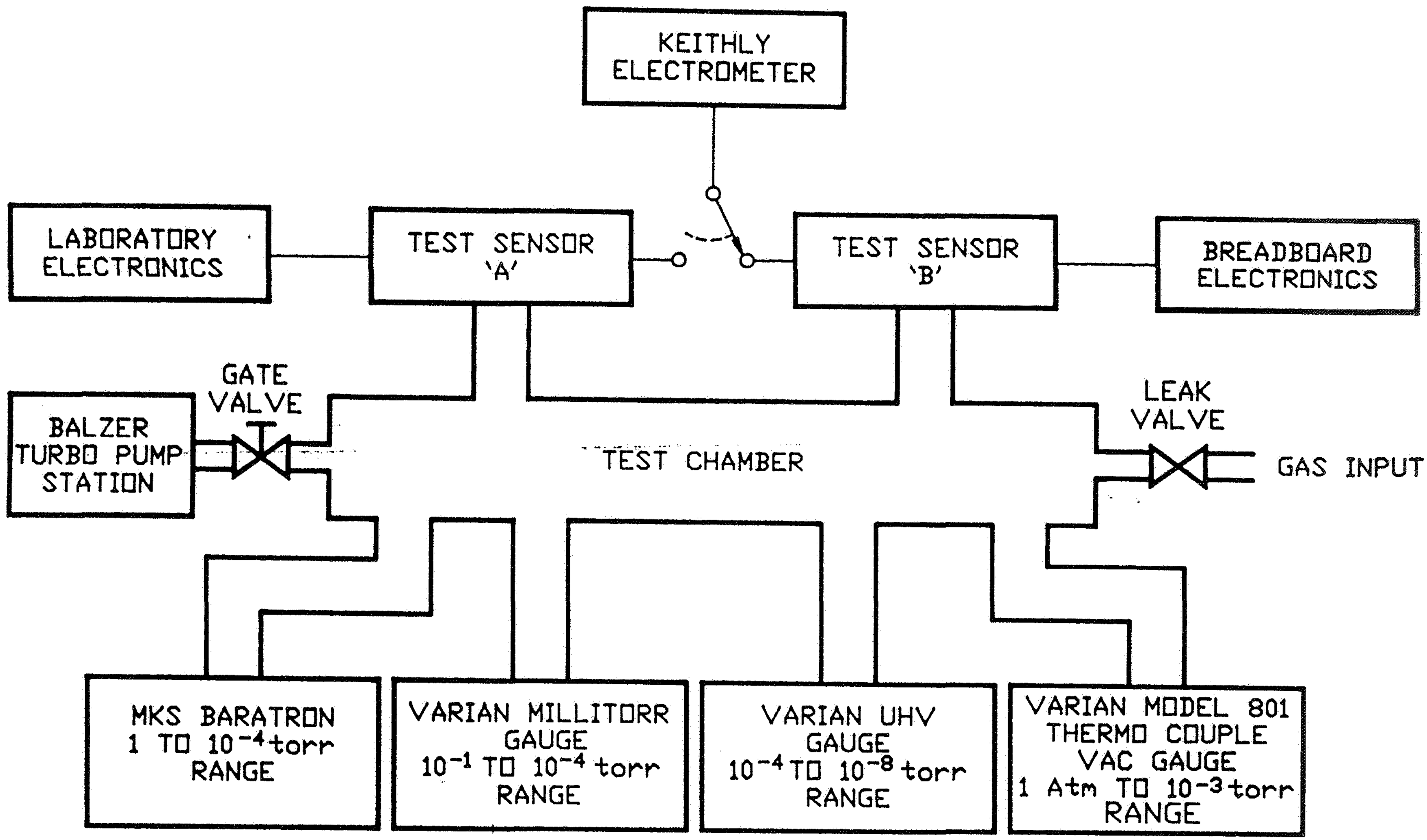

Figure 1. TEST CONFIGURATION

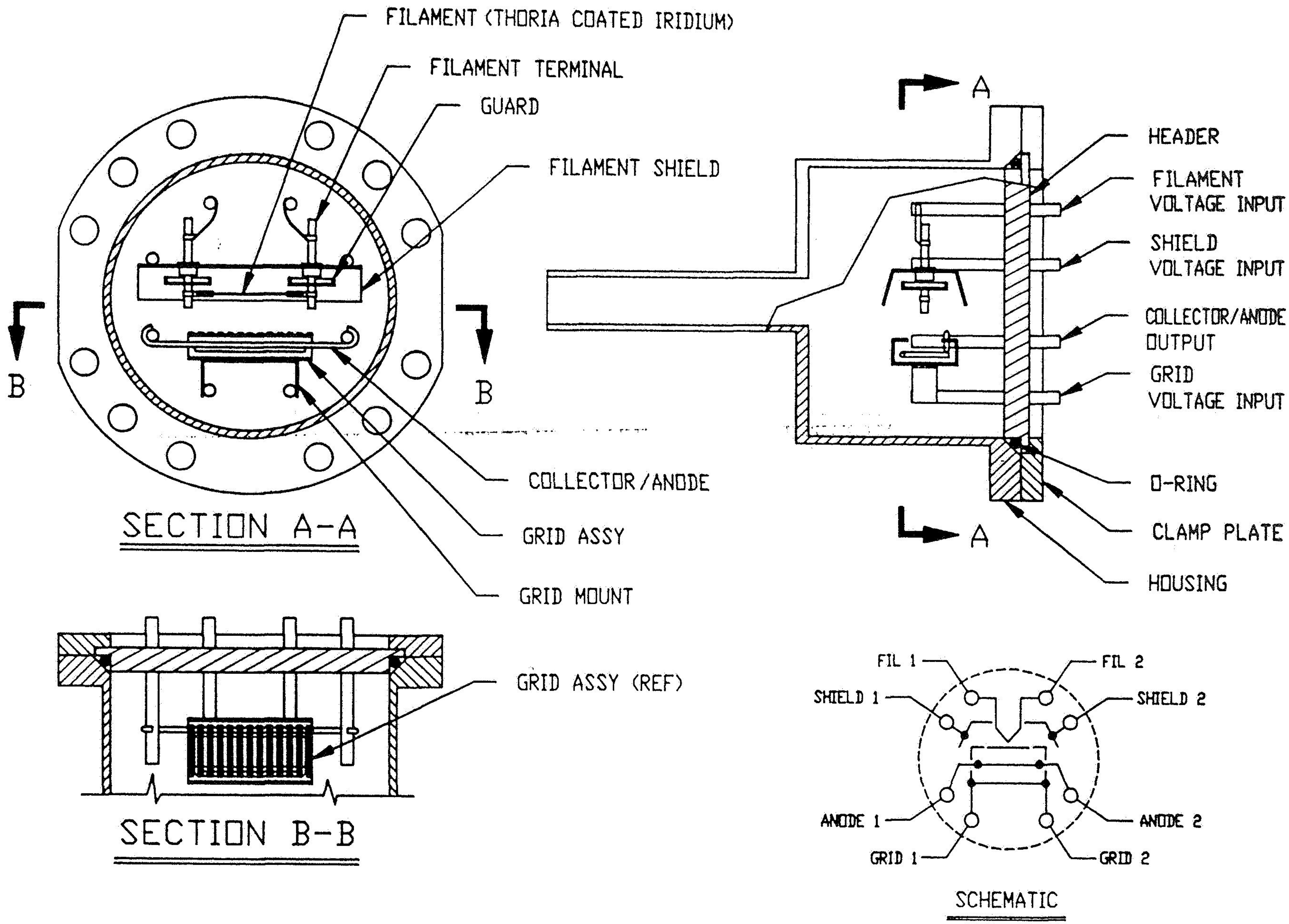

Figure 2. PRESSURE SENSOR

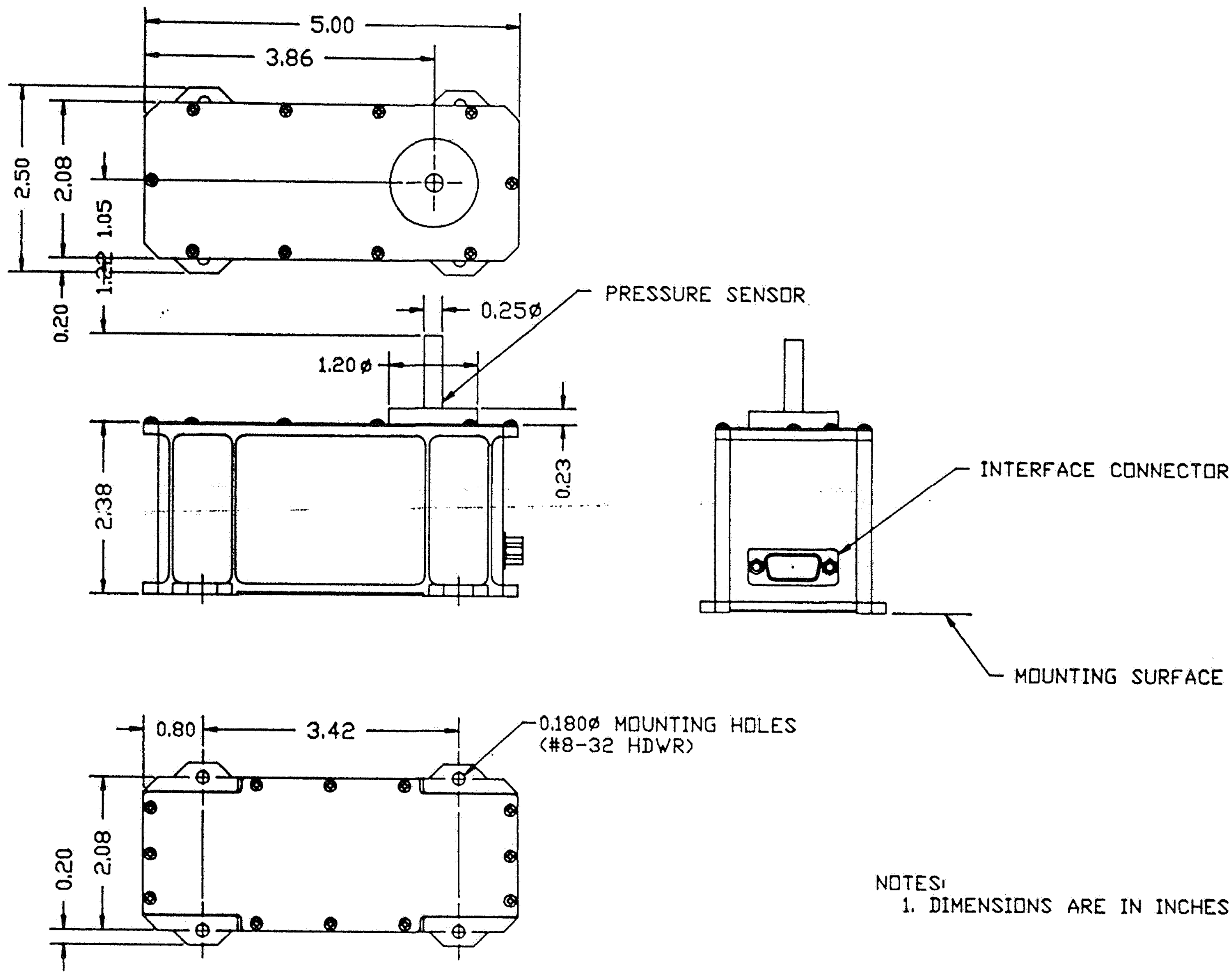

Figure 3. SENSOR AND ELECTRONICS

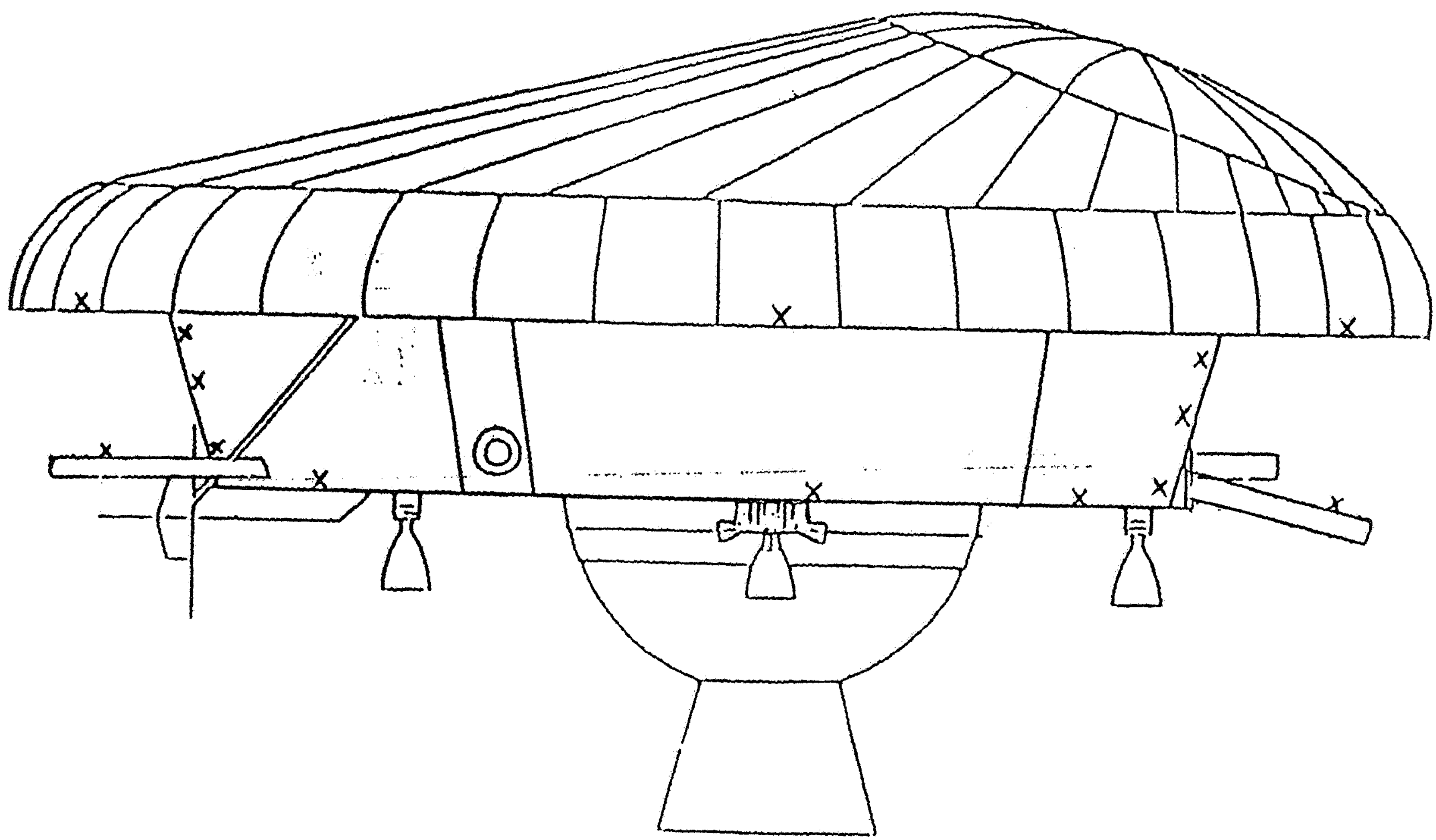

FIGURE 4 - PRESSURE SENSOR LOCATIONS

TEST NO.PS60 NEW FILAMENT(10-6-89)-.003 INCH DIA WIRE- FIL=+30 VDC, GRID=+130
POWER= 28.0VDC*.080A INITIAL; P= 28.0VDC*.085A FINAL
TEST RUN WITH FULL ELECTRONICS BREADBOARD, EMISSION = 14.9 mA REGULATED.
THORIA COATED USING BUTYL ACEATE BINDER -THIS DATA AFTER 77 HRS OPERATION

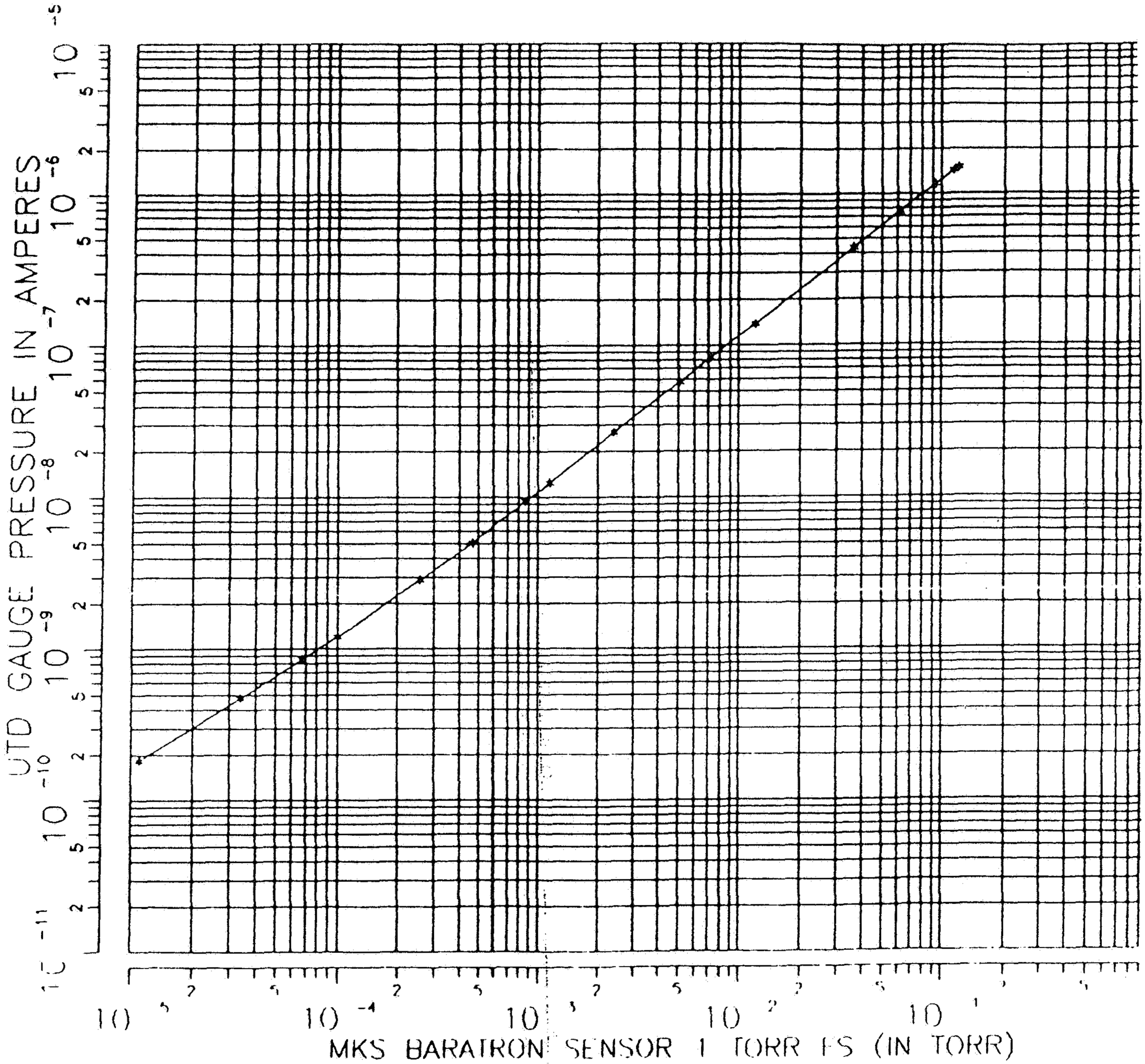

FIGURE 5 - PLOT OF SENSOR OUTPUT VERSUS PRESSURE

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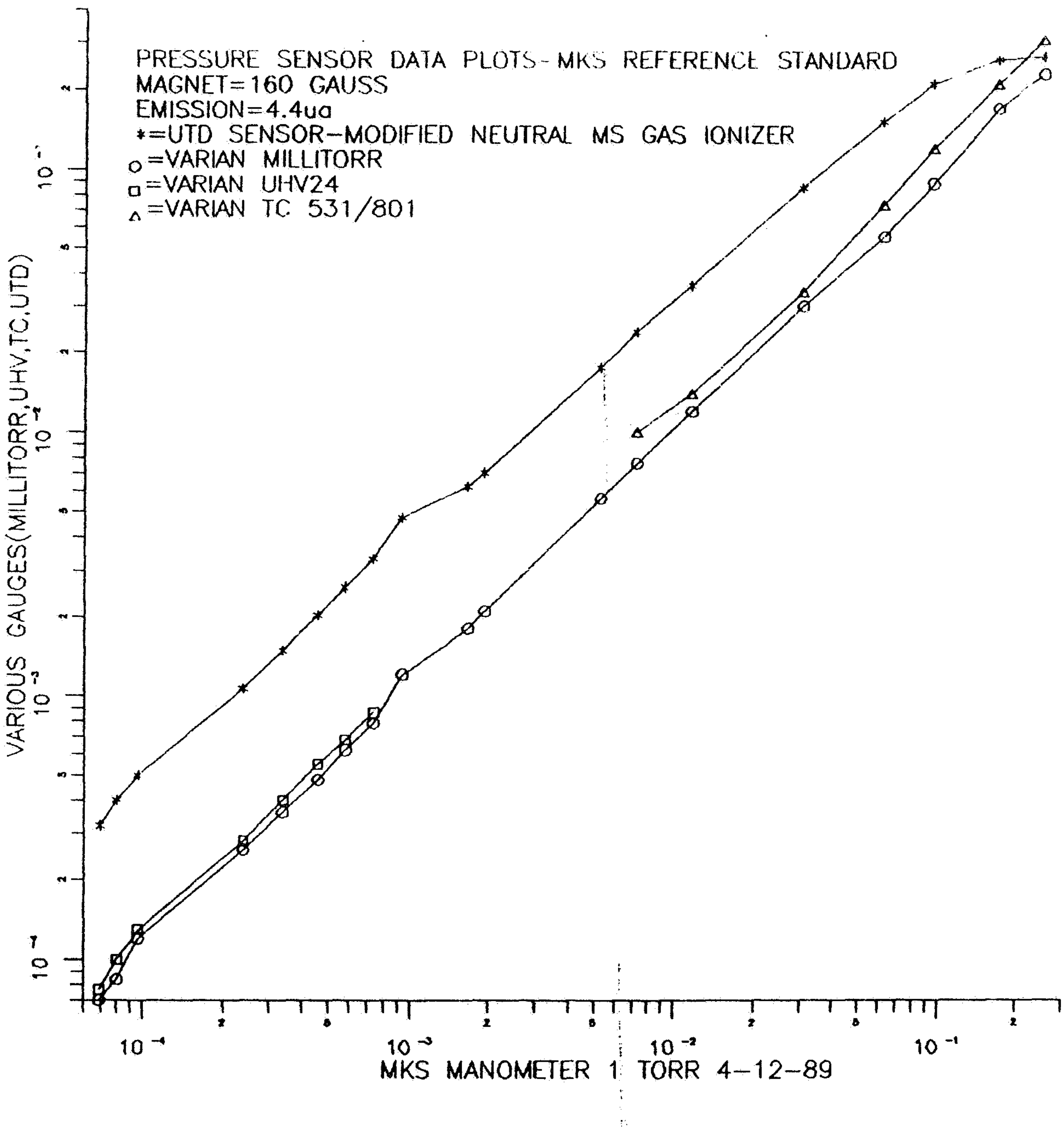
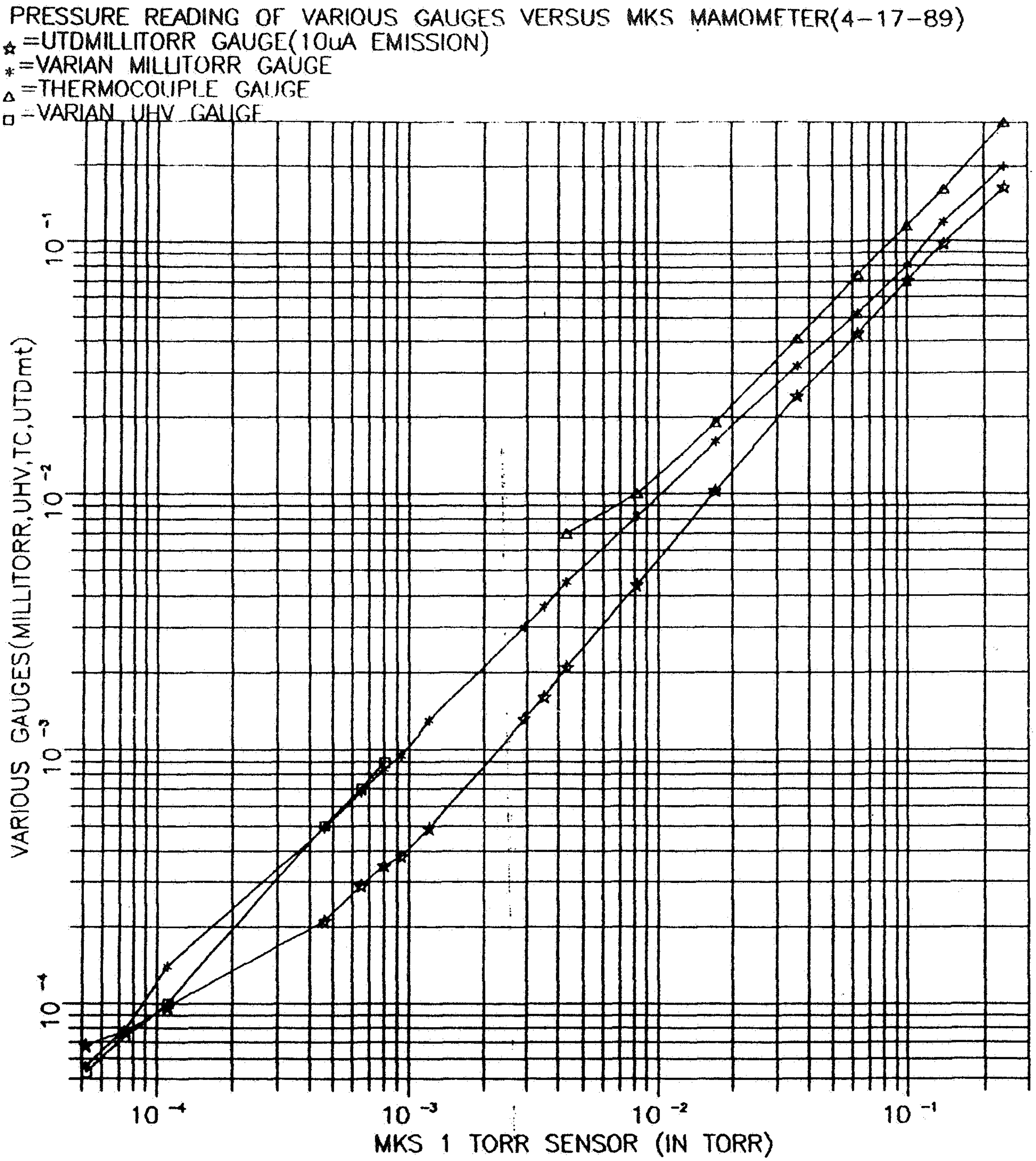
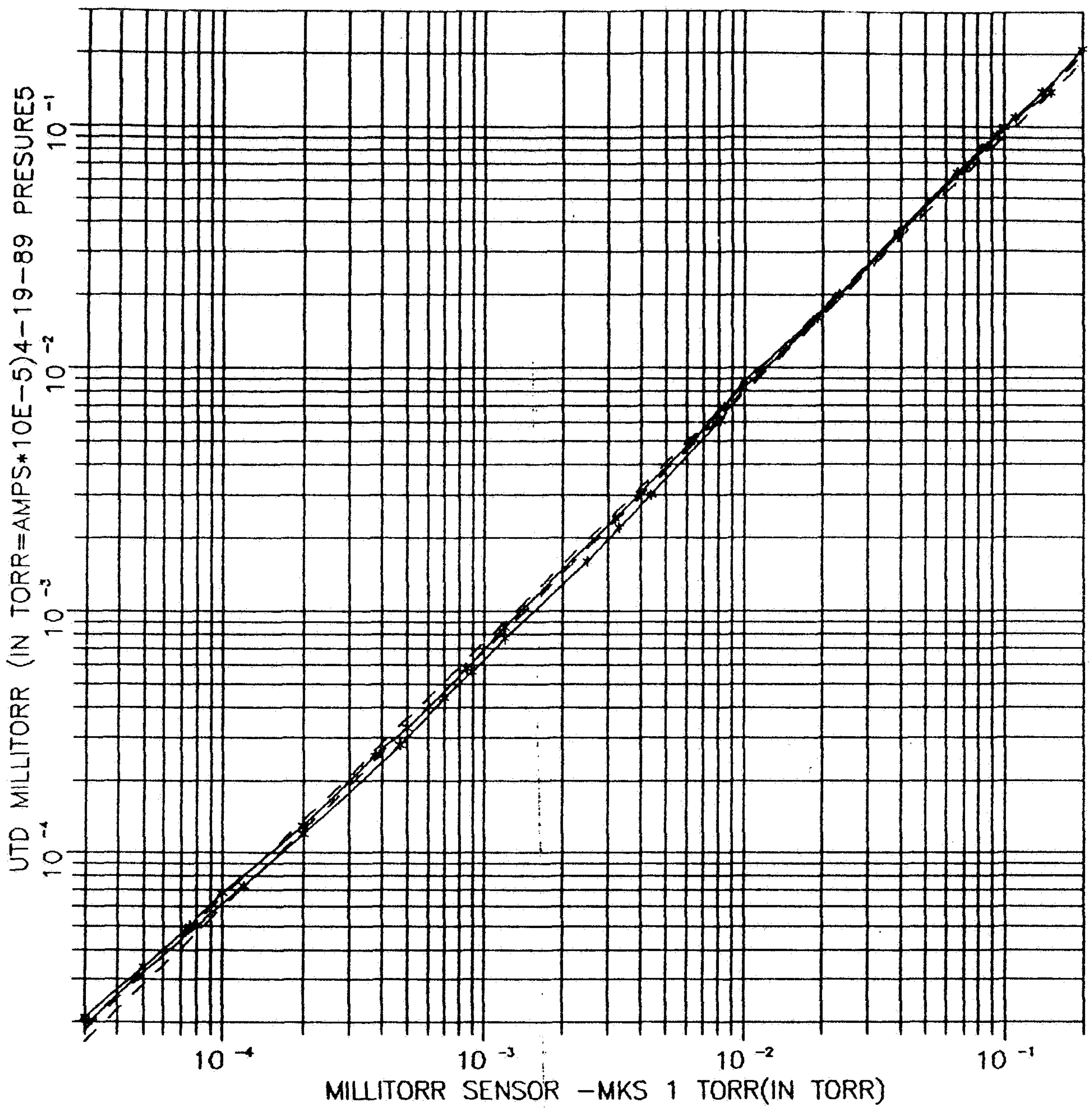
APPENDIX A

The following plots represent the measurements taken in studying the performance of the gauges devised to operate over the 10^{-1} torr to 10^{-5} torr vacuum pressure range.

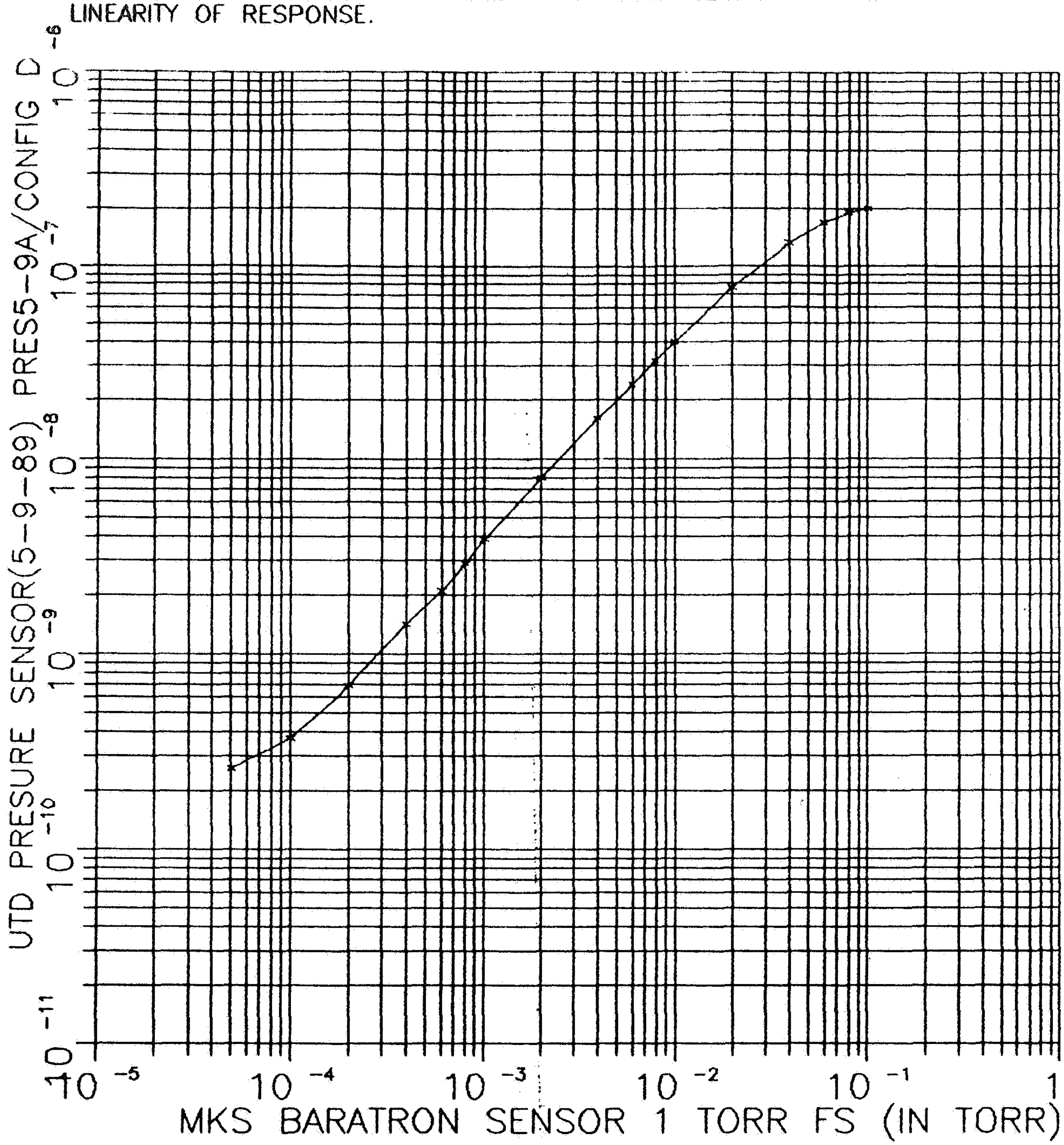

PRESSURE SENSOR DATA PLOTS-MKS REFERENCE STANDARD
MAGNET=160 GAUSS
EMISSION=4.4ua
*=UTD SENSOR-MODIFIED NEUTRAL MS GAS IONIZER
o=VARIAN MILLITORR
□=VARIAN UHV24
△=VARIAN TC 531/801
VARIOUS GAUGES(MILLITORR,UHV,TC,UTD)
MKS MANOMETER 1 TORR 4-12-89


PRESSURE READING OF VARIOUS GAUGES VERSUS MKS MAMOMETER(4-17-89)
☆ =UTDMILLITORR GAUGE(10uA EMISSION)
* =VARIAN MILLITORR GAUGE
△ =THERMOCOUPLE GAUGE
□ =VARIAN UHV GAUGE
VARIOUS GAUGES(MILLITORR,UHV,TC,UTDmt)
10 ⁻¹
10 ⁻²
10 ⁻³
10 ⁻⁴
MKS 1 TORR SENSOR (IN TORR)

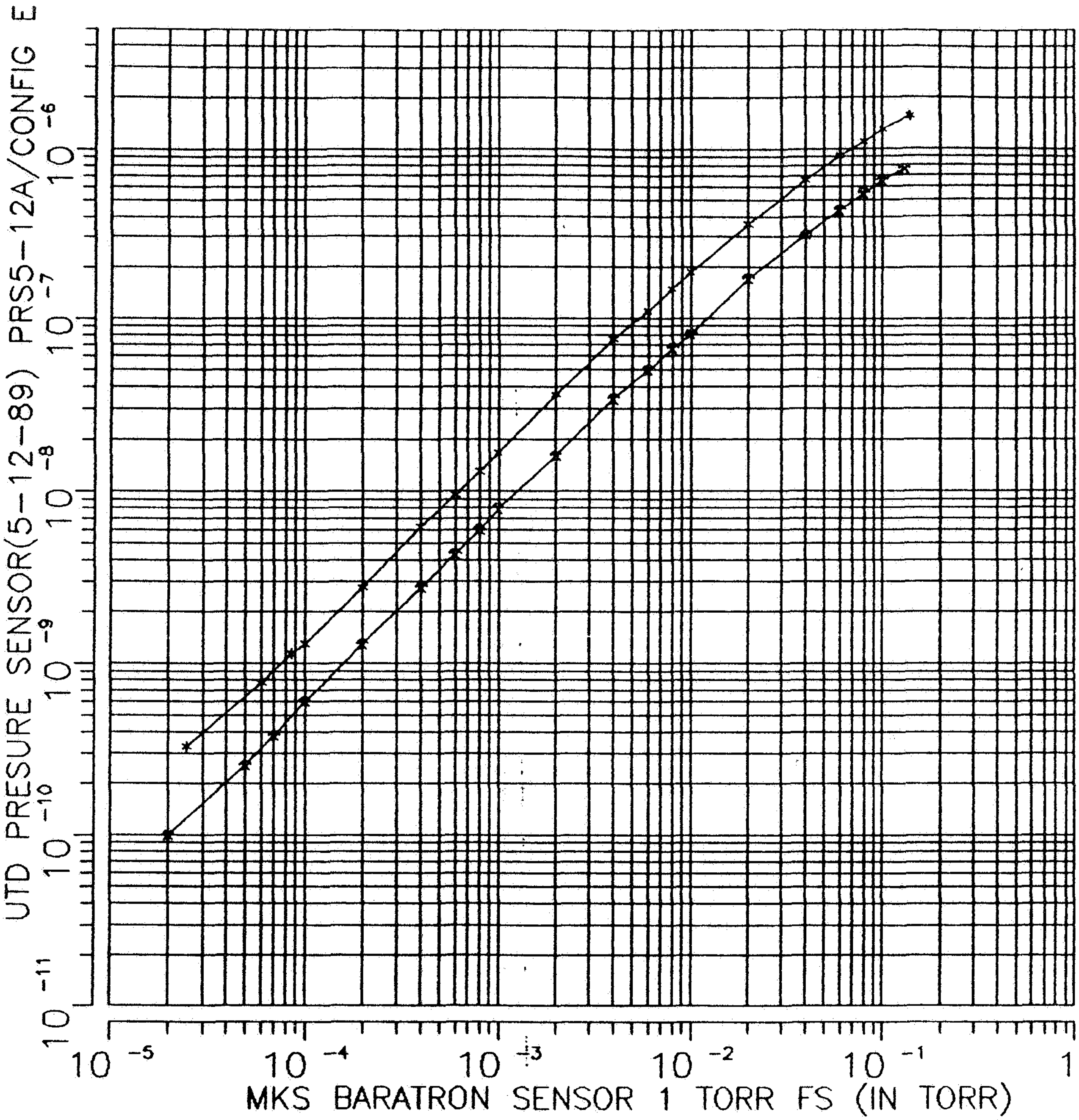
TEST CONFIGURATION–FIGURE 1 DATE: 4–19–89
FIL.VOLTS=–6VDC;GRID VOLTS=+100VDC;COLLECTOR VOLTS=–20VDC
UTD–MT: 11.6uA EMISSION; FIL I=1.7A
GIOTTO FIL. HOLDER/IRIDIUM RIBBON, VARIAN STYLE ANODE
BEGINNING MINIATURIZATION

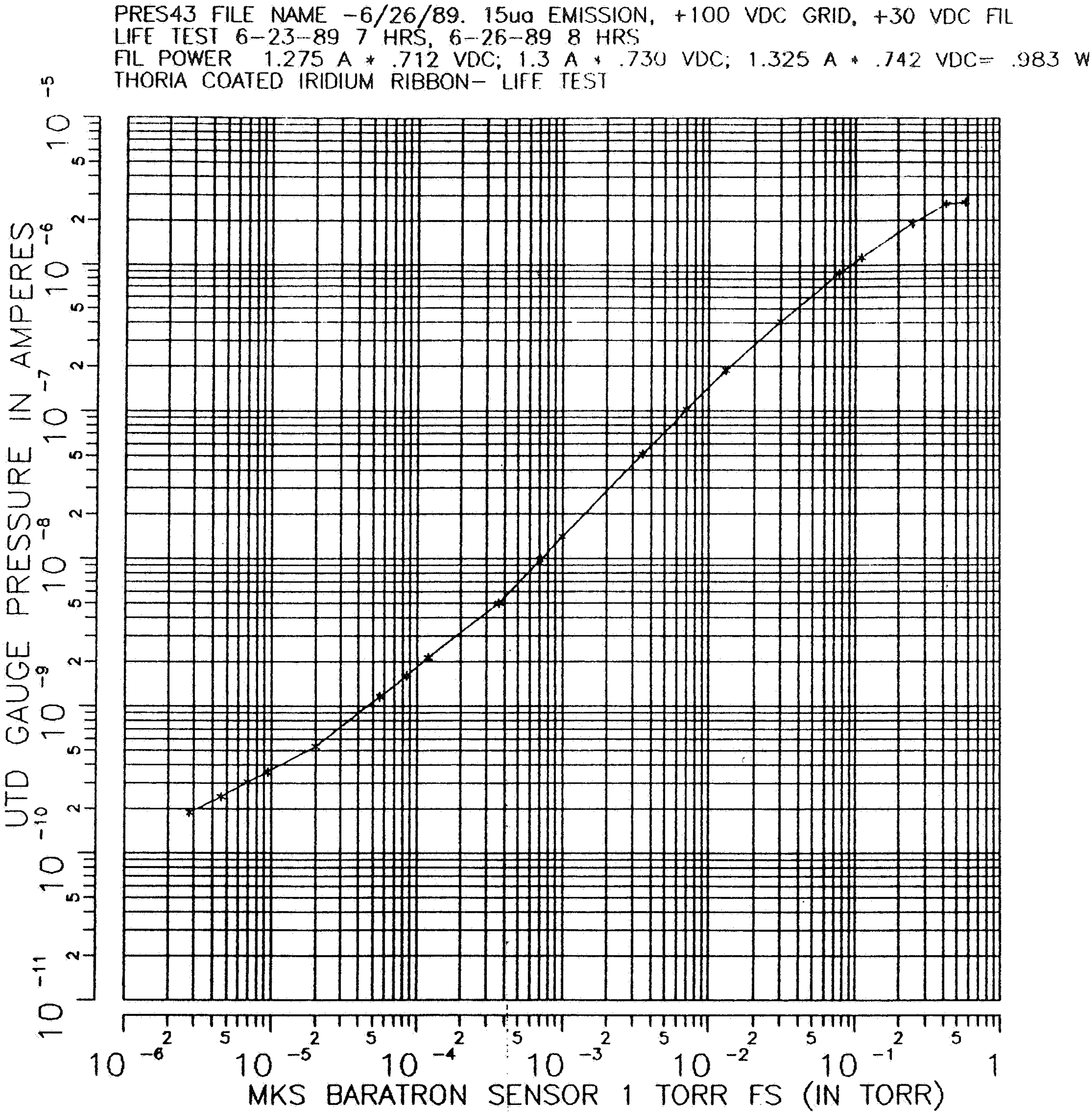


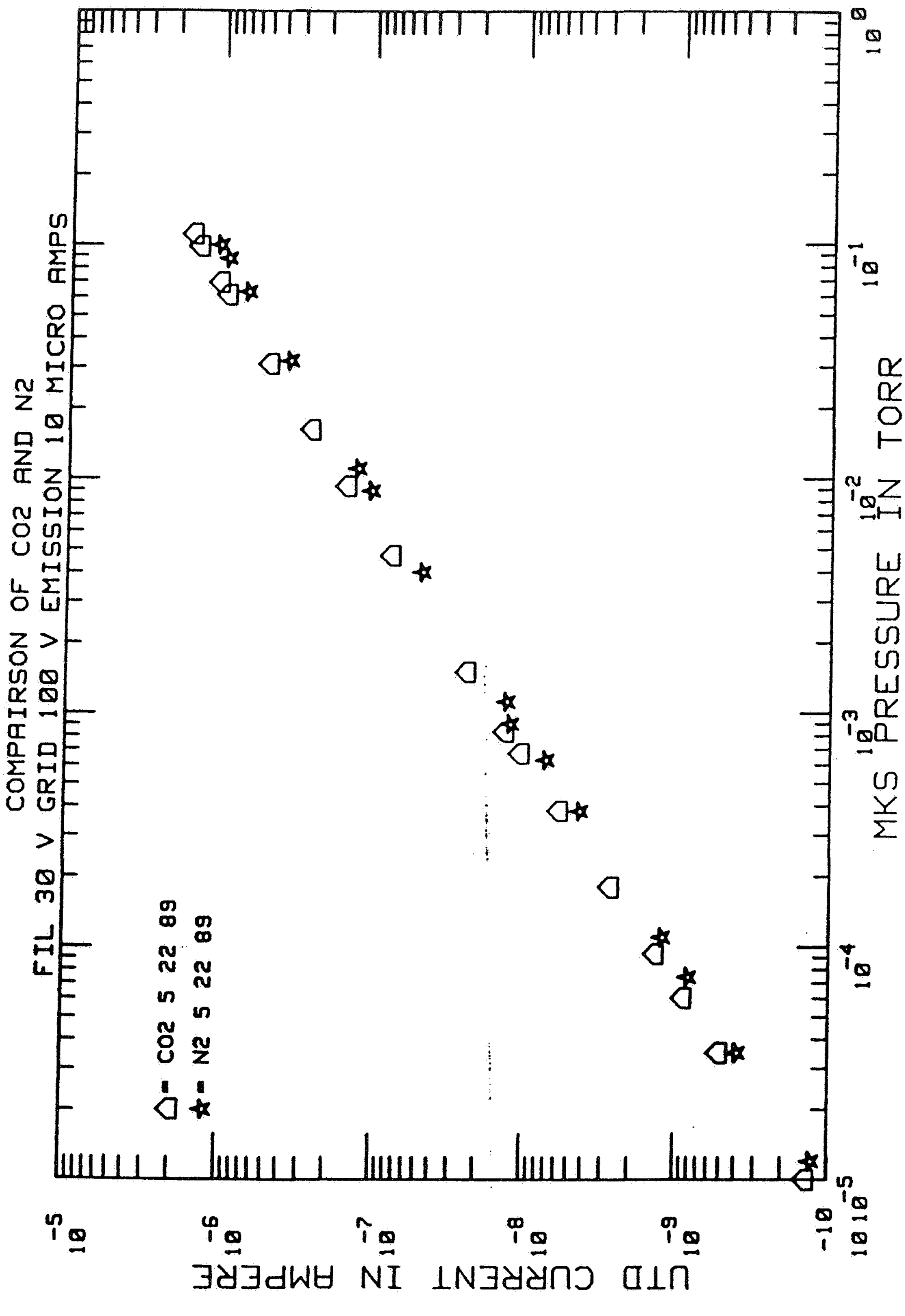
CONFIG. =D; FIL. =+50VDC; ANODE =0VDC; GRID =+151VDC
RING =+162VDC; SHIELD =+15VDC
EMISSION =4uA; FILE =PRES5-9A
INVESTIGATION OF RING AND SHIELD TO IMPROVE SENSITIVITY AND LINEARITY OF RESPONSE.

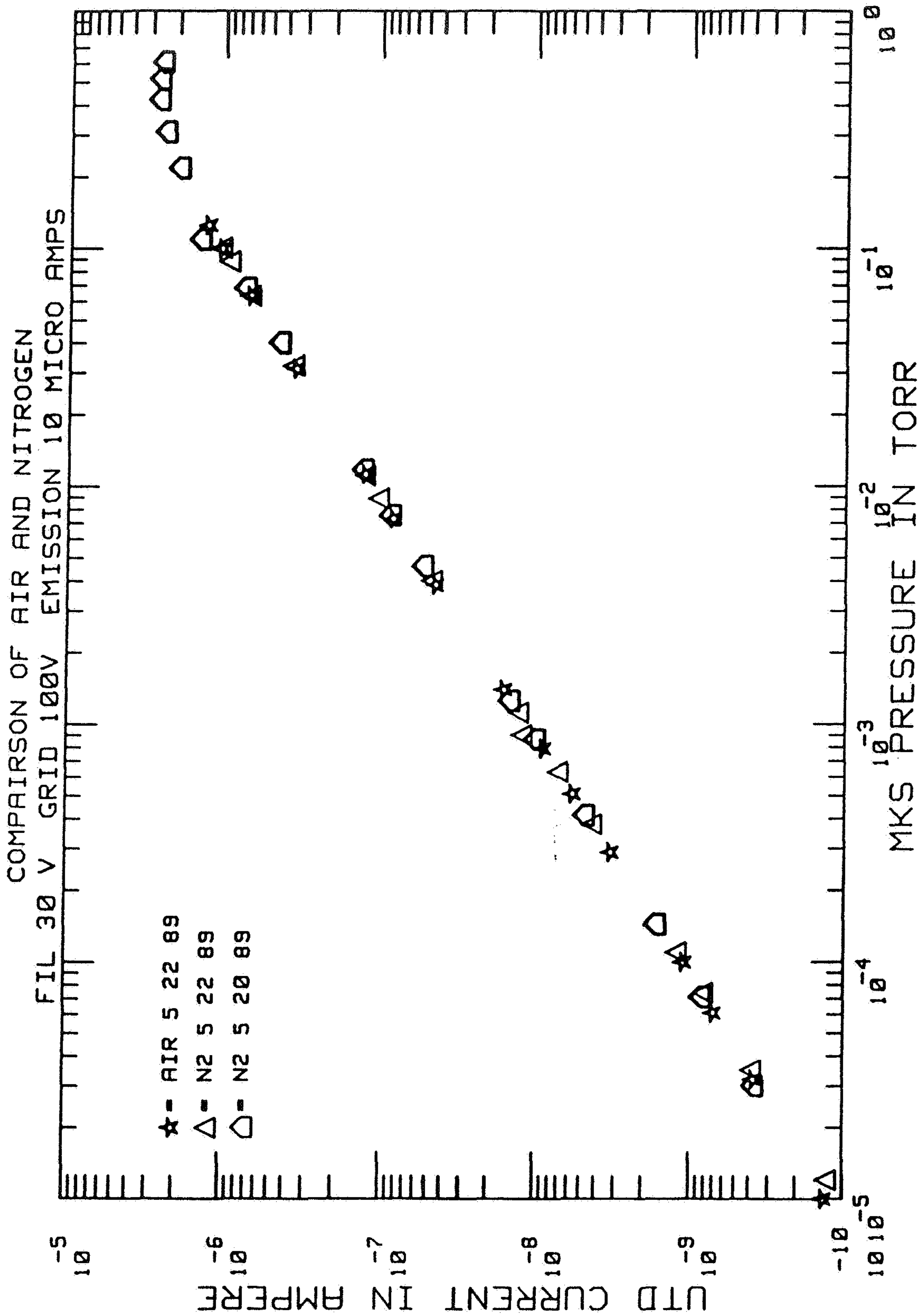


CONFIG E; GRID +124VDC; FIL +24.66VDC; SHIELD -15VDC;
EMISSION CURVE#A=4.6uA; CURVE#B =10.6uA.
EXTENDED IONIZATION CAVITY, ANODE SHIELDED FROM DIRECT VIEW OF FILAMENT

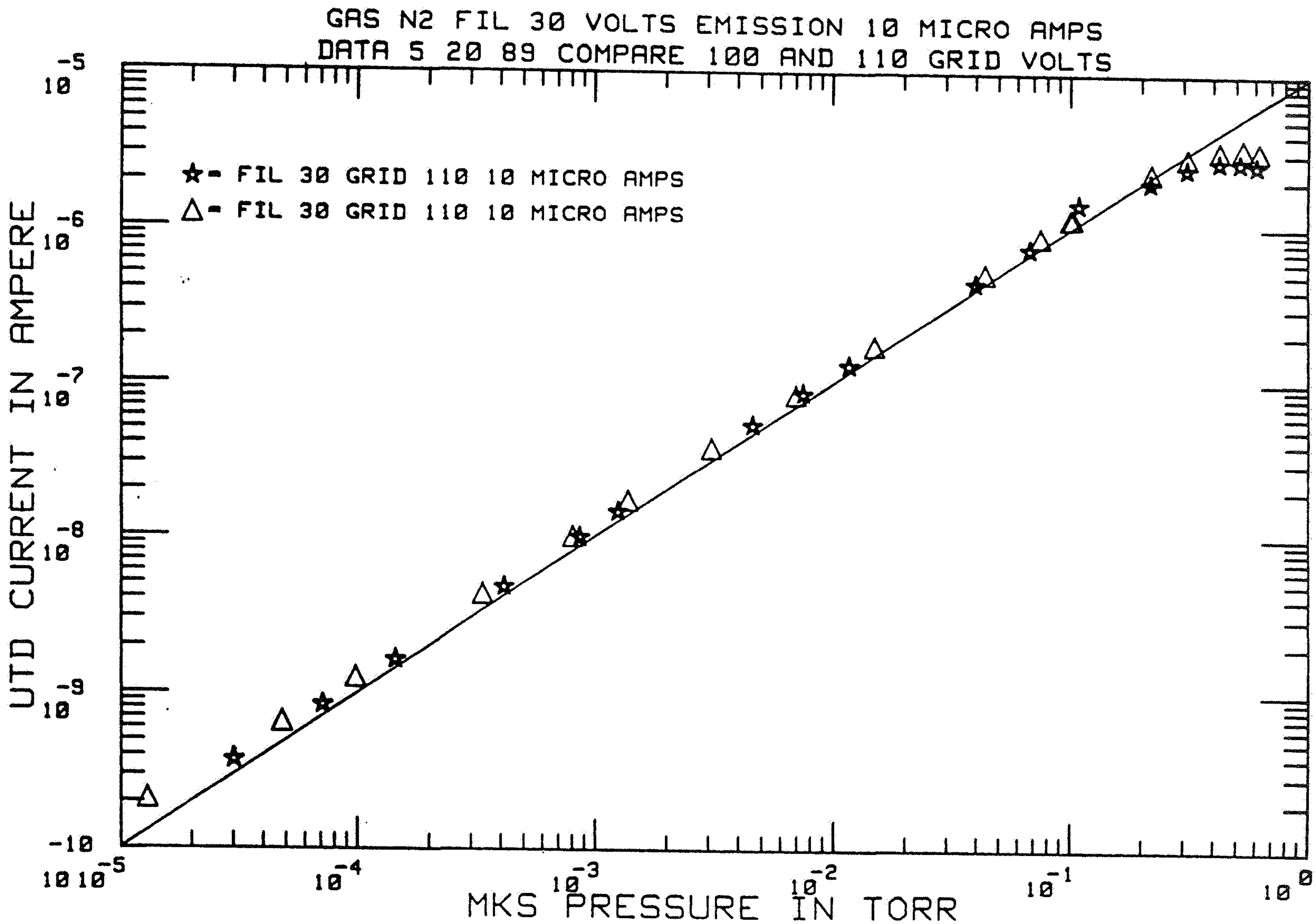


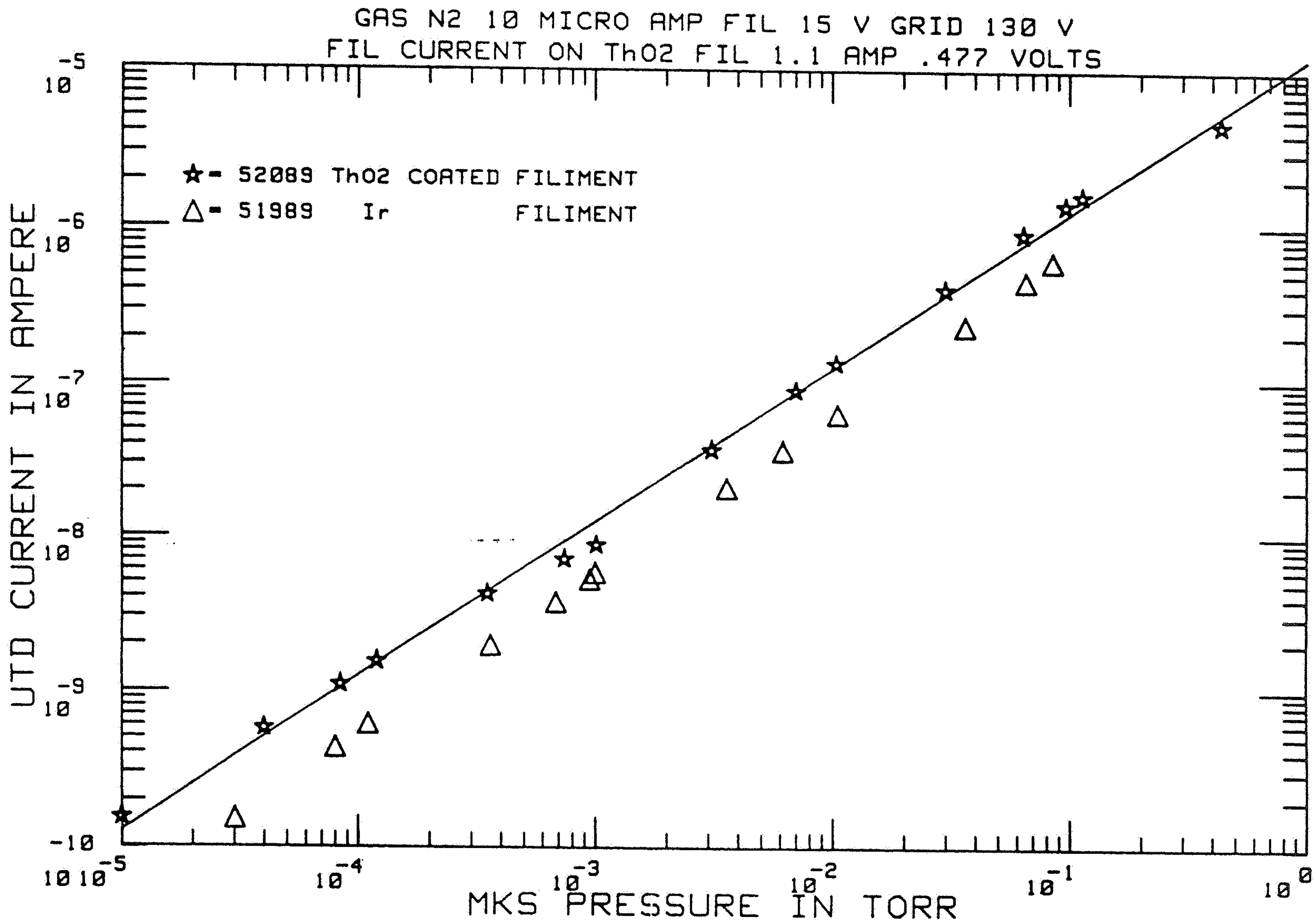

PRES43 FILE NAME -6/26/89. 15ua EMISSION, +100 VDC GRID, +30 VDC FIL
LIFE TEST 6-23-89 7 HRS, 6-26-89 8 HRS
FIL POWER 1.275 A * .712 VDC; 1.3 A * .730 VDC; 1.325 A * .742 VDC= .983 W
THORIA COATED IRIDIUM RIBBON- LIFE TEST
UTD GAUGE PRESSURE IN AMPERES
MKS BARATRON SENSOR 1 TORR FS (IN TORR)

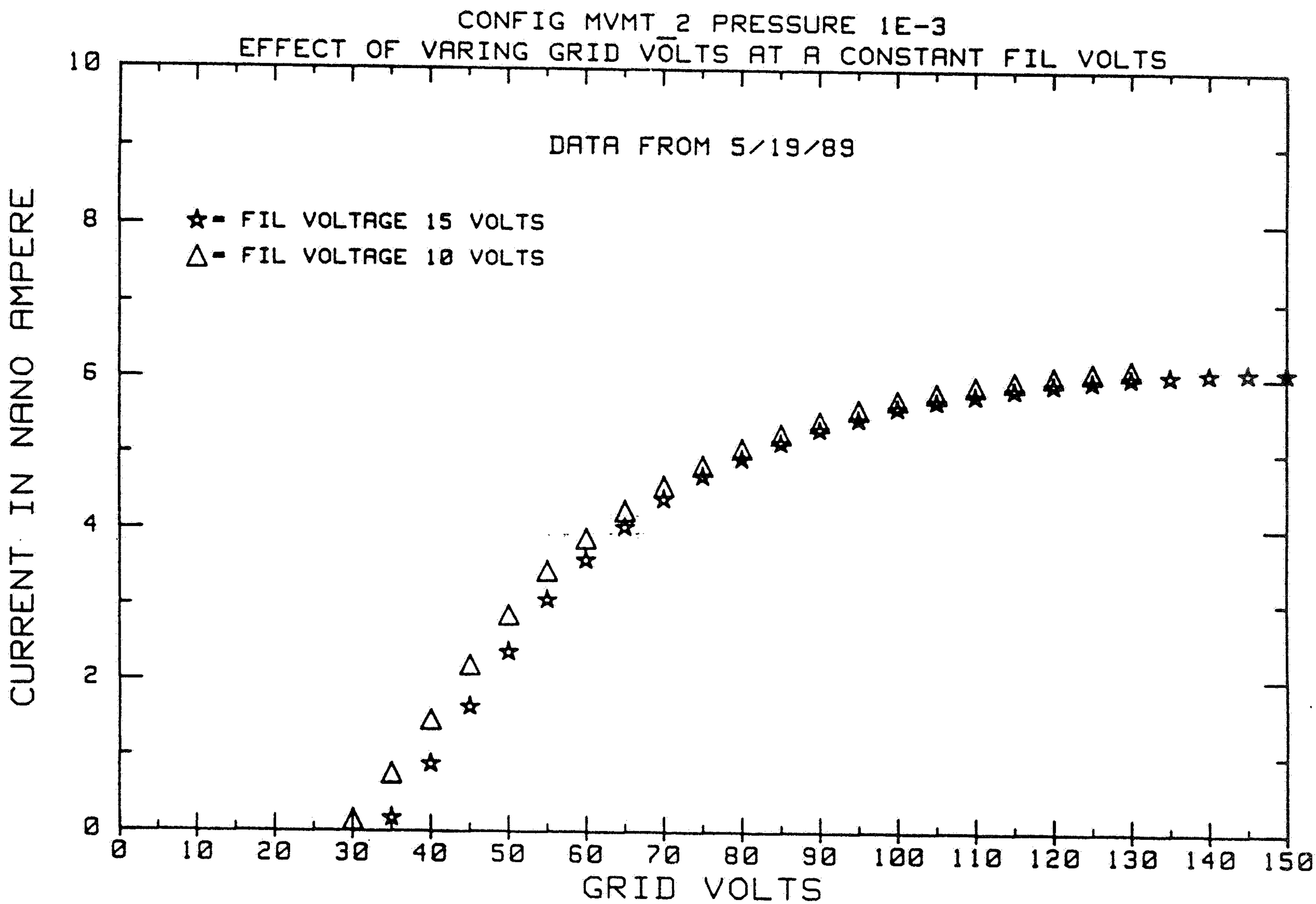

COMPAIRSON OF CO2 AND N2
FIL 30 V GRID 100 V EMISSION 10 MICRO AMPS
= CO2 5 22 89
= N2 5 22 89
MKS PRESSURE IN TORR
UTD CURRENT IN AMPERE

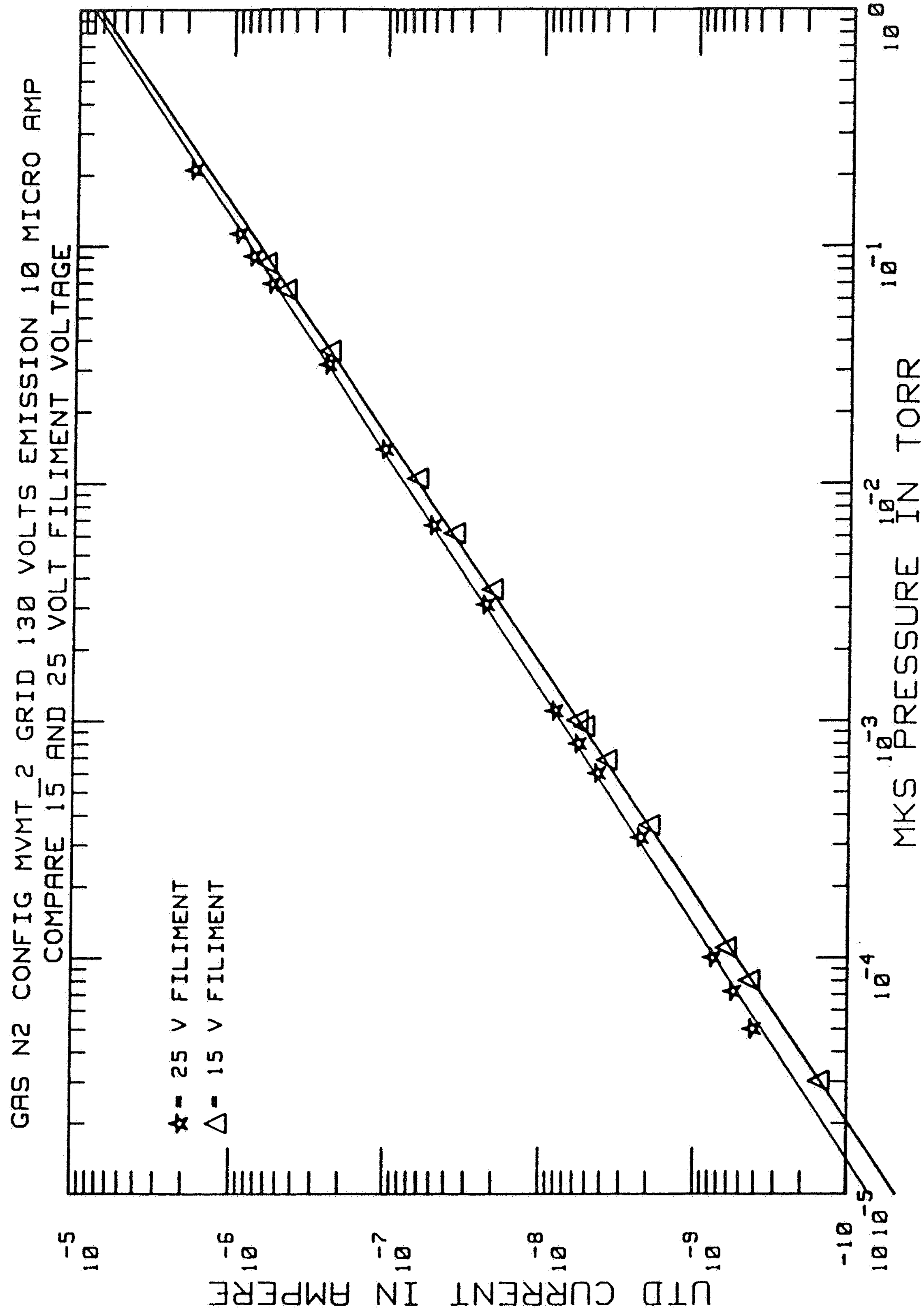


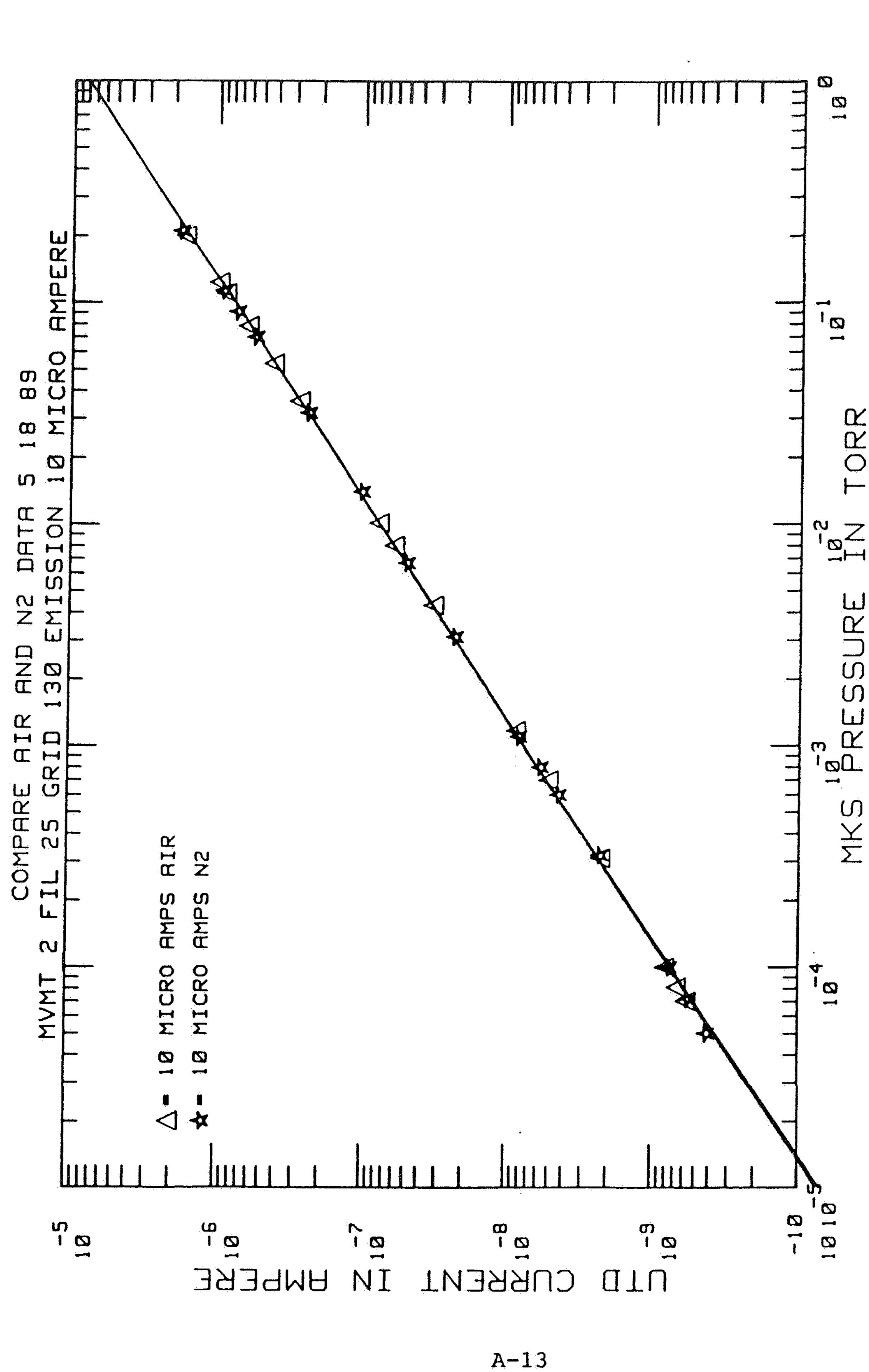
COMPARISON OF AIR AND NITROGEN
FIL 30 V GRID 100V EMISSION 10 MICRO AMPS
☆ - AIR 5 22 89
△ - N2 5 22 89
⬠ - N2 5 20 89
UTD CURRENT IN AMPERE
MKS PRESSURE IN TORR

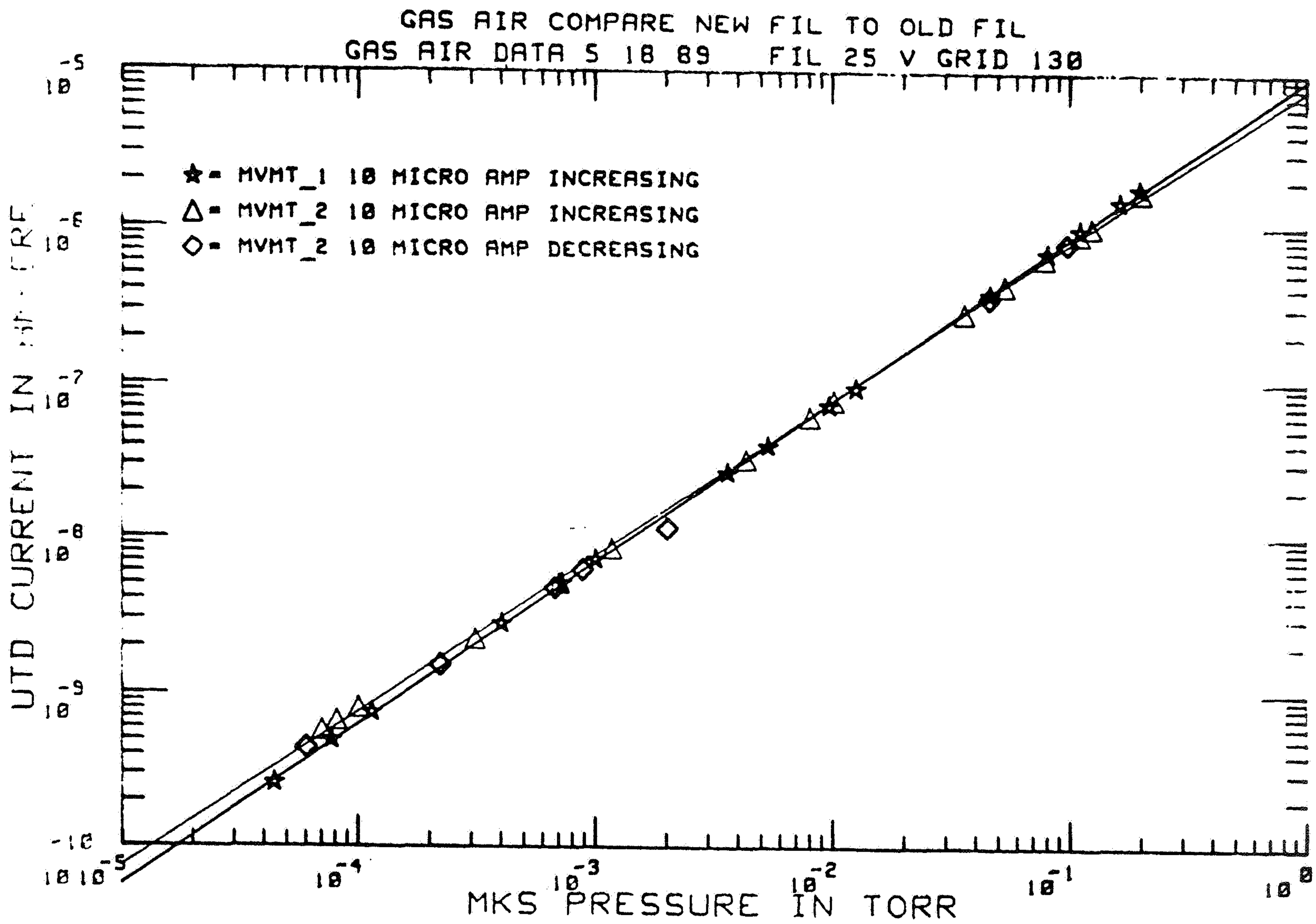

GAS N2 FIL 30 VOLTS EMISSION 10 MICRO AMPS
DATA 5 20 89 COMPARE 100 AND 110 GRID VOLTS
★ = FIL 30 GRID 110 10 MICRO AMPS
△ = FIL 30 GRID 110 10 MICRO AMPS
UTD CURRENT IN AMPERE
MKS PRESSURE IN TORR
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-5
10^-4
10^-3
10^-2
10^-1
10^0

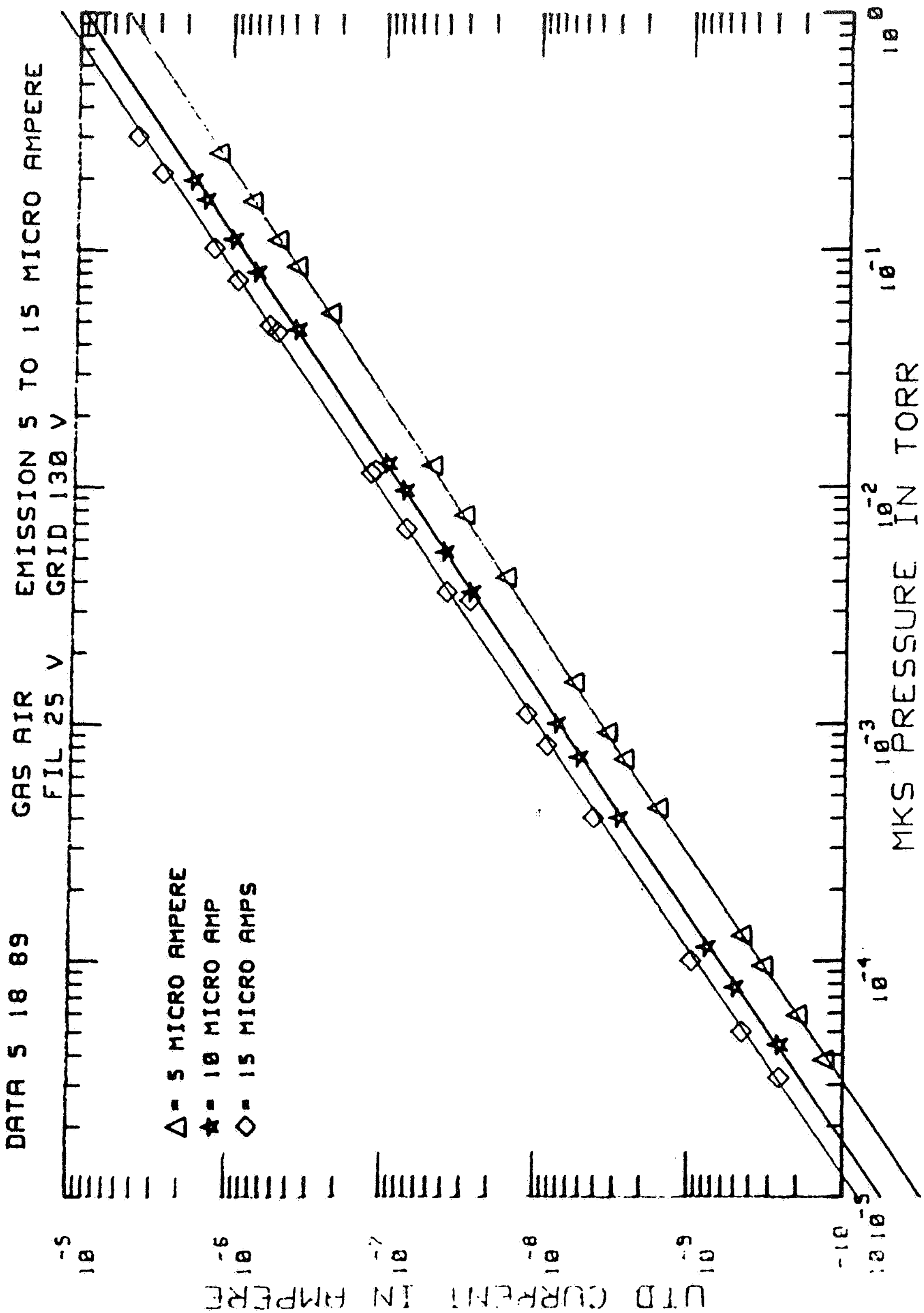

GAS N2 10 MICRO AMP FIL 15 V GRID 130 V
FIL CURRENT ON ThO2 FIL 1.1 AMP .477 VOLTS
☆= 52089 ThO2 COATED FILIMENT
△= 51989 Ir FILIMENT
UTD CURRENT IN AMPERE
MKS PRESSURE IN TORR
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-4
10^-3
10^-2
10^-1
10^0


CONFIG MVMT_2 PRESSURE 1E-3
EFFECT OF VARING GRID VOLTS AT A CONSTANT FIL VOLTS
DATA FROM 5/19/89
☆= FIL VOLTAGE 15 VOLTS
△= FIL VOLTAGE 10 VOLTS
CURRENT IN NANO AMPERE
GRID VOLTS
0
2
4
6
8
10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


GAS N2 CONFIG MVMT_2 GRID 130 VOLTS EMISSION 10 MICRO AMP
COMPARE 15 AND 25 VOLT FILIMENT VOLTAGE
☆ = 25 V FILIMENT
△ = 15 V FILIMENT
UTD CURRENT IN AMPERE
MKS PRESSURE IN TORR
10^-10
10^-9
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
10^0


COMPARE AIR AND N2 DATA 5 18 89
MVMT 2 FIL 25 GRID 130 EMISSION 10 MICRO AMPERE
△ = 10 MICRO AMPS AIR
☆ = 10 MICRO AMPS N2
MKS PRESSURE IN TORR
UTD CURRENT IN AMPERE
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^-10
10^-9
10^-8
10^-7
10^-6
10^-5


GAS AIR COMPARE NEW FIL TO OLD FIL
GAS AIR DATA 5 18 89 FIL 25 V GRID 130
★= MVMT_1 10 MICRO AMP INCREASING
△= MVMT_2 10 MICRO AMP INCREASING
◇= MVMT_2 10 MICRO AMP DECREASING
UTD CURRENT IN
MKS PRESSURE IN TORR
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^-6
10^-7
10^-8
10^-9
10^-10



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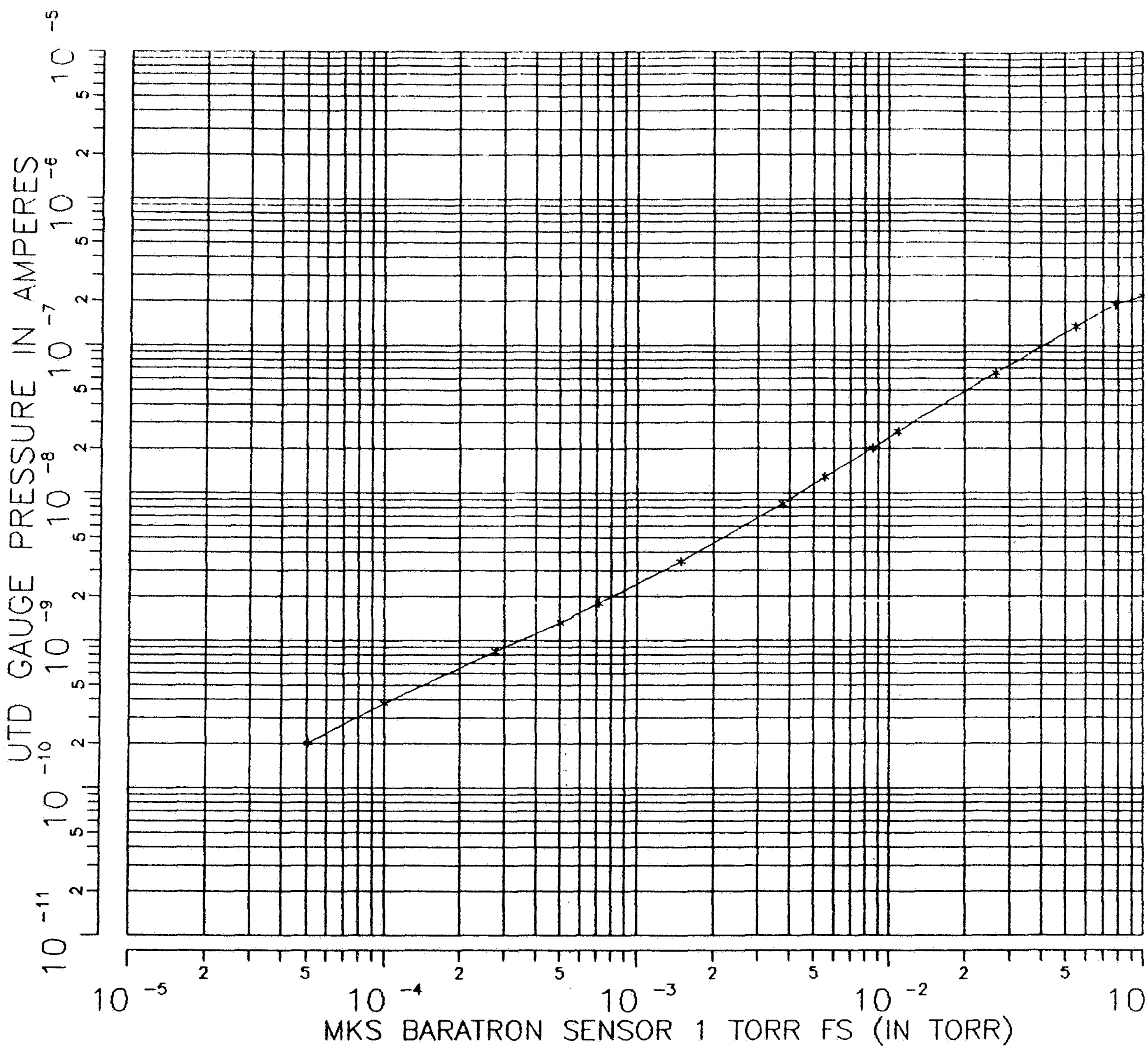
TEST NO.PS51 NEW FILAMENT(9-28)RESTANCE COLD=.→→→→→ OHMS, FIL=+30 VDC, GRID=+130
POWER= 28.0VDC*.083A INITIAL; P= 28.0VDC*.090A FINAL
TEST RUN WITH FULL ELECTRONICS BREADBOARD, EMISSION = 14.9 mA REGULATED.
FILAMENT IS IRIDIUM RIBBON -THORIA COATED



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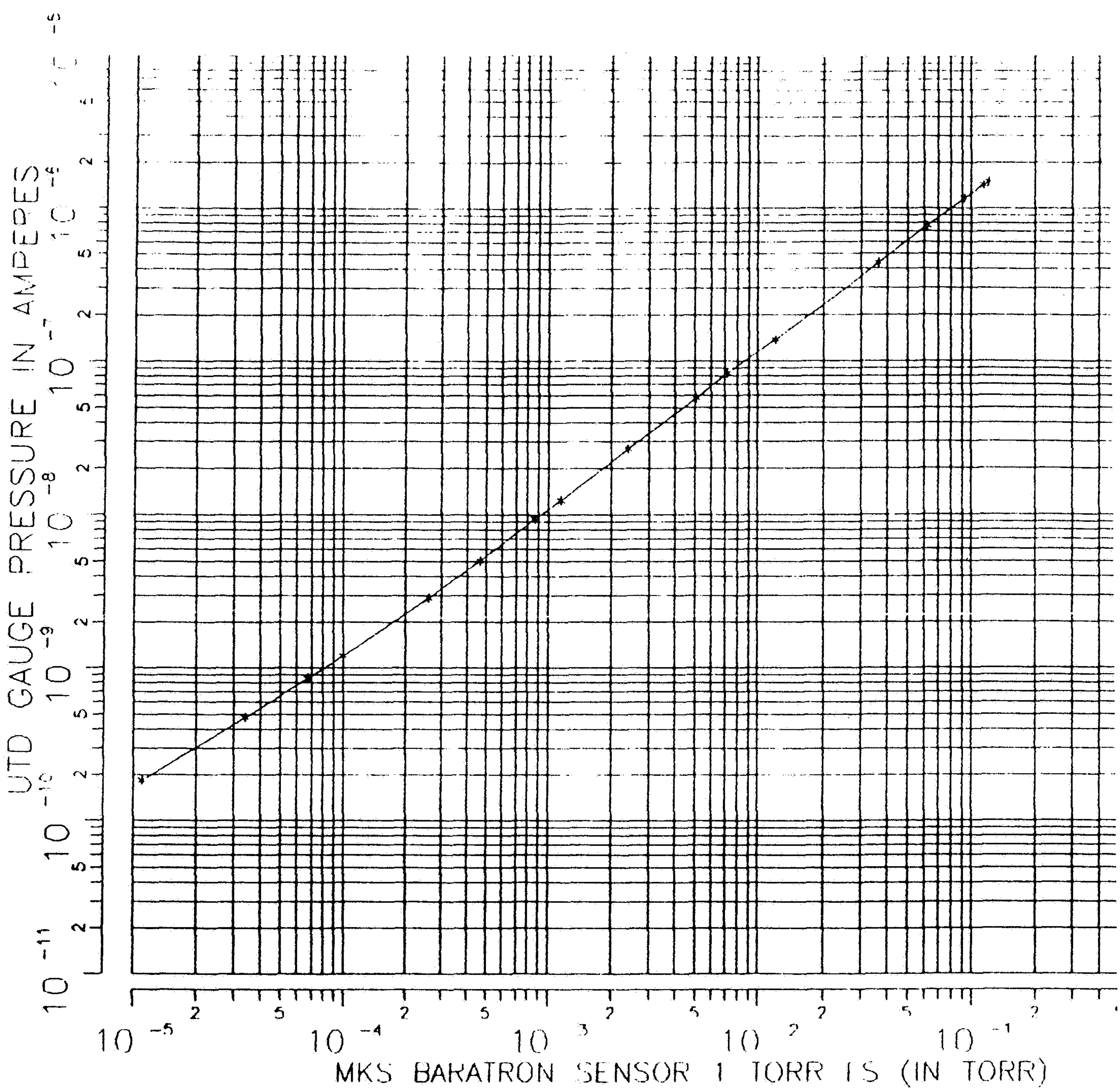
TEST NO.PS60 NEW FILAMENT(10-6-89)-.003 INCH DIA WIRE   FIL=4.30 VDC, GRID
POWER= 28.0VDC*.080A INITIAL; P= 28.0VDC*.085A FINAL
TEST RUN WITH FULL ELECTRONICS BREADBOARD, EMISSION = 14.9 mA REGULATED.
THORIA COATED USING BUTYL ACETATE BINDER   THIS DATA AFTER 77 HRS OPERATION



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