

*N/A-23761*

NASA SP-5954 (01)

# CASE FILE COPY

TECHNOLOGY UTILIZATION

## TRANSDUCER APPLICATIONS

A COMPILATION



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

## Foreword

The National Aeronautics and Space Administration and Atomic Energy Commission have established a Technology Utilization Program for the dissemination of information on technological developments which have potential utility outside the aerospace and nuclear communities. By encouraging multiple application of the results of their research and development, NASA and AEC earn for the public an increased return on the investment in aerospace research and development programs.

The seven major divisions included in this compilation have been organized in a manner which enables the potential user to select the appropriate transducer for his immediate application. It should be stated that these transducers highlighted in the seven application areas are mere representatives of hundreds of similar items which are available for commercial application. Obviously, considering the sophistication that exists in transducer technology today, it would be presumptuous to classify these items as original or novel. However, in most instances vast amounts of effort and money have been expended in improving the performance of available transducers; and as such, these improvement efforts represent a significant contribution by the NASA aerospace program to the commercial interests of the public.

Additional technical information on individual devices and techniques can be requested by circling the appropriate number on the Reader Service Card included in this compilation.

Unless otherwise stated, NASA and AEC contemplate no patent action on the technology described.

We appreciate comment by readers and welcome hearing about the relevance and utility of the information in this compilation.

Jeffrey T. Hamilton, *Director*  
*Technology Utilization Office*  
*National Aeronautics and Space Administration*

NOTICE • This document was prepared under the sponsorship of the National Aeronautics and Space Administration. Neither the United States Government nor any person acting on behalf of the United States Government assumes any liability resulting from the use of the information contained in this document, or warrants that such use will be free from privately owned rights.

# Contents

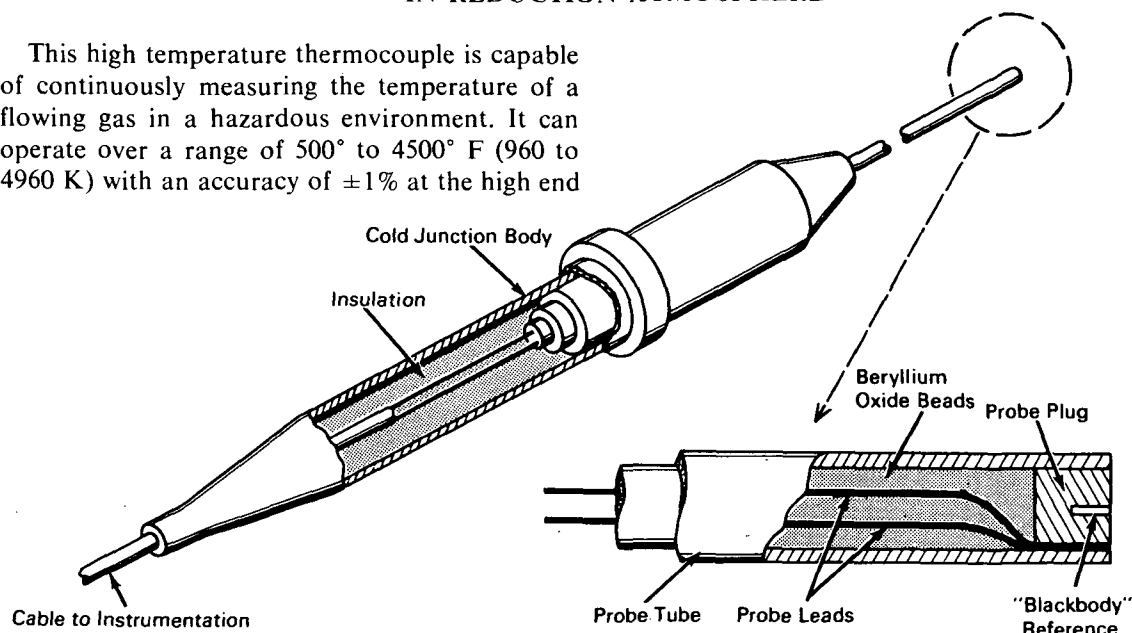
	<i>Page</i>
<b>SECTION 1. Thermal Measurements</b>	
High Temperature Thermocouple Operates in Reduction Atmosphere .....	1
Heat Flux Transducer Eliminates Measurement Errors .....	1
High Temperature Thermocouple Design Provides Gas Cooling Without Increasing Overall Size of Unit .....	2
Electronic Sensor Measures Skin Temperature .....	3
Thermocouple Configuration for Tank Insulation .....	4
Transducer Measures High Temperature Gases .....	4
<b>SECTION 2: Liquid Level and Fluid Flow</b>	
Cryogenic Liquid Level Measuring Probe .....	5
Superconductive Thin Film Used as Liquid Helium Level Sensor .....	5
Improved Capacitance Probe for Liquid Level Measurement: A Concept .....	6
Infrasonic System Measures Liquid Level in Storage Tanks: A Concept .....	7
Remote Moisture Indicator .....	7
Cryogenic Liquid Filling Sensor .....	8
<b>SECTION 3. Pressure Transducers</b>	
Cardiac Catheter with Pressure Transducer .....	9
Cooled Miniature Pressure Transducers Effective at High Temperatures .....	10
New Type Pressure Transducer for Severe Thermal Environments .....	10
Economic Measurement of Ultralow Flow Rates of Fluids .....	11
Cardiovascular Pressure Transducer .....	12
Cryogenic Pressure Transducer .....	13
Silicon Strain Sensors for Pressure Measurement at Cryogenic Temperatures .....	13
Force Balance Pressure Transducer .....	14
Automatic Transducer Switching Provides Accurate, Wide- Range Measurement of Pressure Differential .....	15
<b>SECTION 4. Stress-Strain Measurements</b>	
Miniature Pressure Transducer for Stressed Member Application .....	15
Strain Gage Deflection Transducer .....	16
Strain Gage Ambiguity Sensor for Segmented-Mirror Optical System .....	17
A Magnifying Scratch-Gage Force Transducer .....	17
Strain Gage Wire Feedthrough for Cryogenic Pressure Vessels .....	18
Tilt Sensor .....	19

	<i>Page</i>
<b>SECTION 5. Acceleration and Velocity</b>	
Miniature Piezoelectric Triaxial Accelerometer Measures	
Cranial Accelerations .....	19
Photocell Velocity Transducer .....	20
Damping Technique Gives Accelerometer Flat Frequency	
Response .....	20
Photoelectric Speed Transducer .....	21
Rectilinear Accelerometer Possesses Self-Calibration	
Feature .....	22
<b>SECTION 6. Displacement and Angular Rotation</b>	
Hall-Effect Transducer Gives Electrical Output	
Proportional to Meter-Shaft Rotation .....	23
Noncontacting Optical Strain Device .....	23
Reliable, Self-Calibrating Vibration Transducer .....	24
Measurement of Optical Thickness .....	25
Noncontacting Transducer Measures Shaft Torque .....	26
<b>SECTION 7. Transducer Test and Calibration Methods</b>	
Pneumatic Pressure-Wave Generator Used to Test Transducers .....	27
Concept for Pressure Switch Calibrator .....	27
Liquid-Flow Calibration System .....	28
Detecting Leakage in Pressure Transducers .....	29
Tester Provides Variable Pressure-Wave Amplitudes	
and Frequencies .....	29
Elongation Limit of Strain Gages In Liquid Nitrogen .....	30
Portable Instrument Monitors Transducer Performance .....	31
Automated Calibrator for Pressure Transducers .....	32
Evaluating Thermocouple Systems .....	33

# Section 1. Thermal Measurements

## HIGH TEMPERATURE THERMOCOUPLE OPERATES IN REDUCTION ATMOSPHERE

This high temperature thermocouple is capable of continuously measuring the temperature of a flowing gas in a hazardous environment. It can operate over a range of 500° to 4500° F (960 to 4960 K) with an accuracy of  $\pm 1\%$  at the high end



and better than  $\pm 1\%$  at the low end. The probe may be used to measure high temperature gases in a nonoxidizing atmosphere, and may be modified for use in an oxidizing atmosphere.

The thermocouple probe is made of tungsten-5%-rhenium and tungsten-26%-rhenium wire insulated by beryllium oxide beads inside a tungsten-26%-rhenium tube. The sensor junction is formed near the probe tip by a tungsten-26%-rhenium plug which forces the two wires against the side of the tube and electrically joins them together. The outer end of the plug is fused to form a gas-tight metallurgical seal as well as a mechanical force-fit hold of the plug. A small hole

drilled part way through the plug serves as a blackbody reference for use with an optical pyrometer during furnace calibration.

The thermocouple wires extend continuously without splice or foreign material from the cold junction to the probe tip, thus eliminating errors from secondary thermocouple effects.

Source: R. G. Hoff, et al of Aerojet-General Corporation under contract to AEC-NASA Space Nuclear Systems Office (NUC-00046)

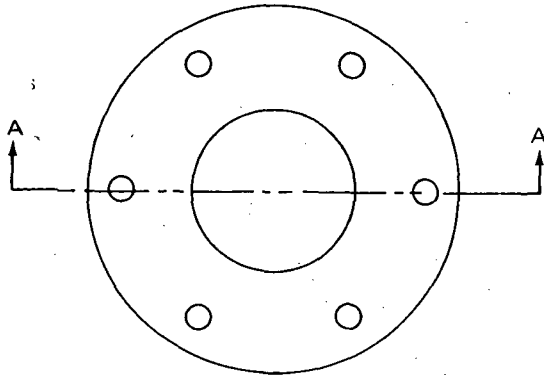
*No further documentation is available.*

## HEAT FLUX TRANSDUCER ELIMINATES MEASUREMENT ERRORS

A heat flux transducer measures the total absorbed heat flux, both radiation and convection, on a material surface. The instrument is designed

specifically to eliminate errors in convective heat flux measurement caused by the disturbance of the thermal environment, resulting from the presence

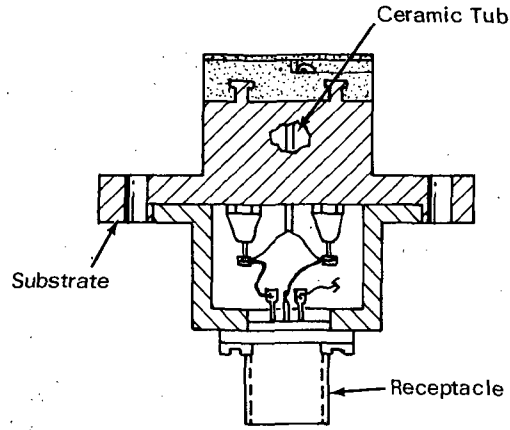
of devices. In order to eliminate these disturbances, the instrument is flush mounted on a surface which has no protruding parts to disturb the convective flow field. Also, the heat-receiving face



of the transducer is constructed of the same material as that of the surrounding surface to which it is mounted; this helps to minimize disturbances in the surface temperature distribution.

The instrument operates on the principle that the temperature gradient at a point on the surface of a material exposed to a heating environment is proportional to the absorbed heat flux at that point. The surface temperature gradient is obtained from two thermocouple temperature measurements taken at different depths near the surface. The thermocouples are connected in series to yield an emf output proportional to the temperature difference between the distance of the two thermocouples. The temperature gradients add, therefore the absorbed heat flux is proportional to the emf output. In addition to the two thermo-

couple measurements required for the heat flux measurement, a separate thermocouple is positioned near the surface to provide a near-surface temperature measurement. Several prototypes



Section A-A

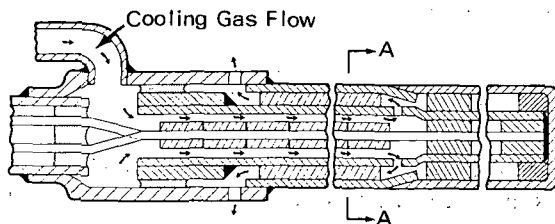
have been fabricated and tested. The sensitivity of the prototypes is equal to or greater than that required for a 5 mV full-range output with absorbed heat flux of 20 W/cm. The response time of the prototypes is equal to or less than 400 msec for a 63% response to a step change in the heat flux.

Source: D. L. Jones of Heat Technology Laboratory, Inc. under contract to Marshall Space Flight Center (MFS-12350)

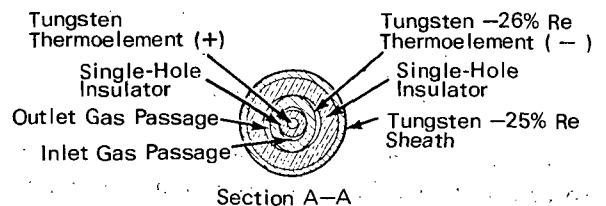
Circle 1 on Reader Service Card.

### HIGH TEMPERATURE THERMOCOUPLE DESIGN PROVIDES GAS COOLING WITHOUT INCREASING OVERALL SIZE OF UNIT

A thermocouple utilizing a thermoelement with a noncircular cross section can operate in temperatures above 4000° R (2222 K). The ther-



mocouple design employs an elliptically shaped tungsten-rhenium tube as a negative thermoelement and a round tungsten wire as the positive ele-



ment. Insulators of circular cross section are used between the elements, thus providing a path for the flow of a coolant gas down the probe. A similar arrangement of insulators between the tungsten-rhenium tube and the outer sheath provides the return path. Several small holes are drilled near the hot end to allow gas to flow through the tungsten-rhenium thermoelement wall. The direction of the gas flow could, of course, be from the outer sheath to the inner sheath if dictated by design considerations. The direction of flow is not a controlling factor.

A corollary to this design would be to use thermoelements of circular cross section with insulators of noncircular cross section. This approach would probably require more space for the same relative performance as the unit described above.

Source: G. J. Zellner of Westinghouse Astronuclear Laboratory under contract to AEC-NASA Space Nuclear Systems Office (NUC-10515)

Circle 2 on Reader Service Card.

### ELECTRONIC SENSOR MEASURES SKIN TEMPERATURE

The electronic temperature sensor has use in a wide variety of biomedical applications where surface temperatures ranging from 0° to 100° C must

sensing head placed in contact with a 0° surface. The sensing head is then placed in contact with a surface having a known higher temperature, and the millivolt reading is taken. The millivolt/tem-

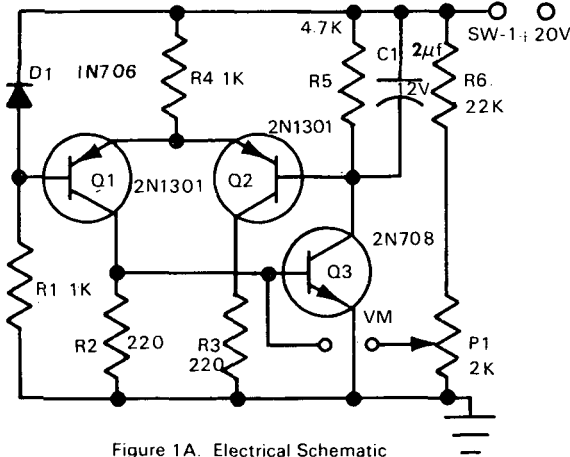


Figure 1A. Electrical Schematic

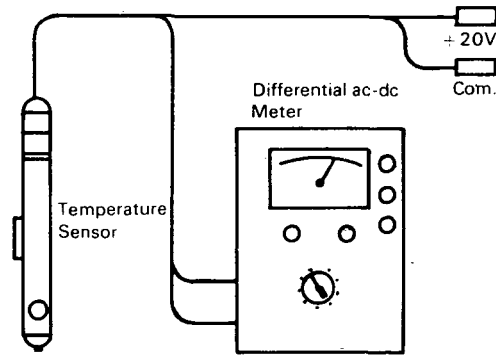


Figure 1B. Instrument Setup

be measured with high precision. The unit consists of a printed circuit with a transistor as the heat sensor, a magnet-operated reed switch, a plastic head and a connector. The plastic head has a groove to lock the transistor in place so that pressure applied to the sensor will not bend the transistor leads. The unit is small and slender and can fit into or on small objects. It removes very little heat from the object under test and can be used to better advantage than a thermocouple since most thermocouples depend on absorbing heat from the source.

temperature relationship is linear, so a conversion chart is easily constructed by drawing a straight line through the data points. The reed switch makes possible the insertion and removal of the printed circuit from the tube without the necessity of connecting and disconnecting wire or mechanically installing and dismantling a switch.

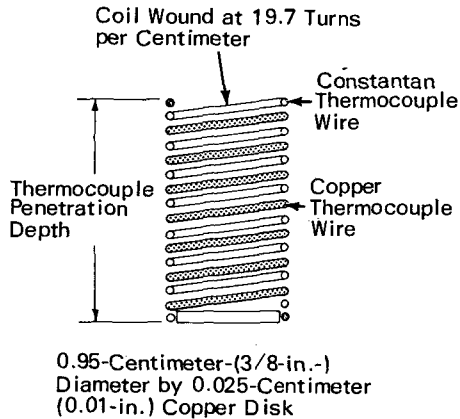
Source: J. Craft of Chrysler Corp. under contract to Marshall Space Flight Center (MFS-14458)

Calibration is accomplished by adjusting potentiometer P1 to obtain a zero reading with the

Circle 3 on Reader Service Card.

### THERMOCOUPLE CONFIGURATION FOR TANK INSULATION

A thermocouple configuration shown in the figure measures temperatures within a low-density polyurethane foam insulation on a cryogenic tank. Good thermal contact is provided between the



thermocouple junction and the foam insulation, and the heat leakage through the electrical leads to the thermocouple junction is reduced significantly. Other applications of this configuration are for measurement of temperature profiles in

materials having irregular or nonuniform structure, e.g., foams, powders, wood, and cork.

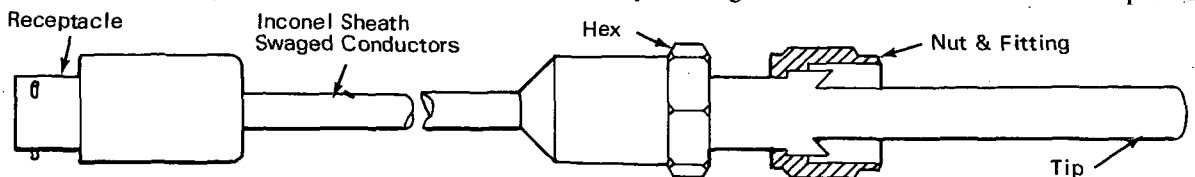
Each thermocouple consists of a 0.95-cm (3/8-in)-diam by 0.025-cm (0.01-in)-thick copper disk which provides a large contact area with the foam, and acts as the thermocouple junction. The teflon-insulated thermocouple wires are soldered to the copper disk to form the thermocouple junction. The thermocouple wires are wound in a coil on a teflon mandrel, to the desired thermocouple penetration depth, and then cemented together. When installed in the polyurethane foam insulation, the copper disk and wire coil are cemented together. When installed in the polyurethane foam insulation, the copper disk and wire coil are cemented into a flat-bottom cylindrical hole drilled to the proper penetration depth in the foam. The interior of the wire coil is filled with a cylindrical plug of foam.

Source: I. E. Sumner of  
Lewis Research Center  
(LEW-11242)

*No further documentation is available.*

### TRANSDUCER MEASURES HIGH TEMPERATURE GASES

A temperature transducer has long-term stable operation in an atmosphere composed of water vapor (steam) and gaseous hydrogen. It can with-



stand temperatures at 2000° F for periods extending to 4 1/2 hours, and at 2500° F for five minutes.

The transducer is a probe-type temperature sensor having a 2-mil platinum element mounted on a high grade alumina mandrel. The platinum element was selected after extensive testing proved it superior to a design using tungsten as the sensing element. The completed assembly is strain-relieved and centered within a platinum sheath. The area between the sheath and mandrel is filled with high purity alumina powder for electrical insula-

tion and mechanical support. Protecting the platinum element from contamination is accomplished by coating the stem material with chrome-plated

thoria-diffused nickel. This coating provides an ablative shield and exhibits excellent corrosion resistance properties at elevated temperatures.

Source: J. P. Surak and  
L. R. Bellamy of  
McDonnell Douglas Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-20318)

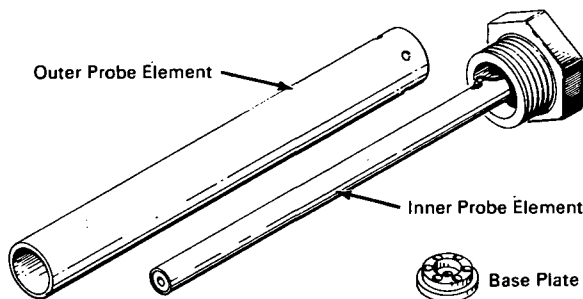
*Circle 4 on Reader Service Card.*



## Section 2. Liquid Level and Fluid Flow

### CRYOGENIC LIQUID LEVEL MEASURING PROBE

Static and dynamic levels of cryogenic liquids in a hydrogen bubble chamber can be measured by a newly developed liquid level measuring probe. This device incorporates a unique fre-



quency discriminator to provide continuous readings of the levels of nitrogen, hydrogen, or helium to an accuracy of  $\pm 1\%$ . The probe has a dynamic response time of less than  $150\mu\text{sec}$ , allowing boiling conditions or other turbulence to be observed throughout all the transition stages.

The coaxial probe, when immersed in a liquid, measures the difference in the dielectric constants

between the liquid and gas phases of the media. The probe capacity is therefore a function of the height of the liquid within the probe elements. The probe and its associated cable constitute the capacity in the tuned circuit of an oscillator, and a liquid level change is reflected as an oscillator frequency change. A voltage controlled oscillator is phase locked to the probe oscillator frequency. The error voltage required to keep the two oscillators phase-locked is then a function of the liquid level.

A percentage readout is used with the probe to provide more efficient use of the instrument's dynamic range and to reduce operator error. In addition, the system may be used as a data logger to record liquid levels in a number of containers through a scanning operation.

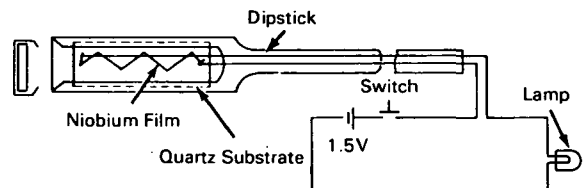
Source: J. A. Dinkel and  
C. R. Wegner  
Argonne National Laboratory  
(ARG-10138)

Circle 5 on Reader Service Card.

### SUPERCONDUCTIVE THIN FILM USED AS LIQUID HELIUM LEVEL SENSOR

The level or depth of liquid helium in a dewar flask may be measured to an accuracy of  $\pm 0.25$  inch by averaging two readings from a superconductive thin-film sensor. A thin film of niobium metal is deposited to a thickness of approximately  $2000 \text{ \AA}$  on a quartz substrate, which is then mounted on a graduated dipstick. The film deposition is performed at  $600^\circ \text{ F}$  in a vacuum of approximately  $10^{-6}$  torr (with an electron beam evaporation source) at an evaporation rate of approximately  $1500 \text{ \AA}$  per minute. For a sensor on a quartz substrate measuring  $1/16 \times 1$  inch, the electrical resistance of the device is 200 ohms at room temperature.

In the measurement of liquid helium levels, the niobium film is connected in series with a 1.5 volt battery, an indicating lamp, and a normally



open pushbutton switch. With the switch closed, the top of the dipstick is held with thermally insulated gloves and the sensor is slowly and carefully lowered into the dewar until the indicator

lamp lights. At this point, sensor contact with the liquid helium reduces the sensor temperature so that the niobium becomes superconducting. The loss of resistance in the sensor permits sufficient current to flow from the battery to light the lamp. The reading on the dipstick then corresponds to the liquid level. Once turned on, the lamp will remain lit (with the switch closed) as long as the sen-

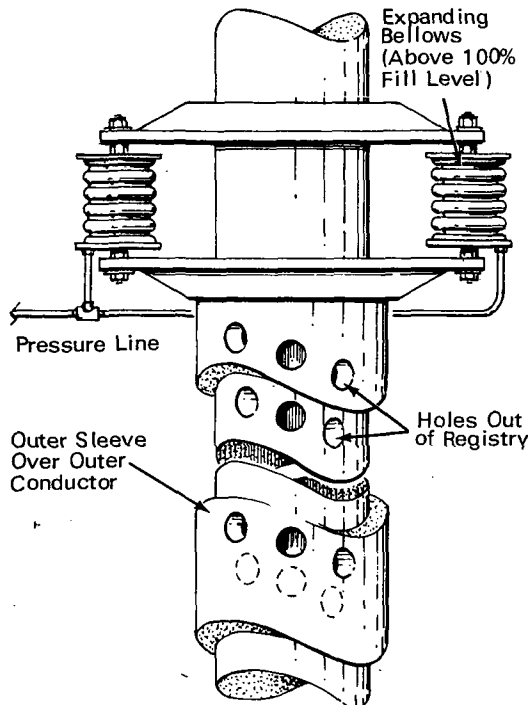
sor is immersed in the liquid or is surrounded by helium vapor immediately above the liquid surface.

Source: H. H. Becker  
Langley Research Center  
(LAR-10289)

*No further documentation is available.*

### IMPROVED CAPACITANCE PROBE FOR LIQUID LEVEL MEASUREMENT: A CONCEPT

A conceptual dual-purpose probe is designed to obtain either a steady, relatively noise-free level measurement, or a measurement of level changes,



including sloshing and surface instability due to boiling. This dual capability is accomplished through the use of a double outer tube with a series of holes, arranged so that movement of the tube leaves only a single inlet for the liquid.

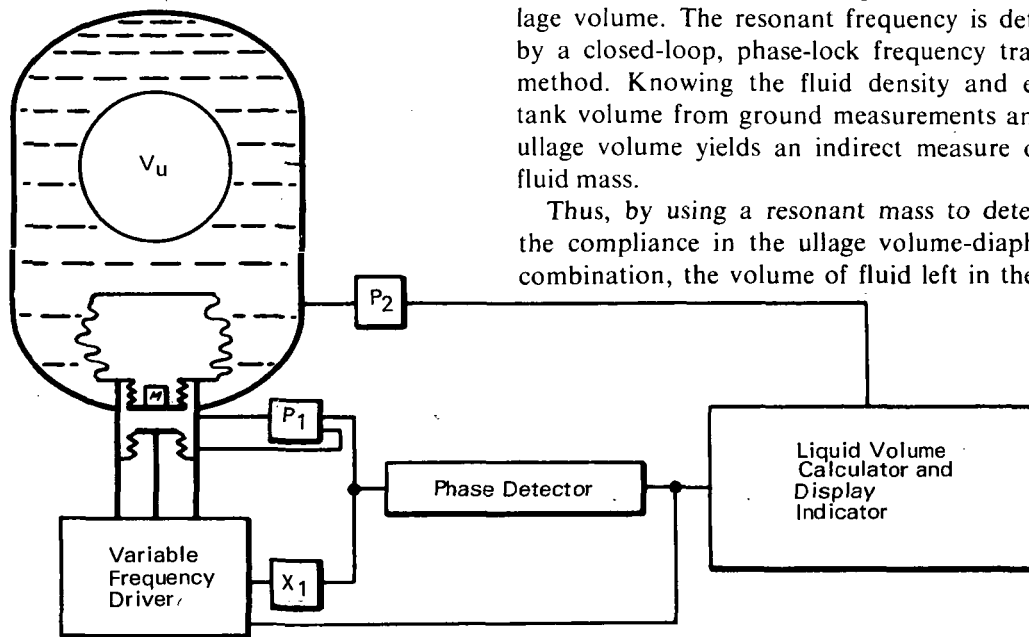
An auxiliary sleeve with a series of holes in it is placed over the outer conductor of a standard coaxial probe. In one position of the auxiliary sleeve, the holes are in registry with those of the outer conductor; in the other position, they are out of registry so that the holes are closed and no liquid can flow through the probe. During periods when the liquid level is being accurately adjusted and maintained, the holes are closed to eliminate effects of surface undulations or liquid convection currents. During periods when sloshing is being evaluated, or when the tank is being depleted at a high rate, the holes are aligned to permit relatively unrestricted flow. The sleeve may be positioned to effect hole registry or nonregistry using either a timed mechanism, which can be hydraulic or electrical, or a gravity device responsive to acceleration, as in the case of a space vehicle fuel tank. Modification of flow characteristics through the probe, as functions of liquid level, acceleration field, tank pressure, time, etc., may be employed to adjust probe accuracy and response characteristics.

Source: C. C. Wilhite of  
Bellcomm, Inc.  
under contract to  
NASA Headquarters  
(HQN-9986)

*Circle 6 on Reader Service Card.*

### INFRASONIC SYSTEM MEASURES LIQUID VOLUME IN STORAGE TANKS: A CONCEPT

An infrasonic system can measure the total amount of fluid present in bladderless storage tanks. The measurement system (see fig.) consists of a resonant gas-filled cavity coupled to a low-frequency sonic generator, a diaphragm-type pressure transducer, and a data display unit. This sys-



tank. The diaphragm is weighted with a mass tuned with the ullage volume to a relatively low resonant frequency. As the ullage volume changes with changes in fluid mass (similar to a resonant chamber), the resonant frequency decreases, inversely proportional to the square root of the ullage volume. The resonant frequency is detected by a closed-loop, phase-lock frequency tracking method. Knowing the fluid density and empty tank volume from ground measurements and the ullage volume yields an indirect measure of the fluid mass.

Thus, by using a resonant mass to determine the compliance in the ullage volume-diaphragm combination, the volume of fluid left in the tank

tem, called a Resonant Infrasonic Gaging System (RIGS), is unaffected by fluid orientation, is easy to install and can be used with all types of bladderless tanks. It should have use in applications such as the noncontact measurements of bulk quantities of toxic or reactive industrial chemicals.

The RIGS consists of a fixed amplitude, variable frequency driver that sets up a pressure perturbation in the cavity to which it is attached. The cavity is mechanically isolated and adjacent to the ullage region (voided portion). A low compliance elastomer diaphragm, compatible with the fluid, acts as the common wall between the cavity and the

can be determined with the required accuracy. Elimination of acoustical resistance makes the system insensitive to temperature and the presence of the resonant circuit makes it insensitive to nonlinearities. The system is light, compact, requires little power, and should be inexpensive to fabricate.

Source: B. Siegel, and  
S. Lieberman of  
TRW Corp.  
under contract to  
Manned Spacecraft Center  
(MSC-11847)

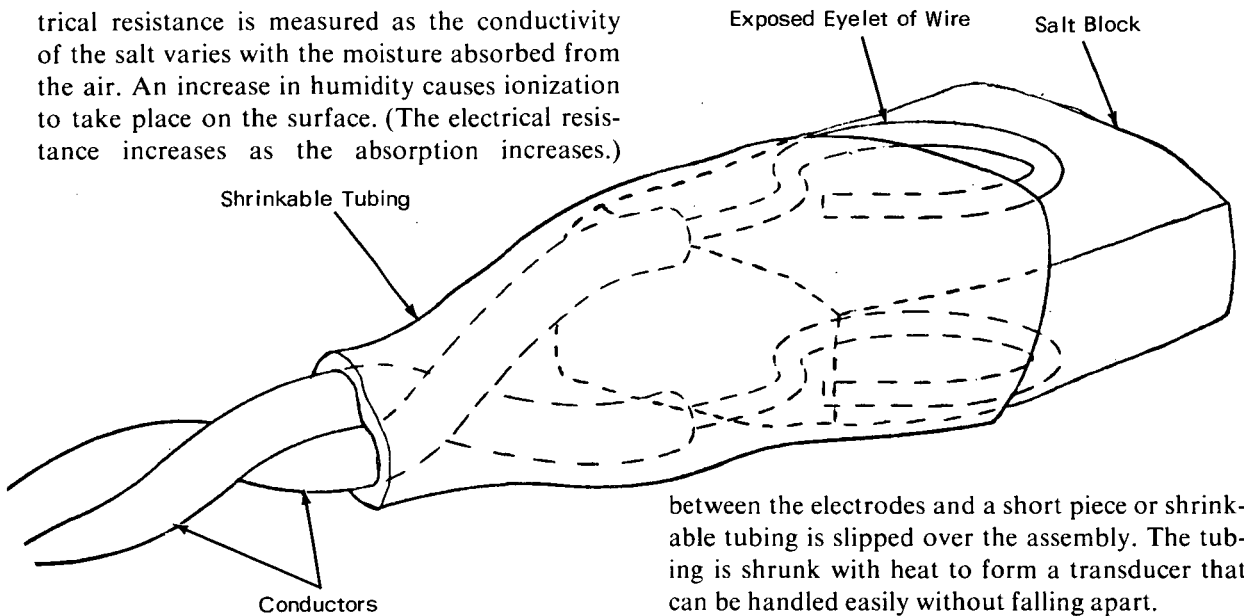
Circle 7 on Reader Service Card.

### REMOTE MOISTURE INDICATOR

A small, inexpensive remote reading moisture indicator transducer can be sealed within sections of load cells containing strain gages so that known

moisture content effects on the gages can be determined. The transducer consists of a piece of rock salt sandwiched between two electrodes. The elec-

trical resistance is measured as the conductivity of the salt varies with the moisture absorbed from the air. An increase in humidity causes ionization to take place on the surface. (The electrical resistance increases as the absorption increases.)



The electrodes are formed by stripping the insulation from the ends of two wires of sufficient length to be used also as conductors for the transducer. The ends of the wire are shaped into the form of eyelets to increase the contact area of the wire touching the salt. The salt is then sandwiched

between the electrodes and a short piece of shrinkable tubing is slipped over the assembly. The tubing is shrunk with heat to form a transducer that can be handled easily without falling apart.

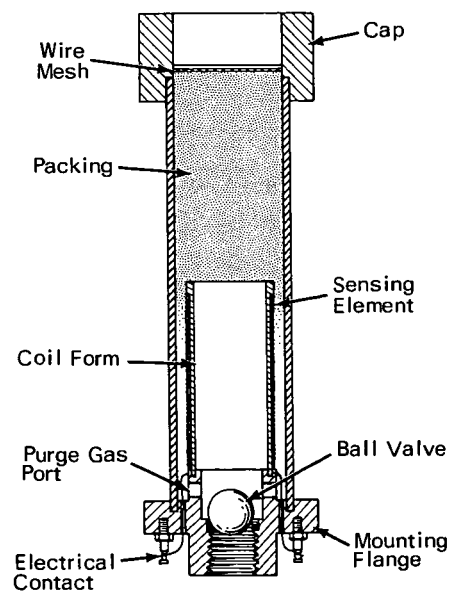
Source: C. N. Steed of  
North American Rockwell Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-13542)

Circle 8 on Reader Service Card.

### CRYOGENIC LIQUID FILLING SENSOR

This sensor can detect the overflow of a cryogenic liquid, in a two phase fluid flow through a cryogenic system, e.g. to automatically fill a liquid Nitrogen ( $LN_2$ ) Dewar or cold trap which must be topped frequently, or to sense the start of liquid flow during cooldown of a liquified natural gas (LNG) or other cryogenic transfer line.

In operation, the sensor is connected to the exhaust or vent pipe of the cryogenic vessel to be filled; or at the most distant point of the transfer line which is to be cooled down. The cold, dry gas (boil-off) which is vented during the filling cycle, does not affect the sensing coil due to the insulating properties of the porous coil form. As the cold liquid enters the coil form, it saturates or "wets" the porous coil form and intimately contacts the inside turns of the fine copper wire sensing coil, sharply lowering its electrical resistance. This reduces the voltage drop across the sensing element



sufficiently to activate a simple latching relay which de-energizes a solenoid valve, stopping the flow at its source.

This device has proven in operation to be reliable, simple, and inexpensive to produce.

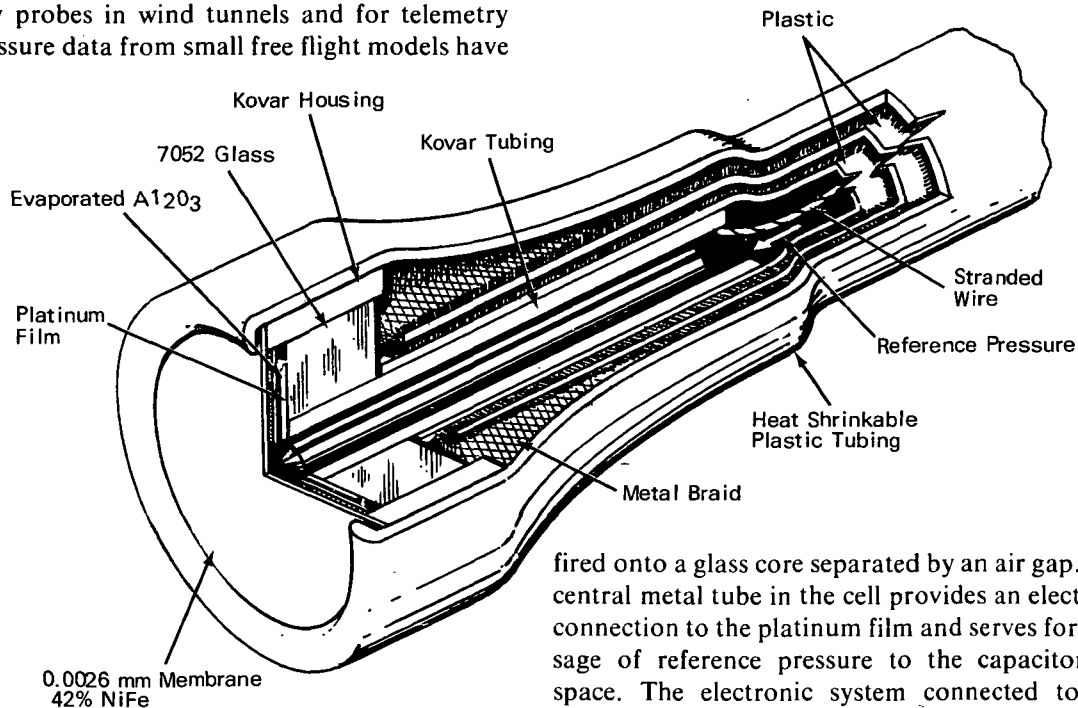
Source: W. M. Tener of  
Caltech/JPL  
under contract to  
NASA Pasadena Office  
(NPO-10619)

*Circle 9 on Reader Service Card.*

## Section 3. Pressure Transducers

### CARDIAC CATHETER WITH PRESSURE TRANSDUCER

Transducers originally designed for pressure survey probes in wind tunnels and for telemetry of pressure data from small free flight models have



fired onto a glass core separated by an air gap. The central metal tube in the cell provides an electrical connection to the platinum film and serves for passage of reference pressure to the capacitor air space. The electronic system connected to the catheter for sensing pressure consists of a capacitance bridge network excited by a crystal oscillator, a low noise transistor amplifier and an appropriate demodulator to produce an analog signal for a recorder or display on an oscilloscope.

Source: G. W. Coon of  
Ames Research Center  
(ARC-10054)

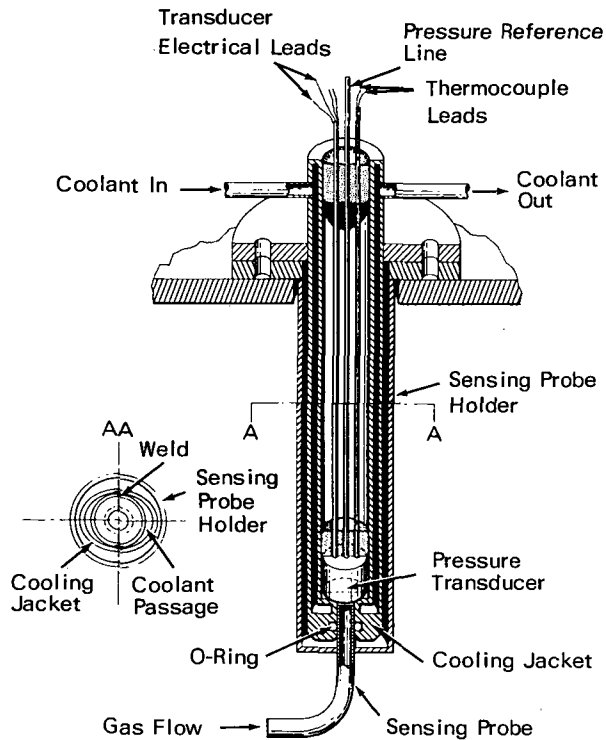
been adapted for measurement of intravascular pressures in humans. A miniature diaphragm-type capacitance transducer (see fig.) has been designed to be fitted on the end of a cardiac catheter and inserted by percutaneous techniques using standard needles which are routinely used for venous or arterial punctures.

The two capacitor plates used to sense pressure consist of a cell diaphragm and a film of platinum

*Circle 10 on Reader Service Card.*

### COOLED MINIATURE PRESSURE TRANSDUCERS EFFECTIVE AT HIGH TEMPERATURES

A compact water-cooled mount for miniature pressure transducers, permits locating the transducers in hotter and more confined environments than previously possible. This instrumentation



makes it possible to measure high-frequency total pressure fluctuations resulting from rotating stall in an axial flow engine compressor. Measurements have determined the initial location of stall and

followed the progression of a stall through the remaining stages of the compressor. Compactness is attained by utilizing pressure transducers 1/4 in. wide by 1/4 in. long, with connecting leads and reference pressure tube extending from the rear. Good response at frequencies to several hundred Hertz is obtained by locating the pressure transducer near the mouth of the sensing probe.

The cooling jacket comprises two concentric tubes. The inner tube is circular, with an inside diameter slightly larger than the outside diameter of the transducer. The outer tube is flattened to an elliptical cross section having a minor axis equal to the outside diameter of the inner tube. The two tubes are roll welded or spot welded together at their line of contact to provide parallel coolant supply and return passages. The coolant passages are connected at the inner or sensing end where the inside tube is reduced in diameter to fit around the transducer. The cooling jacket extends past the end of the transducer, so that the gas adjacent to the pressure diaphragm is also cooled. The transducer rests on a 0.010-in.-wide rim at the end of the inner tube. A thermocouple is attached to the transducer case. Transducer operating temperature is used to determine the coolant flow rate required and to correct the pressure measurements.

Source: E. C. Armentrout  
(LEW-10401)

Circle 11 on Reader Service Card.

### NEW TYPE PRESSURE TRANSDUCER FOR SEVERE THERMAL ENVIRONMENTS

A pressure transducer has been developed which enables the measurement of pressures exceeding 2000 psi in ambient temperatures approaching 7000° F. The application of this transducer can be utilized in various metal processing techniques which require these high temperature and pressure environments. The transducer, mounted in the chamber wall, is capable of measuring dynamic pressures with amplitudes up to 2,000 psi with a frequency response flat within 1% to 10 kHz.

In addition, the pressure transducer is capable of sustained operation in a thermal environment where temperatures reach 7000° F (heat fluxes up to 25 BTU/in<sup>2</sup>/sec).

In order to maintain the high frequency response with good heat-transfer capabilities, the transducer design uses a transpirational-cooled porous beryllium plug and pressure transmitting column. A four-arm semiconductor strain gage bridge, mounted on the lower portion of the

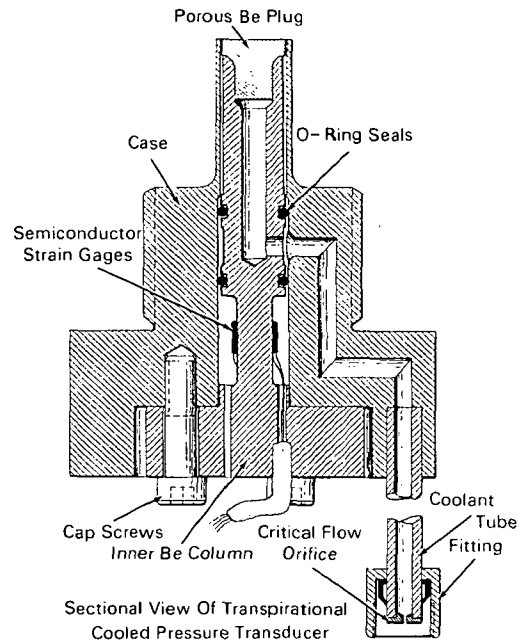
column, senses the compressive strains as a result of the rocket chamber pressure.

The porous beryllium plug at the upper end of the transducer is flush-mounted in the rocket chamber at the desired location. Pressure (both static and dynamic) in the rocket chamber acts upon the porous plug, and the force is transmitted down the inner column to the strain gage.

Heat fluxes are kept from the sensing element by bleeding a gaseous coolant, helium or hydrogen, through the porous beryllium plug. Because of the micron-size passages in the porous material, transient pressures essentially "see" a solid; thus, imposed strains in the lower portion of the column are the same as if a solid plug were used. The coolant is introduced at a constant pressure higher than that encountered in the combustion instability regions. Because of the presence of the upper and lower seals, the coolant pressure is completely balanced within the unit and only strains created by pressure in the rocket chamber are sensed. The only requirement for the coolant mass flow rate maintained by the critical flow orifice is that the coolant pressure must be higher than the maximum rocket chamber pressure.

Beryllium, which has an exceptionally high stiffness-to-weight ratio, was selected for both the pressed-fit porous plug and inner column in order to achieve the required frequency response characteristics. In addition, a very high natural frequency for this system was attained by using a small col-

umn in compression and maintaining low strains for the maximum design pressure. Semiconductor gages were used rather than resistance gages in



order to achieve the required sensitivity commensurate with the low strains.

Source: Battelle Memorial Institute  
under contract to  
Marshall Space Flight Center  
(MFS-20208)

Circle 12 on Reader Service Card.

## ECONOMIC MEASUREMENT OF ULTRALOW FLOW RATES OF FLUIDS

A capillary tube flowmeter measures ultralow flows of corrosive and noncorrosive liquids. The method used is economical and should be of interest to the chemical industry.

A differential pressure transducer measures the linear pressure drop across a coil of capillary tubing. Through calibration with water and analytical conversion, flow rates as low as 0.005 gpm of very corrosive fluids (such as chlorine trifluoride and liquid fluorine) can be measured with reasonable accuracy.

The essential elements of the capillary tube flowmeter, shown in Figure 1, include a length of tubing and a differential pressure transducer. The

flowmeter operates on the principle that, for laminar flow in the tube, the pressure drop is proportional to the flow rate. Since the capillary tube is smaller in diameter than the rest of the system's lines, reducers are required at each end of the line. The abrupt changes in line size are also sensed by the differential pressure transducer and should follow the pressure drop function. The total pressure drop which a transducer senses is expressed by the formula

$$P = K_1 Q^2 + K_2 Q$$

where  $Q$  is the fluid flow, and  $K_1$  and  $K_2$  are functions of the fluid flowing through the meter and the meter geometry. The calibration test using

water results in one set of values for  $K_1$  and  $K_2$ . Once the meter has been calibrated with water, the equation can be modified for any liquid. The coefficients  $K_1$  and  $K_2$  are proportional to the vis-

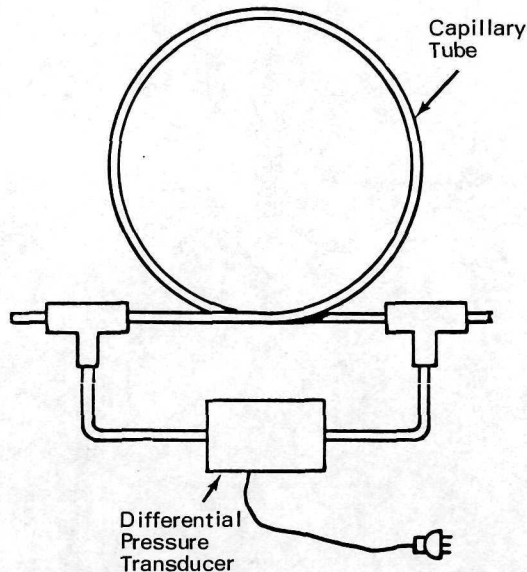


Figure 1. Capillary Tube Flowmeter

cosity and density ratios of the liquid to water, respectively. Applying the viscosity and density for chlorine trifluoride, the result is

$$P = 1314Q^2 + 45.7Q$$

which is shown graphically in Figure 2.

During valve opening and closing transients, flow measurements cannot be made because of

cavitation or water hammer in the differential pressure transducer lines. Once the valve transient has damped out, the flowmeter reading can be made with reasonable accuracy. Flow rate error can be shown mathematically to be a function of pressure differential and pressure differential error.

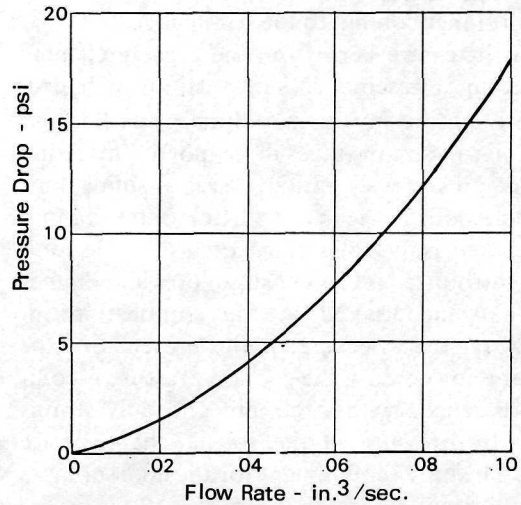


Figure 2. Capillary Tube Flowmeter - Pressure Drop Versus Flow Rate for Chlorine Trifluoride

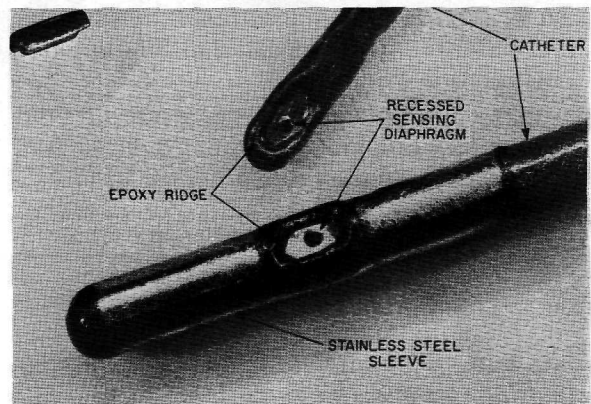
Source: J. A. Bogdanovic and  
W. F. Keller of  
Northrop Corp.  
under contract to  
NASA Pasadena Office  
(NPO-12064)

Circle 13 on Reader Service Card.

## CARDIOVASCULAR PRESSURE TRANSDUCER

A miniature semiconductor (tunnel diode) transducer is capable of transmitting pressure variations that are useful in assessing cardiovascular function. Believed to be the smallest of its kind ever fabricated, it is about two hundredths of an inch thick and uses less than 500 millionths of a watt of electric power.

Medical research, in collaboration with NASA scientists, has demonstrated the medical potential of the cardiovascular pressure transducer for eventual clinical applications. Encouraging results have already been obtained by inserting the tiny





device into the heart and arteries of anesthetized dogs and much smaller animals.

The present design is particularly attractive for biomedical applications for which special configurations and circuitry have been developed. Taking advantage of the tunnel diode switching characteristic, experimental circuitry has been designed to yield pulsewidth and frequency-modulated output with high percentage (0.5%/mmHg) deviation.

The transducer may well significantly advance the state of the art in monitoring blood flow changes especially in cardiac patients with coronary occlusions.

Source: W. Rindner,  
A. Iannini, and  
A. Garfein  
(ERC-10087)

Circle 14 on Reader Service Card.

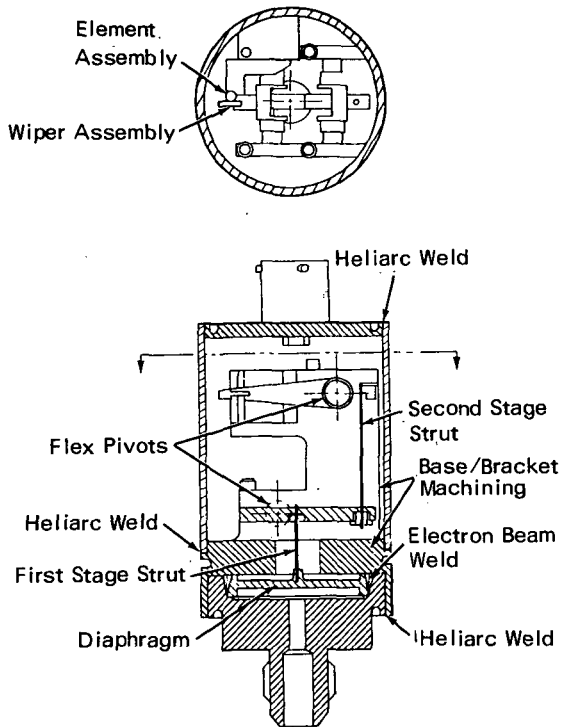
### CRYOGENIC PRESSURE TRANSDUCER

The transducer utilizes a diaphragm which is electron beam-welded to a fitting (see fig.). This assembly is then heliarc welded to the main body of the transducer. The diaphragm pressure deflection is transmitted to a first stage amplifier through a strut wire brazed at both amplifier and sensor ends. The amplifier multiplies the sensor travel by a factor of 4.5 to 6 and feeds this motion to the wiper assembly through a second stage strut wire.

The second amplifier arm further multiplies motion to produce a 0.150 in. wiper travel at the potentiometer. The transducer requires no damping oil, and is capable of operating at both cryogenic and high temperatures. The flex pivots provide frictionless bearings, high lateral stiffness, and low torsional stiffness.

Source: J. M. Hendrix of  
Bourns Inc.  
under contract to  
Marshall Space Flight Center  
(MFS-14909)

Circle 15 on Reader Service Card.



### SILICON STRAIN SENSORS FOR PRESSURE MEASUREMENT AT CRYOGENIC TEMPERATURES

Diffused, heavily doped silicon strain-gage sensor elements have been developed for operation in pressure transducers over a wide temperature range. Improvement in gage characteristics, excitation source impedance, bridge circuit param-

eters, and transducer structure has led to the design of miniature pressure transducers which exhibit zero and sensitivity shifts of less than  $\pm 3\%$  of full scale throughout the temperature range from  $+250^\circ$  to  $-450^\circ$  F. Small thermal mass com-

bined with close coupling between a metallic diaphragm (force summing member) and sensor elements minimizes sensitivity to temperature transients. Silicon is selected as the semiconductor material because of its piezoresistive and mechanical properties. The piezoresistive behavior of silicon is also sufficiently well known to permit prediction of gage characteristics on the basis of impurity type and concentration. Although the sensors were developed for low temperature operation, they perform equally well at much higher

temperatures and provide continuous measurement capability over a 700° F temperature range.

Source: R. Bowman,  
J. Burns, and  
W. McLellan of  
Electro-Optical Systems, Inc.  
under contract to  
Marshall Space Flight Center  
(MFS-14703)

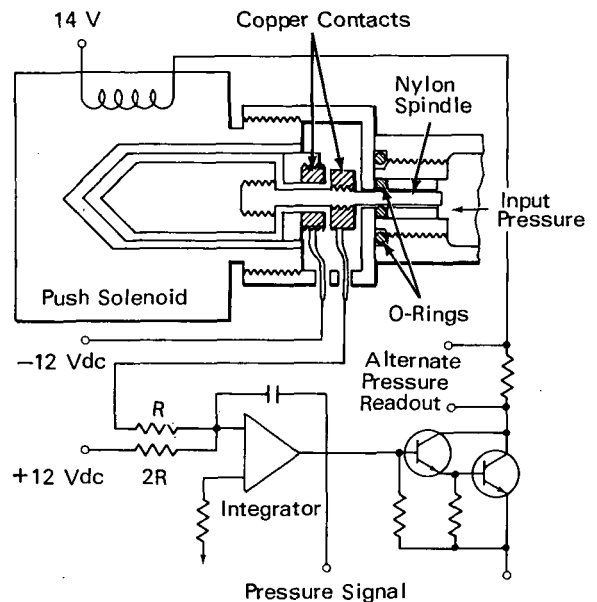
Circle 16 on Reader Service Card.

### FORCE BALANCE PRESSURE TRANSDUCER

A transducer is designed to equate gas pressure to an electromagnetic force. The pressure is indicated by the electric current which must flow through a push solenoid to counteract the force exerted by the gas pressure on a movable member. To maintain balance, the current flow is increased or decreased by an integrator which is activated by electrical contacts on the movable member.

In operation the input pressure acts on the spindle end of a push solenoid (see fig.) and forces the copper contacts together. A -12 Vdc signal is applied to the integrator through R to overcome the +12 Vdc input and reverse the direction of integration. The integrator output, increasing in the positive direction, applies current to the push solenoid in opposition to the force of the input pressure. For low input pressures, the solenoid force overcomes the pressure force as soon as the integrator signal is slightly positive, and moves the spindle, thus opening the circuit. The integrator output is then driven negatively and the solenoid force is reduced to a level below the pressure force, which restores the -12 Vdc signal. The integrator output executes a small oscillation about an average level corresponding to the input pressure.

As the input pressure is increased, the integrator output is forced to a higher level to generate the larger push solenoid force required to remove the negative input to the integrator. The integrator



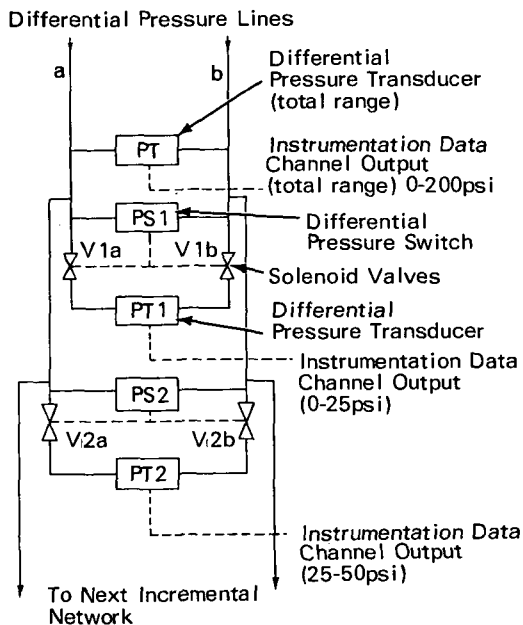
output once again settles at an average level corresponding to the input pressure.

Source: S. J. Rusk of  
Lockheed Missiles & Space Company  
under contract to  
Ames Research Center  
(ARC-10258)

Circle 17 on Reader Service Card.

## AUTOMATIC TRANSDUCER SWITCHING PROVIDES ACCURATE, WIDE-RANGE MEASUREMENT OF PRESSURE DIFFERENTIAL

An automatic pressure transducer switching network that sequentially selects any one of a number of limited-range transducers as the pressure rises



or falls makes possible the measurement of differential gas pressure over a wide range (0-to-200 psi) with great accuracy at any point in the scale.

(High precision transducers usually are limited in the range of measurement and can be easily damaged if the pressure limits are exceeded.)

In operation where no differential pressure exists across lines a and b, the two normally open solenoid valves V1a and V1b are open. As the a-b differential pressure rises, it is measured by transducer PT1 until the 25 psi limit is reached (as detected by pressure switch PS1). At this point PS1 closes valves V1a and V1b to prevent further gas flow to PT1. The pressure is still applied to the next ramp, consisting of PS2, V2a, V2b and PT2, which is set for the 25-50 psi range. Additional networks are added to the system to complete the total incremental coverage. Transducer PT provides full range, but less accurate monitoring of the pressure activity. The 0-to-200 psi range and 25-psi incremental steps are representative ranges only. Greater ranges and more or less precise incremental steps are entirely feasible.

Source: S. K. Yoder of  
Aerojet-General  
under contract to

AEC-NASA Space Nuclear Systems Office  
(NUC-10001)

*Circle 18 on Reader Service Card.*

## Section 4. Stress-Strain Measurements

### MINIATURE PRESSURE TRANSDUCER FOR STRESSED MEMBER APPLICATION

A miniature pressure transducer has been designed to respond to static or dynamic pressures acting against a structural surface without introducing errors caused by stresses in the structural surface. This is accomplished by a thin stainless steel pressure-sensing diaphragm with an attached foil strain gage. The strain gage is bonded to the stressed surface and has a very thin profile and low mass.

A metal film strain gage is installed on the inner surface of the housing diaphragm by conventional

strain gage application procedures, using hard epoxy adhesive. Gold-plated wires are soldered to the three tabs of the strain gage element. These wires are passed through holes in a miniature terminal board that is bonded to a "land" at the center of the transducer housing. Each wire is soldered to one end of the terminal element. Larger lead-in wires are soldered to the other end of each terminal element and passed out through the access hole in the transducer cover plate. The cover plate is then joined to the transducer hous-

ing by an overlapping spot-weld process using a capacitor discharge welder. The void between the cover plate and terminal board is filled with epoxy

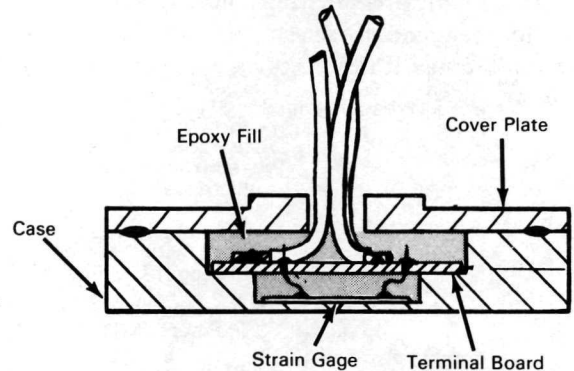


Strain Gage Pattern

to afford maximum protection for lead wire ends and to provide a seal for the back side of the transducer.

Zero balance of 4 transducers tested did not deviate more than 0.03% of full scale per °F over a temperature range of 32° to 120° F. Sensitivity

of the 4 transducers remained within 0.47% of their respective full-scale room temperature outputs over the same temperature range.



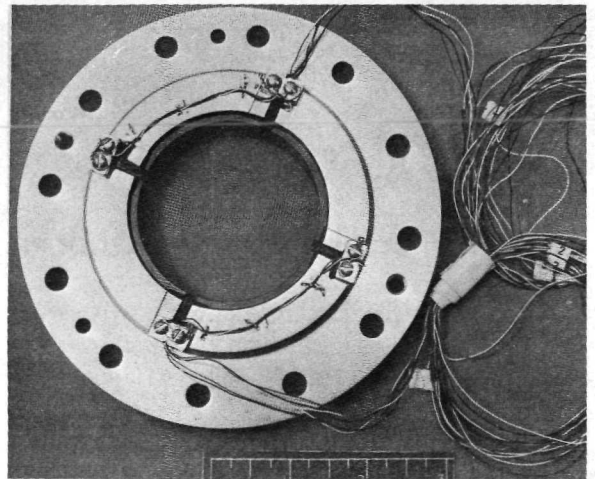
Source: R. R. Walker and  
C. G. Wickham of  
North American Rockwell Corp.  
under contract to  
Manned Spacecraft Center  
(MSC-90748)

Circle 19 on Reader Service Card.

### STRAIN GAGE DEFLECTION TRANSDUCER

During the course of investigating rotary-shaft seal dynamics it became necessary to measure the motion of a face seal relative to a shaft which was free to move axially in its bearings. This was further complicated by the fact that when the face seal lifted from the mating ring, liquid oxygen flowed into the cavity behind the seal, and could possibly damage the pump assembly through fire or explosion if precautions were not taken. These problems were eliminated with the use of a novel transducer assembly mounted on the shaft seal. Data provided with the test setup was subsequently used to ensure the design integrity of the shaft seals.

The transducer cantilever beams are installed on the seal as shown in the figure, and then calibrated for deflection. The seal assembly is then installed in the pump and the entire assembly is calibrated, in place, by applying loads to the shaft and measuring the deflections. A proximity pickup measures the movement of the shaft within the



bearings, and the cantilever beams measure the movement of the seal with respect to the pump structure. The difference between the two is the displacement of the face seal relative to the shaft. The pump assembly is then placed on a test stand

for operation. The data are recorded on tape and played back for analysis on a direct writing recorder. From the time relationship, as measured by the various pickups, it is possible to determine the relative motion of the seal with respect to the shaft or mating ring. The peaks are displaced slightly with reference to the trace showing shaft motion; this indicates that the shaft and the lip seal are traveling in different directions, causing a

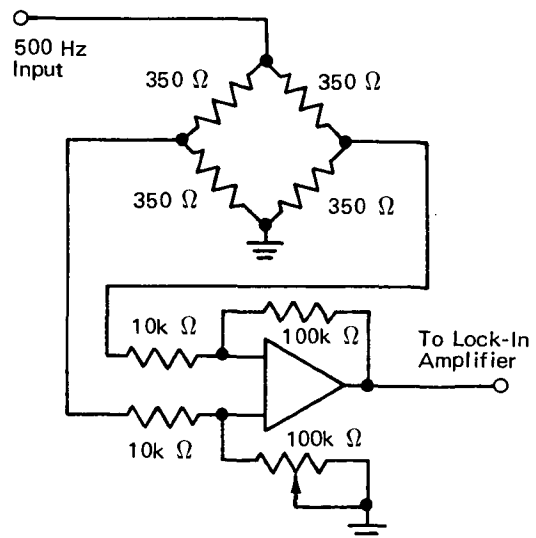
separation at the mating ring and allowing the fluid to flow past the seal into the cavity.

Source: D. W. Nicholls of  
North American Rockwell Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-18193)

Circle 20 on Reader Service Card.

### STRAIN GAGE AMBIGUITY SENSOR FOR SEGMENTED-MIRROR OPTICAL SYSTEM

An edge alignment sensor for actively controlled segmented mirror systems enables the alignment of a number of mirror systems to form one large optical element. The strain gage ambiguity sensor consists of a bridge-type, semiconductor strain gage, (see fig.) cantilevered on one end by bonding to a block of glass. The block of glass is in turn bonded to an active mirror segment near the edge. The other end of the strain gage is inserted into a "V" in a second glass block which is bonded near the edge of an adjacent mirror segment. The "V" serves as a flexible pivot point for the strain gage so that the inserted end will move up or down with relative motion between mirror segments, bending the strain gage and causing an electrical output. When the gage is bent, the bridge becomes unbalanced, providing an output which is fed to a differential operational amplifier. Each side of the bridge supplies an output with respect to ground. One side of the operational amplifier is provided with an adjustable feedback path so as to null the output of the amplifier by balancing the gain of the differential inputs. This technique will also allow electrical nulling of the output for residual strain that might exist in the mechanical setup when the mirrors are actually aligned. This provides greater versatility and greater ease of instal-



lation. Presently the system limitation is determined by the drift of the operational amplifier and is approximately  $\lambda/30$ , which is more than sufficient for the application.

Source: C. L. Wyman and  
T. L. Howe of  
Marshall Space Flight Center  
(MFS-20506)

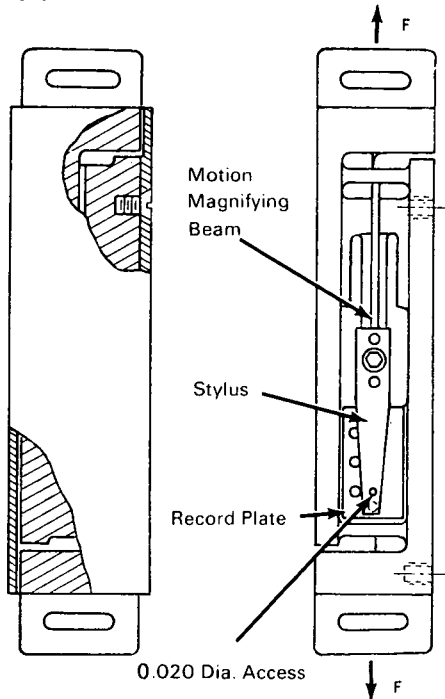
Circle 21 on Reader Service Card.

### A MAGNIFYING SCRATCH-GAGE FORCE TRANSDUCER

A single component scratch-gage transducer incorporates a unique motion magnification scheme to increase the magnitude of the load

measuring scratch approximately 15 times over that of conventional models. The device is small, load carrying, and high in natural frequency.

The transducer shown in the figure is constructed from a single piece of Vascomax-300 maraging steel with the exception of the stylus and recording plate; the stylus is made from Swedish



blue steel and the stylus point, made from heat-treated tool steel is pressed against a stainless steel record plate.

Motion magnification for the recording scratch is obtained through the eccentric beam in the center of the transducer that changes translational motion to a rotational motion, with the effective center of rotation being at the half length of the eccentric beam. Two flexure beams are used at each end of the transducer for assuring pure translational motion in the direction of the applied force. Overall accuracy of calibration, achieved by dead weight loading and measurement of the scratch length, is within  $\pm 2$  percent of the design load range. The motion magnifying scheme can also be used as a mechanical strain measuring device by rigidly attaching each end of the transducer to the specimen being loaded. In this application the input to the transducer would be a deflection which is proportional to the induced specimen strain.

Source: C. E. Scott  
Langley Research Center  
(LAR-10496)

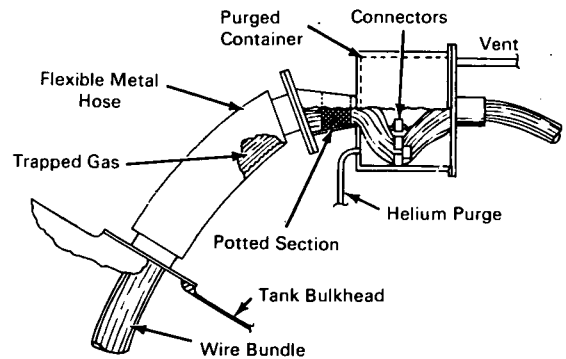
Circle 22 on Reader Service Card.

### STRAIN GAGE WIRE FEEDTHROUGH FOR CRYOGENIC PRESSURE VESSELS

Damage to a wire feedthrough exposed to cryogenic temperatures may be avoided by protecting the instrumentation wires from harmful gases and liquids. Routing the instrumentation wires from inside a cryogenic vessel may be safely accomplished by the use of a 5-foot long flexible hose over the wires, coupled with an inherent trapped gas barrier in the hose and a purge to prevent hazardous gas leakage.

Isolation of an electrical feedthrough from the cold pressure vessel prevents the electrical potting compounds from cracking or pulling away from the metal walls in cryogenic temperatures. As illustrated, this feedthrough was designed to mount on the top side of a pressure vessel, where no liquid would contact the flexible metal hose, and where the warmed gas inside the hose would be trapped as it is forced up by heavier gases below.

In common with the previously described feedthrough, this device is easily constructed and as-



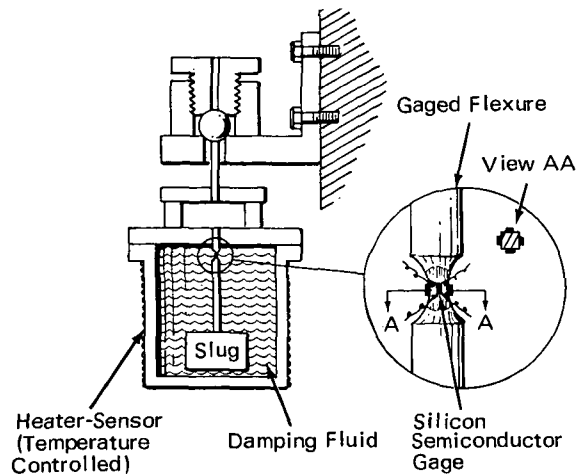
sembled from readily available standard parts and common materials.

Source: J. D. Henson of  
The Boeing Co.  
under contract to  
Marshall Space Flight Center  
(MFS-15040)

Circle 23 on Reader Service Card.

## TILT SENSOR

A simple, yet sensitive system for measuring small distortions in the horizontal plane is shown in the figure. Minute distortions (or angular displacement) can be measured with this pendulum-type device that incorporates strain gages to read out tilt in two axes. The device consists of a heat-treated beryllium-copper rod milled down to a square section; four semiconductor strain gages are installed in two pairs at 90°. The entire assembly is enclosed in a temperature-controlled oven and filled with a viscous damping fluid which serves to damp out vibrations. When not heated, the fluid becomes semisolid, thus protecting the sensor from handling shocks. A ball-joint mounting permits easy rough-leveling and alignment of the axes. Tilt in both X and Y axes are read out simultaneously and the semiconductor strain gages provide arc-second sensitivity. By interconnecting two tilt sensors, relative motion may be measured directly, independent of tilt of the entire assembly.



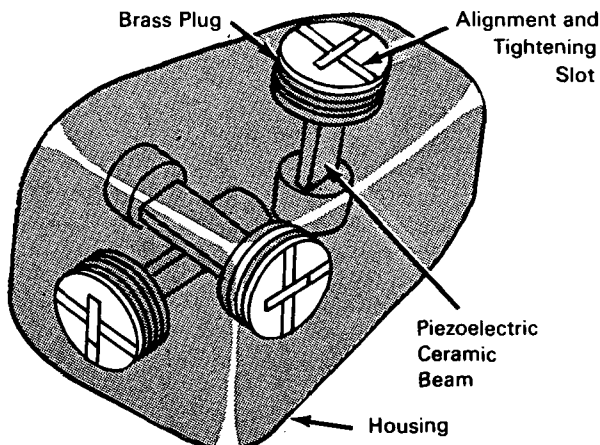
Source: J. Hanyok and  
M. Wilson of  
Goddard Space Flight Center  
(GSC-10781)

Circle 24 on Reader Service Card.

## Section 5. Acceleration and Velocity

## MINIATURE PIEZOELECTRIC TRIAXIAL ACCELEROMETER MEASURES CRANIAL ACCELERATIONS

A triaxial accelerometer shown in the figure measures human cranial accelerations when a subject is exposed to a centrifuge or other simulators'



of g environments. The physical shape of the accelerometer is compatible to a human mouth and may be attached to the teeth by an appropriate bridge.

The accelerometer consists of three orthogonal cantilever beams of piezoelectric ceramic material mounted in an aluminum case having external dimensions approximating those of a human molar. The beams are 0.2 in. in length and each has a gold weight bonded to the free end. The beams are located in a slot cut in a threaded brass plug and bonded in place with a nonconductive epoxy cement. Insulated, soft copper wires are soldered to the top and bottom electrodes of each beam and passed through the open slot of the plug along the beam side. The elements are then inserted into the housing and potted in place with epoxy

cement. The linearity for all components has proved to be excellent. Sensitivity is of the order of 20 mV (rms)/g and the response is essentially flat over the frequency range of 5 to 500 Hz.

Source: V. L. Rogallo and  
G. J. Deboo  
Ames Research Center  
(ARC-00071)

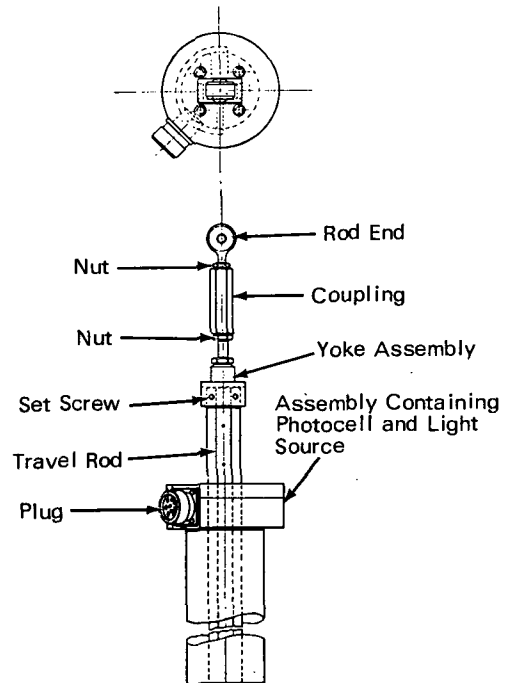
*Circle 25 on Reader Service Card.*

### PHOTOCELL VELOCITY TRANSDUCER

The photocell transducer allows measurement of velocity, acceleration, and travel of relatively large test specimens during explosive-type separation tests. It consists of the cell and light source facing each other across a gap in which a rectangular teflon rod travels. The rod has holes drilled at prescribed distances, allowing light passage to the photocell. The voltage generated by the photocell triggers a circuit to produce a pulse which is recorded on an oscillograph having a predetermined paper speed. The series of pulses, when measured against the oscillograph timebase, enables the operator to calculate velocity, distance, and acceleration. The measured velocity is limited only by the response time of the photocell and the readout device.

Source: J. L. Watts of  
North American Rockwell Corp.  
under contract to  
Manned Spacecraft Center  
(MSC-15082)

*Circle 26 on Reader Service Card.*



### DAMPING TECHNIQUE GIVES ACCELEROMETER FLAT FREQUENCY RESPONSE

This piezoelectric accelerometer achieves a flat response over a wide frequency range in high acoustic environments. It is capable of measuring random or sinusoidal vibrations from 20 to 10,000 Hz in the presence of acoustic levels of 150 to 160 dB. The acoustic response is equivalent to 0.05 g at 140 dB.

The accelerometer is attached to the vibrating surface with a two-part mounting stud electrically isolated by an insulator. Within the cylinder is a circular metal armature, smaller in diameter than

the inside cylinder by a precise amount, so that an annular passage exists between the armature and cylinder. A piezoelectric sensing element with an electrode is cemented to the upper face of the armature electrode. The cavity within the accelerometer body is filled with a viscous silicone damping fluid.

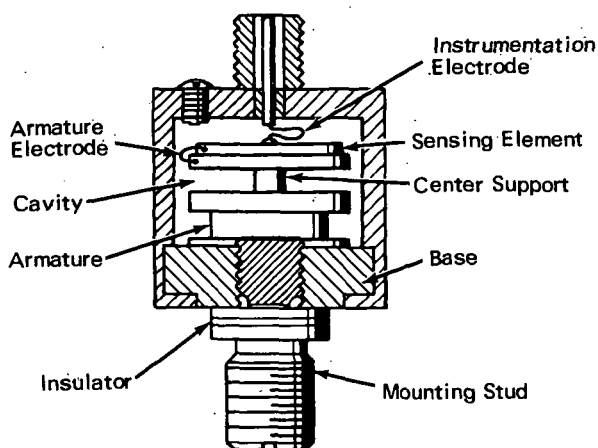
In operation the shock or acceleration forces cause the armature to flex about its center support. This stresses the piezoelectric element and induces a voltage proportional to the applied external



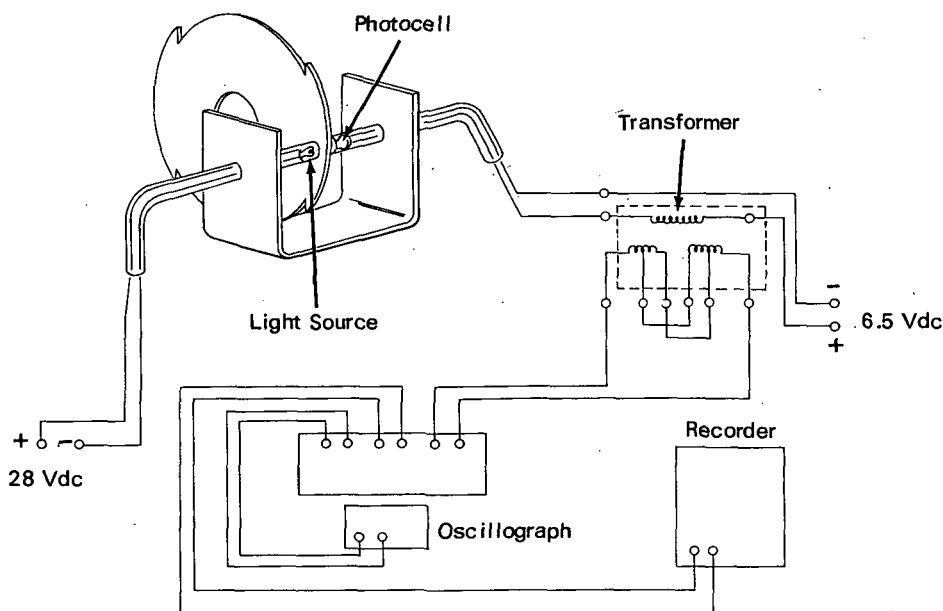
force. Vibrations set up in the armature are quickly damped out by the viscous silicone damping fluid, thus making the instrument immediately available for subsequent force measurement.

Title to this invention, covered by U.S. Patent No. 3,170,076, has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)] to Gulton Industries, Inc., 212 Durham Avenue, Metuchen, New Jersey.

Source: Thomas Wing  
of Gulton Industries, Inc.  
under contract to  
Marshall Space Flight Center  
(MFS-471)



### PHOTOELECTRIC SPEED TRANSDUCER



The transducer can be used in tests conducted on turbine bearings and seals when the angular velocity must be determined to a high degree of accuracy. Previously the accuracy of the data was questionable due to the disturbing influence of the rising and falling electromagnetic field of the drive motor. In operation a cam disk is mounted on the drive train to interrupt the light source, thereby causing an output frequency proportional to the revolutions of the drive motor (see fig.). The

photoelectric speed transducer eliminates the extraneous influences that appeared in the previous systems, thereby increasing the quality of data received from bearing speed recordings.

Source: L. A. Vannucci of  
North American Rockwell Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-1199)

*No further documentation is available.*

### RECTILINEAR ACCELEROMETER POSSESSES SELF-CALIBRATION FEATURE

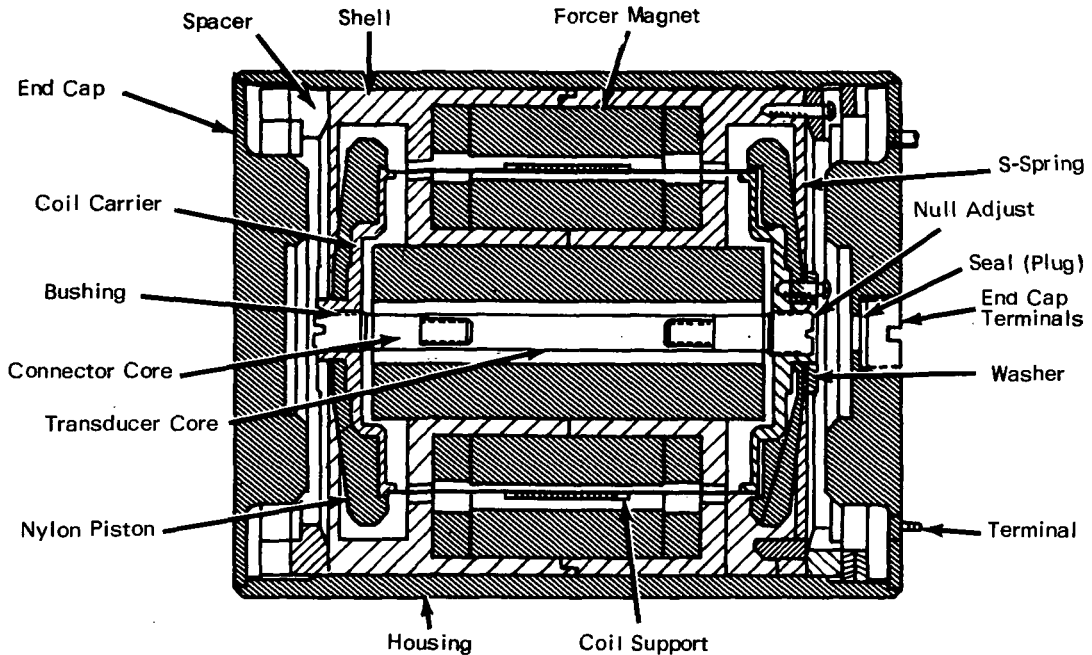
A rectilinear accelerometer provides a phase-sensitive ac voltage output proportional to the applied acceleration. The unit includes an independent circuit for self-test which provides an output simulating an acceleration applied to the sensitive axis of the accelerometer.

The sensitive mass of the rectilinear accelerometer consists of nylon damping rings, coil carrier

either direction, an output signal proportional to the core position is achieved. Because the core is part of the sensitive mass and thus travels or deflects with it, the output signal indicates the mass position. Salient operational characteristics of the accelerometer include:

Range:  $\pm 10$  meters/sec/sec

Output: 0.5 volt rms/meter/sec/sec



supports, and a coil carrier with its winding. In addition, the core of the transducer and its null adjustments are also included in the sensitive mass. Two S-springs are used in the assembly and are symmetrically mounted, one on each end of the sensitive mass. The sensitive mass is mounted to the i.d.'s of the s-springs, which are securely attached to the magnet carrier.

In operation, the core links the flux lines from a primary winding into two balanced opposing secondary windings. With the core at electrical null, the in-phase signal and out-of-phase signal cancel leaving an electrical zero. With motion in

Output Load: 20,000 ohms

Output Impedance: 2,000 ohms max (as a voltage generator)

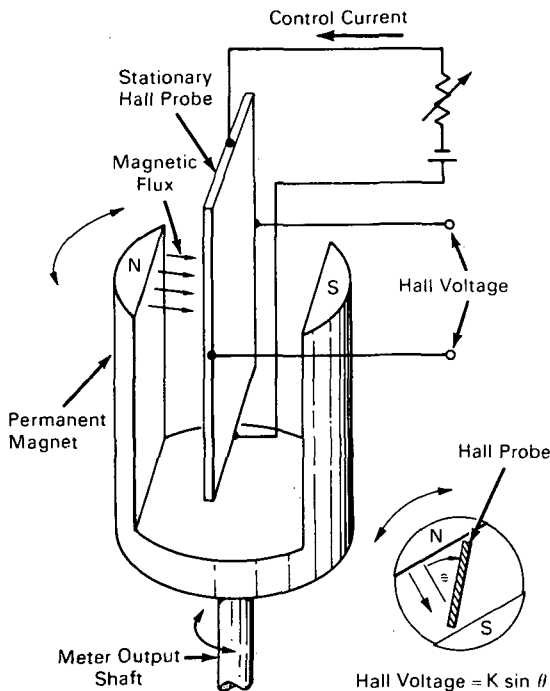
Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to Sanders Associates, Inc. Nashua, New Hampshire.

Source: R. B. Henderson of Sanders Associates, Inc. under contract to Marshall Space Flight Center (MFS-1480)

## Section 6. Displacement and Angular Rotation

### HALL-EFFECT TRANSDUCER GIVES ELECTRICAL OUTPUT PROPORTIONAL TO METER-SHAFT ROTATION

A Hall Effect transducer produces an output directly proportional to small rotary shaft displacements. A primary advantage of this transducer for measuring angular displacements is the



elimination of frictional contact between stationary and moving parts.

As shown in the schematic, a Hall probe is rigidly suspended between the poles of a permanent magnet which is fixed to the meter output

shaft. The Hall probe remains stationary as the magnet and shaft rotate together. With a constant control current supplied to contacts at the ends of the probe, the output voltage (Hall voltage) generated between contacts on the sides of the probe is directly proportional to the sine of the angular displacement or rotation of the meter shaft.

Since the sine of the angle and its measure in radians rapidly approach equality for small angles, the voltage output and meter shaft rotation for angles ranging from  $0^\circ$  to about  $6^\circ$  may be accepted as being directly proportional. A voltmeter connected to the Hall transducer output could then be calibrated to give direct readings of meter shaft rotation (corresponding to differential pressure or other physical magnitude proportional to meter shaft rotation) on a linear scale extending over about  $\pm 6^\circ$ .

The principle of this transducer would be generally applicable to any meter with a rotary shaft that responds to changes in a physical magnitude. With appropriate shaping of the magnetic field between the magnetic poles, or the use of a specially designed Hall probe, the voltage output linearity of the transducer can be extended to a much larger range of shaft rotations (approximately  $\pm 30^\circ$ ).

Source: D. Smith  
Langley Research Center  
(LAR-10620)

*No further documentation available.*

### NONCONTACTING OPTICAL STRAIN DEVICE

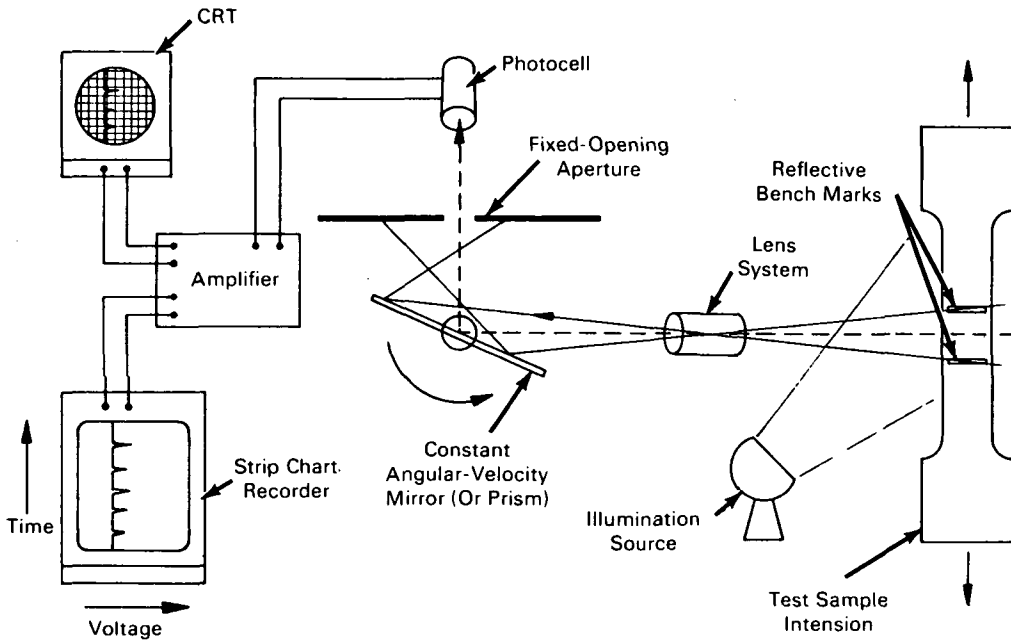
A noncontacting strain measuring gage and extensometer measures mechanical displacement along the entire length of a test specimen. Measurement is accomplished by continuously scanning

light reflected from bench markings or stripes indexed on the specimen.

In the operation of this device, two narrow reflective strips of aluminum foil are attached to

the specimen. The illumination source is positioned to cover the entire test specimen. A lens system and rotating mirror direct reflected light from

Thereafter, as the test specimen is elongated, the scanning and readout provides a new graphic profile with a greater distance between peaks. Thus,



the specimen to the photocell which has a slit-like aperture. A constant-speed motor provides the rotating motion for the mirror. An amplifier and strip-chart recorder convert the electrical output signal from the photocell to a graphic profile having two sharp peaks caused by the reflective bench marks. The chart distance between peaks is then measured, as well as the physical distance separating the reflective marks on the specimen itself; these data provide a calibration factor.

the distance between peaks is proportional to sample movement, and represents a continuous measure of sample movement.

Source: R. H. Silver of  
Caltech/JPL  
under contract to  
NASA Pasadena Office  
(NPO-10778)

Circle 27 on Reader Service Card.

## RELIABLE<sup>1</sup> SELF-CALIBRATING VIBRATION TRANSDUCER

A highly reliable transducer system has been designed to measure the uniaxial vibration amplitudes (deflections) and frequency of a body subjected to mechanical vibration. The basic system is self-calibrating and provides an output which indicates the direction as well as the magnitude of the uniaxial deflections. The transducer system comprises a light source, a small plane mirror mounted on the test body, and a sandwich arrangement consisting of (1) a transparent layer on which are uniformly spaced ruled lines having a

predetermined opacity and width, (2) an optical filter whose optical density varies linearly with displacement of the reflected light beam, and (3) a photoelectric detector which produces a voltage or current proportional to the intensity of the reflected light beam penetrating the other two layers of the sandwich.

If the amplitude,  $Y$ , of the vibrating body varies sinusoidally with time (Fig. 1), the light beam reflected from the mirror will sweep across the sandwich arrangement at a sinusoidal rate in the  $X$  di-

rection. As a consequence, the intensity of the light passing through the variable-density optical filter and the corresponding output of the photoelectric detector will also vary sinusoidally. When the reflected light beam crosses one of the ruled lines on the transparent medium, the intensity of the beam decreases and causes a corresponding decrease or dip in the output of the photoelectric detector, as shown in Fig. 2.

The vibration amplitude is calculated from the number of dips between a maximum and a minimum point on the sinusoid and the geometric parameters of the transducer setup. The vibration frequency corresponds to the cycles per second of the sinusoid.

Source: R. L. McKinney  
Langley Research Center  
(LRC-00089)

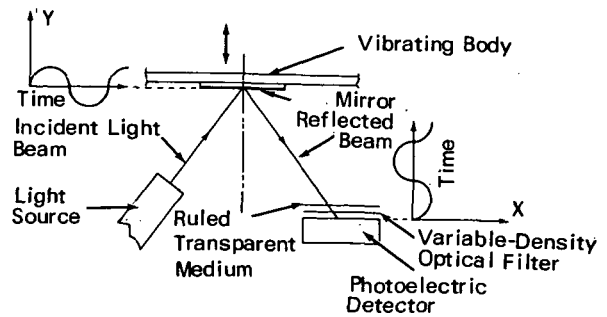


Figure 1

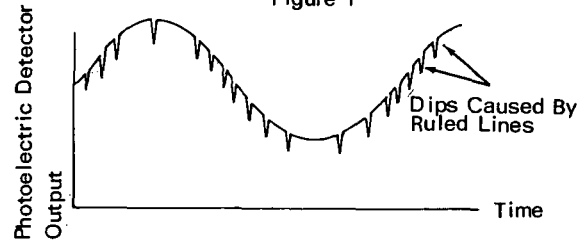


Figure 2

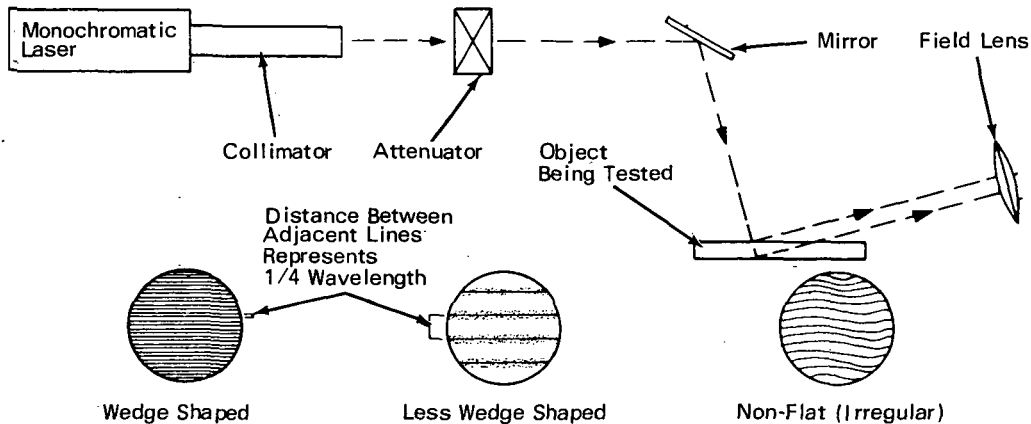
Circle 28 on Reader Service Card.

MEASUREMENT OF OPTICAL THICKNESS

Plane parallelism of the opposite surfaces of a transparent object may be measured to within one-tenth of a micron by using a collimated

typical patterns seen through the field lens.

This technique has been used in the precise determination of the wedge-shape of optical crystal



monochromatic laser beam to illuminate the object under test. The reflections of the beam are projected through a field lens, producing in effect a contour map of the thickness of the object, which reveals the degree of deviation from coplanarity of its opposite faces.

The illustration shows a schematic diagram of the apparatus arrangements, and examples of

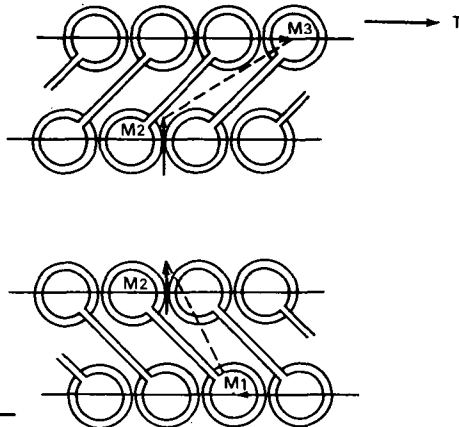
samples, in connection with the determination of the electro-optic response of the crystal.

Source: A. R. Johnston and  
W. A. Hermann  
NASA Pasadena Office  
(NPO-10666)

Circle 29 on Reader Service Card.

### NONCONTACTING TRANSDUCER MEASURES SHAFT TORQUE

A transducer system using a noncontacting pickup measures the output torque of a rotating shaft. It uses a specially designed sleeve of magnetically permeable material that fits snugly over a small section of the shaft and deflects axially in direct proportion to the output torque of the rotating shaft. Stationary inductance pickup coils mounted

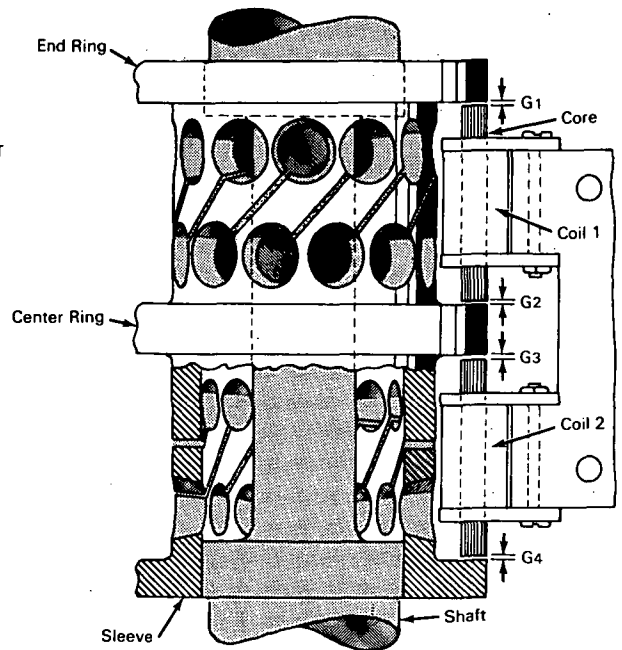


in close proximity to, but not in contact with the sleeve, undergo a corresponding change in reluctance, which is measured by conventional circuitry connected to the pickup coils.

A small section of the shaft is reduced in diameter in order to ensure a relatively large torsional deflection between the two end portions of the shaft when torque is applied. The sleeve of magnetically permeable material is symmetrically positioned over the reduced section and secured by a shrink fit to the ends of the full-diameter shaft adjacent to the reduced section. The sleeve incorporates three integral rings, one at each end and one at the midsection. Two circumferential bands of equidistant holes are radially drilled through each portion of the sleeve between the central ring and the end rings. The holes in each pair of bands are connected by slots cut at an angle of  $45^\circ$  with respect to the shaft axis. The slots in one portion of the reduced section are at  $90^\circ$  to the slots in the other portion. The sleeve constructed in this manner has a much smaller torsional stiffness than the shaft.

When torque is applied to the shaft as indicated by T-T, the end rings will deflect in an axial direction, as indicated by M2. Since for small deflections,  $M_1 = M_2 = M_3$ , axial deflection of the center ring, M2, will be equal to  $M_1 + M_3/2$  (i.e., one-half the total torsional deflection at mean

sleeve radius). This axial deflection may be measured (while the shaft is rotating) by a variable reluctance circuit which incorporates four induc-



tance coils (only one pair is illustrated) wound on laminated cores. A pair of coil assemblies is positioned between the rings to form small air gaps, G1, G2, G3, and G4. As the center ring moves axially, the gap width G2 increases or decreases relative to G3 thus correspondingly increasing or decreasing the reluctance of one coil relative to that of the other. Since the end rings are not deflected axially, G1 and G4 remain constant and do not affect the reluctance of the coils. When the two pairs of coils are connected in an ac Wheatstone bridge circuit, the output signal amplitude will be proportional to the deflection (or shaft torque).

This transducer system operates equally well at all shaft speeds and therefore may be calibrated statically. Since no electrical or frictional contact is made with the rotating shaft, the system would be especially useful for measuring torque at high rotational speeds. The effect of slight axial or radial movement of the coil assemblies is cancelled by the symmetrical design of the system.

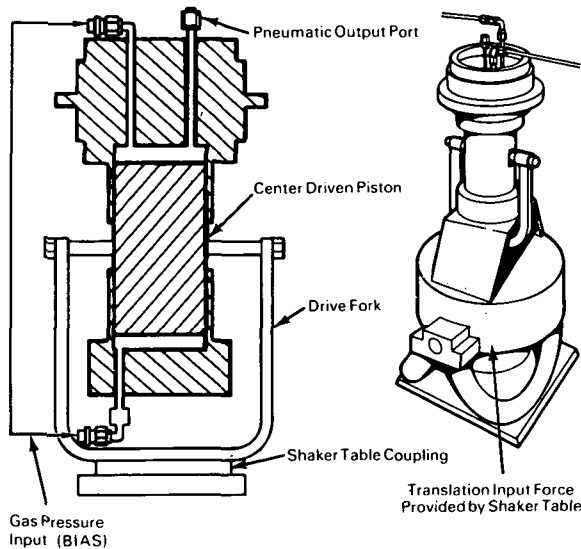
Source: North American Rockwell Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-00474)

Circle 30 on Reader Service Card.

## Section 7. Transducer Test and Calibration Methods

### PNEUMATIC PRESSURE-WAVE GENERATOR USED TO TEST TRANSDUCERS

Pressure fluctuations about a bias or reference pressure level, produced by displacement of a center-driven piston in a closed cylinder, provide a



means of testing pressure transducers and systems to determine their reliability or accuracy. Standard pressure-wave generators have elaborate controls, consume enormous quantities of gas, and are se-

verely limited in operating range by either pressure or frequency.

The generator, shown in the figure, is prepressurized to any desired static level (bias pressure) and is coupled to a shaker table. The transducer or system undergoing test is connected to the output port of the generator. The frequency and amplitude of the generator's pneumatic output are controlled by the movement of the piston, which is directly linked to the drive fork. The fork in turn is driven by the vibration of the shaker table. The pneumatic output of the generator is a direct function of the displacement amplitude and frequency of the shaker table.

Source: A. E. Gaaland and  
T. P. Weldon of

Westinghouse Astronuclear Laboratory  
under contract to  
AEC-NASA Space Nuclear Systems Office  
(NCU-10024)

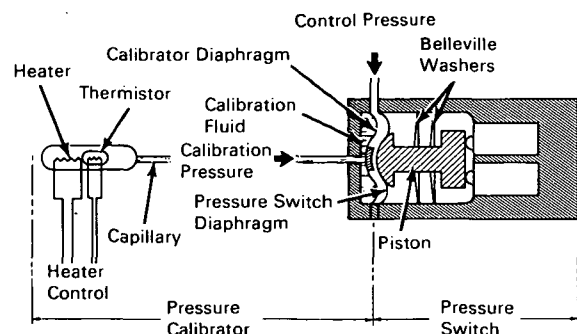
*Circle 31 on Reader Service Card.*

### CONCEPT FOR PRESSURE SWITCH CALIBRATOR

A calibrator and switch design has been developed in which a saturated liquid-to-vapor phase transition at constant pressure is used to produce a known force (on a diaphragm of given area) independent of displacement over a usable range. A calibrator based on this concept would be useful where the calibration could be carried out at a relatively slow rate so that saturated vapor conditions could be maintained in the region enclosing the heater and thermistor.

As shown in the sketch, one end of a conventional pressure switch was modified by the addition of a diaphragm enclosing an appropriate

calibration liquid that communicates with a controlled source of heat by means of a capillary.



For the calibrator diaphragm configuration in the sketch, the calibration liquid was assumed to be cold, so that it was fully contracted. In this condition, any measured or control pressure greater than the vapor pressure of the liquid would not allow a calibrating force on the switch diaphragm. The spacing between the diaphragms would be chosen to allow for expected displacement of the fluid (liquid plus vapor) in the operating environment.

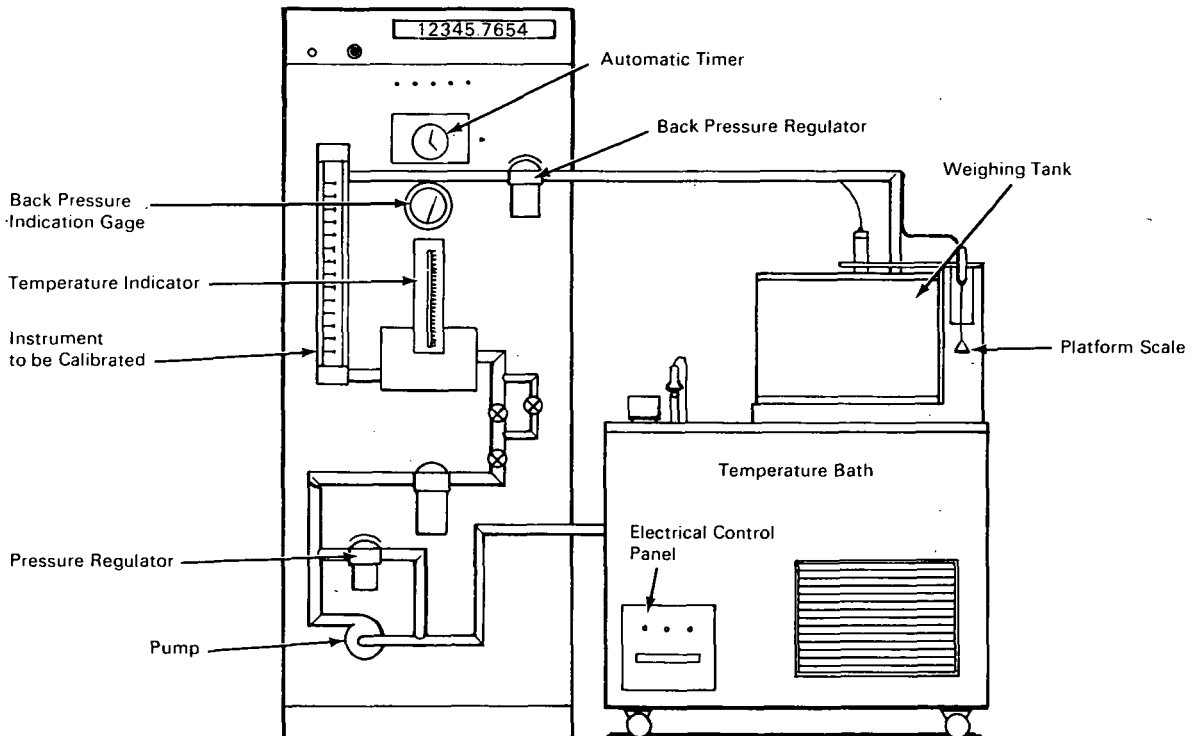
To conduct a calibration, the control pressure is reduced to atmospheric pressure (by valving) and the heater control system is actuated. As the temperature of the fluid near the heater is increased, a point is reached at which the vapor pressure exceeds the atmospheric pressure, on the

liquid (plus any loading pressure from the calibrator diaphragm). The resultant force (the product of vapor pressure and calibrator diaphragm area) displaces the calibrator diaphragm until it contacts the switch diaphragm. When switching pressure is reached, the displacement diaphragm will not affect the calibrating pressure because it is essentially independent of the volume of the calibrating fluid.

Source: M. G. Slingerland of  
General Electric Co.  
under contract to  
NASA Headquarters  
(HQN-90036)

Circle 32 on Reader Service Card.

### LIQUID-FLOW CALIBRATION SYSTEM



Another recently developed calibration system consisting of a platform scale, weighting tank, pressure regulator, automatic timer, and cycle-control devices may be of interest to industrial or-

ganizations that evaluate and calibrate valves and pumps and perform other hydraulic operations. This system is compact, accurate, and is made fully automatic by a unique application of a prox-



imity switch and coaxial relays; it would be particularly suitable for calibrating liquid flowmeters.

In this system a platform scale with a capacity of 300 pounds is mounted on top of a temperature bath. A modified scale-temperature-bath combination allows an air-operated valve mounted at the bottom of an insulated collection tank to return the liquid sample to the temperature bath. A single bay cabinet, which contains the pump, power supply, proximity switch, timer, and other control equipment, is placed adjacent to the temperature bath and platform scale. For example,

when a flowmeter is to be calibrated, it is mounted in proper position and the temperature is stabilized at the desired setting. An operator then depresses the start button, selects the sample weight, and records the raw data when the weighing cycle is complete.

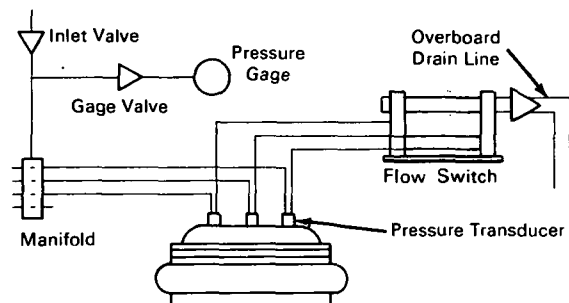
Source: E. E. Brown and  
C. Bailey, Jr. of  
North American Rockwell Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-16028)

Circle 33 on Reader Service Card.

### DETECTING LEAKAGE IN PRESSURE TRANSDUCERS

A new method, in which a manifold and appropriate valves are used, has been devised to eliminate the need for testing separately a series of pressure transducers (see figure).

A pressure gage is installed in the flow-switch panel of the stand where each transducer is plumbed to an individual flow switch. All flow switches are plumbed to an overboard drain line. Then, if the inlet valve is closed and the drain line plugged, the network can be isolated and checked for leaks by pumping gaseous nitrogen into the lines. Leakage is detected by a fall in pressure shown on the pressure gage. If leakage is observed, individual transducers are then pressurized to 125 psi for three minutes to determine the faulty one.



Source: L. Henson of  
North American Rockwell Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-90556)

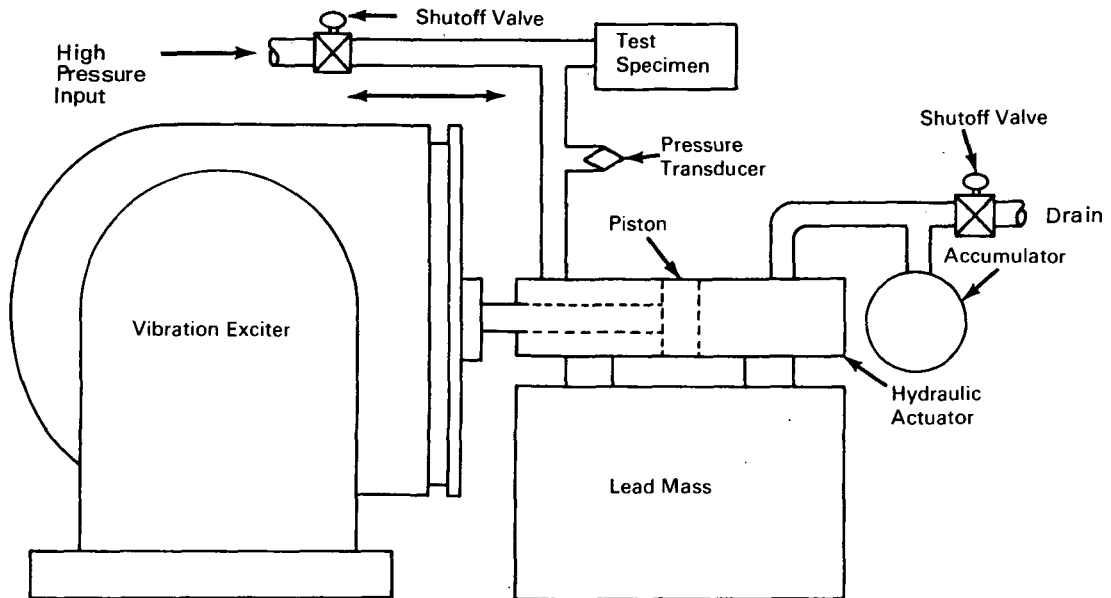
Circle 34 on Reader Service Card.

### TESTER PROVIDES VARIABLE PRESSURE-WAVE AMPLITUDES AND FREQUENCIES

A pulsating pressure, obtained from a hydraulic actuator driven by a vibration exciter, forms the heart of a device used to test hydraulic system components to high vibration pressure or frequency requirements. The device can also be used to test pressure transducers, switches, and other hydraulic components. The pressure levels and

pulsation frequencies can be varied as test requirements dictate.

As shown in the figure, the rod of a hydraulic actuator is attached to the exciter head. The rod-end port of the actuator cylinder is connected to the test specimen and pressurized to the level required by the test item. The shaker head and



hydraulic actuator are maintained in the center of their strokes by trapping the appropriate balancing pressure on the back side of the hydraulic actuator. The actuator is bolted to a lead mass for stability. A pressure transducer and direct-writing oscillograph are used to indicate the pulsation magnitude, and the input to the exciter is adjusted accordingly. The motion of the actuator piston

provides the compressive force necessary to vary the pressure.

Source: J. W. Routson of  
General Dynamics Corp.  
under contract to  
Lewis Research Center  
(LEW-10205)

*Circle 35 on Reader Service Card.*

## ELONGATION LIMIT OF STRAIN GAGES IN LIQUID NITROGEN

A test program has yielded data on the utility of various strain gage and cement combinations for cryogenic applications in which a wide temperature range may be encountered. A wide variety of strain gage types was tested, but no attempt was made to evaluate the effects of minor differences within a single gage type. Hence, the effects of such parameters as thermal-expansion compensation, gage length, and cement-curing procedure were not investigated.

Each strain gage, 3.18 mm (1/8 in.) in length, was mounted on 3003-H14 aluminum beams, 23 cm long by 2.5 cm wide by 3.2 mm thick. After standard installation and curing, each beam was supported horizontally at both ends and subjected to bending under a centrally applied load.

The strain gage output was recorded on the X-axis; this made it possible to determine the mode of failure of the gage. For tests conducted at room temperature, the load was applied until the strain gage failed electrically because of an open circuit in the grid, or mechanically due to failure of the bond between the gage and the beam. The mode of failure was easily determined in most cases from the shape of the curve obtained on the X-Y recorder. Incipient bond failure was indicated by a decrease in the slope of the strain-deflection plot, and electrical failure by an increase.

Cryogenic tests were performed by placing the test fixture in a liquid nitrogen bath and allowing the temperature to stabilize. Although the cessation of violent bubbling indicated approximate

equilibrium, a more accurate indication of equilibrium was given by the stabilization of the X-Y plotter reading. Once the temperature stabilized, the bar was loaded until the strain gage failed.

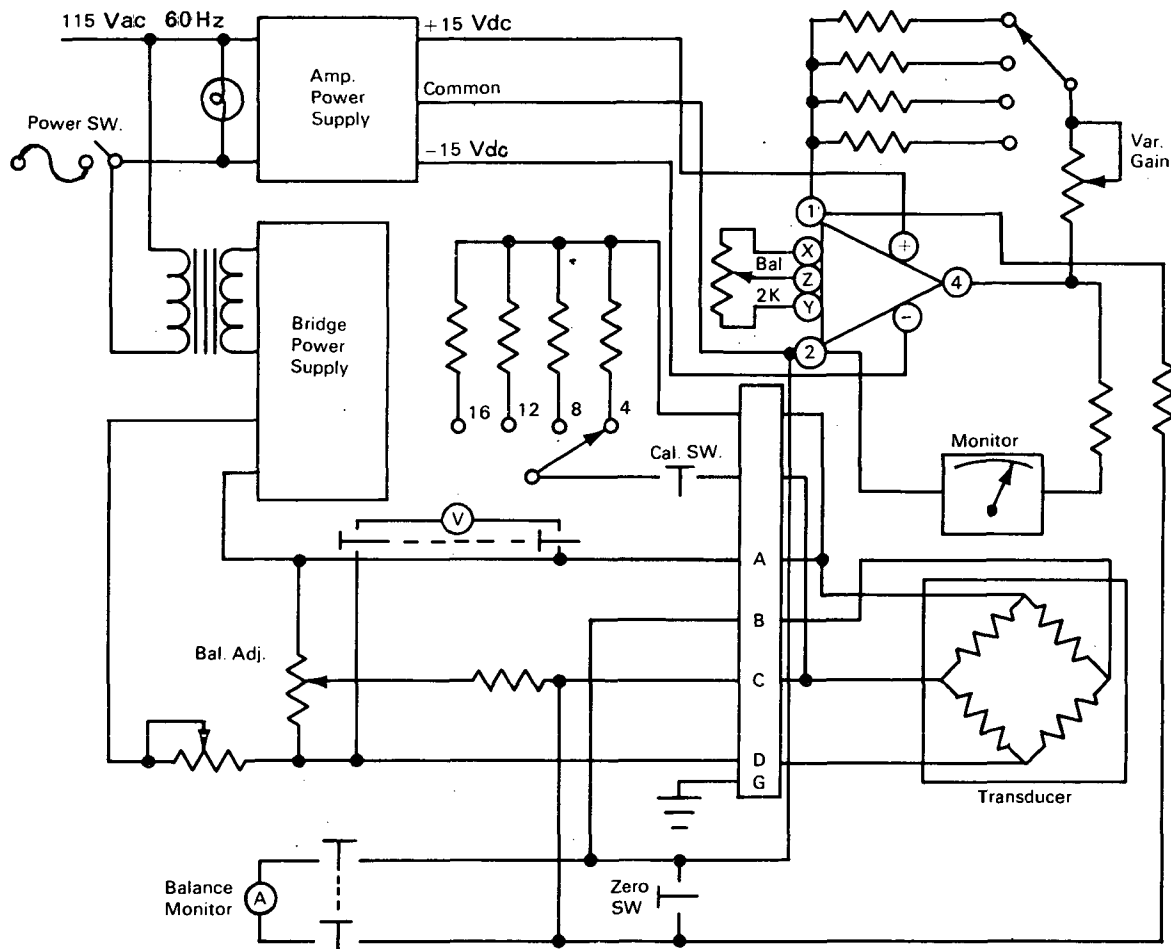
After the gage failed, it was examined under a microscope to determine the presence of cracks in the strain gage grid and backing, and to detect

flaws in the solder joints used to connect leads to the strain gage.

Source: D. W. Nicholls of North American Rockwell Corp. under contract to Marshall Space Flight Center (MFS-18218)

Circle 36 on Reader Service Card.

PORTABLE INSTRUMENT MONITORS TRANSDUCER PERFORMANCE



A portable monitor for strain gage transducers which uses modular plug-in dc operational amplifiers is shown in the figure. Plug-in calibration cards can be changed to calibrate a strain gage bridge of any resistance value. This instrument can be used in any system containing a strain gage bridge and where continuous monitoring is re-

quired. Typical uses include: gas analysis for air pollution studies, critical data points in structures tests, and remote pressure readings associated with hazardous tests.

The unit is a portable package consisting of a bridge power supply, amplifier power supply, bridge balance, shunt resistance calibrator, opera-

tional amplifier, and scale panel meter. The monitor is used in conjunction with strain-gage type transducers to provide continuous transducer output indication, under steady state or gradually changing conditions. A chronic problem, capacitance pickup, is eliminated in this unit by the use of shielding and an encapsulation technique in the operational amplifiers which have excellent long

term stability and temperature characteristics.

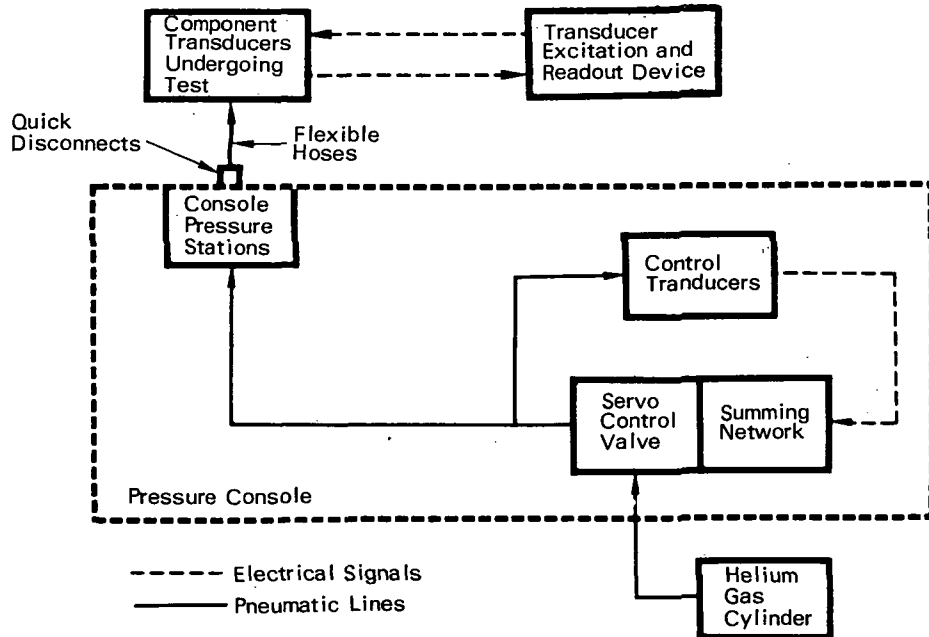
Source: R. R. Walker of North American Rockwell Corp. under contract to Manned Spacecraft Center (MSC-15016)

*No further documentation is available.*

### AUTOMATED CALIBRATOR FOR PRESSURE TRANSDUCERS

An automated, portable transducer checker can be used to calibrate pressure transducers in the range of 207 kN/m<sup>2</sup> to 7.45 MN/m<sup>2</sup> (15 to 1065

psi) to provide the desired test pressure. The outputs of the transducers undergoing calibration can be shown on a strip



psig) with an accuracy of  $\pm 0.05\%$ . The checker consists of a pressure console and equipment for producing the test pressures. The console is connected to other devices for measuring and visually displaying the electrical outputs of transducers being calibrated.

The transducers are connected by flexible hoses to quick-disconnect pressure stations mounted on the rear of the console. The console is connected to a 13.8 MN/m<sup>2</sup> (2000 psig) helium gas cylinder. A servo control valve and a summing network re-

duce the output of the cylinder to provide the desired test pressure. The outputs of the transducers undergoing calibration can be shown on a strip recorder or other types of display equipment.

Source: J. Brinda, J. Shaw, L. Kristoff, and M. Vuckovich of Westinghouse Astronuclear Laboratory under contract to AEC-NASA Space Nuclear Systems Office (NUC-10067)

*Circle 37 on Reader Service Card.*

## EVALUATING THERMOCOUPLE SYSTEMS

A technique has been developed for evaluating the accuracy of thermocouple systems. It is novel in that it allows evaluation of these systems with respect to a variety of parameters, such as material defects, high resistance connections, and poor workmanship. The technique, which can be used to locate and identify all abnormalities in any complete thermocouple system, may be particularly useful in chemical and pharmaceutical processing facilities in which critical temperature control is essential to production.

The normal procedure for verifying the accuracy of a thermocouple system is to check it against one or more reference-temperature points and to assume that the connections and wiring are satisfactory. In this new method, accuracy is verified

by heating sequentially each wiring connection in the system, such as terminal strips or plugs, while monitoring the system output. Polarity reversals are easily determined; impurities in different lots of wire can be observed, and the type of wire, if unknown, can be determined by substituting known types. In addition, the effects of solder, lugs, and foreign metal junctions found in terminal strips or plugs may be studied and minimized as needed to obtain the desired accuracy.

Source: D. A. Worcester of  
North American Rockwell Corp.  
under contract of  
Marshall Space Flight Center  
(MFS-18437)

*Circle 38 on Reader Service Card.*

---