ZERO-G PROPELLANT GAUGING OF CRYOGENICS

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MISSION REQUIREMENTS

In the zero-g environment for the Space Shuttle, the measurement engineer is faced with two significant problems in determining the amount of propellant remaining. These are the temperature of the liquid, and just where the liquid mass might be.

Zero-g propellant quantity measurements are required as "status quo"; i.e., no knowledge of prior usage or venting is available since the measurement must determine the amount of fuel remaining. In the event that the vehicle is docked for a long period of time, an absolute quantity measurement must be made before the mission can proceed.

When the propellant is preferentially positioned, more conventional measurement techniques will, in all probability, be satisfactory.

When the propellant experiences a relatively small change in temperature during the life cycle of the mission, several mass measurement techniques offer a relatively simple measurement method. That is, unfortunately, not the case for cryogenics where liquid is introduced at one temperature and is gradually rising to the vapor temperature.

PROPELLANT CONDITIONS

The temperature of the cryogens and the surrounding structure emerges as one of the most important parameters in determining propellant quantity.

Since the temperature of the liquid is gradually rising, zero-g stratification conditions are in all probability quite unpredictable. Some form of mixing is desirable, and devices to control the location of the liquid are needed.

An accurate measurement of temperature will aid in predicting the degree of thermal stratification, surface tension, and inviscidness present in the liquid. This measurement must represent an average temperature of the ullage or liquid. Point sensors may give improper indications since small amounts of liquid clinging to the sensor would indicate a temperature somewhere between the ullage or wall condition and a representative liquid temperature.

In all gauging techniques, temperature has a pronounced effect on the gauging mechanism. A few important changes brought about by varying temperature are:

Density

Dielectric Constant

Sound Velocity

Electrical Resistivity

Specific Heat

Viscosity

Surface Tension

CANDIDATE SYSTEMS OTHER THAN RF

Two systems, aside from the RF work reported by Bendix, appear to offer a method of determining propellant quantity of specific cryogens.

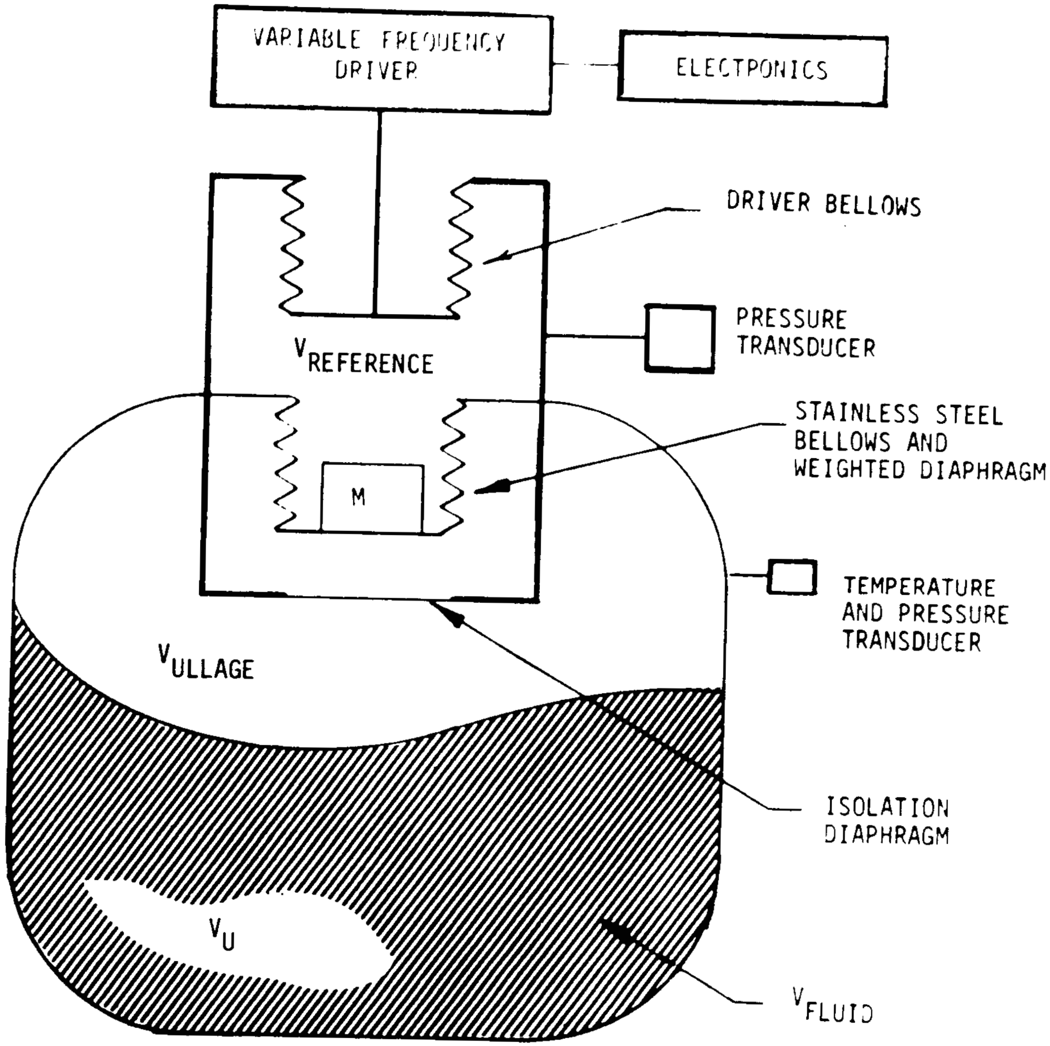
These are the Resonant Infrasonic Gauging System and the Nucleonic Gauging System.

The RIGS is essentially a low frequency ($\sim$10 Hz) loudspeaker. The key element is a weighted diaphragm which is driven at resonance. This resonance is determined by observing the pressure oscillations measured in a small reference volume. The observed resonant frequency is typically very low ($\sim$1.0 to 0.5 Hz for large tanks). It can be shown theoretically and experimentally that for low frequencies, the wave transmission through the ullage gas is a function of the specific heat ratio and ullage pressure. For storable propellants, the technique has been shown to measure propellant quantity accurately, provided the ratio of ullage compressibility to liquid compressibility is very high ($\sim$1000:1). The measurement of average ullage temperature is extremely critical since it determines the specific heat ratio.

RIGS requires three moving parts: i.e., the driver bellows, the resonant bellows, and the isolation diaphragm.

For gauging LOX, the system may be satisfactory provided a flexible isolation diaphragm can be obtained. A newly developed fluorastomer, AF-E-124D, is presently being tested in LN for flexural performance.

For LH_2 the system offers very little promise, since the compressibility of LH_2 and the establishment of a reliable gas gamma from an average temperature measurement introduce variables which make the overall system accuracy unacceptable.



RIGS GAUGE

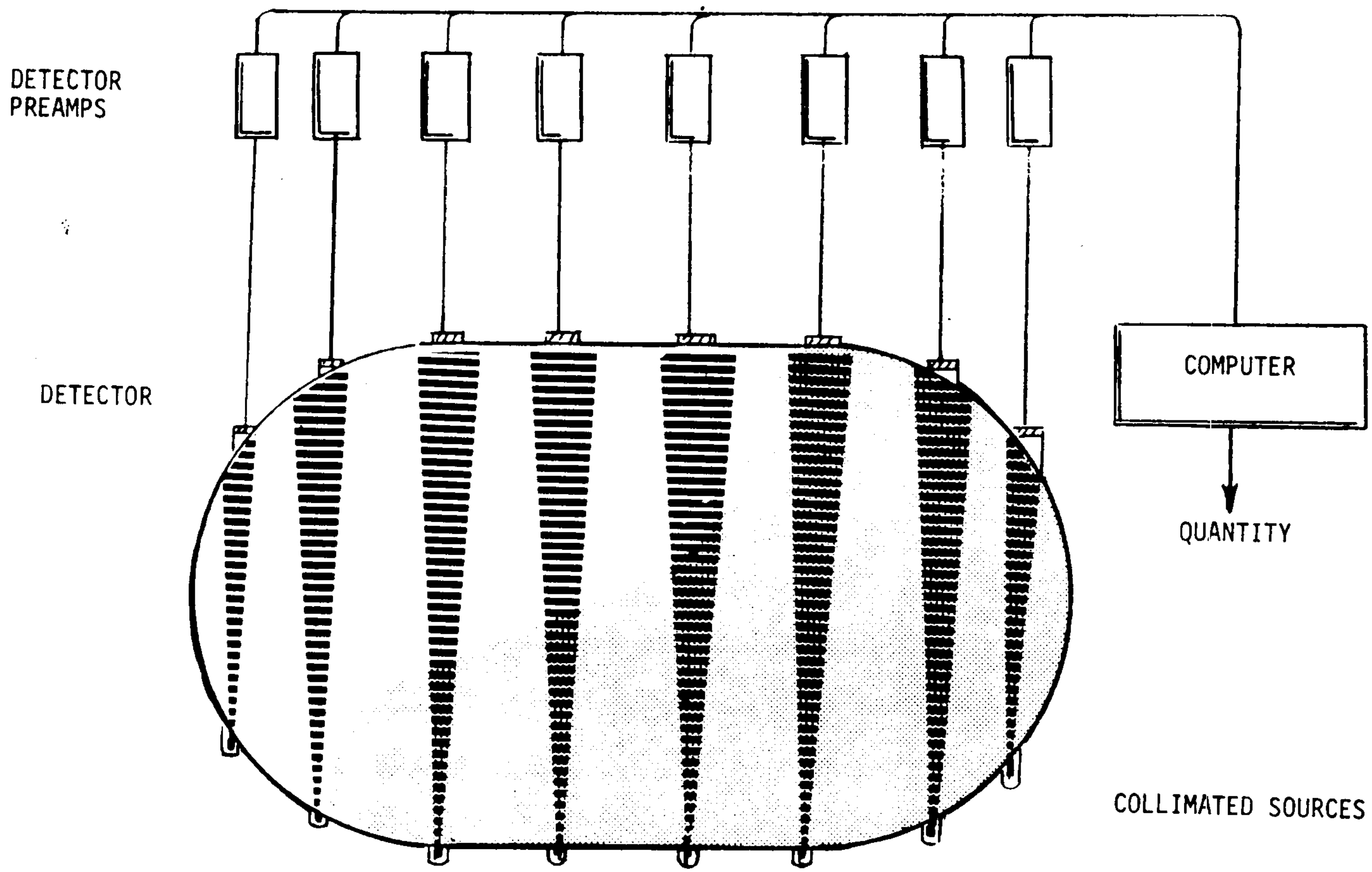
FIGURE 1

The nucleonic gauging technique employs a number of radioactive sources accompanied by a like number of detectors. In effect, each source/detector pair measures a discrete column from which a mass measurement is determined. Since the measurement is one of total mass between the source and detector, a minor correction must be made for fluid phase. This can be determined from a temperature measurement of either the vapor or liquid.

For low density propellants such as LH_2, the system requires very low strength sources. For high density liquids such as LOX, the required source strength must increase. If the present concept of twin tanks for LH_2 and LOX holds, it appears that a nucleonic gauge can be developed to measure propellant in both cryogens.

TRW is presently developing a nuclear zero-g gauging system, and the progress of that contract is currently reported in monthly and quarterly publications.*

* "Development of a Zero-G Gauging System," Contract F04611-71-C0010 AFRPL, Edwards AFB, California.



NUCLEONIC GAUGING SYSTEM

FIGURE 2

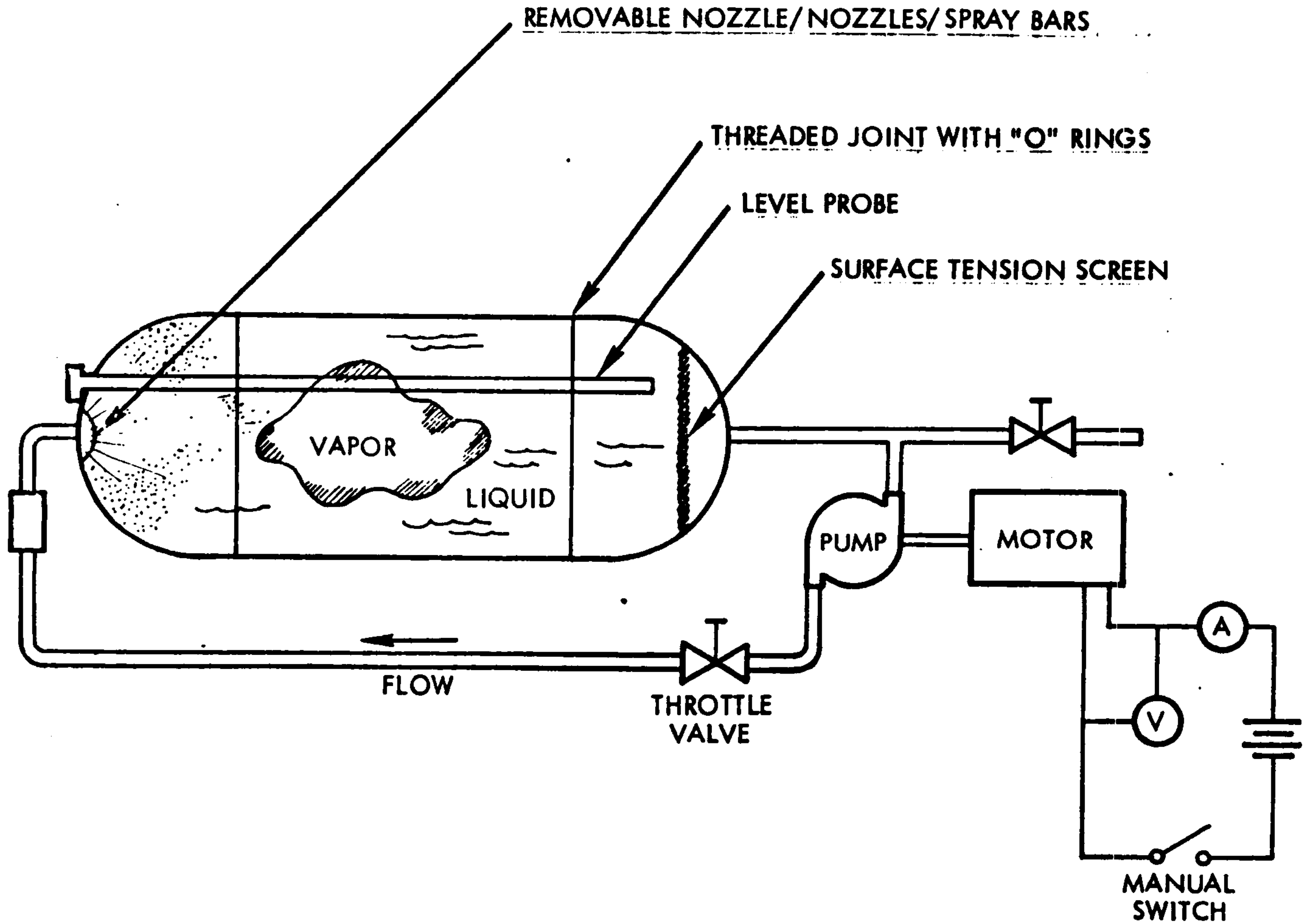
PROPELLANT POSITIONING

Under the current study of possible zero-g gauging systems, an evaluation of several propellant positioning techniques was undertaken.

Since the amount of energy required to position the liquid under absolute zero-g is small ($\sim 10^{-5}$ g), fluid injection systems appear to have merit.

Propellant mixing systems employing nozzles to break up thermally stratified layers of the liquid are being considered. If a vapor piston could be established or if enough momentum could be imparted into the liquid to position it preferentially, all measurement techniques are made much easier.

To establish whether or not the injection approach has merit, a test series utilizing spray injection is under consideration. The design of the nozzle is not trivial, since the pressure must be accurately distributed to prevent geysering of the fluid mass or amplifying of the tank wall meniscus.



PROPOSED PROPELLANT POSITIONING EXPERIMENT

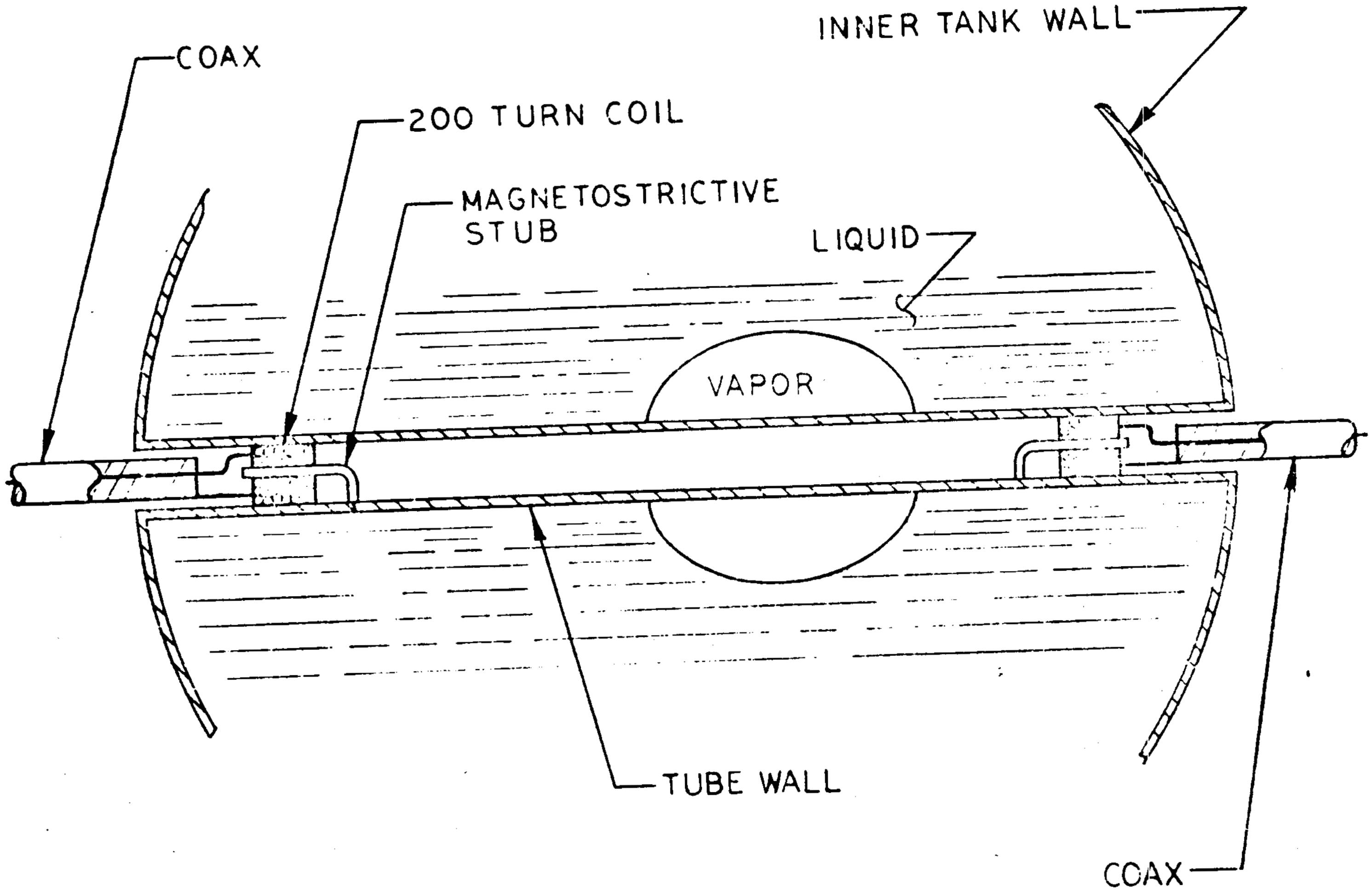
FIGURE 3

ULTRASONIC GAUGING

Under this current zero-g study contract, a close look has been taken at the potential use of a pulsed ultrasonic system. This technique has the unique advantage of being able to obtain an average temperature measurement and measure the density of the liquid. It can extract the density measurement independent of propellant position, provided the ullage can be maintained in a single location.

The sensing hardware is extremely simple and actually displays improved performance in cryogenic temperatures. A copper wire is wrapped around a magnetostrictive core. The core is then attached to a sensing bar, and a measure of the attenuation of the induced shear or flexural wave determines the quantity of liquid in contact with the sensing bar. The time it takes the shear wave to travel from the transmitter to the receiver is an excellent measure of the average temperature of the sensing bar.

At first glance, the technique appears complicated; however if the liquid can be preferentially positioned, the advantages are significant. The transceivers can be mounted externally on the tank wall or on internal piping, and one can obtain two critical measurements (temperature and quantity) with the same measurement tool.

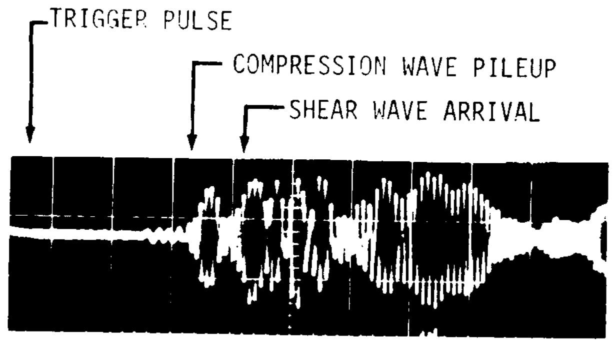


BASIC ULTRASONIC LIQUID QUANTITY GAUGE

FIGURE 4

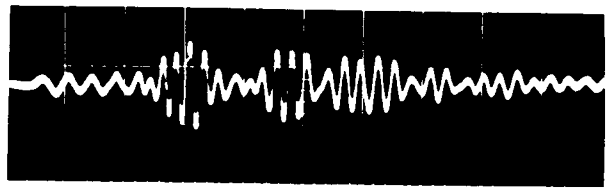
The data shown in Figure 5 are taken from an ultrasonic system in a cryogenic environment. The instrument consists of an aluminum bar with the receiver coil submerged in liquid nitrogen. To extract the desired signal, a gating circuit is designed to isolate a chosen cycle of the shear wave oscillation. By measuring the amplitude of the received signal, the amount of liquid between the sensing coil and driver coil can be obtained. By measuring the time shift of the signal from a given reference (i.e., the input pulse to the receiver coil), the average temperature of the bar can be established.

Preliminary lab tests in liquid nitrogen have confirmed the basic performance of the ultrasonic hardware. The discrete frequency shown in the illustration is a predictable characteristic of the detector. The dimensions of the stub determine the natural oscillation frequency, which in this case is approximately 180 KHz. Since the frequency domain has been established, all unwanted signals can be easily filtered and the desired time window established to extract the two variables (temperature and liquid level).



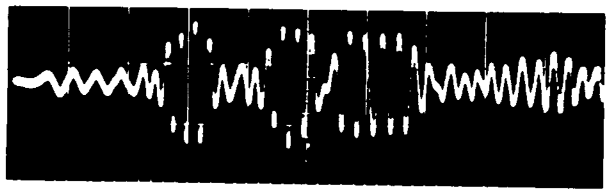
TYPICAL RECEIVED SIGNAL ON 24" ALUMINUM BAR IN LIQUID NITROGEN

SWEEP SPEED 50 SEC cm^{-1}
AMPLITUDE 200 MV cm^{-1}



RECEIVED SIGNAL WITH BAR 55% SUBMERGED IN LIQUID NITROGEN

SWEEP SPEED 20 SEC cm^{-1}
AMPLITUDE 200 MV cm^{-1}



RECEIVED SIGNAL WITH BAR 35% SUBMERGED IN LIQUID NITROGEN

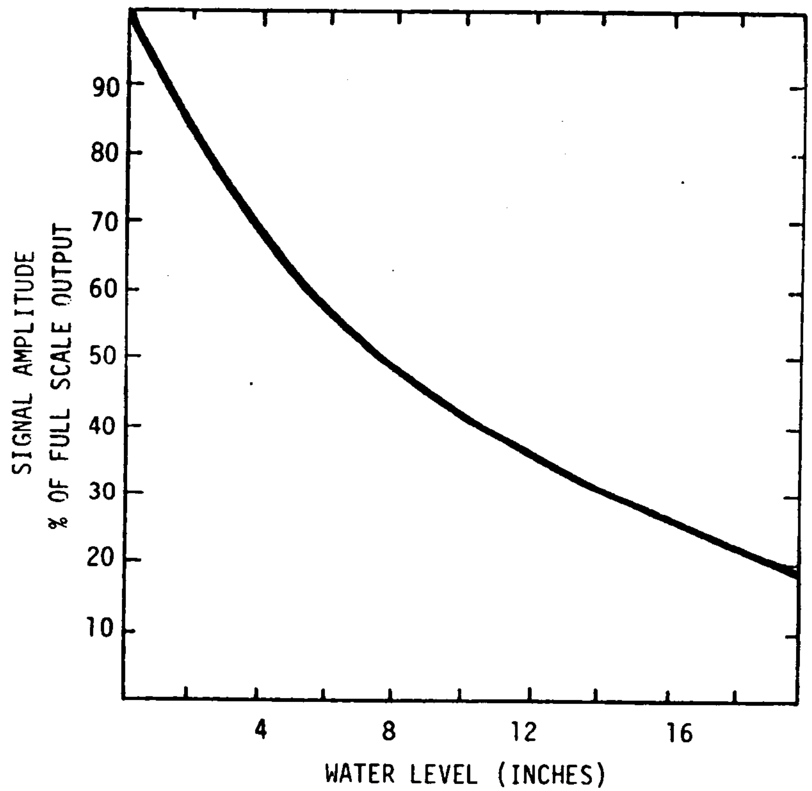
SWEEP SPEED 20 SEC cm^{-1}
AMPLITUDE 200 MV cm^{-1}

ULTRASONIC SHEAR WAVE DATA (ALUMINUM 6061-T6)

FIGURE 5

The fact that the amplitude of the received signal increases with decreasing propellant is significant. This means that the quantity remaining can be gauged more accurately as the fuel is expended.

Figure 6 illustrates a calibration of the ultrasonic gauge in water at room temperature. Preliminary analysis of cryogenic data indicates that the behavior of the transducer performs in the same manner.



ULTRASONIC CALIBRATION CURVE

FIGURE 6

CONCLUSIONS

The nucleonic system offers a distinct advantage in measuring propellant quantity since it requires no electrical penetration of the cryogenic tank.

RIGS has many unanswered questions regarding cryogenic applications. It is not a candidate for LH_2 systems; however it may be adapted to LOX.

If a system can be designed which will preferentially position the liquid, ultrasonic systems may prove to be the simplest and least expensive.