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Research paper

Over view of Complexity in Cryogenic Instrumentation System

Dr. P. Chandrasekar[1*], V. Kannan[2]

[1]Professor& Head, Department of Electrical and Electronics Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai
[2]PG Scholar
**Corresponding author E-mail:hodeee@veltech.edu.in:*

Abstract

‘Cryo meaning icy cold. The suffix 'genics' stands for science. It is defined as the science and technology of temperatures below 120 K. The Cryogenic liquids are used in various fields like medicine, super conducting technology, rocketry etc. The cryogenic propellants Liquid Hydrogen as fuel and Liquid Oxygen as oxidizer are preferred in launch vehicles due to its very high specific impulse and these propellants are very hazardous. This paper explains the properties of the cryogenic propellants and required instrumentation for achieving the safe handling and to meet the accuracy in measurements.

Keywords: *Use about five key words or phrases in alphabetical order, Separated by Semicolon.*

1. Properties of Cryogenic Propellants Affecting The Measurements:

1.1. Boiling point

The cryogenic fluids have a very Low Vaporization and boiling temperature. The state change from Liquid to Vapor depends on the change in pressure and temperature. Any measurement system has a Vapor Liquid interface at any point of measurement which allows measuring both temperature and pressure.

1.2. Co-efficient of Thermal Expansion

Cryogenic fluids have a larger coefficient of thermal expansion than the normal fluids. Compare to normal Liquids Cryo Fluids have larger thermal Expansion and relatively light.

The variation of pressure in the ullage volume of the system affects the level even though the mass content actually remains the same. Also, a small pressure fluctuation leads to oscillations with large amplitudes in flow and level measurements with a differential pressure sensor.

1.3 Specific Gravity

When the Cryogenic Liquid in gaseous form is much denser due to which the Liquid/Vapor density ratio is very low. This leads to error in level measurements when radar or capacitance type sensors are employed.

1.4 Thermal Gradient

Cryogenic liquids are light & experience thermal gradient (stratification) along the height of the liquid column, as a result of which the lighter, warmer and less dense liquid will be at the top of the column and the heavier, colder liquid at the bottom. This creates an anisotropic or non-homogeneous system, which results in sampling problem and error in mass computation.

Due to the above mentioned properties of cryogens, cryogenic instrumentation need to be regarded as a separate field.

1.5. Instrumentation System:

Due to the properties of the cryogenic propellants the instrumentation required need to be carefully selected, installed and signal conditioned for achieving the accuracy and safety.

It is defined as the science and technology of temperatures below 120 K. The instrumentation system provides input/output interface for remote operation.

Redundancy is provided in the Instrumentation based on requirement. Depending on the criticality of the measurement and where control is envisaged based on the measurement, three sensors with independent chains are used for measuring the same process variable and voting logic is incorporated in the automation system based on the safety of the system.

2. Field elements and measurement techniques:

2.1 Temperature

The following requirements were studied while choosing a thermometer for servicing of CRYO propellants.

1. Sensitivity/Resolution Change in output/K
2. Reproducibility & Stability
3. Easiness of measurement/output
4. Response time
5. Ruggedness & withstanding number of thermal cycles

Considering the above points and the usage of the sensor for number of thermal cycles Resistance Temperature Detector that possess positive temperature coefficient is used to measure Cryogenic

temperature measurement. Considering the sensitivity, signal level for the electronics and self-heating effect PT 500 type RTD is used. Also the sensitivity of PT 500 is 5 times better than PT100. Some of the measurement challenges encountered are sensor non-linearity, lead resistance, and thermal emf. The sensor characteristic is non-linear at cryo temperatures and the sensitivity varies from 0.4Ω/K at 20K to 2.0Ω/K at ambient temperature. So the temperature sensors are calibrated for the range 4K to 300K and the resistance versus temperature look up table is incorporated in the linearizer where the piecewise linearization is adopted. The linearization table holds good only when the sensor exhibits high stability, good repeatability and remains inert to thermal cycling.
Measurement of resistance in cryogenic applications is impaired due to spurious DC noise arising from thermocouple junctions formed as a result of cryogenic gradient at the terminals. As the temperature sensor is at a distant location from the signal conditioner, 4 – wire configuration is adopted for lead compensation to eliminate error due to mismatch in lead resistances as per the standard industrial practice. A current output of 4.20 MA is obtained from a signal conditioning module proportional to the resistance. The temperature gradients are high between sensing point (@ approx. 20 K) and the signal conditioner (@ ambient temperature) in case of cryogenic fluids. As the sensor material is platinum and the lead wire material is not platinum, a junction of dissimilar metals is formed resulting in thermoelectric voltages induced in the measuring circuit, which cause errors in the measurement. The thermoelectric emf generated is a DC voltage, which is eliminated using AC (Pulsating DC) current excitation. The measurements taken during the positive and negative excitations when subtracted algebraically will result in cancellation of the DC noise. When +ve and –ve current (direction of the current reversed) flows through the sensor

V+ = VThermal emf + I*R
V- = VThermal emf - I*R
V+ - V- = 2I*R
R= (V+ - V-) / 2*I
Where VThermal emf - Thermocouple voltage due to dissimilar metals @ different temperatures
I - DC excitation current
R - Resistance of the sensor

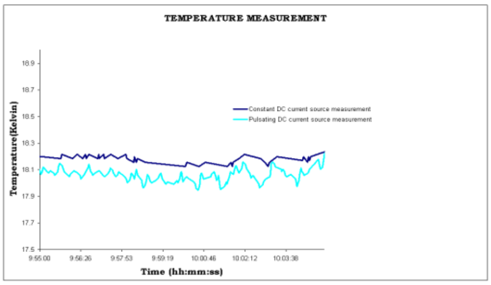

Fig1: Measurement with constant & AC excitation

As the +ve and -ve excitation currents are of same amplitude, R is measured accurately eliminating the thermoelectric emf. The added advantages of using Pulsating DC current excitation is that the excitation current can be higher which improves the noise margin of measurement and as the DC current excitation is pulsed, the localized self heating reduces. The temperature decreases when the sensor output voltage is increased, this can be achieved by increasing the excitation current. The uncertainty in temperature measurement can be reduced by balancing the effect due to self heating and output measurement. Also by keeping optimum operating point.

2.2 Level

The level of cryogenic propellant in storage tanks and coolers is measured using differential pressure measurement. In applications where external plumbing is feasible differential pressure measurement technique is followed. The differential pressure signal acts as input to the differential pressure transmitter, which provides a proportional 4 – 20 mA signal to the remote controller.
Considering the case of LH2 the differential pressure value is low due to density being very low. i.e. 70.78 kg/m3. The differential pressure generated by a tank of height one meter is with LH2 is approx. 7 KPa (10 mm of WC). The pressure fluctuations that occur as a result of opening/closing of valve at inlet/outlet of the tank translate into level fluctuation of very high amplitude, which acts as a false input to the controller. For example a pressure oscillation of 1millibar (≈98 Pa) would lead to a level oscillation of 10 millimeter of water column, which corresponds to 140mm of liquid hydrogen column. The noise level is also Because of the thermal and boiling oscillations at the pressure measurement port of DPT the noise level also is more. A mechanical and electronic damping, with appropriate time constant, is provided to suppress the oscillations which are not the real process level changes. In mechanical damping a dampener with an orifice or impulse coil is introduced in the impulse tubing to the pressure ports. In electronic damping, the time constant is increased to the optimum value by trial and error method to ensure that real process value is not missed and only oscillations are suppressed.
In addition to this, consistency check of level measurement is carried out to eliminate noisy data at control System.

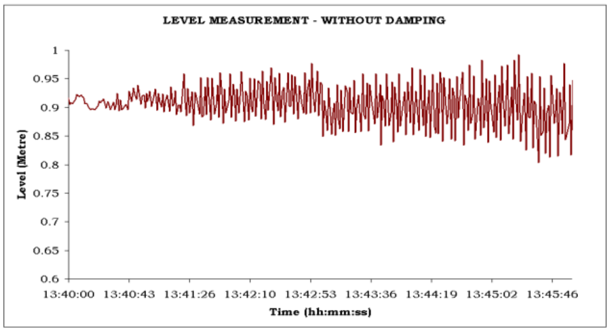

Fig2: Level without damping (DPT)

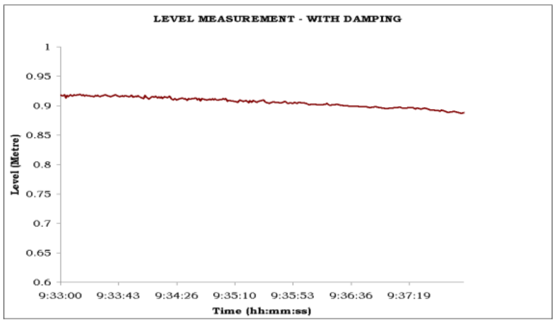

Fig3: Level with damping (DPT)

2.3 Pressure

Cryogenic propellant pressure measurement is envisaged by piezo resistive type pressure sensor. The effect of temperature on its various components affects the output of the pressure measurement. To avoid the temperature effects it is preferred to avoid Environment with Extremes temperature conditions. Also by running a tube from the pressure measurement point to a place where stable temperature location. The most common solution to temperature effects is to avoid extreme temperature environments. When the pressure instrumentation point is subjected to such temperatures, the standard procedure is to run tubing from the pressure source to a remote stable-temperature location. This procedure is adopted as the frequency response required is less than 5 Hz.

2.4 Flow

Turbine, Mass flow meters are not employed in ground system for stage servicing as the requirement is only to control flow rate and not the accuracy of the quantity filled because the filled quantity will evaporate due to heat in leak of the stage. Orifice flow meter is employed for cryogenic flow measurement. Water calibrated orifices are transferred to equivalent process flow rate for use in LOX and LH2 servicing. In cryogenic propellant flow measurement. The two-phase flow elimination and the cavitation suppression are done by pressurizing the cryogenic propellants. Separate paths are identified for high and low flow rate filling and the orifice plate and differential pressure transmitter are selected accordingly to meet the requirements.

III. Safety features:

For efficient and trouble free of Cryo propellant handling safety places a very important vole which can be achieved a by incorporating fail safe and intrinsic configuration system, the safety features are achieved by use of intrinsic safe devices, fail-safe configuration and short circuit protectors and use of gas detectors for sensing leaks of O2 and H2 which form the propellants for cryogenic stage. The following concepts are followed for selection of process instruments for use in CRYO instrumentation:

1. Area classification
2. Apparatus grouping
3. Temperature classification
4. Methods of protection

Area Classification: Areas where there is likelihood of the presence of explosive gas/air mixtures are referred as zones. Zones are classified as shown in the table below. The higher the number in this 'zonal classification' the smaller is the risk of an explosion.

Zone 0	An area in which an explosive gas/air mixture is continually present or present for long periods
Zone 1	An area in which a gas/air mixture is likely to occur in normal operation
Zone 2	An area in which a gas/air mixture is not likely to occur in normal operation, and if it occurs, it will exist only for a short time

Based on all the above, liquid hydrogen availability the area classification is classified as Zone 0 as all the measuring instruments are directly in contact with hydrogen.

Apparatus grouping Based on the ignition characteristics flammable materials are categorized. In Accordance with the Explosive atmosphere properties for which it is intended the groups for the equipment one classified.

1. Group I: Electrical apparatus for mining.
2. Group II: Electrical apparatus for all remaining potentially explosive atmospheres

Electrical equipment of Group II Based on the nature of Explosive gas Atmosphere Electrical Equipment of group-ii are sub divided and also classified based on minimum ignition current and medium expertly save gap.

Apparatus Group	Representative Gas	Energy Band (μJ)
IIA	Propane	>180
IIB	Ethylene	> 60
IIC	Hydrogen	>20

Temperature Classification: The ignition temperature, i.e. The ignition temperature depends up on the type of gas or Vapors. The temperature of the exposed surface of the any equipment should be lower Than the ignition temperature. For hydrogen environment the measuring instruments are selected for Group IIC with temperature classification as T4.

Method of protection: A hazardous area exists only if the three conditions exists i.e, Availability of Flammable liquid/gas vapor dust. Source of energy sufficient to create combustion and source of ignition. In case of any leakage of cryogenic propellants (LH2 & LO2), it evaporates immediately and produces large quantity of gas. Potential fire hazard increases if there is oxygen enrichment of the atmosphere. Enrichment of O2 to about 25% by volume from the normal 21% in atmosphere will cause significant increase in the rate of combustion. The spark which is used to ignite should have sufficient energy which is the specific property of the gas / Vapors.

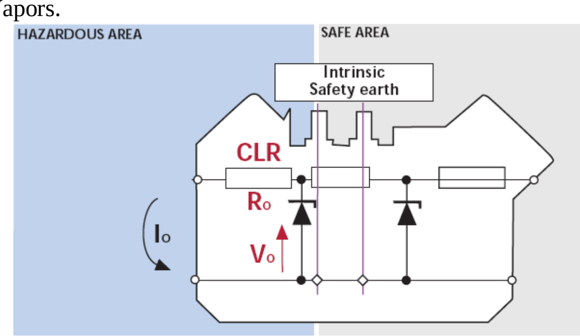

Fig4: Shunt diode safety barrier

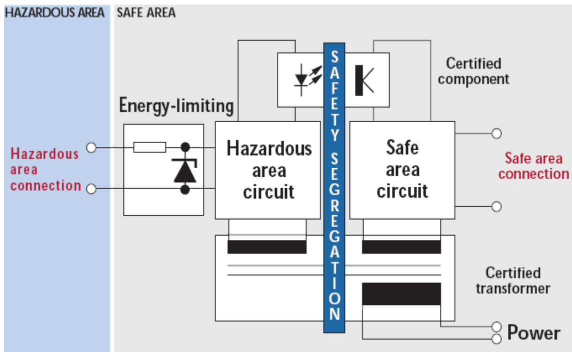

Fig5: Isolator

The circuit values are designed in such way that minimum ignition energy required for ignition. Intrinsic safety is a protective technique that removes ignition from the explosion triangle. The intrinsically safe instrument or chain is not reaching the Hazardous Area. The IS energy chain designed not to produce ignition energy is case of normal power, faults at control room, signal line, sensor or transmitter. All the associated apparatus and instruments and chains used in the cryo systems are intrinsically safe and tolerate two faults (Ex 'i_a'). Two countable faults can occur but the circuit still limits the design voltage and current. There are always at least two or three zener diodes in parallel in each intrinsically safe barrier. If one diode should fail, the other will operate, providing complete protection.

3. Conclusion

The complexity in Instrumentation for handling cryogenic liquids is due the properties of Cryogenic fluids and requirement of accuracy and safety. Selection of proper instruments by ensuring safety standards is vital design criteria. The instrumentation system designed and implemented has yielded satisfactory results ensuring an accurate, reliable, safe, and fault tolerant instrumentation system for handling cryogenic fluids.

Reference

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