Proceedings of the 5th ISSE National Conference (INAC-05) on
Systems Approach for Self-Reliance in Advanced Technologies (SASAT-2023)

Realization of Integrated Data Acquisition for Testing of Human Rated GAGANYAAN Vikas Engine

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Abstract

The L110 VIKAS engine certification testing for the Gaganyaan program, comprised of three long duration qualification tests and four short-duration off nominal tests. The Test Article (The GAGANYAAN Vikas Engine) measurement system comprises of Process Measurements namely Pressure, Temperature, Strain, Speed, and Vibration. Erstwhile Test Article measurement system used individual Signal Conditioning Amplifiers, Excitation Power supplies, and the Data Acquisition system using The PCI Extension for Instrumentation (PXI- Data Acquisition system)

The revamping of the Test Article Measurement System in the Principal Test Stand control centre - was carried out by inducting the state-of art Integrated Data Acquisition systems (IDAS) with inbuilt excitation modules, Sigma delta ADCs thereby replacing the old signal conditioning modules and excitation modules. The induction of the IDAS was pivotal in ensuring accurate and precise measurements required in the GAGANYAAN ground testing. The paper elucidates the arduous Testing of the IDAS and the various Hot Test results of the GAGANYAAN Engine Test Series.

1. Introduction

"That's one small step for a man, one giant leap for the mankind", is what is Neil Armstrong quoted on his team landing on the moon. India from its humble beginnings of ISRO has come a long way in competing with the space faring club and to prove its mettle, it has launched the ambitious GAGANYAAN program with an aim of launching Humans into the space. As a part of qualifying the various subsystems of the Human Rated Rocket, major Engines, crew modules were tested in IPRC, Mahendragiri. Being the maiden attempt of ISRO, in launching Humans in the space, extra precautions and module testing and qualification tests are carried for various stages of the Rocket.

As a part of the qualification program of GAGAYAAN, the High Thrust VIKAS engine was tested in the High Pressure mode to ensure the margin availability and to satisfy the SMC box criteria. Testing of complex system includes various aspects of engineering, like testing of the Propulsion system, control system, electromechanical actuators (EMA) with quadruple redundancy.

As part of the L110 VIKAS engine certification testing for GAGANYAAN program, three long duration qualification tests and four short duration off nominal tests were planned based on SMC-S-025 standard as tabulated below.

The various parameters of the Human Rated GANYAAN VIKAS Engine consist of measurements like pressure, temperature, vibration, heat flux and acoustic measurements. Precision, accuracy and a High CMRR were critical in the test data measurements and the inaccuracy for the Pressure measurement chain is maintained within 1% of the Full scale including the sensor error of 0.7% for the 21 NA sensors used.

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Test	Hardware	Pc, bar	MR	Duration	Criterion
HS - 1	H/W1	58.5	1.7	1.2x T_{nom} = 240s	• 1.2x T_{nom} on 4 engines. [HT3, HS-1, HS-2, HS-3 will meet the requirement]
HS – 2	H/W2	58.5	1.7	1.2x T_{nom} = 240s	
HS – 3	H/W3	58.5	1.7	1.2x T_{nom} = 240s	
HS – 4	H/W4	60.2 bar (+2%)	1.768 (+4%)	25	Thrust and MR margin demonstration with margin of 2%
HS – 5		56.80 bar (-2%)	1.632 (-4%)	25	
HS – 6		60.2 bar (+2%)	1.632 (-4%)	25	
HS - 7		56.80 bar (-2%)	1.768 (+4%)	25	

Figure 1: The various Hot Tests in the GAAGNYAAN program

Figure 2: The VIKAS Hot Test in the GAAGNYAAN program

2. Test Article Measurement And Data Acquisition System

The Principal Test Stand being one of the oldest Control centre's of ISRO, the erstwhile Test article measurement system comprised of independent signal conditioning modules, separate excitation source and the data was acquired in the PXI system.

GAGANYAAN test requirements were critical and to ensure the required accuracy class, the state of art Integrated Data Acquisition System in which the sensor excitation, signal conditioning unit, and Data Acquisition System are incorporated into a single chassis was inducted and elaborate tests were carried out. The total channel capacity of the IDAS is 260 channels.

Figure 3: The Integrated Data Acquisition system (IDAS)

IDAS comprised of pressure, temperature, vibration, modules of make Dewesoft. The various systems of Dewesoft module were synchronized by the proprietary IRIG-B synchronization scheme and were grounded to a separate Instrumentation ground system which is maintained at 1 ohm Ground resistance which is achieved by using special grounding Techniques.

The merits of the IDAS were that it has new technologies like dual Core Sigma Delta ADC (High Dynamic: up to 160 dB, new technology), has a CMRR of 110 dB, good excitation stability and the excitation accuracy is ±0.05 %, and has isolation voltage of 1000 V rms. The input impedance is 10 Mohm. The modules generates the excitation required for the 21 NA pressure sensors (upto 15 V, 40 mA can be provided by the IDAS).

The sampling rate can also varied from 100 samples per second to 200 kS/s as per the need. The filter settings can also be defined as per the requirement and Digital Filter: Upto 8 pole Bessel/Butterworth/Chebyshev low pass filters are configurable through the software

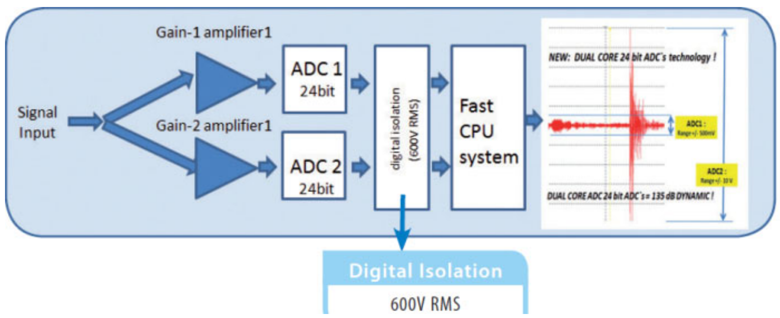

Figure 4: The Dual Core ADC of the (IDAS)

DUAL CORE ADC technology (Fig iii) always gives the full possible measuring range, because the signal is measured with a high and a low gain at the same time. The data acquisition modules are isolated (Fig 2) between themselves and the main board.

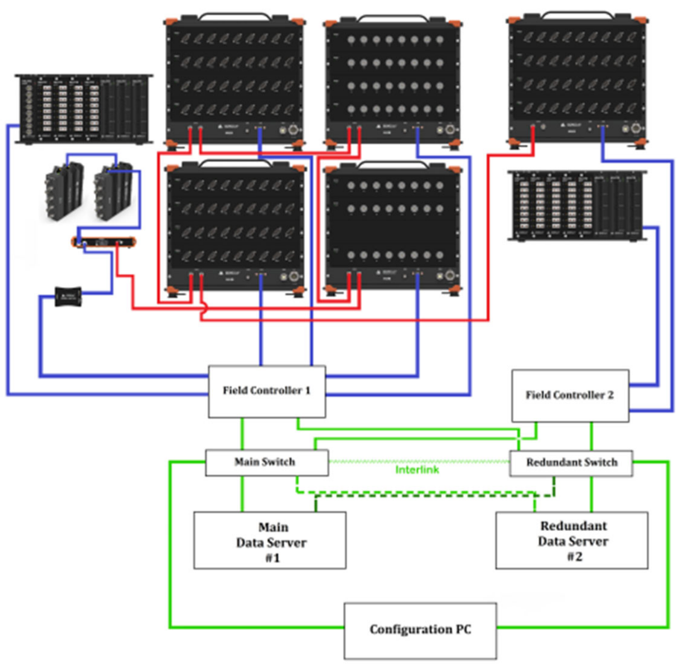

Figure 5: The configuration of the IDAS

3. Pressure Measurement Sytem

Pressure measurement is crucial as it directly relates to performance of Engine and also the Chamber Pressure is also an Abort parameter. Chamber pressure of engines is one of the critical measurement aspects, as it will be used to calculate thrust, analyze performance stability. In the GAGNYAAN engine tests, 4 numbers of Chamber pressure measurements were taken to ensure the redundancy in the measurements.

The following figures show the chamber pressure plots of the 4 tests in which the margin variation of the Chamber pressure and the mixture ratio were varied.

In all the conditions of MR variation and the Chamber Pressure variations, the engine was stable.

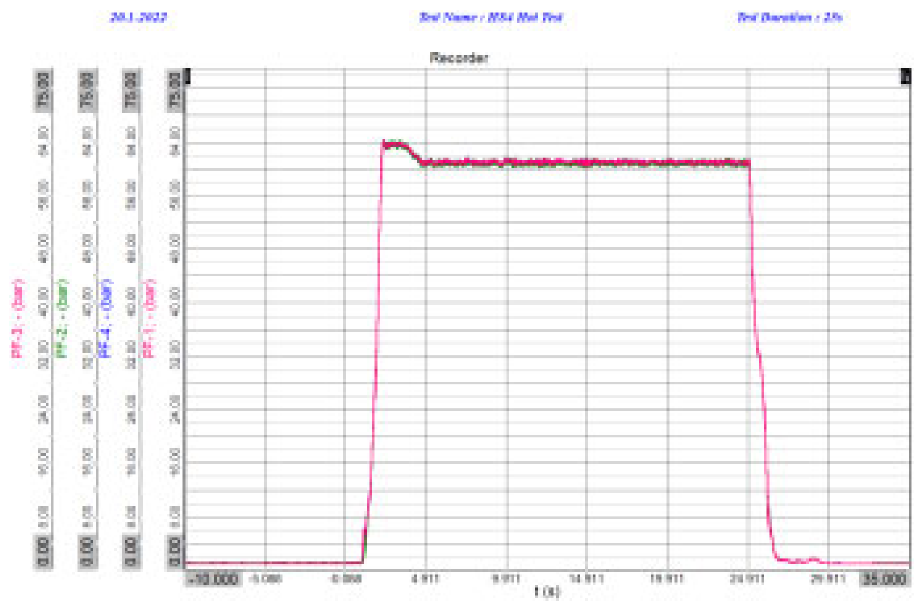

Figure 6 HS4 Chamber Pressure

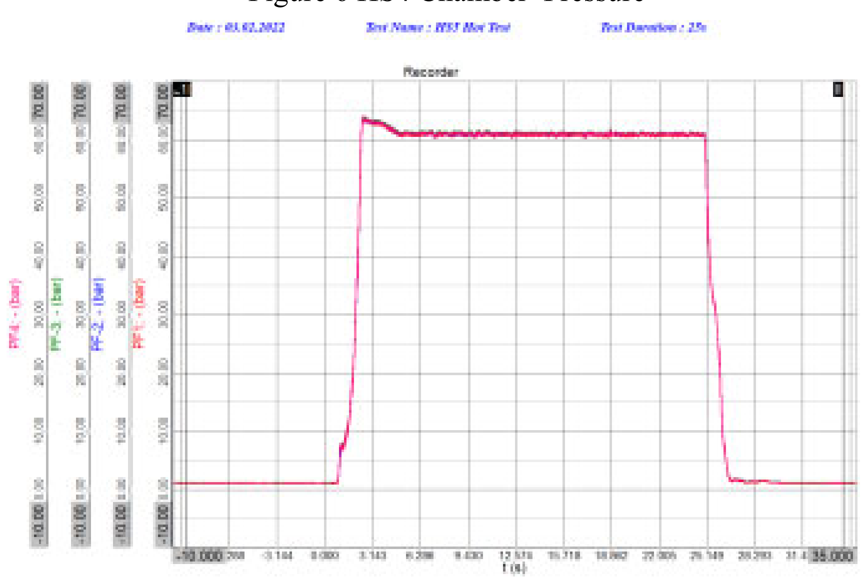

Figure 7 HS5 Chamber Pressure

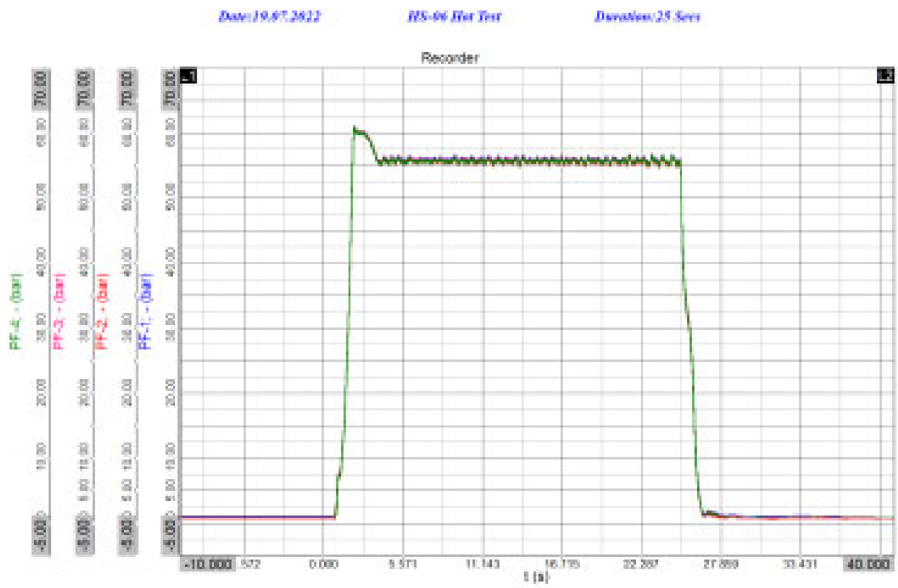

Figure 8 HS6 Chamber Pressure

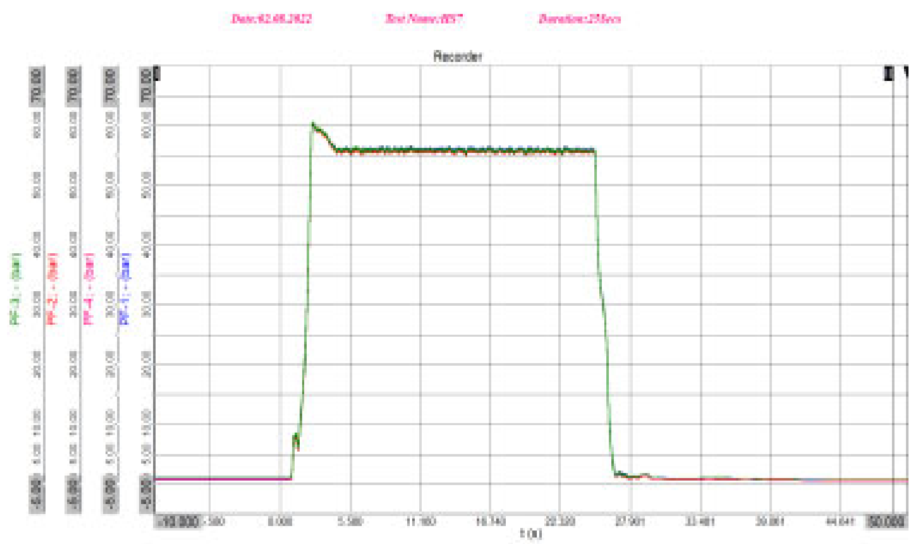

Figure 9 HS7 Chamber Pressure

4. Temperature Measurement System

The Temperature across various parts of the engine namely the Thrust Chamber, Throat, Gas generator, etc are measured using K type thermocouple and the Data Acquisition system of make Dewsoft and IOLITE module is used for acquiring the data at 100 Samples per second.

The IOLITE Module has a real time controller and has additional add-on feature of storing the Data in the module.

The throat back wall Temperature TCH3A, B, C, TCH4 A, B, C and TCH 5A, B, C measurements are critical ins ascertaining the health of the throat. In the event of gas entry because of throat peel off, a sudden raise in the Temperatures 3A, 4A and 5 A will be observed.

ISBN - 978-93-95038-50-8

Similarly, Temperatures in the Gas Generator (GG) namely TGAT (Inlet Temperature) and TGST (Outlet Temperature) are crucial parameters and also are abort parameters. In the GAGANYAAN Engines, the redundancy of TGAT and TGST is ensured by having two measurements (TGAT1, 2 and TGST1, 2) respectively.

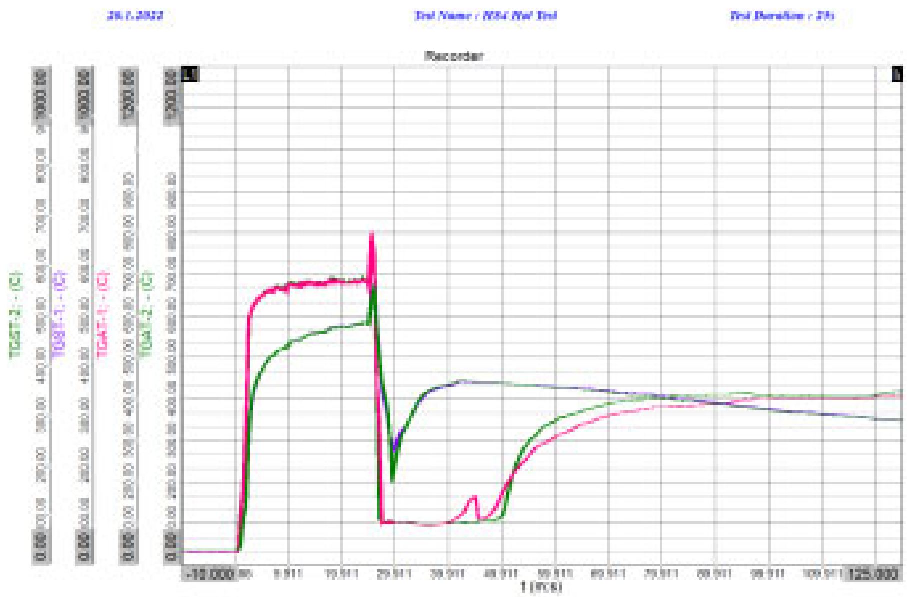

Figure 10 The Gas Generator Temperatures

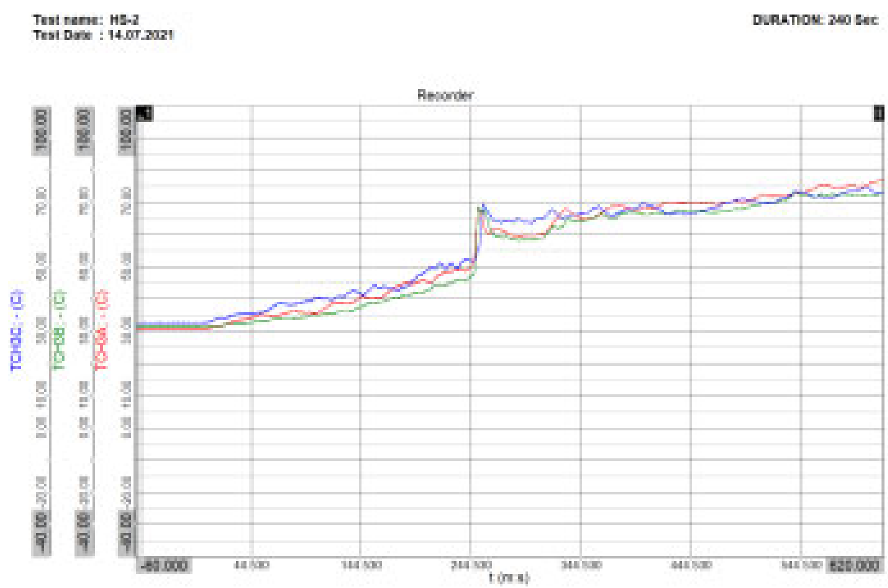

Figure 11 The Temperature plot for Long duration Test of 240 seconds

5. Vibration Measurement System

The Vibration measurement of 32 channels with inbuilt excitation of 24 V was realized for ICP sensors mounted on the Engine at critical locations like the Turbo pump N204 side, UH25 side, Water Pump, Injection cover etc. The data of the vibration is acquired at 50kS/s and the post processing is done with MATLAB 3D FFT plots in which the various frequencies that are excited during the Hot Test can be studied.

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Amplitudes of critical frequencies in dynamic chamber pressure measurement and injector cover vibration are within the acceptable level indicating stability of the engine at the tested off nominal condition.

In the injector acceptance testing of the VIKAS engines, the dynamic pressure of the Engine is also measured and ensured that it is within the specification of 0.5%

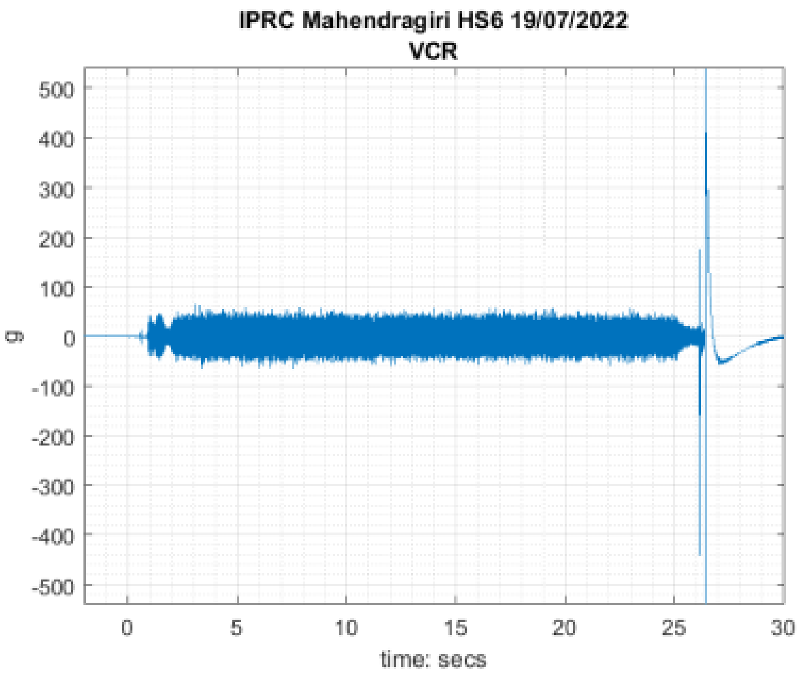

Figure 12 Injection Cover Vibration plot

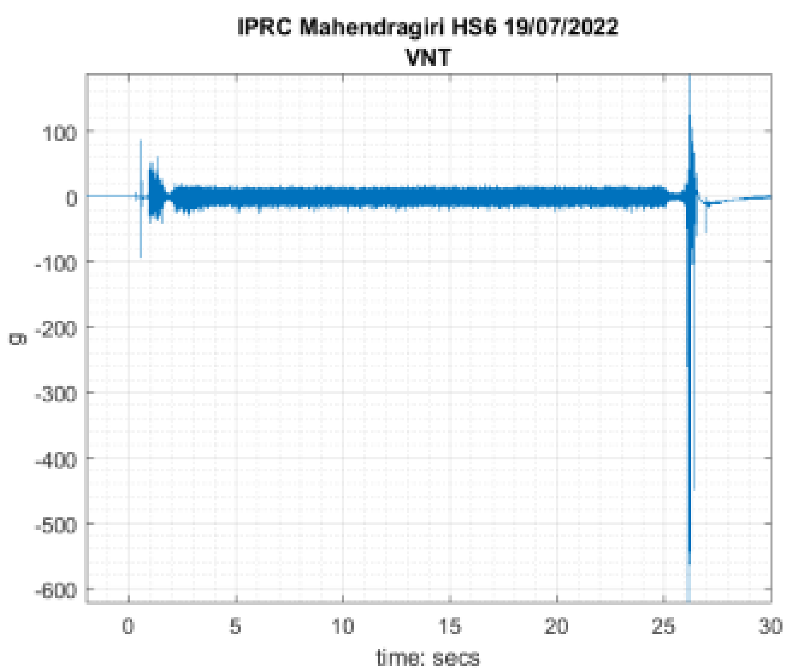

Figure 13 N pump Vibrations

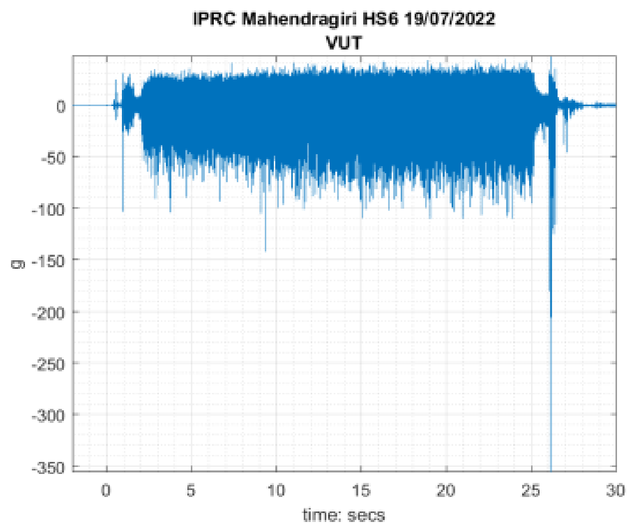

Figure 14 U pump Vibrations

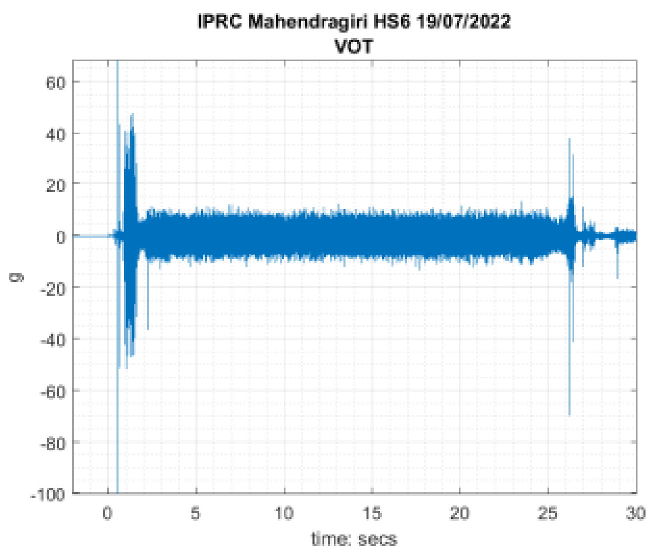

Figure 15 Water pump Vibrations

6. TESTS DONE FOR COMMISIONING THE IDAS

Various tests were carried out to assess the IDAS system and validate for inducting it for the hot test. Following tests are carried out.

Sl No	Name of Test	Sl No	Name of Test
1.1	Input Accuracy	1.2	Linearity
2.1	Gain accuracy	2.2	Gain linearity
3.1	CMRR	3.2	Cross talk
4.1	Filter response	4.2	Input noise
5.1	Input saturation	5.2	Stability
6.1	Signal delay between AI to AO	6.2	Time accuracy
7.1	Analog output availability check	7.2	Data display check

A few test procedures are elaborated below:

6.1 INPUT ACCURACY

- Input accuracy test is carried out to determine the input accuracy of channels.
- This is done by feeding DC voltage signals in steps from high precision calibrated DC source (Yokogawa GS200) to selected channels; this input data is acquired by the system and accuracy is calculated.
- To ensure precision of the source, a 6-digit Digital Multi-meter is used to measure source output. This test is done for several input ranges.

6.2 LINEARITY

It is the proportionality between the input and measurement of the instrument. It is critical that the device has a linear response. The procedure followed:-

- DC inputs are fed to the randomly selected channels (in linear steps) from a high precision DC calibrator.
- The inputs are measured using a six and a half digit digital multi-meter (DMM).
- This is done for different input ranges (±1V & ±10V) of the module.
- The linearity is calculated and results are tabulated below.

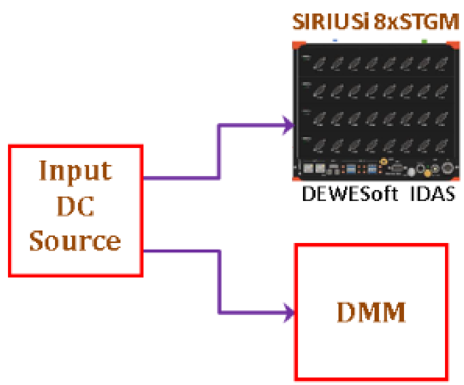

Figure 16

6.3 GAIN ACCURACY

The Sirius STGM module does not have multiple input gains. It only has unity gain with different input ranges viz. 10mV, 100 mV, 1V & 10V. Gain accuracy is measured for selected channels for different input ranges.

- Input, based on selected range, is fed using Yokogawa DC source to the selected channels.
- Applied input is acquired in IDAS and also measured using 61/2 digit multi-meter (DMM).
- Gain accuracy is calculated using following formula;
  - Gain =Input acquired by IDAS/input measured by DMM.
  - Input Gain accuracy= (1-Gain)*100.
- Gain accuracy is measured for all four input ranges.

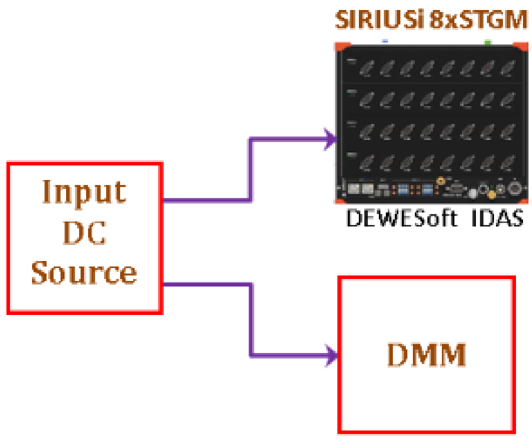

Figure 17

6.4 COMMON MODE REJECTION RATION (CMRR)

CMRR is the metric used to quantify the ability of differential amplifier to reject the common mode voltage signals. It is essential that the device has a high CMRR. This facilitates the rejection of any interference noise in the measurement chain. The detailed test procedure is described below:

- This includes measurement of two gains i.e. Common Gain & differential gain.
- For this two DC sources of same make and model are used to feed input.
- The positive terminals of both the DC sources are connected to two differential input terminals of the amplifier, whereas the negative terminals of both sources are shorted together and connected to the input ground terminal.
- Using both the sources differential and common voltage inputs are fed to the IDAS system. DMM is used to accurately measure the input.
- Following formulae are used to measure the CMRR.
- -Common mode gain (Ac) =IDAS reading/Common mode input.
- -Differential gain (Ad) =IDAS reading/Differential input.
- -CMRR=20log (Ad/Ac).
- CMRR is measured for all the input ranges.

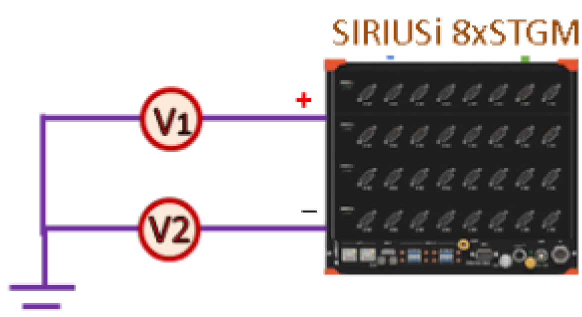

Figure 18 Block diagram of CMRR differential mode

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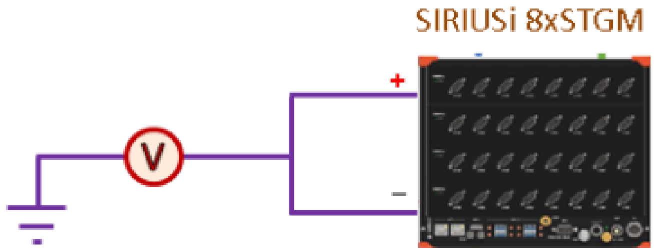

Figure 19 Block diagram of CMRR common mode

6.5 CROSSTALK

Crosstalk is a phenomenon in which a signal fed to a channel gets interfered with the signal in the adjacent channel. The signal cross talk between channels should always be very small for precise measurement. Procedure described below is followed to calculate cross talk:

- Two adjacent channels are selected from each STGM slice module.
- AC signals of different frequencies (100 Hz, 500 Hz, 1 kHz, 2 kHz & 5 kHz) are fed to a channel.
- A DC signal (1V) is fed to the adjacent channels.
- FFT is calculated for the adjacent channel to measure the amount of cross talk.
- Plots are annexed.

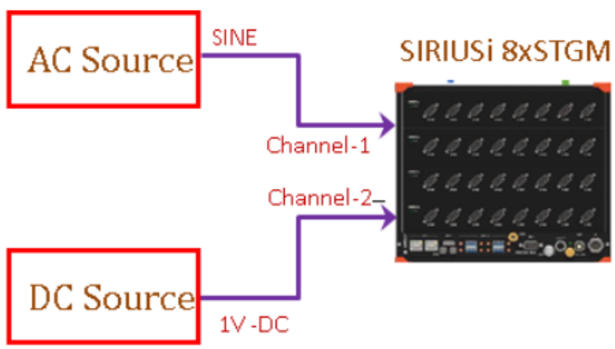

Figure 20 Block diagram of cross talk

6.6 FILTER CHARACTERISTICS

One of the key characteristics of a filter is its' roll-off rate. Roll-off rate is the steepness of filter transmission function with respect to frequency in the transition band between the pass band and the stop band. It depends on the order of the filter used. Ideal roll-off rate of 1st order filter is 20dB/decade. The roll-off rate becomes sharper with increase in the order of the filter. The procedure followed is:

- Roll-off rate is measured for Butterworth filter of different orders (2nd, 4th, 6th & 8th) for a cut-off frequency of 100Hz.
- For this, a channel is selected and configured with the required filter.

- And AC sine signals of 10Vpp and different frequencies () are fed as input.
- Roll-off rate: 20log (w2/w1) is used to calculate the roll-off rate where w1 is filter output response at cut-off frequency and w2 is filter output response at 10 times the cut-off frequency.
- The filter output responses are measured from the FFT.

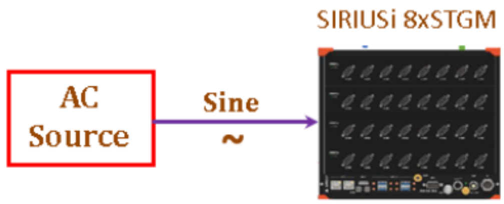

Figure 21 Block diagram of filter

6.7 Input Noise Check

In every measurement channel, inherent noise exists and it should be very low. To check the input noise of the system, input terminals are shorted with 1kohm resistor and data is acquired for different sampling rates (100Hz, 1 kHz and 5 kHz).

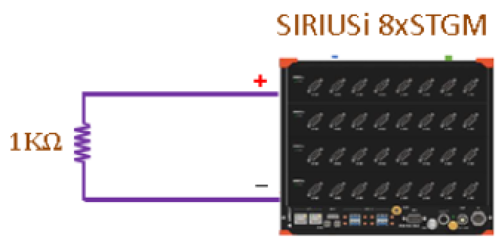

Figure 22 Block diagram of noise

6.8 Input Saturation

In every measurement channel, inherent noise exists and it should be very low. To check the input noise of the system, input terminals are shorted with 1kohm resistor and data is acquired for different sampling rates (100Hz, 1 kHz and 5 kHz).

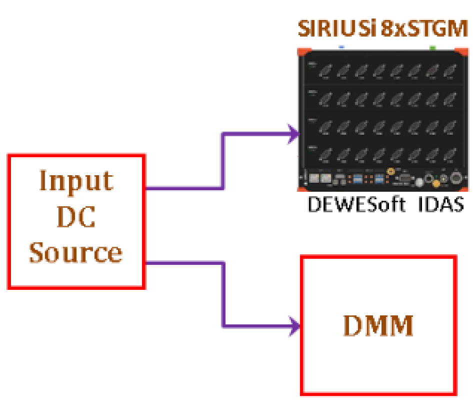

Figure 23 Block diagram of input saturation

7. Command System

Instrumentation system realization includes an important command transmission from command system to remote control valves, either its independent valves for line operation or engine valves for opening of fuel and oxidizer lines. There are two primary ways to implement command system. First is manual command system. In this one can operate each control valve manually by operating from mimic console running on the remote PC using PLC (Programmable logic controllers). Entire set of command is programmed in PLC for auto operation. Then command is relayed through PLC, which in turn gives requisite power to field relay, power required to energize valves is connected through electro-magnetic. Command system is used to implement abort system for auto abort in case of abrupt rise of any of the critical measurement or logic of critical measurements. During the command process function all the commands have worked as planned and auto sequence has executed the sequence of operations.

8. Conclusion

The GAGANYAAN Hot Testing was successfully carried out and precise measurements with the inaccuracy less than 1 % were achieved for all 260 channels with the robust IDAS. The vibration measurements for critical measurements like the Injector cover and the Turbo pump measurements were well within the specified limits.

The IDAS realization, though quite a challenge, paved way for the successful Hot Testing of ISRO's GAGANYAAN VIKAS Engines.

The overall efficacy of the Test article measurement chain has significantly improved with the compact modules with better CMRR, and individual ADC thereby eliminating the cross talk and improving the overall signal conditioning performance.

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