Servo Accelerometer for SRE Navigation system

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ABSTRACT

Servo Accelerometer is a single axis pendulous type closed loop Inertial Navigation grade acceleration sensor which is developed and used in PSLV / GSLV launch vehicles from 1990 onwards. For the first time Servo Accelerometer is used in Spacecraft Recovery Experiment, where the performance requirements are more demanding. The On orbit performance of the sensor is analyzed in detail. Performance parameters achieved On board including Short-term stability are also brought out.

A theoretical approach formulated and necessary design changes to be implemented are explained, which will result in further improvement of the overall performance. This paper describes the approach and the design in detail, and the test carried out for the validation of the design modifications.

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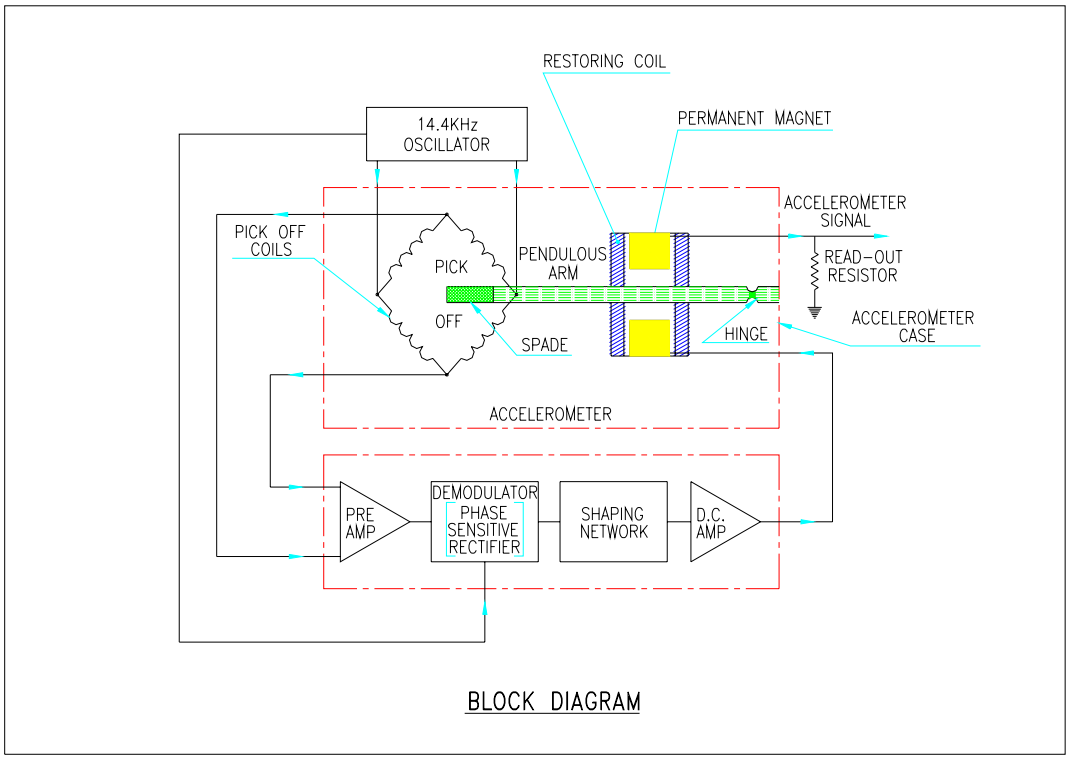
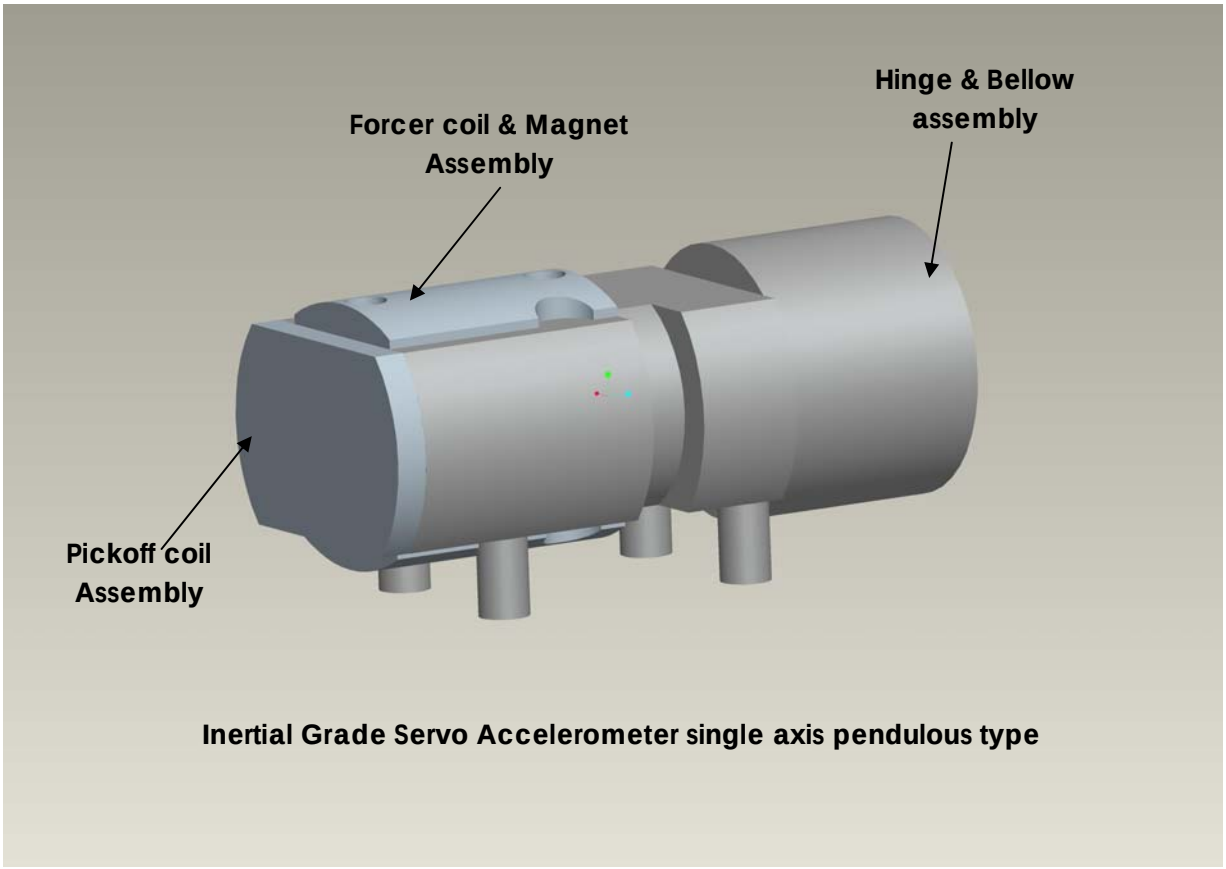
Introduction

Servo Accelerometer is a force rebalanced pendulous acceleration sensor indigenously developed , qualified and used for the Inertial Navigation System of ISRO's launch vehicles namely Polar satellite Launch Vehicle (PSLV) and Geosynchronous satellite Launch Vehicle(GSLV) and for Space Recovery Experiment (SRE) mission. Servo accelerometers are flown in 9 PSLV missions and 4 GSLV missions successfully. A total of five accelerometers are used in Redundant Strapdown Inertial Navigation system with triple redundancy for the thrust axis and one each for the two lateral axes. Resolution is better than 10 µg for an input range of +/- 20 g. In the case of SRE application, incremental qualification and extensive Test and evaluation was mandatory considering the On Orbit environmental conditions and prolonged duration of mission.

Principle of Servo Accelerometer

The principle of operation is that a pendulum on elastic supports (flexure hinges) positioned such that an input acceleration tends to cause the pendulum to rotate about the supports. A pick-off system detects the movement of the pendulum with respect to the accelerometer case, the pick-off signal s amplified shaped and fed as a current through a coil positioned on the pendulum. The current through the coils interacts with the field of a permanent magnet and produces a force which tends to restore the pendulum to its null position. Thus, the current through the coil is nominally proportional to the input acceleration.





Inertial Grade Servo Accelerometer single axis pendulous type

Configuration

Pick Off

Inductively coupled Air core Pick off excited from 6.3volt at 14.4 KHz sine wave supply. Pick off coils are arranged in the form of a Wheatstone bridge. The movement of the pendulum in the air gap between the coils causes to alter the balance of the bridge which gives a proportional pick off output.

Forcer

Designed as a Permanent Magnet moving coil type using high energy magnets. Temperature sensitivity of scale factor is minimized by incorporating temperature compensation in the temperature range of 60 ^{0}C to 70 ^{0}C.

Pendulum Assembly

The pendulum assembly is supported at the end on a pair of hinges. The thin flexural hinges are made to withstand the mechanical shock and vibration loads, and at the same time these flexures are to behave as a near ideal hinge with the minimum flexural stiffness so as to transfer the input force without any loss for rotation of the pendulum about the hinge. The flexure Design and machining process are selected for minimum cross axis coefficient and for maintaining perfect alignment of the pendulum axis with the flexure axis. Perfection of this assembly is a challenging task.

Damping

Non reactive incompressible damping fluid is selected to provide the damping. Damping ratio is selected as 0.7 +/- 0.1 by selecting the oil of suitable viscosity. Metallic bellows provides the necessary control of fluid volume under varying temperature.

Accelerometer Specification

Over all dimension	:	68 mm long X 30 mm dia
Weight	:	130 grams
Restoring Coil Impedance	:	85 ohms @ 25 at ^{0}C
Pickoff Excitation	:	6.3 V, 14.4 Khz
Pickoff Scale factor	:	70 V / rad
Range of Measurement	:	+/-20g
Sale Factor	:	4.2 mA/g
Sale Factor temperature effect	:	150 ppm/ ^{0}C(max)
Bias	:	1.5 X 10^{-3} g (max)
Bias Temperature effect	:	3 X 10^{-3} g/^{0}C (max)
Method of Temperature compensation	:	magnetic Shunt
Operating temperature	:	65 ^{0}C
Storage temperature	:	+5^{0}C to 75 ^{0}C
Type	:	Viscous Damped

Servo accelerometer for SRE Mission- Challenges

The Space Capsule Recovery Experiment (SRE) project has the objectives to launch a 500Kg class recoverable capsule on board PSLV to Low Earth Orbit, carry out micro gravity experiments and recover it in Indian waters. Servo Accelerometers are required for the Navigation of the SRE module during the deboost phase. The accelerometer has to provide the incremental velocities of the SRE module along the pitch, roll and yaw axes to MMU (Mission Management Unit) every 32 milliseconds during the deboost phase. Environmental Requirements are that of Low Earth Orbit(LEO) spacecrafts. During the launch, the sensors are in active condition and it has to withstand the launch environment. The range is limited to 1.5g during the deboost phase as against 15g in launch phase, for better resolution.

Modification for SRE IMU Accelerometer

Presently, developed accelerometer conforming to the specification are realized and used in all PSLV & GSLV missions. The performance is excellent and orbit achieved in the previous missions stand in testimony for this.

The accelerometer for SRE has to withstand the vacuum environment. Modification carried out on the external joints to enable a better vacuum seal which can withstand vacuum to the order of 10^{-5} torr. The accelerometers have undergone thermo vacuum test as per the SRE requirement.

Performance during realization phase

The servo accelerometer selected for SRE mission were realized during 2004 and were extensively tested for about 60 days at sensor level prior to integration in Inertial Measurements Unit of SRE. This was followed by subsystem level checks for a period of more than a year. The overall performance during the period from January 2005 to till launch (more than two Years) for the performance parameters of the sensor namely bias, scale factor, non linearity and misalignment and their stabilities were well within the specifications.

On Orbit Performance during the SRE Mission

Deboost firings were carried out under Closed loop Guidance using Gyros and accelerometers of Inertial Measurement Unit.

Accelerometer Bias variations

	Yaw(XA) (µg)	Roll (YA) (µg)	Pitch (ZA) (µg)
14-01-07	Bias compensated		
17-01-07	07	32	-40
19-01-07(for Deboost-1)	17	-79	-56
21-01-07(for Deboost-2)	18	-84	-64

- ✓ Short term stability of all the channels are very good and maximum variation is less than ***85 micro g over the last 4 days*** against the specification of 1***50 micro g (3 sigma) over 4 hours***.

Further design improvements in Servo Accelerometer

Based on Geomagnetic field sensitivity in the polar orbit of SRE further improvements were incorporated by using the casing material in high permeability Mu-metal. The sensors were realized and evaluated. Test and evaluation including environmental tests namely vibration & Thermovacuum tests were carried out to validate the modifications. Accelerometer coefficient extraction using 4 position tests is done. Excellent short-term stability of the order of 20 micro g obtained.

Status of Servo Accelerometers after recovery

During Visual inspection, except the label for identifying sensor, all parts were in good condition. All the 3 Accelerometers were powered after cleaning externally and are found to be normal and all the coefficients including short term stability were holding to the pre launch values.(within warm up to warm up specification except for degradation in insulation resistance). This was restored by proper cleaning using deionised water / cleaning agents.

Conclusion

- Servo Accelerometer Design has been qualified for prolonged vacuum environment.
- Short Term stability better than 85 µg achieved in all the three channels during the SRE mission.
- Withstood the severe Pre, during and Post launch environments of the mission.
- Performance of Servo accelerometer qualifies it for usage in Reusable Launch Vehicle type of missions and satellite applications.
- Performance of the recovered sensors was satisfactory in all respects.

References

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