Miniaturised Redundant Sensor Electronics for Inertial Navigation System for Launch Vehicles

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***Abstract*— Quality of an Inertial Navigation System is determined by the navigation sensors namely the Gyroscopes and Accelerometers and the precision electronics used to operate them. Development of electronics for a navigation system is an optimal blending of contradicting requirements. Navigation Sensors are closed loop Sensors for which Capture loop electronics has been developed. They also require AC power and Temperature Control. Specialized digitization scheme is implemented for processing the data quality. Health monitoring circuits have been added for implementing fault detection scheme. The system and electronics are configured and partitioned to achieve redundancy and tolerate multiple failures. This paper details the development of Electronics for the new miniaturized Inertial Navigation System around these sensors.**

***Keywords*— Redundant Electronics, Navigation System, VFC, Temperature Control**

I. INTRODUCTION

Accurate Determination of Position, Velocity and attitude are essential for successful Launch Vehicle program. Considering the high velocities achieved during the short flight time this activity has to be carried out with many constraints like fault detection and correction in real-time and non dependence on external sources in addition to minimization of Mass and Power. These requirements make Inertial Navigation System (INS) the preferred Navigation system for Launch Vehicles. Strapdown Navigation System using Dynamically Tuned Gyroscope (DTG) and Pendulous Force Balance Accelerometers (PFBA) can be configured to achieve the above requirements. Accuracy of the INS is essentially determined by the DTG, the PFBA and the electronics used to operate the same. Precision electronics are also required to acquire/convert the data into digital form.

This paper describes the development of electronics for a new Miniaturized Strapdown Inertial Navigation System for Launch Vehicle for achieving the above requirements. Miniaturized DTGs and PFBAs are the sensors used

II SYSTEM CONFIGURATION

The INS is configured around three DTGs and six PBFAs. They are mounted on a sensor cluster in a definite orientation to measure the rate and acceleration data along a set of axes. One DTG, two PBFAs and its associated electronics are grouped as one functional chain. Each chain is kept fully isolated from the others for the fault containment. The chains operate from separate power sources to ensure that failure of an external power source does not vitiate the performance. The outputs from each chain are also sent to two processor units through two separate links to ensure that the fault in one processor does not propagate to the next. All hardware is kept operational during launch to implement hot redundancy and enable reconfiguration in minimum time. A schematic configuration of the system is given below.

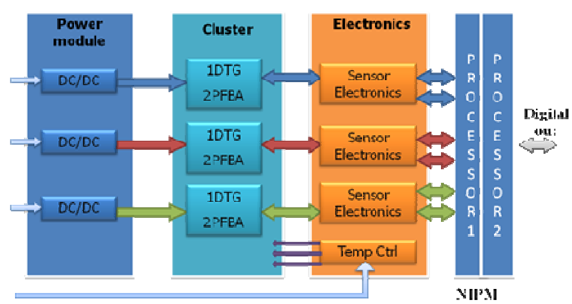

Fig. 1 System Configuration

III. ELECTRONICS FOR DTG

The DTG is a closed loop spinning mass/rotor gyroscope with two input axes. The position of the rotor is sensed by an AC pickoff coil and the same is amplified and demodulated. This signal contains the nutation response of the rotor in addition to its position information. The nutation response is filtered out and the position information is processed to generate a feedback signal to null the rotor position. This forms the Capture loop for one of the axis of the DTG. The magnitude of the feedback signal is a measure of the input rate and is sent for digitization. Processing for generating the feedback signal involves reduction of error during dynamic conditions by PI controller and addition of compensator for achieving necessary bandwidth. Two such electronic loops are used for each axis of the DTG. The bandwidth of the sensor loop is selected as 55Hz considering the Navigation data requirement for Launch Vehicles. The rate is measured to a stability value of 0.05°/hr and a range of ±30°/sec.

The DTG rotor is maintained at a constant rpm by a 3ψ hysteresis motor running at a constant frequency. The rpm for each DTG is experimentally determined with a spread of 10Hz around the nominal value. The power for the 3ϕ motor is generated from a stable crystal clock by a set of presettable counters followed by a power switching circuit. The preset value is loaded to get the desired motor rpm. The AC pickoff for the rotor position measurement also requires a low distortion stable sine wave. This signal is also generated from the same stable crystal clock used for 3ϕ motor power. A LUT stores the data for generation of the sine wave and a DAC is periodically updated with the LUT data. This scheme gives excellent stability for frequency and amplitude. Furthermore, beating from free running oscillators is also avoided. Stability across environment is better than 1% in amplitude and 100ppm in frequency.

IV. PFBA ELECTRONICS

The Pendulous Force Balance Accelerometer is a closed loop sensor which measures acceleration about one axis. A pendulous mass suspended on a hinge deflects for acceleration about its input axis. An electronic pickoff detects the movement of the pendulum from null and the associated processing circuit demodulates and generates a feedback signal to move the pendulum back to null. The feedback signal is used as a measure of the input acceleration. The new indigenous PBFA has all the electronics in built and is miniaturized. The sensor gives current output proportional to acceleration which is converted to voltage and given for digitization. A range of ±20g is realized with a stability figure of 25µg.

V. ANALOGUE TO DIGITAL CONVERSION

Conversion of the Analogue Sensor outputs to digital has to be done with high resolution and accuracy. Conventional ADCs with high resolution have poor linearity and are slow. A precision charge balance type Voltage to frequency convertor is developed to overcome these drawbacks. The input signal is continuously integrated and when the integrator exceeds a threshold a fixed quanta of charge is removed from it. The rate at which the charge is removed is directly proportional to the input and this is accumulated in a digital counter. To achieve good linearity the charge removed from the integrator has to be highly precise. Effect of stray charges/ currents on the charging and discharging path has to be minimized. Switch and Integrator Capacitor imperfections are another source of error which also has to be minimized. A VFC with 10,000 pps/V and non linearity better than $50\mu V/V^2$ has been realised. The output counters of all conversion channels are located together in the digital processor unit. This provides for simultaneous sampling of all the digital channels.

VI. TEMPERATURE CONTROL

The performance of all these precision circuits are affected by environmental factors notably temperature. To improve the performance of each of the sensitive elements (sensors and precision circuits), they have been temperature controlled. All the sensors (3DTGs and 6PBFAs) are mounted on a common cluster block. An efficient Multipoint independent temperature control scheme has been implemented for the cluster block. Temperature of each sensor is controlled within ±0.25°C. Having multipoint independent temperature controllers for the same cluster provides redundancy in the temperature control. In case of failure of one temperature controller the adjacent controllers supply increased power to maintain the temperature of the failed sensor within ±2°C. This scheme is also more efficient as the temperature of the structural elements in the cluster need not be controlled.

The precision voltage to frequency converter is also temperature controlled. An on card temperature controller has been selected for this application. This minimizes the hardware requirement in comparison to a dedicated temperature controlled box. Temperature stability of ±0.25°C has been achieved for this region. The distribution of VFCs in the three chains provide for redundancy in the VFC temperature control.

VII. HEALTH MONITORING

To implement a fault detection scheme, awareness of health of the system is essential. Health consists of key parameters which give direct indication of operation of various components. Major health parameters are DTG rotor speed, motor and pickoff running currents, temperature of the sensors and the other critical regions in the system, Power Status Monitoring and error build up of DTG rotor. These signals are generated and processed by the electronics and fed to the digital processor for decision making.

VIII. POWER REQUIREMENTS

Operation of the navigation system requires multiple power supplies for achieving the various operations. Analogue processing and health monitoring circuits operate from ±15V.Operation of DTG requires higher voltage and ±30V is used. Similarly digital circuit and VFC requires +5V. Temperature controller also requires higher voltage of 28V.These power and their associated ground lines have to be maintained with proper isolation to avoid coupling between sensors and degradation of signals due to power bleeding. Another important reason for signal degradation is due to EMI associated with power generation and running of inductive loads. Design of power supply has been carefully addressed to extract the best system performance. The power supply design is also subjected to fault detection and redundancy requirements. Power supplied to each sensor and its electronics have been kept separate to sustain the system with minimum performance degradation in case of failure of one sensor or its associated electronics.

IX. DESIGN FOR REDUNDANCY

The INS has been designed with full hot redundancy for sensors and electronics. This requires partitioning the system into fully isolated zones where a fault can be contained and propagation to other zones can be prevented. The basic system partitioning into 3 chains has the objective of meeting all performance requirements in the event of a complete failure of any chain. This is fully achieved by usage of redundancy in temperature control scheme, at both the sensor cluster and the VFC circuit. The redundancy in output interface to processors is another requirement for effective system redundancy, lack of which can propagate the failure in one processor to the other. Another implicit requirement for fault Containment is to avoid sharing and reuse of common circuits and power. This is done to avoid faults in one sensor or its associated electronic leading to loss of the entire chain.

These requirements for redundancy management are in direct contradiction to the general requirement of mass and power reduction. However the above redundancy scheme along with the health monitoring provides for "FAIL-OP/FAIL-OP/FAIL-SAFE" operation in acceleration channel and "FAIL-OP/FAIL-SAFE" operation in rate channel.

X. HARDWARE REALIZATION

All electronic circuits have been realized in 3 identical PCBs, one catering to each chain. All circuits including the DTG capture loop electronics, DTG power generation, the sensitive VFC circuit, PFBA interface and health monitoring have been included in this PCB. EMI issues have been reduced by minimizing it at the source, isolation between sensitive circuits and placement of circuit and parts. All parts are selected to meet relevant high reliability specifications; there by ensuring reliability. Miniaturization has been achieved by usage of surface mount devices. The sensitive VFC circuit has been developed as hybrid micro circuit (HMC). A novel on card temperature control scheme has been incorporated for improving the VFC stability. Sensitive precision circuits have been co-located with power circuits and the necessary performance has been achieved.

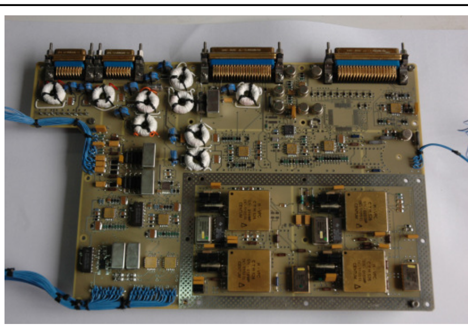

Fig. 2 Sensor Electronics Module (SEM)

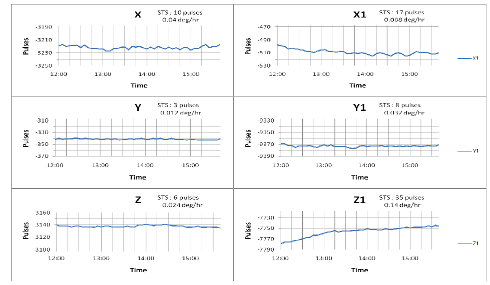

Fig. 3 Stability Of Rate Channel

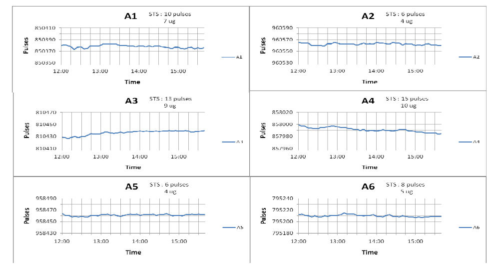

Fig. 4 Stability of Acceleration Channel

XI. RESULTS AND CONCLUSION

Miniature Electronics incorporating all the functional and redundancy requirements for measuring position, velocity and attitude have been designed and developed. All design requirements are fully met and the system has been successfully tested in all environments. Stability figures of 0.05 deg/hr in the rate channel and 25µg in the acceleration has been achieved (Fig 3 & Fig 4). The system was successfully flight tested with a position error of < 5 km in apogee and perigee and inclination error < 0.02 deg.