APPLICATION NOTE

Aeronautical – Attidude and Heading Reference System, Flight Control System

Fig. 1: MS9000 and MS1000 Single axis MEMS accelerometers, LCC 20 hermetic package

Key System Requirements

- ✓ Measurements ranges : ±5g, ± 10g
- ✓ Excellent SWaP
- ✓ Long term bias repeatability less then few mg and excellent scale factor repeatability

Introduction – Inertial Navigation

Inertial navigation is the process of calculating the position and velocity of a body (such as an aircraft) from self-contained accelerometers and gyroscopes. Inertial Navigation Systems of middle accuracies, Attitude and Heading Reference Systems (AHRS) and Flight Control Systems (FCS), require gyros and accelerometers to predict the position of a moving object in free space.

Fig. 2: AHRS

AHRS are multi-axis sensors that provide heading, attitude and yaw information for aircraft or any subject moving in free space. FCS control an aircraft's direction in flight and change speed as well. AHRS consists of gyroscopes, accelerometers and magnetometers on all three axes. Some AHRS use GPS receivers to improve long-term stability of the gyroscopes. A Kalman filter is typically used to compute the solution from these multiple sources.

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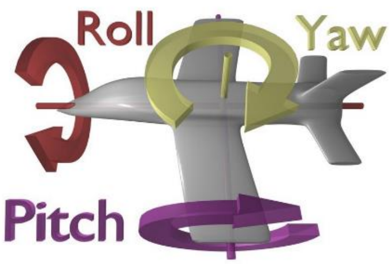
Accelerometer Function in AHRS

Strap down inertial navigation systems require an initialization process that establishes the relationship between the aircraft body frame and the local geographic reference. This process called alignment generally requires the device to remain stationary for some period of time in order to establish this initial state. To initialize, the inertial reference system goes through a self-alignment process to align the vertical axis of the local level coordinate frame with sensed acceleration (leveling) and to measure the horizontal earth rate to determine the initial azimuth (gyro-compassing). If the initial attitude of the vehicle could be known, and if the gyros provided perfect readings, then the attitude processor would be sufficient. However, the initial attitude is seldom known, and gyros typically provide corrupted data due to bias drift and turn-on instability.



The role of accelerometer in an AHRS application is to provide with initial attitude reference (leveling) using gravity and provide attitude corrections during the flight required to correct the gyro drift. Both gyros and accelerometers suffer from bias drift terms, misalignment errors, acceleration errors (g-sensitive), nonlinear effects (second order term or VRE), and scale factor errors. Accelerometers required for inertial navigation systems should have stable and repeatable bias, small bias temperature coefficients and practically non-existing non-linearity.

Classes of AHRS Performance

✓ **The Tactical grade accuracy AHRS or FCS** use generally Fiber Optic Gyro (FOG) or Hemispheric Resonant Gyros (HRG). They need to be very accurate since they are used in the automatic flight mode and have to be accurate enough to prevent the collision to the ground during take-off and landing especially under fog and extreme weather conditions. For this type of applications usually MEMS or Quartz accelerometers with bias repeatability better than 2 mg over all conditions including temperature range, linearity, second order effects and axis misalignment are required.

✓ **The High-End and Medium grade accuracy AHRS** function is to assist to the pilots' sight or serve as backup systems, which do not require such high performance. This type of AHRS is very often used in the small civilian airplanes, Helicopters and some UAVs. In these cases, MEMS accelerometer and MEMS gyros are mostly used. Choice of accelerometer range for AHRS depends on the application and vibrating environments. Global accuracy require is around 5 mg for a high-end system and from 10 to 20 mg for a medium grade systems.

Fig. 3: APIRS™, Tactical grade AHRS by Safran Electronic & Defense

SAFRAN Colibrys accelerometers for AHRS and FCS

The main parameters essential to optimum AHRS and FCS performance are in-run bias stability (Allan Variance), long term bias repeatability, scale factor stability, axis misalignment and its stability and second order linearity effects or VRE (vibration rectification error). The initial deviation of the majority of these parameters from their expected value can be easily calibrated. However, the main issue for measurements

reliability and accuracy is repeatability and stability of mentioned performances over time, temperature ageing, turn-on, post shock and vibration.
Safran Colibrys is recognized by aeronautical market and has been proven so far to be embedded in the applications at the safety critical level. Safran Colibrys is a MEMS accelerometer supplier that provide the repeatability and stability of bias and scale Factor according to approved ageing and environmental tests plan.

The innovative MS1010 MEMS accelerometer is an optimal choice for Tactical and high end AHRS, FCS thanks to its residual bias long-term repeatability over temperature range -40 to 85°C better than 1.2 mg and scale factor better than 400ppm and in-run bias stability of 15 µg.
(all values are typical , ± 10g range)

The **MS9010** MEMS accelerometer is a choice for middle class accuracy AHRS, FCS with long term bias repeatability of ~7.5 to 10 mg and in-run bias stability of 40 µg.

(all values are typical, ± 10g range)

MEMS Accelerometers description

Safran Colibrys MS9000 and MS1000 products are MEMS open loop capacitive accelerometers based on a bulk micro-machined silicon element specifically designed for high stability, with a low power integrated circuit for signal conditioning. Our MEMS accelerometers are low power, fully calibrated, robust and stable, operating from a single power supply voltage (between 2.5V and 5.5V for MS9000 and 3.3V for MS1000) with low current consumption (< 0.5mA at 5V for MS9000 and 3mA for MS1000). Both sensors are packaged in a 20-pin LCC ceramic housing, thus ensuring a full hermeticity.

Fig. 4: MS9000 Architecture

Principle of Colibrys MEMS operation

The core of the accelerometer is the capacitive bulk micro machined silicon sensor. The fundamental technology for the manufacturing of Colibrys accelerometers is based on the structuring of three silicon wafers:
- The center wafer supports the proof mass through a spring
- This inertial mass is also the center electrode of the capacitive sensor
- Upper and lower wafers constitute the external fixed electrodes of the sensor.

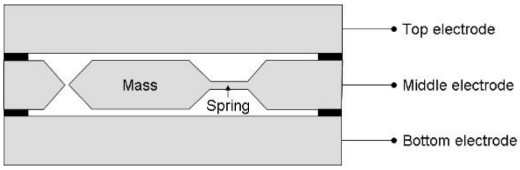


Fig. 6: Principle of capacitive MEMS operation

The three wafers are bounded together by Silicon Fusion Bonding (SFB). This bonding process insures not only a perfect balance between the three wafers of the system but also allows building a hermetic sealed cavity for the spring–mass system. The bonding process is done at high temperature (>1000°C) and at low pressure to ensure an optimal gas damping and bandwidth control. This also allows to avoid any surface contaminant like water molecules in particular and to relax all surface stresses that could be present in the material prior bonding.

The measurement range of the “spring – mass” system is adaptable. Variations of open loop measurement ranges are obtained by modifying the thickness of the spring. Under acceleration or tilt the mass moves between the upper and lower electrodes and changes the values of the capacitors. This differential variation of the sensing capacitors is measured through the interface circuit, which uses a self-balancing capacitor bridge to translate the signal into a calibrated voltage output.

Conclusion

Safran Colibrys is offering one of the best MEMS capacitive accelerometer for AHRS and FCS of Tactical and medium performances. Safran Colibrys is continuously working on new products and new solutions. Thanks to the evolution of manufacturing techniques, the MEMS sensor element, assembly techniques and associated electronics, bias repeatability and stability (“in run” and “run to run” stability) – a key parameter for AHRS and FCS suppliers - is being continuously improved.

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