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Development of High Precision Components for Accelerometer

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Abstract

An accelerometer is an electro-mechanical device that measures acceleration. Highly sensitive accelerometers are used in inertial navigation systems of aircrafts and missiles. An accelerometer assembly typically consists of components with precise dimensional and geometrical tolerances. Geometrical and dimensional accuracies can be controlled by planning proper multistage machining sequence, selecting suitable machining process, machining parameters, planning steps to control distortions, compensating tool wear, suitable work holding devices and taking into account the machine tool accuracy. In realizing quality hardware, it becomes very critical to suitably plan the machining strategy. A manufacturing methodology is established after conducting a number of trials to achieve the required dimensional accuracies and form tolerances for these components. This paper discusses the challenges involved in the manufacturing of the accelerometer components which are design constrained with multiple and precise geometrical and dimensional tolerances.

Keywords: Machining, Precision, Accelerometer

1. INTRODUCTION

In present aerospace industry scenario, it is very important to develop suitable machining methodologies for achieving the maximum quality in machined parts, especially considering the dimensional and geometrical accuracy of the components. Precision manufacturing is the highly formidable area in aerospace industry because of presence of miniaturized electronic/mechanical/optical sub-assemblies to fulfill the functional requirements [1].Accelerometer is one such device which is highly complex and its assembly components of highly precise nature. The selection of cost-effective and reliable manufacturing process is one of the key factors in aerospace industry to sustain in the present market. In aerospace industry the usage of more complex shaped components are becoming high due to their functional capabilities in the final system. The conventional manufacturing processes are replaced with new manufacturing techniques using the new technology advancements in the manufacturing industry. The developments in aerospace industry are mainly due to the level of precision and accuracy achieved during machining process.

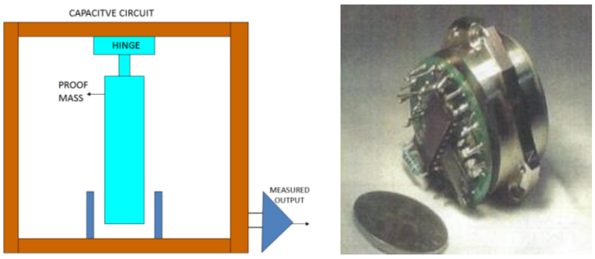

Fig1. Schematic concept of an Accelerometer [2] &typical Accelerometer assembly

An accelerometer is an important sensor device of airborne system which assists a flying object to navigate itself towards the required destination. It is used to determine the linear and rotational acceleration of a body by sensing the inertial effects that the body experiences. The accelerations from the devices are converted into electrical signals which are further processed by on-board computer [3].

As shown in Figure 1, it typically contains an elastically suspended hinged proof mass in a capacitive circuit. The entire body is rigidly attached to the body for which measurements are to be done. Any linear variation along the accelerometer axis shifts the mass from its position and causes change in capacitance. This change in capacitance leads to the measurement of linear acceleration using suitable electronics. The assembly consists of over a half dozen high precision electro-mechanical components as listed in Table no. 1.

Table 1: List of Components in an Accelerometer

S.No.	Nomenclature	Quantity
1	Main Body	1
2	Plug	1
3	Ring	2
4	Magnetic Body	2
5	Bush	1
6	Pendulum	1
7	Spring	1

Each component in this assembly is critical to the desired performance. The components are designed with stringent control over their geometry and size for their functional requirement. Work holding is one the major contributing factor in the realization of these components [4].A process is established after conducting a number of trials to match high accuracy & precision requirements for these components. This paper mainly emphasizes the complexities involved during the development of few of these critical components. The precise control of geometrical shapes and dimensions of these components can be achieved only through precision manufacturing techniques. All the components for the assembly are machined using precision turning, milling, Grinding and other relevant finishing operations.

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2. MATERIAL

The material used for manufacturing the components of accelerometer body is Ni-based alloy FERNI 36 (36% Ni, 0.01% C, 0.20% Mo, 0.3% Mn, 0.10% Co). The material has low thermal coefficient of thermal expansion and desired magnetic characteristics, which makes it suitable for this sensor application.

3 COMPONENT DESCRIPTION& MANUFACTURING CRITICALITES

The complete accelerometer assembly consists of over a half dozen different components with critical complex shaped and high precision requirements. Major components of the assembly are Magnetic body, spring, Ring and Main body, elaborated below:

3.1 Magnetic Body

Fig. 2: Magnetic Body (CAD model, Grinding set-up and Hardware respectively)

The magnetic body, as shown in figure 2, is one of the most critical units of capacitive circuit, since the proof mass is hinged in between the two bodies. The two magnetic bodies are placed within few microns with respect to each other and a hinged proof mass is assembled in between them. This is also the most critical component of the assembly as far as manufacturing is concerned. Table 2 shows the geometrical and dimensional requirements for the magnetic body.

Table 2: Specified geometrical tolerances for Magnetic body

S.No.	Geometrical Tolerance	Specified Value
1	Flatness	1 µm
2	Parallelism	5 µm

Feature height is in range of 0.3mm and nominal thickness of 0.5mm.Functionally, these tolerances are very critical as they govern the capacitance value of the circuit. Any minor variation will significantly affect the output. The component has maximum diameter of 25mm.It also consists of precisely located holes and slots for functional requirements. The main challenge while machining the component is achieving the flatness of 1 micron on the face. This is realized by proper sequencing of manufacturing techniques. The strategy adopted is shown in figure 3.
Lapping is carried out in multiple stages using abrasives of different sizes (20 µm, 12 µm and 3 µm) which are established after several trials. The main challenge is to avoid bending/distortion of face during finishing. Inspection is carried out using optical techniques and requirements are suitably met.

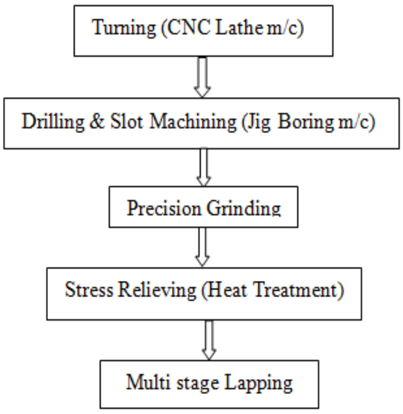

Fig. 3: Manufacturing strategy adopted for Magnetic body

3.2 Spring

Fig. 4: Spring (CAD model, Fixture set-up and Hardware respectively)

The spring, as shown in figure 4, is one of the sensitive elements of the assembly. The spring has outer diameter of 25mm with internal and external profile. It has three, very thin protruding features having thickness of 0.3mm on each side. These features are located at definite angular orientations. The maximum thickness of the component including the protrusions is 1.4mm with dimensional tolerance of 20 microns. Excluding the protrusions, the component is only 0.8mm thick. Manufacturing of such thin walled features involved proper fixturing and precautions to avoid excessive forces on the component. In order to achieve desired accuracies, machining of this component is completed in 4 stages. Firstly, the internal and external profile is made as a single block piece on precision CNC milling. Secondly, this single piece is parted off into individual pieces of required thickness. Thirdly, final thickness is maintained by grinding operation. Finally, thin features of 0.3mm are machined in two set-ups using suitably designed fixtures. The fixture has same matching external profile as on the spring. This profile helps in exactly locating and clamping/locking the component firmly to the base using suitably machined washers. In the first set-up, the three protrusions are machined on any one side. In the second set-up the component is reversed and profile locked to the other face. This second profile additionally has 0.3mm deep pockets in the exact orientation as on the spring component. These pockets will act as cavities for the protrusions and allow the job to rest uniformly on the base.

3.3 Ring

The component has outer diameter of 30mm, length 6mm and internal flange having thickness of 0.6mm and parallelism requirement of 5 microns. The reference features are exactly opposite and blind to each other. Therefore, new external references are generated in order to machine the component. These external references are easily accessible. Machining of this component is done in 3 stages. First stage involved rough turning in which bulk material is removed. In the second stage, precision turning is carried out leaving limited material on certain areas which could be finished by grinding in third stage. Criticality is involved in holding the work piece while machining as the wall thickness is only 0.7mm and could easily deform under the pressure of chuck jaws. Therefore, magnetic chucks are used with proper support elements in order to fix the work piece during finishing operations. The finished component is shown in figure 5 below.

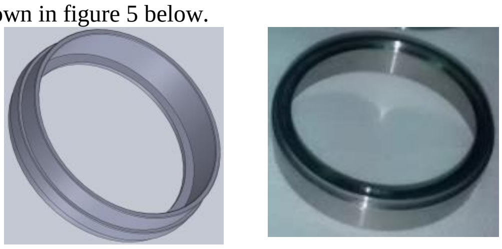

Fig. 5: Ring (CAD model and Hardware respectively)

3.4 Main Body

The main body, as shown in figure 6, can be understood as a housing in which all the individual components and sub-assemblies are assembled. The body is approximately 40mm in diameter and 15mm length. It has a minimum wall thickness of 300 microns and consists of numerous small features, multiple holes with precise geometrical control. The smallest step bore is 0.3mm deep and geometrical accuracy such as parallelism and concentricity requirements are of the order of 5 microns. Machining of the body involved precision turning, milling, drilling and grinding operations at different stages.

Fig. 6: Main Body (CAD model, Grinding set-up and Hardware respectively)

4. INSPECTION& RESULTS

Inspection of micro and precision components are equally critical than that of fabrication. All the machined components are individually inspected. Considering the accuracy required on the components Surface profiler make - Talyor Hobson (measuring accuracy- 0.1A°) and Co-ordinate measuring machine Make- DEA (Volumetric Accuracy-1.3 µm) are used for inspection. Table 3 shows the instrument used and results achieved for a typical component. Similar results are obtained for other components also.

Table 3: Results achieved for critical dimensions

Specifications	Specified value	Observed value	Instrument Used
Component name: Magnetic Body			
Flatness	1 µm	0.92 µm	Surface Profiler (Taylor-Hobson)
Parallelism	5 µm	5.1 µm	CMM (DEA)
Component name: Ring			
Parallelism	5 µm	4.96 µm	CMM (DEA)
Component name: Main Body			
Parallelism	5 µm	4.82 µm	CMM (DEA)
Concentricity	5 µm	4.91 µm	CMM (DEA)
Component name: Spring			
Thickness	0.3mm	0.27	Micrometer (TESA)

5. CONCLUSION

The paper discusses the complexities involved during the development of few of the precision components for an accelerometer. The results of the study are highlighted in the following:

- A manufacturing methodology is established in order to achieve the required dimensional accuracies and form tolerances on the components.
- The accuracies are achieved using multi stage machining sequence (roughing, semi finishing and precision finishing).
- Lapping is carried out in multiple stages using abrasives particles of different sizes. Trials are conducted to establish the process.
- The machining processes, machining sequences and tooling play a vital role in realization of these components.
- Proper machine tool is selected because the machine tool accuracies will directly govern the machining accuracies. Additionally, suitable machining process (IT grade as per the process requirement) is planned.
- It is learnt and also emphasized, that work holding is a major contributing factor in the realization of these components.
- Inspection of micro and precision components is equally critical as their fabrication.

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