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Micromachining – Function in a Small Package

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Abstract

Making small satellites that meet mission objectives within size, weight and cost constraints is quite a challenge. New micromachining technologies are making small mechanical designs that put function in a small package a reality. Micromachining bridges the gap between MEMS manufacturing and the capabilities of conventional machining. The technology creates the opportunity to use familiar materials (e.g. aluminum, titanium, stainless steel) and designs to shorten development time and reduce costs. Unique applications of 10 axis Swiss screw

machines, 5 axis grinding and laser machining technology results in features as small as 0.0013 inches (34μm).

This paper discusses the capabilities of the latest micromachining technologies and guidelines for design for manufacturability. An example of a part produced as an interface with a MEMS device will also be discussed.

Introduction

M^4 or Micro/Meso Mechanical Manufacturing and MEMS or Micro Electro-Mechanical Systems keep broadening their horizons by getting smaller and smaller. The limitations of these devices will eventually be pinned on the processes used to make them. One group of micromachining processes called M4 will be discussed, namely, focused ion beam, micro milling, micro turning, laser machining, and LIGA. The capabilities of these processes, like feature size and tolerance, will determine how they are used in a production setting. While MEMS technology is generally restricted to silicon based materials, M^4 processes are capable of using familiar materials like aluminum, titanium and stainless steel resulting in features as small as 34-microns.

MEMS vs. M4

There are some different understandings of what falls under M^4 in comparison to MEMS technology, but the understanding used here is that MEMS uses a photolithography process of chemical masking, etching, and oxidation as well as other additive processes using mainly silicon and silicon based materials. MEMS unit costs are kept low because of batch production. M^4 technology, more of an individual process, would cover all the rest, miniaturizing conventional manufacturing, other removal processes as well as other non-traditional techniques. Some of the processes are explained and the state-of-the-art technology in that area is stated not based on any particular machine manufacturer.

M^4 Processes

Focused Ion Beam

In this process, ions are accelerated and bent by electrostatic and electromagnetic fields like light bent by a glass lens. The high velocity ions are focused onto a small spot on the workpiece. The kinetic energy of the ions is then transformed into thermal energy and vaporizes the material on the workpiece. This process is usually carried out in a vacuum so the air molecules do not diffuse the ions. The focused ion beam is capable of 2 and 3 dimensional feature geometry. The minimum feature size is 200 nanometers and feature tolerance is 20 nanometers. The positional tolerance is 100 nanometers with a material removal rate of 0.5 cubic microns per second. The focused ion beam is also capable of machining any material.

Micro Milling and Micro Turning

Micro milling and micro turning are conventional manufacturing material removal processes that have been miniaturized. Tool making is somewhat of an issue here, such that they are very small. Micro milling and micro turning have the capability to produce 2 and 3 dimensional features. The smallest feature size achievable is 25 microns with a tolerance of 2 microns. Positional tolerance is 3 microns and capable of material removal rates up to 10,400 cubic microns per second. Materials that are commonly used are engineering-grade plastics, aluminum, brass, mild and stainless steel, titanium, and nickel alloys.

Swiss Turning Center and the Citizen M20

Micro Turning

The Swiss Turning Center and the Citizen M20 both have multi-axis machining capabilities to give complete accurate complex parts in one operation. The Swiss type CNC lathe gives minimized deflection and vibration by cutting close to the guide bushing. They generate parts under 500 microns in length and width, 130-micron holes with an aspect ratio of 15, and 38-micron wall thicknesses. They do all this virtually burr free at 20x and 30x. Tolerances are under 10 microns while maintaining an 8 micro finish. The Swiss machine turns parts that are 250 and 500 microns in diameter and can bore hole that are 250 microns wide with an offset bore diameter of 200 microns with a less than 50-micron wall thickness. It can also broach down to 50 microns. It does all this with an overall tolerance of ± 3 microns. Along with the multi axis capability, the Swiss machine has live tooling that provides milling and drilling operations. The materials that work well on the Swiss machine are polymers, stainless steel, brass, titanium, aluminum, platinum, and iridium.

Micro Milling

The micro milling processes at Remmele are very similar to the micro turning. Micro milling is a CNC, 5-axis process that machines parts smaller than a 25mm cube. This process has the same feature size and tolerance as the Swiss machine and also uses the same materials. The 5-axis capability is very useful for making complex or compound shapes like an airfoil or other 3D parts.

Lasers

Lasers have many applications that include cutting, drilling, welding metals and plastics, marking, hardening, sintering, coating, cladding, cleaning, rapid prototyping, bending, and forming. There are a number of laser types each with their unique capabilities.

Excimer Laser

The excimer laser is capable of feature geometry of 2 and 3 dimensions. It has a minimum feature size of 6 microns and has a submicron feature tolerance and positional tolerance. The material removal rate is 40,000 cubic microns per second. The excimer laser works on polymers and ceramics but metals to a lesser degree.

Femto-Second Laser

The femto-second laser has 2 and 3 dimensional capabilities. It has minimum feature size of 1 micron and has submicron feature tolerance and positional tolerance. This process can handle up to 13,000 cubic microns per second material removal rate. The femto-second laser is also capable of machining any material used in manufacturing.

Remmele Engineering has experience applying lasers in cutting stainless steel and titanium 130 microns thick, 1.3-mm tubing with an 80-micron wall thickness, trepan holes with 100-micron diameter, percussion drill of 50 microns in diameter. Features have been cut on a 30-micron beam with extreme accuracy and minimal burr area. It can also cut through only one side of 368-micron diameter tubing.

Micro-EDM (Sinker or Wire)

The electrode discharge machine emits an electrical spark to the workpiece in an electrolytic solution. The electrical charge then chips away some of the material and the solution washes those chips away. The Micro-EDM process has a feature geometry of 2 or 3 dimensions. It has a 25-micron minimum feature size and a 3-micron feature tolerance and positional tolerance. It has a material removal rate of 25 million cubic microns per second. And the electrode discharge machining process only works on materials that are conductive.

LIGA

LIGA is a German acronym for *lithographie galvanoformung abformung*, which means *lithography electroplating injection molding*. The LIGA process is only capable of 2 dimensional feature geometry. It has submicron feature sizes, and a feature tolerance of 0.02-0.5 microns. It has a positional tolerance of about 0.3 microns across a 3-inch length. LIGA is also capable of handling electroformable materials like copper, nickel and permalloy. LIGA can also be used to fabricate parts in polymers, pressed powders, ceramics, and rare-earth magnets with a little degradation in machining performance specifications.

Material and Feature Size Guidelines by Process Type

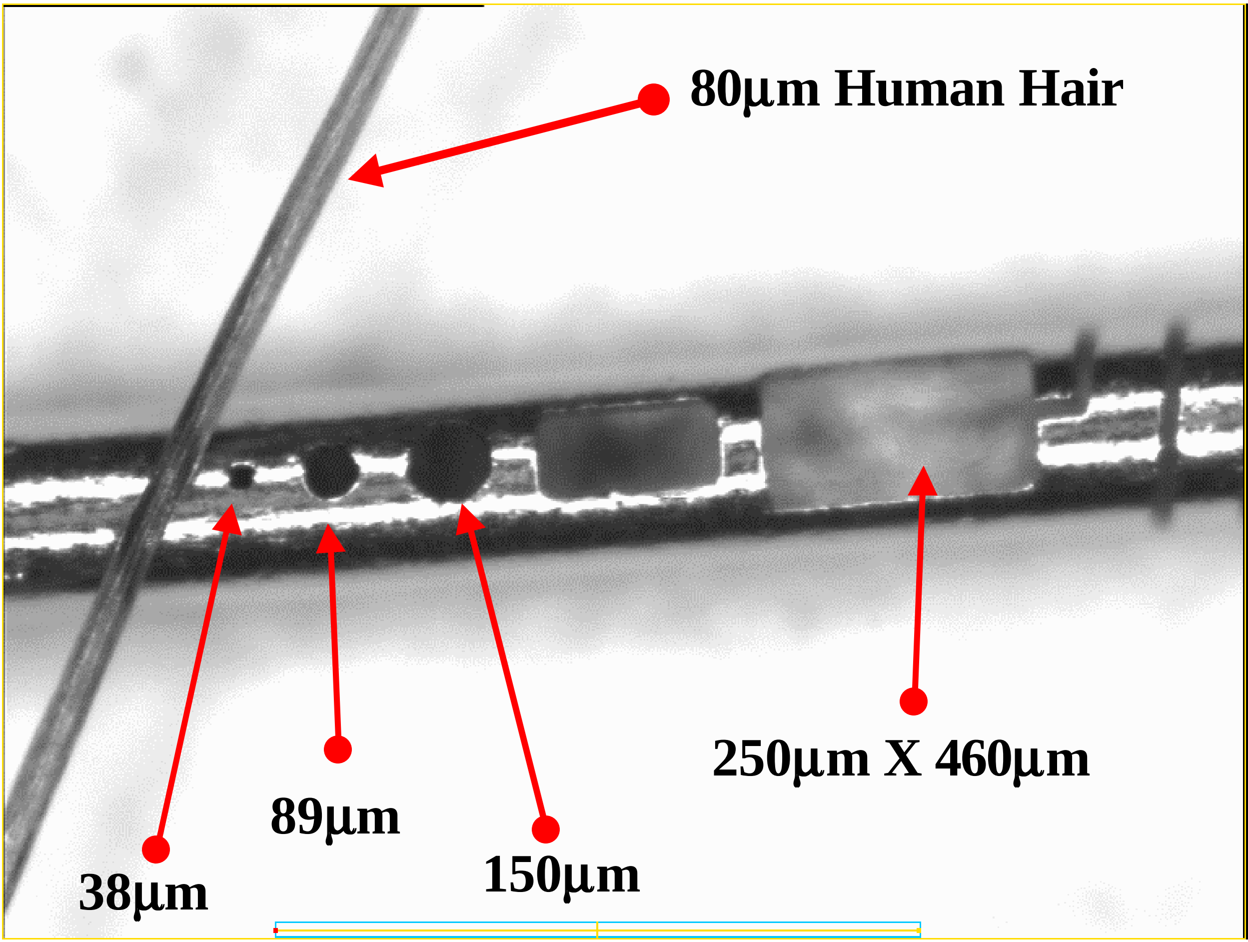
The following table* summarizes the information above:

Technology / Feature Geometry	Minimum Feature size** / Feature tolerance	Feature Positional Tolerance	Material Removal Rate	Materials
Focused Ion Beam / 2D & 3D	200 nanometers / 20 nanometers	100 nanometers	0.5 cubic microns/sec	Any
Micro Milling or Micro Turning / 2D or 3D	25 microns / 2 microns	3 microns	10,400 cubic microns/sec	Polymers, Aluminum, Brass, Nickel Stainless and Titanium
Excimer Laser / 2D or 3D	6 microns / submicron	Submicron	40,000 cubic microns/sec	Polymers, Ceramics, and some metals
Femto-Second Laser / 2D or 3D	1 micron / submicron	Submicron	13,000 cubic microns/sec	Any
Micro-EDM (Sinker or Wire) / 2D or 3D	25 microns / 3 microns	3 microns	25 million cubic microns/sec	Conductive materials
LIGA / 2D	Submicron / 0.02~0.5 microns	~0.3 microns across 3’’	N/A	Copper, Nickel, and Permalloy

*Table provided by Gilbert Benevides[1] from Sandia National Laboratories
**Feature size represents the width of a slot or a diameter of a hole

Laser Machining Example

This is an example of Remmele Engineering's application of laser machining.



Sample produced by Remmele Engineering

CAD Model Verification

One of the big challenges of micromachined parts is verifying that they meet the print requirements. Optical coordinate measuring machines with high magnification are one approach to measuring micromachined components. This has an advantage of electronically digitizing the image, which is very accurate. These systems allow the part to be measured without contact and use the magnification to distinguish the small-scale features. Laser surface analysis is also used to scan surfaces. Scanned parts are then compared to the CAD model and analyzed. This analysis can help the machining process by determining what makes the best final product. Images and data can then be e-mailed to reduce lead times in a production setting.

Conclusion

The technologies available to produce mechanical systems on a small scale are continuing to develop. The technologies discussed in this paper address the manufacture of components that can be used in mechanical systems of the same scale or used to interface with or package systems at the MEMS level. Many M^4 processes have the advantage of being familiar techniques applicable to familiar materials. A key challenge that remains beyond producing the parts is the technology to package such small-scale components.

References

1. Benevides, G., "Meso-machining Capabilities", M^4: Workshop on Micro/Meso-Mechanical Manufacturing, Evanston, IL, May 2000.