PREFERRED
RELIABILITY
PRACTICES

PRECISION DIAMOND TURNING OF AEROSPACE OPTICAL SYSTEMS

Guideline:

Meticulous control of vibration, environmental factors, and machining parameters are required to produce precision diffractive, refractive, reflective and hybrid optical components for aerospace applications.

Benefits:

Highly reliable diffractive, refractive, reflective, and hybrid aerospace optical systems can be produced by a meticulously controlled and protected diamond turning process. The result can be rugged, temperature-compensating achromatic precision optical elements suitable for a wide variety of applications.

Center to Contact for More Information:

Marshall Space Flight Center (MSFC)

Implementation:

Diamond turning is a well-established fabrication process for shaping high quality optical surfaces on metals, polymers, and crystals. Diamond turning has the capability of precision machining with a single point cutting tool to an accuracy of a fraction of a wavelength of light which makes it suitable for fabricating lenses. The surface finish quality of diamond turning is satisfactory for optical components in the mid to long wavelength regions of the infrared spectrum. Diamond machining can be beneficial for metal mirrors because of the ability to machine a reflective surface directly onto a structural substrate which may contain mounting bosses, alignment flanges, and rib reinforcements.

The precision to which components can be machined is partially dependant upon the extent to which the dynamic motion of the machine tool can be controlled with the work piece. The detrimental dynamics of the diamond turning machine can be minimized by stiffening the machine, or mounting it on a vibration isolating mount. Vibration can be reduced by mounting the machine on a block of granite, or in-ground concrete blocks surrounded with vibration isolation material. Other necessary features and components of a diamond turning lathe include stiffness, balanced air bearing spindles, straight square ways and closed loop controllers using laser interferometric feedback. Changes in humidity and partial pressure of atmospheric gases affect accuracy and should be avoided. Thermal considerations are also important. Lack of temperature control is the greatest cause of error in this machining process. Therefore,

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the environment housing the diamond turning lathe should be maintained to ± 0.01°F. To minimize errors caused by temperature changes, the work piece, machine and its components should be at thermal equilibrium before material removal begins.

In diamond turning the surface finish is determined by the radius of the cutting tool, cutting feed rate, depth of cut, rake angle, tool wear, coolant supply consistency, stiffness of the machine and the material being machined.

Materials compatible with diamond turning include: copper, gold, silver, aluminum, platinum, electrolyzed nickel, beryllium, copper, germanium, silicon, plastic, and lithium niobate. Metals that contain carbon are not considered machinable because of the chemical reaction that occurs between the carbon and diamond tool due to the high temperatures of machining.

Diamond turning is insensitive to cutting speed. For example, when facing a circular disk a cutting speed of 4572 meters/minute at the outer edge decreases to zero at the center of the disk, while maintaining a specular finish. Progressively finer cuts are usually taken to reduce damage from previous cuts. Finish depths of 127 to 510 nanometers are not uncommon. The feed rate can be as large as the tool size and shape will permit, but is normally below 0.25 millimeters per revolution.

Rigid machine tools are an essential part of diamond turning. Vibration or sudden impact shortens the life of the diamond tool. Sufficient spindle power is required for high cutting speeds, which reduces the pressure on the cutting edge. The use of cutting fluids reduces wear and aids in chip removal. The most common cutting fluids are kerosene and lightweight machine oil. For protection against inadvertent damage during handling or setup, the cutting edge of the diamond tools should be covered with plastic or rubber caps when not in use.

Design features that distinguish diamond turning lathes from standard machine tools are:

1. Machine base stiffness and stability,
2. Spindle accuracy and repeatability,
3. Slide accuracy and repeatability,
4. Servo performance,
5. Vibration control,
6. Temperature control,
7. Positioning accuracy, and
8. Tool support and setup.

External vibrations, even the sound waves of speech, can affect the surface finish of a diamond turned workpiece. Three point pneumatic damping systems isolate vibrations and shocks from the machine and provide automatic leveling to accommodate changes in the slide position and the workpiece weight. Some machines are built on a solid granite base, other machines use a solid cast metal base. New designs

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should be run through a computer simulation and finite element analysis to determine the machine stiffness and natural frequencies.

Hydrostatic supported spindles are required for accuracy and repeatability from revolution to revolution. Air bearings are used to lower heat generation and to avoid vibration from the hydraulic supply pump. Both systems can provide rotational accuracies below 10 micro-inches.

All motors and drive mechanisms must be dynamically balanced and isolated to eliminate vibration between the tool and the workpiece. The machine slides should give smooth repeatable motion between tool and spindle for control to one micro-inch or less.

Technical Rationale:

Precision diamond turning and other advanced production techniques are gradually replacing conventional lens grinding and polishing procedures because these methods can produce accurate optics more rapidly than traditional methods and because they can produce optical elements such as diffractive and hybrid systems that are not producible by previous methods. The newer optical elements have improved weight-efficiency, reliability, ruggedness and superior precision if machined in a carefully controlled environment.

Impact of Nonpractice:

Failure to properly anchor or isolate optical diamond turning equipment or to protect it from the environment could result in an inferior product and cause unreliable manufacture of precision optics. The results would be costly due to rework, and cause schedule delays.

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