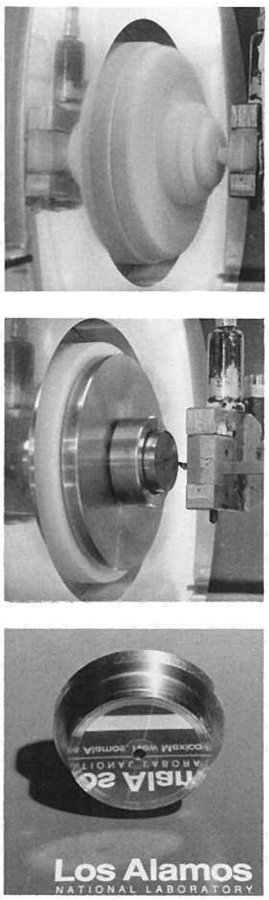
Cryogenic Diamond Turning

Inventors: Ralph L. Lundin and Delbert D. Stewart, Mechanical and Electronics Support Division; and Christopher J. Evans*



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The Cryogenic Diamond Turning machine cuts a stainless steel workpiece buried in a blanket of frost (top). The workpiece has been machined and the frost has melted (middle). The reflection of the Los Alamos logo on a diamond turned steel part demonstrates the quality of the cryogenic diamond turned surface (bottom).

Diamond turning is a method of cutting metal by using a lathe to turn the workpiece and a gem-quality diamond, honed to a precise shape and smoothness, as a cutting tool. One of the primary uses for the technique is the fabrication of mirror-quality optics, especially metal mirrors such as those for focusing lasers. Unfortunately, some of the most useful metals, for example, steel, are not suitable for diamond turning. Steel rapidly erodes the cutting tool; on a disk about 4 centimeters in diameter, the tool will wear out within 1 millimeter of the outside surface where the tooling is started. Los Alamos researchers, in collaboration with the National Institute of Standards and Technology, have developed a method called Cryogenic Diamond Turning that will allow the cutting of steel and other metals that could not previously be diamond cut.

Our technology won a 1992 R&D 100 Award; the awards are given annually by *Research and Development Magazine* for the one hundred most significant technical innovations of the year.

The Invention—Characteristics and Advantages

We hypothesized that the diamond wears out because the iron in steel has a chemical affinity for the carbon in diamond. When the iron and carbon combine, the sharp edge of the cutting tool is destroyed. We found that we can reduce the chemical reaction rate and thus the wear on the tool by chilling the workpiece and the cutting tool to cryogenic, or very low, temperatures. An apparatus attached to a modified diamond turning machine supplies liquid nitrogen to the inside of the fixture that holds the workpiece and to the diamond cutting tool. The nitrogen cools both parts to approximately 150 kelvins, or –123 degrees Celsius, before the cutting begins. We have successfully produced mirror-quality parts in hardened (440V) stainless steel, and we have tested the technique on iron and tantalum.

Our technology provides significant improvements over existing products. Cryogenic Diamond Turning is the best known method for producing aspheric (varying only slightly from spherical) surfaces of steel that are of optical quality. Existing diamond turning machines can produce spheres, aspheres, and almost any shaped surface of revolution (a symmetrical surface that revolves about an axis like clay on a potter's wheel), but they cannot achieve the desired surface finish on steel. Traditional optical grinding and polishing techniques can produce spheres, but they cannot easily produce aspheres. If an optical application requires a steel asphere, the piece is typically precision-machined and then polished to achieve the desired finish. The process is lengthy, and the finish is acquired at the expense of the precision.

Applications

Using Cryogenic Diamond Turning, manufacturers can fabricate many new products such as steel molds for casting aspheric, optical glass lenses. Using glass lenses in products normally manufactured with plastic lenses, such as optical disk drives, compact disk players, cameras, camcorders, and binoculars, will result in higher performance. For example, if glass lenses were used in optical disk drives, information could be stored on CD-ROMs at a much higher density.

Our process is not limited to optical products. A diamond turned surface might have less subsurface damage, such as microcracking, than would a ground surface. Less subsurface damage in ball-bearing races—the rings that hold ball bearings in an assembly—would give the races a longer service life. Less subsurface damage would mean that smaller, lighter assemblies could last as long as today's assemblies. Smaller components translate to reductions in size and weight and more efficient operation of large pieces of equipment. An improved ball-bearing assembly would have enormous potential for product improvement.

Another nonoptical application could be the superprecision machining of steel parts. As dimensional tolerances shrink according to demanding specifications, more and more of the tolerance is used up in surface roughness. However, a diamond turned surface usually has a peak-to-valley surface roughness of less than 0.025 micrometer. Thus, even if a mirror surface is not needed for other reasons, the

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surface smoothness that this technology can produce presents new capabilities for achieving minute accuracies.

We foresee the machining of read heads for computer hard disk drives to gain larger capacity. For this application, our technology would be configured so that the tool rather than the workpiece rotates. The cutting method, known as flycutting, can be used to machine flat surfaces and other shapes that are not surfaces of revolution.

The limits of precision for the diamond turning of steels are still to be established. Further testing is needed to determine which other metals are suited to the Cryogenic Diamond Turning method.

Ralph L. Lundin, a staff member in the Mechanical and Electronics Support Division, came to the Laboratory in 1984 with a B.S. degree in mechanical engineering from Pennsylvania State University (1972) and ten years of experience in manufacturing and mechanical engineering. His research interests include manufacturing development, machining development, and precision engineering. He is currently building a machine that relies on an ultrasonic process to machine advanced ceramics for high-performance applications. His work in cryogenic diamond turning is a spin-off from six previous years of work with diamond turning at the Laboratory and from an interest in developing enabling technologies, specifically the applications of diamond turning.

Delbert D. Stewart, a technician in the Mechanical and Electronic Support Division, is a 1963 graduate of the apprentice program at Sandia National Laboratories, Albuquerque. He came to Los Alamos in 1969 to work with mechanical electronic fabrication, and he has since been involved in numerous and varied projects. As a member of the lidar (light detection and ranging) team, he received a Los Alamos distinguished performance award in 1991. An expert in spherical lapping, he has helped scientists in the United Kingdom with work in that area.


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Two of the inventors of the Cryogenic Diamond Turning method are Delbert D. Stewart (left) and Ralph L. Lundin.

Christopher J. Evans is a research engineer at the National Institute of Standards and Technology. His interest in diamond-turning metals and tool wear brought him to the Laboratory, where his scholarly investigations sparked development of the technology for Cryogenic Diamond Turning. He collaborated on the work in the summer of 1989 and intermittently thereafter. In England, Evans earned his B.Sc. degree in chemical engineering from the University of Manchester Institute of Science and Technology in 1975 and his M.Sc. degree from the Cranfield Institute of Technology in 1987.

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