Three Meter Diamond Turning Machine Enabling Technology for X-Ray Astronomy

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Three Meter Diamond Turning Machine Enabling Technology for X-Ray Astronomy

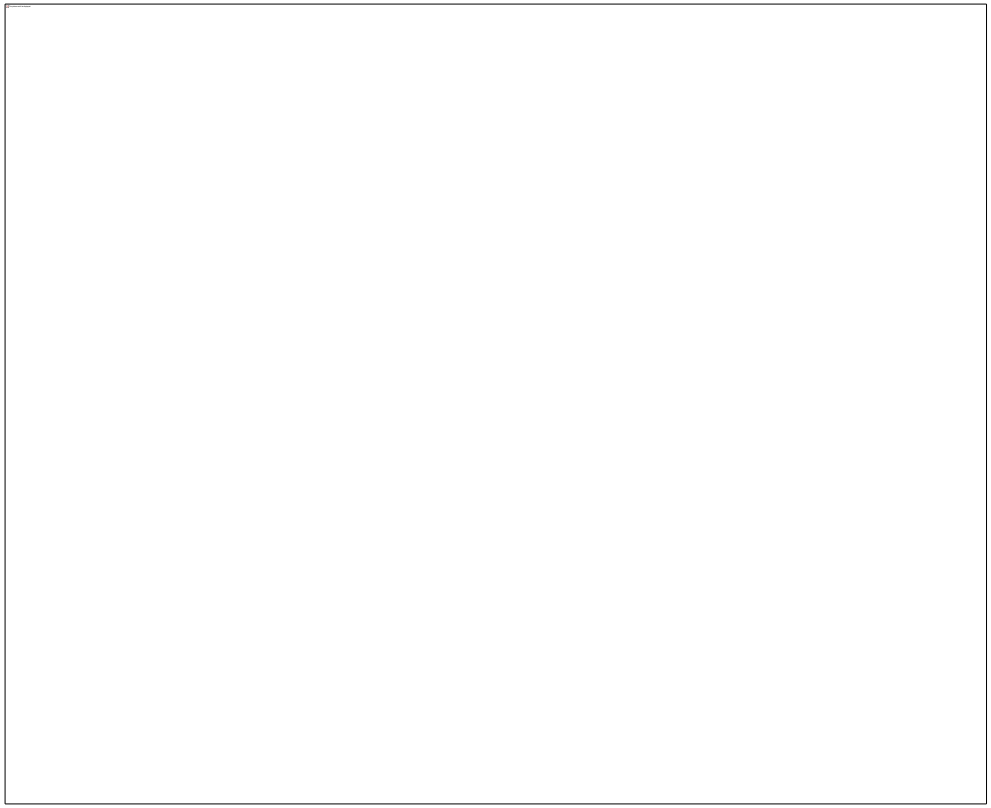
OUTLINE

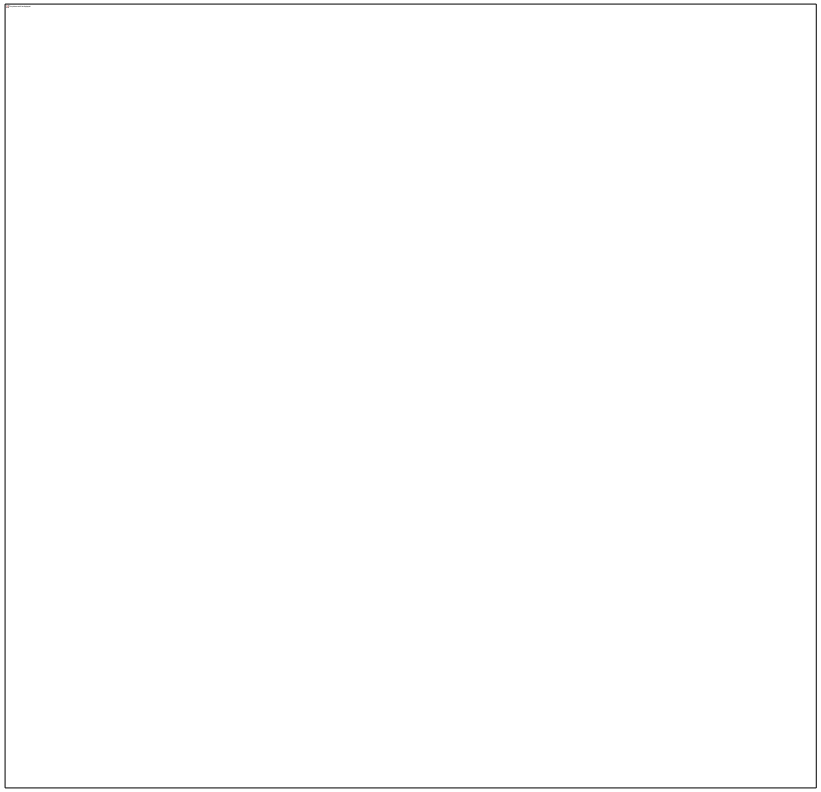
- INTRODUCTION
- ULTRA-PRECISION MACHINING OF X-RAY MIRRORS AND MANDRELS
- LARGE DIAMOND TURNING MACHINE DESIGN
- EXPERIENCE AND TECHNICAL COLLABORATION
- SUMMARY
- CURRENT STATUS

Introduction

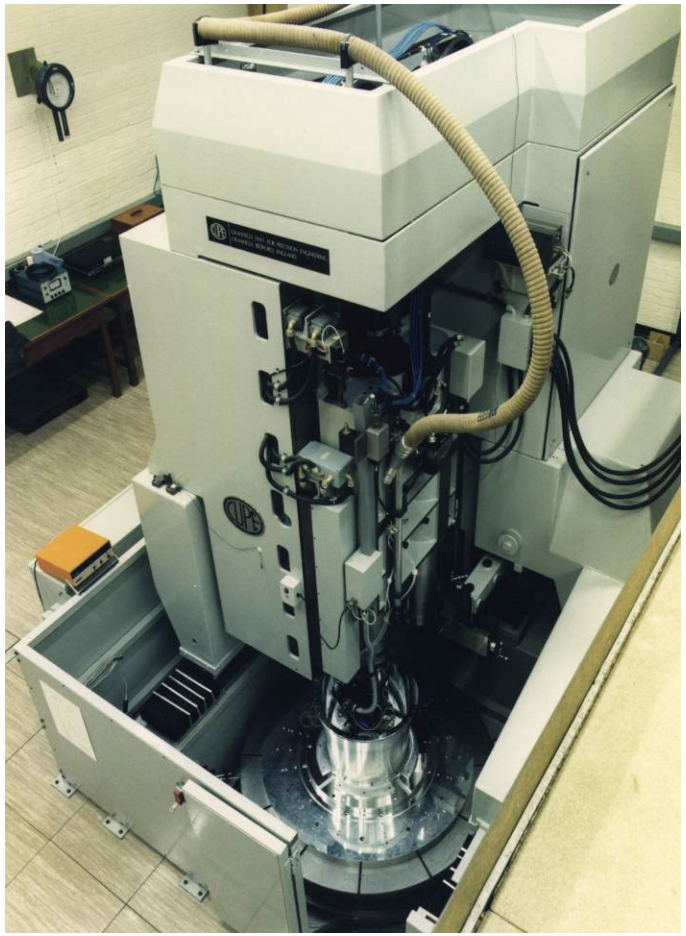
- DT is a proven method of manufacturing aspheric off-axis mirrors to visible quality.
- Vertical turning machines are used for very large and heavy parts.
- The need for very large diamond turning has been recognized for at least 30 years.
- Attempts to meet the need have all failed because no suitable spindle was available.
- Oil hydrostatic spindles large enough to carry the load cannot run fast enough because of viscous frictional heat generated as the 4th power of the bearing radius.
- Air bearings can run at sufficiently high speed to be practical because the viscosity of air is three orders of magnitude less than the lightest liquid lubricant.
- Classical metal to metal air bearings do not work for very large capacity because of prohibitive cost and catastrophic failure modes.
- Porous graphite air bearings are proven to be sufficiently rugged and reliable.
- Development of a giant capacity air bearing spindle is enabling technology for a giant diamond turning machine suitable for manufacture of giant aspheric optics.

Diamond Turned Off-Axis Aspheric Mirrors

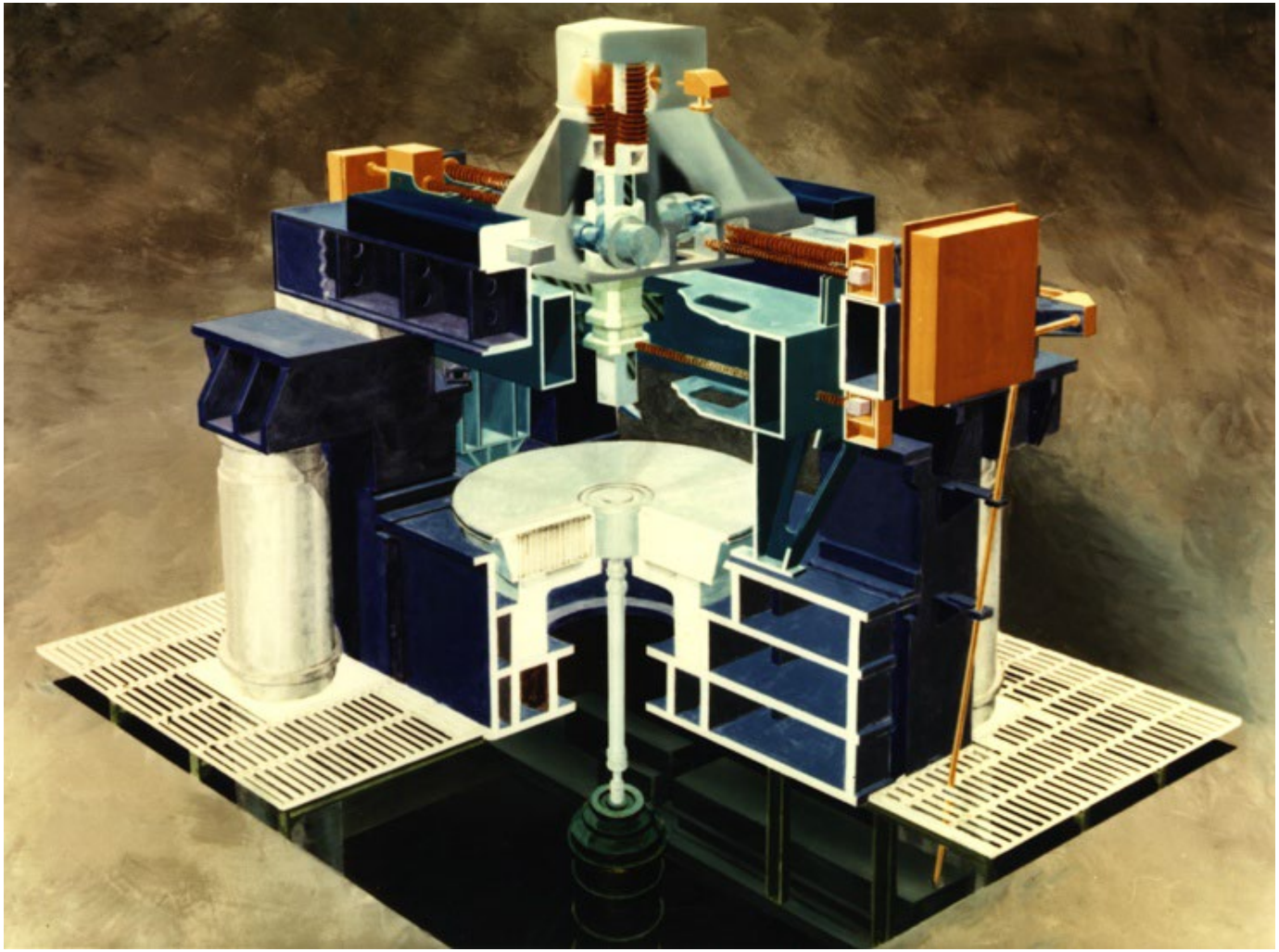




Cranfield Precision (CUPE) – LDTM 1982



LLNL 1983 – Large Optics Diamond Turning Machine



Comparison of Oil Hydrostatic and Air Hydrostatic Bearings

Oil hydrostatic bearings tolerances are 25-75 microns (0.001-0.003")

Oil hydrostatic bearings and air hydrostatic bearings both have flow induced instability issues "water hammer" which must be carefully controlled.

Oil viscosity provides important squeeze film damping which aids control of flow induced instability. Air bearings are very much more sensitive to water hammer effects.

Viscous shear frictional heating limits large oil hydrostatic spindles to less than 100 rpm. This slow speed is unacceptable for diamond turning because the finish requirements of optics require a very small tool advance per revolution.

Dimensional accuracy requirements demand extreme thermal stability and this requirement increases with part size. The large heat generation of oil hydrostatic spindles at even unacceptably low spindle speeds is a severe problem.

Air bearing tolerances are extremely small because of the requirement that the air film must be no greater than about 6 microns (0.0003") to provide the required very high bearing stiffness for diamond turning. Flatness, roundness, squareness < 0.5 μm (0.00002").

Spindle Requirements for Giant Optics Diamond Turning

Fixture weight is usually orders of magnitude heavier than the optic it is designed to hold in a strain-free condition. The diamond turning machine is aimed at producing 3 meter diameter components. This requirement results in the following spindle specification goal.

Working load capacity: > 89,000 N (20,000 lbf.)

Rotational speed: > 1000 rpm

Max. spindle motion error, radial, axial, tilt: < 125nm (5μ inch)

DOS 2.48 Meter Aluminum Mirror

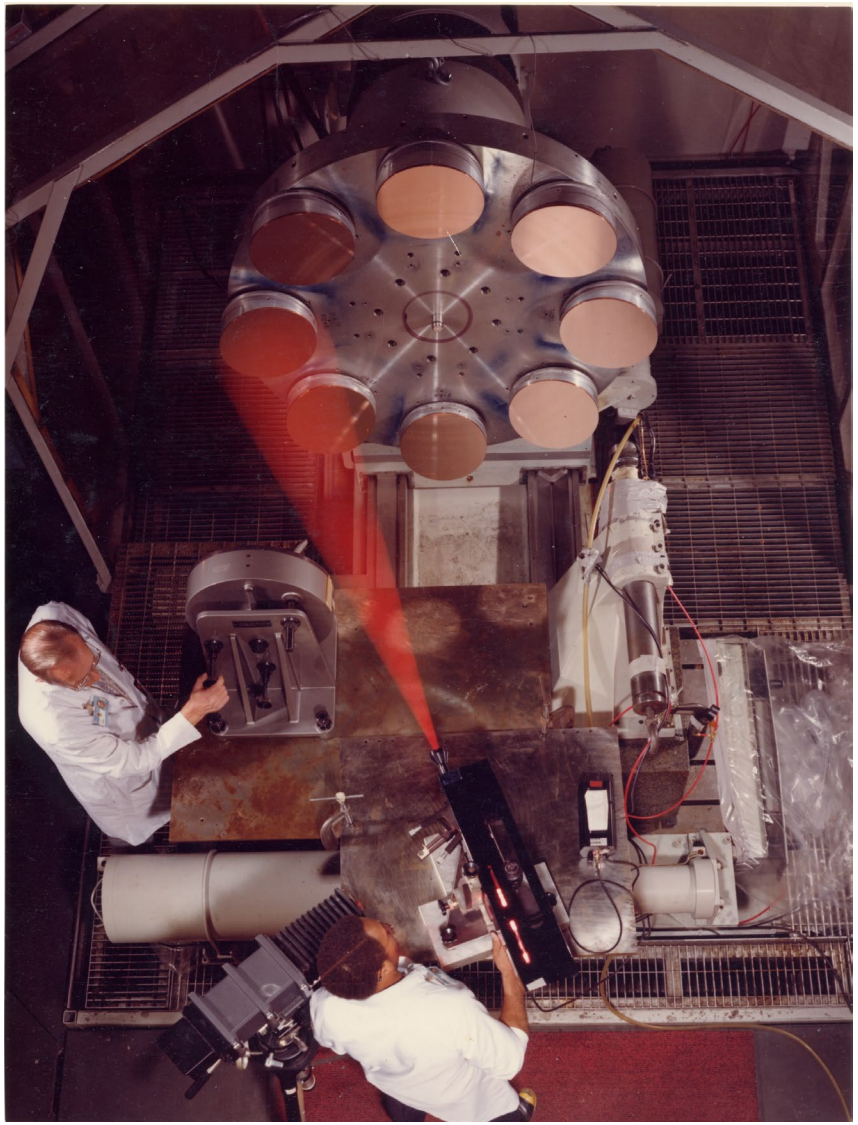
Weight: 3000 lb. Fixture Weight: 3000 lb. Spindle table weight: 3000 lb.

Porous Graphite Air Bearing Technology

Based on my experience with diamond turning and with the manufacture of porous graphite air bearings at the DOE Oak Ridge Y-12 Plant, DOS received a NASA Phase I SBIR contract to design a large porous graphite air bearing spindle in 2010.

Porous graphite air bearings for ultra-precision turning where developed starting in the early 1960's at the Y-12 Plant for use in manufacture of nuclear weapons components. The SBIR spindle development for large diamond turning machines utilizes the extensive experience the Oak Ridge Y-12 Plant in building porous graphite air bearings.

Y-12 Graphite Air Bearing 2.4 Meter Diamond Turning Machine

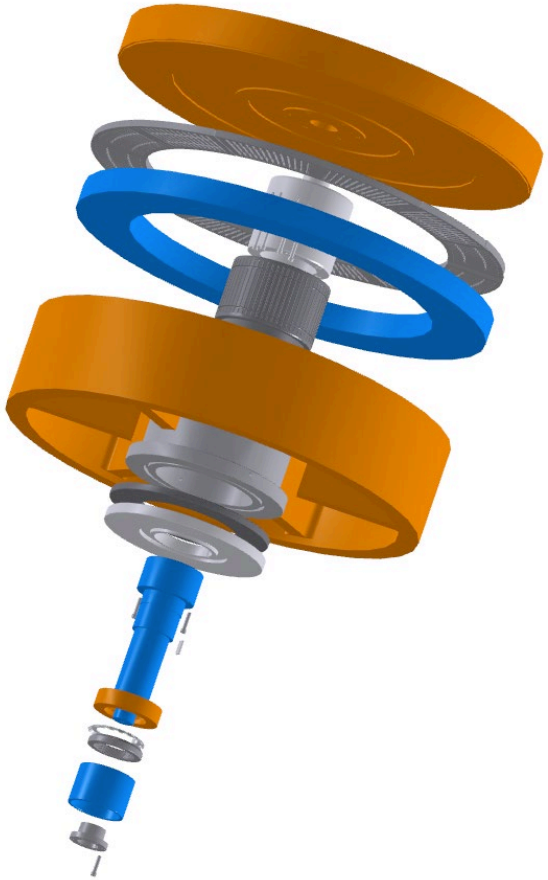


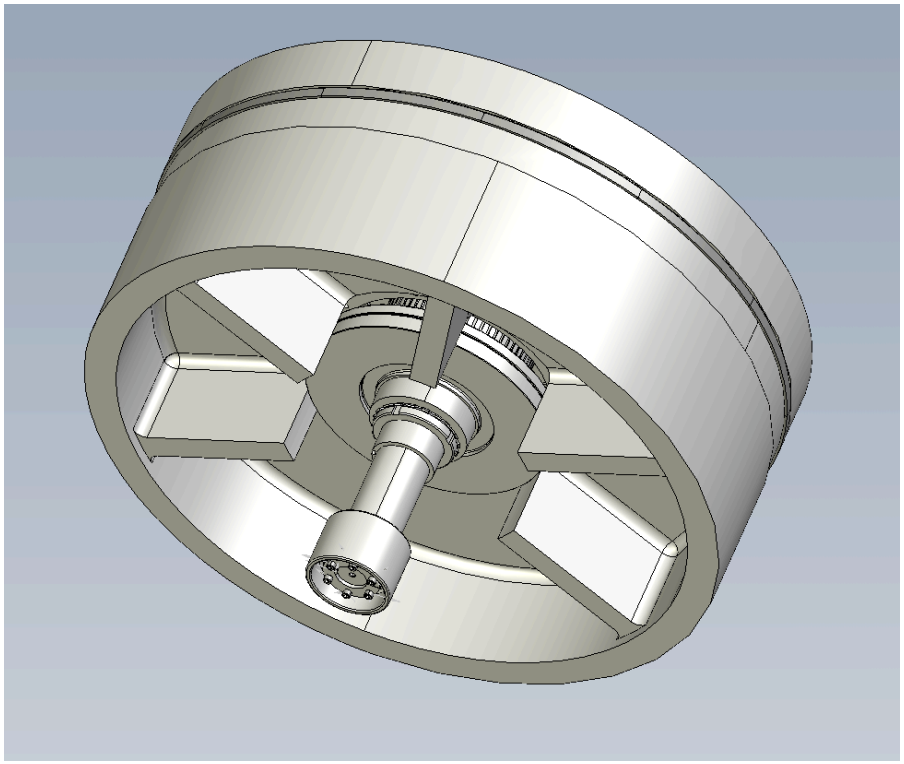
Prototype Air Bearing Spindle

A prototype air bearing spindle developed with NASA Phase I SBIR funding was used to develop manufacturing Methods for the larger capacity air bearing required by the large diamond turning machine.

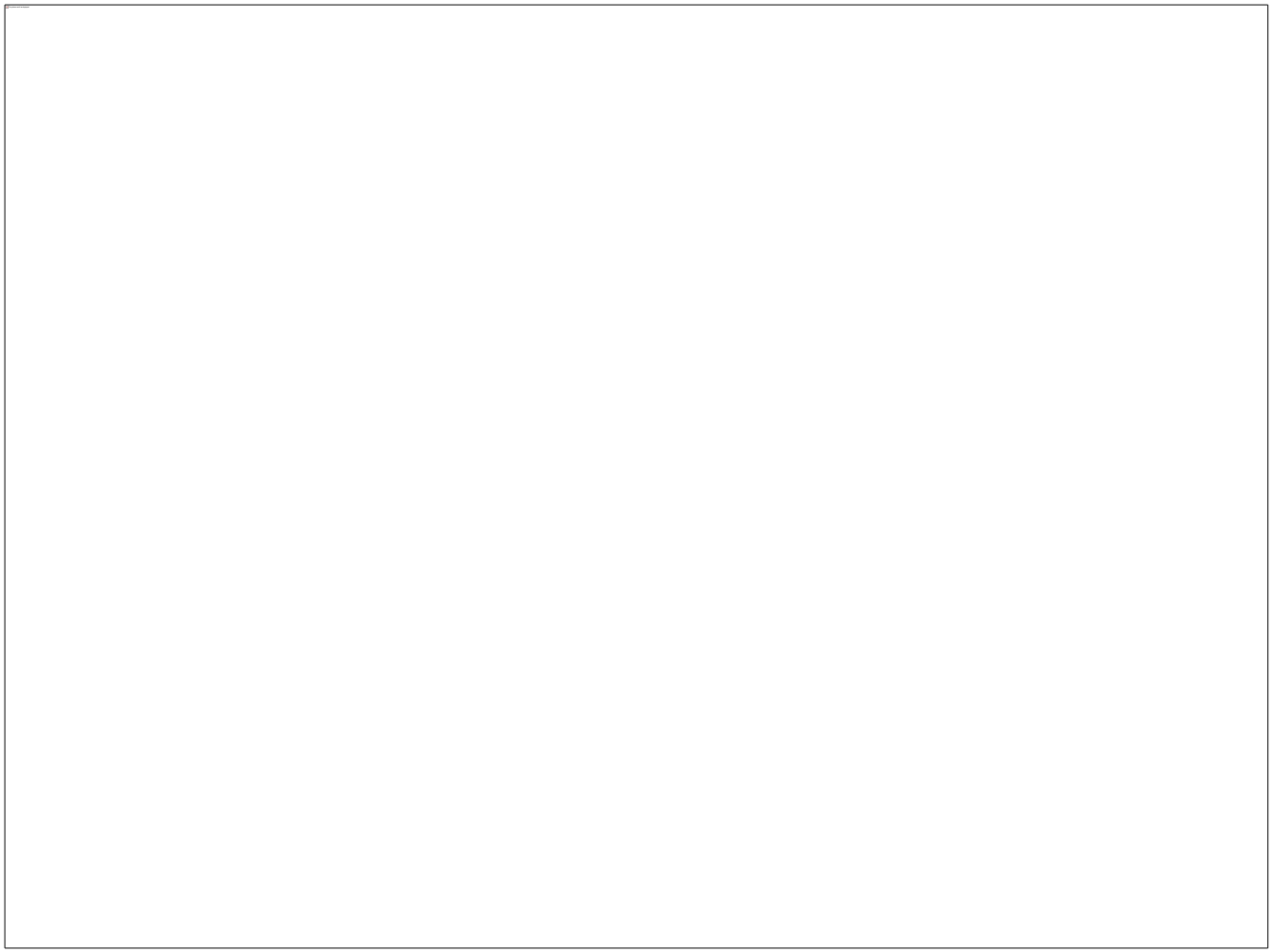
PROTOTYPE AIR BEARING SPINDLE DESIGN

All components of the prototype spindle are complete.
Expected load capacity of the prototype spindle: 16,000 lb. max; 8000 working cap.

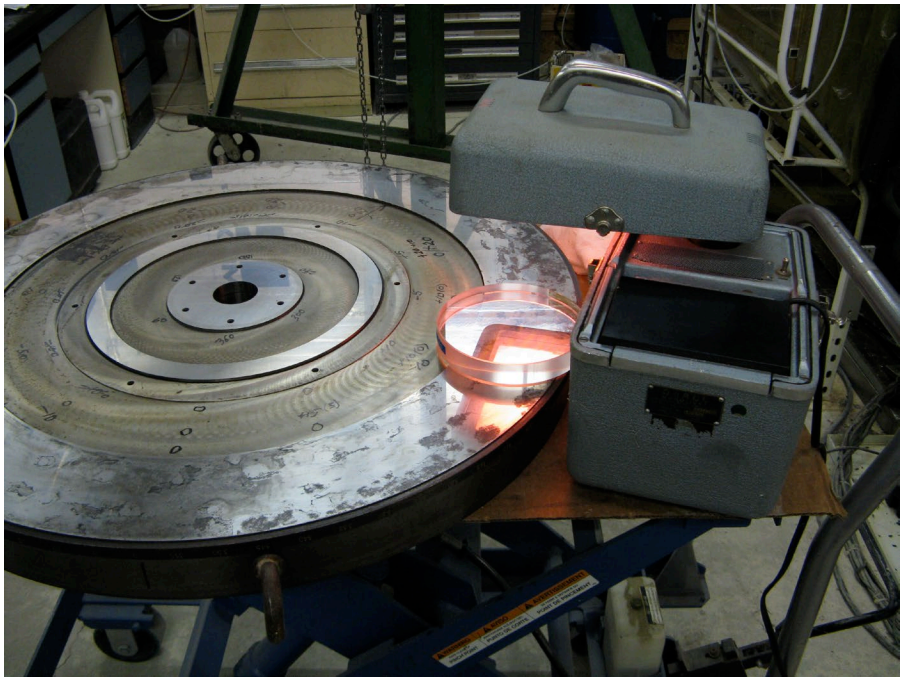


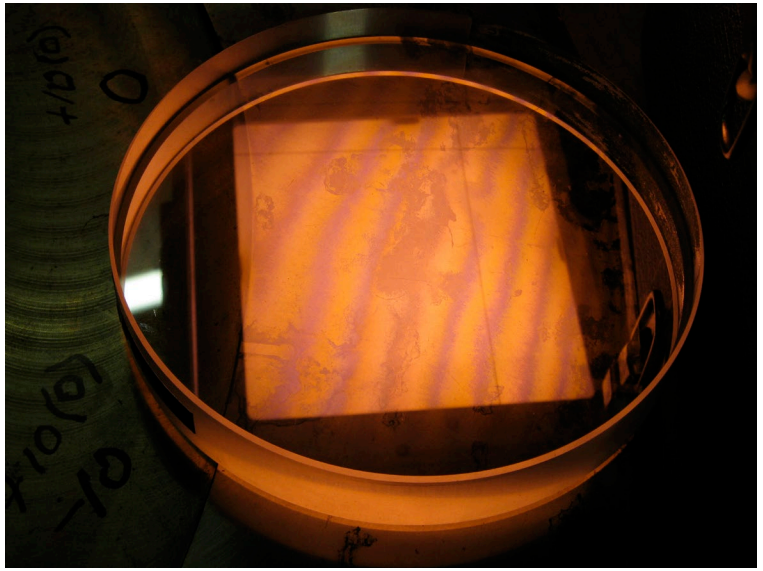


Housing of Prototype Porous Graphite Air Bearing



FLATNESS TESTING BEARING FACE OF 30” DIA. AIR BEARING ROTARY TABLE

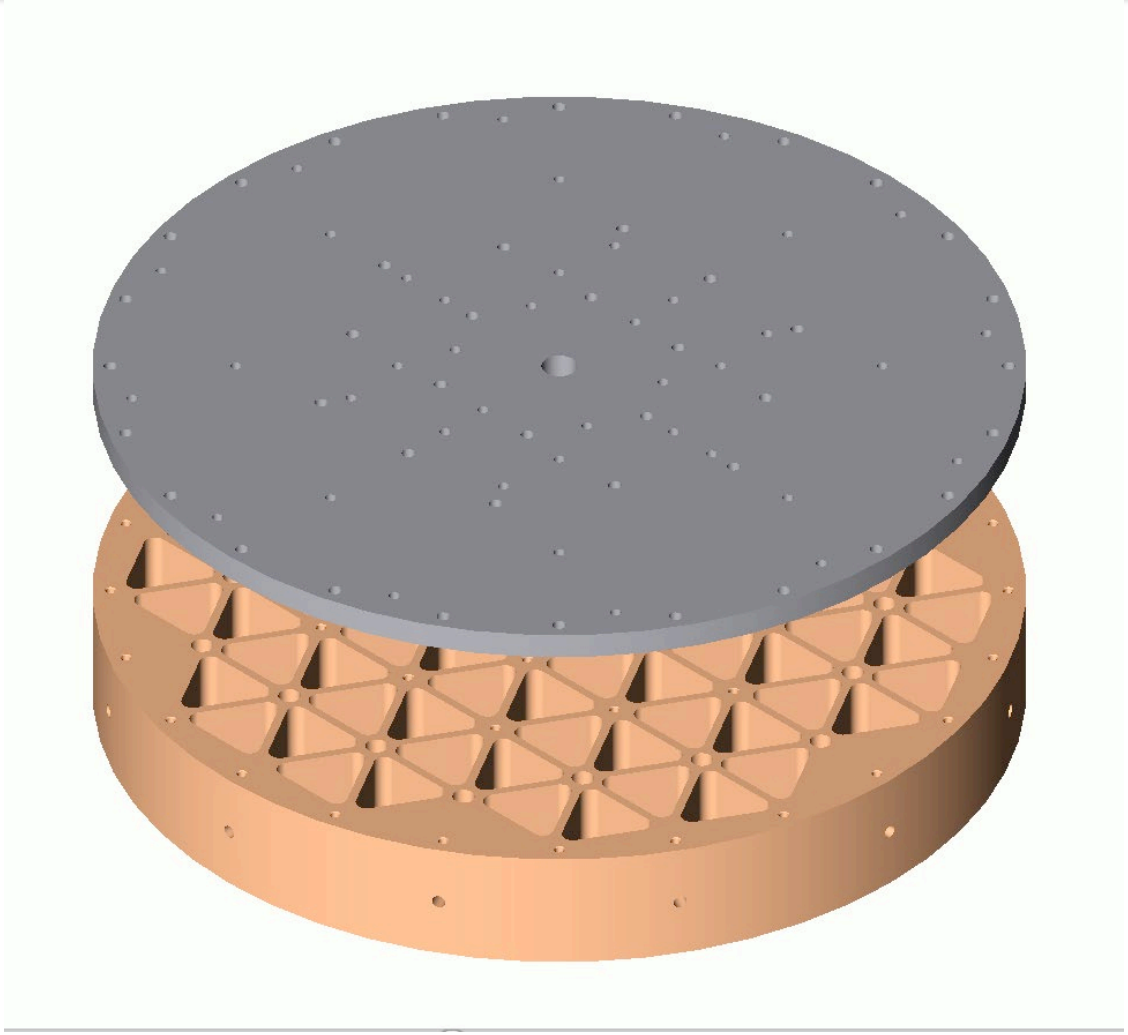




Steel Components of Porous Graphite Air Bearing Spindle

Porous Graphite Air Bearings For Flow and Stability Testing

Design of 98KN (20,000 lb.) Capacity Air Bearing Spindle



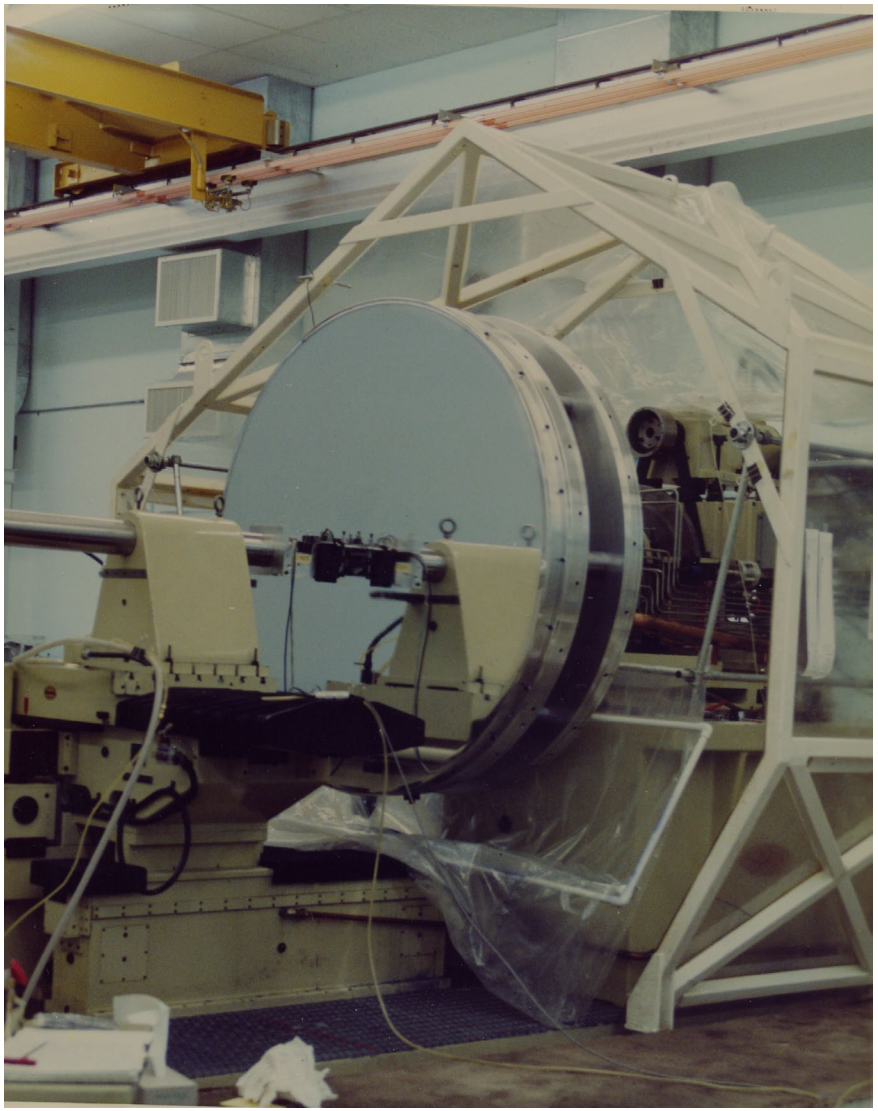
CRITICAL REQUIREMENTS FOR SUCCESSFUL DIAMOND TURNING IN ORDER OF IMPORTANCE

1. EXTREMELY SMOOTH AND ACCURATE **SPINDLE**.
2. EXTREMELY CONSTANT **ENVIRONMENT**.
3. VERY ACCURATE HIGH RESOLUTION MACHINE CONTROL.
4. VERY ACCURATE AND REPEATABLE MACHINE MOTION.

MOORE TOOL CO. IS ONE OF THE FEW MACHINE TOOL BUILDERS IN THE WORLD THAT HAS THE CAPABILITY AND EXPERIENCE TO BUILD VERY LARGE DIAMOND TURNING AND GRINDING MACHINES.

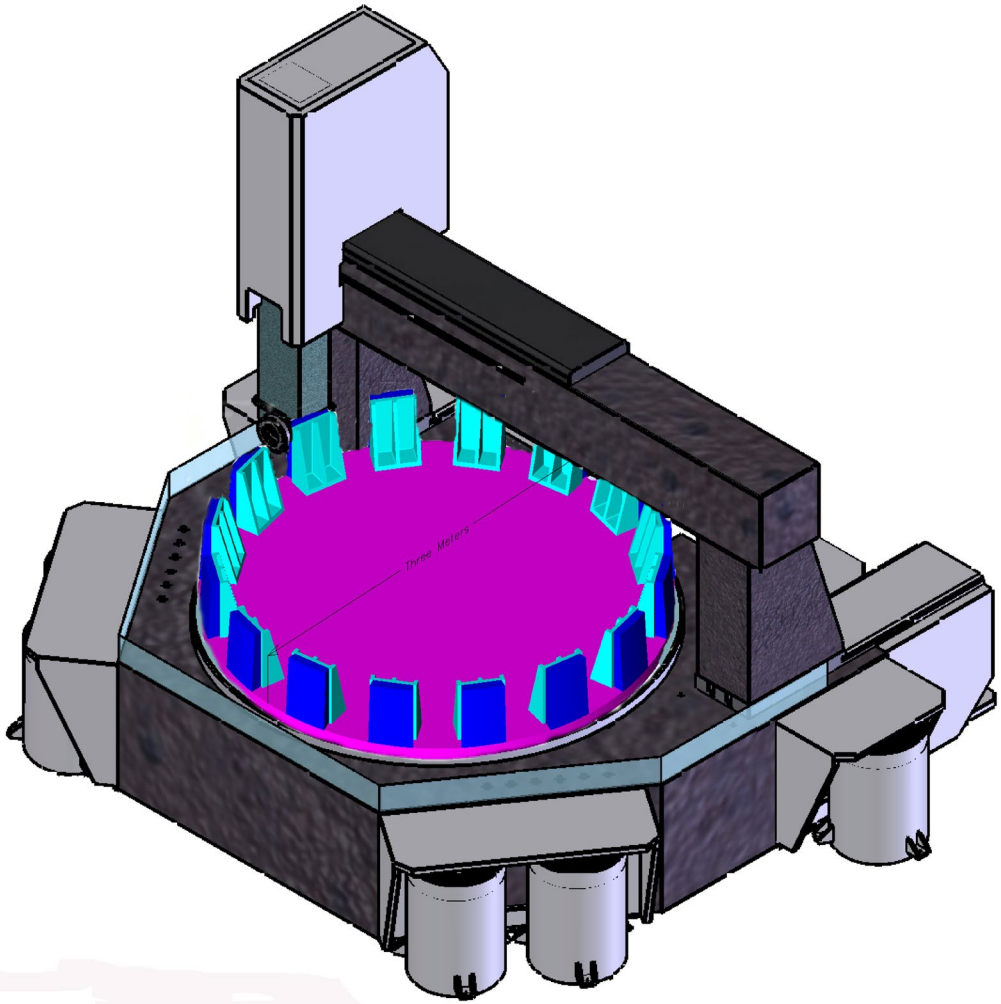
DOS HAS WORKED WITH MOORE TOOL CO. FOR MANY YEARS IN BUILDING LARGE DIAMOND TURNING MACHINES AND HAS PROVEN EXPERTISE IN BUILDING THE CRITICAL SPECIAL SUPPORTING FACILITIES REQUIRED FOR SUCCESSFUL ULTRA-PRECISION MANUFACTURING.

Moore M-40 Diamond Turning Machine at OEC



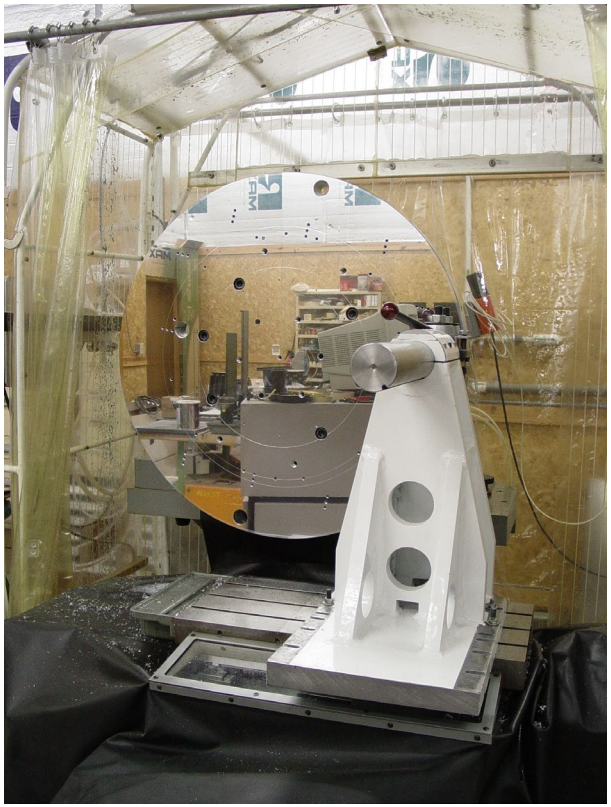
Moore Nanotechnology World Class Ultra-Precision Tool Builder

DOS/MOORE 3 METER DIAMOND TURNING MACHINE



DIAMOND TURNING X-RAY MIRROR SLUMPING MANDREL

Dallas Optical Systems Experience in Large Optics Fabrication



Two axis diamond turning machines 0.9 meter capacity and 2.5 meter aluminum spherical mirror on one of the two DOS large capacity polishing machines.

SUMMARY

Diamond turning can directly produce visible quality highly aspherical surfaces with machined reference surfaces to allow easy alignment of multiple complex optical contours.

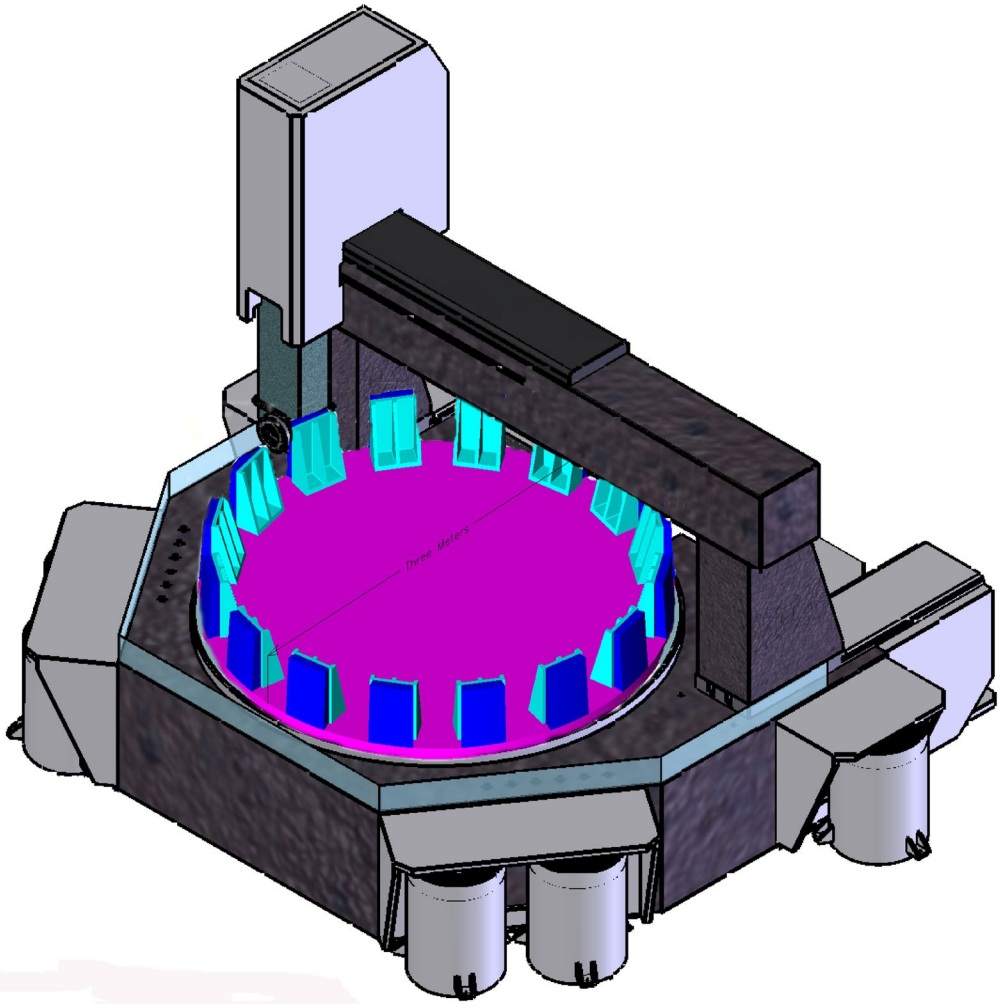
Diamond turning enables high rate production of large highly aspheric mirrors at a cost an order of magnitude less than conventional optical fabrication methods.

- **A very large load capacity porous graphite air bearing is the critical enabling feature of a practical very large optics diamond turning machine.**

- **A high speed porous graphite air bearing is the technical path to the required 10 ton load capacity super precision air bearing.**

- **A diamond turning machine capable of diamond turning and/or contour grinding 3 meter optical components will drastically reduce large optical systems cost.**

DOS/MOORE 3 METER DIAMOND TURNING MACHINE



Thermal expansion super alloys and Schott D263 and A45

CURRENT STATUS

- NASA PHASE I SBIR TO STUDY DIAMOND TURNING SUPERALLOY X-RAY MIRROR SLUMPING MANDRELS
- CONTINUING IR&D WORK ON PROTOTYPE AIR BEARING BEGUN WITH NASA PHASE I SBIR
- COLLABORATION WITH MOORE NANOTECHNOLOGY ON DIAMOND TURNING MACHINE DESIGN
- BUSINESS DISCUSSIONS WITH L-3 COMMUNICATIONS