Development of Automated Machining of Precision Inertial Instrument Components

Extended Abstract

by

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Overview

High performance inertial instruments require ultra high precision in their manufacturing processes in order to achieve their desired performance. While these precision processes are possible, they usually rely on the skill of one or two operators and are expensive to maintain. With the decline in the support base for precision inertial instruments, due to contractions and mergers, maintaining these skills is continuous challenge to both the government and contractors. One solution is the use of state of the art machining systems developed for the optics industry for use on precision inertial instrument components. While these machines have been used traditionally for manufacturing of visual and infrared optics, their micro-inch resolution and repeatability make them ideal for high performance inertial instrument component manufacturing. This paper describes the work being carried out by Draper Laboratory to determine the suitability of utilizing these machines for machining and finishing precision gas bearing wheels assemblies. Examples of wheel machining experiments will be described as well as the results obtained from a number of different systems on two different gas bearing wheel designs.

Introduction

Draper Laboratory has a program for the investigation into the worth of developing an automated finishing system for precision gas bearing wheel components. This paper documents the work to date on the finish machining experiments being carried out both in-house and by suppliers of precision machining equipment. The work in-house is being carried out on a Precitech Nanoform 200, which we have in our machine shop. This is a diamond turning machine that was purchased to be used as a precision grinding machining. Draper Laboratory also has provided support to two machine suppliers, which produce precision machining and finishing machines. They are Precitech of Keene, New Hampshire and OptiPro from Ontario, New York. A third machine tool supplier, Moore Machine Tools of Keene, New Hampshire, declined to support our effort. This paper documents the results obtained from the three systems used to obtain a finish on wheel parts without the use of manual (hand lapping) labor.

Wheel Parts

Two gas bearing wheel designs are the focus of this investigation. The first wheel design is a spool wheel, which has a pyroceram rotor, and an aluminum oxide bearing material, which requires finishing operations. Figure 1 shows this wheel design. The second wheel design, called a hemispherical wheel, has a concave and convex aluminum oxide coated bearing surface, which requires finishing operations. Figure 2 shows this wheel design. Both require the surface to be better than 1 micro inch surface finish and a form tolerance of less than 10 micro inches after the finishing
operations are completed. These specifications can presently be met, but only after a lengthy and expensive series of manual operations.

**Experimental Results**

Precitech was provided with some spool rotors to experiment on as well as some aluminum oxide coated hemispherical parts. The spool rotors were measured to have in excess of a 40 micro inch finish prior to any work being performed on them by Precitech. Precitech only worked on the face of two spool rotors in order to get a feel for the tolerances and precision that the wheel parts are required to attain. With spindle speeds of 30,000 rpm, a part speed of 359 rpm, and two grit size wheels were used. The 1,200 grit wheels produced a finish of 7 nano meters (.28 micro inches) while the 3,000 grit wheels produced a finish of 5.5 nano meters (.22 micro inches). After these two rotors were worked on, the effort was redirected to working on the hemispherical parts. No results have been obtained from Precitech at this time on these parts.

The work OptiPro carried out was on hemispherical parts, both rotors and bearings and someroughed up spool rotors. The initial male bearing parts had a plasma spray coating, which was not as consistent as the rotor coatings. The ground bearing surfaces had a finish that ranged from 10 micro inches to 7.5 micro inches. When the male bearing parts were polished on OptiPro’s polishing machine, the finish went down to 2.5 micro inches. The dummy hemispherical rotors parts were ground to a surface finish of 8 to 9 micro inches with a polished surface finish of 1.5 to 3.5 micro inches.

Draper Laboratory followed the path that we gave to Precitech, which was to machine the spool wheel parts first to get a feel for the machine and then precede on to the hemispherical parts. Using a 1200 grit wheel, we were able to attain a surface finish of .4 micro inches on the pyroceram rotors, which duplicated the results of Precitech. Draper Laboratory next worked on aluminum oxide coated thrust plates to see what could be learned when machining this material. Using grinding wheels with grit up to 2200, the best surface finish, which we attain, was 4.5 micro inches. The geometry of the male hemispherical bearing, Figure 3, allowed for only a grinding wheel grit size of 600 to be used. With this wheel, Draper Laboratory was able to get surface finishes of 7.5 to 9 micro inches.

**Discussion**

The purpose of the paper was to show a path for success for precision finishing of gas bearing wheel parts without manual labor involved. Figure 4 shows the plot of surface finish of the aluminum oxide coated surfaces versus diamond grit size. The plot shows, as the diamond grit size gets smaller, a higher wheel grit number, the surface finish improves, goes down. The trend line is very linear. It also indicates that pure grinding alone may not meet the 1 micro inch surface finish currently called out for the aluminum oxide coated wheel components. A secondary operation of polishing might be required. The 1 micro finish has been obtained on the spool rotors both at Draper Laboratory and Precitech. Draper Laboratory has ordered and received additional sets of finer grit grinding wheels that we plan to use for work in-house in the near future.

**Conclusions**

Both Draper Laboratory and Precitech obtained a surface finish of better than 1 micro inch on face grinding of the spool rotor. Since this was used only for set up tests, no further work has been performed on these parts. Grinding alone does not appear able to get to a 1 micro inch finish on the aluminum oxide coated surfaces both for the thrust plates, used for set up, and the dummy hemispherical bearing parts. There is potential for the automated polishing system, developed by OptiPro, being able to meet this goal, based on the limited, but promising, results so far.
Figure 1
Spool Gas Bearing Wheel Assembly

Figure 2
.375 Hemispherical Gas Bearing Wheel
Figure 3
Dummy .375 Diameter Hemispherical Bearing Mounted on In-House Precitech Nanoform 200

Figure 4
Surface Finish to Grit Size Trend Line

PLASMA SPRAYED Al₂O₃ COATING -- PRECISION GRINDING / POLISHING

- Surface Finish (μ in.) vs. Diamond Grit Size (μ)

Polish Parts