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A FLEXIBLE ALIGNMENT FIXTURE FOR THE FABRICATION OF REPLICATION MANDRELS

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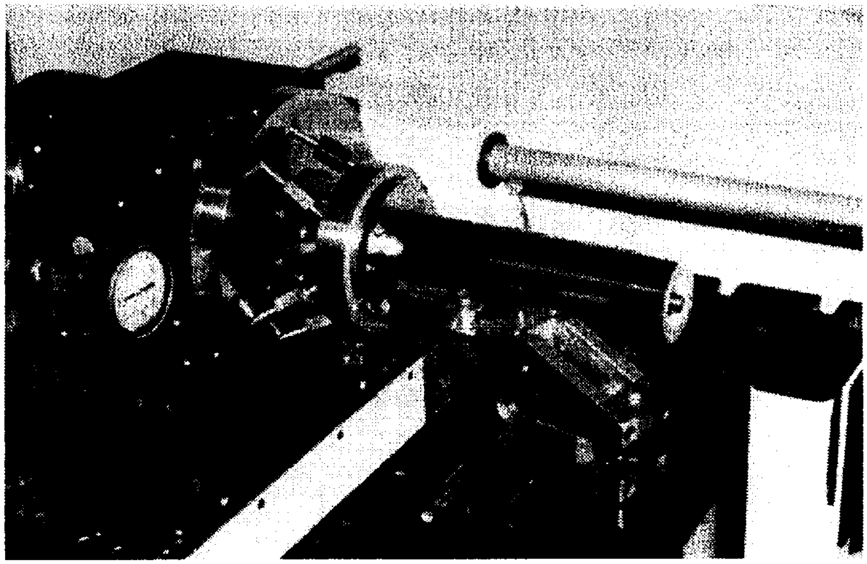


INTRODUCTION

NASA uses precision diamond turning technology to fabricate replication mandrels for its X-ray Calibration Facility (XRCF) optics. As shown in Figure 1, the XRCF optics are tubular, and the internal surface contains a parabolic profile over the first section and a hyperbolic profile over the last. The optic is fabricated by depositing layers of gold and nickel on to the replication mandrel and then separating it from the mandrel. Since the mandrel serves as a replication form, it must contain the inverse image of the surface. Figure 1 shows the components of the fabrication mandrel that are necessary to facilitate mounting, handling, and polishing during the fabrication process.

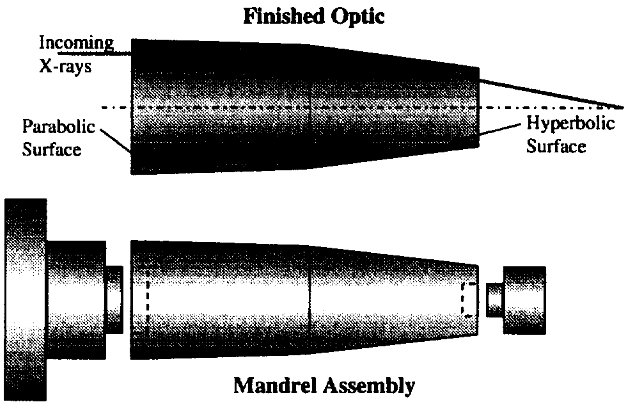


Figure 1: Geometry of XRCF Optical Surface and Replication Mandrel

The difficulty in aligning the mandrel comes from the fabrication steps which it undergoes. The mandrel is rough machined and heat treated prior to diamond turning. After diamond turning, silicon rubber separators which are undercut in radius by 3 mm (0.12") are inserted between the two end caps of the mandrel to allow the plating to wrap around the ends (to prevent flaking). The mandrel is then plated with a nickel-phosphor alloy using an electroless nickel process. At this point, the separators are removed and the mandrel is reassembled for the final cut on the DTM. The mandrel is measured for profile and finish, and polished to achieve an acceptable surface finish.

Wrapping the plating around the edges helps to prevent flaking, but it also destroys the alignment surfaces between the parts of the mandrel that insure that the axes of the parts are coincident. Several mandrels have been realigned by trial-and-error methods, consuming significant amounts of setup time. When the mandrel studied in this paper was reassembled, multiple efforts resulted in a minimum radial error motion of 100 μm. Since 50 μm of nickel plating was to be removed, and a minimum plating thickness of 25 μm was to remain on the part, the radial error motion had to be reduced to less than 25 μm. The mandrel was therefore unusable in its current state.

DESIGN OF FIXTURE

To provide the motion necessary to align the mandrels, the *Flexible Alignment Fixture*, or *FAF*, was designed to replace the vacuum chuck normally used on the DTM. The design goals were to allow for linear displacements of 250 μm and rotations of 0.003 radians at the platform of the alignment fixture (over a 8" long mandrel, 0.002 radians results in an equivalent translation of one end of 400 μm, or 0.016").

The design utilizes a 6 legged hexapod arrangement to provide full flexibility and high stiffness. Figure 2 is a conceptual drawing of the *FAF* mounted on a diamond turning machine. The fixture has a base that mounts directly to the spindle bearing and a platform suspended by the six legs. The workpiece is mounted directly to the platform.

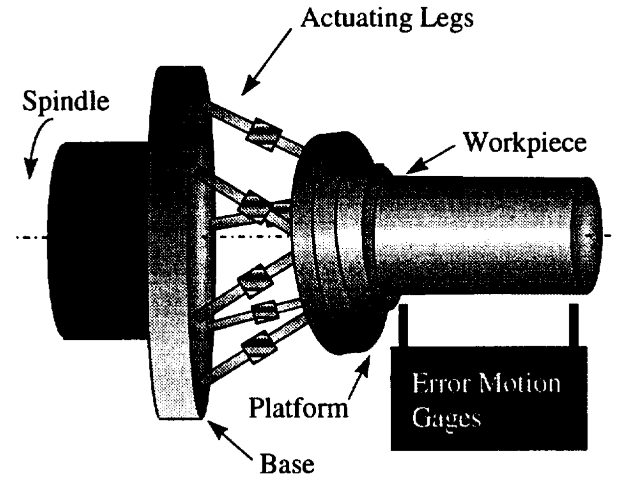


Figure 2: Flexible Fixture on a Lathe Spindle

Since the required motion was very small, the flexure was designed to rely on deformation of the legs rather than joints to allow relative motion of each leg. The stress was calculated for each leg based on a maximum deflection, and the legs were designed to provide a factor of safety of 8 to 10. The legs were threaded on each end and screwed directly into the base and the platform, and preloading was achieved by lowering the platform towards the base, thus introducing a bending moment in each leg.

The legs of the *FAF* utilized a differential pitch arrangement to provide high resolution motion. A 3/8-24 UNF thread was machined on the portion of the leg inserted into the base of the *FAF*, and a 7/16-20 UNF thread was machined on the end inserted into the platform. This differential pitch in the screw provides a linear displacement of 210 μm per turn of the leg. In order to facilitate assembly of the *FAF*, the legs were fabricated in two sections joined in the middle by a hex nut. The legs were constructed from AISI 410 stainless steel and were heat treated for additional strength.

ERROR MOTION AND KINEMATICS

Two dial indicators were used to measure the error motion of the mandrel at four equally spaced rotational positions. By placing the indicators at determined positions along the axis of the mandrel, two measurements at each of the four rotational positions provided the necessary error motion information. The required translation and rotation of the platform were determined in a MATLAB program based on these measurements. The hexapod kinematics were then developed to transform the required platform motion into leg rotations, bringing the axis of the mandrel on to the axis of rotation of the spindle.

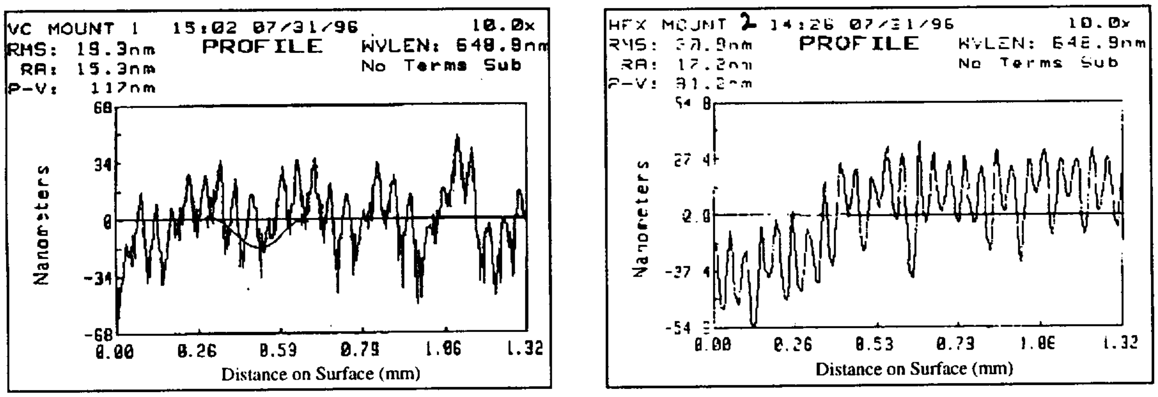
EXPERIMENTAL RESULTS

The vacuum chuck of the DTM was replaced with the *FAF* for testing. When mounted on the original equipment vacuum chuck, the test mandrel had a minimum error motion of 100 μm, which was only achieved after significant effort to align the mandrel pieces. Mounting the mandrel on the *FAF* provided the necessary freedom to align the axis of the mandrel to that of the DTM spindle. Once mounted, the error motion was measured by two dial indicators at four equally spaced rotations of the spindle to determine the proper adjustment. The measurement values were input to the kinematic program to determine the required leg rotations. With the *FAF*, the same mandrel was aligned to within 8 μm error motion with minimal effort, representing a 92% reduction in the error. The 8 μm error was significantly less than the target requirement of 25 μm.

The measures for success in the project included not only the ability to diamond turn the mandrel without penetrating the nickel plating, but also to achieve surface finishes and *form* errors (low frequency errors) that were comparable to or better than those on the conventionally turned mandrels. The mandrel cut on the *FAF* was therefore compared to one that had been successfully aligned on the vacuum chuck without the *FAF*. Visual inspection of the mandrel cut on the *FAF* showed significant improvement over the mandrel cut on the vacuum chuck. This conclusion was verified using a WYKO *Topo-2D/Topo-3D* surface interferometer.

Figure 3 shows the surface profiles of the benchmark mandrel cut on the vacuum chuck and the mandrel cut on the *FAF*. The traces were limited to 1.32 mm. As shown in Figure 3a, the mandrel cut on the vacuum chuck has several components of error. The scan appears to consist of three fundamental components with wavelengths of approximately 0.25 mm, 0.05 mm, and a high frequency noise with wavelength of around 0.001 mm. The feedrate of the slide was 3 mm/min (0.05 mm/s), and the spindle speed was 1000 rpm (17 Hz). Based on the feedrate, the surface components had frequencies of 0.2 Hz, 1 Hz, and 50 Hz respectively. The fact that no component appears at 17 Hz indicates that the error motion is not one due to spindle error but rather slideway or tool post error. The rms amplitude of the error was 19.3 nm. A complex mounting configuration unfortunately prohibited more than one scan of this specimen.

Several traces were taken of the mandrel cut with the *FAF*. Figure 3b shows one trace which is representative of all of the traces taken, but a significant discrepancy was realized in the amplitude of the error, which ranged from an rms value of 17 nm to 60 nm. Since only one trace was made of the benchmark mandrel, the amplitude data is considered inconclusive. The trace shown in Figure 3b has an rms amplitude of 20.9 nm and shows an error component with a 1 Hz frequency (wavelength = 0.05 mm) superimposed on a very low frequency trend (possibly not even periodic) which is outside the scan range of the interferometer. While the discrepancies in the results require further investigation, it appears that using the *FAF* actually reduced the 0.2 Hz and 50 Hz error motions seen in the benchmark mandrel. The form error (low frequency component) is not conclusive since the trace is so small. It seems likely that this error may also show up in the benchmark case given longer surface traces. The elimination of the 50 Hz component in the mandrel cut on the *FAF* explains the visible improvement in surface finish on the part.



a) Mandrel cut on Vacuum Chuck   b) Mandrel Cut on *FAF*

Figure 3: Surface Profiles of Mandrels

Both parts are currently being measured off-site using a *Long Trace Profilometer* to determine the actual error in each part. The preliminary results above, however, seem to indicate that the hexapod may help to reduce the error motion while salvaging the part.

CONCLUSION

A six-degree-of-freedom Flexible Alignment Fixture (*FAF*) has been developed to adjust the position and orientation of a workpiece on a diamond turning machine spindle. The device uses a hexapod design and kinematic analysis to reposition the workpiece. The designed range of motion allows for displacements of 250 μm and changes in orientation of 0.003 radians.

A fabrication mandrel for NASA's XRCF project which was unusable due to alignment problems has been salvaged using the *FAF*, which was able to reduce the error motion from 100 μm to 8 μm. The *FAF* also greatly reduces the effort necessary in insuring the alignment of the mandrel components prior to cutting. Preliminary results indicate that improved surface finish may be an added benefit to using the *FAF*. Pending results from a long trace profilometer will yield more information on the effectiveness of the *FAF*.

ACKNOWLEDGEMENTS

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