Fabrication of affordable aspheric mirrors by electroforming

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ABSTRACT

The Fabrication of Affordable Aspheric Mi[1]rrors by Electroforming (FAAME) program seeks to lower the cost of aspheric mirrors by developing electroforming processes suitable for optical-quality electroforms. To achieve this goal, two major areas of improvement were pursued: optimizing the electroforming process and utilizing a multi-generational approach. To improve the process, we studied electroforming variables, identifying key factors that affect an electroform's optical quality. Once the factors were identified, the electroforming process was refined, producing mirrors that met the quality goal of 1/4 wave in the infrared. We drew all of this experience together to demonstrate replication of a wildly aspheric mirror for use in a Trans-Atmospheric Interceptor (TAI).

Keywords: Electroforming, optics, electroformed optics, mirrors, reflectors, aspheric, nickel-cobalt

Optics are one of the most challenging applications of electroforming. The required fidelity in terms of surface finish, micro geometry, and geometric tolerances is the highest in the field. Mass-produced metal optics such as mirrors and reflectors are usually manufactured by machining and polishing or diamond machining to net shape. Therefore, such items are quite costly. Electroforming holds the promise of reducing the cost of mass manufactured optics, but in order to provide consistent quality, it is necessary to understand what variables affect the fidelity of the replicated components. In this study, a proprietary nickel cobalt electroforming process, NiColoy™, was used to produce

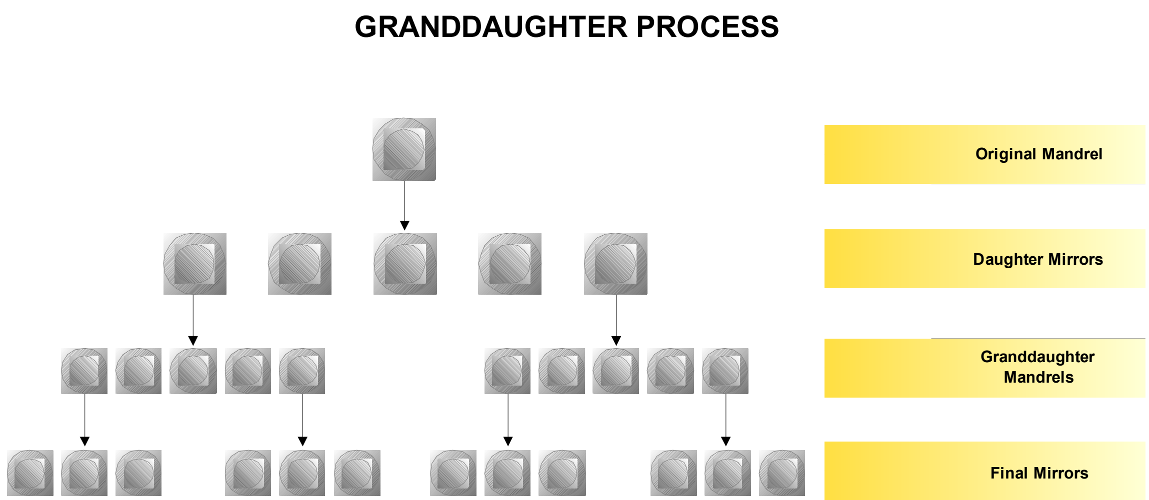

Figure 1: Mirror replication tree

electroformed mirrors and study the influence of such variables as: circulation rate, plating rate, current density, shielding, electroform thickness and deposit internal stress on replication fidelity. The goal was to establish a process window allowing to consistently electroform accurate replicas from a diamond machined master or subsequent

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generation electroforms. As a result of sequential optimization, an improved process was developed and validated for optical replication.

In the course of this study, close to 100 mirrors were electroformed from 3 diamond machined 4 inch diameter masters or their daughters and granddaughters (first and second generation replicas), using the multi-generational approach as shown in Figure 1. In this approach, one master mandrel is used to make several electroforms that are in turn used as daughter mandrels. From each of the daughter mandrels, several granddaughter mandrels are created; those granddaughter mandrels are then used to create the final mirrors. This method has the benefit of greatly increasing the number of mirrors that can be produced from a single master before it degrades irreparably. It can also increase the production rate, since a single mandrel can be a production bottleneck. Multiple daughter or granddaughter mandrels can be used at the same time in the same electroforming tank.

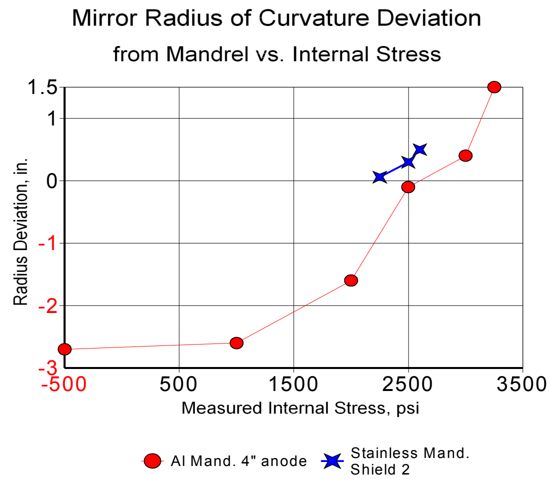

Figure 2: Electroform radius of curvature deviation from the mandrel

The master substrate for diamond turning was electroless nickel, deposited on either aluminum or stainless steel plate. This substrate, when used with optimized pre- and post-electroforming treatments, turned out to be quite durable, withstanding numerous repeated electroforming cycles without visible deterioration. Occasionally, light haze would appear on the surface which could be readily removed by gentle polishing.

To evaluate replication fidelity, the radius of curvature of each electroform was measured with a profilometer and compared to that of the mandrel. Based on the deviation of the replica from the original, adjustments were made to electroforming parameters and the next replica was created and evaluated. A strong relationship between deposit internal stress and deviation of radius of curvature was established, as shown in Figure 2. We also used a number of other metrics to measure mirror quality, including mirror thickness and interferometric measurements of the surface.

Figure 3: Gold faced electroformed NiColoy™ mirror

The developed procedures ensured repeatability and process consistency. By the end of this process, we were consistently producing mirrors whose surface matched the mandrel to within 3 waves RMS (@632nm).

The electroformed replicas, ranging in thickness from 0.010” to 0.060”, were sufficiently rigid to be handled, their optical characteristics measured, without affecting their performance.

Having completed this phase of the study, an additional master was produced by diamond turning an aluminum substrate without an electroless nickel coating. The purpose here was to prove the possibility of utilizing electroforming directly on aluminum, as well as compare the mandrel and electroform radii of curvature for a wildly aspheric object. This optic, referred to as the Foviated Panoramic Seeker (FPS) mirror, pushes the limits of what can be manufactured by current methods because of its steep surface gradients. Several FPS mirrors were successfully electroformed using FAAME’s electroforming processes.

Quite frequently, optical surfaces need to be coated with a material, possessing specific reflective properties. Electroformed metal optics can be produced with such coatings as gold, silver, rhodium and others with the highest surface finish. This capability was demonstrated by electroforming several mirrors with a golden reflective surface as shown in Figure 3. Application of this coating has not affected the geometry of the optical surface and had a minimum effect on the component’s cost.

This study has confirmed that electroforming is a viable, inexpensive alternative to diamond machining of precision metal optics.