High precision grinding of large-aperture off-axis aspheric mirror with form-damage controlling methodology

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KEYWORDS: Precision grinding, Form accuracy, Damage controlling, Aspherical mirror, Large-aperture

The demand for Large-Aperture Off-axis Aspheric Optical Elements (LAOAOE) has grown substantially in space/ground-based large-aperture telescopes, aerial optoelectronics, and ground tracking and sighting instruments. Moreover, the increasing aperture of elements and the shortening processing cycle make high-efficiency and high-precision manufacturing the core problem of LAOAOE processing. Precision grinding is an efficient material removal process for LAOAOE. The surface form accuracy and subsurface damage depth directly affect the removal volume and the difficulty of precision convergence in subsequent polishing. These two parameters are the key to improving the processing quality and shortening the processing cycle of elements. Therefore, the study on high-precision grinding of LAOAOE is carried out to improve the surface form accuracy, reduce the depth of grinding damage, and perform collaborative numerical approximation, which is of great value for applications. In terms of surface form accuracy improvement, a kinematic model of aspheric grinding is established. The main factors of the machine tool structure affecting the low-frequency surface shape and accuracy are identified. Several factors are explored to achieve collaborative control and accuracy optimization of process parameters, including the A-axis zero error, Y-axis centering error, grinding wheel shape and size error, grinding wheel path, and Z-axis surface compensation. In addition, a mathematical analysis and simulation model for the medium-frequency texture of the aspheric grinding surface is proposed. The texture and surface roughness of the grinding surface can be significantly reduced by uniformly optimizing the grinding texture. In terms of grinding damage suppression, the variation rule of the grinding damage depth with the grinding parameters is obtained. Moreover, the mapping relationship between the grinding damage depth and the grinding surface roughness is established. A subsurface damage suppression strategy for LAOAOE is presented. The surface form accuracy PV (Peak-Valley) can reach 3 μm after the grinding test of the 640 mm off-axis aspheric lens, with the surface roughness Ra of less than 24 nm and Rz lower than 0.2 μm. According to the mapping relationship between surface roughness and subsurface damage layer depth, the estimated subsurface damage layer depth is approximately 5 μm, similar to the PV value. Engineering verification of actual optical element processing shows that the subsequent polishing duration can be significantly shortened, which is important for the efficient high-precision processing of large-aperture optical elements.