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Manufacturing of Lightweight Mirror

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Abstract: Fabrication of the lightweight mirror is one of the key techniques for many large optical systems. CAD, CAM and CNC technologies are adopted in designing and manufacturing such mirrors in CIOMP. Better working efficiency and higher lightweight grade have been achieved. The results show that mirrors up to 70% weight reduction and 0.02λ(rms.) surface accuracy or better can be obtained.

Key words: lightweight mirrors; polishing; optical testing
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1　Some points on the design of the lightweight mirror

It is known that the lightweight mirror plays an important role in those fields where the weight of the optical system is a determining factor. The lightweight mirrors have such advantage over solid ones for their highest shape stability with low weight and heat capacity. In order to obtain the restricted weight reduction and the expected accuracy of the mirror, the following points should be carefully considered.

- Optical and mechanical requirements of the mirror
- Environmental condition, gravity, temperature, acceleration, orientation
- Properties of the material used to make the mirror, ULE, Zerodur, SiC, etc
- Structure of the mirror substrate
- Structure of the mirror support, in operation and during processing

All the factors above are taken into consideration during the process of all the research and development of the mirror. Some modern design strategies are adopted, especially CAD technology. Whether the mirror could have met the requirements should be simulated in the computer and the well-designed mirror should be optimized. The process of the simulation is shown in Figure 1 and some examples are presented in Figure 2 and 3.

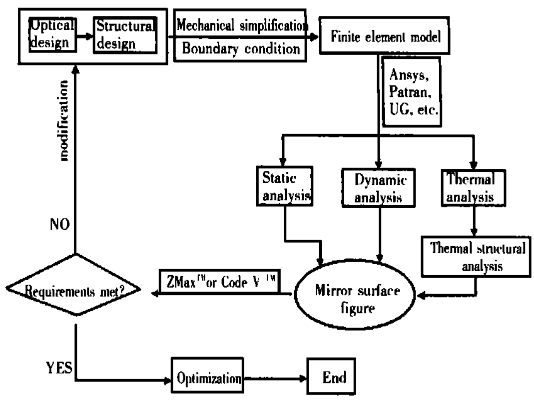

Fig. 1　CAD routines for R& D of mirror and optical instrument

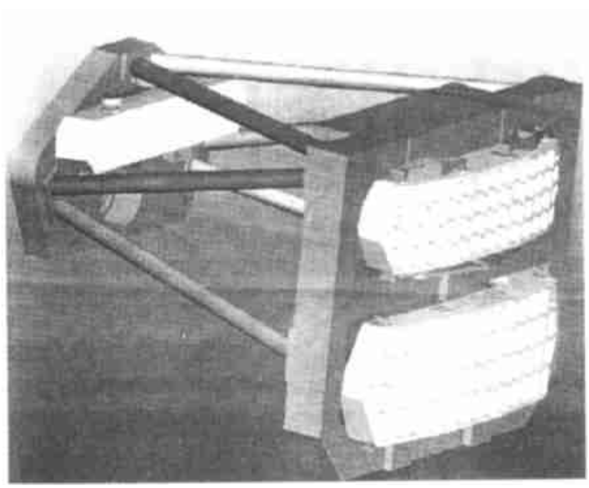

Fig. 2　Schematic view of an optical remote sensor

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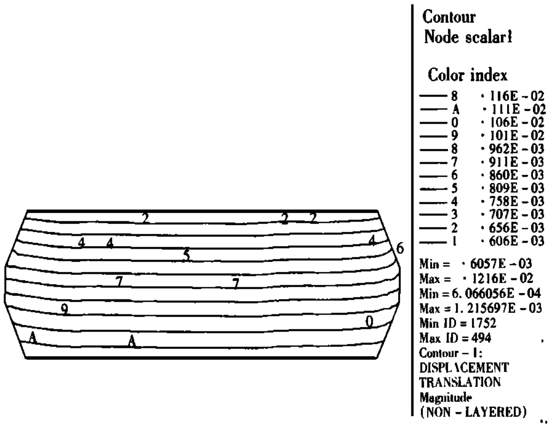

Fig. 3 Contour curves of the surface elements of the third mirror due to gravity

Table 1 shows the design analysis results of a space lightweight mirror sized Dia950 × Th130 after optimization.

Table 1 CAD analysis results of the lightweight mirror

	Specification required	Design results
Weight reduction	65%	71%
Surface accuracy in space (rms.)	15nm	11.2nm
Surface accuracy on ground (rms.)	12nm	7.4nm
Surface accuracy in process (rms.)	12nm	6.5nm

2 Mirror substrate lightweighting by CNC machining

Computer controlled milling is applied for the mirror substrate lightweighting in CIOMP. An abundant data bank of the processing has been constructed by accumulating fabrication and experiment results in recent years. It mainly includes:

– diamond tools, high performance nature and \ or artificial diamond with different mesh size and concentration for various type of substrate material, mechanical structures of the tool suitable for different geometric shapes of the blind holes to be machined, typically hexagon, triangle, conic, under- cut circular blind holes of varied sizes.

– processing factors, mode of tool motion, mode of workpiece motion, feeding speed rotation speed of the tool for different types of materials and shapes of holes.

– CNC machine, 2 CNC machine equipped in CIOMP, one used for bigger substrates up to 2000mm in diameter, and the other for smaller ones up to 800mm in diameter.

Unigraphic CAD/CAM software is applied for the programming at CNC machining. The program is then confined by computer simulation test. Fig. 4 shows the CNC programming by UG CAD/CAM system.

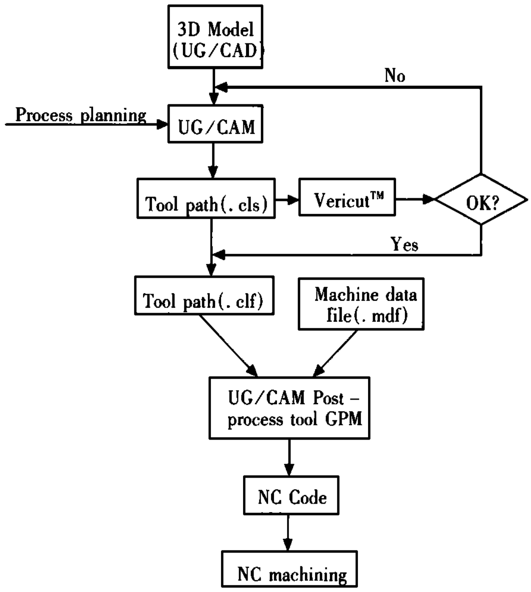

Fig. 4 CAD/CAM diagram

Basic procedure of mirror CAM

– 3D model structuring
– Tool path with process planning
– NC code

. 3D model can be solid, surface or wireframe model with normal dimensions. The accuracy of the cut mirror is determined by process planning and properties of the machining system.

UG/CAM is a famous tool of computer aided manufacture. It can meet 5- axis machining tool.

Whether the tool path for the mirror is right or not should be verified in the computer. It can be shown at 2D or 3D style.

MDF is the interface file for UG/CAM between a specified machining tool.

NC codes can be input into the CNC machine by RSC- 232 or network.

CAM employed can bring our enormous benefits, such as

- Reducing labor strength
- Increasing cutting success ratio
- Reducing cutting time and saving cost
- ...

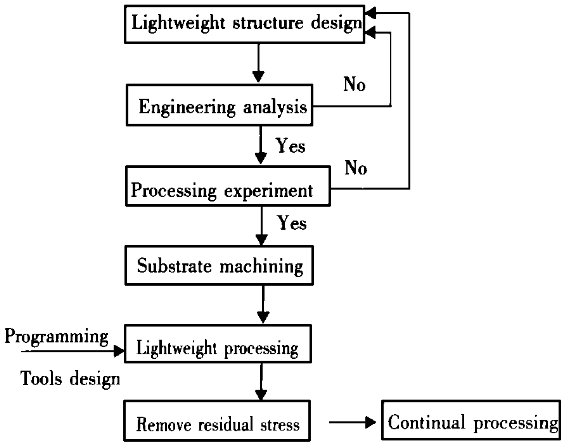

Fig. 5 Process of the lightweight mirror manufacturing

The basic procedures of the lightweight mirror CAM include 3D model structure, tool path with process planning and NC code. 3D model can be solid, surface on wireframe model with normal dimensions. UG/CAM is a powerful tool of computer aided manufacturing. It is suitable for the 5- axis CNC machine to be used for lightweighting process. The process planning is done on the basis of the data from the above mentioned data bank of processing. The tool path can then be verified in the computer. It can be shown in 2D or 3D style. MDF is the interface file for UG/CAM linking a specified machine tool. It is edited according to NC system and performance data of the CNC machine. NC code is put into the CNC machine by RSC-232 interface or network.

Experimental matching is done by running the CNC program to test and modify the program of lightweight mirror manufacturing. Fig. 5 shows the principle lightweighting process.

The residual stress and micro- cracks induced on the surface of substrate during lightweighting process are unavoidable. Such defects can either increase the difficulties in the polishing of the mirror and/or shorten the working life of it. Some physical and chemical treatments are adopted to remove the residual stress and micro- cracks. The results of several polishing and environmental experiments show that the optical and mechanical performances of the mirror are obviously improved ofter these treatments.

Fig. 6 and Fig. 7 are samples of the lightweight mirror substrates

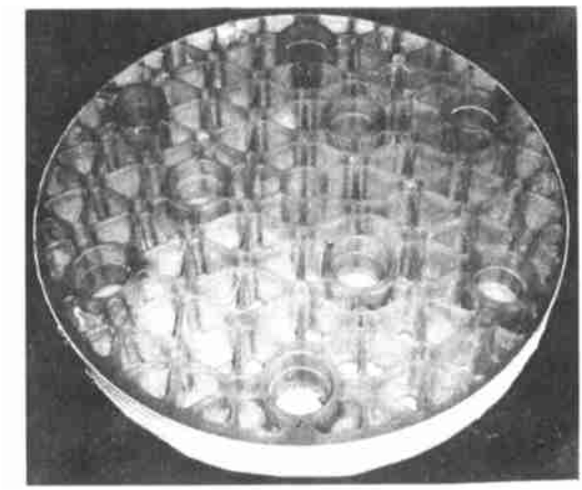

Fig. 6 A lightweight mirror (φ610mm)

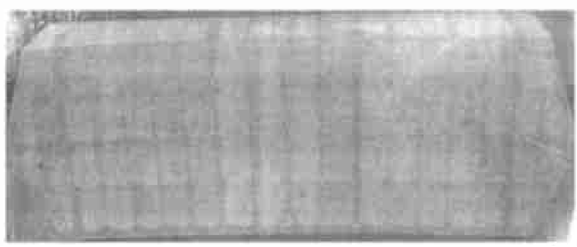

Fig. 7 A lightweight mirror (854mm× 270mm)

3 Polishing and testing of the lightweight mirror

The main difference between a lightweight mirror and a solid one is that the former is deemed as softened with its relatively low stiffness. Therefore, it is of the first importance to hold the substrate in a proper support. Such support should simulate actual mirror support of the optical instrument or even better to use the actual mirror support itself.

The supporting status of the mirror on the polishing machine under test installation and in the optical instrument should be coincident as much as possible, otherwise the surface accuracy of the mirror could change along with the different supporting conditions from step to step. It is a major task to design high performance supports for the mirror before polishing and testing. CAD technology is applied for optimization and analysis.

Both computer controlled surfacing (CCOS) and traditional polishing techniques are adopted for the lightweight mirrors in CIOMP. CCOS is suitable for aspheric mirror, especially for off- axis aspheric mirrors. While traditional methods is good for planar, spheric and on- axis aspheric mirrors. These two techniques are actually combined to improve the working efficiency or solve special processing difficulties such as ripples.

The testing methods for the lightweight mirror are almost the same for the solid mirrors. 2D and 3D profilometer, knife- edge and digital laser interferometers are used in each manufacturing process.

Table 2 Actual results of the lightweight mirrors

	Weight reduction	Material	Surface accuracy (rms@ 633nm)
Scanning mirror size 400× 266mm	54%	Fused silica	0.016λ
Primary mirror size Φ610mm	62%	Zerodur	0.025λ
Folding mirror size 810× 310mm	71%	K4	0.019λ

Some successful achievements of the manufacturing of the lightweight mirrors have been realized. Table 2 lists a few examples of the mirrors worked out in CIOMP.