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Finite Element Analysis and Optimization Design of the Optical Path Seat about the Refractometer

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ABSTRACT : *Reasonable structure of optical path seat needs to be designed in order to reduce the error of mechanical system for refractomer and ensure the accuracy of measurement.The model of optical path seat is designed by the SolidWorks and the stress variation of the optical path seat is acquired through finite element analysis.The structure of optical path seat is optimized on the basis of the result of static strength analysis. The result of optimization design indicates that the mass is decreased by 25.2% , the workpiece is processed and assembled easily, the production cost is reduced too much and the economic benefit is largely improved under the premise of ensuring the mechanical properties.*

Key words: *optical path seat; refractometer; finite element analysis; optimization design*

I. INTRODUCTION

Refractometer is a precise instrument which is applied to measure the refractive index about transparent, translucent material and liquid. In order to make refractomer transform into a intelligent digital display instrument, a higher precision of the instrument and the overall performance must be required, so the error of the mechanical system and the optical system must be reduced. The refractive index measurement formula[1] is deduced based on the critical angle measurement method [2-3]about refractometer measurement principle:

$$n_x = n_1 \sin\{\alpha - \arcsin[\frac{n_0}{n_1} \arctan(\frac{x}{f} + \beta)]\} \quad (1)$$

In this formula: n_0 、 n_1 and n_x respectively represent the refractive index of the air, optical glass, and liquid. α 、 β repectively resprent the base angle of optical prism , the angle of the optical axis and the normal. f and χ respectively resprent the focal length of imaging lens group and the terminator's distance to the center of the image sensor. Optical path seat is a important skeleton in refractometer and support optical system.The deformation of optical path seat has an effect on the numerical value of β and χ , so the strength, stiffness and weight of the optical path seat have a very important influence on mechanical and optical syestem, furthermore, whether the precision and performance of instrument largely depend on the structural design of optical path seat.

The optical path seat which is traditional has some disadvantages such as the complicated structure, the difficult processing technology and the bigger assembly error, which bring a biggermechanical system error and severely the accuracy of measurement . To solve this problems, compared with traditional optical path seat, modified optical path seat is designed by the SolidWorks software and analyzed by the finite element analysis. The optimization design[4] about optical path seat is put forward on the basis of the result of the finite element analysis in this paper.

II. THE STRUCTURAL DESIGN OF OPTICAL PATH SEAT

The positions of traditional optical path seat in mechanical system and the optical system is shown in Fig.2, however the traditional optical path has the following disadvantages:

(1) The light path consists of five connecting plate through the socket head bolts to connect, as is shown in figure 2.

(2) When the milled connection plate is assembled ,there is a bigger error for assembling, etc.

(3) The milling process have some shortcomings, such as trival process, slow speed, the higher processing cost.

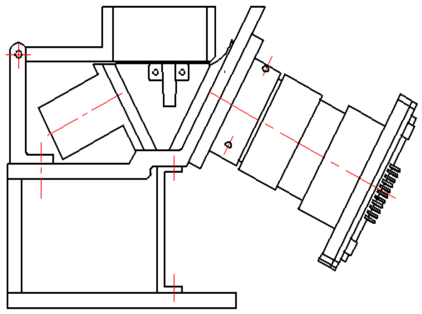

Figure 1 The main light path about mechanical structure for refractometer

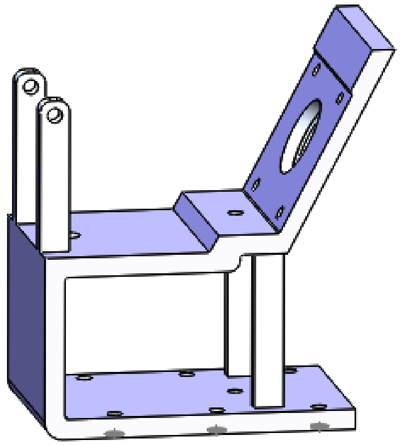

Figure 2 Traditional optical path seat model

Therefore, the 3d parametric mode of light path, which is designed by SolidWorks, is shown in fig. 3 to solve above problems. The modified light path, which adopts the method of extrusion processing technology, has the following advantages, such as rapid forming, high processing efficiency, no assembly error of connection plate, simple structure, enough strength and stiffness, achieving batch production and low production cost , and so on .

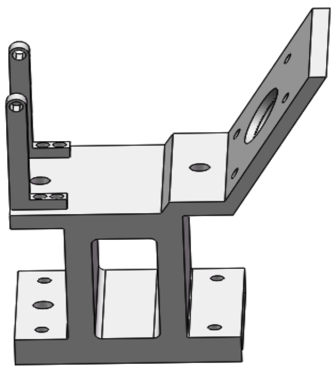

Figure 3 The modified optical path seat model

The material of modified optical path seat, which adopts 1060 aluminum alloy, has the following characteristics such as suitable for extrusion forming, not heat treatment strengthening, small density, light quality, good mechanical performance, etc. Material properties are shown in table 1.

Table 1 Material properties of optical path seat

material	modulus of elasticity /GPa	Poisson's ratio	density/（kg/m^3）	yield strength /MPa
1060 aluminum alloy	69	0.33	2700	27.57

III. FINITE ELEMENT ANALYSIS

Optical path seat in refractometer bears the stress and bending moment brought only by the gravity of other parts, so Simulation plug in Solid Works analyzes light path only by static modal analysis. For acheieving convenient finite element analysis, the light path model needed to be simplified without considering the strut of four socket head bolts, generally observing the following steps[5] : example creation, material definition, meshing, adding constraints and load , operation and results analysis.

3.1 Meshing

After creating a new case and defining material properties, the 3d model of optical path seat should be checked to achieve the success of meshing or not by Solid Works Simulation . The method of Aspect ratio and Jacobian should be adopted to check the quality of the meshing. Aspect ratio check is defined as the concept that length-width ratio of regular tetrahedron is usually used to calculate the length-width ratio of other units, including the aspect ratio of a very small regular tetrahedron element which can be approximately regarded as 1.0. Jacobian checks the Jacobian value to judge the bending degree of the unit and all nodes is precisely located in central point of straight edge for regular tetrahedron, besides Jacobi is 1.0. In order to ensure the veracity and reliability of optical path seat in finite element analysis, so higher grid density is applied to optical path seat for meshing. The formed meshing model of finite element, which is shown in figure 4. The size of grid density unit is 2.5211585 mm, tolerance is 0.09408226 mm, the number of nodes and units is respectively 53320 and 83559.

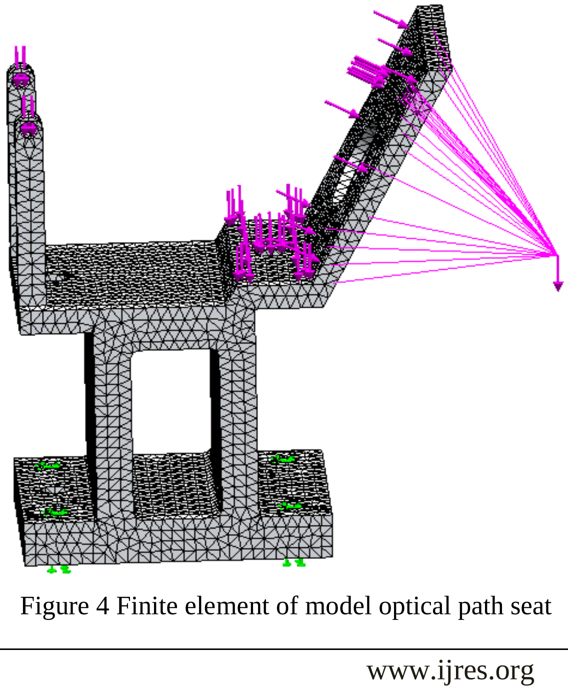

Figure 4 Finite element of model optical path seat

3.2 Adding loads and constraints

Through the quality attributes of Solid Works software tools, the quality of parts which is born by opticsl path seat can be calculated and then the force of three bearing surface can be calculated. Horizontal plane forces of light path bears 10 N. The size of normal load is about 3.48 N on cant. Gravity of lens group is simplified as a role of remote load which is about 3 N on light pat, and the reaction on the hole of two fulcrum bar which is handled by the parting line with the equivalent is about 1.5 N . The four threaded holes of floor on light path is constrainted by fixed connection.

3.3 Solution and the analysis of result

Finite element model of optical path seat is solved by the solver of Simulation, then the analysis result which is obtained is that the stress distribution is shown in Fig.5, and the displacement distribution is shown in Fig.6 and so on.

Some message about finite element analysis can be known from Fig.5, maximum stress of optical path seat which is 2.6223835 MPa, is located in the slope with the upper horizontal connection in section 66130 . Minimum stress which is 0.074891 MPa is located in section 74891.

The Fig.6 shows that the cant of optical path seat has a small angle relative to the upper level due to stress and bending moments , therefore the maximum displacement which is 0.01945 mm occurs in the top and the slope .

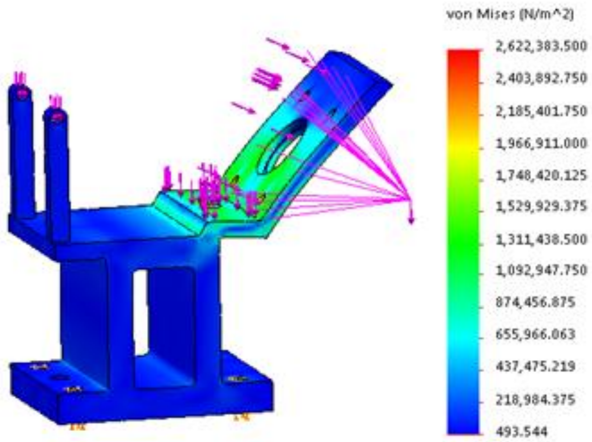

Figure 5 The stress distribution of optical path seat(the deformation ratio706)

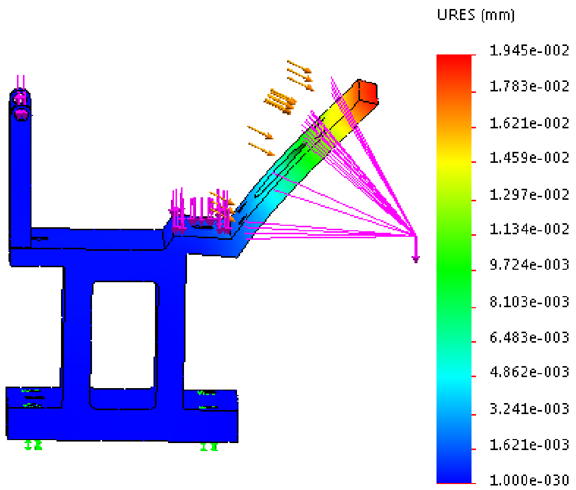

Figure 6 The stress distribution of optical path seat(the deformation ratio706)

Above all, although the maximum stress of optical path seat is far less than the yield strength[6] and the maximum displacement which is very small belongs to little deformation [7]to lead to a very small impact on the mechanical system error and fully guarantee the measurement precision of instrument, the results of the analysis of the optical path seat shows that strength and stiffness are very large, therefore it is necessary to use the optimization design for the structure of optical path seat under premise of guarantee mechanical properties so as to reduce the quality of the optical path seat.

IV. THE STRUCTURAL OPTIMIZATION DESIGN LIGHT PATH

The optimization design model for optical path seat is established by optimization Analysis function of SolidWorks Simulation and the design problem can be described as thefollowing general mathematics model [8, 9]:

To solve design variable vector $X = (x_1, x_2 \cdots x_n)$, $x \in R^n$ and make $f(X) \to \min$ under the premise of satisfying the following constraint conditions:

$$s.t. \begin{cases} h_k(X) = 0 & (k = 1,2,\cdots,l) \\ g_j(X) \le 0 & (j = 1,2,\cdots,m) \end{cases} \quad (2)$$

In this paper, the quality of optical path is treated as the objective function . There are following design variables: length of rectangular hole is x_1 and width is x_2 among light path, besides, the thickness of base plate about light path path is x_3. The strength and stiffness are treated as constraint conditions. The scope of the above variables are: $30mm \le x_1 \le 58mm, 15mm \le x_2 \le 35.5mm,\ \ 6mm \le x_3 \le 12mm$. After accomplished 52 iterations, the scheme of optimal design is achieved from many feasible solutions, as is shown in figure 7. It is convenient for parts processing to do with the relevant data results of optimum design by using the roundness, as is shown in table 2.

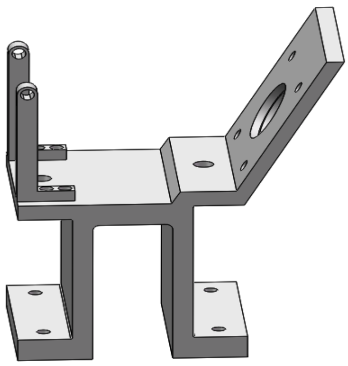

Figure 7 The optimized optical path seat

Table 2 The data comparison for the seat of light path

	design variables			constraint		
	x_1/mm	x_2/mm	x_3/mm	maximum stress/MPa	maximum displacement /mm	quality for seat of light path/kg
initial value	40	19	10	2.62	0.01945	0.119
optimal value	52.05	23.17	8.21	2.60	0.01910	0.091
roundness value	52	23	8	2.61	0.01925	0.089

There are following message can be obtained from the table 2 : the optimization design of optical path seat is more reasonable and the dimensions of the rectangle hole of the base plate is reduced and optical path is again analyzed by finite element analysis after rounding parameters . The maximum stress increases by 2.60 MPa to 2.61 MPa, and the maximum displacement changes by 0.01910 mm to 0.01925 mm, but both are within the scope of the permission and the strength and stiffness meet the requirements so that the mechanical system error is very small. Compared with previous project, quality of the light path is reduced by a 25.2% from 1.19 kg to 0.091 kg. The result indicates that the optimized optical path seat is more reasonable and can fully meet the accuracy requirement of the refractometer.

V. CONCLUSION

(1) In this paper, the improved optical path seat which is processed by extrusion mould based on the traditional structure has the following advantages: the smaller mechanical system error, high efficiency, rapid forming and so on .But after finite element analysis by the Solid Works Simulation , the result shows that the opticalt path seat of material yield stress is greater than the maximum stress, and maximum displacement is very small, the modified optical path seat exists excessive strength and rigidity so that material is wasted greatly.

(2) The optimized optical path seat has following advantages that mechanical properties such as strength, stiffness fully meet demands and structure is more reasonable, besides, quality is reduced by 25.2%, raw materials is saved and the production cost is reduced largely.

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