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FINITE ELEMENTT SIMULATION AND ANALYSIS ON WEAR OF MECHANICAL GRAVER FOR DIFFRACTION GRATING

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ABSTRACT

Mechanical ruled diffraction grating is a kind of super-fine technology. During the process, the material distortion happens along with the geometry nonlinearity and material nonlinearity. In this paper, start from the dynamic assembly , measure the mechanical property by nano-indenter and scratching test , establish the finite element simulation model based on Deform software, analyze the main factors which affect the wear of linear graver, simulation analyze the wear of graver on flow velocity of material ,stress change and temperature change , predict and validate the area where the wear is most serious .It drew the conclusion that the wear was prior to appear on main and side blade, optimizing the edge radius and increasing the surface roughness is effective method to improve the anti-wear ability of tool.

Keywords: *Diffraction Grating, Finite Element, Wear*

1. INTRODUCTION

Diffraction grating is the key element of spectrum instrument in the field of aviation and military. The theory of mechanical scratching diffraction grating is indenting and polishing on the substrate cladding with metal film (Aluminum film) by diamond engraver to obtain groove. At present, Ngau Tau planing developed by Rowland is usually used. The fixed shank moves forth and back, the bench drive the grating sub-slab to dividing move to make mount of parallel and, equal and straight grooves (see figure 1). As the anisotropism of diamond, the hardness on its different crystal planes and different direction of the crystal plane is different. As diamond engraver is easily worn during the grating scratch and the reason is undeterminable, it is difficult to scratch large area and high density grating. Research on orient anti-wear designing of diamond engraver is significant.

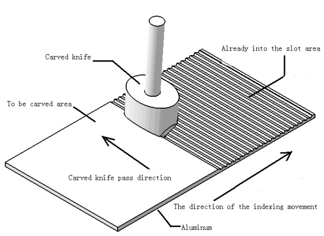

Figure 1: Ngau Tau Planing Scratching Gratings

The mechanical scratching technology has been 2 centuries worth of history since German Fraunhofer made the first diffraction grating in 1823 and it had preliminary business application in 1967[1-2]. Since the beginning of last century, many experts began the research on scratching machine manufacture, theory of diamond scratching grating, crystal orient of diamond engraver and blade grinding technology. In 1910, Woodrow scratched low density infrared diffraction grating with flare [3].Hall and Sayce from Britian develop the crystal orient grinding technology of diamond engraver [4]. Davies and Stiff from Australia made research on this kind of technology [5]. Verrill from Britain made comparative test on grating scratch which area is $100 \times 150 mm^2$ and density is1200g/mm against the installation and load technology [6] and brought forth that it is possible to improve the groove quality through tool design parameter compensation [7]. Experts from US ever made mount of low density and large area diffraction grating scratching test on MIT-C scratching machine and found the tool factor is one of main reasons which lead to some scratching test fail [8]. Experts from Carl Zeiss Company Germany made the simulation optimization on mechanical scratching groove process and obtained the diffraction grating with excess 85% flare efficiency. Although experts obtained some achievement from the research mentioned above, there is no theory and technology on diamond engraver anti-wear designing.

Definite element analysis technology is a kind of effective method to solve complex engineering

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problem. It can provide mount of direct data and information on stress change, strain and temperature field against metal plastic deformation .Grating scratching belongs to sub-micron ultra-precise process, the deformation of material includes geometry nonlinearity and material nonlinearity which lead to the difficulty of test measure and analysis, so it is a better way to research on wear of scratching graver through combining the material test and definite element simulation. In this paper, through establishing the finite element simulation model based on Deform software, measure the mechanical property precisely ,simulation analyze the wear of graver during the grating scratching, find the main factors which lend to the tool wear and predict the break-out position of tool.

2. MECHANICAL SCRATCHING GRATING SIMULATION MODEL ESTABLISHMENT AND SIMULATION

2.1 Tool, Aluminum Film Structure Model Simplify

The diamond scratching tools of diffraction grating are divided into straight-line tip chopper, arc blade chopper and tetrahedral tool. The tip chopper is widely used. The curved blade chopper and tetrahedral tool are less in use as it is difficult to be polished .The graver consists of shank and tip(Figure2).The chopper is made of natural single crystal diamond with two rake surface(orient and non-orient), a flank surface, a main scratching blade and two side scratching blades. It is a triangle pyramid with three surfaces and blades based on tip The grating scratching is the process that exert load and driving force on the shrank, tip scratches on the Aluminum film and oriented surface indent and polish on the Aluminum film to make grating groove under the main and side blades.

The grating blank work consists of Aluminum film, chromium layer and optical glass .Optical glass is the substrate , Aluminum film is the ruled layer and chromium layer is the medium .During the mechanical grating scratching , indenting happens between tool and Aluminum and none of chromium and optical glass. So the model of grating blank work is simplified into Aluminum film.

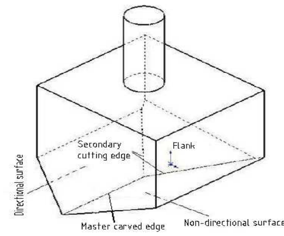

Figure 2: The Geometry Structure Of Tip Chopper

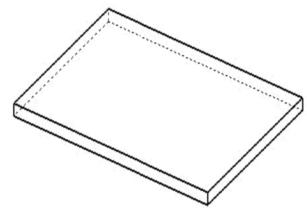

Figure 3: The Simplified Model Of Grating Aluminum Film

2.2 Determination of Mechanical Parameters of Aluminum Film

As it is difficult for Aluminum film to fix and orient, high accuracy contact tests(nano-indenter and nano-scratching test) are applied to measure the main mechanical parameters which affect quality of grating scratching, such as elastic modulus ,hardness ,stress-strain curve and friction coefficient. This method made it easy to simulate. The average value of elastic modulus is shown as Table1.The average value of friction coefficient is shown as Table2.The average value of hardness is shown as Table3. Refer to the reference [9] and [10], based on dimension theory and inversion method, combine finite element simulation and nano-indenter test to obtain stress-strain curve. At last put the mechanical parameter into Deform program.

Table1 : Average Value Of Elastic Modulus

Test	一	二	三	四	五	Average value
E(GPa)	39.59	34.13	31.97	27.33	37.42	34.088

Table2 : Average Value Of Friction Coefficient

Test	一	二	三	四	Average value
Friction coefficient	0.3	0.38	0.38	0.4	0.365

Table3 : Average Value Of Hardness

Test	一	二	三	四	五	六	Avarage value
Hardness(MPa)	701.56	647.05	631.28	2710	543.65	593.59	623.426

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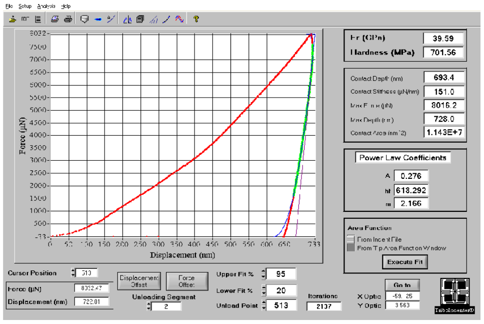

Figure 4: Nano-Indenter Chart Of Aluminum Film

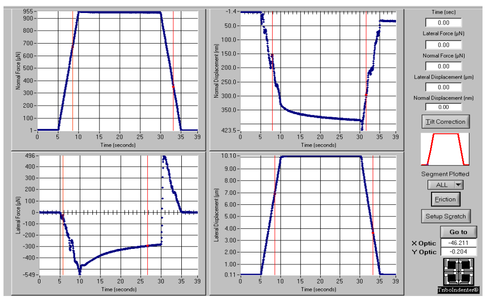

Figure 5: Nano-Scratching Chart Of Aluminum Film

2.3 The Simulation of Tool Wear Process

1. As scratching blade is made of diamond and its strength and hardness are much higher than Aluminum material, we suppose it as rigid material.

2. Plastic deformation happens associated with non-linear elastic deformation for Aluminum film. So we suppose it as elastic-plastic material.

3. In order to solve the contradiction between the calculation accuracy and simulation time, it is necessary to set refined mesh partly and redistributed mesh automatically in the area where scratching blade works on the Aluminum film (See as Figure6). Both calculation precision and calculation time can be assured, which make simulation test to be feasible.

4. Deform 3D offers two kinds of tool wear model: Archard model and Usui model. Archard model is applicable to the non-continuous process, but Usui model is applicable to the continuous process. So we choose Usui as the mathematical model of tool wear simulation analysis.

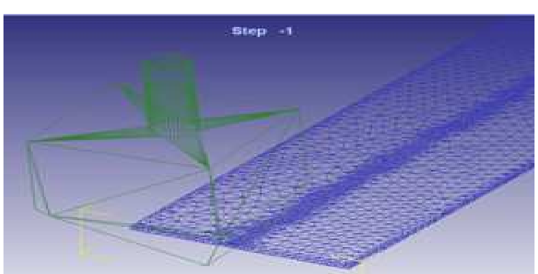

Figure 6: Partly Refined Grid

3. ANALYSIS ON WEAR AND TEAR AREA OF TOOL

Refer to Usui wear model formula(1),it is clear that contact stress , absolute temperature of contact surface, relative slip velocity are the main factors to affect the wear of scratching tool.

$$w = \int a \cdot p \cdot V \cdot e^{-b/T} dt \qquad (1)$$

Where W-wear amount of tool, p-stress on contact surface, V-relative slip velocity, T-absolute temperature of contact surface, a, b-calibration coefficient.

3.1 Stress Analysis on Tool Wear

Stress is one of the main factors that affect the amount of wear in Usui model. The larger is stress on the contact surface, the more serious is wear. We can get the Stress distribution on the aluminum film during the grating ruling process through Finite Element Simulation. Figure7 shows the location of the tool at the 2500th step during the scratching simulation. Meanwhile the tool has completely cut into the aluminum film and stress distribution is stable. As shown in the figure7, the bottom of grating groove contacts blade directly and the equivalent stress is larger （In the red area）and value is from 168MPa to 179MPa. The stress decreases gradually along with the diffusion of blade to two rake faces. That is to say the stress concentrates mostly on the blade and the size of the blade radius affects the stress distribution and then the life of tool. The stress on the two side cutting edges is larger, and then the two rake face and the flank face is the least.

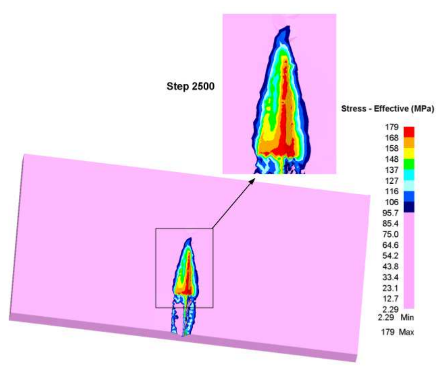

Figure 7: Equivalent Stress Distribution On The Aluminum Film At The 2500th Step During Simulation

3.2 Temperature Analysis on Tool Wear

According to the differential wear model put forward by Usui, the absolute temperature on the contact surface is another important factor that affects tool wear. Higher is the temperature, more

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serious is tool wear, which is more obvious in ordinary metal cutting. However, mechanical scratching grating is made in constant temperature lab, which assures temperature stable. On the other hand, the velocity of scratching is low, load on the tool is low and the friction and indent between tool and film are not severe. All these factors result in less heat from scratching process and temperature change less, which is to be proved in the simulation test. The temperature change and distribution on tool and Aluminum film during stable scratching period are shown as Figure8.

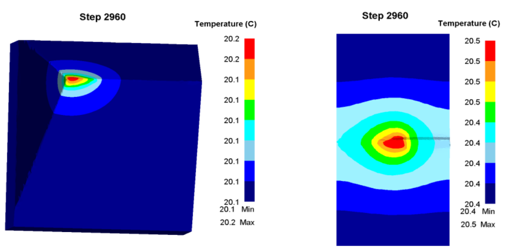

Figure 8: Temperature Change On Tool And Aluminum Film

The ambient temperature is to be set 20 during the simulation process. By analyzing the result, we know that the highest temperature of Aluminum film is 20.5 which distributes in the area of the first contact area between tool and Aluminum film. The highest temperature of scratching tool is 20.2 which distributes around the blade. The temperature increases by 0.5 and 0.2 respectively and the changes are too small. That is to say, the effect of temperature can be neglected in the simulation of mechanical scratching grating .But simulation is just a period of real scratching not the whole process. Temperature can accumulate during the scratching process. Tool travels tens of kilometers when machining the grating with large area and high accuracy, the effect of temperature cannot be ignored.

3.3 Flow Velocity Impact Analysis on Tool Wear

From finite Element Simulation, we can find that the flow phenomena of material appear during scratching process (shown as figure9). This phenomenon is caused by the friction between blade and Aluminum material. The flow rate of Aluminum film is one of the factors which affect the degree of tool wear .So research on the regularity of Aluminum's flow rate is also very important for studying the wear of diamond tool and predicting on the wear areas.

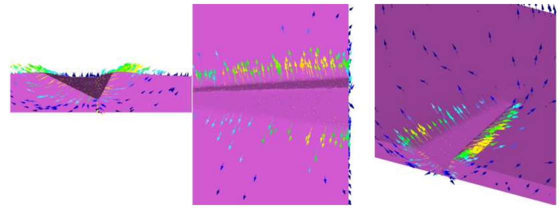

Figure 9: The Flow Of Material During Scratching (Arrows Note The Flow Direction)

The location of the tool at the 2380th step is shown as Figure10. The flow rate of Aluminum material is stable at this point. The highest flow rate appears at the bottom of grating which is about 9.81 to 11.2mm/s. The flow rate on the two side faces is from 7.8 to 9.81mm/s.

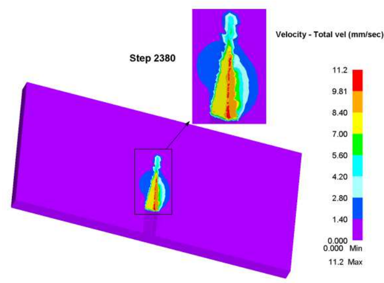

Figure 10: An Aluminum Film Material Flow Velocity Distribution In The Section 2380 Of The Simulation Step

According to Usui wear model, higher is the relative slid velocity, greater is the amount of tool wear. So the prediction is that the blade will be first worn, then the two side faces.

4. CONCLUSION

According to Usui's wear model along with the result of finite element simulation analysis, it can draw the conclusion as the following:

1. The amount of wear is proportional to stress during the scratching process. That is to say that higher is the stress, more serious is the tool wear. It is most easy to be worn near the blade. Wear on the two rake surfaces is more serious than flank surface.

2. Considering the temperature, wear is most easy to appear near the blade. Under normal condition, the effect of temperature can be ignored. But during scratching large density, large size and long stroke grating, it must be considered carefully.

3. According to the analysis on material's flow rate, the highest flow rate happens at the blade, two rake surfaces and flank surface.

According to the analysis on the three points above, it drew the conclusion that wear happened at main and side blades prior to the two rake surfaces.

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So it is the most effective to optimize edge radius to extends the life of tool and avoid from wearing easily. Next, increase the finished surface and decrease the friction coefficient. In addition, reduce the scratching speed along with ensuring the efficiency of scratching.

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