Surface Texture on Diamond Turned Optical Reflector

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Abstract

This paper presents the parameters of surface texture of optical reflector generated by ultraprecision single-point diamond turning and emphatically discusses the existence of waviness and its formation factors. At the last of this paper, a suggestion is given on improving surface performance.

Key Words: Single-Point Diamond Turning (SPDT), Optical Reflector, Surface Texture, Roughness, Waviness

1. Introduction

Metal reflective mirror surface fabricated by single-point diamond turning is used more and more in optical domain. Now in this country major are applied to infraed wavelength device and CO_2 laser(wavelength $=10.6\mu m$), i. e. metal reflector of large power laser process equipment and scanner polygon in the thermal imaging. It is necessary that designer must consider peculiar properties of diamond turned surface and effect on the optical system. Now that the ultraprecision optical surface is generated by turning, it is inevitable that exists periodic tool marks on the surface, those irregularity which has a few micrometers in period according to feed rate are inherent in the production process, that is major components, and smaller period surface roughness is due to tool micronicks and another high frequency artifacts of the diamond turning process.

Another texture also appears on diamond turned surface —— surface waviness, i. e. texture is millimeters in period, this long period surface features is a universal characteristics of diamond turned surface. The purpose of this paper is to discuss some particular properties and parameters of waviness.

Research result on reference[1] shown: very low roughness surface i. e. $R_a = 20A$ is low in wide angle total integrated scatter (WATIS), but near angle total integrated scatter (NATIS) is very high, because of large period features of diamond turned surface. Therefore we must pay attention to its magnitude and distribution, because scatter is a power loss in a laser resonator and can seriously degrade the resolution in an imaging system.

2. Roughness and Waviness

Roughness is usually measured traverse to tool marks, for an optic surface, it is measured radially, neglecting other errors, the microgrooves on surface is a series of fan-shaped tool marks relative to tool radius, that is theoretical model of roughness:

$$R_t = f^2/8r$$

here, R_t——P—V value of theoretical roughness (mm)

f——feed rate of tool (mm/rev)

r——radius of tool nose (mm)

Because of high precision of cutting equipment itself and integrity of diamond tool, ultraprecision diamond turning can be regarded as ideal cutting status, the above theoretical formula appears to give answers of right order of magnitude. In actual, when feed is big, i. e. larger than 10μm/rev, roughnes (R_a or R_t) fits the above theoretical formula, shown as Fig. 1, we can see typical fan-shaped tool marks, the comparison of theoretical calculated results and measured results is shown in Table 1, the error is small.

While feed rate is small, i. e. smaller than 5 μm/rev, fan-shaped tool marks is unobserved, and the measured result(R_a) does not fit the above theoretical formula. There is a critical value, under our experiment, for tool radius $R = 1.524$μm(0.06in), it is fc = 10μm/rev.

Fig. 2 is variation curve of R_a relative to feed rate f, it can be noticed while feed rate is big, the curve is regular, while feed rate is small, the curve is irregular.

Waviness is a kind of long periodicity, low frequency surface texture, it is carrier of roughness, like low frequency carrier wave of radio, roughness is superimposed on it, as shown in Fig. 3, the lower frequency components is seen, its periodictity is tens, hundreds of micrometer or a few millimeters. Some scholar[1] called it long period roughness features, we think that it is more exact to be defined as waviness, because waviness and roughness is different, Fig. 4 is a waviness curve filtered out roughness, the millimeter period can be observed.

If feed is big, it is difficult to learn waviness from roughness. Fig. 5 is a roughness curve of big feed and Fig. 6 is its filtered curve, the difference is very small, for the low amplitude of waviness and also the large feed, roughness magnitude is so high that waviness is merged by big roughness; If feed is small, fan-shaped tool marks is not predominant, but waviness is observed clearly. As feed is usually small in the course of cutting optical surface, roughness in this surface superimposed on waviness, therefore, it is necessary to research roughness and waviness respectively, because of difference of cause to form them and difference of influence on performance of metal -optical reflector.

3. Manufacture and Measurement of Sample

1. Sample is manufactured by MSG—325 2—axis CNC Diamond Tool Lathe, condition of cutting is as follows:

Objective of cutting: plane reflector

Material of sample: LD2

Diameter of workpiece: 120mm

Radius of tool nose: 1.524mm(0.06in)

Revolution of spindle: 1000rpm

Cutting temperature: $20° + 0.2℃$

Material of tool: natural diamond

To reduce other errors, the experiment is done in the same plane. The feed rate vary from 0.1μm/rev to 60μm/rev, and every 3 millimeters as one cutting segment. Theu the surface texture is measured with Form Talysurf, experimental control setting lists below:

Cut—off: 0.08mm

Filter: ISD for roughness

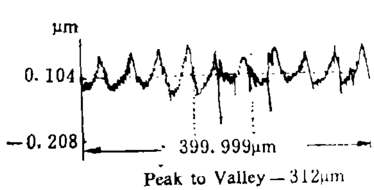

Fig. 1 Fan-shaped tool marks of diamond turned surface

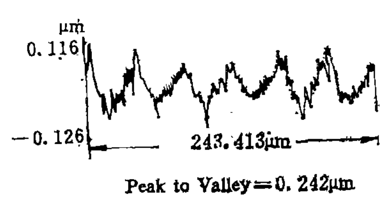

Fig. 2 Cuver of R_a relative to feed rate f

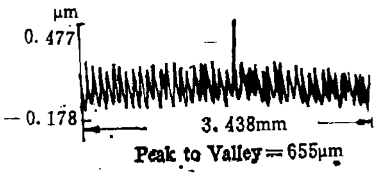

Fig. 3 Roughness is superimposed on waviness

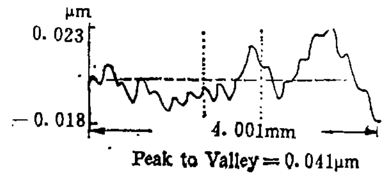

Fig. 4 Waviness curve filted out roughness

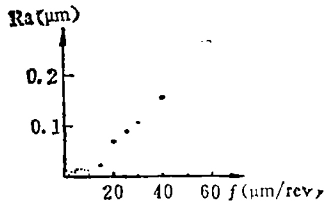

Fig. 5 Roughness curve of large feed

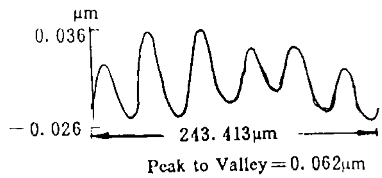

Fig. 6 Waviness curve filted out roughness

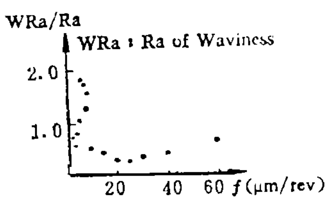

Fig. 7 WR_a/R_a related to feed rate f

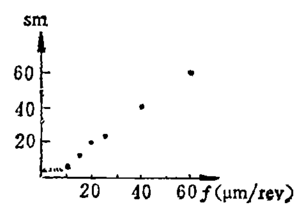

Fig. 8 Sm related to feed rate(Sm: Mean spacing of the profile irregularities)

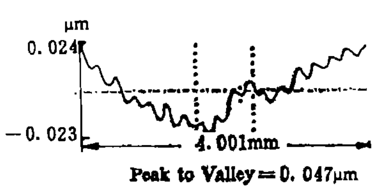

Fig. 9 (a) Waviness curve

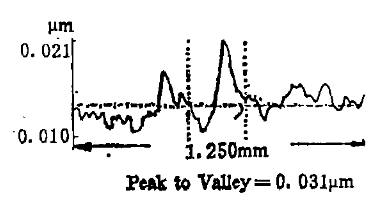

Fig. 9 (b) Waviness curve

PC for waviness

Reference: straight

Measurement results are shown in Fig.7 and Fig.8, there exists a critical value of feed rate, fc= 10μm/rev.

2 Another φ 120 workpiece is manufactured, feed rate is 40, 20, 15, 12.5, 10, 7.5, 5, 2.5μm/rev respectively, width of cutting segment is 7mm, below is the conditions for measuring waviness of its surface:

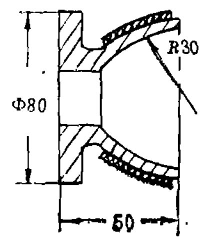

Fig. 10 Thin workpiece stucked a damping material

Cut—off: 0.8mm, 0.25mm

Filter: PC

Waviness in different peirodic are shown in Fig.9, in the meantime it can be seen that the frequency component is more complex.

Table 1 Comparison of calculated and measured R_t

Feedrate (μm/rev)	Calculated R_t (μm)	Measured R_t (μm)
60.0	0.300	0.325
40.0	0.135	0.187
20.0	0.033	0.165
15.0	0.0185	0.141
10.0	0.0082	0.112
7.5	0.0046	0.097
5.0	0.0025	0.074
2.0	0.00032	0.052
0.5	0.000025	0.043

4. Exploring of Waviness

In general, roughness on single-point diamond turned surface is the irregularities which are inhe rent in the production process, resulting from the process rather than from the machine tool, resulting from defect of tool, instability of chip flow and high frequency lower amplitude vibration of environment.

Waviness can be attributed to the characteristics of an individual mauhine tool, variation of equipment in the course of cutting, such as face runout of spindle, we think that the asynchronous error motion of spindle may cause waviness; in the meantime, here may also have asynchronous error motion in tool slide resulted in waviness.

Ultraprecision machine tool is a complexity, any fluctuation of electrics, supplied air system, temperature and random nonlinear factors in machine tool all will be duplicated on the surface of workpiece:

1. φ 350mm workpiece 30kg in weight is manufactured, while loading the workpiece, the system of workpiece and spindle is unbalanced, thus, waviness exists on the surface of the workpiece and it appears periodic, obviously, the waviness is caused by the system out of balance.

2. A small-sized workpiece is glued on a base which attracted directly to the vacuum sucking disc to be turned, after turning, there exists waviness on the workpice also, it results from small fluctuation of workpiece in the course of cutting, because contact area is small and the quality of the glue is bad.

3. A concave workpiece is manufactured by means of linear interpolation, although surface inrface increment is small, there exists obvious waviness on the surface, it results from cutting of linear interpolation, the curve between two adjacent joints forms a wave.

4. The inner spherical surface of a thin-walled component, its material is engineering plastics, is manufactured, shown as Fig. 10. Because of the vibration caused by elastic deformation in the course of cutting, there appears obvious large periodic waviness on the surface; after damping material being stuck, the waviness is smaller.

According to our experiments, tool slide of MSG-325 is perhaps accompanied with lower frequency vibration in the course of movement in straight line, because the amplitude of this vibration is small, it is difficult to measure and control accurately, we are trying to set up its random mathematical model and then install an adaptive device to control it, it is evaluated that this method will be benefit to improve waviness of the optical surface.

5. Conclusion

For ultraprecision single-point diamond turning (SPDT), while feed rate is big, the roughness on surface fits that theoretical formula ($R_t = f^2/8r$); while feed rate is smaller than a critical value, it does not fit the theoretical formula. The feed rate is usually small in the course of cutting ultraprecision optical reflector, so its roughness can not be calculated by means of theoretical formula.

There exists periodic waviness on optical surface generated by single-point diamond turning, this periodicity is in millimeter range sometimes, therefore, to evaluate optic performance of the surface generated by SPDT, we should take account of not only roughness but waviness, since the former can cause lower wide-angle scatter and the latter can cause strong near-angle scatter, so waviness will ham the optic system seriously. The problems how to improve a cutting equipment and related environment conditions, to reduce waviness and evaluate optical quality of surface texture are urgent to be solved.

References

[1] Hurt, H. H., et al.; Proceeding of SPIE, 676, 1986, 153—158
[2] Church, E. L., et al.; Proceeding of SPIE, 676, 1986, 142—152
[3] Church, E. L., et al.; Proceeding of SPIE, 508, 1984. 83—96

金刚石切削光学反射镜的表面纹理

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摘要：讨论了单点金刚石超精切削光学表面的表面纹理参数，重点的讨论了波纹度的存在及其形成因素，本文还提出了一些改进的设想。