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DESIGN DEVELOPMENT OF A NEW SIX COMPONENTS DYNAMOMETER: APPLICATION TO GLASS GRINDING

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Abstract: *With the laser power improvement in recent years, research on glasses fused silica damage took an economic stake. The knowledge of the full energetic statement during the grinding of fused silica is essential to understand the removal mechanism on the fused silica damage. Previous works on fused silica grinding, had shown the need of the adequacy between the measurement material and the cutting phenomena. This study presents a design and development of a new six components dynamometer using for measuring fused silica grinding mechanical actions.*

Key words: *experimental, cutting process, cutting model, glass grinding, six-component dynamometer.*

1. INTRODUCTION

The economic and technologic stake in high-peak-power laser requires knowledge of constraint linked to the abrasion removal process [1]. Sub-surface mechanical damage (SSD) consisting of surface cracks are induced by manufacturing fused silica glass. Grinding, lapping and polishing process allow obtaining a fused silica glass composing laser. The aim is to highlight possible damages induced by the grinding operation.

In order to reduce fused silica damages, a study will develop a model of the removal mechanism during grinding operation. To have an accurate model, the cutting power must be evaluated.

Last studies performed in turning [2, 3, 4, 5], and more recently in milling [6], have shown the importance of the moments in the cutting energy balance. The measurement of these moments is realized with a six component dynamometer developed in our laboratory and is issue from precedent studies [7].

This metrological device composed of six unidirectional quartz sensors have been used in our previous works on fused silica grinding. During these tests, forces and moments were measured. The level of these measures was lower than other cutting process (turning, drilling, milling…). As the dynamometer was developed and used for metal processes, measures were not acceptable.

This work presents a method of design and development of a new dynamometer which will be able to measure fused silica grinding mechanical actions. This device will be used in future studies to model the cutting phenomena during fused silica glass grinding.

2. RESULTS FROM THE PRE-STUDY

The purpose of this study was to identify the possible impact of the grinding operation on the fused silica glass.

The test consisted of a single pass along the Y axis of the grinding machine (Fig. 1.).

The cutting conditions of and grinding wheel are illustrated in Table 1.

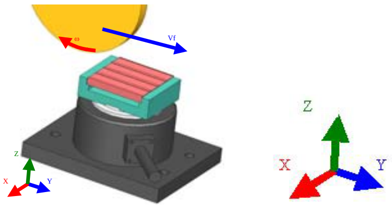

Fig. 1. Grinding configuration.

Table1

Cutting conditions

126 µm grits wheel		**46 µm grits wheel**	
Feed rate (mm/min)	**Depth of cut (mm/min)**	**Feed rate (mm/min)**	**Depth of cut (mm/min)**
150	0.1	150	0.05
150	0.2	150	0.1
250	0.1	250	0.05
250	0.2	250	0.1

The glass grinding forces and moments are measured with a six component dynamometer. These results show a low level of the mechanical actions. It shows that this dynamometer is not adapted to measure glass grinding mechanical actions. This dynamometer was, designed, developed and used to measure forces in metal cutting process. So, dynamometer measures range was too high for this grinding operation as some forces and moments have the same intensity as measurement noise (Fig. 2.).

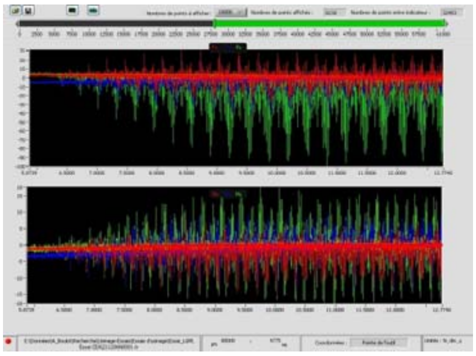

Fig. 2. Low level of mechanical actions.

The design of a new dynamometer with a measurement range in adequacy with the grinding glass cutting forces was necessary to allow future studies. This dynamometer is designed for a plano-grinding machine (SMP 500-2C manufactured by OptoTech) acquired for this study.

3. FUNCTIONAL SPECIFICATIONS

Functional specifications have been imposed to design and develop this new dynamometer:

- ±5000 N measurement range (*X* ,*Y* and *Z* axis);
- ± 10 N accuracy (*X*,*Y* and *Z* axis);
- 50 Nm maximum moment (*X*, *Y* and *Z*);
- Exciting vibration frequency > 3000 Hz;
- Specific geometry for the SMP 500 grinding machine;
- 250 × 250 × 100 mm (external dimension).

4. COMPONENT DYNAMOMETER TESTS

Different sensors are used in cutting actions measurement. Gauge and piezoelectric sensors are the main technologies.

Last studies performed [7] on gauge dynamometer have shown an exciting vibration frequency lower than ours needs.

So, as piezoelectric sensors are stiff, they are able to measure signals with high vibration frequency and are adapted to our dynamometer.

4.1. Components

These sensors are tri-axis forces sensors 206A12 of PCB PIEZOTRONICS (Fig. 3).

4.2. Tests

In order to verify the real sensors characteristics and range of measurement, each of them have been characterized. As these sensors operate in compression, they must be preloaded. According to the sensor manufacturer, the preload depends on the levels of the measured force and a series of tests to characterize them have been realized.

4.2.1. Experimental devices

To achieve these tests, an assembly allowing applying forces at various points has been made (Fig. 4, Table 2).

This assembly is placed on a tension/compression bench (Fig. 5). Then, a force is applied with a known value and verified using a reference test sensor (Fig. 6).

The aim of these tests has been to highlight with different preload the sensor behavior and responses in its measuring range.

The new dynamometer design and development should take into account functional specifications given by these test results.

Fig. 3. Sensor 20A12.

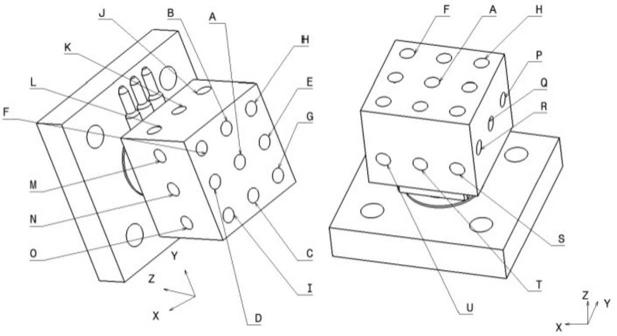

Fig. 4. Assembly test.

Fig. 5. Tension/compression bench.

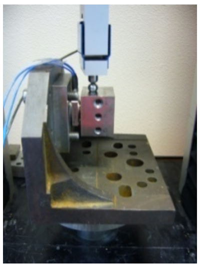

Fig. 6. Assembly test with referent sensor test.

Table 2

Direction forces applied

Point	Direction
A, B, C, D, E, F, G, H, I	Z -
J, K, L	Y -
S, T, U	Y +
M, N, O	X -
P, Q, R	X+

In order to show the linearity, measurement symmetry and cross talking of the sensor, different forces are applied on the test assembly (Fig. 7). These forces are applied in the three principal directions (X, Y and Z). Z is the preloaded direction.

The sensor is fixed in vertical and horizontal position. After the application of a preload on the quartz sensor (10 kN, 20 kN or 25 kN), different test series have been done in different points of the test assembly. Forces applied on the assembly are also measured with a referent test dynamometer. The applied forces level is approximately 5000N along Z and 10% of the preload along X and Y.

4.2.2. Results

4.2.2.1. Linearity**:**

Results have shown the linearity of sensor responses with a minimal preload. Sensor linearity evolution is calculated by the ratio between the applied force and the measured force. Results are presented in Fig. 7. Before a minimal preload, the sensor responses are not linear. The sensor linearity response can be evaluated by the linear regression slop. Fig. 7 represents the force response sensor (*x*) and the force reference dynamometer (*y*). So, results are acceptable when the slope is close to or equal to 1. Fig. 8 shows the variation of slope with the different preload. The sensor linearity is improved with the improvement of preloads.

Future tests will be performed to determinate the minimal preload force necessary to have a sensor linearity response.

4.2.2.2. Measurement symmetry

Tests has revealed measurement symmetry on *X* and *Y* axis. Forces have been applied on the sensor to determine the symmetry measurement errors. Tests were performed on *X* and *Y* axes at three different points.

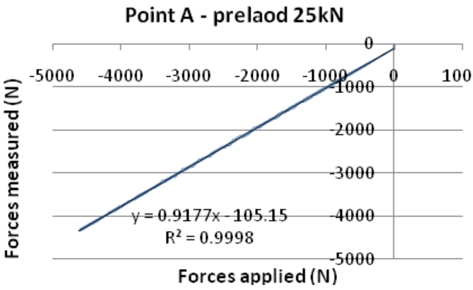

Fig. 7. Slope determination at point *A*.

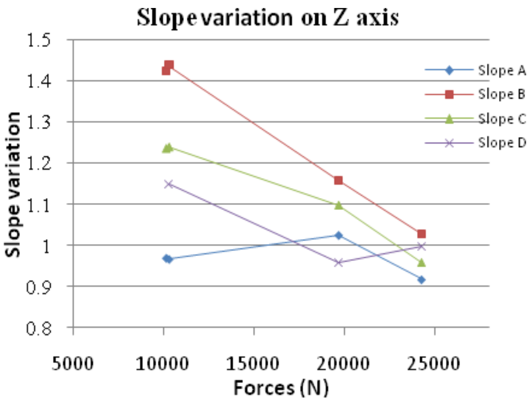

Fig. 8. Slope variation.

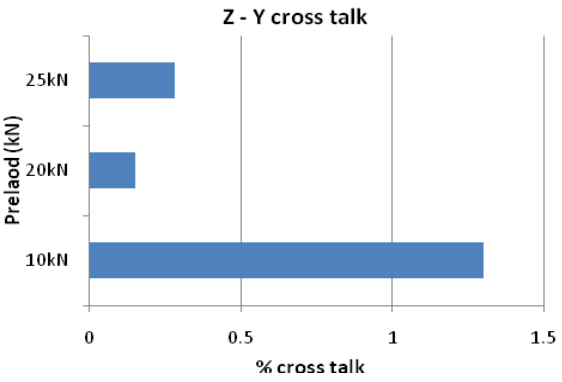

Fig. 9. *Z-Y* cross talk.

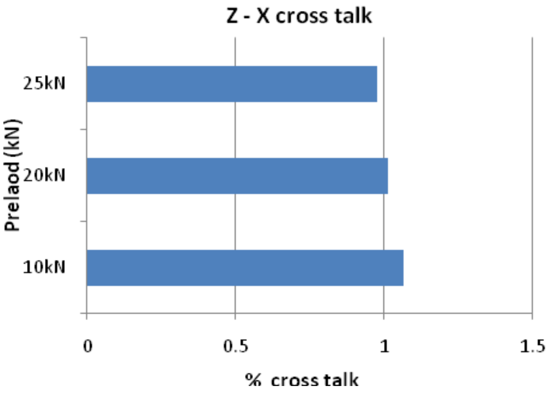

Fig. 10. *Z-X* cross talk.

The error percentages were calculated (2 to 3 %) and are acceptable for measuring grinding mechanical actions.

4.2.2.3. Sensor Cross talking

The sensor cross talk levels on Z axis have been also evaluated (expressed in %). Results are given in Fig. 9 and Fig. 10.

Future experiments will define cross talk for *X* and *Y* axes.

Fig. 9 shows a decrease of the cross talk between *Z* and *Y* with the improvement of preload. After 20 kN preload, cross talk does not vary more including measurement error variation.

Fig. 10 shows the same cross talk with different preloads.

This results show the importance of preload of sensors.

5. DYNAMOMETER DESIGN AND VALIDATION

The dynamometer design is imposed by the functional specifications and the layout on the grinding machine.

Fig. 11 presents device architecture which is composed of three quartz sensors. They are disposed at 120°, between a grinding surface and a ring beryllium-copper.

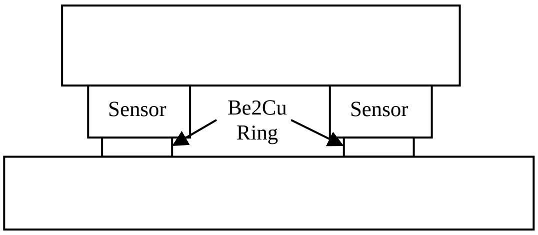

Fig. 11. Dynamometer architecture.

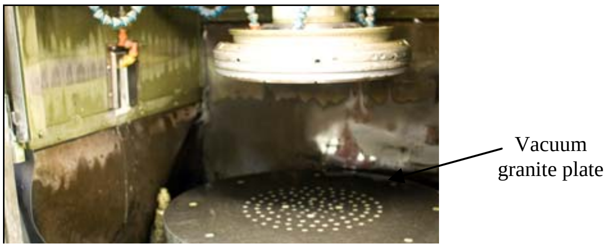

Fig. 12. Plano-grinding machine: OptoTech SMP 500 - 2C.

5.1. Materials

Materials used for this dynamometer were chosen for their hardenability and stiffness (36NiCrMo16). The rigidity and exciting vibration frequency of dynamometer are been dependent on the material used but also of its design. In the future, tests of vibration frequency will execute to know the exciting vibration frequency of the dynamometer. A finite element analysis will be done to validate these choices.

5.2. Layout on grinding machine

A plano-grinder machine (OptoTech SMP 500 – 2C) (Fig. 12) will be used for the study on the grinding fused silica.

The measurement device is positioned on the vacuum granite plate of the SMP500-2C.

The dynamometer has been designed according to the geometrical specifications of the plano-grinding machine.

The dynamometer was clamped to the SMP500 by screws and localized with pin.

5.3. Calibration

The calibration principle is given by Y.Couétard [7], in his PhD report.

Known pure forces and pure torques are applied in different point of this dynamometer. Based on these reference tests, a calibration matrix is defined with a mathematical expression:

$$[C]_{[6*9]}(U_i) = [T]_{[6*6]} \qquad (1)$$

where, $[C]$ is the calibration matrix determined by the calibration and $[T]$ is the actions matrix; (U_i) are the tensions issued from the sensors.

6. CONCLUSIONS

This study presents a new six components quartz dynamometer. This dynamometer will measured the six cutting actions (3 forces and 3 moments) during grinding fused silica glass process. It will allow understanding the phenomena of fused silica grinding and will have a dynamic, a range of measurement, an exciting vibration frequency really adapted to this process. It will make it possible to study more specifically the abrasion removal phenomena and the damage occurring during grinding process.

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