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Procedia Engineering 100 (2015) 428 – 434

Procedia Engineering

www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Optimization Criteria of Plane Lapping Machines

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Abstract

This paper reviews experimental research regarding brittle materials processing with superfinishing machine The main criteria for determining the characteristics of superfinishing machines can be grouped into: energy consumption criterion, technologically criterion and dynamic criterion can be determined and the main criteria optimization plan lapping machines. The optimization of the characteristics of brittle materials superfinishing machine is very important because they directly influence the quality of workpieces surfaces. The performances of the superfinishing machine linkages are increasingly higher, due to the following requirements: very high quality workpieces surface, reduced time for feed workpieces to machine tools, better interconnections between machine tools are used in the technological process, high flexibility.

Peer-review under responsibility of DAAAM International Vienna

*Keywords:*plane lapping machines; silicon wafers; plane lapping process; cutting force; lapping plates

1. Introduction

The development trends of the superfinishing machine can be specified in this situation through the following specific requirements: more productive, more rigid and cheaper. Main criteria for determining the characteristics superfinishing machines can be grouped into: energy consumption criterion, technological criterion and dynamic criterion.

Energy consumption criterion- as higher are the properties "cutting" of abrasives materials, as lower the consumed energy for removal of material units is [1].

Technological criterion - the machinability through superfinishing of brittle materials depends on a series of technological factors: the shape and the size of the abrasive micro grains, the quality of the transport fluid, viscosity

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Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.387

of the abrasive suspension, speed and pressure of superfinishing [1]. Material removal rate increases along with the size of the abrasive particle, increasing pressure and increasing the superfinishing speed. As higher superfinishing pressure is, as lower the roughness of the super-finished surfaces is. The superfinishing pressure is upper limited by the fragility and reduced thickness of the parts.

Dynamic criteria - the influence of the dynamic behaviour of superfinishing machines on superfinishing processes with abrasive suspensions is not studied enough yet. Stiffness characteristics must be experimentally determined according to the standard dimensions of the superfinishing machine, processing precision required, roughness and productivity forecasted, given the characteristics of abrasive suspension used [1].

2. Energy consumption criterion and technological criterion

To evaluate energy consumption in the plane parallel superfinishing is more rational to use specific mechanical work instead of the absolute values of mechanical work consumption on removing a certain material volume V.

The specific mechanical work of super finishing depends on many factors including physical and mechanical properties of the material which is to be processed [2].

From experimental data obtained at the plane parallel superfinishing of various materials, using the same abrasive suspension, showed that the mechanical work of superfinishing varies from 80 [Nm/mm^3] in the case of the steel processing, to 4 [Nm/mm3] in the case of the germanium processing, i.e. over 20 times [1]. The Power of the super finishing machines used today ranges from 1.5 to 10kW. These high values of power are justified using the intensive cutting regimes.

The values of the power supplied by the motor of the upper plate in the lapping process are listed in Table 1. The value of the power from the table is calculated as average powers measured 5 times for each condition lapping.

Table 1.The values of the power supplied by the motor of the upper plate.

Specific pressing force of superfinishing [N/cm^2]	4.144 Standard	3.315 80%	2.486 60%	1.657 40%	0.828 20%
Abrasive particle size [µm]	Power [W]				
18	134	122	119	117	108
8	97	99	103	92	76
4	84	87	88	79	70

The areas of adjustment of plane superfinishing machines are determined by extreme limits of speed in addition by specific pressure force of superfinishing as at any cutting machine-tool.

So, the arising question is what values of cutting speed and specific pressing force of superfinishing must have a superfinishing machine to justify efficient use of abrasive suspension.

To answer this question we analysed the influence of these technological parameters (rotation speed of the super finishing plates and the specific pressing force of super finishing) on the surface roughness (R_a) and material removal rate (Q_W) [1].

Table 2. Material removal rate.

Specific pressing force of superfinishing [N/cm^2]	4.144 Standard	3.315 80%	2.486 60%	1.657 40%	0.828 20%	
Abrasive particle size [µm]	The material removal rate (Qw) determined through the measuring of the weight silicon wafer [mm^3/min]					
18	25.178	21.961	14.947	11.38	9.771	
	2.463	1.982	1.121	1.147	1.063	Max. error
8	8.098	7.698	7.087	6.830	6.655	
	1.256	0.745	0.963	0.852-	0.876	Max. error
4	0.239	0.220	0.206	0.148	-	
	0.094	0.083	0.076	0.000	-	Max. error

The results of experimental tests relating to the removal of the material are shown in table 2.

The value of material removal rate (table 2) is calculated as average material removal rates determined by measuring the weight of seven wafers simultaneously processed.

Table 3. The values of the average roughness Ra of silicon wafer processed.

Abrasive particle size [µm]	18					8					4				
Load [N/cm]/ lapping time [min]	4.14 ST.	3.31 80%	2.48 60%	1.65 40%	0.82 20%	4.14 ST.	3.31 80%	2.48 60%	1.65 40%	0.82 20%	4.14 ST.	3.31 80%	2.48 60%	1.65 40%	0.82 20%
0	620	644	695	686	678	223	221	220	218	234	108	101	105	106	103
5	227	231	228	228	268	134	123	122	124	128	74	72	70	69	70
10	227	229	227	228	240	124	110	108	112	122	72	68	67	68	67
15	224	220	222	228	236	113	102	106	105	114	70	66	67	64	65
20	225	218	218	220	238	107	104	102	104	103	69	64	62	66	64
40	223	221	220	218	234	108	101	105	106	103	67	64	62	67	64
Max. error [nm]	4					3					2				

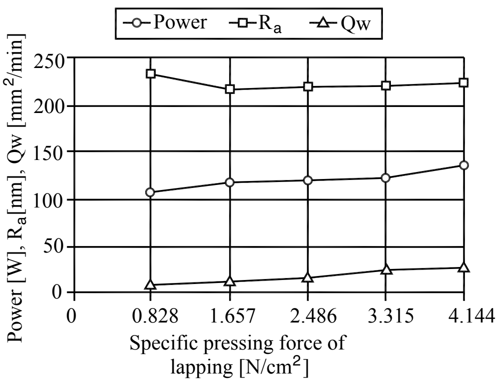

Fig. 1. The power, the surface roughness and the material removal rate when using abrasive particle size of 18 µm.

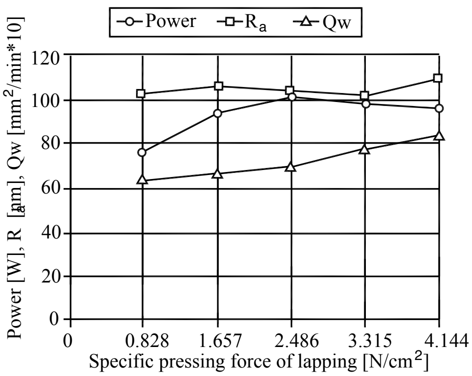

Fig. 2. The power, the surface roughness and the material removal rate when using abrasive particle size of 8 µm.

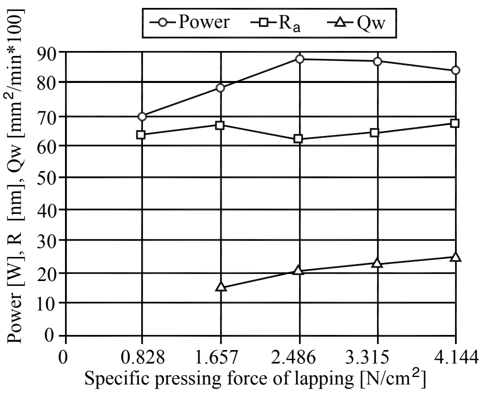

Fig. 3. The power, the surface roughness and the material removal rate when using abrasive particle size of 4 μm.

The results of the silicon wafer surface superfinishing are presented in table 3. The mean roughness value in the table is obtained as an arithmetic mean average surface roughness R_a of the seven silicon wafer simultaneously processed (in the same conditions).

Superfinishing plates rotation speed is upper limited by the need to maintain a uniform abrasive suspension film which is uniform distributed between the superfinishing plate and workpieces (with the rotation speed increase of superfinishing plates, the centrifugal force acting on the abrasive particles also increase, which will lead to "breaking" abrasive suspension film between superfinishing plate and workpieces).

Another factor which limits the increase rotation speed of superfinishing plates is the induced temperature in the workpiece [1].

The intensive study of dependence of the material removal rate depending on specific pressure force concluded that increase the specific pressure force leads to the increase material removal rate. In the experimental research of superfinishing of silicon wafer it was noted that specific pressure force should not exceed 5 N/cm^2.

Using higher specific pressure force leads the compromise of surface quality. Maximum specific pressure force is determined by the maximum allowable depth of penetration of cracks in the mass of workpiece, which are generated by the penetration of sharp vertex or sharp edges of abrasive micrograins. Specific pressure force in the processing of silicon wafers is upper limited by the fragility and their reduced thickness.

More information on the phenomena that occur during the lapping process can be extracted from fig. 1, 2, 3 where there are graphic represented the power, surface roughness and material removal rate depending on the specific pressing force of lapping (normal load applied during the lapping plate). In these graphs the values of the roughness are representative for the finishing process of the wafer surface.

3. Dynamic criterion

Although in literature there are some general recommendations regarding the conditions to be accomplished by the superfinishing machines, these cannot be considered satisfactory for those who want to use these machines with maximum efficiency.

The influence of dynamic behaviour of superfinishing machines on superfinishing process of abrasive material with abrasive emulsions is not studied enough.

Some qualitative aspects are presented in [3], [4] and [5] which show that by increasing the vibration amplitude, it also increases: the height of workpiece surface micro-roughness and the specific pressure pulsation of superfinishing. The elastic systems of superfinishing machines are considered as possessing a single degree of freedom.

The system simplification is justified by the deformations of the workpiece; bed and pillar are very small compared with those of the whole upper plate and lower plate.

Stiffness characteristics must be experimentally established according to the standard size experimental machine tools, the precision of the machining required the roughness and the expected productivity given the characteristics of the abrasive material and the workpiece.

3.1. Finite Element Analysis of stiffness of lapping plate

For structural modelling were used solid type elements (SOLID 72) with six degrees of freedom per node type tetrahedron, hexahedral elements with 3 degrees of freedom per node (translations in X, Y, Z) (SOLID 45) .
The two types of elements were considered two variants of the geometric model:

- Variant 1 (with SOLID45) - normal plate;
- Variant 2 (with SOLID72) - the plate with the delimitation of application area of pressure specific lapping.

The realization just of one specific area of application of the lapping pressure from 360°/7 in 360°/7 (fig. 5 and fig. 6) is justified by the unpropitious situation, but also by hardware and software restrictions.

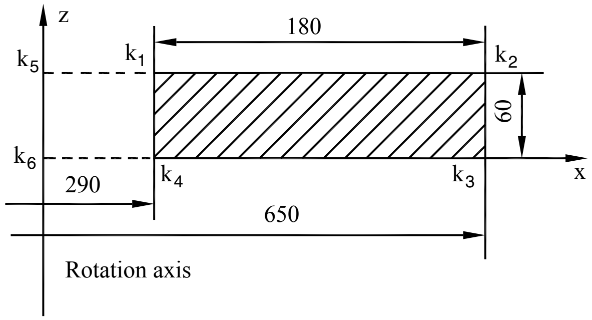

Fig. 4. The main element (pattern) to generate normal plate.

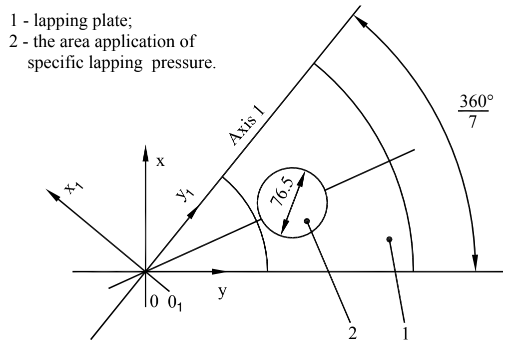

Fig. 5. The main element (pattern) to generating of the plate with the delimitation of application area of pressure specific lapping.

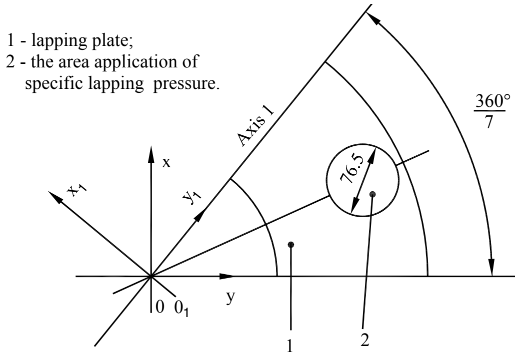

Fig. 6. The base (pattern) to generate plateau delimiting the application of specific pressure forces lapping (near the outer diameter of the plate).

The realization of geometric model for the two types of plates was done like this:

- Normal plate (fig. 4). It has been defined six key points (KEYPOINTS) that helped to realize an area K1, K2, K3, K4 which has been rotated around the axis defined through K5 and K6;
- The plate with the delimitation of application area of specific lapping pressure (fig. 5 and fig. 6).

Tetrahedral elements have been used to control a mesh in overall structure through DESIZE variable.

Have been used cylindrical elements which have been brought together through the Boolean operation of addition of solid elements.

Volume resulting from the unification of the two solids used must have a continuous mesh.

For meshing is necessary that besides DESIZE to be manual divided the unique volume lines in a number of divisions required to be as small as possible to minimize the number of elements and nodes of the structure.

The complete structure is obtained through successive reflections around the axis 1 through the rotation of coordinate system $x_1 0_1 y_1$.

3.2. Static Analysis

For plate static analysis of the lower plate of the superfinishing plane parallel machine MELCHIORRE SP3/600/2RP, it has been defined the load under the form of uniform distributed along the entire plate (unreal case) especially on the surface where the wafers are disposed (real case).

For the second case, the most unfavourable situations of positioning of the silicon wafer (in the vicinity of the internal diameter of the plate and in the vicinity of the outside diameter of plate). The units used are: N, kg, m and s.

The Restrictions are at the base of the plate (the X, Y, Z, rot X, rot Y) for all nodes of the structure. The uniform distributed pressure has been calculated using the formula (1):

$$p = \frac{F}{A_p} \tag{1}$$

where: F is the maximum force of pressure and A_p is the useful action area of the pressure.

3.3. Modal analysis

In the modal analysis we are seeking to determine their own frequencies and vibration modes.
As input data we have: the plateau structure meshing and movement restrictions. Obtained own frequencies, maxim modal displacements on the three directions and own modes allure.

3.4. Interpretation of results

In the static analysis it has been obtained very low values of the displacements in the three directions in both cases considered. This is due to the large surface area support and relatively large thickness (80 mm) of the lapping plate. The values are below 0.02 μm, which leads to the validity of the precision processing of the silicon wafer on this type of machine. These values were obtained with the maximum pressure force (in practice the processing of silicon wafers, due to of their fragility, using a press force of 20% from the maximum pressing force).
In the case of applying pressure only at the site of plate, static analysis on the direction Z highlights the allure strains that are focused on the application of pressure lapping. In this case, the displacements have very small values.
In modal analysis their own different frequencies are obtained (about double in the case of 2) due to the introduction of application of lugs of the pressure as elements of reinforcing plate.
Very small values of their frequencies lead us outside influences that could appear from other machines or appropriate equipment. The obtained values are much closed to the radio domain.

Conclusions

Silicon wafer lapping with abrasive particles of 18 μm has been obtained as a result of the arithmetic average surface roughness having a value closed at the different specific pressing force of the lapping (standard 80%, 60% and 40%).

These forces of specific lapping pressure which provide different material removal rates, with the possibility of choosing depending on the needs and characteristics of the machine.

To obtain the less arithmetic mean roughness value R_a with the specific pressure on lapping standard it lasts five minutes. This is very important from the point of view of productivity.

In the case of abrasive particles lapping of 4 μm to 8 μm - there was an optimum specific pressing force of lapping between the specific pressing forces of lapping used in the experiment cases (in the case of the use of particles of 8 μm the specific optimum pressure force of lapping is 80% from the specific pressure force of standard lapping, and in the case using particle of 4 μm the specific optimum pressure force of lapping is 80% from specific pressure force of standard lapping).

The existence of a specific pressure force of optimal lapping for each size of abrasive grains is due to the different action of the mechanism of removing of the material with each specific pressing force of lapping.
After processing experimental tests and comparing the results with those obtained in the world of superfinishing brittle materials machines has reached the following conclusions:

- The lapping on plane parallel superfinishing machines may lead the achievement of silicon wafer which have a roughness surface R_a less than 65 nm;
- The size of the abrasive particles is one of the most important factors in the lapping process. The material removal rate, wear of abrasive particles and finishing of the surface are strongly influenced by the size of the abrasive particles. In addition to the abrasive type, should be clearly defined and also the average size of the abrasive particles;
- The material removal rate is proportional with the speed of rotation of the lapping plates. The surface quality obtained after parallel plane lapping process is practically independent of the rotation speed of the lapping plates;

Based on the three criteria: energetic criterion, technological criterion and dynamic criterion we can determine the optimum power drive motors of lapping plates, of speed rotation lapping plates, of specific pressure force of lapping and stiffness superfinishing plan machines with abrasive suspension.

Environmental considerations and their legal and economic implications will play a major role in the development of new superfinishing technologies, particularly in fluid minimization or elimination strategies.

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