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Analysis of Variance for Surface Roughness Produced During Vibration Assisted Lapping Process

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Abstract

Lapping is a crucial surface super finishing technology which includes rubbing of flat surfaces by introduction of abrasive slurry between them performed either by hand reciprocating movement or assisted by machine. Graphite, being commonly used material as base for precision measuring instruments is selected for experimentation and hence required high level of accuracy. By making slight modifications in the conventional lapping process, enhanced level of resulting surface finish can be achieved. In the current experiment, static pressure plate is replaced by vibratory mechanism. Analysis of variance has been carried out to identify the most influencing input parameter on the response parameters by performing series of experiments.

Keywords—Lapping; Vibration; Surface roughness; DOE; ANOVA

1. Introduction

Lapping is very fine machining method that allows getting very high surface qualities, form accuracies, and close dimensional tolerances. In this experiment, pressure plate of lapping machine has been replaced by vibrating plate. Main objective was to find out the effect of vibration on surface roughness and compare the result with conventional lapping. Design of Experiments can be carried out by varying the input parameters like abrasive size, cycle time and mode of lapping (with and without vibration). From the experimental results, Analysis of Variance can be carried out to find out the most influential input parameter on surface roughness. Conventional lapping applies constant load on the work piece whereas vibratory lapping applies dynamic. This load will provide space for the abrasive slurry to move between the pressure plates and the work piece which results in uniform lapping. Also, dynamic force will have more impact on work piece as compared to static one. This will help in faster material removal rate and better finished surface.

2. Literature Review

Frank A. Pizzarello et. al. have made an assembly where lapping plate is reciprocating with the help of spring actuating mechanism and this was patented. In this mechanism, drive or vibration is provided by peripherally mounted electromagnetic solenoids whose force is applied tangential to the direction of rotation. The results show that vibrating force gives better roughness that static. [2]

Hyuk-Min Kim, et. al. studied double sided lapping for sapphire work piece using diamond abrasive pad plus alumina slurry TEA (Triethanolamine) as dispersant. It has been found that material removal rate and surface roughness increase with the increase in alumina to dispersant ratio, lapping pressure as well as size of diamond particles used. [3]

S. M. Fulmali, et. al. found that wedge and seat rings are in constant pressure due to opening and closing of a gate valve. Hence, they often require lapping. In their research, portable lapping machine uses mounting gears on drilling machine to obtain the shaft speed of 80-100 rpm and then connected to pressure plate. This setup would require minimum manual efforts and save setup time. [4]

N. Umehara et. al. found out that in traditional methods of super finishing material removal is random and cannot be concentrated to specific area as per requirement. Diamond abrasive grain with the diameter less than 0.25 μm was used. By using magnetic properties, constant material removal rate is obtained with uniform and smooth surface finish. [9]

3. Experimentation Details and Material Selection

3.1. Work piece

The material of work piece is Black Galaxy Granite having a dark black background with golden sparks in it. Its dimensions are 50 × 50 × 17 mm^3.

Property	Value
Compressive Strength	2777 kg/cm^2
Ultimate Tensile Strength	274 kg/cm^2
Coefficient of Thermal expansion	0.0045 mm/m°C
Water Absorption	0.04%
Specific Gravity	2.960 kg/m^3
Hardness (Mohr's scale)	6.5

Table 1: Properties of granite

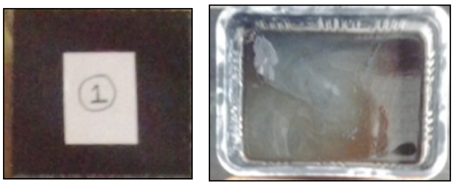

Figure 1: Work-piece and abrasive slurry

3.2. Abrasive

Carborundum (SiC) slurry has been used as abrasive for experimentation, with Density 3.21 g/cm3, Bulk Modulus 250GPa and Thermal Conductivity 3.6W cm-1K-1.

Abrasive	Grit size	Grain Size (μm)
Fine	150	89
Medium	80	165
Coarse	60	254

Table 2: Carborundum size

3.3. Setup Modification

Pressure plate of the machine is replaced by vibrating plate. 220 Volt DC motor with 3100 rpm is connected with an eccentric weight (mild steel - rotor). The difference of weight between vibrating plate and pressure plate has been welded, to maintain constant weight of plates, i.e. 2.3 kg. Circuit is completed to convert DC motor to AC supply.

Outer Diameter	Hole Diameter	Weight	Eccentricity
36mm	6mm	0.05kg	5mm

Table 3: Rotor Dimensions

Figure 2: Views of DC motor with eccentric weight and vibrating pressure plate

3.4. Amplitude and Frequency calculation for vibrator

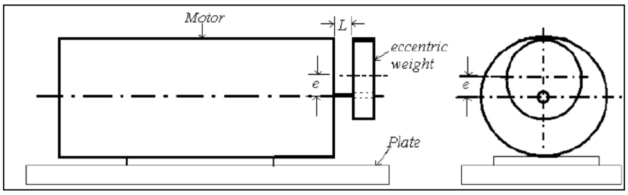

Figure 3: Block diagram of vibrating plate

- Eccentricity e = 5 mm
- Length L = 10 mm
- Modulus of elasticity E = 130 GPa (For rotor material)
- Angular Frequency of motor ω = $\frac{2\pi N}{60}$ = 324.63 rad/s
- Moment of Inertia I = $\frac{\pi}{64}$ (D4 – d4) = 8.23 * 10-8 m4

Considering it as a cantilever beam,

- Stiffness of the shaft k = $\frac{3EI}{L^3}$ = 32.128N/m
- Natural Frequency ωn = $\sqrt{\frac{k}{m}}$ = 8.01 rad/s
- Amplitude of vibrations X = $\frac{\left(\frac{\omega}{\omega n}\right)^2 e}{\left(1-\left(\frac{\omega}{\omega n}\right)^2\right)}$ = -5 mm

(Negative sign indicates out of phase displacement)

- Deflection of rotor δ = $\frac{WL^3}{3EI}$ = 0.1556 m i.e. 15 mm
- Frequency f = $\frac{N}{60}$ = 54.66 Hz

Hence, from the above calculations, amplitude is 5 mm (absolute) and frequency is 54.66 Hz.

3.5. Input parameters and their levels

Initial lapping has been carried out for a work piece having initial roughness 1.98 µm for 5 min and final roughness measured was 1.82 µm. This indicates that there is no significant effect on surface roughness until 5 minutes of lapping. Therefore, minimum time of lapping is taken as 10 minutes and time interval between the levels is taken as 15 minutes. Hence, 3 levels of cycle time selected are 10, 25 and 40 minutes. Experiments are done in 2 different modes, conventional and vibrating. Hence, we select 3 input parameters, having levels 2, 2 and 3 respectively. Hence, total number of experiments performed is $2^2 \times 3^1$=12.

Parameter	L_1	L_2	L_3
Abrasive Grit size / Grain size (X_1)	Fine (150) / 89 µm	Medium (80)/ 165 µm	-
Cycle Time (min) (X_2)	10	25	40
Mode of Lapping (X_3)	Steady Pressure Plate	Vibrating Pressure Plate	-

Table 4: Levels of input parameter

3.6. Work-piece preparation

Initial lapping is carried out using coarse abrasive having grit size 60 (Grain Size 254 µm) for 20 minutes. As a result, all the work pieces with same initial conditions are obtained.

Sr. No.	Initial Surface Roughness (µm)
1	1.82
2	2.59
3	2.22
4	2.07
5	2.22
6	1.66
7	1.48
8	2.16
9	2.66
10	1.55
11	1.90
12	1.84

Table 5: Rotor Dimensions

4. Design of Experiments

In this experiment, 2 factors having 2 levels, and 1 factor having 3 levels have been considered. Such a design is called mixed level design. Hence, we perform $2^2 \times 3^1=12$ experiments.

Std. order	Run order	Abrasive size	Cycle Time	Mode of Lapping
5	1	1	3	2
1	2	1	1	2
2	3	1	1	1
11	4	2	3	2
3	5	1	2	2
12	6	2	3	1
9	7	2	2	2
4	8	1	2	1
10	9	2	2	1
8	10	2	1	1
7	11	2	1	2
6	12	1	3	1

Table 6: DOE Table

Randomized order for performing experiments is as shown in Table 6. Experiments are performed as per the run order and final surface roughness is measured as shown in Table 7.

Sr. No.	Abrasive Size	Cycle Time (min)	Mode of Lapping	Final Surface Roughness (µm)
1	150	40	2	0.97
2	150	10	2	2.79
3	150	10	1	2.24
4	80	40	2	1.89
5	150	25	2	1.49
6	80	40	1	1.52
7	80	25	2	1.98
8	150	25	1	2.76
9	80	25	1	2.78
10	80	10	1	2.93
11	80	10	2	2.16
12	150	40	1	1.3

Table 7: Final Reading

5. Analysis of Variance (ANOVA)

Analysis of Variance is one of the most powerful tools for analyzing data in designed experiments. It determines whether an important difference observed in the data is true, or just because of sampling variations.

5.1. ANOVA of experimentation result

General Full Factorial Design is created with 3 factors out of which 2 factors have 2 levels and 1 factor has 3 levels. Results of surface roughness obtained after experimentation are entered and ANOVA is carried out.

Factor	Levels	Values
Abrasive size	2	1, 2
Mode of Lapping	2	1, 2
Cycle Time	3	1, 2, 3

Table 8: General linear model

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Abrasive size	1	0.2437	0.2437	0.2437	1.2	0.31
Mode of Lapping	1	0.4219	0.4219	0.4219	2.08	0.193
Cycle Time	2	2.6696	2.6696	1.3348	6.57	0.025
Error	7	1.4223	1.4223	0.2032	--	--
Total	11	4.7574	--	--	--	--

Table 9: ANOVA

ANOVA result is shown in Table X. Here, α-level selected is 5 %. Hence, it is clear that cycle time is the most significant input parameter for roughness, as its P-value is 0.025 which is ≤ 0.05 (i.e. Confidence level). Cycle time largely affects the surface roughness. The significance of abrasive size and mode of lapping on roughness is very less. This is because quantity of abrasive particles added and its time interval play an important role in producing surface roughness. Also, in this case frequency of vibration used is 50 Hz. It also indicates its less significance on affecting the surface roughness.

5.2. Main Effect and Interaction Plot

In order to analyze the result effectively and easily, we use graphical approach. Main Effects Plot and Interaction Plot for surface roughness are displayed in fig. 4.

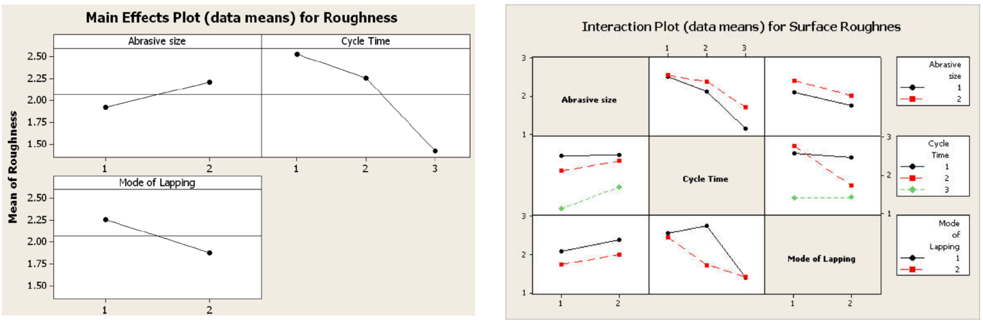

Figure 4: Main Effects and Interaction Plot for Roughness

From the fig. 4, surface roughness increases as the abrasive grit size decreases. This is because, finer is the work piece, easier it is to roll and remove the material by cutting. Hence, finer abrasive gives better surface finish. Surface roughness decreases as the cycle time increases. Surface roughness value is less for vibrating mode even if all the other parameters are same. Vibration produces variable pressure. As known from hammering action, vibrating pressure/ force always have more impact than static. Hence, it results in higher lapping.

Abrasive Size	Cycle Time (min)	Mode of Lapping
150 (Fine)	40	2 (Vibrating)

Table 10: Condition for Optimum Surface Roughness

6. Conclusion

Cycle time is one of the most significant factors for producing better surface finish. This indicates that cycle time must be controlled and designed in such a way so as to achieve desired surface finish. Abrasive grit size and mode of lapping should be selected appropriately based on the characteristics of work piece. As the abrasive grains become fine, value of surface roughness improves. Also, as the cycle time increases, surface roughness value decreases, i.e. surface finish improves.

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