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Effect Of Process Parameters On Material Removal Rate In Internal Gear Honing

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Abstract

Abrasive machining is one of the key technologies in gear manufacturing. Amongst abrasive finishing processes of hardened gears, internal gear honing process characterized by cutting speeds as low as 0.3–5 m/s in order to obtain fine finishing of gear tooth flank. A lot of effort has been spent to increase the productivity of such low speed internal gear honing process. From the discussion with company peoples and with the help of research paper it strongly felt that productivity of internal gear honing process bears a direct relationship with material removal rate. In this investigation, an effective approach based on Taguchi method, analysis of variance (ANOVA), multivariable linear regression (MVLR), has been developed to determine the optimum conditions leading to higher material removal rate. Experiments were conducted by varying wheel speed, honing amount, machining time using L9 orthogonal array of Taguchi method. The present work aims at optimizing internal gear honing process parameters to achieve high material removal rate without affecting surface quality. Experimental results from the orthogonal array were used as the training data for the MVLR model to map the relationship between process parameters and material removal rate. The experiment was conducted on primary helical gear of Bajaj Disc-125 two wheeler having material 16MnCr5H steel. From the investigation it concludes that machining time is most influencing parameter followed by wheel speed and honing amount on material removal rate (MRR).

Keywords: ANOVA; Internal gear honing; MRR; MVLR analysis.

1. Introduction

Gear honing was applied for the first time in the 70's of the last century to remove transportation damages on hardened tooth flanks. The honing distinguishes from established tooth flank grinding processes in the kinematics and the tool, which usually has a gear shape. Internal gear honing is a crossed-axis, fine, hard finishing process that uses pressure and abrasive honing wheel with geometrically undefined cutting edges to remove material along the tooth flanks in order to improve the surface finish and improves run out, lead and profile characteristics[1]. It performs the simultaneously rotational and reciprocation movement. The process is similar to shaving in that a crossed-axis setup is used to produce the sliding velocity necessary to remove stock means of high pressure, sliding action and an abrasive honing wheel [2]. Generally a conventional gear honing is done after gear profile grinding process for fine finishing of gear flank. The stock remove in conventional honing process is 5 -10 µm per tooth flank. But now a day a high performance internal gear honing is done directly after case hardening with increased stock removal as a substitute for gear grinding and conventional gear honing. This process also known as "Direct honing" or "Power honing". About 20 -40 µm per flank material remove in power honing [3]. The primary Benefits of internal gear honing are the higher contact surfaces offered by rolling a given gear with an internal honing wheel. Due to the higher overlapping ratio and the resulting better force distribution the achievable honing quality is more constant[4]. The cutting speed has an axial component in the tooth trace direction and a tangential component in the profile direction. This produces a up-root-oriented surface structure that has improved noise qualities [5]. The advantages of the low cutting velocities is the induction of high residual compressive stresses on the flank surface which results in greater wear resistance and a longer gear lifetime, also there is no thermal damage of gear tooth[6]. In internal gear honing the cutting speed is very low i.e from 0.3 -5 m/s which results in achieve very high quality of surface finish ranges from Rz= 2-5 µm with very low material removal rate which affect the productivity of process[7].

So that in this investigation we have increase the productivity of internal gear honing process by increasing material removal rate without affecting the quality of surface finish. During complete investigations, after honing process check the surface quality of lead and profile of gear teeth with the help of graph which is plotted by maag gear testing machine, the aim was to achieve the smallest possible cycle time along with the required surface quality. Before going to the main experimentation, some discussion with company peoples and with the help of research paper I was selected three input parameter like wheel speed, honing amount, machining time. By performing OVAT (One Variable At a Time) analysis it is clear that wheel speed, honing amount, machining time are influencing parameters on MRR and selected three levels for each parameter according to results. According to OVAT analysis following input parameters namely wheel speed, honing amount, machining time are selected by keeping other process parameters constant which are less influencing on material removal rate.

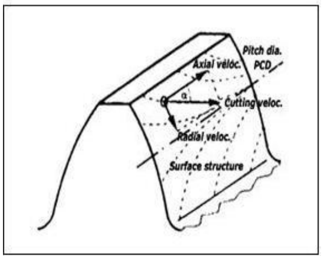

Figure 1 Surface structure of honed gear

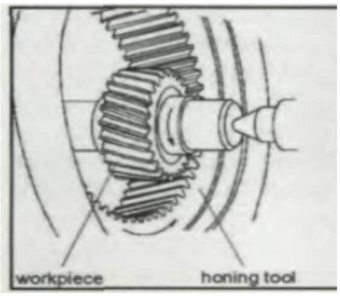

Figure 2 Internal gear honing

2. Experimental details

2.1 Design of experiments

Taguchi and Konishi had developed Taguchi techniques[8]. These techniques have been utilized widely in engineering analysis to optimize the performance characteristics within the combination of design parameters. Taguchi technique is also power tool for the design of high quality systems. It introduces an integrated approach that is simple and efficient to find the best range of designs for quality, performance, and computational cost [9]**.** In this study we have consider 3 factors which affect majorly on quality characteristic such as (A) Wheel Speed , (B) Honing Amount ,(C) Machining Time. The design of experiment was carried out by Taguchi methodology using Minitab 14 software. In this technique the main objective is to optimize the material removal rate that is influenced by three input process parameters.

2.2 Selection of control factors

From the discussion with company peoples and with the help of research paper it strongly felt that the productivity of gear honing process bears a direct relationship with material removal rate. So that MRR in gms/sec are selected as response parameter for experimentation.

2.3 Selection of orthogonal array

Since 3 controllable factors and three levels of each factor were considered L9 (3**3) Orthogonal Array was selected for this investigation.

2.4 Experimental set up

A Series of experiment was conducted to evaluate the influence of internal gear honing process parameters on material removal rate. The test was carried out on K-300 Fassler Gear Teeth Honing CNC Machine (Siemens Auto.). Internal geared honing wheel consist of a grit material is a mixture of refined aluminium oxide (70%) and Sol-Gel- Corundum (30%) with a grain size 180.The grains were bonded in synthetic resin. The modulus of elasticity of the alloy wheel is 21 N/m2 and it has a density of 2.45 g/cm3[10]. During gear honing, honing oil 'HON7'was used. The experiment was conducted by keeping all other parameter constant. The constant parameters was honing oil pressure (1.5 bar), radial infeed (2µm/stroke), rapid infeed end position (0.01mm), tailstock pressure (1KN) applied to clamp the gear during operation, hydraulic pressure (17.20 Kg/cm²) applied to expand the fixture and hold the gear by exerting the pressure at bore diameter.

Figure 3 K-3OO Gear teeth honing CNC machine (Siemens Auto.)

2.5 Work material

A primary helical gear of Bajaj Disc-125 cc two wheeler selected for experimentation having material 16MnCr5H steel. The chemical composition and hardness of the material is given in the table 1 below,

Table 1 Chemical Composition and Properties of 16MnCr5H Steel

16MnCr5H						
Chemical elements	C	Si max	Mn	P max	S	Cr
Chemical Composition (%)	0.14-0.19	0.4	1.00-1.30	0.035	≤ 0,035	0.80-1.10
Property		Value in metric unit				
Density		7.872×10^3			kg/m^3	
Modulus of elasticity		205			GPa	
Thermal expansion (20 °C)		12.6×10-6			$°C^{-1}$	
Specific heat capacity		452			J/(kg-K)	
Thermal conductivity		44.7			W/(m-K)	
Electric resistivity		2.28×10-7			Ohm-m	
Surface hardness		79 - 84			HRA	
Core hardness		29 - 43			HRC	

The specification of helical gear is given in the table 2 below,

Table 2 Specification of helical gear

Two wheeler Disc-125 helical gear specifications	
Outer Diameter	120.3 - 120.5 mm
Number Of Teeth	75
Module	1.5
Helix Angle	17 °
Direction Of Helix Angle	Right
Pressure Angle	17.5°
Pitch Circle Diameter	117.64 mm
Over Pin Diameter	120.731 - 120.796 mm

2.6 Weight measurement

The weight of the gear taken before and after the experimentation to find out the material removal rate. For weight measurement digital balance machine was used of Phoenix Gold 300 P having maximum capacity of 300 grams and minimum 0.2 grams having error value up to 0.01 grams. The material removal rate is calculated by taking weight difference and divided it by machining time.

3. Experimental conditions

A series of experiment was carried out on K-300 Fassler Gear Teeth Honing CNC Machine (Siemens Auto.). From OVAT analysis three input controlling parameters selected having three levels. Details of parameters and their levels used shown in the table 3,

Table 3 Process parameters and levels

Notation	Process parameters	Level 1	Level 2	Level 3
A	Wheel Speed (rpm)	250	300	350
B	Honing Amount (mm)	0.01	0.02	0.03
C	Machining Time (sec)	25	30	35

The experimental design matrix is obtained by Taguchi methodology by using Minitab 14 software is shown in table 4 below,

Table 4 Layout for Experimental Design according to L9 Array

Exp. No.	A Wheel Speed (rpm)	B Honing Amount (mm)	C Machining Time (sec)
1	250	0.01	25
2	250	0.02	30
3	250	0.03	35
4	300	0.01	30
5	300	0.02	35
6	300	0.03	25
7	350	0.01	35
8	350	0.02	25
9	350	0.03	30

4. Results and Discussion

4.1 S/N Ratio Analysis

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), or larger is better (LB). Larger is better S/N ratio used here because the quality characteristic is MRR. Larger -the-better quality characteristic was implemented and introduced in this study.

Larger the better characteristic,

$$S/N = -10 \log10 (MSD)$$

Where MSD= Mean Squared Division

$$MSD = (1/Y_1^2 + 1/Y_2^2 + 1/Y_3^2 + \ldots\ldots\ldots\ldots)/n$$

Where Y1, Y2, Y3 are the responses and n is the number of tests in a trial and m is the target value of the result. Table 5 indicate avg. MRR and S/N ratios for different combinations of design matrix. A combination of factors with highest S/N ratio is the optimum situation where the MRR is maximum.

Table 5 summary Report for different trial conducted during Experimentation

Trial No.	MRR (gms/sec)			Avg. MRR (gms/sec)	S/N Ratio
	Trial 1	Trial 2	Trial 3		
1	0.0398	0.0391	0.0399	0.0396	-28.0461
2	0.0377	0.0373	0.0368	0.0373	-28.5658
3	0.0361	0.0374	0.037	0.0368	-28.683
4	0.0401	0.0403	0.0404	0.0403	-27.8939
5	0.0397	0.0396	0.037	0.0388	-28.2234
6	0.0349	0.0356	0.035	0.052	-25.6799
7	0.038	0.0376	0.039	0.0382	-28.3587
8	0.0471	0.0468	0.0465	0.0468	-26.5951
9	0.0349	0.0354	0.0343	0.049	-26.1961

Table 6 Estimated Model Coefficient for SN ratios

Term	Coef	SE Coef	T	P
Constant	-27.582	0.07203	-382.926	0
Wheel Ro 250	-0.8492	0.10187	-8.336	0.014
Wheel Ro 300	0.3167	0.10187	3.109	0.09
Honing A 0.01	-0.5171	0.10187	-5.076	0.037
Honing A 0.02	-0.2123	0.10187	-2.084	0.173
Machining T 25	0.8087	0.10187	7.939	0.015
Machining T 30	0.0305	0.10187	0.3	0.793

Summary of Model- S = 0.2161 R-Sq = 99.1% R-Sq(adj) = 96.3%

Table 7 Response Table for Signal to Noise Ratios - Larger is better (MRR)

Level	Wheel Rotation (rpm)	Honing Amount (mm)	Machining Time (sec)
1	-28.43	-28.1	-26.77
2	-27.27	-27.79	-27.55
3	-27.05	-26.85	-28.42
Delta	1.38	1.25	1.65
Rank	2	3	1

The level of a factor with the highest S/N ratio was the optimum level for responses measured. From the Table 7 and Figure 4 it is clear that, the optimum value levels for higher material removal rate are at a wheel speed (350 rpm), honing amount (0.03 mm), and machining time (25 sec). The response table includes ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values; rank one to the highest Delta value, rank two to the Second highest, and so on. From both ANOVA and response tables it is clear that the most significant factor is machining time (C), followed by wheel speed (A) and honing amount (B). Figure 4 shows graphically the effect of the three control factors on material removal rate.

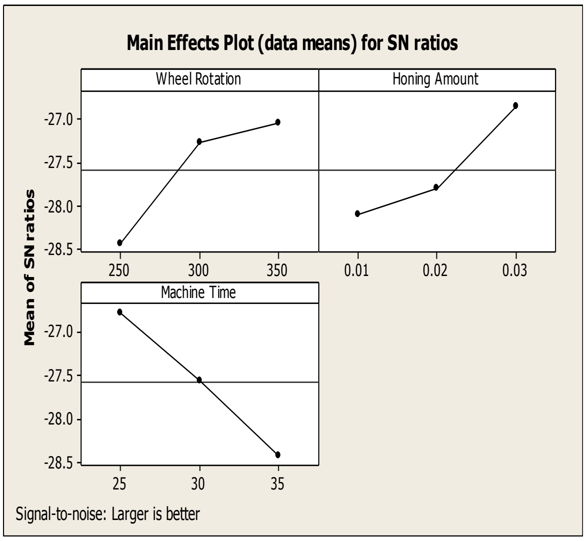

Figure 4 Effect of process parameters on S/N Ratio

4.2 Analysis of Variance (ANOVA)

The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 14 specially used for design of experiment applications. In order to find out statistical Significance of various factors like wheel speed (A), honing amount (B), and machining time(C), and their interactions on material removal rate, analysis of variance (ANOVA) is performed on experimental data. Table 8 shows the result of the ANOVA with the material removal rate. The last column of the table indicates p-value for the individual control factors. It is known that smaller the p-value, greater the significance of the factor. The ANOVA table for S/N ratio (Table 8) indicate that, the machining time (p=0.022), wheel speed (p= 0.027) and honing amount (p=0.036) in this order, are significant control factors effecting material removal rate. It means, the machining time is the most influencing factor and the honing amount has less influence on the performance output compared to machining time.

Table 8 Analysis of Variance for S/N ratios (Material Removal Rate)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Wheel Rotation (rpm)	2	3.315	3.315	1.658	35.5	0.03
Honing Amount (mm)	2	2.5337	2.534	1.267	27.1	0.04
Machining Time (sec)	2	4.0781	4.078	2.039	43.7	0.02
Residual Error	2	0.0934	0.093	0.047		
Total	8	10.02				

4.3 Percent contribution

Percent contribution to the total sum of square can be used to evaluate the importance of a change in the process parameter on these quality characteristics

Percent contribution (P) = (SS'A / SST) *100

Table 9 Optimum Condition and Percent Contribution

SR. No.	Factors	Level Description	Level	Contribution (%)
1	A: Wheel Speed	350	3	33.08
2	B: Honing Amount	0.03	3	25.28
3	C:Machining Time	25	1	40.7

From the Table 8 it is clear that machining time is most influencing while honing amount is least influencing parameter on MRR.

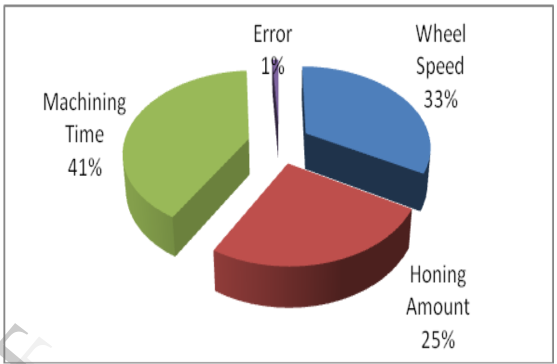

Figure 5 Percentage contribution of machining parameters

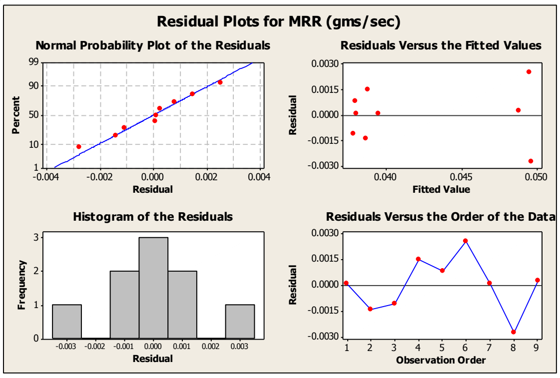

Figure 6 Residual Plots for MRR

4.4 Regression Analysis

Mathematical models for process parameters such as wheel speed, honing amount and machining time were obtained from regression analysis using MINITAB 14 statistical software to predict material removal rate. The regression equation is

Y= 0.0398 + 0.000068*A + 0.328*B - 0.000820*C ………………….. (1)

S = 0.00201025 R-Sq= 92.1%

R- Sq(adj)=87.3%

Where, Y = Response i.e. Material Removal Rate (gms/sec), A = Wheel Speed (rpm), B = Honing Amount (mm), C = Machining Time (sec). If we put optimum parameters which are drawn by ANOVA in equation 1 it will give optimum value of quality characteristic which is maximum MRR.

$$Y_{opt} = 0.0398 + 0.000068*A_3 + 0.328*B_3 - 0.000820*C_1$$

$$Y\ opt = 0.0398 + 0.000068*350 + 0.328*0.03 - 0.000820*25$$

Y opt = 0.05294 gms/sec (Predicted by Regression Equation)

In multiple linear regression analysis, R2 is value of the correlation coefficient and should be between 0.8 and 1. In this study, results obtained from MRR in good agreement with regression models (R2>0.80).

4.5 Conformation Experiments

In Order to test the predicted result, confirmation experiment has been conducted by running another four trials at the optimal settings of the process parameters determined from the Analysis i.e. $A_3B_3C_1$

Observation	Trial			Avg. MRR (gms/sec)	S/N Ratio
	1	2	3		
1	0.0532	0.0528	0.053	0.053	-25.5

The results are shown in above table and it is observed that the average MRR i.e. 0.053 gms/sec and average S/N Ratio -25.50 which falls within predicted 80% Confidence Interval

5. Conclusions

The Taguchi method was applied to find an optimal setting of the internal gear honing process. The result from the Taguchi method chooses an optimal solution from combinations of factors if it gives maximized normalized combined S/N ratio of targeted outputs. The L-9 OA was used to accommodate three control factors and each with 3 levels for experimental plan selected process parameters are Wheel Speed (250, 300, 350 rpm), Honing Amount (0.01, 0.02, 0.03 mm), Machining Time (25, 30, 35 sec). The results are summarized as follows:

1) From the analysis, it is clear that the three process parameters, wheel speed, honing amount and machining time have significant effect on material removal rate.
2) The analysis of variance proves that the most influencing parameters on MRR are machining time and wheel speed. While honing amount is least significant as compared to machining time and wheel speed.
3) The result of present investigation is valid within specified range of process parameters
4) Also the prediction made by Regression Analysis is in good agreement with Confirmation results.
5) The optimal levels of internal gear honing process parameters are found to be $A_3B_3C_1$:

Wheel Speed (rpm)	350
Honing Amount (mm)	0.03
Machining Time (sec)	25

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