OPTIMIZATION OF CAM INDEX DRIVE FOR IMPROVING FINISH AND DIMENSION ACCURACY

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Abstract : Main body120 is the main casing of global cam index drive.it is the assembly of cam shaft and turret assembly connected in 90^0 with each other. Any misalignment and improper surface finish between connecting parts of assembly creates the jerk in motion and hence produce the excess vibration and unwanted noise. Consecutively to decrease the excess vibration and to improve the production quality in this work optimization of the process parameters for milling process is carried out. Experimentation is done on Vertical machining centre (VMC-640) machine. For optimization of process parameters Taguchi optimization technique is used and experimental work is done by using L_9 Taguchi orthogonal array. The control factors for this research involved are spindle speed, feed rate and depth of cut. While the response variables are Surface Roughness and accuracy of Dimensional Deviation. Through the study of statistical analysis of response variables and signal-to-noise ratios, the shown important variables are spindle speed, feed rate and the best possible combination of cutting parameters is chosen.

Keywords —Dimensional deviation; End milling operation; Surface Roughness; Taguchi Design;

I. INTRODUCTION

In today's automotive industry where simulation and virtual prototyping are increasingly used to reduce time to market, the design process has changed considerably since Taguchi invented the quality planning concept. And found that it is often more costly to control the causes of manufacturing variation than making a process insensitive to these variations. In general, standard deviation is used as a measure for the robustness of the outputs: the smaller the output standard deviation, the more robust the output. As a robust design optimization software solution, Optimum incorporates the Taguchi method for robust design to deliver designs that are more robust with respect to manufacturing and geometric tolerances.

Main Body 120 is the main part of the global Cam indexing drive. It is used for mounting the indexing plate of machines. Indexing plate is mainly used in a Production and Packaging machines. Main body is an assembly of cam and turret assembly, in which turret assembly is connected at 900 with cam shaft. So that any misalignment in the cam and turret assembly mounting produces the jerk in cam motion which creates the unwanted noise and excess vibrations during the working of machine and it affects the production rate and quality of product. The "Globoidal Cam Index Drives" are mechanical index tables which convert, continuous rotary input motion into intermittent, indexing output motion. The input shaft carries the Globoidal cam. This cam has a groove, which obeys the acceleration control "motion law". The output shaft carries the cam followers, which engage in the groove of the cam.

II. TAGUCHI METHOD

2.1 Taguchi Design

One method presented in this study is an experimental design process called the Taguchi design method. The main principles behind the Taguchi method for robust design are,

1. Robustness is first, adjusting average to meet the target is last.
2. To improve product quality, parameter design is first, tolerance design is last.

From Taguchi's point of view, there are three sequential stages for optimizing a product (or process): system design, parameter design, and tolerance design. The system design stage occurs when new concepts or methods are introduced to a new product or process. The parameter design stage is for improving the uniformity of a product. At this stage, Taguchi believes that the performance parameters of a product (or process) should be set to make the performance less sensitive to environmental (uncontrollable) conditions such as road temperature or humidity. Tolerance design stage is for determining the acceptable range of variability around the nominal value determined in the parameter stage. Taguchi utilizes traditional method like ANOVA and orthogonal arrays with a new class of statistics called signal-to-noise ratios in designing an experiment. He calls these types of designs methodology "Taguchi robust design". Taguchi Methods to Robust design focus on the principles of producing higher quality goods faster and cheaper, with more consumer satisfaction.

Taguchi's approach is totally based on statistical design of experiments, and this can economically satisfy the needs of problem solving and product/process design optimization. By applying this technique one can significantly reduce the time required for experimental investigation, as it is effective in investigating the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence, which less.

2.2 Selection of Control Factors, Response Factors and Orthogonal Array

The primary factors in milling operation are Spindle speed, feed rate, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course but these three are the ones the operator can change by adjusting the controls, right at the machine. In this Investigation, Response Parameters like surface roughness and dimensional deviation were considered.

Table 2.1: Machining Parameters, Codes, and Level Values Used For Orthogonal Array.

Parameter	Code	Level 1	Level 2	Level 3
Control factors				
Spindle Speed,(rpm)	A	3000	3200	3400
Feed rate, (mmpm)	B	1400	1600	1800
Depth of cut, (mm)	C	0.3	0.5	0.7
Response variables				
Surface finish,(µm)	Ra	_	_	_
Dimensional Deviation, (mm)	D	_	_	_

After the control factors are determined, the next step is to select a proper orthogonal array. Taguchi method is a powerful tool in quality optimization that makes use of a special design of Orthogonal Array (OA) to examine number of experiments used to design the orthogonal array for 3 parameters like Spindle speed, feed rate and depth of cut for each parameter at three different levels. The minimum number of experiments to be conducted for the parametric optimization is calculated as

Minimum experiments = $[(L - 1) \text{ X } P] + 1$
$= [(3 - 1) \text{ X } 3] + 1$
$= 7\sim L_9$.

Where L= No. of Levels.
And P= No. of Parameter.

Taguchi Design

Taguchi Orthogonal Array Design
L_9 (3^3)
Factors: 3
Runs: 9
Columns of L_9 (3^3) Array.

Three levels are specified for each factors, first column is assigned for spindle speed A, second column is for feed rate B and third column is for depth of cut C. The test is performed for each combination and resulting in a total of 9 experiments which allows analysis of variance of results. For the study purpose each experimental run is replicated twice. Since there are three control factors, the standardized Taguchi-based experimental design, a L_9 (3^3) orthogonal array, is used as shown in Table 2.2. This L_9 (3^3) orthogonal array can make use of up to three control factors, with three levels of each factor. A total of nine experimental runs must be conducted, using the combination of levels for each control factor.

Table 2.2: The basic Taguchi L_9 (3^3) orthogonal array

Run Order	Control Factors		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

After the orthogonal array has been selected, the second step in Taguchi parameter design is running the experiment.

III. PLAN OF EXPERIMENTS

3.1 Experimental Results

After conducting the experiments according to the Taguchi orthogonal array following results have been taken for surface finish and accuracy of dimensional deviation. Each experiment is replicated twice. It means that total 18 experiments are performed.

Table 3.1 Experimental Results for Surface Finish and Dimensional Deviation

Run Order	Control factors			Surface Finish (Ra) (μm)	Dimensional Deviation (D) (mm)
	A	B	C	Ra	D
1	3000	1400	0.3	1.77	0.03
2	3000	1600	0.5	2.84	0.02
3	3000	1800	0.7	2.11	0.035
4	3200	1400	0.5	2.40	0.02
5	3200	1600	0.7	2.70	0.045
6	3200	1800	0.3	1.98	0.02
7	3400	1400	0.7	1.67	0.02
8	3400	1600	0.3	1.85	0.02
9	3400	1800	0.5	1.39	0.017

3.2 Analysis and Discussion of Result

The procedures after the experimental runs have been completed are analyzing the data and identifying the optimal levels for all the control factors. In Table 3.1, surface roughness measurements and dimensional deviations are noted for each run in the array. To better evaluate the experiments performance, not only response variables (surface roughness Ra and dimensional deviation D) are analyzed, but also one column has been added to this array to indicate the signal-to-noise (S/N) ratio.
The statistical measure of performance like Signal-to-Noise (S/N) ratio depends on optimization of the quality characteristics and is used to identify the best set of parameters for the responses generated in operations of end-milling processes. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the smaller the better, the higher the better, and the nominal the best. The formula used for calculating S/N ratio is given below.

Smaller the better:
It is used where the smaller value is desired.

$$S / N\, ratio\,(\eta) = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n} y_i^2$$

Where y_i= observed response value and
n = number of replications.

Nominal the best:
It is used where the nominal or target value and variation about that value is minimum.

$$S / N\, ratio\,(\eta) = -10\ \log_{10}\frac{\mu^2}{\sigma^2}$$

Where μ = mean and
σ = variance.

Higher the better:
It is used where the larger value is desired.

$$S / N\, ratio\,(\eta) = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$$

Where y_i= observed response value and
n = number of replications.

3.3 Analysis for Surface Roughness

Calculation of S/N Ratio for Ra

Table 3.2 S/N Ratio Table for Surface Roughness

Run Order	Control factors			Surface Finish (Ra) (µm)	S/N Ratio
	A	B	C	Ra	
1	3000	1400	0.3	1.77	-5.047
2	3000	1600	0.5	2.84	-9.2325
3	3000	1800	0.7	2.11	-6.519
4	3200	1400	0.5	2.40	-8.2840
5	3200	1600	0.7	2.70	-8.8321
6	3200	1800	0.3	1.98	-6.590
7	3400	1400	0.7	1.67	-4.9613
8	3400	1600	0.3	1.85	-6.0924
9	3400	1800	0.5	1.39	-3.391

Effect of Input Factor on Ra

For Ra, The calculation of S/ N Ratio follows "smaller the better" as we required smaller value of surface roughness. The ANOM (Analysis of Means) for S/N Ratio is calculated.

Table 3.3 Response Table for Means of S/N Ratio of Surface Roughness Using Minitab 17

Level	A	B	C
1	-6.9328	-6.0974	-5.9098*
2	-7.9020	-8.0523	-6.9691
3	-4.8149*	-5.500*	-6.7708
Δ(max−min)	3.0871	2.5523	1.0593
Rank	1	2	3

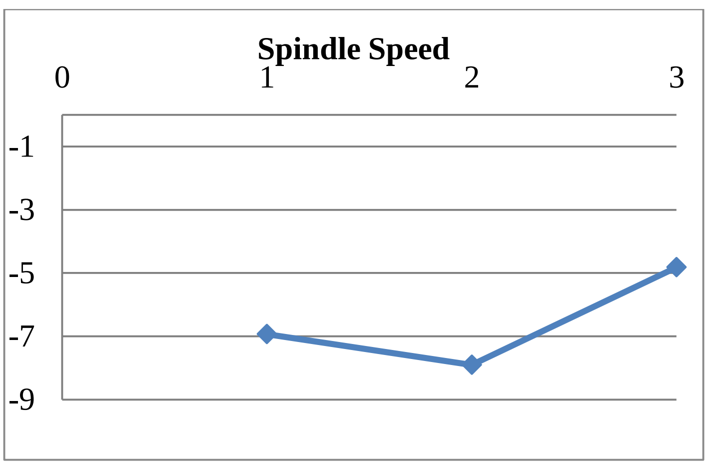

Figure 3.1 S/N Ratio Vs Spindle Speed for Surface roughness

From Figure 3.1, it is observed that, the means of S/N ratio for surface roughness increases with the increasing spindle speed for moderate to high level of the spindle speed. As the level 3 of the spindle speed is corresponds to high value of S/N ratio level 3 is the optimal level of the spindle speed (i.e. A_3=3400 rpm).

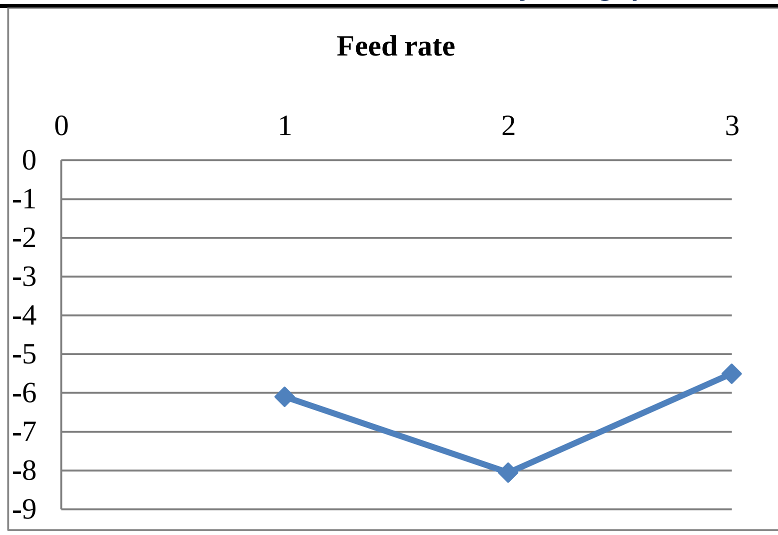

Figure 3.2 S/N Ratio vs feed rate for Surface roughness

From Figure 3.2, it is observed that, the means of S/N ratio for surface roughness increases with the increasing feed rate for moderate to high level of Feed rate. As the level 3 of the feed rate is corresponds to high value of S/N ratio level 3 is the optimal level of the feed rate (i.e. B_3=1800 mm/min).

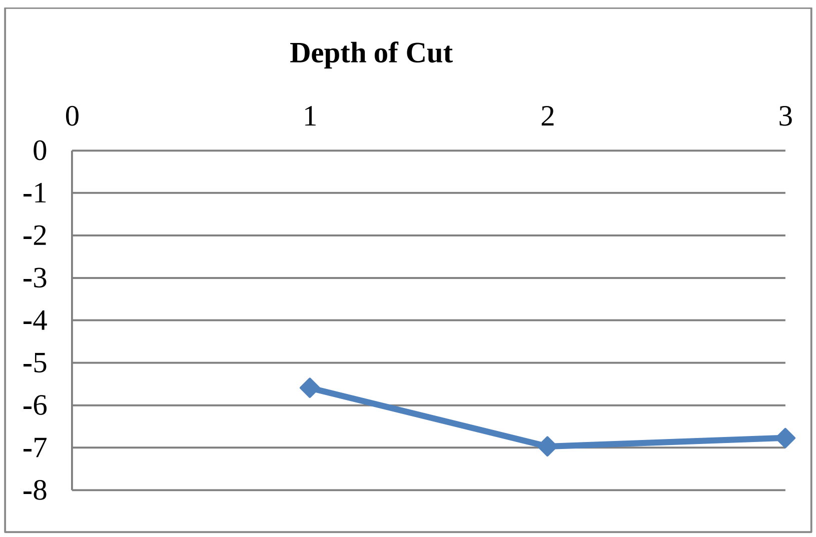

Figure 3.3 S/N Ratio vs. Depth of cut for Surface roughness

From Figure 3.3, it is observed that, the means of S/N ratio for surface roughness decreases with the decreasing Depth of cut. As the level 1 of the Depth of cut is corresponds to high value of S/N ratio level 1 is the optimal level of the Depth of cut (i.e. C_1=0.3 mm). For Ra, The calculation means follows "smaller the better" as we required smaller value of Surface finish.

Table 3.4 Optimum Parameters for surface roughness.

	Spindle speed (rpm)	Feed rate (mm/m)	Depth of cut (mm)
Surface Roughness (Ra)	3400	1800	0.3

Taguchi Analysis for Surface Roughness:

$\eta_{opt} = \eta_m +$ (Optimum level for factor A - η_m) + (optimum level for factor B - η_m) +

(Optimum level for factor C- η_m)

$\eta_{opt} = 1.1785$ µm.

Table 3.5 Confirmation Test Result for Surface Roughness

η Confirmation (µm)			Average (µm)
Run1	**Run2**	**Run3**	
1.212	1.224	1.213	1.216

Table 3.6 Comparison of η and S/N ratio for Surface Roughness

	η (µm)	S/N ratio
Taguchi analysis	1.1785	-1.4229
Experimental	1.216	-1.70

3.4 Analysis for Dimensional Deviation

Calculation of S/N Ratio for D

Table 3.7 S/N Ratio Table for Dimensional deviation

Run Order	Control factors			Dimensional deviation (D) (mm)	S/N Ratio
	A	B	C	D	
1	3000	1400	0.3	0.03	29.029
2	3000	1600	0.5	0.02	53.979
3	3000	1800	0.7	0.035	36.7264
4	3200	1400	0.5	0.02	53.010
5	3200	1600	0.7	0.045	45.7675
6	3200	1800	0.3	0.02	53.010
7	3400	1400	0.7	0.02	35.0514
8	3400	1600	0.3	0.02	53.010
9	3400	1800	0.5	0.017	35.0514

Effect of Input Factor on D (Dimensional deviation)

For D, The calculation of S/ N Ratio follows "smaller the better" as we required smaller value of Dimensional deviation. The ANOM (Analysis of Means) for S/N Ratio is calculated.

Table 3.8 Response Table for Means of S/N Ratio of Dimensional deviation Using Minitab 17

Level	A	B	C
1	39.9114	40.4836	45.0163
2	50.5958 *	50.9188 *	47.3468 *
3	42.4911	41.5959	40.6352
Δ(max – min)	10.68	10.43	6.71
Rank	1	2	3

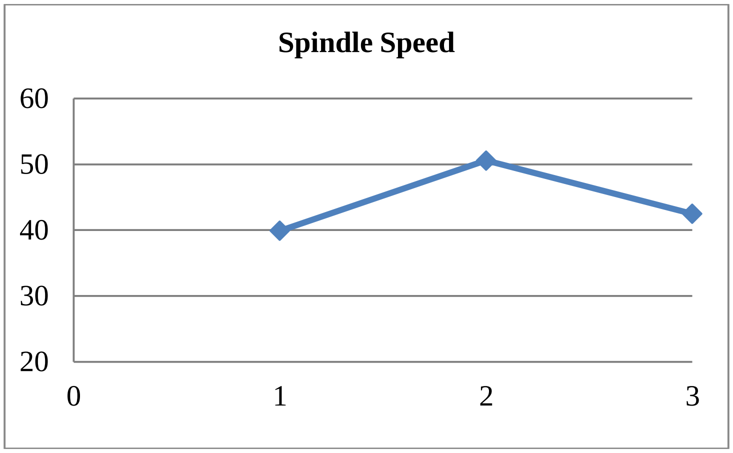

Figure 3.4 S/N Ratio Vs. Spindle Speed for Dimensional deviation

From Figure 3.4, it is observed that, the means of S/N ratio for Dimensional deviation increases with the increasing spindle speed from low to moderate level of spindle speed. As the level 2 of the spindle speed is corresponds to high value of S/N ratio level 2 is the optimal level of the spindle speed (i.e. A_2=3200 rpm).

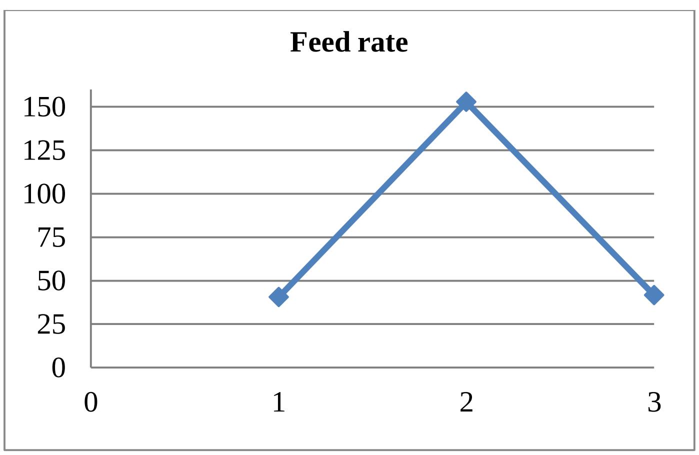

Figure 3.5 S/N Ratio vs. Feed rate for Dimensional deviation

From Figure 3.5, it is observed that, the means of S/N ratio for Dimensional deviation increases with the increasing feed rate from low to moderate level of feed rate. As the level 2 of the feed rate is corresponds to high value of S/N ratio level 2 is the optimal level of the feed rate (i.e. B_2=1600 mm/m).

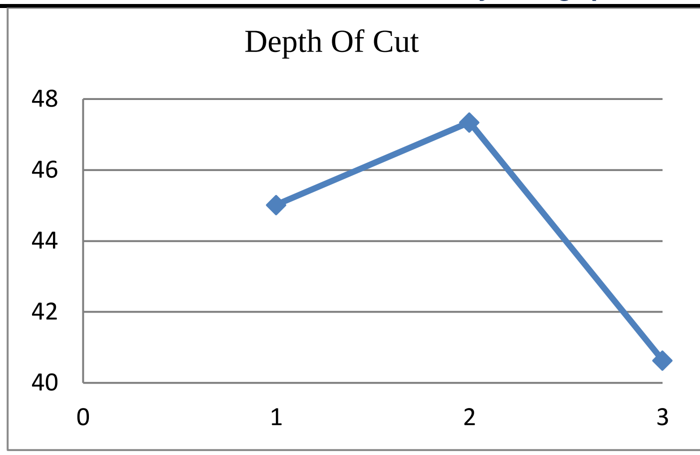

Figure 3.6 S/N Ratio Vs Depth of cut for Dimensional deviation

From Figure 3.6, it is observed that, the means of S/N ratio for Dimensional deviation increases with the increasing Depth of cut from low to moderate level of Depth of cut. As the level 2 of the Depth of cut is corresponds to high value of S/N ratio level 2 is the optimal level of the feed rate (i.e. C_2=0.5 mm).For D, The calculation means follows “smaller the better” as we required smaller value of Dimensional deviation.

Table 3.9 Optimum Parameters for Dimensional Deviation.

	Spindle speed (rpm)	**Feed rate (mm/m)**	**Depth of cut (mm)**
Dimensional Deviation (D)	3200	1600	0.5

Taguchi Analysis for Dimensional Deviation:

$\eta_{opt} = \eta_m +$ (Optimum level for factor A - η_m) + (Optimum level for factor B - η_m) +

(Optimum level for factor C- η_m)

ηopt=0.02566mm

Table 3.10 Confirmation Test Result for Dimensional Deviation

η Confirmation(mm)			**Average (mm)**
Run1	**Run2**	**Run3**	
0.029	0.028	0.028	0.028

Table 3.11 Comparison of η and S/N ratio for Dimensional Deviation

	η (µm)	**S/N ratio**
Taguchi analysis	0.0256	50.85
Experimental	0.028	50.45

IV. RESULT AND DISCUSSION

Table 4.1 Validation Results

	Initial cutting Parameter	Optimal cutting Parameter	
Surface Finish:			
		Experiment	**Taguchi Analysis**
Level	$A_1B_3C_2$	$A_3B_3C_1$	$A_3B_3C_1$
		1.212	
Ra (µm)	3.380	1.224	1.178
		1.213	
S/N ratio	**Improvement of S/N ratio**		
	-10.578	-1.70	-1.4229
Dimensional Deviation:			
Level	$A_1B_3C_2$	$A_2B_2C_2$	$A_2B_2C_2$
		0.029	
D (mm)		0.028	0.0256
		0.028	
S/N ratio	**Improvement of S/N ratio**		
	35.39	50.85	50.45

The results of Surface roughness and accuracy of dimensional deviation for 18 work pieces are studied. The optimum process parameters on surface roughness are obtained as Spindle speed at level 3 (3400 rpm), Feed rate at level 3 (1600 mm/min) and depth of cut at level 1 (0.3 mm). The optimum process parameters on accuracy of dimensional deviation are obtained as Spindle speed at level 2 (3200 rpm), Feed rate at level 2 (1400 mm/min) and depth of cut at level 2 (0.5 mm).

V. CONCLUSION

Based on the above experiment the following conclusion can be drawn,

- The main objective of work is to finding out optimum combination of process parameter for Surface Roughness and accuracy of dimensional deviation of component is found and validate.
- The optimum value for Surface roughness are found to be 3400 rpm spindle speed, 1800 mm/min feed rate and 0.3 mm depth of cut.
- Similarly, the optimum value for accuracy of dimension deviation is 3200 rpm spindle speed, 1600 mm/min fed rate and 0.5 mm depth of cut.
- Validation of experiment is carried out and it is found that the predicted optimum characteristics are to be within limit.

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