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Optimization of Turning Process Parameters by Taguchi–Based Six Sigma

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In this paper, Six Sigma approach is used for improving the quality process outputs in turning of Galvanized Iron. The objective is to optimize the turning parameters and maximize the MRR (Material Removal Rate). A L16 orthogonal array based on Taguchi experiments consisting of three controlling factors viz. spindle speed, feed rate, and depth of cut, each with four levels as required in traditional DOE setting is used here. Taguchi's parameter design offers an approach in Design of Experiments (DOE) with control parameters optimization to attain best outcome. An orthogonal array offers a set of balanced least experiments which help in data analysis and prediction of optimum results. For each experiment, the Material Removal Rate (MRR) is calculated. The Taguchi method results in reducing the quality characteristic variation due to uncontrollable parameter through the study of response variation using the Signal to Noise (S/N) ratio by the use of Minitab 16 software. Moreover, statistical investigation shows that standard deviation and mean value of confirmation run data are reduced when compare with before Taguchi design run data was performed.

Keywords: Taguchi method, Galvanized Iron, Six Sigma, MRR, Process Parameters, S/N Ratio.

1. Introduction

Turning process is a basic machining operation in lathe. The process output depends on so many factors such as tool material, work-piece material, operating conditions, coolant used, tool geometry, etc. [1]. It is a difficult task to find out a set of parameters giving optimum output. Six Sigma provides a step by step approach to achieve better quality [2]. At the same time Taguchi approach guides towards finding a set of optimal parameters by minimizing the number of experiments in a cost effective way [3]. The starting material is generally a work-piece generated by other processes such as casting, forging, extrusion, drawing etc. The path typically followed a non-rotary tool bit in turning process and is helical with respect to the work-piece. In turning process, there are several parameters that are needed to be considered based on work-piece material, tool material, tool size, etc. Some of the factors affecting the process are spindle speed, feed rate, depth of cut. It is a commonly used technique that allows a systematic methodology for optimizing process and is a powerful tool for the design of high quality systems. Taguchi approach is a versatile method and can be used for optimization of wide variety of problems ranging from mechanical engineering problems like optimization of high-pressure jet [4], micro-end milling process [5], and squeeze casting process [6] to marine engineering problems like determination of Cu and Pb in marine sediments [7].

S/N ratio and orthogonal array are two major tools used in this process. The S/N ratio characteristics can be divided into three categories, there are Nominal is best, Smaller the better and Larger is better characteristics [8-10]. The Taguchi DOE design analysis method practices orthogonal experimental groupings to decrease product development cycle. This analysis reduces the time and cost. Taguchi analysis were used for various manufacturing process like drilling, milling and turning for optimizing the parameters combinations for improved quality product. A Six Sigma practice can be applied to increase the quality of the service part or component.

In this paper a combination of six sigma practice and Taguchi analysis for optimizing the turning process parameters is used. In any process of manufacturing, to meets customer's conditions might require an assessment of 4 to 6 factors. Due to this costs of assessment will rise consequently and increases time spent on DOE which eventually will reduce the productivity. Taguchi DOE design analysis is the best method for providing reduced number of optimized experiment runs. After implementing the optimum value if the defect rate remains high, the manager needs more capital to invest in new equipment keeping in mind the highest product quality and lowest defect.

2. Experiment setup

All the experiments are conducted by using a single point cutting tool on Lathe. The tool signature of the used HSS (High Speed Steel) single point cutting tool in the order of side rake angle, back rake angle, side cutting edge angle, end relief angle, side relief angle, end cutting edge angle and nose radius are 140, 80, 190, 60, 80, 80 and 1 mm respectively. Galvanized Iron is used as the work-piece material for carrying out the experimentation to optimize the MRR. The work-piece material is taken to be Galvanized Iron (GI) with its composition as detailed in Table 1. MRR

Table 1 Composition of GI

Sl. No.	Metal	Range
1	Carbon	<0.25%
2	Silicon	<0.04%
3	Manganese	<1.35%
4	Sulphur	0.040%
5	Phosphorus	<0.04%

Table 2 Process parameters

Level	Spindle speed (rpm)	Feed rate (mm/rev)	Depht of cut (mm)
	A	B	C
1	95	0.2	0.5
2	150	0.45	0.7
3	230	0.5	0.9
4	390	0.8	1.2

is calculated for each set of experiments. S/N ratio is calculated by using MINITAB 16 software. The process parameters for different levels are indicated in Table 2. The MRR is calculated as per relation given below:

$$MRR = \frac{Initial\ weight - Final\ Weight}{Time\ Taken} \tag{1}$$

3. Analysis and discussions

Six Sigma approach is taken for improving the quality process outputs. All the defects that are possible during turning process based on perceptions of material, man, method, measurement, machine and environment. Based on the perceptions, three factors have been chosen viz. spindle speed, feed rate, and depth of cut.

Using three controllable factors, an L16 Taguchi experiment run is constructed with same weightage for all controllable factors. For each parameter combination setting, three runs were performed and their averages are tabulated in Table 3, Table 4, and Table 5. In total of 48 experimental runs are performed. The average value, standard deviation, variance and S/N ratio of the three runs were calculated. Table 3, 4, and 5 shows the experimental data by Taguchi analysis for the MRR. The response of all factors on MRR and S/N ratio are shown in Table 6. In this experiment, the quality characteristic is larger the better approach is adopted. The MRR response table, Table 7 shows the mean response of variable from all factor at every level in Taguchi analysis design. For every level of factors it has four response values, which is detailed in Table 6 and is calculated by averaging all four response values. The response for the S/N ratio as shown in Table 8. With S/N ratio and response value, the response values is utilized to decide the optimized required combination of run of the factors that gives the required MRR.

Table 3 Observation of first run

Spindle speed (rpm)	Feed rate (mm/rev)	Depht of cut (mm)	Time (s)	Diff. in weights (gm)	MRR I (gm/sec)
95	0.2	0.5	36	7.9	0.2218
95	0.45	0.7	20	3.64	0.182
95	0.5	0.9	15.7	3.18	0.203
95	0.8	1.2	9.8	1.536	0.157
150	0.2	0.7	30.15	5.9	0.196
150	0.45	0.5	13.51	2.89	0.209
150	0.5	1.2	11.22	2.86	0.256
150	0.8	0.9	9.6	1.8	0.1894
230	0.2	0.9	27.19	5.98	0.22
230	0.45	1.2	11.6	2.34	0.202
230	0.5	0.5	9.81	1.72	0.176
230	0.8	0.7	8.02	2.23	0.279
390	0.2	1.2	33.9	7.87	0.232
390	0.45	0.9	20.67	3.9	0.19
390	0.5	0.7	11.23	2.49	0.2219
390	0.8	0.5	9.39	1.87	0.199

Table 4 Observation of second run

Spindle speed (rpm)	Feed rate (mm/rev)	Depht of cut (mm)	Time (s)	Diff. in weights (gm)	MRR II (gm/sec)
95	0.2	0.5	34.3	7.1	0.2035
95	0.45	0.7	20.6	3.85	0.191
95	0.5	0.9	17.01	3.42	0.201
95	0.8	1.2	12.72	2.1	0.165
150	0.2	0.7	32.8	6.2	0.189
150	0.45	0.5	14.22	3.12	0.221
150	0.5	1.2	13.25	3.01	0.227
150	0.8	0.9	11.52	2.35	0.204
230	0.2	0.9	28.5	6.25	0.219
230	0.45	1.2	11.58	2.19	0.189
230	0.5	0.5	10.17	1.78	0.175
230	0.8	0.7	11.31	2.9	0.261
390	0.2	1.2	29.49	7.09	0.239
390	0.45	0.9	19.83	3.65	0.184
390	0.5	0.7	13.14	2.59	0.197
390	0.8	0.5	10.45	2.12	0.201

Table 5 Observation of third run

Spindle speed (rpm)	Feed rate (mm/rev)	Depht of cut (mm)	Time (s)	Diff. in weights (gm)	MRR III (gm/sec)
95	0.2	0.5	21.42	7.5	0.35
95	0.45	0.7	15.22	4.72	0.31
95	0.5	0.9	9.25	3.1	0.335
95	0.8	1.2	6.65	1.91	0.287
150	0.2	0.7	26.31	7.9	0.298
150	0.45	0.5	23.3	4.2	0.18
150	0.5	1.2	16.96	3.02	0.178
150	0.8	0.9	10.18	2.3	0.226
230	0.2	0.9	29.45	6.98	0.237
230	0.45	1.2	15.21	3.21	0.211
230	0.5	0.5	13.44	2.81	0.209
230	0.8	0.7	12.62	2.41	0.191
390	0.2	1.2	26.45	8.2	0.31
390	0.45	0.9	10.95	2.41	0.22
390	0.5	0.7	11.22	2.38	0.212
390	0.8	0.5	7.17	2.58	0.36

Table 6 Experimental results, corresponding σ, S/N ratio

Run	A	B	C	MRR I	MRR II	MRR III	Average	σ	σ^2	S/N ratio
1	1	1	1	0.221	0.203	0.35	0.25843	0.07982	0.00637	-12.4418
2	1	2	2	0.182	0.191	0.31	0.22766	0.07144	0.00510	-13.5543
3	1	3	3	0.203	0.201	0.335	0.24633	0.07679	0.00589	-12.8578
4	1	4	4	0.157	0.165	0.287	0.20300	0.07285	0.00530	-14.7442
5	2	1	2	0.196	0.189	0.298	0.22766	0.06101	0.00372	-13.3770
6	2	2	1	0.209	0.221	0.18	0.20333	0.02107	0.00044	-13.9347
7	2	3	4	0.256	0.227	0.178	0.22033	0.03942	0.00155	-13.4391
8	2	4	3	0.189	0.204	0.226	0.20646	0.01842	0.00033	-13.7709
9	3	1	3	0.22	0.219	0.237	0.22533	0.01011	0.00010	-12.9604
10	3	2	4	0.202	0.189	0.211	0.20066	0.01106	0.00012	-13.9773
11	3	3	1	0.176	0.175	0.209	0.18666	0.01934	0.00037	-14.6652
12	3	4	2	0.279	0.261	0.191	0.24366	0.04649	0.00216	-12.6275
13	4	1	4	0.232	0.239	0.31	0.26033	0.04315	0.00186	-11.9025
14	4	2	3	0.19	0.184	0.22	0.19800	0.01928	0.00037	-14.1441
15	4	3	2	0.221	0.197	0.212	0.21030	0.01253	0.00015	-13.5746
16	4	4	1	0.199	0.201	0.36	0.25333	0.09238	0.00853	-12.8420

Table 7 Response of controllable factors to average MRR

	A	B	C	Optimum
Level 1	0.233858	0.24302475	0.2254415	combination
Level 2	0.21445	0.20741675	0.22732525	smaller
Level 3	0.214083	0.21590825	0.21903325	the better
Level 4	0.230492	0.22661675	0.22108325	A3-B2-C3

Table 8 Response of controllable factors to S/N ratio

	A	B	C	Optimum
Level 1	-13.3995	-12.670425	-13.470925	combination
Level 2	-13.6304	-13.9026	-13.28335	larger
Level 3	-13.5576	-13.633175	-13.4333	the better
Level 4	-13.1158	-13.49615	-13.515775	A4-B1-C2

Fig. 1 and Fig. 2 are the graphical representations of the response of factors to average MRR and S/N ratio.

The Optimal setting combination for turning process is A3-B2-C3, which is interpreted as spindle speed to be 230 rpm, feed rate of 0.45 mm/rev and Depth of cut 0.9 mm. For the S/N ratio, the largest value is considered. Then, the S/N ratio response optimal setting combination is A4-B1-C2. The A4-B1-C2 denotes the spindle speed is 390 rpm, feed rate of 0.2 mm/rev and Depth of cut 0.7 mm. The arrows in Fig. 1 and Fig. 2 specify the chosen run of each controllable factor.

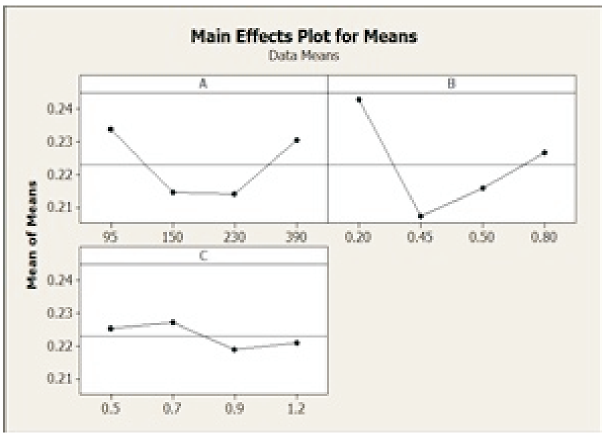

Figure 1 Effect of Turning Parameters on MRR for means

A confirmation run has been conducted for turning process, after optimized combination setting. With optimized combination setting A4-B1-C2, 30 cuts were made to test the MRR. The test results shows better results and no need to carryout rework. The standard deviation and mean value of data which is collected during confirmation run were improved than before run Taguchi analysis.
The Six Sigma is used to overcome the probable reasons of undesirable abnormality accordingly Taguchi analysis can be performed to get continuous enhancement. If some problem occurs later following the optimal condition then it is required to follow the six sigma procedure to follow the next cycle.

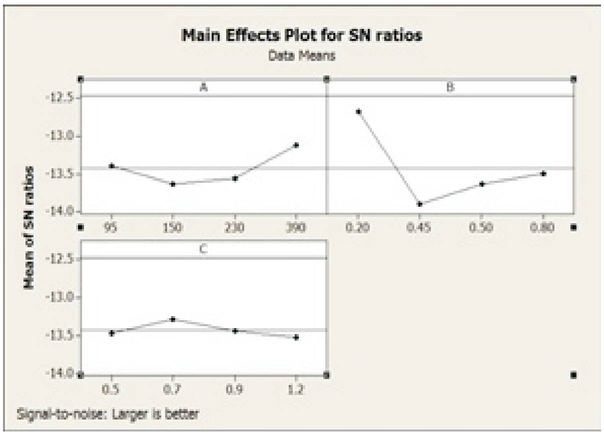

Figure 2 Effect of Turning Parameters on MRR for S/N ratio

4. Conclusion

By Six Sigma process, we can reduce the time and money of the manufacturing process which are the main goal of all manufacturing industries. In this work, Taguchi optimization analysis to optimize the process parameter of turning was employed. By means of Taguchi analysis, the number of experiment runs were reduced. In total 48 experimental runs were performed. The best optimized combination setting by Taguchi analysis design is A4-B1-C2, which means spindle speed is 390 rpm, feed rate of 0.2 mm/rev and Depth of cut 0.7 mm which maintains the existing feed rate for productivity and improves the quality of product.

References

[1] **Schwartz, M.**: Encyclopedia and Handbook of Materials, Parts and Finishes, *CRC Press*, **2016**.

[2] **Kwak, Y. H. and Anbari, F. T.**: Benefits, obstacles, and future of six sigma approach, *Technovation*, 26, 5, 708-715, **2006**.

[3] **Roy, R. K.**: Design of experiments using the Taguchi approach: 16 steps to product and process improvement, *John Wiley & Sons*, **2001**.

[4] **Sekulic, M., Kovac, P., Gostimirovic, M. and Kramar, D.**: Optimization of high-pressure jet assisted turning process by Taguchi method, *Advances in Production Engineering and Management*, 8, 1, 5, **2013**.

[5] **Periyanan, P. R., Natarajan, U. and Yang, S. H.**: Multi-objective optimisation for the micro-end milling process using Taguchi quality loss function, *International Journal of Productivity and Quality Management*, 10, 4, 484–497, **2012**.

[6] **Vijian, P. and Arunachalam, V. P.**: Optimization of squeeze casting process parameters using Taguchi analysis, *The International Journal of Advanced Manufacturing Technology*, 33, 11–12, 1122–1127, **2007**.

[7] **Vlachogiannis, J. G. and Vlachonis, G. V.**: An experimental design for the determination of Cu and Pb in marine sediments using Taguchi's method, *Intern. J. Environ. Anal. Chem.*, 83, 12, 1021–1034, **2003**.

[8] **Das, M. K., Kumar, K., Barman, T. K. and Sahoo, P.**: Optimization of material removal rate in EDM using taguchi method, *Advanced Materials Research*, 626, 270–274, **2013**.

[9] **Das, M. K., Kumar, K., Barman, T. K. and Sahoo, P.**: Optimisation of EDM process parameters using grey-Taguchi technique, *International Journal of Machining and Machinability of Materials*, 2, 15, 3–4, 235–262, **2014**.

[10] **Roy, A. K. and Kumar, K.**: Effect and Optimization of Machine Process Parameters on MRR for EN19 & EN41 materials using Taguchi, *Procedia Technology*, 14, 204–210, **2014**.