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Grinding analysis based on the matrix experiment

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Abstract: This paper presents the analysis of plunge centreless grinding process based on the matrix experiment. The fundamental aspect of the presented method, appropriate for the off-line quality control, refers to combining the experimental design with the quality loss. Experimental design matrix is founded on standard orthogonal array. The objective of this research refers to determination of optimal process set-up for the minimization of surface roughness. The later single-objective problem is solved by the concept of signal-to-noise (S/N) ratio.

Keywords: Grinding; Matrix experiment; Orthogonal array; S/N ratio;

1. INTRODUCTION

Grinding is a complex material-removal process with a great number of influencing factors, which are non-linear, interdependent and difficult to quantify. The problem on hand is the determination and design of grinding process factors that will yield the desired component quality. The assessment of the grinding process quality usually includes the surface roughness of the ground component. There are many different methodologies and strategies for the process design and analysis [1].

Every grinding related research is closely linked with high costs, referring to experimental set-up and inevitable machining interruption. Therefore, it is necessary to conduct the experiments adequately, fast and inexpensively. Discussed matrix experiment is based on the employment of standard L8 orthogonal array. The concept of quadratic loss function is ideally suited for evaluating the quality level of a ground component. Minimization of surface roughness is a typical static problem of smaller-the-better type [2].

2. CENTRELESS GRINDING

Plunge centreless grinding is mostly employed in industries that require large batches of complex, rotationally symmetrical components. Ground surface roughness, has been investigated with respect to the following system factors:

- Geometrical grinding gap set-up factor: the component centre height, H;
- Dressing factor: the longitudinal dressing feed-rate, f_d;
- Kinematical factor: the control wheel speed, n_r;
- Kinematical factor: the in-feed speed, v_{fa}.

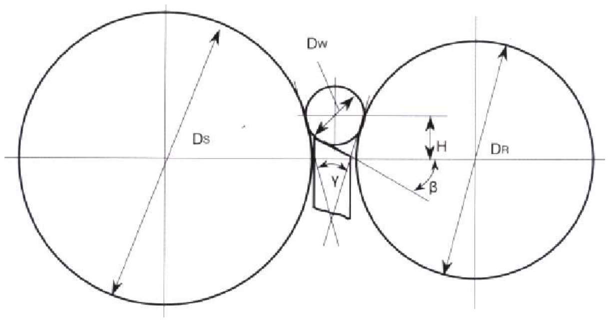

Figure 1. Centreless grinding gap

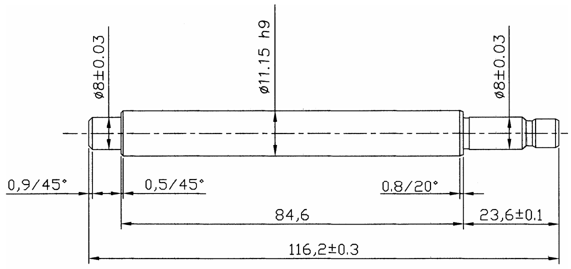

Figure 2. Experimental component

Grinding experiments were conducted on a Schaudt Mikrosa BWF - Kronos M centreless grinding machine-tool. The machine is equipped with a Sinumerik 840D CNC controller and a dynamic grinding wheel balancing unit. The component material was 9SMn28 (DIN standard), free-cutting unalloyed steel. A vitrified grinding wheel, 22A60L6V63L, with an abrasive blend of special monocrystalline and white aluminium oxide was used. Wheel dimensions were 500 x 88 x 304.8 mm. Further, a standard rubber bonded control wheel of 300 x 103 x 304.8 mm dimensions was employed.

3. GRINDING EXPERIMENT

The main precedence of the matrix experiment is the ability to evaluate several factors in minimum of tests. This is considered as an efficient experiment since much information is obtained from a few experimental runs. The conducted experiment involves a two-level L8 orthogonal array, which allows estimation of four main factors and two interactions, shown in Table 1. The array column assignment of the main factors and interactions is based on a standard linear graph [3]. The surface roughness R_a is the average reading of three consecutive measurements. Surface roughness measurements employed a stylus type instrument, a high-pass Gaussian filter, a sampling length of 0.8 mm and an evaluation length of 4 mm.

Table 1.
Experimental orthogonal array

Run	A: H [mm]	B: f_d [mm/min]	AxB {coded}	C: n_r [rpm]	Error {coded}	BxC {coded}	D: v_{fa} [μm/s]	R_a [μm]	S/N [dB]
1	11.5	200	1	51	1	1	20	0.77	2.286
2	11.5	200	1	61	2	2	40	0.70	3.027
3	11.5	400	2	51	1	2	40	1.32	-2.390
4	11.5	400	2	61	2	1	20	1.26	-2.032
5	14.5	200	2	51	2	1	40	0.70	3.051
6	14.5	200	2	61	1	2	20	0.67	3.416
7	14.5	400	1	51	2	2	20	1.34	-2.546
8	14.5	400	1	61	1	1	40	1.32	-2.416

It is important to conduct the experiments under chatter-free conditions and to keep the cutting speed (60 m/s), the grinding depth (0.2 mm), the depth of dressing (0.02 mm) and spark-out time (0.1 s) constant.

4. DATA ANALYSIS

The first step in the data analysis is the numerical determination of the average S/N ratios, summarized in Table 1, for a smaller-the-better type static problem [2]:

$$S/N_i = -10\log\left(\frac{1}{3}\sum_{j=1}^{3}(Ra_i)_j^{\ 2}\right)$$

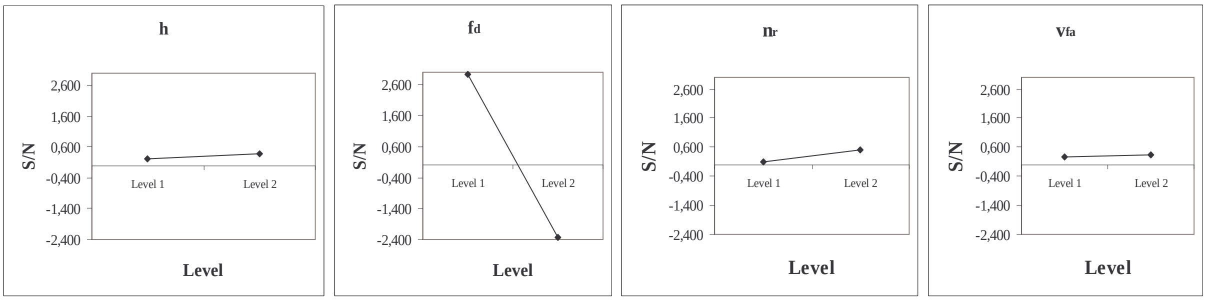

Figure 3. The smaller-the-better S/N response graphs

The upper figure shows the separate S/N effects of the main factors. The relative magnitudes suggest that dressing factor f_d has the strongest effect on the measured response.

A better feel for the relative effect of the different factors can be obtained by the decomposition of variance. In this way the analysis of variance (ANOVA) was employed to investigate, which process factors and interactions significantly affect the process response, i.e. the surface roughness and the S/N ratio.

Table 2.
ANOVA for surface roughness

Source	Sum of Squares	Degrees of freedom	Mean Square	F-value	P-value
h	2.222 E-5	1	2.222 E-5	0.04	0.8743
f_d	0.716	1	0.716	1289.81	0.0177
n_r	3.472 E-3	1	3.472 E-3	6.25	0.2422
v_{fa}	4.426 E-28	1	4.426 E-28	0.00	1.0000
h x f_d	3.756 E-3	1	3.756 E-3	6.76	0.2338
f_d x n_r	5.000 E-5	1	5.000 E-5	0.09	0.8145
Residual	5.556 E-4	1	5.556 E-4		
Total	0.724	7			

For the selected factorial model values of P-value less than 0.05 indicate that model terms are significant. In this case only f_d is significant. The surface roughness model is defined in a form of non-reduced final equation in terms of coded factors:

$$R_a = 1.01 - 1.667\cdot 10^{-3}h + 0.3f_d - 0.021n_r + 0.022h\cdot f_d + 2.5\cdot 10^{-3} f_d\cdot n_r$$

Table 3.
ANOVA for S/N ratio

Source	Sum of Squares	Degrees of freedom	Mean Square	F-value	P-value
h	0.047	1	0.047	1.03	0.4950
f_d	55.887	1	55.887	1229.23	0.0182
n_r	0.318	1	0.318	6.98	0.2303
v_{fa}	2.749 E-3	1	2.749 E-3	0.06	0.8466
$h \times f_d$	0.358	1	0.358	7.87	0.2180
$f_d \times n_r$	0.048	1	0.048	1.05	0.4924
Residual	0.046	1	0.046		
Total	56.816	7			

For the selected factorial model only f_d is significant. The S/N model is also defined in a form of non-reduced final equation in terms of coded factors:

$$S/N = 0.30 + 0.077h - 2.65 f_d + 0.2 n_r + 0.019 v_{fa} - 0.21 h \cdot f_d - 0.077 f_d \cdot n_r$$

5. CONCLUSION

A primary goal in conducting a matrix experiment is to determine the best level for each controllable factor in order to optimize a process. The optimum level for a factor is the level that gives the highest value of S/N ratio. The solution refers to setting the process factors to Level 2, Level 1, Level 2 and Level 2, respectively.

The analysis of the grinding process based on the matrix experiment is justified provided that the concept of additivity is achieved. The additivity, i.e. no interactions, property required for the conducted computational technique to be valid refers to S/N ratio; it is not with respect to the measured response [3]. ANOVA for S/N ratio indicates that the major interactions do not significantly affect the response; hence the analysis approach is appropriate.

Our future research activities will extend the preliminary analysis to a more formal Taguchi's parameter design. In this way we will employ a 3-level orthogonal array, supplement additional process factors and conduct a verification experiment.

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