An Investigation of the Impact of Cylindrical Grinding Parameters on Surface Roughness

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Abstract -This paper presented an investigation of impact of cylindrical grinding parameter to surface roughness on SUS316 stainless steel. Grinding is the most common process when the workpiece demands good surface, dimensional and geometrical quality. In this experiment, the finding is the actual effect of surface roughness and the relationship for each parameter that have been choosing. The method that has been used to design the experiment was Design of Experiment (DOE) full factorial with two levels. The surface roughness of the workpiece has been analyzed by using a Portable Roughness Measurement Machine. The data will be compared and analyzed using MINITAB 14 software. The graphs have been created to shows the optimum factor and interaction between the factors. This experiment runs using three factors which are traverse speed, work speed and depth of cut.

Keyword: Cylindrical Grinding, Surface Roughness, DOE

I. INTRODUCTION

Grinding is the indicated process when the workpiece demands good surface, dimensional and geometrical quality [2]. Grinding is a machining process that employs an abrasive grinding wheel rotating at high speed to remove material from a softer material [3]. Due to this, the grinding process is one of the last steps in the machining operation chain.

In modern industry, grinding technology is highly developed according to particular product and process requirements.

The important thing to concern is the relation between the input parameters and output characteristics. Most of the machining researchers said that this process is very a tough task in grinding. Kwak showed that the various grinding parameters affect the geometric error generated during the surface grinding by using the Taguchi method and the geometric error was been predicted by means of the response surface method [4]. Many experimental investigations reveal that depth of cut, wheel speed, and work speed are the major influential parameters that affect the quality of the ground part [1]. In this study, the Design of Experiment (DOE) has been use in order to see the relationship between the variables: feed rate, depth of cut and speed rate, of cylindrical grinding on surface roughness of Stainless steel 316L. By doing this project, the surface roughness for different parameter will be determined and will be compared to the various run in surface quality. This research will be focus on understanding the effects of three specific parameters within a small range operating condition.

II. LITERATURE REVIEW

A. Surface roughness

Roughness is defined as closely spaced, irregular deviations on a small scale; it is expressed in terms of height, width and distance along the surface [5]. There are several factors that should be considered in finishing process to improve surface quality. Surface waviness and surface roughness are the parameters that are most common in surface metrology. The Roughness produced by grinding ranges from 0.2 to 0.8 µm [6].

Surface roughness generally describe by two methods. Firstly, the arithmetic mean value (Ra) is based on the schematic illustration of a rough surface. Secondly, the root-mean-square roughness (Rq) formerly identified as RMS.

The unit generally used for surface roughness is µm (micron). However, the surface cannot be described by its Ra or Rq value alone, since these values are average [5]. Two surfaces may have the same roughness value but have actual topography which is very different.

In engineering practice, there are several requirements for manufacturing products, for instant 0.025 µm bearing ball, 0.32 µm crankshaft bearing, 1.6 µm brake drum and 3.2 µm clutch-disk faces. The result from the experiment can be compared with these values. Surface roughness on workpiece can be determined by study the process parameters. These factors can be divided into three groups:

- Setup variables
- Tool variables
- Workpiece variables

It is impossible to find all the variables that impact surface roughness in cylindrical grinding. In addition, it is costly and time-consuming to discern the effect of every variable on the workpiece. In order to simplify the problem, needs to eliminate or select specific variables that correspond to practical application. In this study, the setup variables will be chosen to complete this analysis.

According to previous study, surface roughness is significantly depended on the feed rate and work speed [8]. It was recorded that the roughness increases along with the in-feed rates [7].

Furthermore, the surface roughness also shows a decrease when an increase in cutting speed and depth of cut happens. The feed rate has the most dominant effect on the surface roughness value produced by coated carbide tools [9].

B. Vibration

In grinding operations, common problems that can degrade the quality of machined part are chatter and vibration. Chatter can greatly reduce the life of tooling, dimensional accuracy and the quality of a part finish or surface roughness

The source of the energy that creates vibration can be either from externally induced leading to force vibration or from instability of the grind process leading to self-excited vibration. A possible source of such vibrations is the imbalance of the wheel and/or workpiece which is reflected in the power spectra as peaks at the wheel and work piece revolution frequencies and a few of their higher harmonics [10].

The one parameter that affects chatter conditions the most is rpm; it also happens to be the quickest and easiest parameter to obtain or change to maximize the machining operation [12]. Thus, in this investigation, the vibration factor cannot be neglected and must be overcome prior to experiment execution.

C. Design of Experiment (DOE)

Many people familiar with DOE have heard of Taguchi design, full and fractional factorial design and central composite design. The benefit of DOE is the ability to analyze the effect or “response” of many factors and levels with a minimum amount of experimentation [13]. Factors are the independent variables that are expected to affect the response whereas levels are the quantitative or qualitative settings which will be tested. Quality professionals use DOE to identify the process conditions and product components that influence quality and then determine the input variable (factor) settings that maximize results [14].

Design of Experiments (DOE) has documented substantial savings to thousands of companies by solving difficult quality problems, reducing product and process variation, and optimizing product/process performance and consistency [15].

DOE is a very powerful analytical method that can be taught to technical professionals at a very practical level, providing a cost-effective and organized approach to conducting industrial experiments [15]. Multiple product design or process variables can be studied simultaneously with this efficient design, instead of in a hit-and-miss approach, providing highly reproducible results. Due to the statistical balance of the design, thousands of potential combinations of numerous variables (at different settings or levels) can be evaluated for the best overall combination, in a very small number of experiments. This not only saves experimental costs, but it greatly increases the odds of identifying the hard-to-find solution to nagging quality problems.

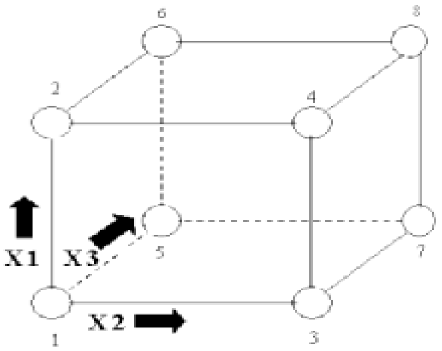

Figure 1: A 2^3 two-level, full factorial design; factors X1, X2, X3 (Nist/Sematech, 2006)

Full factorial designs, with repetitions, allow hypothesis testing of every factor effect and all possible factor interaction effects on the response variable (CSR, 1998).A common experimental design is one with all input factors set at two levels each. These levels are called `high' and `low' or `+1' and `-1', respectively. A design with all possible high/low combinations of all the input factors is called a full factorial design in two levels.

Consider the two-level, full factorial design for three factors. This implies eight runs (not counting replications or center point runs). This full factorial design is shown graphically in Figure 1, experiment will be performed with 3 factors and 2 levels. The arrows show the direction of increase of the factors. The numbers `1' through `8' at the corners of the design box refers to the `Standard Order' of runs (Table 1), thus the number of experiment will be 8 .

Table 1: A 23 two-level, full factorial design table showing runs in 'standard Order'

Run	X1	X2	X3
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1

III. METHODOLOGY

A. *Design of experiment*

Various different methods have been used to quantify the impact of all of these parameters on part finish quality [17]. Design of experiment is a relevant method that allows for a systematic approach to quantify the effects of a finite number of parameter. Feng and Wang used this method to develop a complete empirical model of surface roughness [18]. After performing the test, the data was analyzed by MINITAB 14 software and a regression equation was generated [17]. The regression analysis determines which factor and interaction are significant.

Obtaining good result from a DOE involves these seven steps [16]:

- Set objectives
- Select process variables
- Identify suitable response variable
- Select an experimental design
- Execute the design
- Analyzes and interpret the result
- Conclusion and recommendation

Process variables include both inputs and outputs factors and responses. The most popular experimental design is the two-level design. This is due to the suitability for screening design, simple and economical. Furthermore, it also gives most of the information required to go to a multilevel. The standard layout for a 2-level design uses +1 and -1 notation to denote the "high level" and the "low level" respectively, for each factor. Table 2 shows the machining parameters and their variation levels.

Table 2: Factors and Levels selected for the Experiments

Factors	Level	
	High (+1)	Low (-1)
Traverse speed	76.2 mm/min	127 mm/min
Work speed	60 rpm	150 rpm
Depth of cut	3 µm	5µm

The factor settings consist of high value and low value. This high value is noted with +1 whereas the low value with -1. These labels to be used during experiment.

In order to improve its effectiveness, this number should be increased up to 16 runs. The duplicated runs were taken in random order to allow an estimation of the experimental error and take the variation in network and database traffic into consideration. In this experiment, there were a total of eight runs (k). In general, the greater the number of replicates per run the easier it is to see variations in the mean. In planning any experiment, it is important to consider the experimental error where there are the combined affects of many uncertainties or random variations, such as the repeatability of measuring instruments or small fluctuations in conditions like ambient temperature [19]. One approach to dealing with experimental error is through replication, where the same experiment is run in repeated trials and then the measurement averaged. Replication is effective, but increases the cost of the experiment.

IV. RESULT AND DISCUSSION OF EXPERIMENT

They were 16 specimens that underwent grinding process and four data measurement were taken for every specimen. The average of surface roughness (Ra) was calculated.

Table 3: Experimental result for surface roughness

Run	Traverse speed (ipm)	work speed (rpm)	depth of cut (µm)	Average Ra (µm)
1	3	150	5	0.2200
2	3	60	5	0.3800
3	3	60	3	0.1767
4	5	60	3	0.3167
5	5	60	5	0.3233
6	3	150	3	0.1767
7	3	60	5	0.4167
8	3	150	5	0.2533
9	5	150	5	0.6067
10	5	150	5	0.5700
11	5	60	5	0.4067
12	3	150	3	0.2533
13	3	60	3	0.4367
14	5	150	3	0.2657
15	5	150	3	0.2167
16	5	60	3	0.4067

From Table 3, it clearly shows that the highest value of surface roughness is 0.6067 from experiment 9 while the lowest surface roughness value is 0.1767 from experiment 3 and experiment 6.

Figure 2 shows the normal probability plot of effects for surface roughness. From the graph, the main effects A (traverse speed), C (depth of cut), and interaction effects AB (traverse speed x work speed) and interaction ABC (traverse speed x work speed x depth of cut) gives a 95 % significant level. It signifies that these parameters designs gave an optimum effect to surface roughness of the Stainless Steel 316L.

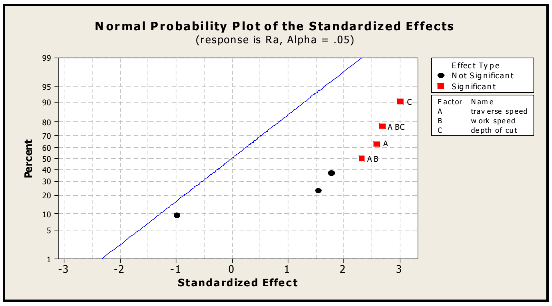

Figure 2: Normal probability plot of effects for surface roughness

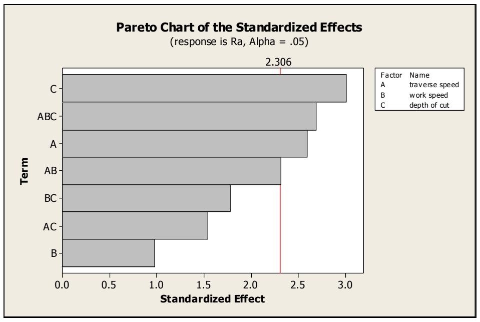

Figure 3: Pareto chart of the effects for surface roughness

Figure 3 show the Pareto chart of the effect parameters to the surface roughness. Noted that there are four bars past the references line (2.306) which are arranged in order of importance. The most important parameter affecting surface roughness is depth of cut (C) followed by interaction of traverse speed, work speed and depth of cut (ABC) then traverse speed (A) and lastly the interaction of traverse speed and work speed (AB). The rest of the effects and interaction have very little impact on surface roughness of the Stainless steel SUS 316L.

Figure 4 shows the main effects plot for surface roughness. This graph shows that the values of Ra increase with the factor of depth of cut and traverse speed. Meanwhile the values of surface roughness tend to decrease under the work speed factor.

An interaction plot shows the impact of changing the settings of one factor has upon another factor. Since an interaction can magnify or diminish the main effects, evaluating interactions is extremely important.

The relation of depth of cut to surface roughness is directly attributed to large increase in tool forces that accompany an increase in depth of cut. Eventually leads to an increase in the surface region plastics, surface damage and then high average surface roughness [22]. According to Norton, it has been found that surface finish is inversely proportional to the depth-of-cut in grinding [20]. Low depth-of-cut results in a better finish and vice-versa. Therefore, the obvious way to improve finish is to reduce the depth-of-cut to a minimum value.

The depth of cut also gives the greatest influences on temperature [5]. An increase in cutting speed and depth of cut resulted in an increase of the cutting zone temperature [21].

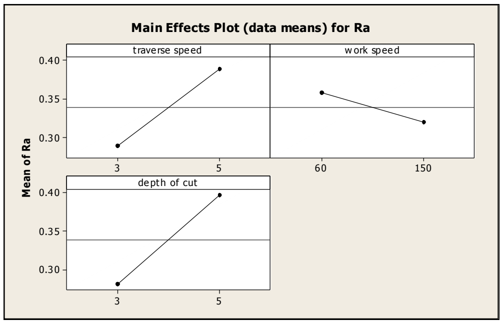

Figure 4: Main effects plot for surface roughness

The result (Fig. 4) also indicates that the surface roughness (Ra) tends to increase when the traverse speed increase. Norton noted that the finish can be improved by reducing the traverse speed [20]. The manual handbook highlighted the importance of the wheel position. It is a not a good practice to allow the wheel to entirely leave the work at the end of each traversing stroke. The correct amount of run-off should be half the wheel width. The overhang cutting must never be greater than the width of the wheel to avoid grind the sample accidentally.

It can be seen from the Figure 4 that an increase of work speed causes a considerable reduction in the machined average surface roughness Ra. An increase in the feed rate (work speed) will increase the volume of material removed from the workpiece in the form of chips, which in turn, produces an increase in the surface damage and roughness [22].

A result of an experiment proves that feed rate (workspeed) was the dominant parameter associated with the surface roughness [21]. This is expected because it is well known that the theoretical surface roughness was primarily a function of the feed rate (work speed) for a given nose radius and changes with the square of the feed rate (work speed) value.

☐ Mathematical Model development for Surface Roughness

The regression model provides the relationship between the surface roughness and the critical effects which are depth of cut (C), traverse speed (A), product of traverse speed and work speed (AB) and the product of traverse speed, work speed and depth of cut (ABC).

The regression model for the surface roughness is given by:

$$Ra = c0 + c1\,(A) + c3\,(C) + c12\,(AB) + c123\,(ABC)$$

$$Ra = 0.33912 + 0.04994\,(A) + 0.05797\,(C) + 0.04453\,(AB) + 0.05173\,(ABC)$$

Table 4: Estimated effects and coefficients for surface roughness (coded units)

Term	Estimate of effect	Coefficients
Constant		0.33912
Traverse speed (A)	0.09989	0.04994
Depth of cut (C)	0.11594	0.05797
Traverse speed x work speed (AB)	0.08906	0.04453
Traverse speed x work speed x depth of cut (ABC)	0.10346	0.05173

From Table 5, it is noted that the highest value of vibration is 0.6 which is from experiment 1, 8, 9, 10, 11, 12, 13 and 14. The other experiments show the same lower value of vibration which is 0.4.

Figure 5 shows the Pareto chart of the effects corresponding to the vibration parameter. It displays that only one bar effect the vibration but the value is not significant for a confidence level of 95%. The rest of the effect or interactions have no impact on vibration. From the data finding, it is clear that the cylindrical grinding parameters give little or no impact to the vibration.

Vibration increased with specific chip volume, with higher rate of increase when subjected to higher workpiece velocities [22]. A higher workpiece velocity generates a stronger cutting condition, resulting in higher cutting forces and, consequently, higher vibration. Moreover, vibration can be used to monitor the wheel condition.

Table 5: Experimental result for Vibration during Machining

Run	traverse speed (ipm)	work speed (rpm)	depth of cut (µm)	vibration During (mm/s)
1	3	60	3	0.6
2	3	150	3	0.4
3	5	150	3	0.4
4	3	150	5	0.4
5	3	150	5	0.4
6	3	150	3	0.4
7	5	150	3	0.4
8	5	60	3	0.6
9	5	60	5	0.6
10	3	60	5	0.6
11	5	60	5	0.6
12	5	60	3	0.6
13	3	60	5	0.6
14	3	60	3	0.6
15	5	150	5	0.4
16	5	150	5	0.4

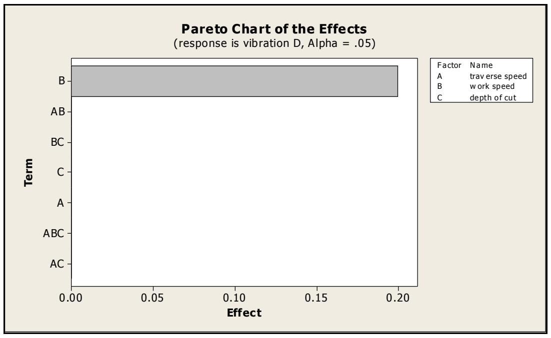

Figure 5: Pareto Chart of the Effects for Vibration

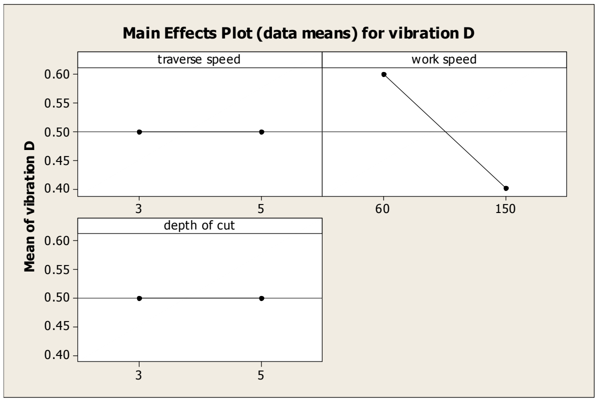

Figure 6: Main Effects plot for Vibration

Figure 6 shows that the main effects plot for vibration. As shown in these graphs, the value of vibration decreases significantly with the factor of work speed. Other factors which are traverse speed and depth of cut have no impact to the vibration value since the graphs show a straight line.

The main effects plot and Pareto chart shows that the cylindrical grinding parameters give little or no impact to the vibration value. This shows that the machine is under good condition.

Figure 7 shows the graph of interaction or relation between vibration during the machining and surface roughness. There are only two values or vibrations which are 0.40 and 0.60. The result shows that the values of surface roughness increased when the values of vibration increased.

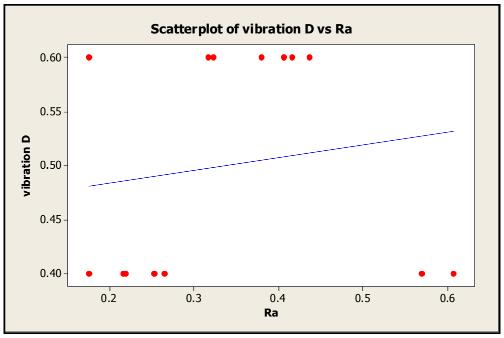

Figure 7: The scatterplot of vibration vs. surface roughness

V. CONCLUSION

The SUS 316L was machined in the present work by using a cylindrical grinding. There were 3 different machining parameters such as traverse speed, work speed and depth of cut. This project presented a machining characteristic which is surface roughness on the workpieces and the following conclusion can be drawn from this study:

The depth of cut was the most importance factor that had affected the surface roughness of SUS316L.

From the observation, there was four effects that were significant which were depth of cut, traverse speed, interaction of traverse speed and workspeed and interaction of depth of cut, workspeed and traverse speed.

The regression model was developed to provide a relation between the surface roughness and the critical effects. The equation is:

$$Ra = 0.33912 + 0.04994 (A) + 0.05797 (C) + 0.04453 (AB) + 0.05173 (ABC)$$

In this study, there was less or no impact of the parameters on the vibration value.

VI. REFERENCES

[1] Alagumurthi, K.Palaniradja, V.Soundararajan (2006)., Optimization of grinding process through design of experiment (DOE), Materials and manufacturing process, Volume 21, Issue 1 Jan 2006, pp 19-21.
[2] Steve, F.K., Arthur, R.G.,Peter, S.,.(2005).”Technology of machine tools”.6th Edition. NY. McGraw-Hill.
[3] Ioan, D. M., Mike, H., Eckart, U., Brian, W. R.,Ichiro I., (2007)“Handbook of Machining with Drinding Wheels“. Boka Raton. CRC Press Taylor & Francis Group.
[4] Jae-Seob Kwak, Sung-Bo Sim, Yeong-Deug Jeong.(2005)An analysis of grinding power and surface roughness in external cylindrical of hardened SCM440 steel using the response surface method.
[5] Kalpakjian, S., Schmid, S.(2006).”Manufacturing engineering and technology”.5th Edition.Singapore. Pearson Prentice Hall.
[6] Luca, L., Ventzel, S.N., Marinescu, I.(2004) ”Effects of Working Parameters on Surface Finish in Ball-Burnishing of Hardened Steels”. Technical Note pp 253-256, 2004, November 21.
[7] Eduardo, C. B., Carolina, G. F., Paulo, R. de A., Rodrigo, E. C. (2004).” Analysis of the Influence of Infeed Rate and Cutting Fluid on Cylindrical Grinding Processes Using a Conventional Wheel”. Vol7, Issue July/Sept 2004.
[8] Saglam, H., Unsacar, F., Yaldiz, S.(2005)” An Experimental Investigation as to The Effect of Cutting Parameters on Roundness Error and Surface Roughness in Cylindrical Grinding”, International Journal of Production Research, Volume 43, No 11, Issue 1 June 2005, pp. 2309-2322 (14).
[9] Sahin, Y.,Motorcu, A.R., (2005)” Surface Roughness Model for Machining Mild Steel with Coated Carbide Tool”, Material and Design 26, (2005), pp. 321-326.
[10] Gradisek, J., Baus, A., Govekar, E., Klocke, F. Grabec, I. (2003)“ Automatic chatter detection in grinding“. International Journal of Machine Tools & Manufacture, 43 (2003). pp. 1397-1403.
[11] John W.S.(2004), “ Terminology”, [Online], Available: http://www.mfg.mtu.edu/cyberman/quality/sfinish/terminology.html .[2007, September 27].

[12] Harper, R. (2008) “Chatter myths: Pieces of the puzzle in maximized machining”. Gardner Publications, Inc, [online]. Available:http://www.moldmakingtechnology.com/articles/090402.html [2008, March 23]

[13] Ronald, C., Prof. Daryl, S., Joseph, R.C. (2002).”An effective Design of Experiment strategy to optimize SMT processes”. Dartmouth College. NY.

[14] Minitab Inc., (2007)” Meet Minitab 15”. USA.[online] Available: [2008, March 5].

[15] Qualityi2, (2001)” Design of experiments2”. Quality Improvement International.[online] Available: http://www.qualityi2.com/doe.htm [2008, March 24].

[16] Nist/Sematech, (2003)” e-handbook of Statistical Methods” [online] Available: http://www.itl.nist.gov/div898/handbook/pri/pri.htm [2006, Jan 5].

[17] Vernon, A., Ozel, T.,(2003)”Factors Affetcing Surface Roughness in Finish Hard Turning”. New Jersey. Department of Industrial and Systems Engineering Rutgers.

[18] Feng, C.X., Wang, X., (2002)“ Development of Empirical Models for Surface Roughness Prediction in Finish Turning“, The International Journal of Advanced Manufacturing Technology, Vol. 20, 2002, pp. 348-356.

[19] Daniel, D.F., Edward, M.G. (2004).” One step at a time”. The American Society of Mechanical Engineers.

[20] Grindwell Norton Ltd.(2006) “ Selection of process parameter in precision grinding”.[online]. Available: www.grindwellnorton.co.in/GrindingTech/pdfs/SelProcessParameters.PDF [2008, March 13]

[21] Tugrul Ozel, Tsu-Kong Hsu, Erol Zeren., (2004).“ Effects of Cutting Edge Geometry, Workpieces Hardness, Feed Rate and Cutting Speed on Surface Roughness and Forces in Finish Turning of Hardened AISI H13 Steel“. Int J Adv Manuf Technol (2005) 25: 262-269.Published online : 11 August 2004

[22] Mashal, Y.A-H., El-Axir, M.H., Kassem, M.A(2001)., “The Machinability and Tribology Characteristics of aluminium alloys with Improved Elevated temperature properties using Rapidly Solidified Powder”. Wear 250 (2001), pp. 518-528.

[22] Hassui, A.,Diniz, A.E.(2003) Correlating surface roughness and vibration on plunge cylindrical grinding of steel.