DESIGN AND FABRICATION OF A BALL BURNISHING DEVICE FOR SURFACE FINISH ADAPTABLE ON A PLANT LATHE

Beşliu- Băncescu Irina[1], Tamaşag Ioan[2]

[1,2]*University Stefan cel Mare from Suceava, irina.besliu@usm.ro, ioan.tamasag@usm.ro*

Abstract: *In the present work, a burnishing device was designed and constructed for the execution of plastic deformation finishing processes on a plant lathe type SN 320x1000. The burnishing finishing process is carried out by applying a pressure with a ball or roller on a surface with the aim of correcting the irregularities of the surface generated by prior cutting processes. The burnished surface will result with smoother surfaces and increased hardness of the superficial surface of the part. With the advancement of technology and the complexity of the production processes, the industry focuses on the design of the products by which it is desired that the obtained parts present smooth surfaces and tight accuracies, polished or finished surfaces, in other words, present an aesthetic appeal for potential customer. Burnishing is an accessible process that can be performed with low production cost and does not require specific training. This paper presents a design for a ball burnishing device that can be mounted on a plant lathe. The capabilities and working performance of the device were tested by carrying out a full factorial experimental design. Analysis of the procedure was performed by a three-level two-factor factorial design and analysis of variance (ANOVA). Through these statistical quality analysis methods, the parameters influencing the surface quality of the tested parts were determined.*

Keywords: *ball burnishing, surface texture, surface roughness, surface finish*

1. Introduction

In today industry there is an increasing focus on aspects related to the aesthetics and design of the mechanical products. So, within the production processes special attention is paid to finishing, smoothing and polishing processes. The appearance of the surface and its integrity, are always related to the manufacturing processes that contribute to maintaining the quality of the product. The main parameter to evaluate quality surface is surface roughness. In most situations if the surface roughness of a part has poor surface quality, the performance of the product is affected, especially for the part surfaces that must maintain contact with other parts of the assembly. At the same time the aesthetic attraction that a customer might exhibit for a product can be affected. Therefore, improving the properties and quality characteristics of surfaces is a permanent concern for the industrial field. Among the parameters of interest surface roughness, microhardness, residual stress and the depth of the hardened layer are usually analyzed. There are several surface finishing processes, and among them the most common are: scraping, polishing, surface finishing by plastic deformation of the superficial layer, lapping, honing, super finishing, vibro-smoothing, etc.

In general, abrasive and polishing processes mostly used as finishing processes, but more recently hybrid technologies such as processes assisted by high-frequency vibrations or processes supported by thermal action with induction heating or laser assisted cutting processes are also used .

Roll burnishing can be applied to various parts with cylindrical, flat, conical, spherical, complex and contoured surfaces. The process can be performed with one or several balls, with one or several cylindrical rollers, or with single or double conical rollers, for one or many surfaces simultaneous.

The burnishing tools and the burnishing process specific parameters are responsible for the gloss or a fine finish of the machined surface. In the burnishing process the material is plastically deformed due to the pressure applied to the tool, ball or roller that is in contact with the part surface and moved along it generating a finished surface. As a result of this finishing processing, the asperities and deviations resulting from the previous processing are removed, namely: irregularities and non-uniformities of the surfaces, asperities or feed traces, deformations or damages due to applied heat treatments, etc. Surfaces acquire greater fatigue resistance, increased wear resistance and corrosion resistance.

Several burnishing tools and devices were proposed and investigated in the research literature in the last 70 years since it has been first purposed. Gómez-Gras G et al. [Gómez-Gras, 2015] had designed a ball burnishing tool for burnishing processes assisted by vibration, considering that vibrations can help to make the development of this finishing process easier because it helps to deform the workpiece material more easily. Travieso-Rodríguez et .al [Travieso-Rodríguez, 2019] use the same burnishing tool design to investigate the hardening effect and fatigue behavior enhancement through ball burnishing of AISI 1038. The tool was equipped with a ball of hardened chromium steel (100Cr6) with a hardness value of approximately 57–66 HRC and a diameter of 6 mm and had been used for conventional ball burnishing without vibrations. Ahmed Raza et. Al. [Ahmed Raza, 2022] had presented a critical review of tool design in burnishing process. In their work they had reported that the surface properties and surface roughness are strongly affected by the burnishing tool design parameters. Among these design parameters the ball diameter, contact width (for the roller type burnishing tools), the applied pressure and tip radius (for the case of diamond burnishing tool) are considered the most important. The diameter of the ball significantly influences the surface roughness and hardness of burnished surface. Burnishing tool with larger ball diameter will generate high surface finish whereas burnishing tool with smaller ball diameter will produce high surface hardness. Under certain burnishing force, big diameter balls have less depth of penetration than small balls diameter because of larger contact area between the surface of the ball and the workpiece surface. A big diameter ball will come in touch with the asperities on the work material for a greater duration of time than a small diameter ball. Deepak Mahajan et al. [Deepak Mahajan, 2013] carried out an review on the burnishing process investigations. They stipulated that amongst the ball burnishing process parameters burnishing force, speed and feed were considered the most compared to burnishing ball material, rotational speed and burnishing direction. Yang Hua et. Al. [Yang Hua, 2019] had reported that compared with finishing turning process, the low pressure burnishing processes enhanced the fatigue life by about 37- 82%. Rotell et. Al [Rotella, 2020] purposed a new roller burnishing tool design and investigated the influence of different cooling/lubrication conditions on the surface integrity of Ti6Al4V parts. Jagadeesh and Gangi Setti [Jagadeesh, 2022] presented an review of on latest trends in ball and roller burnishing processes for enhancing surface finish. The paper presents the optimum burnishing parameters of commonly used engineering materials and advanced biomedical materials and the optimized conditions for surface roughness. They reported that the process parameters for ball or roller burnishing process to achieve lowest surface roughness are medium burnishing force (50–300 N), low burnishing feed (0.05–0.5 mm/rev) and medium burnishing speed (200–1500 rpm). L. Prabhu et al [Prabhu, 2020] purpose a new design for a ball burnishing tool and used the prototype for surface finishing of mild steel, brass and copper. Tadic et. al. [Tadic, 2013] have designed a ball burnishing tool of high stiffness conducted experimental investigations over a wide interval of most influential process parameters (burnishing forces, burnishing feed, and number of burnishing passes). Abu Shreehah [Shreehah, 2008] had developed and investigated an elastic ball burnishing tool. Hemanth et. al. [Hemanth, 2018] had designed a roller burnishing tool and studied its effect on the surface integrity of Al 6061 parts. Fang-Jung Shiou et al. [[Shiou, 2017]] develop a new ball-burnishing tool embedded with a load cell integrated with a CNC lathe, to improve the surface roughness and hardness of the fine turned stainless steel parts. In another work, Fang-Jung Shiou et al. [Shiou, 2016] purpose a an innovative small ball-burnishing tool embedded with a load cell suitable to be mounted on a machining center. Oxygen-free copper specimens were used as the tested samples for the tool and the effects of several process parameters can be investigated by carrying out experiments designed using the Taguchi's orthogonal array. El-Axir et al. [El-Axir, 2005] had designed and manufactured three ball burnishing tools replacing the three original adjustable jaws of the moving rest. They also conducted experimental work on a lathe to study the effect of this new burnishing tool and the lathe parameters, such as burnishing speed, burnishing force, and burnishing feed on some surface characteristics like surface roughness, surface roundness, and reduction of diameter.

2. Experimental setup

For the study of the finishing process by ball burnishing process, a burnishing tool was designed and executed; the burnishing tool was mounted on a support that can pe mounted on the cross slide of a plant lathe. The main parts of the burnishing tool are presented in figure 1.

Figure 1: *Burnishing tool design.*

This burnishing tool is composed of the following components:

1 - tungsten carbide ball;

2 - support bush for the burnishing ball, it is threaded onto the support shaft;

3 - bearing;

4 - support shaft for mounting the elements;

5 - elastic element (spring);

6 - nut for fixing the device

7 - support piece

8 - nut-type part for tightening the support shaft and the support part.

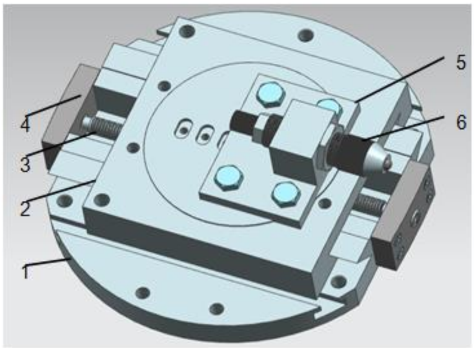


Figure 2:*The burnishing device.*

The burnishing tool is mounted on a moving device that allows the positioning of the burnishing tool at different diameters and facilities the application of working pressure. The device is composed of the following components: 1 – motherboard; 2 – upper plate; 3 - threaded rod; 4 - end plate; 5 - fixing support; 6 – burnishing tool.

The motherboard sustains all the components of the devices and it is special designed to be mounted on cross slide of the lathe. The movement of the burnishing tool on a transversal direction is realized by the actuation of the threaded rod. The longitudinal feed motion is controlled by the lathe feed system.

The experiments were carried out on a normal SNA 320x1500 lathe with the following characteristics:

- workpiece material: C45;
- working feed: 0.06 mm /rot, 0.1 mm /rot, 0.18 mm /rot;

- rotating speed: 160 rpm, 250 rpm, 400 rpm;
- ball material: tungsten carbide - CW /WC; ball diameter - 9mm;
- characteristics of the elastic element: material, spring steel; De = 10.5mm (outer diameter); d = 1.1mm (wire diameter); Di = 8.3 (inner diameter); L0 = 32.3mm (spring length at rest); n = 7.5 (active coils); Ln = 11.3mm (admissible compressed length); sn = 21mm (spring stroke); Fn = 48.3N (spring force).

The working pressure applied in the experiments was the same and was controlled by using a dynamometer key. A full factorial DOE plan with 2 factors on 3 levels was designed to observe the relationships between the process input parameters (cutting feed and cutting speed) and to determine the optimal output parameters and machining conditions for obtaining the best surface quality. The Minitab software was used, software that helps to statistically analyze the experimental data.

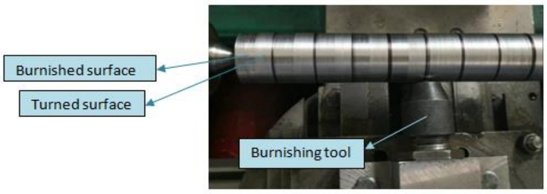


Figure 3: *Burnishing tests setup.*

Figure 3 presents the aspect of the workpiece surfaces after the turning tests and after the burnishing tests. As it can be seen, after applying the burnishing processes to the turned surfaces due to sliding contact with the tungsten carbide ball became smoother and shinier. The main advantages of this burnishing device is that it can be used simultaneous during the turning processes and that can be set to various cylindrical surfaces diameters.

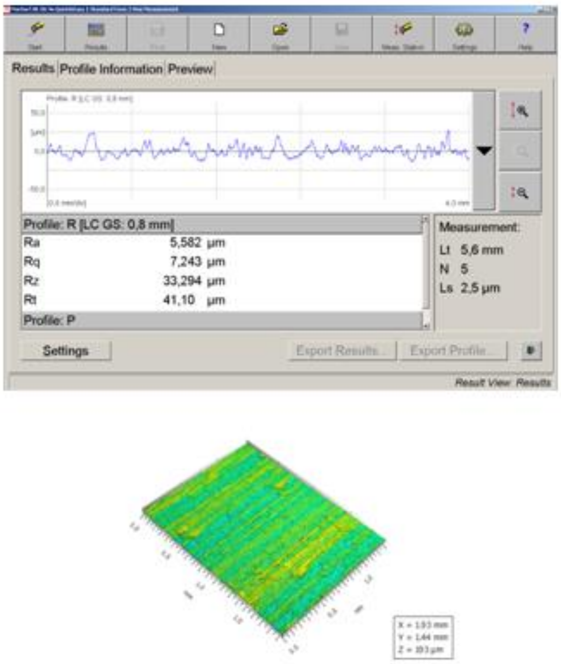
3. Results and discussions

After the turning and burnishing processes have been performed on the established sections of the part, the surface roughness and micro topography of the machined surfaces were evaluated using a contact type roughness measuring device- Perthometer M2, and a confocal microscope type MarSurf CWM 100 produced by Mahr. The measurement and analysis devices mentioned above allow the saving of the results, profiles and values of the measured parameters via the software in the form of reports. The roughness parameter investigated was Average Maximum Height of the Profile, Rz which measures the difference between the highest peak and lowest valley within the sampling length of five lines. The experimental results obtained are presented in table 1. For each sector of the part the surface roughness improvement percents were calculated. The biggest improvement was obtained for the machining tests that were carried out with the lower values for the two input factors considered (the cutting speed of 160 rev/min and cutting feed of 0.06mm/rev). This result could be related to the higher stability of the process when lower machining parameters are used.

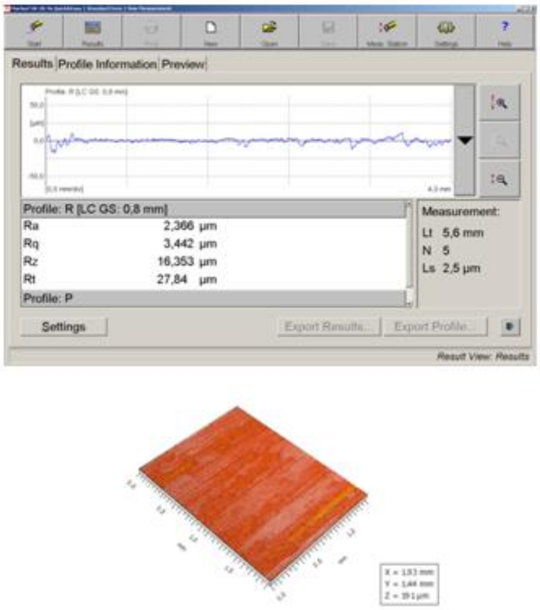
Table 1 *The design of experiments matrix and results obtained*

Exp. No.	Rotating speed	Feed	Rz (turning)	Rz (burnshing)	Surface roughness improvement
	N (rev/min)	F (mm/rev)	(μm)	(μm)	(%)
1.	160	0.06	33.29	16.35	50.89%
2.	160	0.10	38.54	23.11	40.04%
3.	160	0.18	47.96	33.50	30.15%
4.	250	0.06	25.16	24.04	4.45%
5.	250	0.10	41.29	22.91	44.51%
6.	250	0.18	43.41	39.36	9.33%
7.	400	0.06	28.79	18.89	34.39%
8.	400	0.10	26.97	24.80	8.05%
9.	400	0.18	37.13	28.25	23.92%

Figure 4 presents a sample of the surface micro textures of the surfaces obtained by turning and by burnishing. As it can be seen the microscopic peaks were pressed down and forced to flow into the valleys, creating a smooth plateau that significantly reduced the surface roughness of the machined surfaces.



a.



b.

Figure4: *Surface texture improvement a. surface texture after turning (f=0.06mm/rev, s=160rev/min) b. surface texture after burnishing tests (f=0.06mm/rev, s=160rev/min)*

Experimental results are also analyzed with analysis of variance (ANOVA), which is used to identify factors that significantly affect the interest parameters investigated. The results of the analysis are presented in Table 2. This analysis was performed for a significance level of α = 0.05, i.e. for a confidence level of 95%. Sources with a P value of less than 0.05 are considered to have a statistically insignificant contribution to the response parameter variations.

Table2: *ANOVA analysis.*

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Statistically significant
Model	4	354,02	88,50	6,84	0,045	
Linear	4	354,02	88,50	6,84	0,045	
n(rot/min)	2	42,86	21,43	1,66	0,299	No
s(mm/rot	2	311,16	155,58	12,02	0,020	Yes
Error	4	51,78	12,94			
Total	8	405,79				

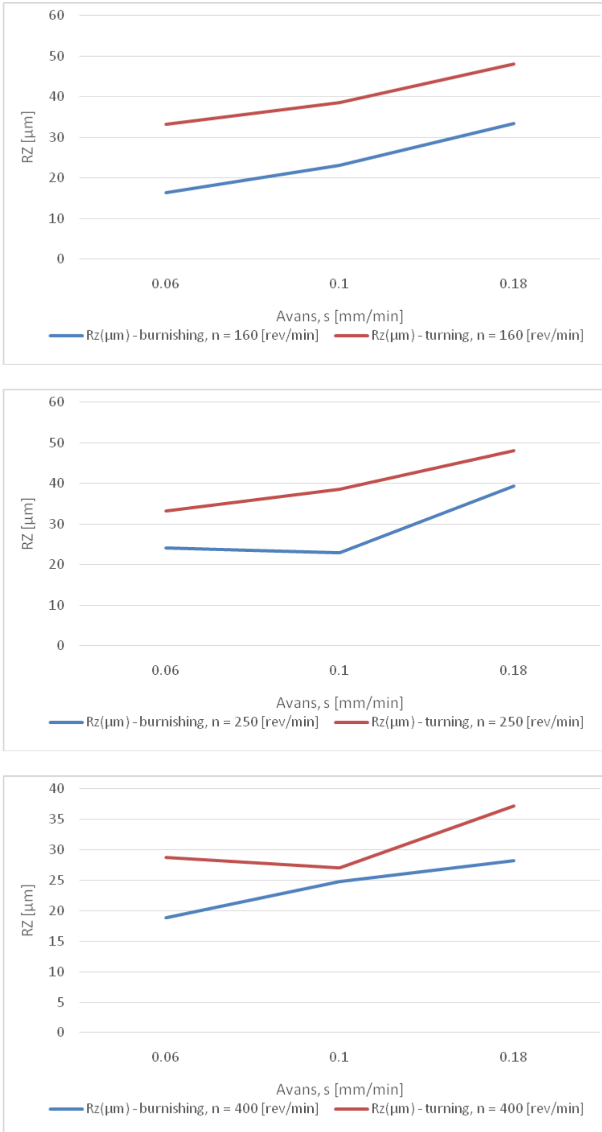


Figure 5: *Working feed influence on the surface roughness Rz parameter*

The variation graphs presented in figure 5 shows that for the both machining processes –

turning and burnishing lower surface roughness parameters were obtained when the machining processes were carried out with lower working feed values.

The contours present in the graph in figure 6 are curved because the model contains quadratic terms that are statistically significant in the process. This graph shows the responses of the best combinations of A (rev) and B (feed) factor values.

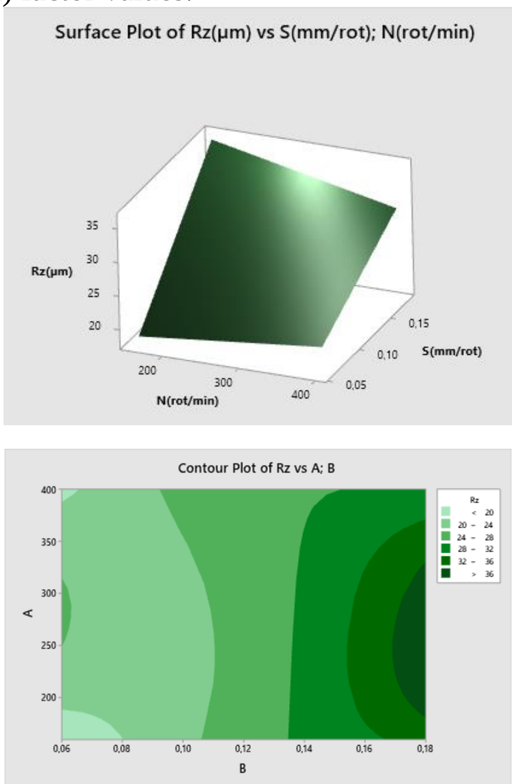


Figure 6: *Surface and contour graphs for the surface roughness parameters Rz.*

It can be seen from the surface and contour graph that the lowest roughness values were obtained for the working feed values between 0.06 - 0.08mm/rev, respectively for the working speed values of 160 – 200rev/min. According to the graph, good surface roughness results can also be observed by using low values of the working feed and medium to high values for the working speed. Medium to small values of the surface roughness are also obtained by burnishing tests carried out with feeds between 0.10 - 0.14mm/rev and speeds from 150 to 400 rev/min.

4 Conclusions

From the studied research literature regarding the burnishing process, it can be concluded that there is a wide applicability of it in many areas of the industry. The burnishing process has been widely used in the automotive industry to finish transmission parts, brakes, and pistons as well as other types of pars such as plumbing fixtures and valves. In this processes the burnishing tool, has usually one or several balls or rollers work to compress the metal without removing any metal from the surface.

Through this process the quality of the surface of the piece is improved, the roughness value is undoubtedly improved and the surface hardness value is increased due to the superficial plastic deformation. This process is able to generate a very high degree of surface finish with very tight dimensional accuracy.

In this paper a new design for a burnishing device mountable on a SN 320 type lathe is proposed and the functionality of it is studied by carrying out a set of experiments. From the experimental results obtained it can be concluded that the working feed is one of the main parameters responsible for the surface roughness values. By using smaller working feeds, surfaces with lower roughness values are obtained.

The main advantages of this burnishing device is that it can be used simultaneous with the turning processes and that can be adapted to various cylindrical surfaces diameters.

From a constructive point of view, but also functionally, the device can be improved according to the needs, it can also be adapted to other categories of machines - tools - milling machines, CNC machines (lathes, milling machines).

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