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Determination of the optimal working gap for the Magnetic Assisted Ball Burnishing tool

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***Abstract* – In this paper, the authors present the results of experimental work regarding permanent Magnetic Assisted Ball Burnishing (MABB) tool. This type is a special tool using the magnetic field to produce the necessary force for burnishing. The tool applicable especially to rolling flat and 3D surfaces. For the correct operation of tool, it is needed to set up an optimal distance between the tool and workpiece. In order to define it the authors measured the F_z force, which occurs between the tool and workpiece while the magnetic force pulls the rolling balls on a cone which located at the end of the tool. The evaluation was completed by advanced measuring and IT equipments.**

I. INTRODUCTION

All surfaces of mechanical parts consist of valleys and peaks. The main goal of the conventional ball or roller burnishing is to achieve high-quality surfaces. During the process one or more balls makes plastic deformation on the surface layer. In the case, if this stress is higher than yield strength of the material, the material near the surface starts to flow. As the balls moves across the surface of workpiece, the peaks of surface are pressed down into the surface and the material then it flows into the valleys between the peaks as you see in Fig. 1. [1, 2, 3,].

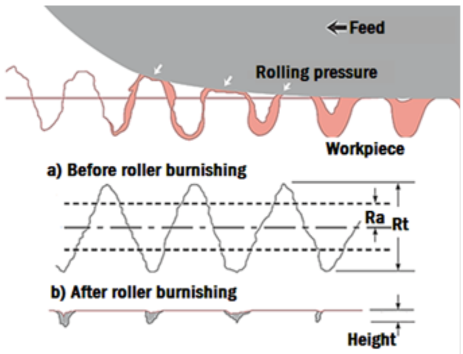

Fig. 1. Evolution of surface by burnishing [1]

Several studies have investigated the effect of burnishing on the workpiece properties (e.g. increasing the residual stress, hardness, corrosion and wear resistance further to enhance the fatigue life and surface quality). [4, 5, 6]

Because ist's simplicity and economical usability, the burnishing is a widely used cold treatment process. The type of burnishing process depends on the form of the workpiece (e.g. flat or cylindrical). In this study a newly designed flat-surface ball burnishing tool was examined. To burnish a flat or maybe 3D surface needs special tool and/or equipment (e.g. hydraulic hose and pump). For example F. Gharbi, S. Sghaier and T. Benameure designed a tool by it's own, it consist of four burnishing tools which are adapted in a special tool holders (Fig. 2.). [7]

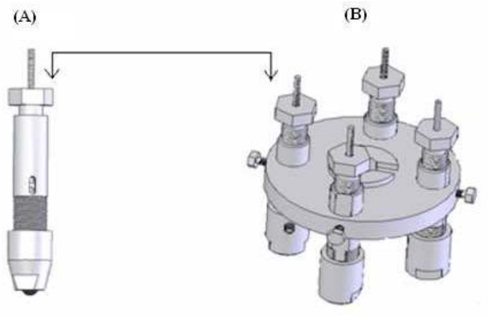

Fig. 2. (A) The simple ball burnishing tool and the (B) tool holder with four ball burnishing tools.[7]

The main problem with most of the burnishing tools (such as Fig.2.) is the applicability in CNC machine because it is difficult to place into the tool magazine.

Taken in consideration avoiding the expensive and complicated construction, the authors designed a novel MABB tool. During the design process it the Magnetism Aided Machining or Magnetic Assisted Machining (MAM) technologies were investigated [8, 9, 10, 11, 12], which are relatively new industrial machining processes. The MAM technologies are mainly suitable for finishing and surface improving. The MABB tool was developed to reduce the surfaces roughness, increase the surface hardness and deburring edge of flat (in some cases even 3D surfaces) metal parts. The magnetic force makes this process simple, more productive and also environmental friendly. The machining force is generated by the magnetic field between the workpiece and tool, so this is the reason why it is so important to set up the right tool-workpiece distance to ensure the necessary rolling pressure. [13]

To achieve the best burnishing results several controlling parameters, namely burnishing speed, feed rate, force, number of burnishing passes, workpiece material and hardness, ball material, ball size, number of balls and lubricant have to be considered. [14, 15]

A.M. Hassan, A.S. Al-Bsharat in their research showed that the burnishing forces and the number of tool passes are the most predominant parameters that have an effect on the surface roughness of the workpiece during the burnishing process. [16]

II. MAGNETIC ASSISTED BALL BURNISHING

The MABB tool contains four magnetizable bearing balls and by the magnetic force these balls pulls on a cone which located the end of tool and this creates the necessary rolling force (Fig. 3.).

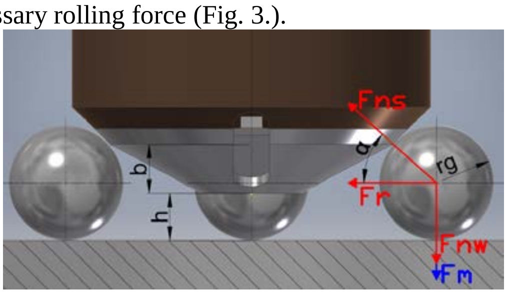

Fig. 3. The generated force during ball burnishing

The first generation MABB tool works with an electro magnet (see on Fig. 4.). The constructions' main advantages are the adjustable magnetic force which gives less importance to the gap distance. But this adjustable function causes problem in the usability, because it requires cables and so it is not appropriate to a modern CNC machine. Furthermore, during machining the electromagnetic coil heats up and, as a result, decreases the magnetic field strength. [13]

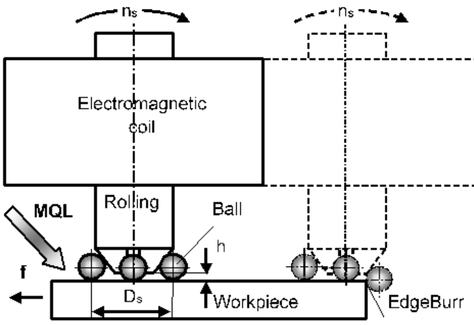

Fig. 4. Concept of the electro MABB tool [13]

The new type of MABB tool works with NdFeB permanent magnet instead of the electromagnet (see Fig. 5.). Thanks to the permanent magnet design, the tool can be placed in the tool magazine, removing edge burr and following the topology of surface.

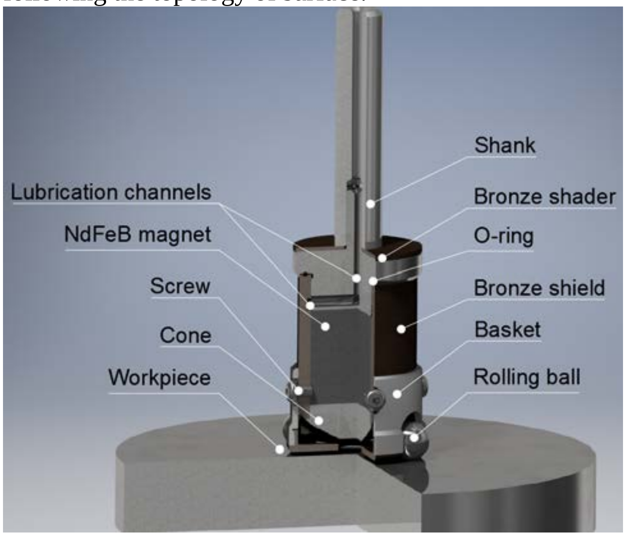

Fig. 5. Parts of new MABB tool

In a recent study M.M. El-Khabeery and M.H. El-Axir have identified some of the main effects of the burnishing. Their results are useful and contains essential statements (e.g. the burnishing speed should not exceed about 120 m/min to obtain high surface quality), but as it was mentioned the tool gap has great significance and so it maust be on an optimum value. [17]

III. DETERMINATION OF WORKING GAP BY CALCULATION

The optimum *h* distance can be determined by calculation and experiments. For calculation the necessary parameters were known (r_g=mm and *b*=5 mm) so they can be used in the equations (1) and (2) by the Fig. 2. vectors:

$$h = r_g \cdot (\sin\alpha + 1) - b \qquad (1)$$

$$F_{nw} = F_r \cdot \tan\alpha \qquad (2)$$

The equalization of (1) and (2):

$$F_{nw} = F_r \cdot \tan \cdot \left(\arcsin\left(\left(\frac{h+b}{r_g} \right) - 1 \right) \right) \qquad (3)$$

In the equation (3) the F_r is a constant, because there is no change in the permeability of the ball and the gradient of magnetic field during the rolling. The calculations are initiated with *h*=4mm gap and tested up to *h*=12 mm. Under the *h*=4mm the balls can fly away, because the balls reach the tool edge which made from bronze and there cannot be affected by the magnetic field strength. Reaching the *h*=11mm gap and the α=90° there is not solution for the tangent. By the equations (3) was set up a graph function of the *h* and F_{nw}/F_r (Fig. 6.).

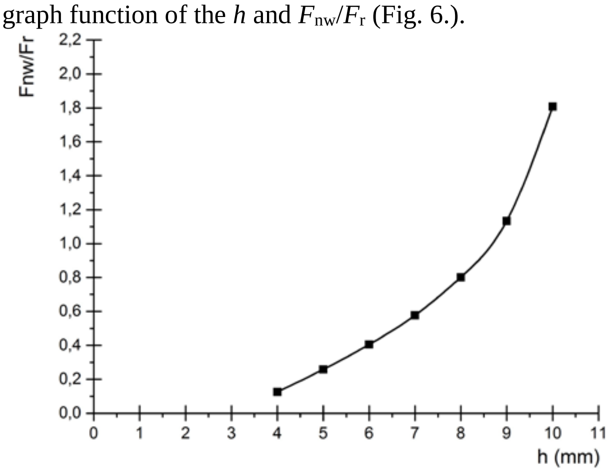

Fig.65. The relationship between *h* and F_{nw}/F_r by calculations

So that, the optimum gap distance where the burnishing force is the biggest is about *h*=10mm by calculations.

IV. DETERMINATION OF WORKING GAP BY EXPERIMENT

The results of the calculations it may be different from the reality and therefore the determination of the gap is carried out by experiments. For the experiments a CNC milling machine and a KISTLER Type 9125A24A2 force and torque measuring instrument were used (Fig. 7.).

Fig. 7. KISTLER rotating dynamometer [18]

The measuring tooks 100sec while the sampling rate was 500Hz. The measuring range of F_z was set up -400–700N.

As a first step, to avoid accidents, the tool was tested in a standing position (without the main rotating movement) and after knowing the optimum gap, the the rolling force while the tool is rotating.

A. Standing tool

For the experiment the results of the calculations were used, so the starting position was the maximum *h*=11 mm gap and tested down to *h*=4 mm. The measurement arrangement is shown in the Fig. 8.

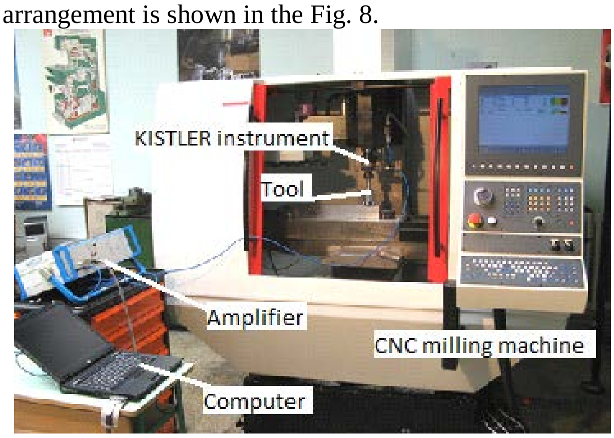

Fig. 8. Experimental setup of the force measuring

The measurement started in h=14 mm, without balls.. Then the balls were included and the tool began to move away from the surface with 1mm steps. The result of the measurements are shown in Fig. 9.

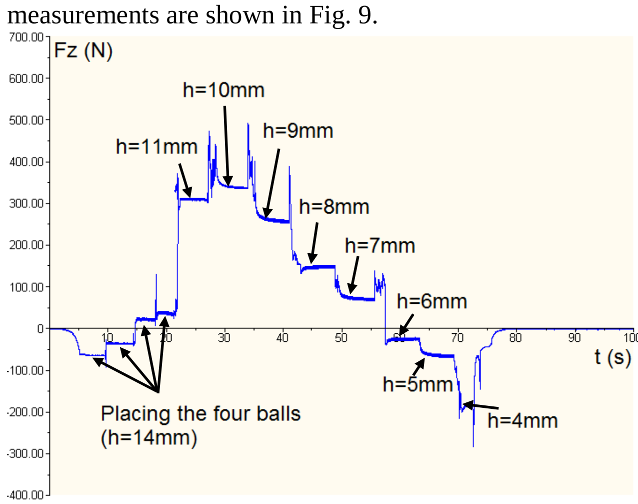

Fig. 9. The magnetic force depending on the tool distance

As shown in Fig. 9. without balls the tool attracts the workpiece, consequently, this is the reason for the negative F_z force. After that are placed the balls into the work space, the tool began to pushing the workpiece by the balls. sAs it can be seen in Fig. 9., the maximum force with *h*=10mm gap and under *h*=6mm the F_z force will be again negative. This means that the tool started to attract again the workpiece by the balls and the cone of the tool.

According to the expectations and the calculation, the maximal force (F_z=350N) was measured at h=10mm. Because there are four balls the force of 87,5N per ball with standing tool is expected.

B. Rotating tool

The main problem with a rotation is that it increases the centrifugal force which can critically reduce the burnishing force and also the balls can fly away. In order to avoid it, the rolling force was measured during increasing rev too. The revolution was increased from 0 to 1400rev/min. The F_z values are summarized in Fig. 9.

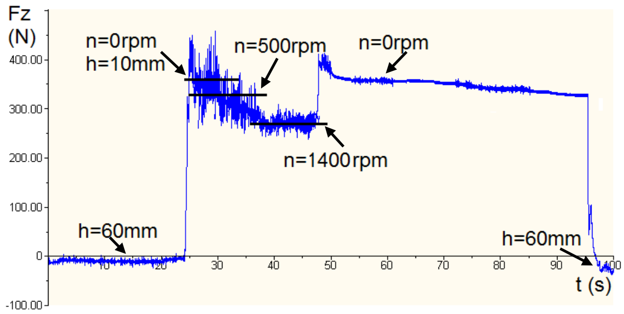

Fig. 10. Changing magnetic force depending on the rev

As shows the Fig. 10. the effect of the increasing revolution is the decrease of the rolling force from 350N to 280N. This represents that the force was decreased by 20%. This decline does not a big value and in the practice experts never use higher revolution than 1400rev/min, because of the high revolution that negatively affects the quality of the surface [17]. So the tool can be safely used until 1400rev/min. In practice, the best revolution range is between 150-500rev/min [13].

V. TEST BURNISHING WITH THE OPTIMUM GAP

The influence of roller burnishing parameters on the machined surface roughness was experimentally studied applying the previously determined gap. Actually beside the gap distance, the burnishing speed (v_b) and feed per ball (f_g) technological parameters have the main effects on surface roughness. In the consciousness of this was defined to find optimal values for v_b and f_g.

A. Experimental details

Testing sample was a grinded (technical parameters of grinding: v_c=35m s^{-1}, v_f=100mm min^{-1}, a=0,02mm) C45-type steel with the length of 350mm and the width of 130mm. The burnishing tool diameter was 43mm, and the gap was h=10mm. The balls' diameters were d=Ø16mm, and the bearings were made from steel. For machining, a Minimum Quantity Lubrication (MQL) system with 20 °E synthetic oil was used.

During the selection of technological parameters the primary goal was to easy determine the effect of technological parameters on the burnished surfaces, therefore, the experiments had two variables (v_b and f_g). Both variables have given two values so the number of experiments was 2^2=4.

In the practice, the best revolution range is between 150-500rev min^{-1} (Fig. 10.), so, the chosen revolution values were 150rev min^{-1} and three times of that. Takeing into consideration the tool diameter, the chosen burnishing speed were 20 and 60m min^{-1}. Based on this logic the feed per ball were 0,033mm ball^{-1} and three times of that. The full technological parameters of burnishing are shown in Table 1.

Table 1. Technological parameters of burnishing operations

No.	n (rev min^{-1})	v_b (m min^{-1})	f_g (mm ball^{-1})
1	150	20	0,033
2	150	20	0,1
3	450	60	0,1
4	450	60	0,033

The quality of burnished surfaces were better than expected which shows in Fig. 11. The surfaces can reflect the background like a mirror..

Fig. 11. The machined surfaces from 1 to 4

B. Evaluation

The machined surfaces were measured by roughness tester (type of MITUTOYO Formtracer SV-C3000). Each surface was measured three times and the average of them are presented in the Fig. 12. The original grinded average surface roughness Ra was 0,469 μm. The reason of the grinded premachined workpiece was chosen to avoid every confusing effect (e.g. tool vibration or surface structure and roughness inhomogeneity).

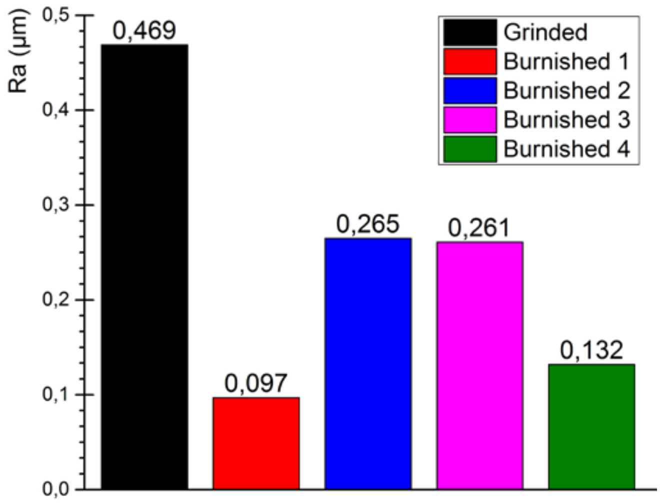

Fig. 12. The surface roughness evaluation

As it can be seen in Fig. 12. the value of the surface roughness was reduced to one fifth compared with the grinded surface. Furthermore, it is also visible that the feed per ball has the greatest effect of the roughness reduction.

VI. CONCLUSION

The aim of this paper is to analyze the optimum gap of MARB tool. Calculation were used for the analyses of the KISTLER rotating dynamometer. Both of method gave the optimum gap, furthermore it was determined that the burnishing force of 80N per ball using the KISTLER rotating dynamometer.

As shown in Fig. 9. the influence of gap is not negligible because 1mm displacement of the tool means about 50-80N force reduction. This reduction is very important because the hardening and the surface improvement depend on the burnishing force as can be seen in equation, too (4) [19]. This is the main reason, while the optimum gap has to be determined:

$$\Delta l = \sqrt{\frac{F}{R_{eH}}} \quad (4)$$

where Δl the thickness of hardened surface layer, F (N) is the burnishing force and R_{eH} (MPa) is the upper yield strength. The equation (4) shows that the Δl thickness cn be increased by increasing F.

In the second part of the experimental results revealed that the feed per ball affects the workpiece surface improvement significantly.

Based on the results, it has been proved that the MABB tool is suitable to roller burnishing flat or thanks to the flexible balls almost flat (3D surfaces with flat extension).

VII. OUTLOOK

The further scheduled tests are the examination of the effect of the gap distance (between h=8mm and h=12mm) on the surface roughness and hardness.

A further examination is also important to get the tool usability for 3D surfaces. It should be examined what is the maximum surface topology, when the MARB toll can be used.

VIII. NOMENCLATURE

h	gap between the tool and workpiece (mm)
b	cone high (mm)
r_g	ball radius (mm)
F_{ns}	magnet attraction force (N)
F_r	radial attraction force (N)
F_{nw}	burnishing force (N)
F_m	magnetic attraction force of workpiece (N)
F_z	z-axis force (N)
v_b	burnishing velocity (m rev^{-1})
f_g	burnishing feed per ball (mm ball^{-1})
n	revolution (rev min^{-1})

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