SURFACE FINISHING BY ROLLER BURNISHING USING APPARATUS OF PERMANENT MAGNET

János Kodácsy, János Líska, Zsolt Kovács

Original scientific paper

The authors present the results of experimental and developing work regarding Magnetic Aided Roller Burnishing (MARB) process and apparatus using permanent magnet that operates by surface finishing, deburring and by the strain hardening effect. Additionally, the paper demonstrates the benefit of using the apparatus with permanent magnet against using the apparatus with electro magnet. Finite Element Method (FEM) modelling software system was used in support of the experimental results.

Keywords: burnishing; deburring; FEM; magnetism; simulation; strain hardening

Završna obrada površine poliranjem valjkom uz primjenu naprave s permanentnim magnetom

Izvorni znanstveni članak

Autori predstavljaju rezultate eksperimentalnog i razvojnog rada koji se odnosi na postupak poliranja pomoću magnetičnog valjka (MARB) i napravu s permanentnim magnetom u završnoj obradi površine, brušenjem i učinka otvrdnjavanja. Dodatno se demonstrira korist od primjene uređaja s permanentnim magnetom u odnosu na uređaj s elektro magnetom. Podrška eksperimentalnim rezultatima dana je primjenom softvera za modeliranje metodom konačnih elemenata (FEM).

Ključne riječi: brušenje; FEM; magnetizam; otvrdnjavanje; poliranje; simulacija

1 Introduction

There are a lot of known solutions of mechanical roller-burnishing technologies [1÷4]. In this paper, the results of a comprehensive research work of roller burnishing metal parts in magnetic field will be presented. This recent fine finishing process is based on the following concept: the surface roughness of steel workpieces made of annealed steel or other ductile, magnetisable materials can be considerably decreased by burnishing in magnetic field using hardened steel balls. In addition, the hardness of the surface layer remarkably increases and there is a possibility to eliminate fine burrs. The necessary pressure and relative speed between the tools and the workpiece are ensured by the magnetic force using apparatus with electro or permanent magnet.

2 Magnetic Aided Roller Burnishing of flat surfaces using electro magnet

Magnetic Aided Roller Burnishing of flat surfaces was designed and adapted to a vertical milling machine. The design is illustrated in Fig. 1a, while the experimental setup can be seen in Fig. 1b. During rolling, the bearing (HRC64) balls were kept between the burnished surface and the conical end of the rotating arbor (as a magnetic core) by magnetic force. In the course of the burnishing tests, ferromagnetic construction steels (HB = 150) and non-ferromagnetic Al-alloy workpiece materials were investigated [5÷8]. As a result the ferromagnetic steel was burnished with better results than the non-ferromagnetic Al-alloy material, because of the higher magnetic force and continuous ball rotation. Therefore each ball has a point of rotation where it comes into contact with the workpiece. By the machining, a Minimal Quantity Lubrication (MQL) system with synthetic oil of 20 °E viscosity was used.
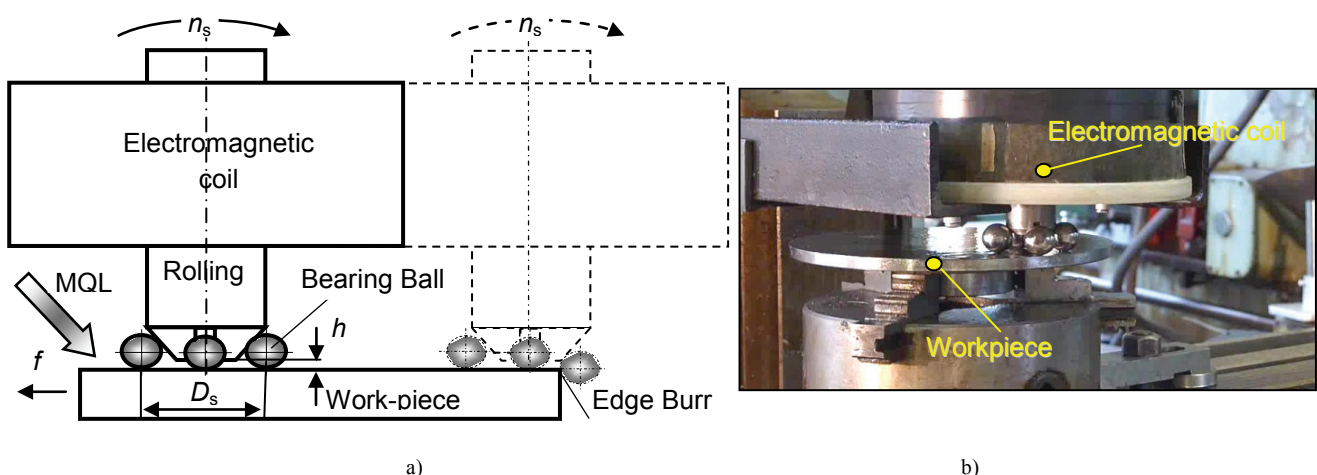

a)   b)
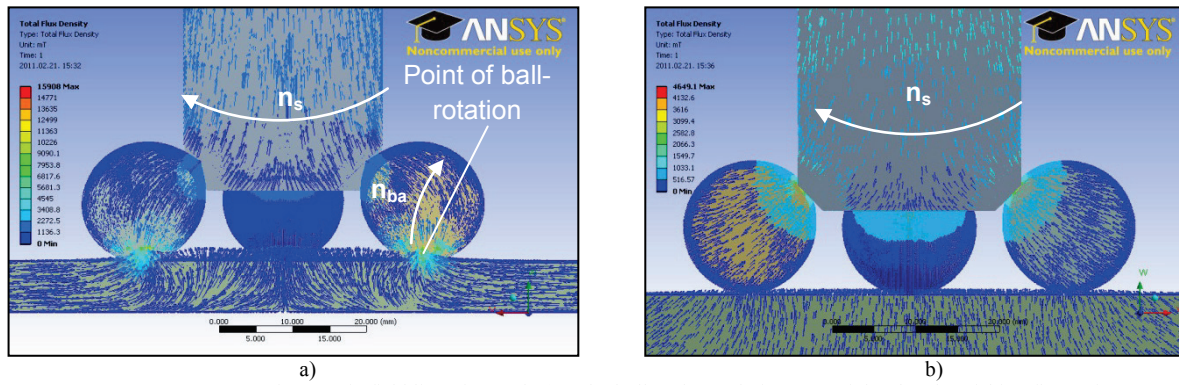**Figure 1** Design of Magnetic Aided Roller Burnishing of flat surface (a) and the photo of the equipment (b)

Figure 2 Arrangement of magnetic field lines for steel (a) and Al-alloy (b) workpiece materials when burnishing flat surfaces
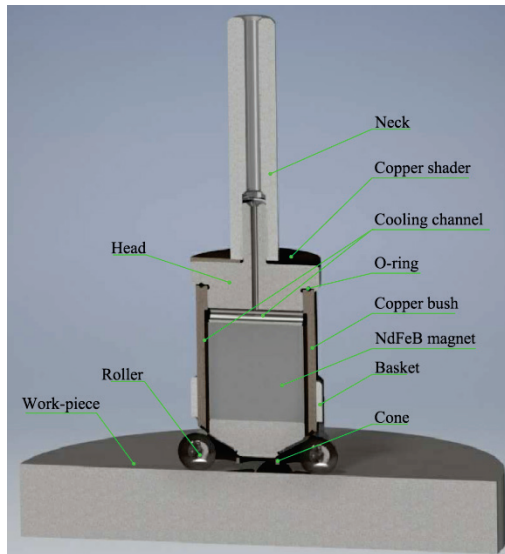

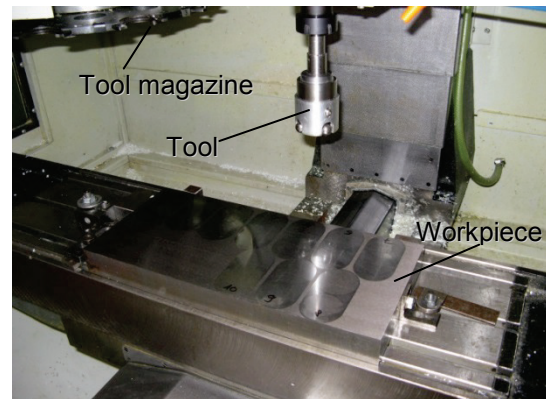**Figure 3** The MARB tool with permanent magnet

Figure 4 The MARB tool during roller burnishing

During the tests, the electrical parameters of the electromagnet were: charging voltage $U = 40$ V, amperage $I = 5 \div 20$ A (adjustable direct current) generating $B = 1,3 \div 1,8$ T magnetic induction in the $h \approx 3$ mm gap. The electromagnetic coil has 800 winds with $\varnothing 2$ coil-wire and the measure of the magnetic core is $\varnothing 25 \times 100$ mm.

By burnishing flat surfaces, the arrangement of the magnetic field lines for ferromagnetic (construction steel) and non-ferromagnetic (Al-alloy) workpiece materials is illustrated in Fig. 2. For modelling the ANSYS 11.0. Workbench, Magneto static module FEM software was used. In Fig. 2 it is visible when rolling ferromagnetic materials, the point of ball rotation occurs by the magnetic adhesion, while in case of non-ferromagnetic materials it does not.

3 Magnetic Aided Roller Burnishing of flat surfaces using permanent magnet

By the MARB with electro magnet, the process automation is a relevant problem, for example the usability of the apparatus on the CNC machine. Therefore, a new MARB tool with permanent magnet was developed. Fig. 3 shows the tool-parts and the 3D image of the tool.

The new tool can be positioned in the tool holder and can be taken to working position according to the machining process. Fig. 4 shows the tool after burnishing

in the tool holder. The shiny surfaces of the workpiece are burnished surfaces.

During roller burnishing of ferromagnetic materials (Fig. 2a) the magnetic field lines are condensed towards the direction of rolling arbour. As a result, the ball is attracted toward the centre line by having the arbour tapered and by lifting it in the right height h from the surface of the workpiece while pushing the surface by force F_{nw} (Fig 5a).

Force F_{nw} can be calculated by using Eq. (1), while the distance between the tool nose and the workpiece (h) and the α angle between vectors F_r; F_{ns} can be calculated by Eq. (2).

$$F_{nw} = F_r \cdot \tan\alpha, \quad (N) \tag{1}$$

$$h = r_g \cdot (\sin\alpha + 1) - b. \quad (mm) \tag{2}$$

From this:

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

According to Eq. (4), F_r at a given permanent magnetic tool depends only on the magnetic-field strength (H) and on its gradient ($\partial H/\partial r$), which can be changed by value h.

Evidently, the volume of the balls (V_g) and their permeability (μ) do not change during the roller burnishing process.

$$F_r = V_g \cdot H \cdot \left(\frac{\partial H}{\partial r}\right) \cdot (\mu - \mu_0). \quad (N) \qquad (4)$$

In Fig. 5a, the F_m magnetic force constituted between the magnetic ball and the workpiece is increasing the roller burnishing force in a small extent.

The force measurements were preceded by calculations and the results are shown in Fig. 5b. The radius of the balls of the tool constru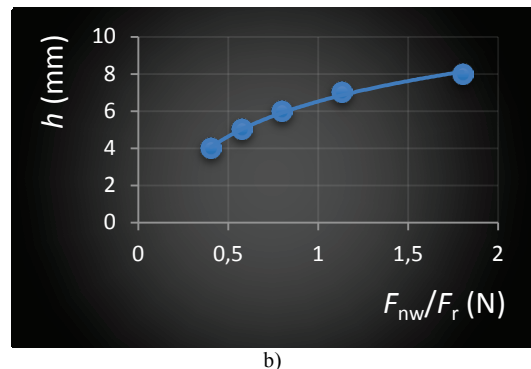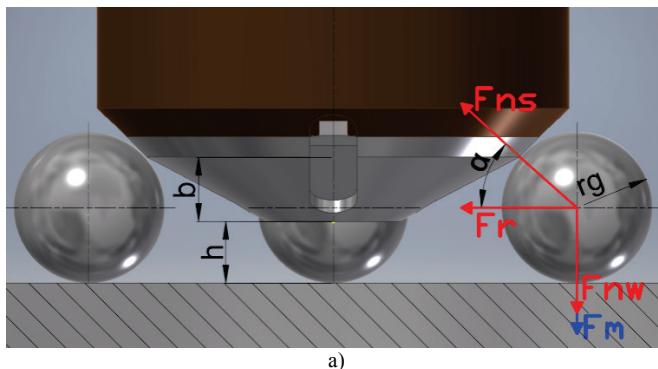ction is $r_g = 8$ mm, $b = 7$ mm and the size of the NdFeB magnet part is $\varnothing 40 \times 40$. The calculations are initiated with $h = 4$ mm gap and tested up to $h = 9$ mm. At $h = 9$ mm, equation (3) does not have valuable result because of $\alpha = 90°$. If height h is being increased, the burnishing force F_{nw} is also increasing, however, as the diagram shows the contact and the force transfer become uncertain over $h = 8$ mm. During the measurements, similar results are given. These values allow the roller burnishing of the free form surfaces of low wave to avoid having the burnishing force reduced and resulting in uneven surface roughness.

Figure 5 Vector figure of roller burnishing (a) and the change of F_{nw}/F_r depending on h

The change of the roller burnishing force depending on tool distance (h) is shown in Fig 6. The measurements are initiated by the distance of the workpiece tool nose $h = 10$ mm without balls. Without the balls the sinuous diagram in the figure is in the negative domain. This means that the tool and the workpiece are attracted. After placing the balls into the work space, positive force value is given. From that point the tool is not attracting the workpiece but pushing the workpiece by the balls. Then the tool is approached gradually to the surface of the workpiece until the gap reaches $h = 2$ mm. In this position, negative force is registered to be similar to the position without the balls. This means the pressure on the surface by the balls and the peak started to attract the workpiece. According to the expectations, the maximal burnishing force was measured at $h = 8$ mm. KISTLER 9125A24A2 force and torque measuring instrument is used for the measurements.
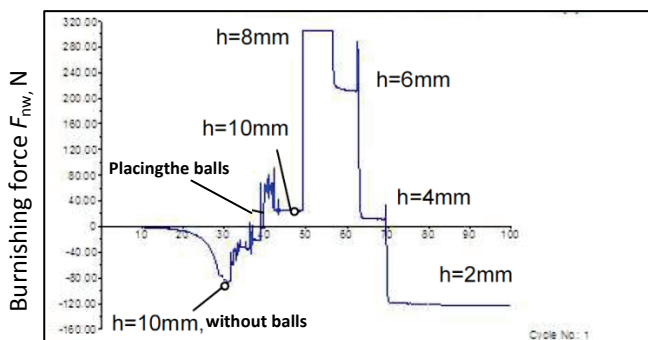
revolution domain should be defined first, because after a certain revolutions, the centrifugal force is increasing and can critically reduce the burnishing force. While testing, the rev are increased from $n = 100$ rev/min to $n = 1200$ rev/min. The diagram of Fig. 7 shows that the force decreases by 30 %. This decline does not affect the safe use of the tool.
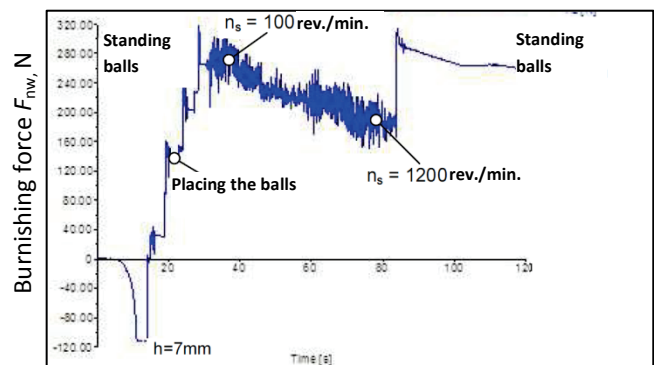

Figure 7 Changing magnetic force by changing tool revolution

4 Practice results of MARB

As it was mentioned, the surface roughness can be improved after the MARB, the burnished surface layer hardens and the burr can be removed from the side of burnished surface.

Some of these practical results should be presented as follows.

The surface roughness after MARB process plate C45 should be machined in normalized conditions (HB 150) by CNC milling machine after grinding in more technological variants. The two variants of technological

Figure 6 Changing magnetic force depending on the tool distance to the workpiece

Considering the expected force and geometrical data, test burnishing could be carried out, but the applied tool

parameters of burnishing are presented in Tab. 1, the results are shown in Fig. 8.

**Table 1** Surface burnishing conditions at permanent magnet after grinding

Technology		1	2
Tool revolution	n_s / rev/min	130	413
Tool diameter	D_s / mm	$\varnothing44,5$	$\varnothing44,5$
Burnishing speed	v_b / m/min	18,2	57,7
Feed speed	v_f / mm/min	18,23	62,87
Feed rate	f_g / mm/ball	0,036	0,036
Tool distance	h / mm	7	7

The ball diameter in both cases was $d = \varnothing16$ mm, and the ball bearings were made from magnetisable steel. By the machining, a Minimal Quantity Lubrication (MQL) system with 20 °E synthetic oil was used.
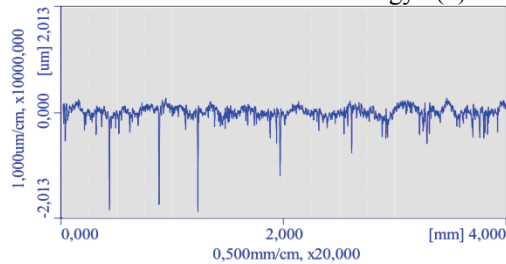
Grinding parameters were applied as follows: v_c = 35 m/s, w_w = 30 m/min. Flat-grinding machine was used, the grinding tool dimension was $\varnothing300\times30$ mm and the grain was Al_2O_3 with 280 μm size.
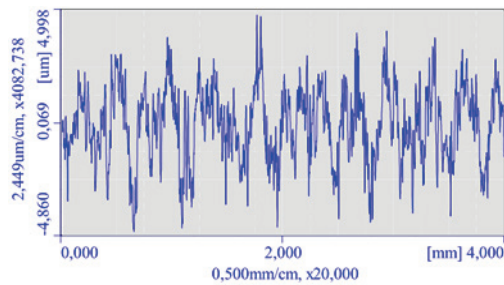
Surface after grinding (a)
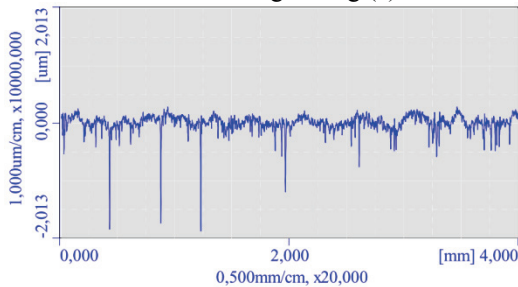
Surface after MARB technology 1(b)

Surface after MARB technology 2(c)

| Parameter Table			
Surface roughness	Average after grinding	Average after technology 1	Average after technology 2
Ra / μm	1,296	0,078	0,112
Rq / μm	1,596	0,104	0,187
Rz / μm	8,226	0,757	1,857
Rt / μm	9,389	0,976	3,308

Figure 8 The Surface roughness and its parameters after grinding (a) and MARB (b, c)
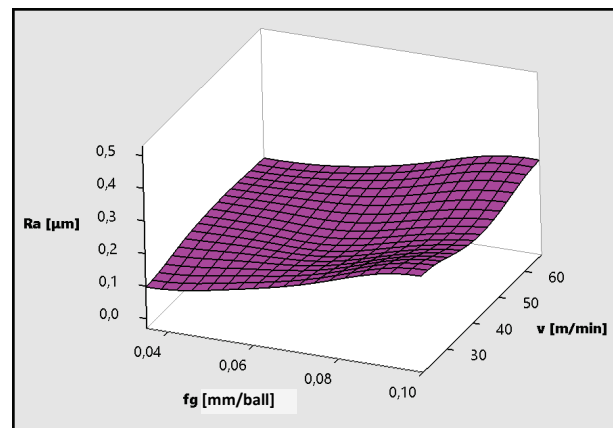
Fig. 9÷10 show the evaluation of Ra and Rt before and after MARB during changes of burnishing speed - v_b (1 and 2 technology).
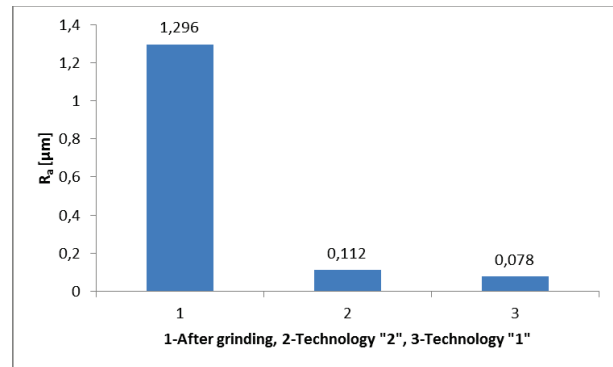
Figure 9 The surface roughness average (Ra) evaluation
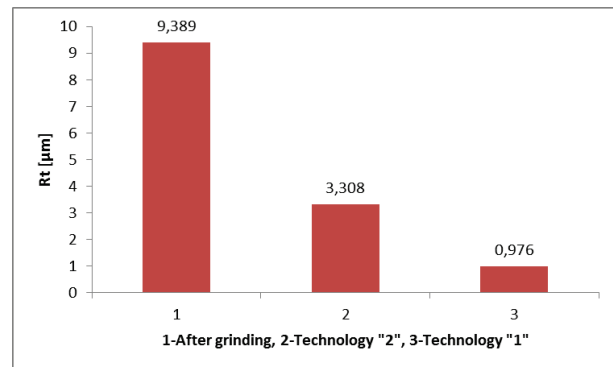
Figure 10 The surface roughness total height (Rt) evaluation

Figure 11 3D map of surface roughness average after MARB

Fig. 11 shows the MARB evaluation on surface roughness (Ra), if the feed rate $0,03 < f_g > 0,1$ (mm/ball) and the burnishing speed $18 < v_b > 63$ (m/min) was changed.

5 The hardening by MARB

Using MARB in one stroke, the hardness of the surface layer can increase one and a half times more at $\Delta r = 20÷30$ μm thickness (Fig. 12). By the machining, the ball diameter was D_g = 8 mm; the forming speed: v_b = 40 m/min; the forming force: F_{nw}= 90 N/ball; the workpiece material: C45 annealed.
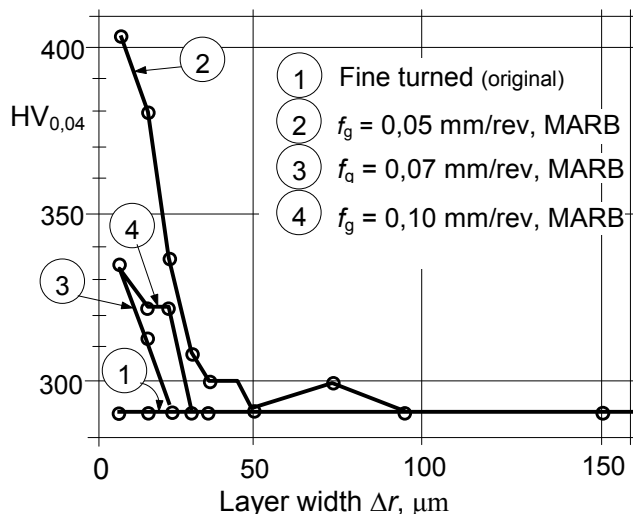
Figure 12 The hardening of surface layer after MARB

6 Deburring by MARB

The process is also suitable for eliminating fine burrs from the edges of flat surfaces, because the balls – in the case of ductile workpiece materials – may press the burrs into the workpiece-edge or the extra sharp edge to the other side of the workpiece (see Fig. 1a). The machining makes the sliding movements (v_s) of the slippery surfaces easier and impedes the possible jam in the guide way of metal parts (Fig. 13). Actually, this process is the magnetic version of the edge rolling operation of sheet stocks using pinch rolls to remove burrs or reroll the material into the edges [9, 10].
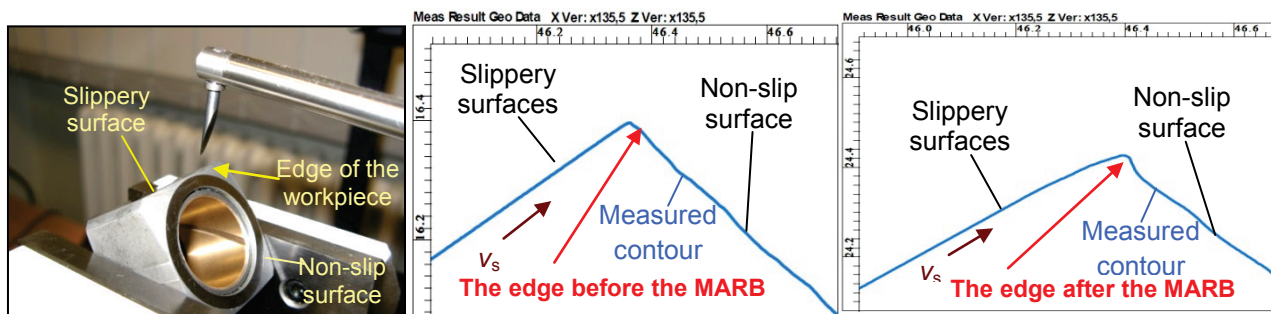

Figure 13 Slippery surface measurement and its evaluation

7 Conclusion

Experimental devices were constructed by the authors for performing finish machining tests by Magnetic Assisted Roller Burnishing (MARB) process, using steel and Al-alloy specimens. During the tests, geometrical and kinematical parameters of the surface quality were investigated and determined in detail.

The main results obtained in this experimental work are summarised as follows:

- Based on the results of the experiments, it has been proved that this process can be effectively and economically used for finishing (burnishing) flat surfaces of magnetisable metal workpieces. The result depends on the technological conditions and the design of the tool.
- In addition to the decrease of the surface roughness, the hardness of the surface layer may considerably increase within the depth of 10÷30 µm due to the strain hardening.
- In some cases, MARB technology gives opportunity for improving of sliding properties by burnishing of burrs or sharp edges.

MARB tool with newly developed permanent magnet allows the integration of technology into automated machining processes

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Authors' addresses

János Kodácsy, Dr.
Pallasz Athéné University, GAMF Faculty of Engineering and Computer Science, Department of Vehicle Engineering
H-6000 Kecskemét, Izsákiút 10, Hungary
kodacsy.janos@gamf.kefo.hu

János Líska, Dr.
Pallasz Athéné University, GAMF Faculty of Engineering and Computer Science, Department of Vehicle Engineering
H-6000 Kecskemét, Izsákiút 10, Hungary
liska.janos@gamf.kefo.hu

Zsolt Kovács
Pallasz Athéné University, GAMF Faculty of Engineering and Computer Science, Department of Vehicle Engineering
H-6000 Kecskemét, Izsákiút 10, Hungary
zsolt.kovacs@gamf.kefo.hu