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Manufacturing of Twist-Free Surfaces by Magnetism Aided Machining Technologies

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Abstract—As a well-known conventional finishing process, the grinding is commonly used to manufacture seal mating surfaces and bearing surfaces, but is also creates twisted surfaces. The machined surfaces by turning or grinding usually have twist structure on the surfaces, which can convey lubricants such as conveyor screw. To avoid this phenomenon, have to use special techniques or machines, for example start-stop turning, tangential turning, ultrasonic protection or special toll geometries. All of these solutions have high cost and difficult usability. In this paper, we describe a system and summarize the results of the experimental research carried out mainly in the field of Magnetic Abrasive Polishing (MAP) and Magnetic Roller Burnishing (MRB). These technologies are simple and also green while able to produce twist-free surfaces. During the tests, C45 normalized steel was used as workpiece material which was machined by simple and Wiper geometrical turning inserts in a CNC turning lathe. After the turning, the MAP and MRB technologies can be used directly to reduce the twist of surfaces. The evaluation was completed by advanced measuring and IT equipment.

Keywords—Magnetism, finishing, polishing, roller burnishing, twist-free.

I. INTRODUCTION

THE turning always creates a twisted surface, namely regardless of the machined material or whether that is hardened or not. This type of surface has regular structures corresponding to a thread shaped structure by the tool along the rotating workpiece are producing a screw pitch [4]. The reason for this phenomenon is that the feed motion of the tool will cause twist structures on the surface of workpiece which can cause leakage. Those surfaces produced by conventional turning tool have typical roughness structure and spiral pattern, which is responsible for the conveyor effect in the gap between the seal ring and the shaft. However, the grinding process also can produce twist structure, because of the dressed grinding wheel. The dressing diamond creates twisted structure on the surface of grinding wheel, which is able to copy onto the surface of workpiece.

There are also other techniques to make a twist-free surfaces like tangential turning, vibration-processing methods or start-stop turning [1], [2].

The main problem about these techniques is that they require special machine and thus demand significant investment. Moreover, the special tools and techniques also have disadvantages like the price, limited length and long manufacturing time.

II. STRUCTURE OF TWIST SURFACE

Twist structures are characterized by microscopic structures which are comparable with a thread structure on a shaft surface. Fig. 1 shows the surface of a turned shaft schematically. The parameters are described in the Mercedes-Benz standard MBN 31007-7 in 2009 [3], [4].

- DP – period length (mm),
- Dγ – twist angle (°),
- Dt – twist depth (μm),
- DG – number of threads (no.),
- DF – theoretical supply cross section (μm^2)

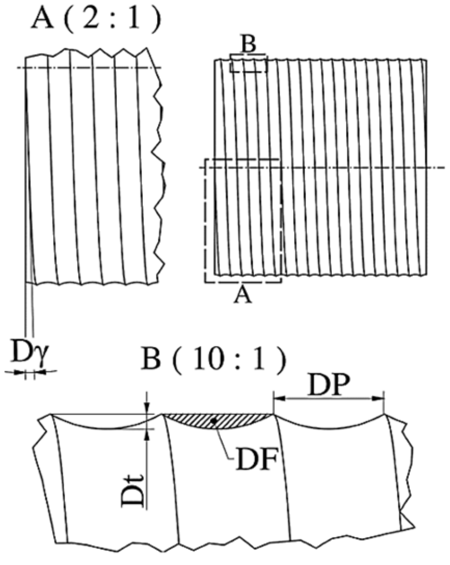

Fig. 1 Parameters of twist surface [5]

The parameters of twisted surfaces are dependent on process parameters (feed, nose radius etc.). During the rotation, the liquid entrains in the circumferential direction and is deflected axially because of the twist structures [5].

The industry is currently looking for alternative manufacturing processes, for example hard turning, milling, burnishing or laser polishing. Besides these processes, there are two similar technologies, the MAP and the Magnetic Assisted Roller Burnishing (MARB) which are also able to produce twist-free surface.

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III. MAM TECHNOLOGIES

The Magnetism Aided Machining (MAM) is actually a relatively new industrial machining processes (mainly finishing and surface improving). The magnetic force makes these processes so simpler and productive. The machining force is generated by an adjustable electromagnetic field between two magnetic poles within the working gap to ensure the necessary machining (rollling or pollishing) pressure between the tool and the workpiece [6].

A. MAP

The polishing is used to decrease the surface roughness and increase the wear resistance, corrosion resistance and produce twist-free surface. MAP is one such unconventional finishing process developed recently to produce efficiently and economically good quality finish. During the process were used ferromagnetic particles which are sintered with fine abrasive particles like Al_2O_3, SiC, CBN or diamond. The MAP equipment for cylindrical surfaces was adapted to a universal engine lathe (Fig. 2) [7].

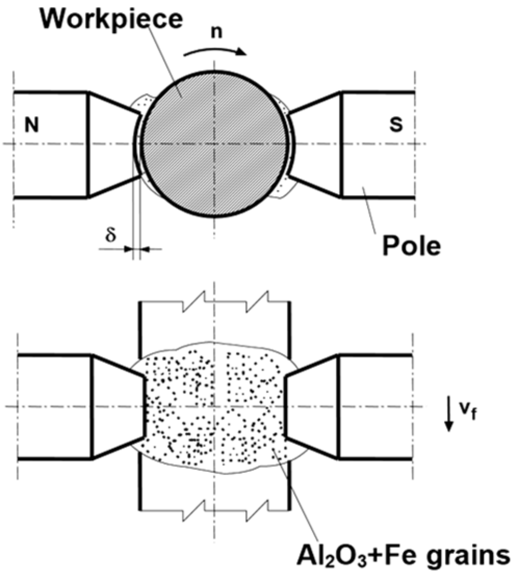


Fig. 2 MAP technology [7]

B. MARB

The main goal of roller burnishing is to achieve high-quality smooth surfaces or surfaces with pre-defined surface finish. During the process, steel bearing balls plasticity deforms the workpiece surface (Fig. 3). In case if this stress is higher than yield strength of the material, the material near the surface starts to flow. As the ball moves across the workpiece surface, the peaks of surface are pressed down, almost vertically, into the surface and the material then flows into the valleys between the peaks as one can see in Fig. 4 [8].

Most manufacturing processes which result high-quality surfaces can be replaced by roller burnishing (e.g. fine turning, grinding, superfinishing, lapgrinding). The roller burnishing technology is able to reduce the surfaces roughness (Rz <10 μm) and increase the hardness in micron depth [8].

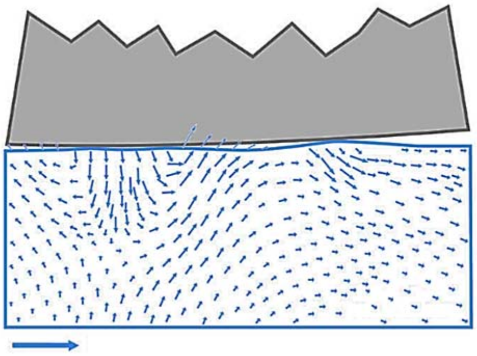


Fig. 3 Material flow [8]

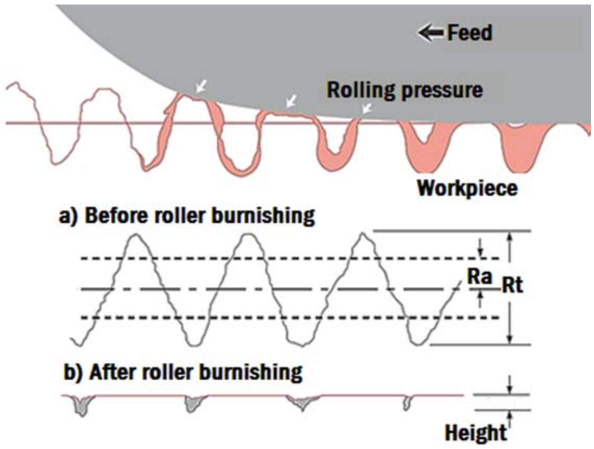


Fig. 4 Evolution of surface by roller burnishing [8]

During roller burnishing, the rolling force was created mechanically (the rolling toll is pressed onto the surfaces). To avoid the harmful deformation by mechanical pressing, the necessary pressure and relative speed between the tools and the workpiece are ensured by the magnetic force.

The burnishing operation was performed by hardened steel balls of 6…12 mm diameter (HRC = 60), with v = 20…800 m/min peripheral speed and f = 0,05…0,3 mm/rev feed. The balls were set above or under the jaws in radius-shaped slots preventing the balls from any kind of axial displacement. The magnetic force kept the balls in the slots and – depending on the scale of magnetic induction – pressed them to the surface of the workpiece with a force of 50 ... 100 N. The balls could freely roll perpendicularly to the rotational axis of the workpiece following the eventual macro-unevenness of the cylindrical surface. The burnishing operation consisted of a double-stroke motion of the slide along the rotating workpiece, in feed direction.

The MRB equipment for cylindrical surfaces was adapted to a universal engine lathe (Fig. 5). In case, if the workpiece non-magnetic, the magnetic forces line cannot press the ball onto the surface and the process does not work, because the necessary rolling pressure does not occur (Fig. 6).

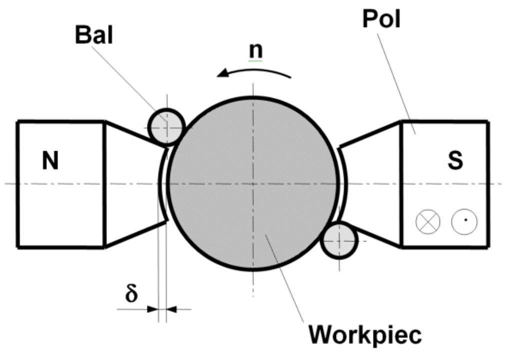
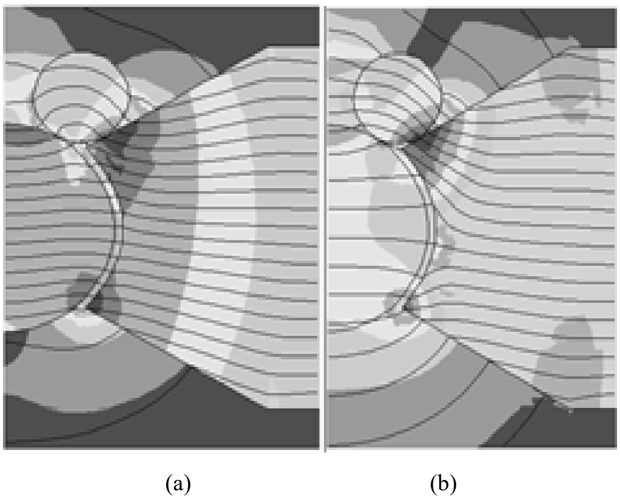


Fig. 5 MARB technology [7]



(a) (b)

Fig. 6 Magnetic lines for steel (a) and Al-alloy (b) workpiece material [7]

For the modelling system, the magnetic force components were computed using (1)-(3) [7]:

$$F_x = V \cdot H \cdot \left(\frac{\partial H}{\partial x}\right)(\mu - \mu_0) \tag{1}$$

$$F_y = V \cdot H \cdot \left(\frac{\partial H}{\partial y}\right)(\mu - \mu_0) \tag{2}$$

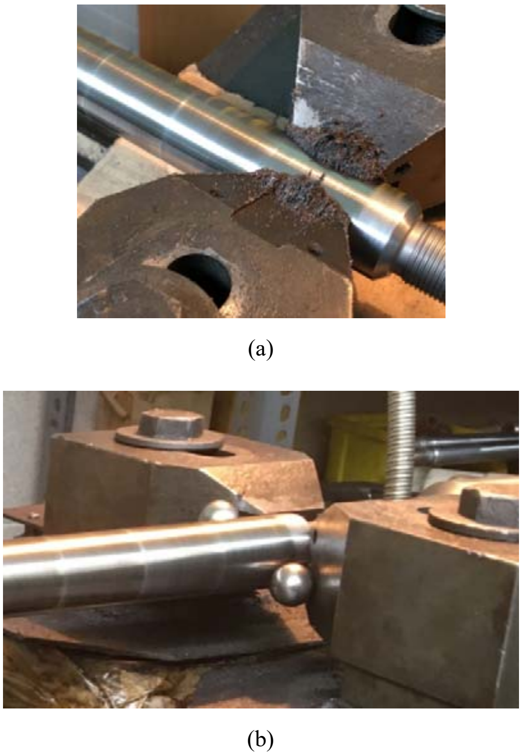
$$F = \left(F_x^2 + F_y^2\right)^{\frac{1}{2}} \tag{3}$$

where F is the magnetic force (including the components too), V is the volume of the burnishing ball, H is the intensity of the magnetic field, μ and μ_0 are magnetic permeability of the ball material and the vacuum, respectively.

IV. EXPERIMENTAL SETUP

In the performed investigations the shaft surfaces were manufactured purposefully by turning using different cutting tool. Then, the surfaces were machined by MAM technologies (MARB and MAP), as seen in Fig. 7.

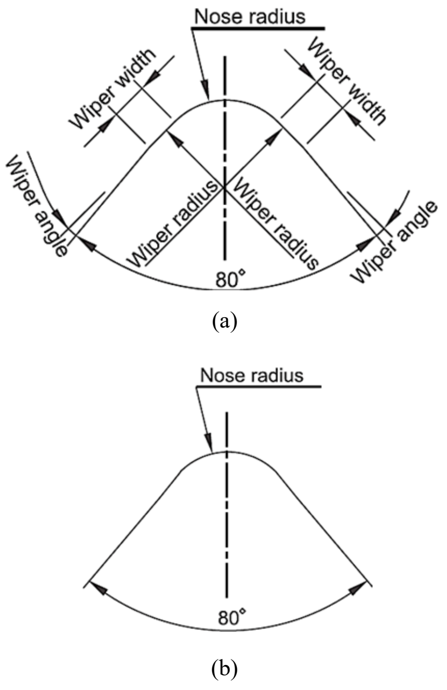
During processing the workpieces, C45-type steel with a diameter of 26 mm and a length of 100 mm was selected as processing element. The cutting tools were a wiper geometrical carbide insert (WNMG080404W-MF2, TP2501) and conventional geometrical carbide inserts (WNMG080404-MF2, TP2501) (Fig. 8).



(a)

(b)

Fig. 7 MA Polishing (a) and Roller Burnishing (b)



(a)

(b)

Fig. 8 Geometry of Wiper (a) and conventional (b) insert [4]

This MAM equipment is suitable for polishing and rolling where the electromagnetic poles were fixed onto the slide of the lathe. In the tests, the voltage (U = 40 V), current (I = 10 A) (direct current, adjustable) and the generating magnetic induction (B = 0.96 T) were the same of both technologies. The generated magnetic induction was reduced (B = 0.75 T) with polishing grain because of the applied Al_2O_3 shielding properties. The magnetic jaws (poles) surrounded the workpiece with a δ = 3 mm gap (clearance).

The applied technological parameters are shown in Table I.

TABLE I
TECHNICAL PARAMETERS OF MACHINING OPERATIONS

Turning	f (mm/min)	0,133
	v_c (m/min)	117
	a_p (mm)	1
Rolling	f (mm/rev)	0,1
	v_r (m/min)	22
Polishing	t (min)	1,5
	v_p (m/min)	62

f=feed; v_c cutting speed; a_p= cutting deep; v_r= rolling speed; t= time; v_p= polishing speed.

V. EVALUATION

After the manufacturing (grinding, turning, rolling and polishing), surface roughening was measured by MITUTOYO Formtracer SV-C3000 roughness tester. The results presented in Table II.

TABLE II
ROUGHNESS VALUES AFTER MACHINING

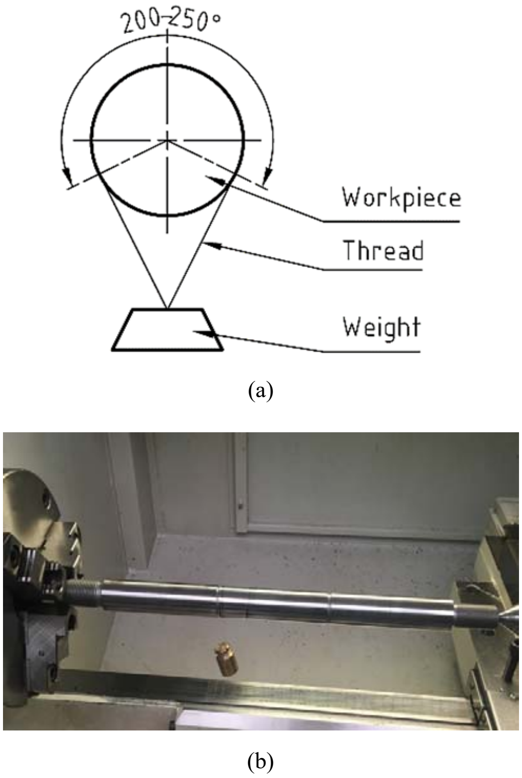
Technology	Ra (µm)	Rz (µm)
Grinded	0,54	3,43
Turned (simple)	1,2	6,09
Rolled	0,40	2,40
Polished	0,96	4,93
Turned (Wiper)	0,45	3,05
Rolled	0,27	1,92
Polished	0,38	2,79

After the rolling and polishing, the twisted surfaces were measured by thread method. This method is a simple and fast method because it consists of a thread and weight. The thread is made from steel, plastic or wool (e.g.: fishing line or sewing thread). Steel thread was used for the measurement (where the steel thread diameter of 0.04 mm). The weight depends on the applied thread material, in these case 50 g [9].

A. Measuring Procedure

The setup of the measurement is shown in Fig. 9. Measuring takes one minute and during this time the workpiece rotated with 20 m/min. After the one minute, we had to measure the displacement of thread to get the a_1 value. The experiment must be carried out in the other direction and also have to measure a_2. The average of two values (4) is the characteristic number of twist surface (a_m) [10]. The results are presented in Fig. 8.

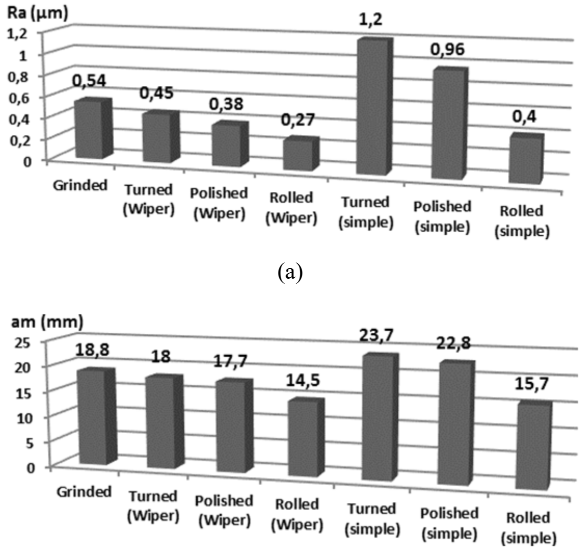
$$a_m = \frac{a_1+a_2}{2} \text{ (mm)} \tag{4}$$



(a)

(b)

Fig. 9 Thread method (a) [9] and during measurement (b)



(a)

(b)

Fig. 8 Measurement results of Ra roughness (a) and characteristic number (b) of twist surface

VI. CONCLUSION

The research shows that MAM technologies are new manufacturing opportunity for surfaces to obtain desired functions such as surfaces with tribological functions.

The Wiper insert produced less twisted surfaces compared to the simple insert and as you see in Fig. 8 (a) the grinded surfaces were worse than the rolled one.

In Fig. 10 (b) we can see that instead of grinding the MAMRB technology applicable because it is faster, economical, easier and in some case does not require workpiece transfer. Also the MAMRB has negatives, for example the accuracy (size and position) depends on the previous manufacturing.

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