

MAGNETO-ABRASIVE FINISHING OF COMPLEX SURFACES

Deaconescu Tudor [1] and Deaconescu Andrea [2]
[1] Transilvania University of Braşov, Romania, tdeacon@unitbv.ro
[2] Transilvania University of Braşov, Romania, deacon@unitbv.ro

ABSTRACT: Magneto-abrasive finishing is a machining process where the tooling allowance is removed by media with both magnetic and abrasive properties, with a magnetic field acting as binder of the grains. Such machining falls into the category of erosion by abrasive suspensions and lends itself to the finishing of any type of surface. The possibility of finishing complex surfaces is a special benefit of this machining, reflected in a number of recent studies on developments of interest. The paper presents two examples of magneto-abrasive finishing installations, one for machining spur or helical cylindrical gears, the other for finishing bearing balls. Both pieces of equipment are characterised by simplicity and high performance.
KEY WORDS: magneto-abrasive finishing, complex surfaces

1. INTRODUCTION

Erosion by abrasive fluids and suspensions pertains to the category of finishing machining processes aimed at ensuring dimensional, form and positional accuracy of surfaces. A further paramount aspect is the quality of the machined surfaces, some processes yielding roughness of nanometre order of magnitude. Also of interest is the structure of the machined material layers, or of those adjacent to the processed areas, which are little or not at all affected by the action of the erosive agent involved in machining [1], [2].

Considering these requirements, Japanese researcher Norio Taniguchi has introduced the concept of „nanotechnology”, placing abrasive erosion within this category of cutting procedures [3].

Amongst the final machining processes of workpiece surfaces, abrasive erosion has recently known increasing expansion. One of the important processes of this category is magneto-abrasive finishing.

The first mention of a magneto-abrasive machining procedure is connected to the name of the Russian scientist Karol, who in 1938 proposed the use of an alternating magnetic field for finishing the interior surfaces of pipes, by means of magneto-abrasive powders. Further major contributions acknowledged in literature are inter alia those of M. Baron, E.G. Konovalov, L.M. Kozuro in Russia, Al. Makedonski in Bulgaria, and K. Kato, Nakagawa, Taakeo Shinmura, Koya Takazawa, Eiji Hatano in Japan [2].

Magneto-abrasive finishing of surfaces is achieved by working media with both magnetic and abrasive properties, the magnetic field acting as binder of the grains. The utilized working media are magneto-abrasive powders in various compositions and concentrations, forming the so-called “magneto-abrasive brushes” or “magneto-abrasive tools”.

Machining with magneto-abrasive grains is based on the effects generated by the relative motions and pressures generated between the processed workpiece surface and the abrasive grains acting as tools, maintained in the machining area by means of a magnetic field.

Magneto-abrasive machining entails the existence of permanent contact between the abrasive grain and the workpiece surface. Two conditions need to be satisfied simultaneously for this contact to be maintained at the same time with the motion of the grain and/or of the workpiece: i) the existence of a sufficiently strong magnetic field, and ii) ferro-magnetic properties of the abrasive grain.

The existence of relative displacements between the “hairs of the abrasive brush” and the workpiece surface determines a micro-cutting process – if grain edges are sufficiently sharp, or a superficial micro-deformation process – for less sharp grain edges. For micro-cutting or micro-deformation to take place, the grains need to have sufficient hardness, and, as the case may be, cutting edges. Figure 1 presents the principle of this machining process [4].

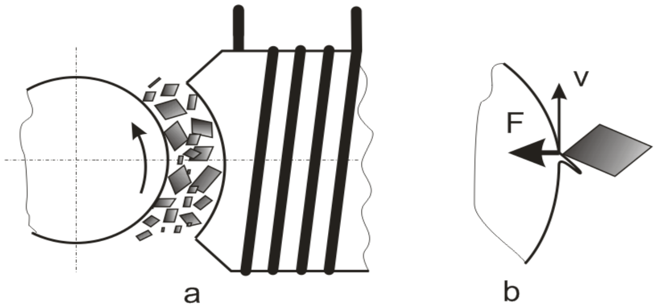


Figure 1. Principle of magneto-abrasive machining

As can be noticed in figure 1, in order for material removal to be possible, a relative motion (rotation and/or translation) needs to be generated between the workpiece and the "magneto-abrasive brush". Finishing of a surface requires at least one working motion, the rotations or linear displacements being carried out by the workpiece, the "brush" or by both components of the system.

Due to the motions of the workpiece and/or the magnetic poles, as well as to the characteristics of the magnetic field, the resulting forces cause material to be removed in form of chips.

For this reason magneto-abrasive erosion is considered part of dimensional machining involving mass modification based on tearing (dismembering) of the substance, where the tooling allowance is removed in form of chips. Magneto-abrasive erosion falls into the category of dimensional machining methods at the border of conventional and non-conventional processes. The conventional character of the machining is given by the modality of tooling allowance removal (cutting with abrasive grains), while the non-conventional one is represented by type of energy (magnetic energy) fed to the working area.

The main characteristics that define magneto-abrasive erosion are [5]:

- the energy introduced into the working area determines elementary processes that are continuous, progressive and cumulative;
- the 3D form of the transfer object can be copied onto the machined object;
- small mechanical strains on the components of the machining installation;
- possible complex automation of the machining processes.

Magneto-abrasive erosion is selected as the machining method for parts due to its many advantages:

- the presence of a so-called "self-sharpening" phenomenon of the "magneto-abrasive brush", by continuous orientation of the used edges of the grains;
- the absence of the "clogging" phenomenon characteristic of abrasive tools (grinding stones, polishing stones, etc.);
- easily adjustable hardness of the "magneto-abrasive brush", between certain limits, depending on the type of machined material;
- low remaining stresses due to the forces generated during machining.

This type of machining also entails a number of disadvantages that, however, do not cancel its efficiency and utility:

- a remanent magnetic field is generated by machining;
- elevated cost of obtaining of powders both abrasive and magnetic;
- the process cannot be applied to large workpieces, because of the complexity of required equipment.

Due to its performance related to surface quality, dimensional and geometrical accuracy, machining by magneto-abrasive erosion pertains to the category of superfinishing procedures. The obtained performance is close or even exceeds that of lapping or vibrosmoothing.

Magneto-abrasive machining is applicable to any form of surface to be finished. This paper discusses two variants of complex surface finishing installations, designed at Transilvania University of Braşov.

2 MAGNETO-ABRASIVE FINISHING EQUIPMENT OF GEARS

The finishing of cylindrical gear flanks can be achieved by magneto-abrasive erosion based on a principle similar to grinding. Figure 2 presents such a universal installation, capable of finishing spur or helical cylindrical gears of diameters between 100 and 200 mmm. The components of the installation were designed and dimensioned based on the kinematic diagram of figure 2:

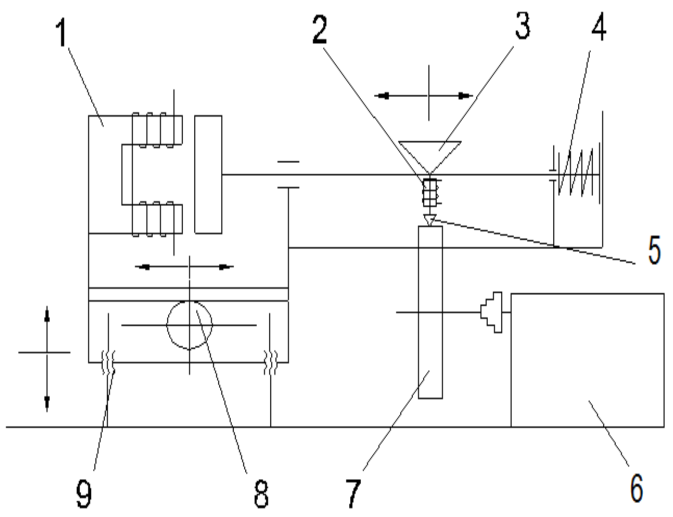


Figure 2. Kinematic diagram of the gear finishing installation

The main components of this equipment are:

- electromagnet;
- tool magnetic yoke;
- feeding funnel;
- repositioning spring;
- abrasive brush;
- indexing mechanism;
- workpiece (gear);
- pinion-rack mechanism;
- screw-nut mechanism.

A special importance in designing this device comes to the vibratory motion generator. It consists mainly of a sufficiently strong electromagnet to move the tool-bearer. Other components of the installation are:

- the elements causing tool withdrawal, thus allowing stepwise indexing of the workpiece;
- the vertical motion mechanism required for adjusting the vertical position of the tool, in order to machine gears of different diameters.

As can be noticed from the kinematic diagram, electromagnet 1 generates a vibratory motion, driving the assembly consisting of the magneto-abrasive grains feeding funnel, the magnetic yoke and the finishing tool. The pinion – rack mechanism 8 allows the longitudinal displacement of the upper part of the device, required for the rapid withdrawal of the magneto-abrasive brush upon completion of the finishing operations of one gap between two teeth. The indexing head 6 then rotates the gear by one angular step. The screw-nut mechanism 9 allows height adjustment of the tool, such as to adapt the device to different workpiece diameters.

Figure 3 presents the construction of the magneto-abrasive finishing equipment of gears, and figure 4 shows two views of the working area.

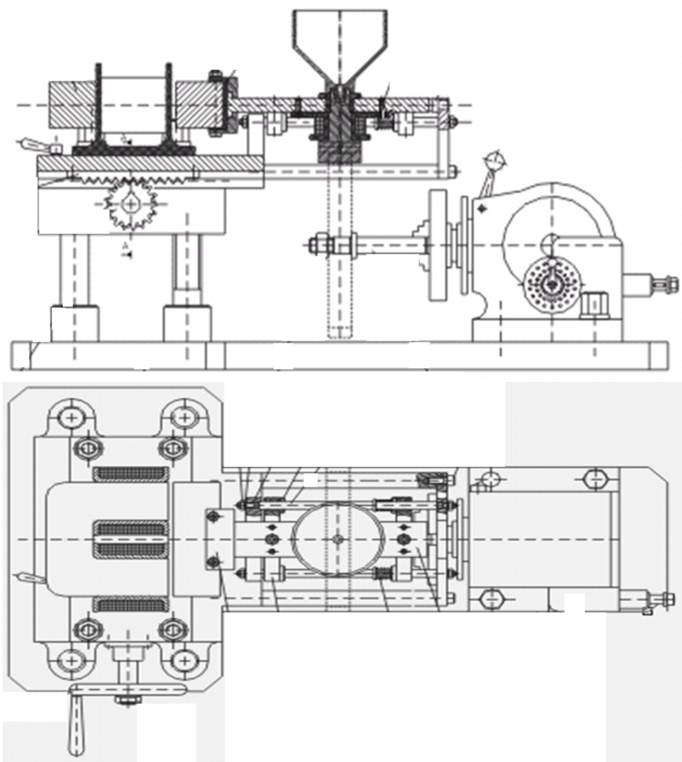


Figure 3. Construction of the equipment

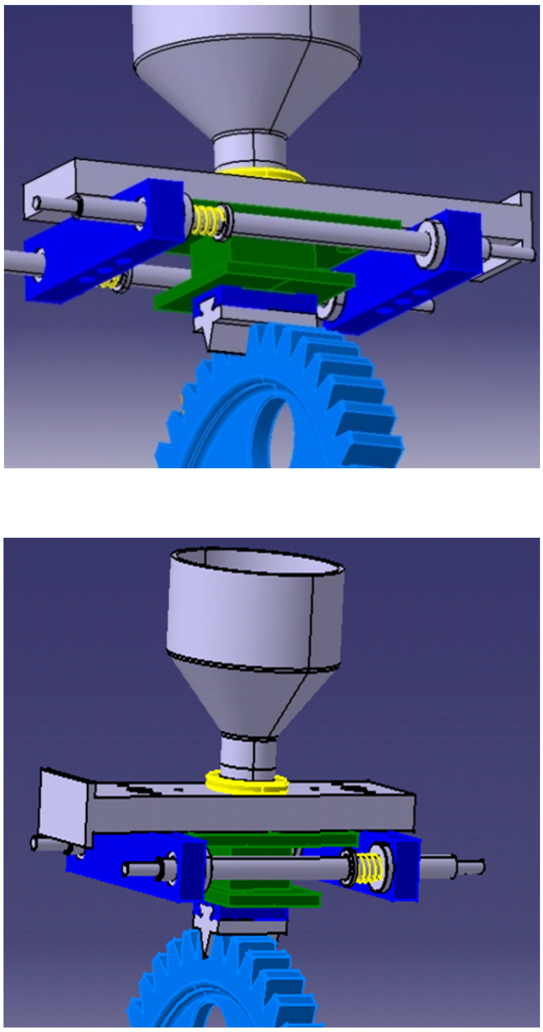


Figure 4. Views of the finishing installation

Magneto-abrasive finishing of gears is a new, non-conventional machining method, still subject of research. The obtained results confirm the utility of this procedure, based on the very good roughness of the machined gear flanks.

The disadvantage of the method consists in the low productivity of finishing, which is performed tooth by tooth. An alternative for improving this aspect is finishing by rolling, that is by developing magneto-abrasive brushes of geometry similar to that of hobs.

3 MAGNETO-ABRASIVE FINISHING EQUIPMENT OF BEARING BALLS

The second equipment introduced and discussed in this paper is developed for finishing bearing balls of diameters between 8 and 18 mm. the device is mounted in the table of a FUS22 milling machine, and can thus become an accessory of this.

Finishing consists in the continuous rolling of the balls in contact with a “magneto-abrasive brush” that is generated by six electromagnets displayed at equal angles. Figure 5 presents the kinematic diagram of this equipment.

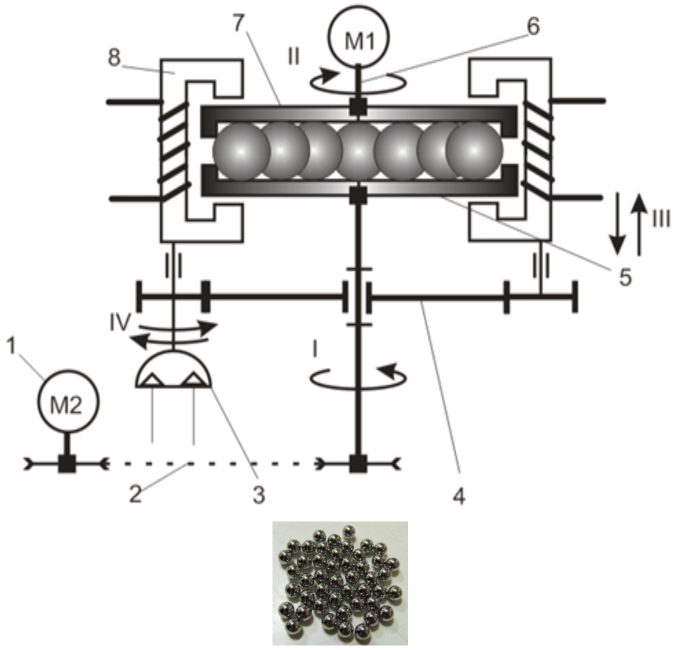


Figure 5. Kinematic diagram of the finishing equipment

The main components of the equipment are:

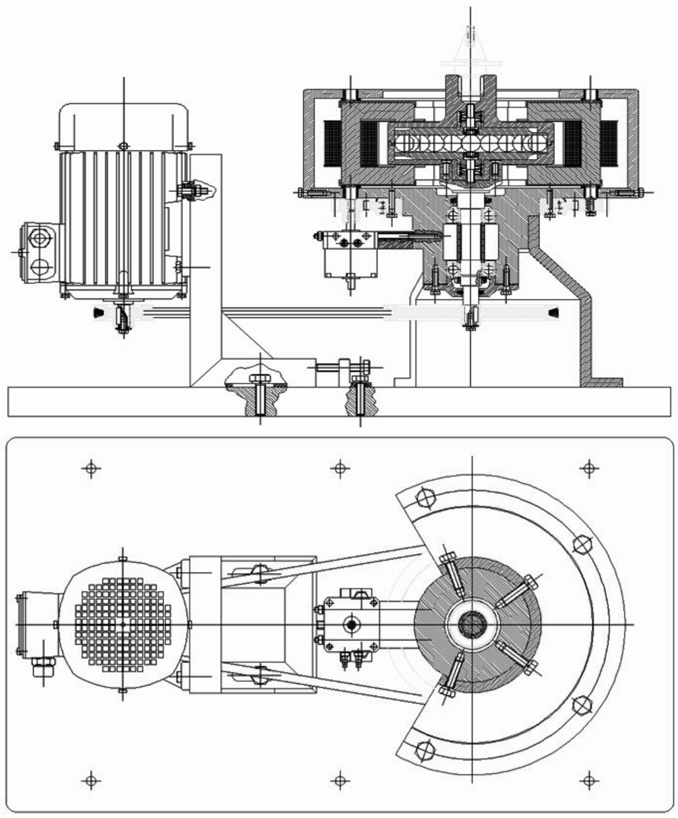
1. Electric motor;
2. V-belt transmission;
3. Oscillating pneumatic motor;
4. Gear – pinions mechanism;
5. Inferior disk;
6. Main shaft of the milling machine;
7. Superior disk;
8. Electromagnet.

The bearing balls to be finished, together with the magneto-abrasive grains are introduced between the two disks that are set into rotation in opposite directions. The superior disk receives rotation motion from the main shaft of the milling machine, while the inferior disk is rotated by an electric motor via V-belts.

The unfinished/machined balls can be introduced/ removed by rotating the six electromagnets (denoted by 8) by a 90º angle, by means of oscillating pneumatic motor 3. This drives a gear mechanism consisting of a central gear and six pinions, each of which synchronously rotates an electromagnet. Once the electromagnets have turned by 90^{o}, the table of the milling machine withdraws the device from the superior disk, thus allowing access to the balls.

Figure 6 presents a number of sections and views of the designed equipment.

The performance of this equipment consists in improving the geometrical form of the machined balls. Figure 7 presents the results of finishing balls of 12 mm diameter, whose deviation from sphericity of about 200 µm prior to machining, was reduced to mere 0.15 … 0.20 µm.



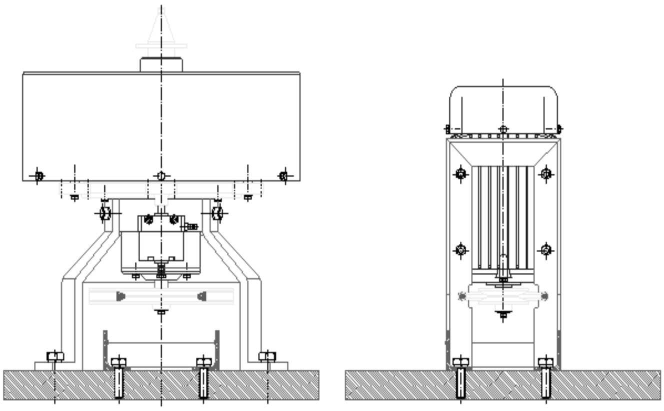


Figure 6. Sections and views of the bearing balls finishing equipment

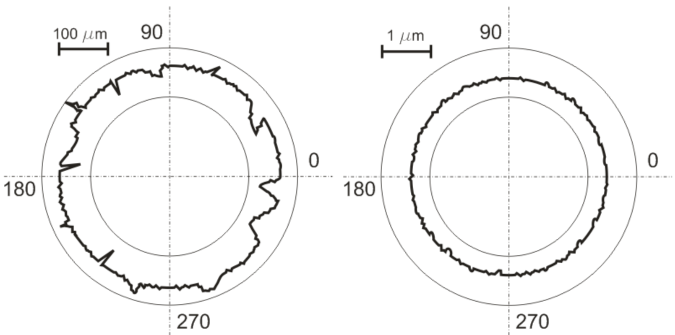


Figure 7. Deviations from sphericity corrected by magneto-abrasive finishing

The materials recommended as working media can be divided into several categories:

- (a) ferro-magnetic grains, obtained from materials with both abrasive and magnetic properties. The most frequently used materials of this type are ferro-boron, ferro-tungsten and hard cast iron.
- (b) composite grains, made from a matrix with ferro-magnetic properties and holding a multitude of abrasive particles.

While the dimensions of the composite grains are of order of magnitude D = 100...200 μm, those of the abrasive grains are of d = 5...30 μm. The main materials included by the ferro-magnetic matrix of a composite grain are: Al_2O_3 (10...20%), TiC (15%), WC (20%), Cr_3C_2 (20...30%), ZrC (10...20%), and diamond [6].

Magneto-abrasive material graining is one of the determining factors of the yielded performance, indicated by roughness R_a and productivity P_r. Experiments showed that a graining of d = 100/125 μm is recommended for obtaining best surface roughness and highest productivity, when using 15% TiC + 85% Fe magneto-abrasive material (figures 8 and 9).

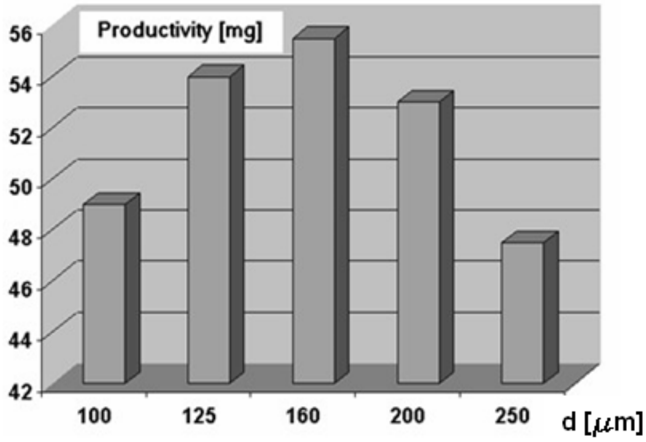


Figure 8. Productivity vs. graining

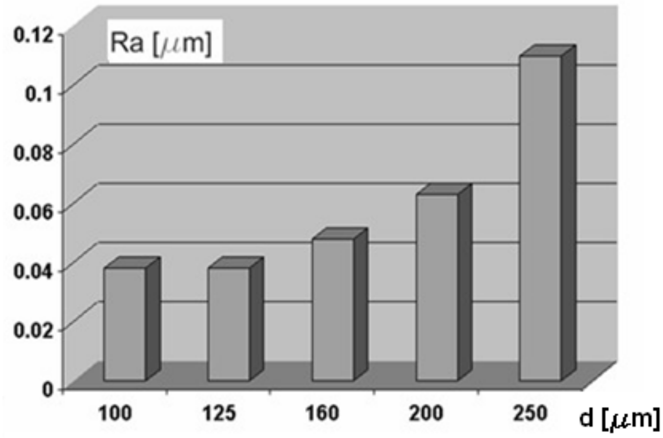


Figure 9. Roughness vs. graining

For the above equipment the most important technological parameters influencing machining performance are cutting speed, magnetic induction, dimensions and configuration of the working gap, characteristics of the magneto-abrasive materials, the filling degree of the working area, etc.

In deploying the above device at 1T magnetic induction and with magneto - abrasive grains of 15% Ti + 85% Fe and d = 160…200 μm graining, the thickness of the removed material layer in relation to working speed was [7]:

- v =10 m/min, h = 1.27 μm,
- v =15 m/min, h = 2.68 μm,
- v =50 m/min, h = 4.11 μm,
- v =150 m/min, h = 4.48 μm.

4 CONCLUSIONS

The two installations for magneto-abrasive finishing described in this paper are characterised by constructive simplicity and high performance. If series produced and added as accessories to universal milling machines, such installations will extend the range of possible machining provided by the latter.

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