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Laboratory studies of an electromagnetic mill inductor with a power source

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Summary. The article presents the laboratory research of a prototype device for grinding and mixing materials, known as an electromagnetic mill. Studies were made of the circuit of the mill inductor, covering the analysis of the current intensity, magnetic induction and power factor during operation. The article further shows the laboratory stand and research equipment used during the measurements.

Key words: electromagnetic mill, magnetic field inductor, current intensity, magnetic induction, power factor.

INTRODUCTION

Technological advances, especially in the preparation (grinding) of raw materials and aggregates, forces the use of different, often sophisticated technological processes. They are increasingly highly energy-intensive. Therefore, designers are looking for new, high-performance methods for both obtaining the appropriate product graining [3, 8, 15, 24, 28, 30] and the appropriate methods of controlling these processes [4, 5, 14] as well as their research and modelling [7, 23 26, 27, 29].

The construction of the mill shown in this work is prototypical. In such a case it was necessary to conduct experimental research on the physical object. This was aimed at getting to know the most important electrical, magnetic, structural and operating parameters of the device under test.

The electromagnetic mill is a device whose essential feature is the intensification of many processes, and through an effect on the shredded material also many force fields. Therefore, in comparison with commonly used devices, the operation of the electromagnetic mill is many times faster, depending on the application even several thousand fold faster. This also allows to obtain a series of effects of the treatment of materials impossible to achieve by other methods and with conventional equipment. The electromagnetic mill's possibilities include [2, 12, 13, 16, 19, 25]:

- dry and wet grinding of hard materials;
- mixing loose, liquid and gaseous materials;
- grinding elements, beans, etc.;
- activation of volatile dust;
- manufacture of composite materials in the process of mechanical alloying;
- acceleration of chemical reactions;
- obtaining high durability emulsion;
- utilisation of heavy hydrocarbons – waste product of petrochemical or carbochemical processes – emulsification;
- obtaining substances of relevant physical and chemical properties.

Figure 1 shows the model of the electromagnetic mill constructed at the Lublin University of Technology and being the subject of research presented in this article. To the author's current knowledge it is the first construction of this type of mill using an asynchronous motor stator for an inductor. This statement is based on the analysis of publications from various research centres in Poland and in the world dealing with the grinding of materials, as well as applications in patent offices [9, 10, 12, 16, 18]. For this reason an application was filed for a patent of the invention in the Polish Patent Office [22].

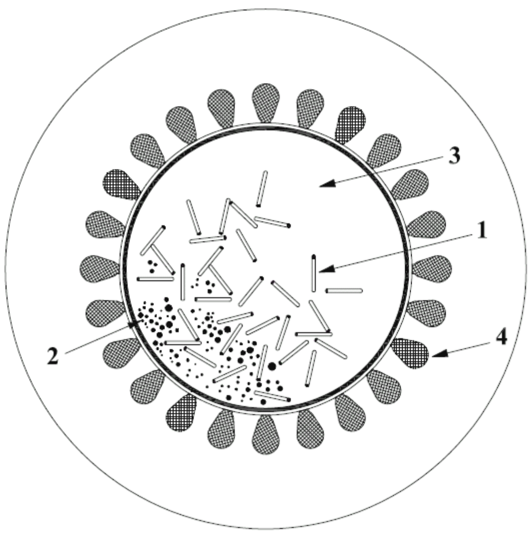


Fig. 1. Electromagnetic mill with non-salient poles: 1 – grinding aids, 2 – ground material, 3 – working chamber, 4 – winding in the grooves

METHODOLOGY OF RESEARCH

Laboratory tests were performed for the electromagnetic mill using for an inductor a three-phase general purpose asynchronous motor stator with parameters and structure described in the references [20, 21, 22]. The general wiring diagram used during the study is shown in Figure 2. The test stand was developed on the basis of the literature [1, 6, 11, 18].

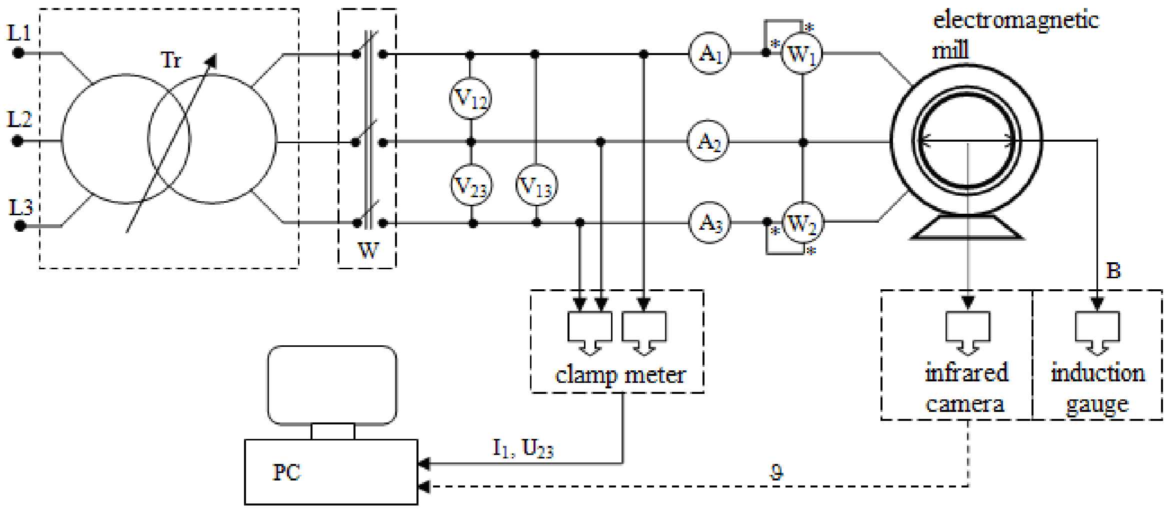


Fig. 2. The measuring system of the electromagnetic mill: L1, L2, L3 – different phases of the power supply; Tr – autotransformer; V12, V23, V13 – voltmeters (phase-to-phase voltage); A1, A2, A3 – ammeters (current phase), W1, W2 – watt-meters (power consumed by the mill); PC – computer

The study used the following measuring instruments and specialised software:

- universal voltmeter MX-620's MAXCOM,
- universal ammeter M890C + UNI-T
- wattmeter LM-1,
- clamp meter ST-3347Ws Standard Instruments,
- infrared camera ThermaCAM E45 FLIR,
- magnetic induction gauge 4048 F.W. BELL,
- operational software supplied with the ST-3347W meter,
- operational software for the analysis of thermal images QuickReport.

The laboratory tests included:

- changes in the intensity of the current powering the inductor during operation,
- distribution of magnetic induction inside the inductor,
- power factor of the electromagnetic mill.

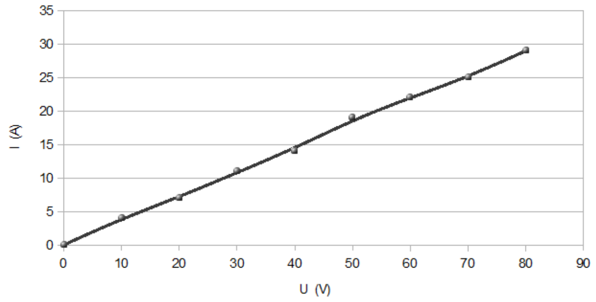
INTENSITY CHANGES OF THE CURRENT POWERING THE INDUCTOR DURING OPERATION

During the study, the inductor winding was connected to the auto-transformer with a capacity of 3·6 kVA. The supply voltage was gradually increased while observing the increase in the value of the inductor current and the magnetic induction in the axis of symmetry of the inductor. Following the research it can be concluded that it is a linear growth (Fig. 3).

Due to the lack of a ferromagnetic magnetic circuit inside the inductor, the research was carried out with a lowered voltage. As a regulatory criterion the nominal value of the supply current of the electromagnetic mill inductor was assumed. When the machine was powered without a magnetically active area, the irregularity of the supply current of each phase was ΔI = 1.5 A (current equal to 13 A), which is typical of an induction motor stator windings, and can be caused by varying the length of the leading connections.

The linear current waveform as a function of voltage (Fig. 3) shows the lack of magnetic hysteresis. Due to the absence of a magnetic rotor, there is a large air gap, which significantly increases the magnetic reluctance. For this reason, a very small value of magnetic induction is achieved. It is several times smaller than the magnetic induction in the electrical machine.

a)



b)

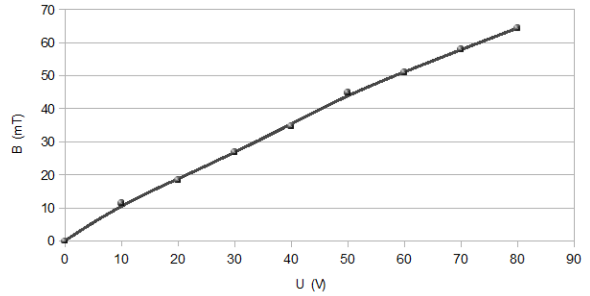


Fig. 3. Current intensity (a) and magnetic induction (b) depending on the supply voltage

The next step of the research was to place a non-magnetic working chamber in the active area of the mill. After powering the mill with 13 A current, grinding media were introduced into the chamber and began to swirl. The introduction of ferromagnetic elements into the active area of the mill caused a reduction in the intensity of the supply current of the inductor as shown in Figure 4. The arrow indicates the moment of filling the grinding media. Their filling also caused the alignment of the currents in the individual phases ΔI = 0.2 A.

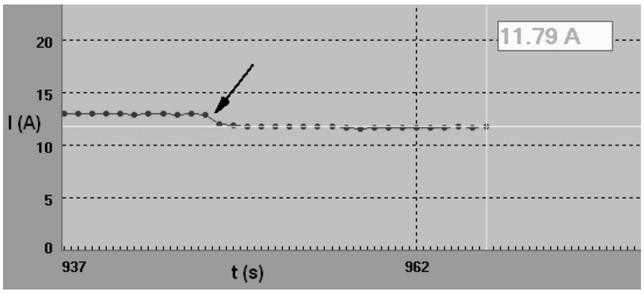


Fig. 4. Waveform of the current powering the mill inductor during the filling of the grinding media

Reducing the supply current indicates an increase in magnetic permeability, and thus an increase in the inductance of the inductor windings. Under the influence of the ferromagnetic elements the magnetic flux distribution alters both inside the working chamber and in the magnetic core of the inductor. As is apparent from Figure 4, the current was reduced by approximately 10%. This value depends primarily on the number, shape and arrangement of the ferromagnetic elements within the process chamber.

Switching a direct supply voltage makes the start-up current slightly stronger than during a normal operation. It does not therefore increase the load of the grid powering machine as it happens in three-phase electric motors. In addition, upon switching the mill, in a short time the grinding elements achieve the maximum speed, causing the milling process to take place from the time of supplying the device with voltage. The low inertia moment of the load makes the start-up very fast. The study was performed using a clamp meter with a sampling rate of 500 ms (Fig. 5). To accurately determine the transient/temporary states, additional tests were performed using an oscilloscope with the possibility of recording waveforms, as well as an analogue ammeter. Following the research we can say that the start-up current reaches a value of 1.75 of the nominal current. The fast start-up time and small overloads allow a direct start of the electromagnetic mill without additional start-up devices.

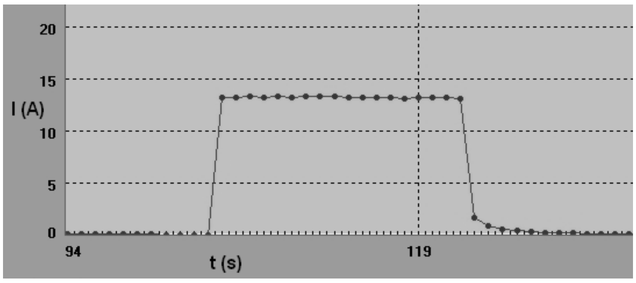


Fig. 5. Waveform of the current powering the mill inductor during the switching on and off of the supply voltage

Analysing the current consumption from the point of view of power supply, during long-term operation of the mill (Fig. 6) it can be said that the current intensity decreases in a linear fashion. This is due to the fact that the ground material will be fragmented into smaller grains. This contributes to the reduction of motion resistance of the grinding media, and thus the ability to quickly follow the rotating electromagnetic field. In addition, the inductor winding resistance increases with temperature.

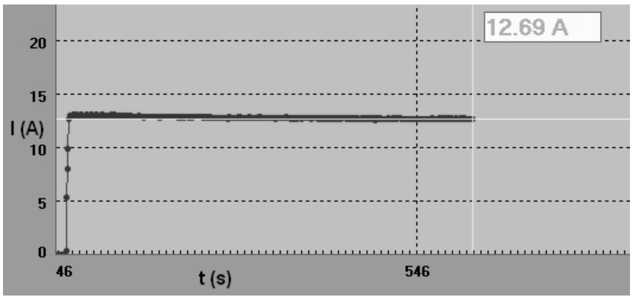


Fig. 6. Waveform of the current powering the mill inductor during the grinding of material (time 300 sec.)

During the above investigations a rapid increase in temperature of the windings and of the working chamber was observed. This can be a serious problem for continuous operation of the mill without an additional electromagnetic cooling circuit, as shown in the author's publications [20, 21].

DISTRIBUTION OF MAGNETIC INDUCTION INSIDE THE INDUCTOR

Figure 7 shows the distribution of magnetic induction designated in the transverse axis of the inductor (without the working chamber and grinding medium). Selecting the diameter of the chamber included increasing the induction in the vicinity of the magnetic poles of the inductor. In order to eliminate the "sticking" of the grinding media to the walls of the working chamber, its diameter was reduced to 83 mm (air gap between the inductor and the working chamber is 1.5 mm). The thickness of the working chamber made of austenitic steel is 1 mm, which is critical in reducing the passage of the magnetic field. From the characteristics it also results that increasing the value of the supply current of the inductor by 20% increases the magnetic field by 40%. This contributes to the rise in the efficiency of grinding by obtaining larger grain size distribution of the product in a shorter time.

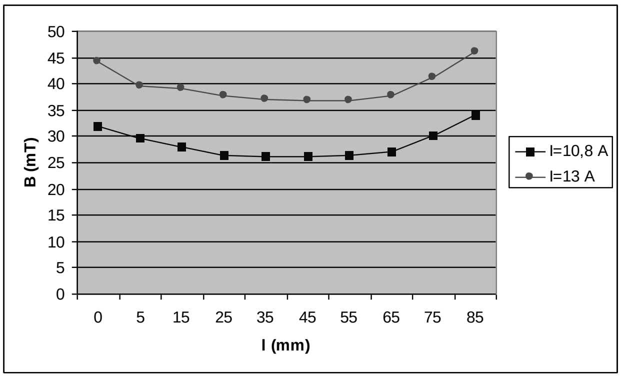


Fig. 7. Characteristics of the distribution of magnetic induction within the process chamber of the mill with the inductor windings delta-coupled

Analysing the value of the magnetic induction inside the air gap during the operation of the mill together with the grinding media it can be concluded that the induction value is twice as high compared to the flux density without ferromagnetic elements. The value of the induction in this case is the 40 mT to 75 mT, indicating a substantial increase in the magnetic flux. This increase depends on the number of the grinding media (or the filling of the working chamber). The study was conducted for the optimal filling of the working chamber with grinding media, placing the sensor of the magnetic induction meter between the windings of the inductor and the working chamber.

POWER FACTOR OF THE ELECTROMAGNETIC MILL

Studies of the active power consumed by the electromagnetic mill were performed using two wattmeters connected in an Aron circuit.

The electromagnetic mill under investigation has a high power factor. With a current equal to 10.8 A the ratio is 0.86, and with a current intensity of 13 A it is equal to 0.56. The active component remains constant, while the reactive one increases. It can be concluded from this that the work performed does not change.

Compared to the two structures of electromagnetic mills with salient poles described in the references [12, 17, 19], the power factor in the mill with non-salient poles developed by the author is much better. Previous solutions in mills with salient poles, through the use of such poles, had a relatively greater dispersion of the magnetic circuit reactance. They thus reached a low power factor of about 0.2. A large value of passive induction losses caused the above machines to draw from the grid an apparent power of 200 kVA [19], which was a considerable burden for the supply system.

CONCLUSIONS

Based on the results obtained in the course of the studies, the following conclusions have been formed:

1. In the absence of a magnetic rotor, there is a large air gap which significantly increases the magnetic reluctance. This contributes to the reduction of magnetic induction. Induction and current versus voltage accept a linear waveform, suggesting the absence of a magnetic hysteresis;
2. A low weight of the grinding media (their small inertia) makes the milling process take place from the moment of supplying the voltage. Direct switching of the supply voltage causes the start-up current not to

increase significantly, as is the case in the induction motor;

3. Magnetic induction within the process chamber of an electromagnetic mill with non-salient poles reaches values close to each other across the diameter of the chamber, which contributes to the uniform milling of the raw material in the entire working area. Changing the grinding efficiency is possible by changing the current powering the inductor.
4. The power factor in the present electromagnetic mill with non-salient poles, filled up with ferromagnetic grinding media, is 0.86. This value is much improved compared to the mills with salient poles described in the references, where the power factor was 0.2.

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