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DEGRADATION OF MAGNETIC PROPERTIES OF NON-ORIENTED SILICON IRON SHEETS DUE TO DIFFERENT CUTTING TECHNOLOGIES

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ABSTRACT

The magnetic properties of non-oriented silicon iron alloys are strongly influenced by the cutting technology. Medium quality electrical steel M800-65A samples were cut through mechanical punching, laser, water jet and electro erosion technologies and were characterized with an industrial Single Strip Tester at the peak magnetic polarizations Jp of 0.5, 1 and 1.5 T, in the frequency range starting from 10 Hz to 200 Hz. The influence of the cutting technology on the energy losses and magnetic permeability was investigated.

KEYWORDS

Non-oriented electrical alloys, Cutting technology, Energy losses, Relative magnetic permeability.

1. INTRODUCTION

Non-oriented electrical steels have a crystalline texture, which is characterized through a very low magneto-crystalline anisotropy. They are intensively used in the manufacture of the high efficiency electrical machines, in order to save energy and to avoid the overheating phenomenon. It is well known that the electrical machines have an energy consumption of 50% from the worldwide electricity consumption and almost 6040 Mt of CO2 emissions are due to these devices. According to the newest regulations, it is expected that in 2030, without proper environmental decisions, the energy consumption of the electrical motors will increase until 13360 TWh/year and the emissions will be equal to 8570 Mt/year. Recently the energy losses of the newly produced electrical machines have been decreased with an amount of 20%, by comparing them with those, measured before 2016. The most important machine producers made motors in classes of premium efficiency (IE3) and above, i.g. Super Premium Efficiency (IE4) and Ultra Premium Efficiency (IE5) [1, 2, 3]. Nowadays it is a great challenge to produce an efficient electric motor, because thermal stresses, insulators' aging and low energy losses have to be taken into account. The most efficient motors are based on rare earth permanent magnets, but copper rotor electrical machines and synchronous reluctance motors could have comparable efficiency standards. Alternative current motors are designed to work at a constant speed, and its electronic drives improve the electrical machine flexibility. When a variable speed drive (VSD) is used, the inrush currents are decreased, the power factor has a good value, the effects of torque variation and speed drop are eliminated. In order to increase the efficiency of the electric motor, good quality of non-oriented materials, with low energy losses should be used [4, 5]. Usually the magnetic cores of the electrical machines are prepared, by cutting the non-oriented alloys through mechanical punching, because this method is very fast and cheap, although it generates inside the material mechanical stresses that affect the energy losses and the magnetic properties. A work hardening phenomenon is expected to appear at the cut edge and deformation of the crystalline grains is present. Usually during a recrystallization process, these deformed grains are entirely transformed in new magnetic grains with better properties. The most important parameters of the cutting procedure are the clearance and the cutting angle, but also the hardness of the blade it is usually taken into consideration. When it is chosen a proper value of the clearance the induced mechanical stresses are minimal, and this fact contributes to the life increase of the cutting shears. A good quality cut edge is obtained, based on empirical determination for each cutting

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machine. When a strip is cut, only a small part is cut, and the rest is separated through fracture phenomenon [5]. The samples involved, in the paper were prepared, using a classical Computer Numerical Control (CNC) Turret punching machine. This device has a 3 axis Siemens special CNC system and uses AC servomotors. Its main components are actioned pneumatically, and it is equipped with concentrated lubricating systems, which decrease the friction during the cutting procedure.

Sometimes the electrical machines' producers want to obtain a free burr cut edge and they choose the non-conventional cutting technologies as laser. Laser method is a very flexible one, but unfortunately it induces important thermal stresses and the method is expensive. In the case of CO2 laser, the single generated wavelength is in Infra-Red spectrum. The beam has an 0.025 mm diameter, when it travels from the laser resonator to the beam path. It is guided through a mirror or a special lens' system and finally is focused on the material. The laser beam is accompanied by a compressed gas, as Oxygen or Nitrogen. The cut edge is almost perfect, but the high power density of the beam has an unwanted result, which consists of a rapid heating, melting or partial vaporizing of the material. In the paper a Morn Laser machine was used to cut the samples. This machine is a very performant one and the laser cut has no cracks or supplementary deformation due to the thermal stresses and it has a very high stability of the cutting tool [6, 7].

Other non-conventional cutting technologies are the electro-erosion and water jet methods. The electro-erosion (EDM) produces any stresses, but the process is very slow, and it can be used only for small dimension electrical machines. Today EDM machines are very stable, starting with 1980 due to the introduction of the CNC in the EDM technology and they could be used to cut complex shapes. The basic phenomenon involved in the EDM cutting procedure is the energy transformation from electrical into thermal energy, using a series of electrical discharges that appear between an electrode and a workpiece, introduced in a dielectric fluid. This fluid is a very special one, because it has to avoid the electrode electrolysis. The EDM procedure is a modern technique, based on material erosion, when a spark appears as a result of an applied voltage between the electrode and the material surface. The dielectric fluid is a cooler medium and it helps the discharge energy to be concentrated on a small area. As the erosion advances, the electrode is moved through the dielectric fluid. Recently, servo systems are used, to assure a constant gap voltage, between the material and the wire and to retract the electrode, when a short circuit occurs [5, 6, 7, 8]. A Kingred Wire EDM, controlled by a CNC system, which utilizes brass electrode wire and high frequency impulses, was used. This machine is very suitable for cutting materials with high precision [9].

The water-jet leads also to a very good quality of the cut edge, but special expensive equipment is needed, and the cutting speed is relatively slow. Abrasive particles as Garnets are used and the price of the cutting procedure is very high. The abrasive particles do the material cut through a sawing action and it leaves a precision cut surface. This method is suitable to cut almost any type of steels and it has a narrow kerf width. Physical properties such as melting point, thermal and electric conductivity, density have a limited importance, although the hardness of the material could reduce the cutting speed. This process induces no heat affected zone

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and no hard oxidation layers on the cut edges, which could lead to the microcracks apparition. This technology damages minimal the magnetic properties of the material due to the plastic deformation. An Omax Waterjet machine was used. This device performs a very high accurate edge cut and it uses Garnet as abrasive particles.

The non-conventional methods are adequate in the prototyping production.

2. MATERIALS AND METHODS

A medium quality commercial non-oriented steel M800-65A was investigated. The material properties and the geometrical parameters are shown in Table 1.

Table 1. Properties and geometrical parameters of the M800-65A samples.

Material	Cut direction	Density [g/cm^3]	Electrical resistivity [Ω/m]	Mass [g]	Length [mm]	Width [mm]	Thickness [mm]
M800-65A	Rolling direction	7.80	25×10^{-8}	44.73	300	30	0.65

The influence of the cutting procedure on the energy losses was analyzed using the energy loss separation method. According to this theory, the total energy losses are divided into hysteresis, classical (Foucault) and excess energy losses.

The hysteresis losses are due to the pinning points and impurities that are present in the medium quality non-oriented steels and they are usually analyzed, by taking into account the coercivity mechanisms. They can be computed, by extrapolating in zero the measured total energy losses.

The classical energy losses are generated by the eddy currents and the material is treated as a homogenous medium [10]. They can be computed with the following equation:

$$W_{cl} = \frac{\pi^2 \sigma J_p^2 d^2}{6\rho} f, \qquad \textbf{(1)}$$

where d is the sample thickness, σ is the electrical conductivity, ρ is the non-oriented steel density and f is the experimental frequency.

The excess losses are due to the micro eddy currents, which are formed in the vicinity of the domain walls. They are computed, subtracting the classical and hysteresis losses from the total energy losses.

The magnetic measurements were done, by using an industrial Brockhaus Single Strip tester, with a double C yoke, which is a standardized device and it controls at each step of the measurement the form of the secondary voltage, in order to be a sinusoidal one according to DIN 50 462 standard. This device permits the measurement of the energy losses and of the relative magnetic permeability with its components: real and imaginary parts. An external magnetic field is applied, and a magnetic flux is generated into the tested sample. The current, in the magnetizing coil, is determined with the help of a shunt resistor. The magnetic polarization is computed, by integrating the experimentally induced voltage on the measuring coil with a 16-bit processor. The accuracy of the measurements is very high, and the device provide a 0.2% repeatability of the results. The maximum current is equal to 5 A and the maximum voltage is set at 32 V. The magnetic path length, between the polar pieces is 240 mm. Along this path are placed the measuring (723 windings) and the magnetizing (704 windings) coils. A sample of minimum 280 mm length and maximum 30 mm width could be investigated.

3. RESULTS AND DISCUSSIONS

Samples of medium quality commercial electrical steel of M800-65A grade were cut through punching, laser, water-jet and electro-erosion technologies.

The normal magnetization curve, defined as the geometrical place of the symmetrical hysteresis cycle peak points, which extends from the demagnetized state to the saturation is presented in Figure 1. The demagnetized state could be obtained, by increasing the sample temperature to a value, higher than the Curie temperature, followed by a normal cooling, in the absence of a magnetic field. Another technique consists of applying an alternative magnetic field, whose amplitude is progressively decreased through zero, starting from a higher reference value, which implies the technical saturation point. After the material demagnetization, if a monotone magnetic field is applied, the sample behavior follows the virgin magnetization curve. If this procedure is done after the cyclic demagnetization of the material, the normal magnetization curve is obtained. In the soft magnetic material case there are some minor differences between these two curves and also the magnetic polarization J is considered to be equal to the magnetic flux density B [1].

In order to experimentally determine the normal magnetization curves of the samples, measurements were done at the industrial frequency of 50 Hz. In the case of each sample, symmetrical hysteresis loops were determined at a peak magnetic polarization Jp of 5 mT, 10 mT, 20 mT, 50 mT, 100 mT, 200 mT, 500 mT, 750 mT, 900 mT, 1000 mT, 1100 mT, 1200 mT, 1300 mT, 1400 mT, 1500 mT, 1600 mT. It can be noticed from Figure 1 that the electro-erosion and water jet technologies determines an easier magnetization of the material, because the cutting procedure induces any thermal or mechanical stresses. The punching and the laser procedures leads to a more difficult magnetization process due to the generated stresses, although the M800-65A grade is an alloy, which contains a relative high percent of non-magnetic impurities that acts as pinning points for the magnetic domain wall movement. All the normal magnetization curves meet at the saturation point of the material, for a magnetic field strength of 2000 A/m. The principal magnetization process in this type of steel is the reversible domain wall movement and near the saturation zone rotating of the spin magnetic moments occur.

In Figure 2 is presented the variation of the total energy losses as a function of the frequency, for three values of the peak magnetic polarization Jp of 500 mT, 1000 mT and 1500 mT. At 500 mT the water-jet technology leads to the lowest value of the total energy losses, followed by the punching method and the highest energy losses are measured in the case of laser. These observations are valid in the case of 1000 mT, but for 1500 mT the lowest value of the energy losses is determined for the electro-erosion technology. It can be noticed that with increase of the peak

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magnetic polarization, the influence of the cutting technology on the energy losses is reduced.

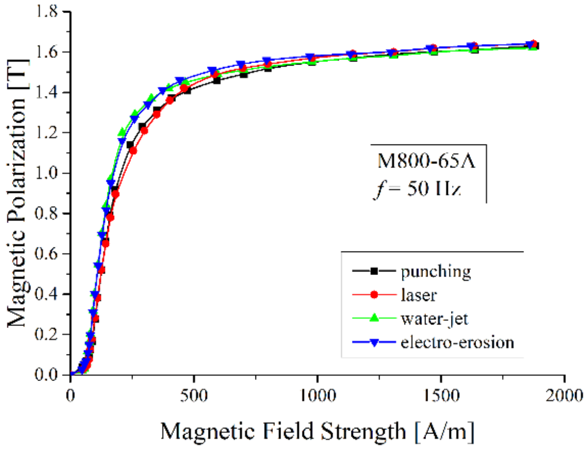


Figure 1. Normal magnetization curve for M800-65A samples, cut through punching, laser, water-jet and electro-erosion.

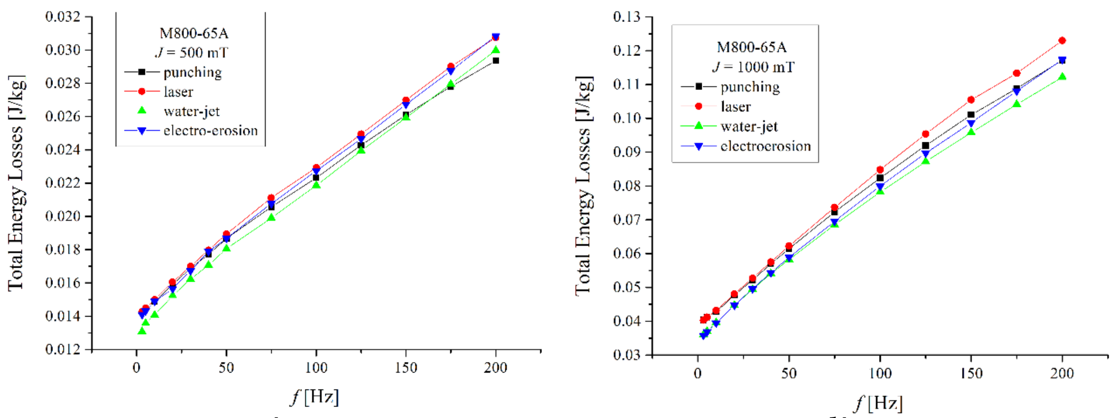
The hysteresis energy losses are invariable with the frequency and they are a direct consequence of the magnetization processes, which are due to the magnetic domain wall movements.

It can be observed from Figure 3 that the most important variation of the hysteresis energy losses is noticed for the high magnetic polarization domain, especially in the case of punching and laser. The lowest values of the hysteresis energy losses are determined for the electro-erosion and water-jet cutting technologies.

The classical energy losses are generated by the eddy currents and they are directly proportional with the peak magnetic polarization and the frequency.

It can be noticed that from a specific value of the frequency these losses become predominant with higher values than in the case of excess and hysteresis energy losses.

In Figure 4 is presented the variation of the classical energy losses with the frequency.



a) **b)**

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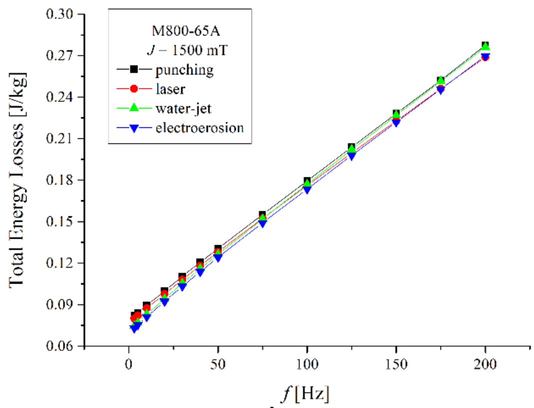


c)

Figure 2. Total energy losses versus frequency at three peak magnetic polarizations of 500 mT (a), 1000 mT (b) and 1500 mT (c).

The excess energy losses are influenced by the cutting procedures in the case of all the peak magnetic polarization values. The water-jet technology leads to the lowest value, followed by the laser and the electro-erosion procedures.

The mechanical punching has a strong influence on the magnetic domain structure and is directly linked to the existence of higher values of the excess energy losses.

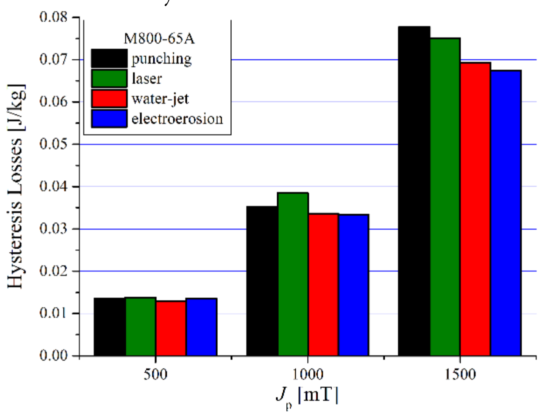


Figure 3. Hysteresis energy losses versus peak magnetic polarization, in the case of different cutting technologies.

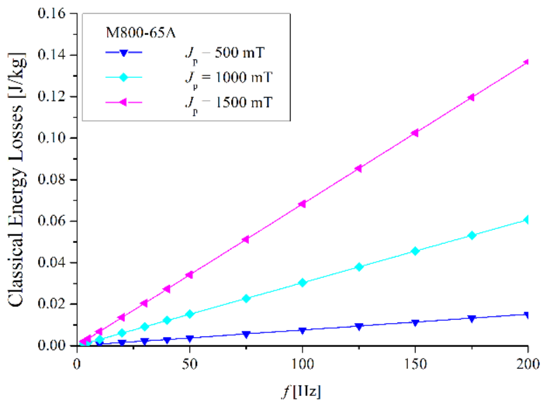
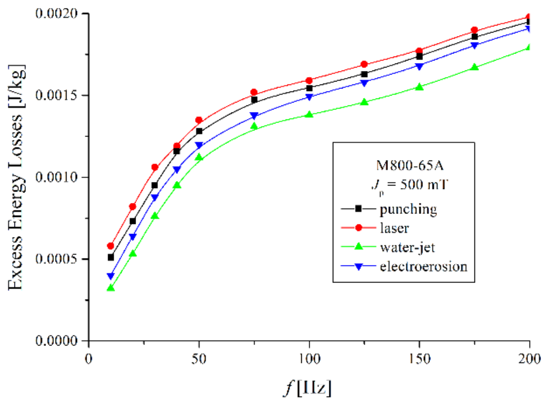
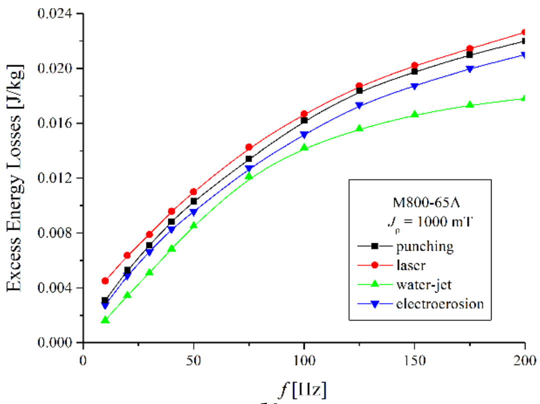


Figure 4. Classical energy losses versus frequency at three peak magnetic polarizations of 500 mT, 1000 mT and 1500 mT.



a)



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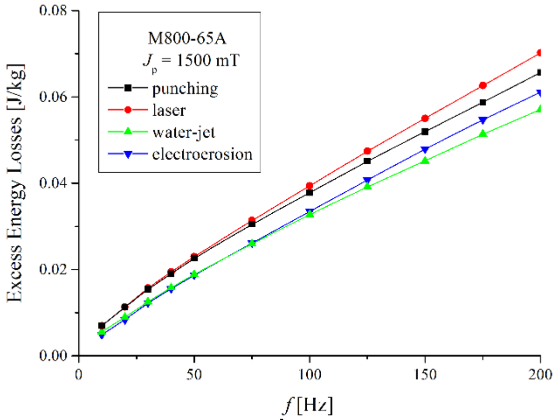

c)

Figure 5. Excess energy losses versus frequency at three peak magnetic polarizations of 500 mT (a), 1000 mT (b) and 1500 mT (c).

The relative magnetic permeability μ_r is a physical quantity, which describes the material property to concentrate the magnetic field lines, when an external magnetic field is applied. A magnetic material is more adequate to be used in industrial applications in the case of high values of magnetic permeability. In Figure 6. is presented the variation of the relative magnetic permeability for two peak magnetic polarization of 500 mT and 1000 mT. It can be noticed that the magnetic permeability presents an inversely proportional variation with the frequency. The influence of the cutting procedure is more pronounced for frequency values lower than 100 Hz. The highest value of the magnetic permeability is obtained for the water-jet and electro-erosion technologies.

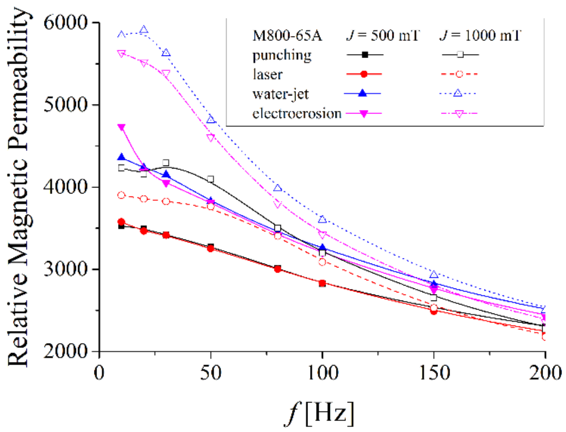

Figure 6. Magnetic permeability versus frequency at two peak magnetic polarizations of 500 mT and 1000 mT, in the case of different cutting technologies.

4. CONCLUSIONS

The cutting procedure damages the magnetic material microstructure, more pronounced in the case of laser, followed by punching, electro-erosion and water-jet. To reclaim the initial magnetic properties of the alloy some thermal recrystallization treatments are required, but this step is not taken into consideration by the electric motor manufacturers, because it damages the insulator layer that covers the magnetic core sheets. The use of water-jet or electro-erosion technologies that have a reduced impact on the energy losses and the relative permeability is taken into consideration only in the prototyping and special cases, because of their slow cutting speed. As a compromise between cutting speed and the

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induced damage on the magnetic properties the electrical motor manufacturers still prefer the classical mechanical punching.

5. ACKNOWLEDGEMENTS

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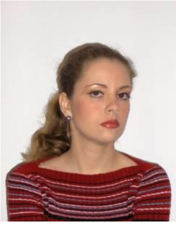

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