TOTAL POWER LOSS IN SILICON-IRON SHEETS

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Abstract — In this paper we study a modern method used for reducing the total power loss in silicon-iron sheets. We present the principle of this method (surface irradiation with electron beams), experimental results and comparation between our results obtain in MAGNAT Laboratory - Electrical Engineering Department with data obtains in the laboratory of I.C.P.E. – C.A.
Index Terms — power loss, silicon iron sheets.

INTRODUCTION

The way of decreasing of the total power loss of the soft magnetic materials represent the best criteria to illustrate the evolution of those materials. In AC current those losses depends on the amplitude B_m of the magnetic flux density, the frequency f of the excitation field, the thickness Δ of the sample, the hysteresis area and the electrical conductivity of the material.

The total power losses have two components: the hysteris losses and the Foucault losses. Between the power losses which are determined theoretically and those which are experimentally obtain there are small differences due to a new category of losses, the "anomal losses".

$$P_{Fe} = P_h + P_F + P_{an} \quad (1)$$

where:

- P_h: hysteresis losses;
- P_F: Foucault losses;
- P_{an}: anomal losses.

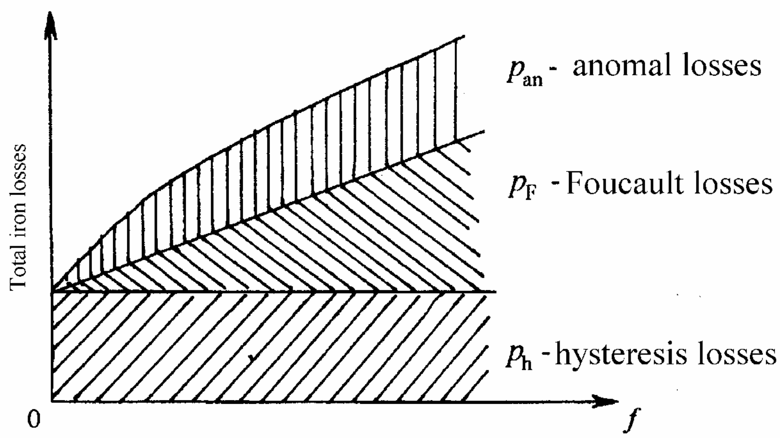


Fig. 1. Schematically representation of the iron losses in soft magnetic materials.

All of those three components can be improved. The P_h can be controlled by treatments capable of developed the desire microstructure and the P_F and P_{an} can be reduced by the increasing of the electrical resistivity , by increasing the solvent content and the reduce of the sheet thickness. The anomal losses can also be reduce by increasing of the magnetic domain number with the help of special technological or metallurgical process which generates regular centers for the pinning of the domain walls. In this way the walls are less mobile which determine that the sample magnetization will be made especially by the rotation of the magnetization vector.

Table 1: Power losses control methods

Material	Hysteresis losses	Foucault losses		
		Rezistivity	Thickness	Domain width
Steel	- grow of the grain dimension - better texture orientation	- Al and Si content - interlayer lamination	- lamination	- laser strips or mechanical induced -stress inducing coverings
NiFe	- grow of the grain dimension - better texture orientation	- isolation	- lamination	- special compositions for obtaining desire values for Ka and λs
Ferrite	- microstructure - grain dimensions	- chemical control		
Amorphous alloys	- average cooling speed - better quality of the surface	- isolation	- shape parameters	- laser strips or mechanical induced -partial recristalization

THE MAGNETIC DOMAIN STRUCTURE IN STRESS SILICON IRON SHEETS

A grain-oriented material presents a inner structure with big grains that determined domain with large 180° walls which generates energy losses due to the Foucault currents.

The Foucault losses are due to the macroscopically induced current and the anomal losses are generated by the Bloch wall displacement. At a given frequency this microscopic currents grow with the moving speed of the Bloch walls and to limit those currents we can decrees the dimension of the Weiss domains [1].

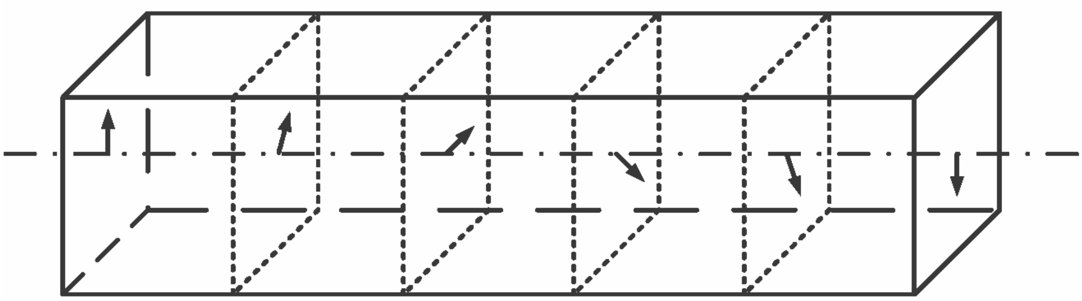


Fig. 2. Schematically principal of a Bloch wall.

The decreasing of the magnetic domain can be done by inducing mechanical stress in the sheets with different technique [2]:

- scratching the surface of the sheet;
- laser irradiation;
- electron beam irradiation;
- thin film covering.

MECHANICAL STRESS METHOD

We want to increase the number of the magnetic domain on a Fe-Si 3% sheet by applying some local stress on the surface through two ways: scratching and pointing.

On the surface of the sheet we realize an electrolitical grinding and we observe the magnetic structure.

Fig. 3. Magnetic structures on stress free sheet.

On the grind surface we applied a scratch with a pressure of 1 kN/mm2 and the magnetic domains are observed in the figure 4. For the second determination we do a local stress of the surface with a pointer at a pressure of 1 kN/mm2.

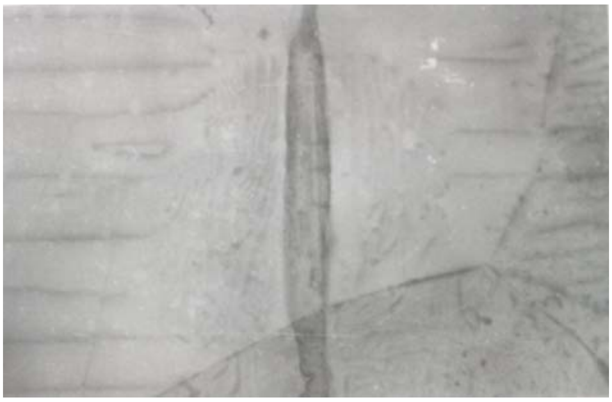


Fig. 4. Magnetic domains in stress sheet.

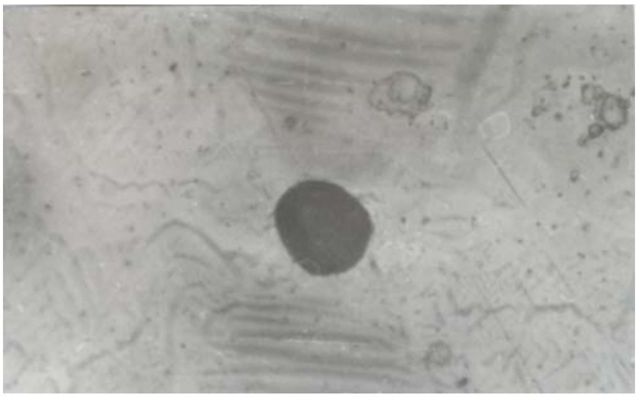


Fig. 5. Magnetic structures of a point stress.

For comparing the results obtain by two method we put in the table 2. The values of the minimal, maximum and average width of the observed domain.

Table 2: Results of the mechanical tension

Type	Minimal width [μm]	Maximal width [μm]	Average [μm]
Stress free	5	70	45
Scratching	5	60	30
Pointing	5	10	9
Lines of scratching	5	50	30

The point tension is the best method for increasing the number of domains.

THE LASER IRRADIATION METHOD

The principle that is the base of this method is that when the sheet surface is irradiated with the laser, the superficial layer from the attack area is instantly vaporized. Due to the high local pressure are generated elastic and plastic zones, which in the case of multiple irradiation lines, appear high tensions which make the magnetoelastic energy to decrease.

The irradiation device is compose of a impulse solid laser with a power density of 5×10^8 W/cm2, the pulse energy is E = $3{,}75\times10^{-3}$ J.

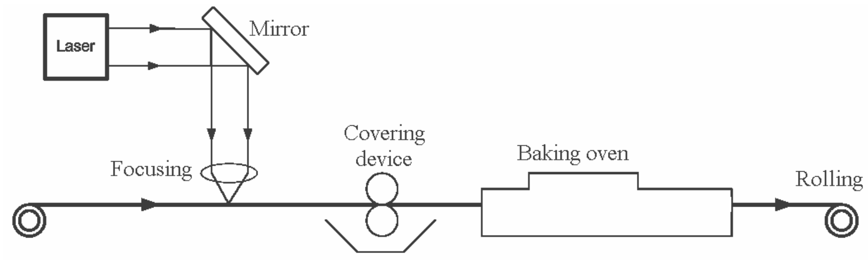


Fig.6. Block diagram of a laser irradiation device.

When the irradiation is done on a single line the number of magnetic domains with 180° walls from the main structure do not increase, but in the near side of the irradiation line are observed transversal subdomains and spike-like subdomains.

When are made several lines between those are generated some stretching stresses which determine the reduce of the transversal magnetic domain and the grow of spike-like subdomains [4].

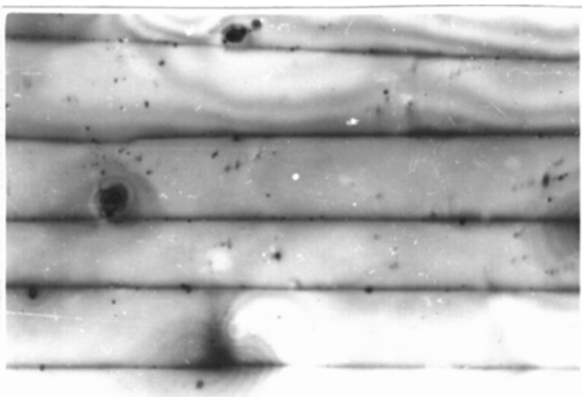


Fig. 7. Magnetic domains on grain oriented sheets on stress free state.

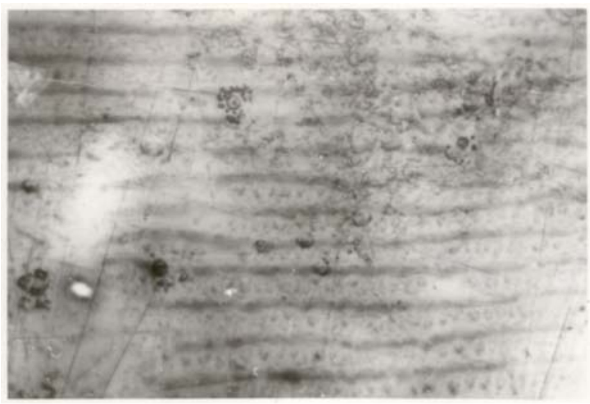


Fig. 8. Magnetic domains between two lines of irradiation.

ELECTRON BEAM IRRADIATION METHOD

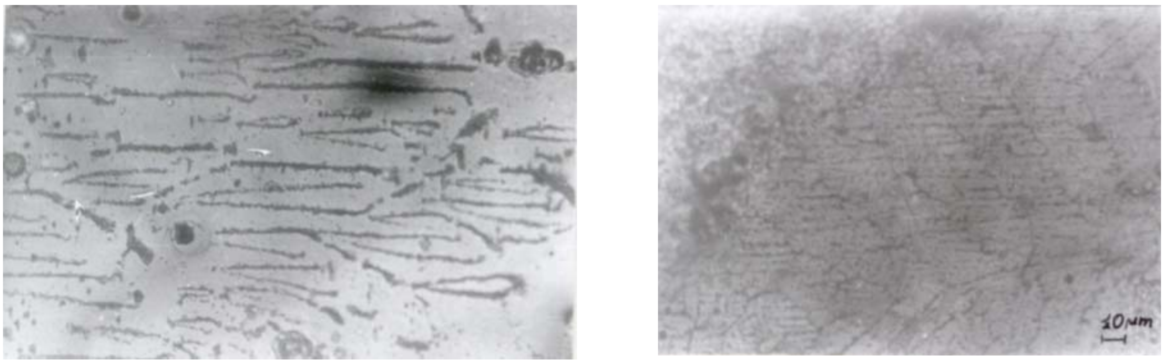
The process the material prelucration by electron beam it's based on a phenomena of deceleration of the electrons in the material in which the electron beam energy it's transform in thermal energy in the attack zone.

We use the program for the electron beam source in order to increase the current intensity and to reduce the maintaining time. The local stresses were induced by points, the diameter of the spot is 300 μm, the electron beam source has an acceleration voltage of 40 kV. First we induced local stresses for 20 sheets (set for Epstein frame) at a current intensity of 5 mA and maintaining time 1 ms and 20 mA and 0,1 ms. The results are presented in Table 3. The stresses were induced for the optimum distance of 0.6 mm between points and 1,02 mm between lines, observed in the previous tests.

Table 3: Power losses measurements on an Epstein frame for stressed and non stressed samples

No.	Type	Losses at 1.5 T [W/kg]	Losses at 1.7 T [W/kg]
1.	M0H – not stressed	0.70	1.04
2.	M1H – not stressed	0.74	0.98
3.	M0H stressed 40 kV; 5 mA; 1 ms	0.86	1.15
4.	M1H stressed 40 kV; 5 mA; 1 ms	0.91	1.20
5.	M1H stressed 40 kV; 20 mA; 0.1 ms	0.72	0.99

The results presented in Table 3 were obtained for the same set of sheets before and after inducing stresses. For the test no. 5 we observed that for a current intensity of 20 mA and maintaining time of 0,1 ms there is a small decrease for the losses. We worked in order to obtain smaller maintaining periods. The smallest maintaining time we obtained is 40 μs.



a) b)

Fig.9. Microstructures before and after the irradiation.

We realize a characterization of those sheets with a single sheet tester on which we apply the following parameters of the measurement: frequency 50 Hz; magnetic flux density: 500 mT, 1000 mT, 1300 mT, 1500 mT, 1600 mT, 1700 mT, 1800 mT, 1900 mT. Before each measurement we made a demagnetization of the probes.

In the table 4 we present the values obtain before we induce stresses on the sheets.

Table 4: Before electron beam irradiation

Nr.	B_n [mT]	B_r [mT]	H_c [A/m]	P [W/kg]
1	500	398,3	10,7	0,12
2	1000	822,9	15,1	0,36
3	1300	1107,4	17,2	0,55
4	1500	1353	18,9	0,72
5	1600	1477,7	19,4	0,82
6	1700	1592	20,5	0,96
7	1800	1690	21,7	1,18
8	1900	1756,4	24	1,53

Table 5: After electron beam iradiation

Nr.	B_n [mT]	B_r [mT]	H_c [A/m]	P [W/kg]

1	500	376,3	9,5	0,1
2	1000	780,9	14,1	0,32
3	1300	1037,4	16,2	0,49
4	1500	1257	17,9	0,64
5	1600	1378,7	18	0,73
6	1700	1489	18,8	0,83
7	1800	1611	19,7	0,99
8	1900	1751,4	20	1,28

A comparison between the power losses obtain for the two set of sheets (not stress and stress) was made in the figure below.

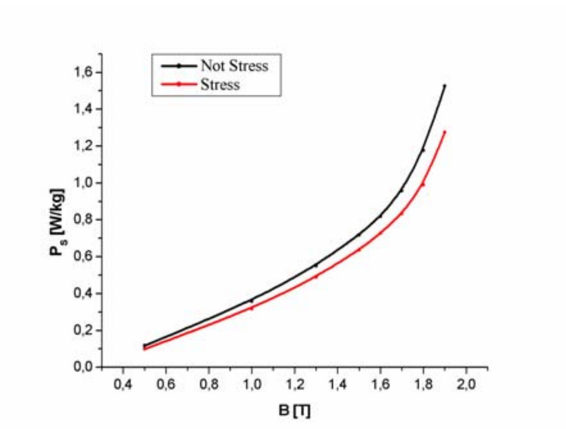


Fig. 12. Total iron losses for not stress sheet and for the stress sheet.

CONCLUSIONS

In this paper we present three methods for reducing the total power losses in the silicon iron sheets. In the first method, the mechanical induced stress, we observe that the magnetic domains width is decreasing from approximate 70 µm in stress free state to almost 30 µm after the scratching was applied and to 9 µm after the pointing technique was done. A very important aspect of this method is the pressure that it is applied because, if it is too strong, can determine the increase of the power losses.

The method of laser irradiation it is a very precise method and can be use in industry. With this method we reduce the width of the magnetic domains from 45 µm to approximate 20 µm.

The electron beam irradiation method it is use mostly in the laboratory because we have to do some preparations of the samples. From our experiments we obtain a decreasing with 11,1 % of the iron losses because of the reduction in half of the width of the magnetic domains.

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