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A New Soft Magnetic Material for ac and dc Motor Applications

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A new soft magnetic material has been developed for ac and dc motor applications. The motor components are made by a powder metallurgical process, in contrast to the traditional method of stacking punched laminations. This new material offers many manufacturing advantages. Also, because of its low eddy current loss, it has good high-frequency magnetic properties, 90 W/kg core loss when measured at 400 Hz and at an induction of 1.5 T. Components manufactured from this new magnetic material have demonstrated comparable performance at 60 Hz and superior performance for frequencies >60 Hz when compared to cold-rolled motor lamination steels. The new pressed material also has outstanding dc properties when sintered.

Keywords core loss, density, magnetic, motor, permeability, powder metallurgy, pressed

1. Introduction

All electromagnetic devices that operate at power frequencies (50 or 60 Hz) use lamination steel sheet, which for most devices (motors, small transformers, ballast transformers, etc.) is punched, annealed, and stacked by the manufacturer to form the magnetic core of the device. This manufacturing process has some major shortcomings. The energy content to make lamination steel is substantial, and since a significant amount of scrap is generated in the lamination punching operation, sometimes exceeding 40%, the *net* energy content of the usable steel in the magnetic core is significantly increased. Often the device manufacturer must reduce scrap at the expense of optimizing the electrical efficiency. Also, the freedom to design the most efficient motors is limited by the two-dimensional constraints of stacking laminations using right angles.

The market for variable-speed permanent magnet motors is increasing. These motors use permanent magnet rotors rather than rotors made from stacks of laminations. The net effect is a dramatic increase in the scrap rate, because there is no use for the hole punched from the motor stator. Variable-speed motors place different demands on the lamination steel because the speed is controlled by changing the frequency in the motor stator windings. Frequencies as high as 800 Hz are currently being used. As the frequency increases, the core loss of the steel increases dramatically. The resultant high core losses not only reduce motor efficiency but also limit its operating range, and will ultimately have to be addressed by the motor designer as well as by the steel manufacturer. The higher alloy contents and thinner gages that are needed to reduce eddy current losses increase both the cost and energy required to produce these steel grades.

A pressed magnetic component can address many of the shortcomings of a stacked lamination component. The pressing process is scrapless. Because a powder metal part is scrapless it will not have any design constraints based on reducing scrap. Also, a pressed magnetic component does not have the same design constraints as a stack of laminations. Three degrees of freedom are available to the designer rather than the two degrees imposed by simply stacking steel laminations one on top of the other. The zero scrap and increased degree of design freedom allow a reduced energy cost of producing the material used in the device, and they also allow for optimization of the magnetic circuit around an improved electrical efficiency of the device.

Another advantage of a powder metallurgically pressed component is related to the frequency dependence of the core loss. It is possible to make a magnetic component that exhibits an almost linear dependence of core loss with magnetizing frequency, as opposed to the almost squared dependence of core loss on frequency that is typical of most lamination steel grades. Because variable-speed permanent magnet motors operate at frequencies up to 800 Hz, higher efficiency in these devices is possible.

2. ac Magnetic Properties

The new pressed magnetic material has good magnetic properties, especially at high frequencies. Yet even at the standard frequencies of 50 or 60 Hz, it has losses to those of comparable cold-rolled motor lamination steel (CRML) (Fig. 1).

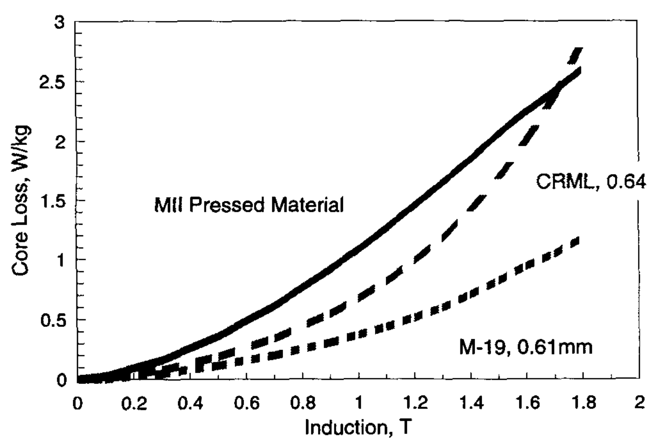

Fig. 1 A comparison, at 60 Hz, of the core loss of the pressed material to a phosphorus-bearing CRML steel that is 0.64 mm thick and an M-19 steel that is 0.61 mm thick

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At 1.5 T (15 kG) and lower induction levels, the core loss of the pressed material is slightly higher than the core loss of the CRML steel. Yet at higher induction levels, greater than 1.6 T, where many motors operate, the core losses are comparable. At induction levels over 1.8 T, where motors also operate, the pressed material has a lower core loss. Figure 2 shows the total core loss of the pressed material at 60 Hz separated into its hysteresis loss and eddy current loss components. (The eddy current loss is composed of all losses, both the classical eddy current loss and anomalous loss, excluding the hysteresis loss.) The eddy current losses are a very small part of the total losses, less than 10% up to 1.8 T.

The relatively small eddy current losses keep the total losses low at higher frequencies. Figure 3 shows the comparison of the total core losses, measured at 1.5 T, of the pressed material to a phosphorus-bearing CRML steel and a non-oriented silicon steel, M-19. In both comparisons the hysteresis loss of the pressed material is greater, but the eddy current loss is less. At low frequencies the pressed material has the highest core loss. At around 60 Hz the pressed material losses are comparable to the phosphorus-bearing CRML steel losses, and they are much lower at higher frequencies. The M-19 steel has the lowest core losses at the lower frequencies. Yet by around 400 Hz the core loss for the pressed material is comparable to that of the M-19 steel. The pressed material has the lowest losses at frequencies higher than 400 Hz.

The lower total core loss for the pressed material is due to the lower eddy current losses. Figures 4 and 5 show the percent eddy current loss for each of the materials at 60 and 400 Hz, respectively. At both frequencies the percent of the total core loss due to eddy current losses is lowest for the pressed material. The low eddy current loss for this new magnetic material makes it a good material for motors. In most motor applications the induction level is greater than 1.5 T, and the wave form of the voltage is not sinusoidal and has a high harmonic content. The higher harmonics result in higher eddy current losses.

3. Motor Results

Pressed stators were made for a four-pole brushless motor. Table 1 compares the magnetic properties of the pressed core

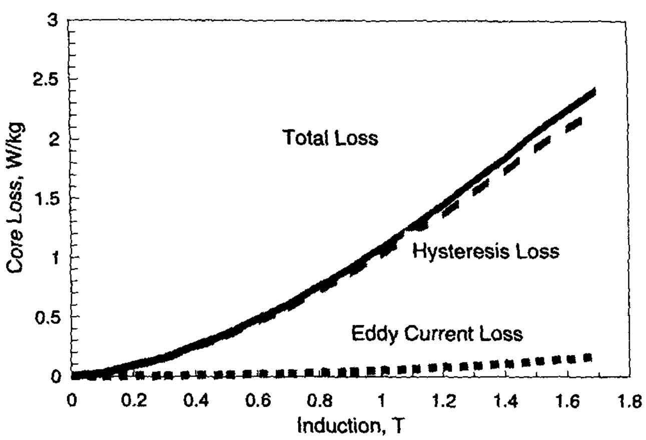

Fig. 2 The total core loss, at 60 Hz, of the pressed material, separated into its hysteresis loss and eddy current loss components

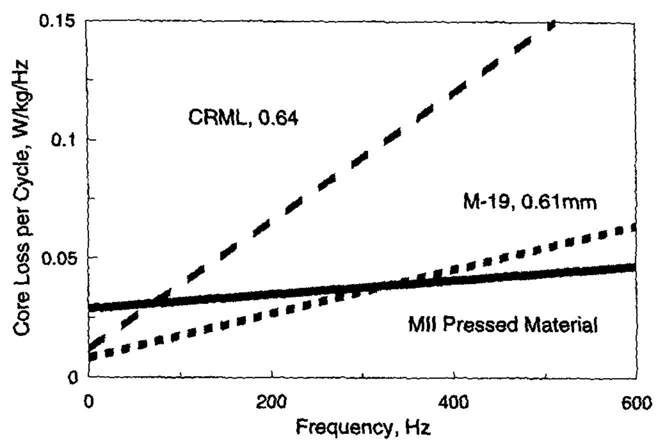

Fig. 3 Comparison of total losses, measured at an induction of 1.5 T, of the pressed material, a phosphorus-bearing CRML steel 0.63 mm thick, and an M-19 silicon steel 0.61 mm thick

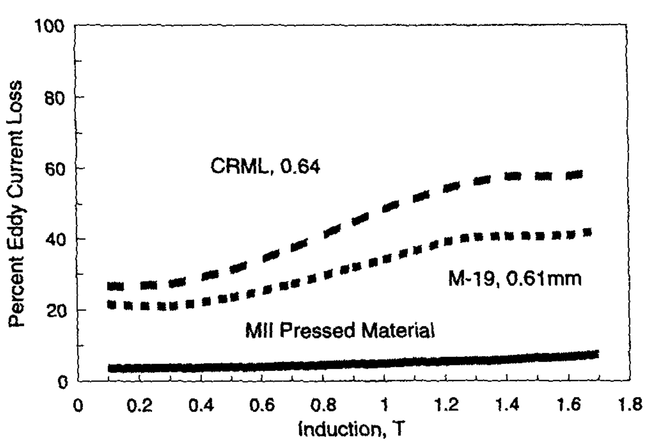

Fig. 4 The percent eddy current loss of the total core loss for the pressed material, a phosphorus-bearing CRML steel, and an M-19 silicon steel. Results are from 60 Hz tests.

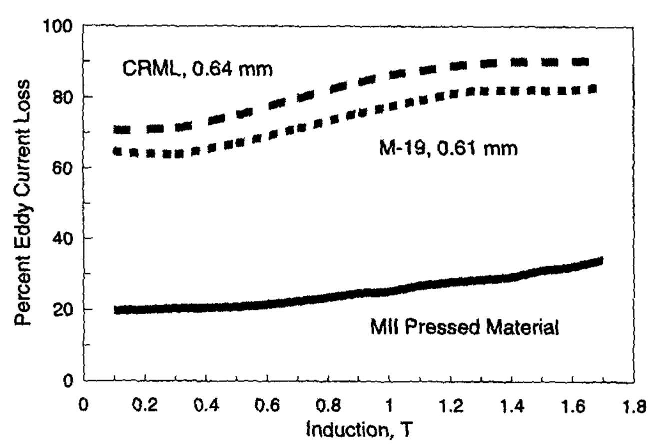

Fig. 5 The percent eddy current loss of the total core loss for the pressed material, a phosphorus-bearing CRML steel, and an M-19 silicon steel. Results are from 400 Hz tests.

Table 1 Performance of standard core and pressed core

Core type	Torque, N · m	Amps	Speed, rad/s	Efficiency, %	Temperature rise, °C
Standard	0.066	7.1	1649	64.5	49.4
Pressed	0.066	6.6	1768	74.5	27.8

Table 2 Magnetic properties of the new material

As-pressed dc properties		Sintered dc properties	
Wh at 8000 A · t/m	1300 J/m^3	B at 1200 A · t/m	1.42 T
B at 8000 A · t/m	1.65 T	B at 8000 A · t/m	1.75 T
Br from 8000 A · t/m	0.34 T	Br from 8000 A · t/m	0.93 T
Hc from 8000 A · t/m	192 A · t/m	Hc from 8000 A · t/m	80 A · t/m
Maximum permeability	800	Maximum permeability	7000

motor with those of a standard lamination core motor (0.64 mm M-19). The torque in both test cases was held constant. The pressed core dramatically outperformed the standard core. It had a lower draw of current, ran at a higher speed, and had a lower temperature rise. Overall, the efficiency of the pressed core was greater by 10%. The material used in these motor cores was an early version of the pressed magnetic material. Refinements of the material have led to more than a 10% decrease in its core loss; therefore, even better results are expected with the new material. Several universal motors have been produced with the pressed material. They exhibited similar and slightly better performance than the standard CRML steel cores.

4. dc Properties

The density of the pressed magnetic material is up to 7.70 g/cm^3, a high density, especially compared to other pressed powder metal materials. The high density results in good dc magnetic properties. Table 2 shows the magnetic properties for the new pressed magnetic material in the as-pressed state and after sintering. The pressed and sintered core has a higher magnetization, shown at 1200 A · t/m (15 Oe) and 8000 A · t/m (100 Oe), a higher maximum permeability, and lower coercive force than typical pressed and sintered pure iron powder and 0.45% P iron cores (Ref 1). These properties show that the new material is a good soft magnetic material for dc applications.

5. Conclusions

CRML steel and non-oriented silicon steel have traditionally been used in stacked laminations for motor and electromagnetic device applications. The stacked lamination method has many shortcomings, such as significant scrap loss, constraints on design freedom, and high eddy current losses at higher frequencies. A new, powder metallurgically pressed, soft magnetic material has been developed that can address many of these shortcomings. The material has a very low eddy current loss component compared with that of CRML steel. At 60 Hz the total core loss is comparable to that of CRML steel at motor operating induction levels, and it is significantly less at higher frequencies. By 400 Hz the total core loss is comparable to that of non-oriented silicon steel. Now that many motors run at higher frequencies, up to 800 Hz, and have high harmonics, the benefit of the pressed magnetic material should be significant. Also, with the high density, the pressed and sintered core has a higher induction level and lower coercive force than commercially pressed powder cores do.

Acknowledgments

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Reference

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