# New Magnetodielectric Materials for Magnetic Flux Control

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## ABSTRACT

Magnetodielectric materials play an important role in improvement of induction systems for heat treatment, brazing, soldering, sealing and other technologies. This presentation is a continuation of the report made at HIS-01. Current report shows the results of development of new magnetodielectric materials for magnetic flux control and intensive study of their properties.

Presentation contains information on new MagnetoDielectric Materials (MDM's) Fluxtrol 25, Fluxtrol 50 and a third new material developed specifically for low frequency (less than 10 kHz) applications. It is shown that some magnetodielectric materials have significant property anisotropy. This anisotropy may be beneficially used for optimal design of magnetic flux controllers. A presentation is accompanied by table-top exhibition with samples of magnetodielectric materials and inductors with magnetic flux controllers.

## INTRODUCTION

There are four main families of electromagnetic applications where soft magnetic materials are used: electromechanical devices, low frequency industrial applications, high frequency industrial applications, and telecommunications. Figure 1 shows the common frequency ranges of different electromagnetic applications. The requirements for soft magnetic materials are quite different depending upon the type of application.

Electromechanical devices consist mainly of electrical motors, relays, solenoid and drives, which generally work at frequencies between DC and several hundred hertz. These products are typically relatively high volume (thousands of parts) and warrant specific tooling for manufacturing. The main requirements to materials in electromagnetic devices are high permeability, high saturation flux density, low core losses (if AC) and good mechanical strength. The core losses for these materials are typically due to hysteresis losses.

The low frequency industrial applications that utilize soft magnetic materials are typically large induction installations for melting, mass heating, forging, etc. In these applications, the processing temperature is high and the magnetic materials must be in close proximity to the load. The frequency range for these applications is typically between 50 Hz and 3 kHz. The number of installations of a given type is relatively small due to the huge production rates and the shape of soft magnetic materials required varies. The main requirements to materials in low frequency industrial applications are high permeability, high saturation flux density, low core losses and good temperature resistance.

Communications applications often use soft magnetic materials for radio electronics transformers, chokes, antennas and other devices. The frequency range for these applications is above 500 kHz to several GHz. These applications typically are very high volume and the shapes used are relatively simple.

The high frequency industrial applications that use soft magnetic materials consist mainly of a wide variety of induction heating processes including heat treating, small quantity or low conductive material (ie glass) melting, preheating, joining, etc. This family of applications is much more diverse than the low frequency industrial applications. In addition, each of these applications require special know-how for proper electromagnetic system design. The following sections discuss the role of soft magnetic materials, the materials available and considerations for their use that must be taken into account when working in this area of application with special attention paid to magnetodielectric materials.

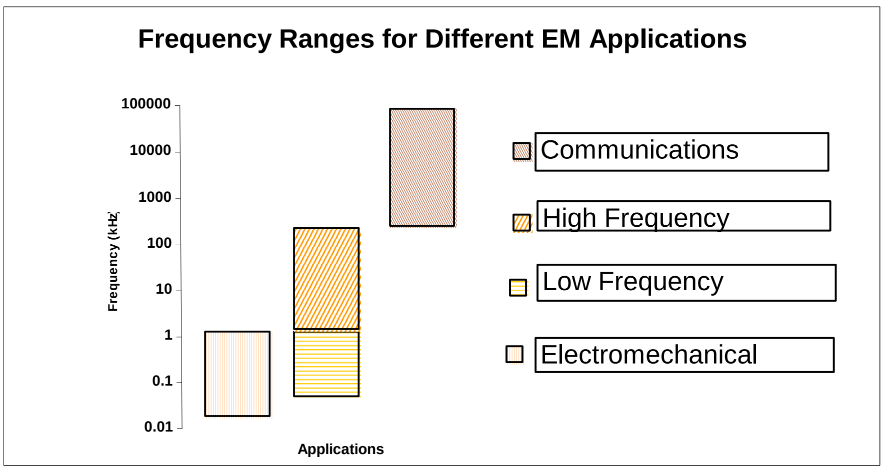


Figure 1 Frequency ranges for electromagnetic applications

## ROLE OF MAGNETIC FLUX CONTROLLERS

Magnetic flux controllers are a powerful tool in induction heating technology [1]. Recently, better understanding of their role in different induction heating systems has been obtained through a comprehensive study using computer simulation and experiments at Centre for Induction Technology, Inc. The results of this study show that the proper use of a magnetic flux controller is always beneficial in an induction heating system [1]. They can play different roles in induction heating installations and in various applications are being named as concentrators, controllers, diverters, cores, impeders or screens.

Magnetic flux controllers may provide the following effects:

- improvement of the induction coil and process efficiency;
- improvement of the coil power factor;
- protection of machine components and certain workpiece zones against unwanted heating;

- precise control of the magnetic field and the resulting heat pattern
- improvement in efficiency of the high frequency power supplying circuitry;
- elimination of external magnetic fields in close proximity to the coil.

In most real applications more than one of these benefits usually occur. For processes such as case hardening, tempering or brazing where the results are very critical to operating conditions of heating process, quality improvement is usually the most important. Application of magnetic flux controllers strongly influences the power density value and its distribution along the surface of the workpiece enabling faster heating and better heat pattern control. In addition to improvements in metallurgical results and physical properties of parts, heat pattern control allows you to control stresses and strongly reduce part distortion.

To illustrate how magnetic flux controllers may be used in the optimal design of an induction heating process, we'll describe shortly a real world installation for stress relieving of spiral welded heavy walled steel pipe for the oil and gas industry. The induction heating user purchased an installation for weld seam annealing on large diameter seam annealing (T>900 C) after arc spiral welding (figure 2). The unit was working fine for its intended application. Then, the specifications for the tube heat treatment were changed. Instead of full annealing of the weld seam, the process required was specified as a high temperature stress relieving (550-650 C) and the Heat Affected Zone (HAZ) was widened from 30 mm to 60 mm.

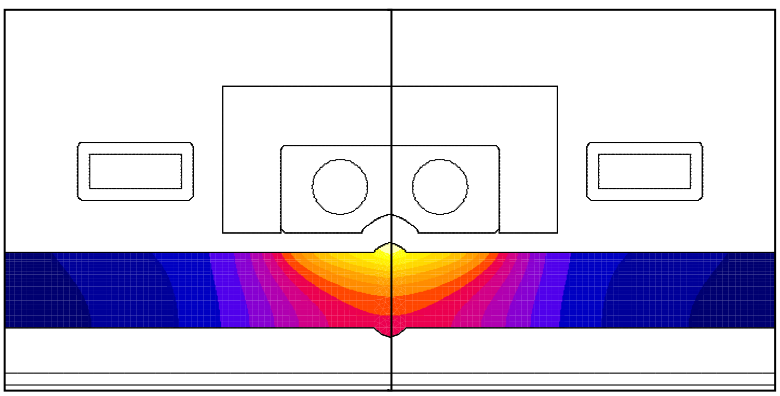

Figure 2. Final temperature distribution for the weld seam stress relieving process using the same coil as for weld seam annealing

When the user tried to set up the new process, they found two things: the heat affected zone was too narrow and they were not able to get the inside of the weld seam up to the specified temperature without overheating the surface and there was no space for a longer coil. They tried slowing the process down significantly, but they were still unable to meet the new heat treating specifications. The reason for their difficulties can be easily explained using computer simulation. Figure 3 shows the color shade of the temperature distribution at the end of the heating process and the temperature on the inner and outer weld beads over the course of the process using their seam annealing inductor.

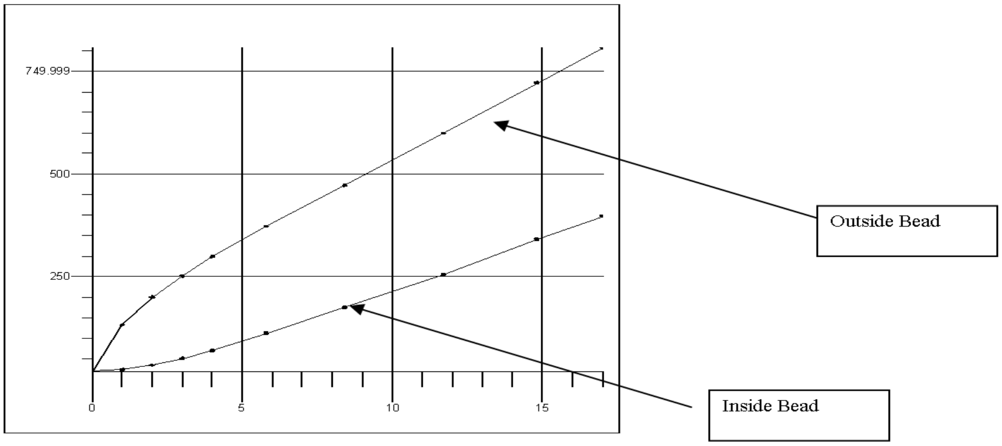


Figure 3. Inner and outer weld bead temperature evolution for the existing stress relieving process

Compared to the old process, the pipe is magnetic throughout the entire process so the induced heat sources flowed only in a shallow surface layer of the workpiece. This meant that the center of the workpiece was heated entirely by heat conduction from the surface

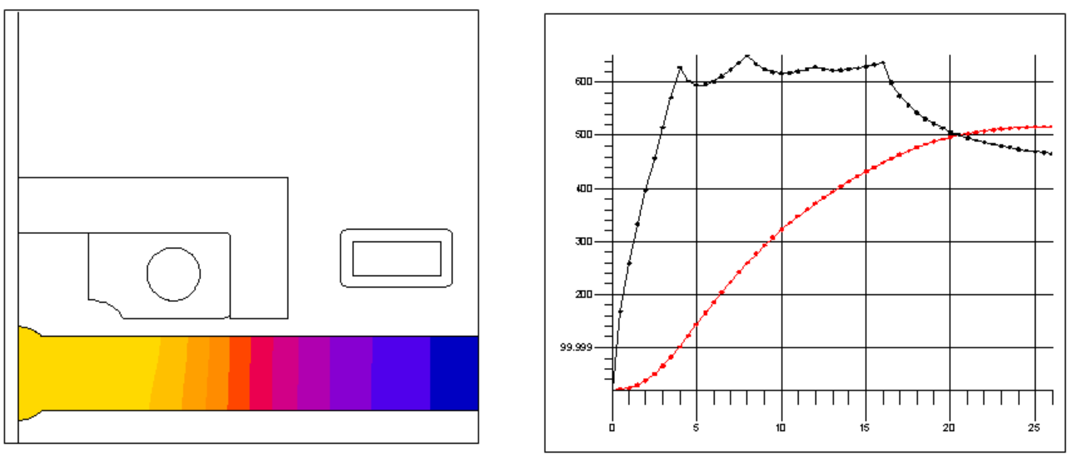


Figure 4. Final temperature distribution and inner and outer weld bead temperature evolution for the optimized coil and process

To provide the wider HAZ, the turns were separated. The best solution to get the inside of the weld bead up to temperature is magnetic flux controller variation in the coil length. Fluxtrol A magnetic flux concentrator was applied for this application. The initial stage is a ramping to the maximum surface temperature and the full C-shape cross-section is applied. After the maximum temperature is reached, we begin to cut back some of the concentrator pole to hold the maximum temperature constant. More concentrator is removed until the final stage is reached and we have no concentrator at all. Figure 4 shows the temperature distribution in the weld seam area 6 seconds after the point has left the coil. Figure 4 also shows the temperature on the inner and outer weld beads over the heating process. You can see that the temperature is uniform in thickness and in width with the new design.

## MATERIALS FOR MAGNETIC FLUX CONTROL

Requirements for magnetic flux contolling materials in induction heating processes can be very severe in many cases. They must work in a very wide range of frequencies, possess high permeabilities and saturation flux densities, have stable mechanical properties and exhibit resistance to elevated temperatures from losses in the concentrator and radiation from the heated part surface. In heat treating and brazing, the material must withstand hot water attack, quenchants and active technological fluxes. Machinability is also a very important property for successful application of flux controllers, because it allows you to obtain the exact concentrator dimensions necessary to assure consistent results and precise magnetic field control.

As was discussed above, there is a very wide range of requirements for the various induction heating applications and therefore more than one magnetic flux controlling material is required to cover the whole range. Three groups of magnetic materials may be used for magnetic flux control: laminations, ferrites and MagnetoDielectric Materials (MDM) [2]. Laminations have long been used in electromagnetic systems and their abilities and limitations, especially in manufacturing and frequency, are well documented. The use of ferrites relatively uncommon in induction heating due to very low machinability, sensitivity to thermal shock, and low saturation flux density. MDM's are well suited to induction requirements and have the potential for use in the entire application range.

### *Special Properties of MDM's*

MDM's are an evolving material class and there is currently rapid progress in their improvement and understanding. They have some special properties, that when properly utilized, can lead to significant induction system parameter improvement. Two of these properties that have not been adequately discussed before are electrical resistivity and anisotropy.

MDM's are a wide family of materials ranging from good dielectrics to traditional powder metal magnetics. Electrical resistivity is an important parameter of the material which is contradictory to magnetic permeability. The higher the permeability is, the lower the electrical resistivity when using the same materials and manufacturing technology. The nature and proper evaluation of electrical resistivity are rather complicated. At DC current and 50/60 Hz there are only galvanic currents due to random contact between individual metal particles and defects of insulation layers. The resulting resistivity is non-linear with declining values as applied voltage is increased. This effect is especially strong for high-resistive, low permeability materials. At high frequency (hundreds kHz) additional capacitive currents can result in a higher value of measured resistivity.

It is necessary to underline that electrical resistivity does not characterize correctly losses in material. When using computer simulation, we calculate losses in concentrator due to its electrical resistivity, those are only a fraction of total losses caused by hysteresis and eddy-currents in individual particles of the composite. In properly designed induction coils with concentrators, they are a small fraction of total magnetic losses. Proper understanding of electrical properties of MDM is essential for prediction of its performance under application conditions.

Similar to electrical resistivity, anisotropy of MDM's is also not well described in literature. All pressed metal powder materials have certain anisotropy in mechanical, electrical and magnetic properties. This anisotropy is caused by magnetic particle alignment and deformation during the manufacturing process. Magnetic permeability is minimal in direction of pressing and maximal in the perpendicular plane. For toroidal parts, which are widely used in electronics, anisotropy does not play any role while for induction heating applications it may be essential in many cases. Anisotropy may be effectively used, especially in 3D magnetic fields in order to reduce field in less desirable direction. The level of anisotropy depends on material composition, shape of particles and pressure applied.

It is more pronounced in high-permeability materials such as Fluxtrol A and the new low frequency material manufactured by Fluxtrol Manufacturing, Inc. The difference in permeability may be up to two times. Besides permeability, other properties essential for successful concentrator application are also directionally dependent including thermal conductivity and magnetic losses. For advice related to anisotropy of materials, please contact Fluxtrol Manufacturing, Inc.

*<u>MDM's for Magnetic Flux Control</u>*

Since the HIS '01 conference, Fluxtrol Manufacturing, Inc. has introduced 3 new materials for magnetic flux control in induction systems. These new materials are Fluxtrol 25, Fluxtrol 50, and a new low frequency material. The magnetization curves for the main materials manufactured by Fluxtrol are shown in Figure 5. The curves of the resulting relative magnetic permeability for these materials are shown in Figure 6.

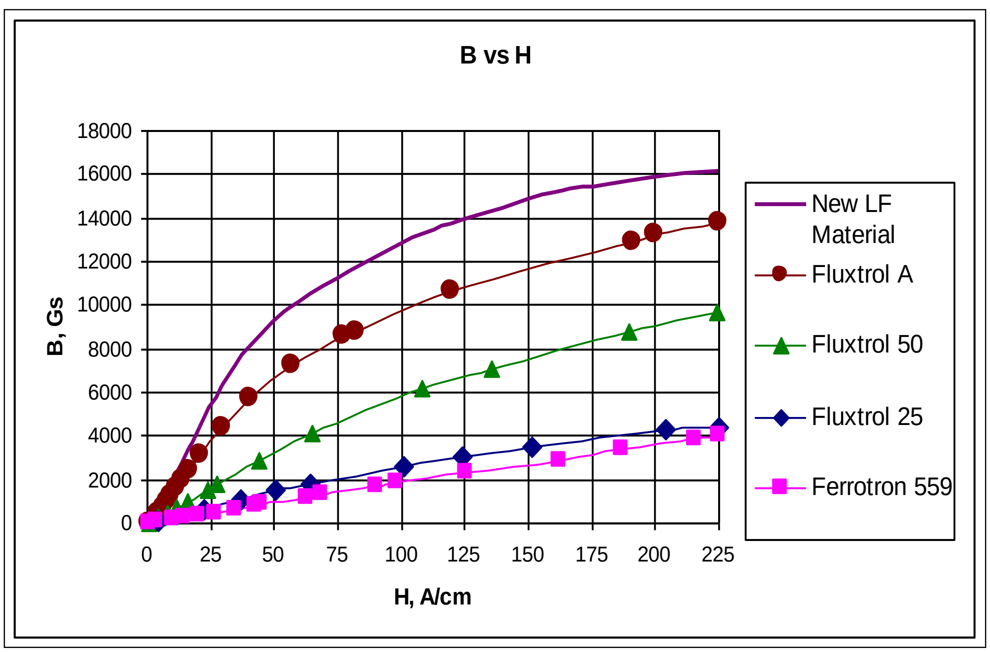


Figure 5. Magnetization curves for MDM's manufactured by Fluxtrol Manufacturing, Inc.

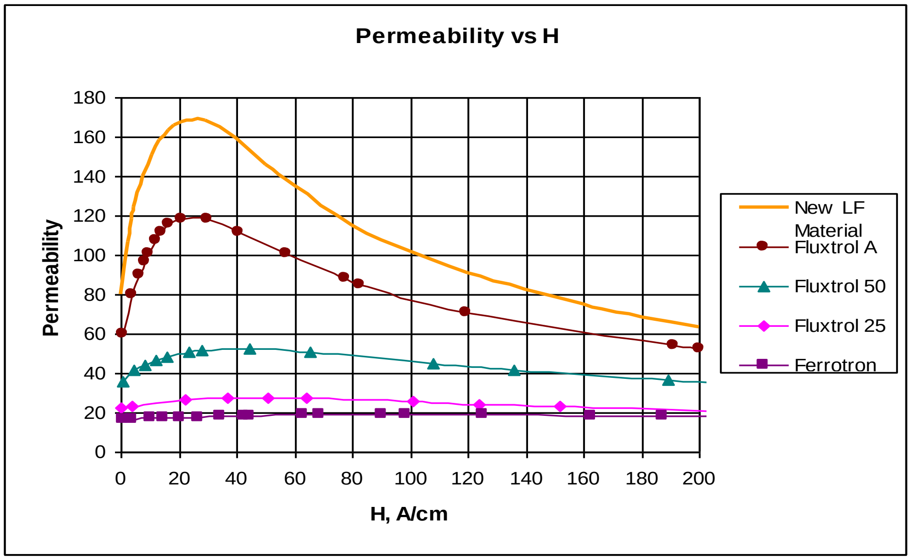


Figure 6. Permeabilities of MDM's manufactured by Fluxtrol Manufacturing, Inc.

The nomenclature for the new materials in the Fluxtrol family is based upon the normal "working permeability" of the materials. The magnetic permeability of MDM's depends upon the magnetic field strength. The general trend is that the permeability increases with field strength until reaching a maximum value and then the permeability declines. For higher frequency MDM's, this distribution is relatively smooth. The "working permeability" is an average value of the permeability in the normal range of field strengths the material was designed to work in.

Fluxtrol 25 is a material that was designed to replace Fluxtrol B in medium and high frequency applications (20 kHz to 500 kHz). The magnetic properties of Fluxtrol 25 are the same as those of Fluxtrol B, making it possible for direct replacement. Fluxtrol 25 has improved temperataure resistance (250 C long term and 300 C short term compared to 200 C long term and 250 C short term for Fluxtrol B), making it more reliable in heavy duty applications, while maintaining its excellent machinability.

Fluxtrol 50 is a material that was designed to fill a gap that was not currently covered in Fluxtrol's old product line. Fluxtrol 50 has high enough permeability for effective use in low frequency applications (working permeability around 50, but it can also be used in higher frequency applications (60 Hz to 500 kHz) and. Fluxtrol 50 has the same temperature resistance as Fluxtrol 25. Fluxtrol 50 has very good machinability and is relatively strong even in thin sections (1.5 – 2 mm).

The other new material that is currently available was designed for use in low frequency applications, such as mass heating, melting and continuous casting. The new low frequency material has a lower price than the materials in the Fluxtrol and Ferrotron families. This makes it cost effective in most cases to use it as a replacement for laminations.

## CONCLUSIONS

Induction applications provide many challenges for soft magnetic materials. These applications are typically low volume and there is a great degree of variation in process type and material requirements. This makes properties such as machinability and chemical stability more important than in other electromagnetic applications.

MagnetoDielectric Materials (MDM's) are a type of soft magnetic material that are gaining increased acceptance in induction applications. They have special properties, which make them very favorable for induction heating conditions. At the same time, the specific features of these materials are not as well understood as for other soft magnetic materials. Two of these properties, electrical resistivity and anisotropy, were discussed in this paper.

Since HIS '01, Fluxtrol Manufacturing, Inc. has introduced 3 new materials for magnetic flux control in induction heating systems: Fluxtrol 25, Fluxtrol 50 and a new material for low frequency applications. These new materials have superior properties to other soft magnetic materials in many applications.

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