Division of Spang & Company

Technical Bulletin

BULLETIN NO. KMC-S1

KOOL MU®

A Magnetic Material for Power Chokes

Introduction

As operating frequencies of switching power supplies increase, circuit components such as power inductors are affected by increasing core losses, causing heat build-up. Iron powder cores are very economical and therefore ideal in lower frequency applications, but at higher frequencies they can exhibit excessive temperature rise.

KOOL MU cores were developed to minimize the core losses and heat generation at the higher frequencies. **KOOL MU** evolved by taking an older magnetic material, Sendust, and refining its process technology in order to significantly lower core losses.

This article describes the processing of **KOOL MU** cores and details the magnetic and electrical properties that make it a viable inductive component. Comparison of **KOOL MU** characteristics with those of iron powder are included. This will assist engineers in the right material selection for power chokes in high frequency power conversion equipment.

Core Processing

KOOL MU is one of several magnetic components known generally as powder cores. Powder cores had their origin in the early years of electronics. Iron powder was used in the early radios in the 1920s; Sendust and Molypermalloy materials (80% Ni-Fe) were developed in the 1930s; High Flux cores (50% Ni-Fe) were developed in the 1970s.

Powder cores are made by grinding the base alloy into fine powder particles, then coating these particles with an insulating material (which controls the size of the air gap). The powders are then pressed into various core shapes under high pressure.

KOOL MU has a material phase diagram shown in Figure 1. The base material is approximately 85% iron, 6% aluminum and 9% silicon. Proprietary methods for processing the powder and the use of a proprietary insulation system yield cores with core losses lower than those of the original sendust types, and much lower than the core losses of iron powder cores.

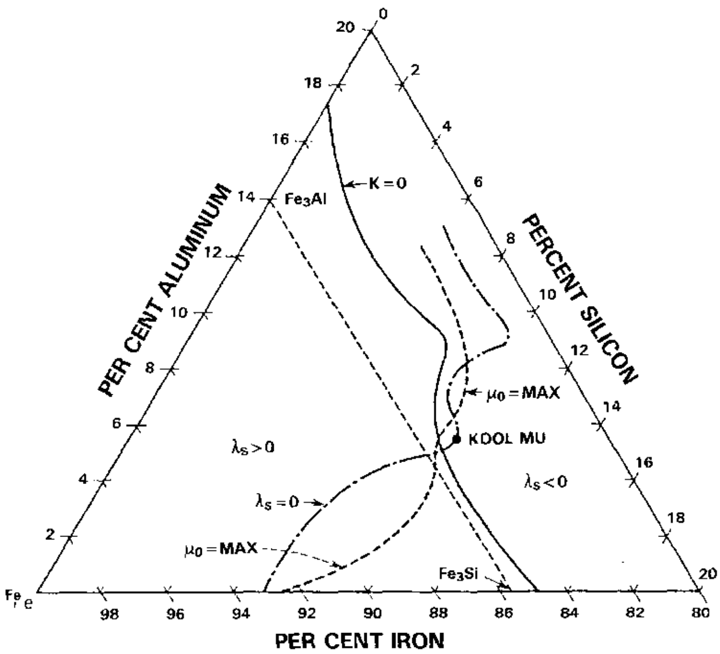


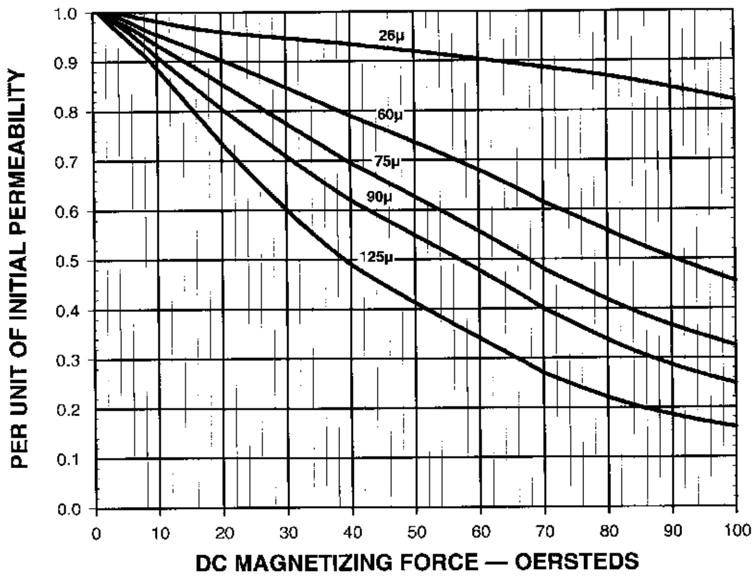
FIG. 1: MATERIAL PHASE DIAGRAM OF FE-SI-AL ALLOYS SHOWING KOOL MU MATERIAL

KOOL MU Features and Applications

The small air gaps distributed evenly throughout the cores, while reducing the effective permeability of the cores, increase the amount of direct current that can be passed through the winding before core saturation occurs. This is a primary advantage of **KOOL MU** cores, making them ideal as power inductors, especially in switching power supplies.

KOOL MU cores are also ideal for transformers in flyback circuits and unipolar transformers. The distributed air gap in the cores keeps them from saturating during the application of direct current pulses.

FIG. 2: PERMEABILITY VS. DC BIAS CURVES FOR KOOL MU ON STANDARD GRAPH PAPER



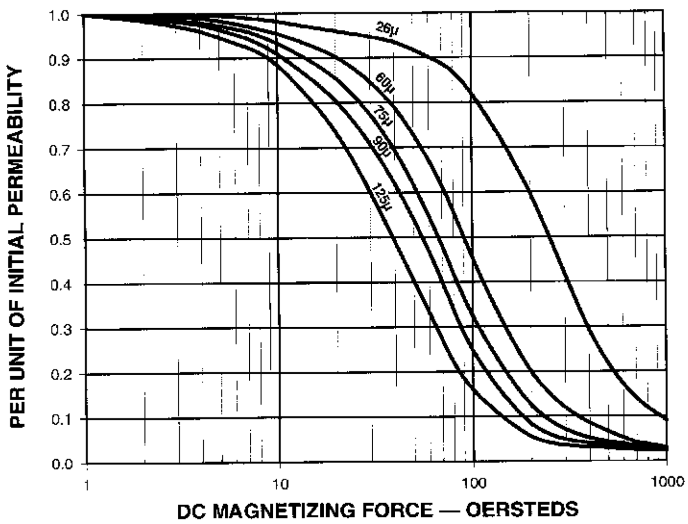
DC Bias

An important magnetic parameter of **KOOL MU** cores is the dc bias characteristic. The curves in Figure 2 show the reduction in permeability as a function of dc bias for all five permeabilities of **KOOL MU.**

Figure 2 illustrates the capability of these cores for swing chokes. In switching regulators and some power supplies, a swing choke can improve both circuit regulation and efficiency because the core provides a high inductance as the dc current approaches zero.

Figure 3 provides the same data as Figure 2 except it uses a semi-log plot. This is done to show the effect of dc bias at high values of magnetizing field.

FIG. 3: PERMEABILITY VS. DC BIAS CURVES FOR KOOL MU ON SEMI-LOG GRAPH PAPER



For comparison, the dc bias characteristics of both iron powder (permeability = 55) and **Kool Mu** (permeability = 60) are plotted in Figure 4.

Although the curves in Figure 4 are for two different materials, they are quite similar in shape. This is to be expected because the size of the air gap governs the effective permeability of the core as shown below:

$$L = \frac{.4\pi N^2 \times 10^{-8}}{\frac{1}{\mu e} \times \frac{\ell c}{Ae}}$$ (general equation for magnetic core inductance)

Inserting an air gap in the core allows the denominator to be modified as follows:

$$\frac{1}{\mu e} \times \frac{\ell c}{Ae} = \frac{1}{\mu m} \times \frac{\ell c}{Ae} + \frac{1}{\mu g} \times \frac{\ell g}{Ag}$$

where ℓg = length of air gap (cm)
Ag = cross section area of air gap (cm²)
ℓc = effective magnetic path length of core (cm)
Ae = effective cross section area of core (cm²)
μe = effective permeability
μm = permeability of core material (100,000 and greater)
μg = permeability of gap (air = 1)

However, $\mu m >>> \mu g$; thus,

$$\frac{1}{\mu m} \times \frac{\ell c}{Ae} << \frac{1}{\mu g} \times \frac{\ell g}{Ag} \text{ and } L = \frac{.4\pi N^2 \times 10^{-8}}{\frac{1}{\mu g} \times \frac{\ell g}{Ag}}$$

Therefore, the inductance of a core with an air gap is a function of gap size rather than the permeability of the core material, hence the similarity of both curves in Figure 4. This similarity is retained until reaching high values of magnetizing field. Here the permeability of **Kool Mu** drops below the iron powder because it reaches saturation earlier.

FIG. 4: PERMEABILITY VS. DC BIAS CURVES FOR Kool Mu AND IRON POWDER

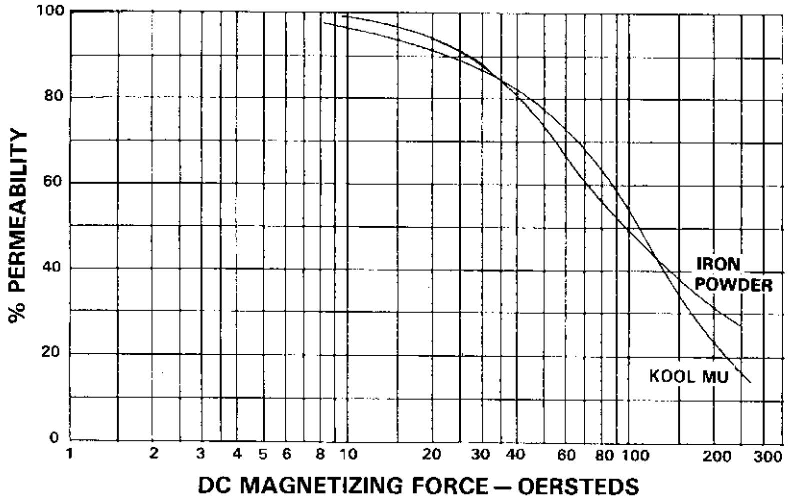
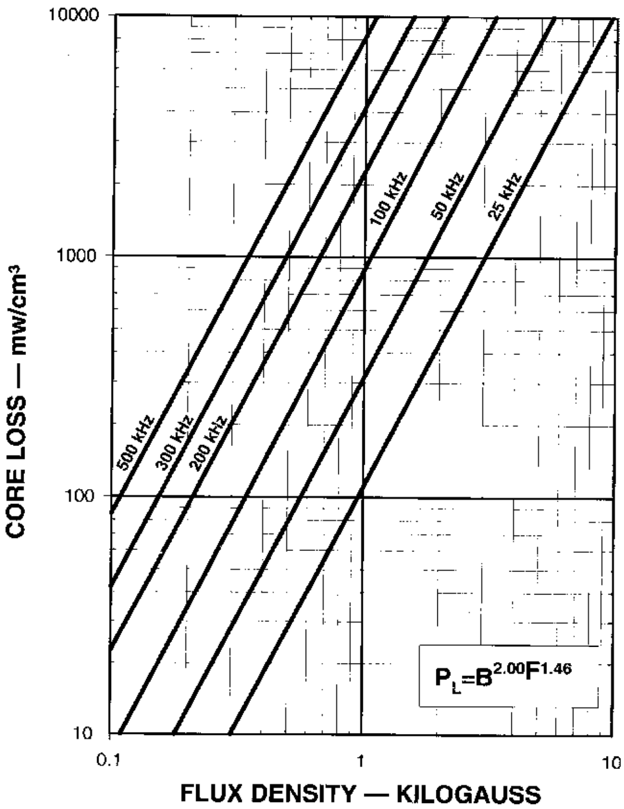


FIG. 5: CORE LOSS VS. FLUX DENSITY AND FREQUENCY FOR Kool Mu AT VARIOUS FREQUENCIES



Core Loss

Another important magnetic parameter of **KOOL MU** is core loss. Figure 5 is a graph of core loss vs. flux density and frequency for this material at various frequencies. Figure 6 compares core loss of **KOOL MU** and the lowest loss iron powders currently available. The two iron powder mixes, A and B, were compared to 60 permeability **KOOL MU** data as it is the closest in permeability to them. This comparison was done as a function of flux density @ 100kHz.

It is obvious from Figure 6 that **KOOL MU** is a superior low-loss core material as its losses are only ½ as much as iron powder mix A and ¼ as much as mix B, at any flux density employed.

Figure 7 shows the same comparison of core loss versus frequency at 100 gauss. It can be seen that **KOOL MU** retains its low-loss advantage over available iron powder materials over a wide frequency range.
A similar effect occurs at any gauss level.

FIG. 6: CORE LOSS CURVES FOR IRON POWDER AND KOOL MU AT 100 kHz

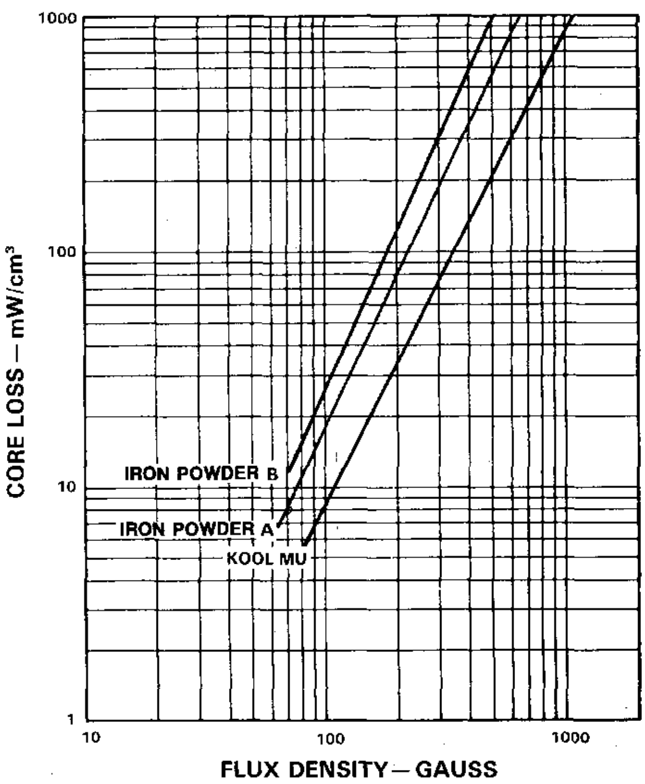
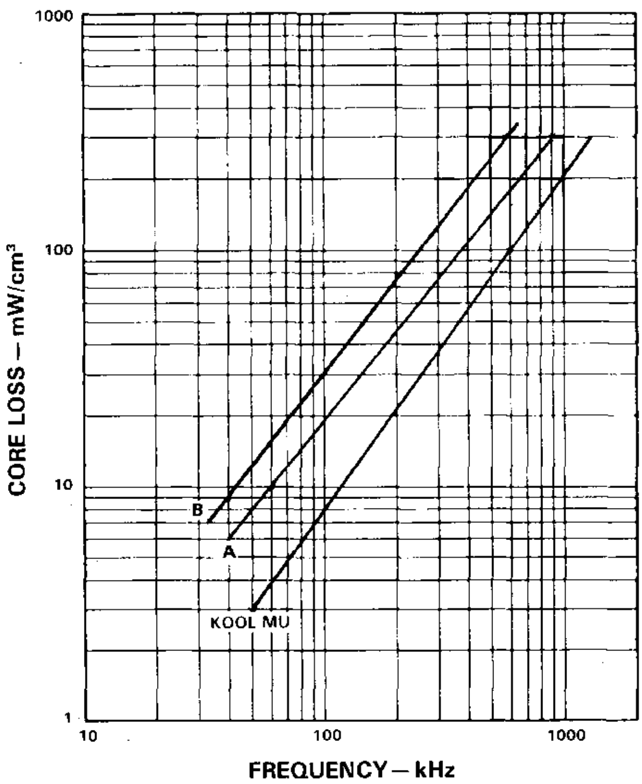


FIG. 7: CORE LOSS CURVES FOR IRON POWDER AND KOOL MU AT FLUX DENSITY OF 100 GAUSS



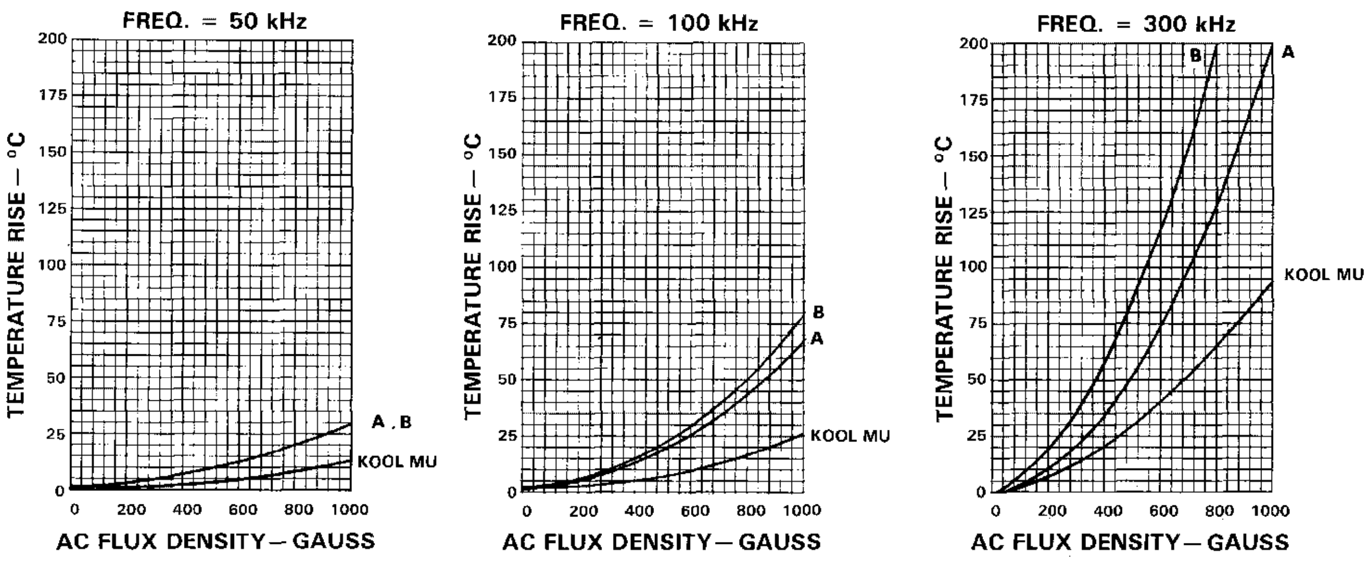
Temperature Rise

Another approach that illustrates the advantages of **KOOL MU** over iron powder is to compare the temperature rise of equivalent cores under identical operating conditions. Figure 8 is a series of plots of temperature rise versus flux density at several frequencies. The iron powder curves are for mixes A and B. Other mixes would make the temperature rise worse under the same conditions.

These graphs show that the temperature rise of **KOOL MU** cores is always less than half of iron powder cores under the same test conditions regardless of the frequency or the amount of ac flux.

Similar results were obtained in tests done on both medium and large toroids, and with both single layer and full winding. Various dc bias currents were not tested as dc does not cause core loss.

FIG. 8: COMPARISON OF TEMPERATURE RISE OF KOOL MU AND IRON POWDER CORES DUE TO FLUX DENSITY AND OPERATING FREQUENCY



Other Magnetic Parameters

Other **KOOL MU** characteristics appear in Figures 9 and 10. Figure 9 shows the variation in permeability of **KOOL MU** over a wide temperature range. This material is unique in that the permeability decreases as the temperature increases above room temperature.

Although curie temperature for **KOOL MU** is 500°C, the core coating is guaranteed only to 200°C, and operation above this temperature is not recommended.

Figure 10 is a series of permeability vs. dc bias curves for 60µ **KOOL MU** at several temperatures. At all dc bias levels the inductance is reduced as temperature increases. This must be taken into account in designs that are subject to temperature variations.

FIG. 9: PERMEABILITY VARIATIONS OVER TEMPERATURE FOR KOOL MU

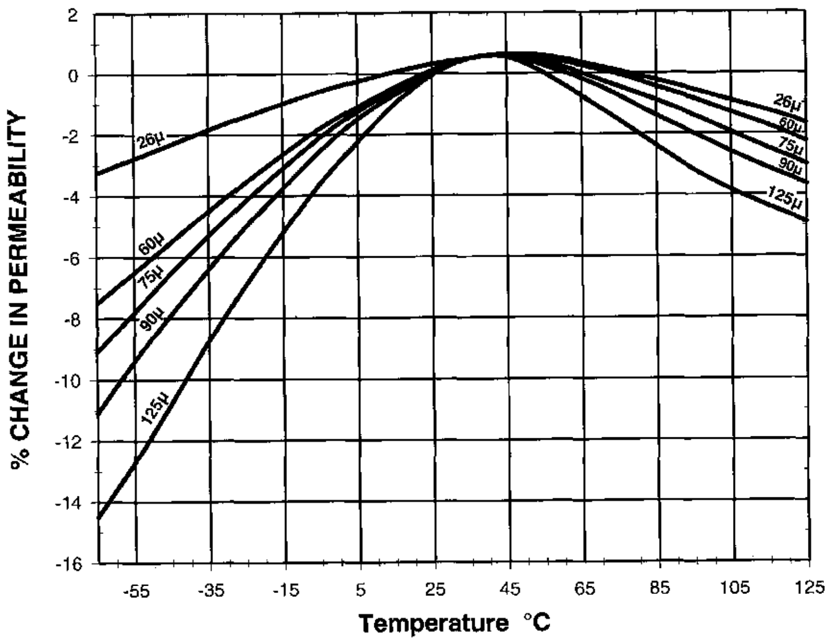
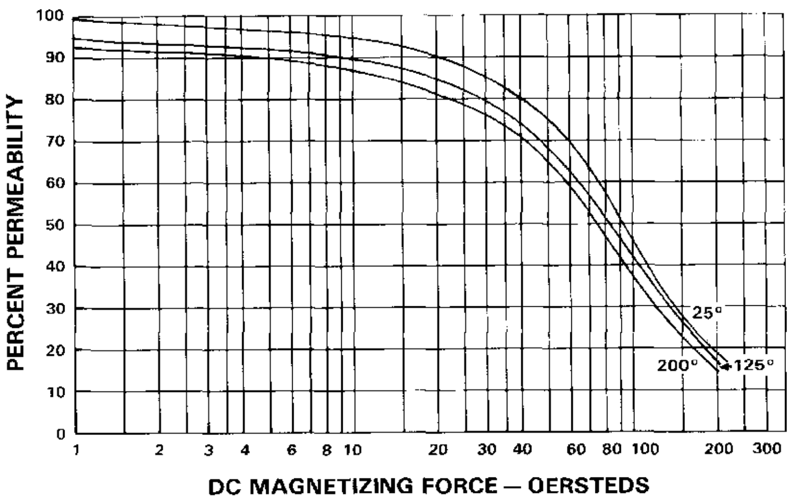


FIG. 10: KOOL MU PERMEABILITY VS. DC BIAS CURVES AT VARIOUS TEMPERATURES



KOOL MU Core Selection

KOOL MU cores are available in five permeabilities (26, 60, 75, 90 and 125). Core sizes range in O. D. from .140” to 2.25”; other sizes are being added as needed by users’ requirements. All cores are coated with a black polyester paint guaranteed to withstand 500 volts through the paint to the core, or 1000 volts between windings.

Performance vs. Cost

Although **KOOL MU** offers superior performance to iron powder, it is slightly more expensive. At 25 kHz, power chokes in commercial power supplies often use iron powder because of the lower cost. As frequencies of switching power supplies increase to 100 kHz and above, iron powder cores become too large or generate excessive heat due to the high core losses. **KOOL MU** cores are the better choice: the greater circuit efficiency and lower temperature rise (or a smaller core size) easily outweigh the slight increase in cost.

Conclusion

KOOL MU cores are ideally suited for power inductors in switching power supplies. They are superior at high frequencies to iron powder cores and fill the need for very efficient inductors in high frequency power conversion equipment.

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