

SAFE RELIABLE DESIGNS USING IRON POWDER CORES

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In past articles, the very complex issue of core loss characterization, prediction, and measurement have been discussed in detail. Much work has been done in this area, but there are now new considerations of applications of cores that make design work more difficult.

Engineers are constantly under pressure to increase power density and reduce cost of power designs. The output filter inductor of a switching power supply is a component that stands out as a target for size reduction. One method of increasing the power density of the

inductor is to drive the core flux to higher levels of operation. In recent years, many companies have pushed the ac excitation of the cores very hard, and this increase in the drive level has exposed a previously undetected weakness in iron powder cores. This phenomenon, known as thermal aging, was first experienced about 10 years ago in a design that pushed the functional limits of iron powder.

Since the discovery of thermal aging, Micrometals has endeavored to understand and characterize this phenomenon. Micrometals' goal was to provide tools to aid the

designer in ensuring that iron powder cores from Micrometals can be used safely and reliably over the expected lifetime of their designs.

Ferrite cores have an order of magnitude lower core loss than iron powder cores, but their lower saturation flux levels usually means that they are less suitable for high dc-current applications. The iron powder material is usually the core of choice, so it is crucial to understand the thermal aging issue thoroughly for reliable design.

Thermal Aging

Iron powder cores achieve low eddy current losses by electrically isolating iron powder particles from each other. The iron powder particles are pressed into the desired core shapes, bringing the powder particles into close proximity to each other, yet maintaining the electrically insulating layer between particles. The electrical insulation between particles confines the eddy currents to traveling only within a particle. When iron powder cores are exposed to elevated temperatures, the electrically-insulating layer between particles is gradually broken down, and losses due to eddy currents become time dependent. This phenomenon, known as thermal aging, results in an irreversible increase in core loss.

Thermal aging can cause a catastrophic failure in operation due to thermal runaway. If a core is operating at a certain temperature, and the core loss contributes to the temperature rise of the inductor, an increase in core loss will cause the operating temperature to increase further. This in turn will accelerate the rate at which thermal aging is occurring. The temperature will continue to increase until the inductor fails.

There are several factors that influence the longevity of a design using iron powder cores. Thermal aging is a function of time, ambient temperature, airflow, copper losses, core geometry, operating frequency, peak AC flux density and material type. Micrometals has characterized the effect that each of these variables has on the rate of change of core loss. The result is a tool that can predict the operating temperature of the inductor as a function of time. By using this tool, the design engineer can build designs that will perform safely and reliably for the lifetime of the device.

One of the more difficult parameters to quantify is the effect that the ambient temperature and the airflow have on the operating temperature. Ideally, the worst-case operating temperature is needed to be sure that the thermal aging calculation will not understate the effect. One way to obtain an accurate worst-case operating temperature is to measure the internal temperature of the core while the core is in operation. This can be done by drilling a small hole in the core material and embedding a thermocouple probe. The thermocouple should be placed in the spot of the core that is likely to be the hottest. This is typically in the center-leg of an "E-E" geometry, or in the shadow of any existing airflow. The temperature rise factor "k" can then be adjusted to match the measured worst-case temperature rise as in the following equation:

$$\Delta T = k \left(\frac{P_d}{A} \right)^{0.833}$$

where P_d is the total power dissipation and A is the surface area of the core.

The following examples illustrate the effect that several of these variables have on determining the useful lifetime of an iron powder core.

Example 1: Effect of Ambient Temperature on Thermal Aging

The ambient temperature in which the inductor is operating is a significant factor in determining the thermal aging characteristic of a device. If we assume the following design characteristics using a Micrometals part number T106-52 (OD=26.9 mm, ID=14.5mm, Height=11.1 mm, Material=Micrometal-52):

Reference condition:

| | |
|----------------------|---------------------|
| Ambient Temperature: | 55°C |
| Air Flow: | No forced air |
| Copper Losses: | 1.0 W |
| Part #: | Micrometals T106-52 |
| Switching Frequency: | 85 kHz |
| Peak AC Flux: | 0.05T |

The thermal aging characteristic of this design is shown by Curve #1 in Figure 1.

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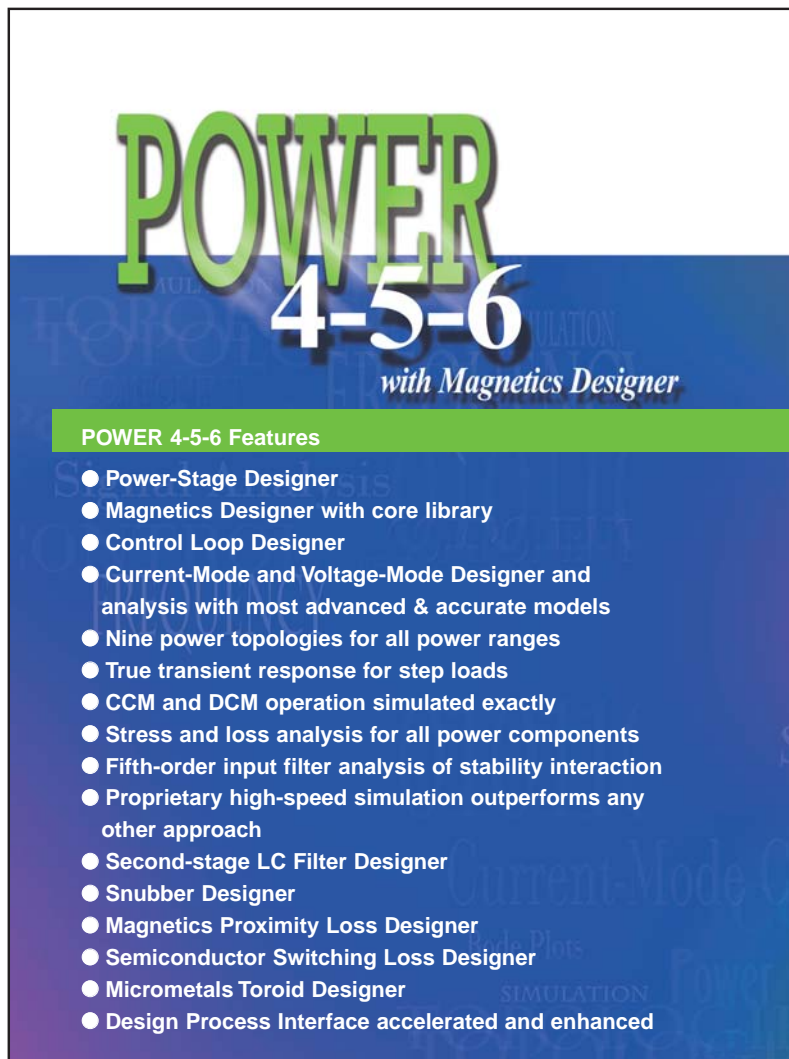
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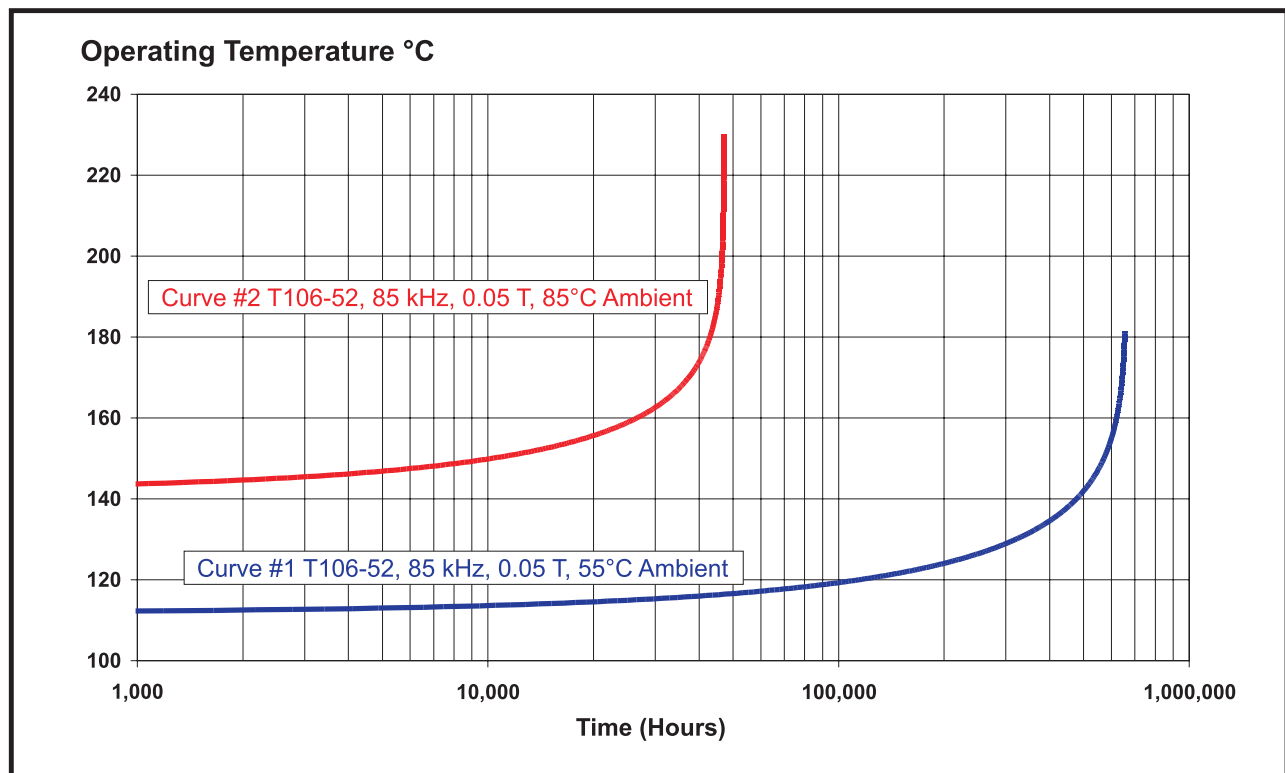


Figure 1: Effect of Ambient Temperature on Thermal Aging

If the ambient temperature is increased to 85°C, the lifetime of the core is less than one tenth of the time, as shown by Curve #2 in Figure 1.

Example 2: Effect of Core Geometry on Thermal Aging

The larger the magnetic cross-section, the more quickly thermal aging will become a factor in a design. This is illustrated in Figure 2. Curve #1 is the same curve as the previous example. Curve #2 shows Micrometals part number T175-52 (OD=44.5mm, ID=27.2mm, Ht=16.5mm, Material=Micrometal-52 material). The peak AC flux density for Curve #2 was lowered to 0.047T, in order to achieve the same initial operating temperature.

Reference condition:

| | |
|----------------------|---------------------|
| Ambient Temperature: | 55°C |
| Air Flow: | No forced air |
| Copper Losses: | 1.0 W |
| Part #: | Micrometals T106-52 |
| Switching Frequency: | 85 kHz |
| Peak AC Flux: | 0.05T |

While both designs will last in excess of 100,000 hours, it can be seen that the T175-52 with a larger magnetic cross-sectional area will thermally age more quickly than the T106-52.

Example 3: Effect of Different Core Material Suppliers

Perhaps the most critical factor influencing thermal aging is the process used to manufacture the core material. Micrometals is able to reliably predict the thermal aging characteristics of its cores due to the consistency of the manufacturing process. The raw material supply chain and application of the insulating layer to the iron powder particles are critical to the thermal aging of the final inductor. Careful control over every step in the manufacturing process results in predictable performance.

Substitution of core materials from Micrometals to a lower cost supplier has already been the cause of several costly recalls in the power supply industry. Designs that had been tested and verified using Micrometals thermal aging analysis have burned-up in the field due to the inferior thermal performance of the substituted cores. If

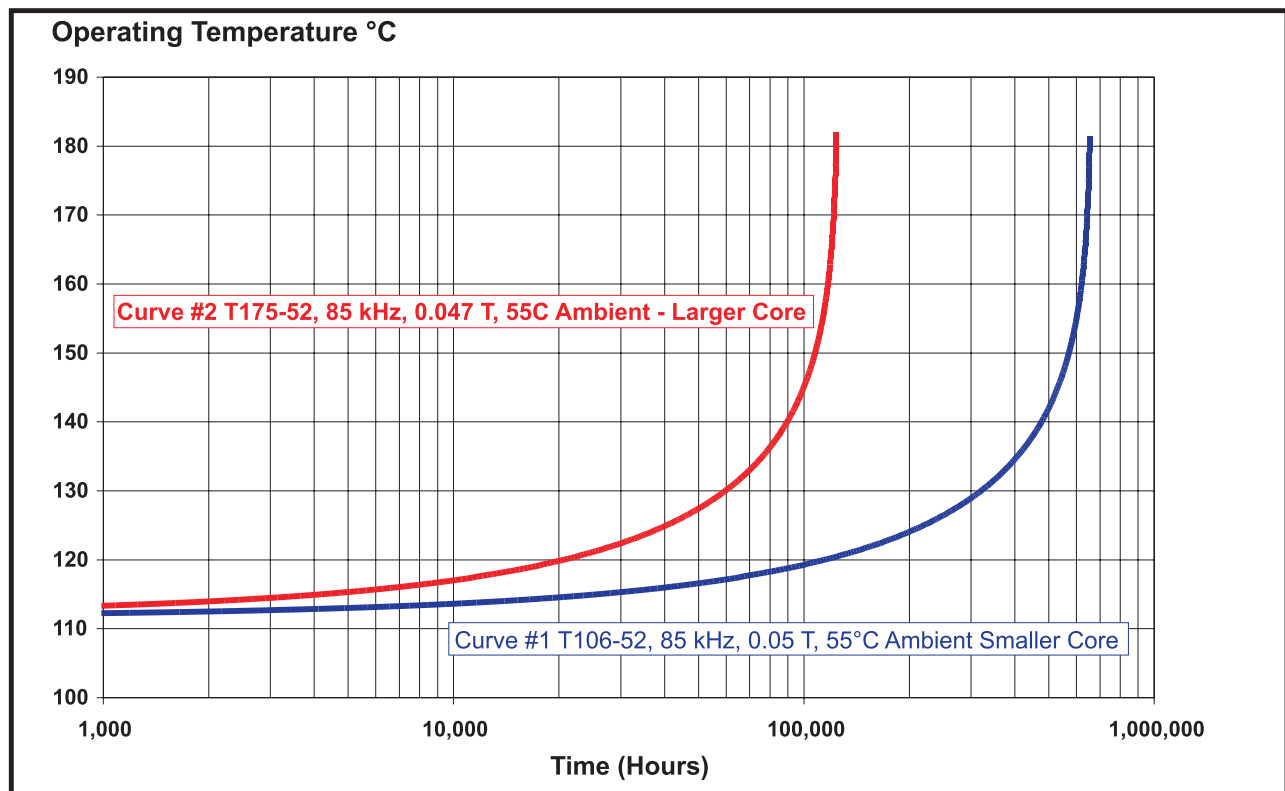


Figure 2: Effect of Core Geometry on Thermal Aging

such a substitution is to be made, the thermal aging evaluation must be provided by the new iron powder core vendor.

What is truly dangerous about substituting cores with a vendor that does not provide thermal aging characteristics is that the cores may pass typical incoming evaluations. Inductance and core loss may initially be within specification. Only after the core has been in the field for months or years will the differences in the core's performance become apparent.

Figure 3 shows 3 curves. Curve #1 shows Micrometals part number T184-26 (OD=46.7mm, ID=24.1mm, Ht=18.0mm, Material=Micrometal-26 material) being used under the following conditions:

Reference condition:

| | |
|----------------------|---------------------|
| Ambient Temperature: | 55°C |
| Air Flow: | No forced air |
| Part #: | Micrometals T184-26 |
| Switching Frequency: | 50 kHz |
| Peak AC Flux: | 0.05T |

Curve #2 in Figure 3 shows a core from a competitor that is marketed as equivalent to Micrometals part number T184-26. The core is within dimensional tolerances of the Micrometals part and is color coded to match the Micrometals -26 material color code. While this vendor does not supply specific thermal aging data for their cores, Micrometals developed a thermal aging characteristic for this material based on measured data. Under the same operating conditions, the competitor core initially operated at 20°C higher than the Micrometals T184-26 due to higher initial core loss. When the long term thermal aging is considered, the competitor core would experience thermal runaway in less than 1 year, while the Micrometals core would still not be in thermal runaway after 40 years.

Curve #3 in Figure 3 shows the aging prediction for the competitor's core after the ambient temperature has been lowered by 20°C to achieve the same initial operating temperature. Even in a significantly lower ambient temperature, the competitor's core will still be in thermal runaway in less than one tenth the time of the Micrometals core.

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Morning Theory

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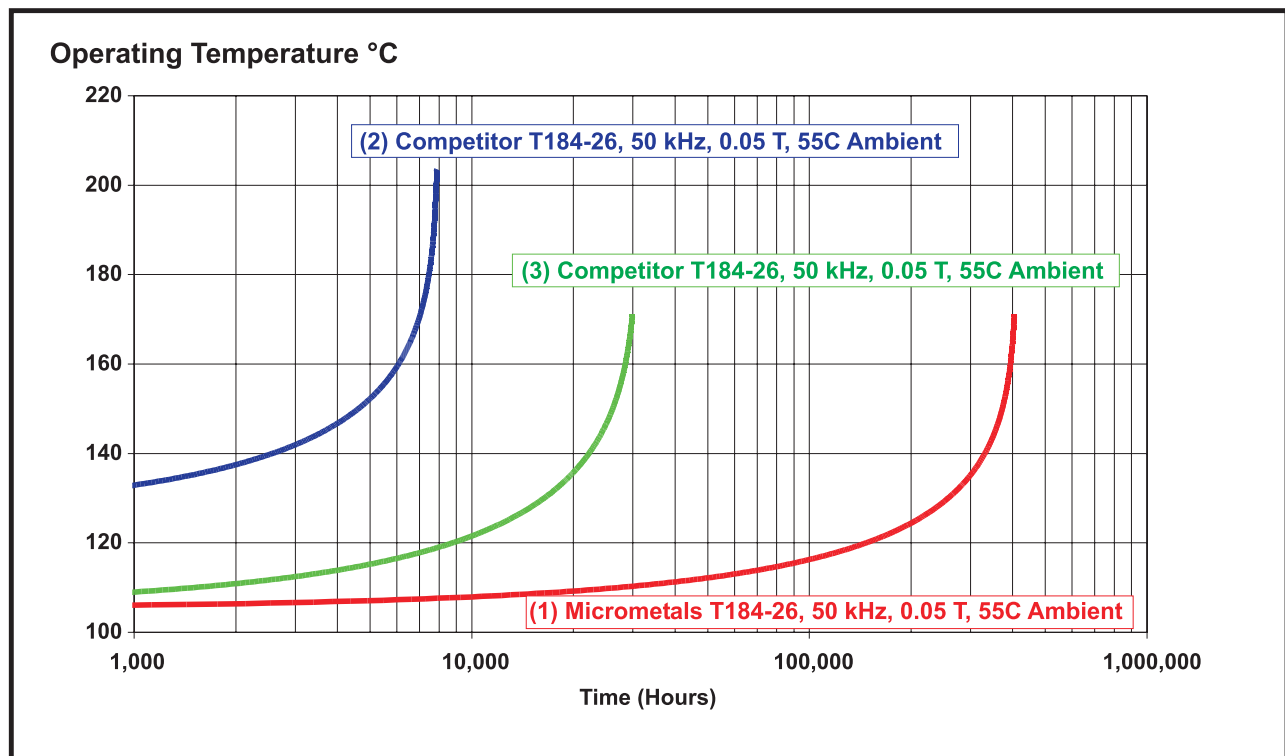


Figure 3: Effect of Different Manufacturers on Thermal Aging

Conclusions

Iron powder cores are an attractive design solution for many applications due to their wide range of properties and low cost. It is very important, however, for today's design engineers to be aware of thermal aging of iron powder cores. Designs that operate above 75°C should be evaluated for thermal aging. The manufacturer of the core should be consulted for an assessment of how their cores will thermally age in a particular design.

An iron powder core that goes into thermal runaway can lead to catastrophic field failures and costly recalls. This can be prevented by addressing thermal aging during the design stage and ensuring that only approved sources of iron powder cores are used when the designs are brought into manufacturing.

Micrometals has provided engineers with design software that will show the expected lifetime of Micrometals cores in their designs. This tool can be used to prevent designs that will experience thermal aging during the required lifetime of the design.