Using IHLP’s in Automotive Applications

Introduction

Most innovation in automobiles is driven by electronics and these innovations are becoming a steadily growing portion of automotive production costs. There is an industry push to reduce size, increase dc-to-dc converter switching frequency and power density. Add to this; harsh environments and strict qualification procedures mean designers have a difficult job ahead of them.

There are several technology drivers in the automotive industry such as passenger comfort and safety as well as environmental considerations. All of this requires expanding electronics in decreasing available space. Vishay’s low-profile, surface-mounted, fully shielded IHLP composite inductors were designed to address this issue. The IHLP was created for, among other things, two major applications: EMI filtering for the high power line and energy storage for high frequency dc-to-dc converters.

To meet the requested PC board real estate, available height and power densities the designers require a low profile, high current fully shielded power inductor. The IHLP series of inductors from Vishay meets these needs and has been used in numerous automotive applications since 2002.

IHLP Basics

The IHLP inductor is constructed using a wound copper coil that is ultra-sonic welded to a lead frame. Iron powder combined with an epoxy binder is then pressed around the inductor coil, giving the inductor its final shape or footprint. Fig. 1 illustrates how the IHLP inductor is constructed.

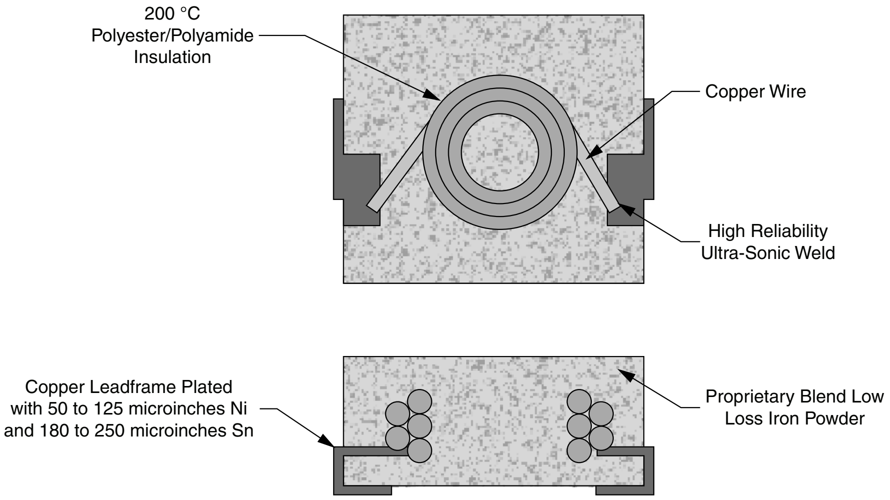

Figure 1.

The enameled copper winding inside of the IHLP inductor is isolated and can withstand operating temperatures up to 200 °C.

The powder materials used in the IHLP series deliver stable performance under worstcase overload conditions up to 125 °C operating temperature. The operating temperature is defined as the self-heating temperature of the inductor plus ambient temperature. At present, the IHLP has a maximum operating temperature of 125 °C and are qualified according to AEC-Q200. The IHLP can be operated above 125 °C provided the effects of thermal aging are taken into consideration (see below). Vishay is developing an IHLP material that will operate at 155 °C with no aging and this product will be announced when it is available.

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EMI Filtering

An EMI (Electro Magnetic Interference) filter is a specific type of filter used to reduce electro magnetic interference generated by power electronic equipment. This is an important circuit element as EMI will negatively impact other electronic devices within the automobile. Important characteristics for EMI filter designers are attenuation, insertion loss, voltage drop, and the number of filter sections required. The IHLP’s advantage of lower DCR for its package size will be of great assistance to the filter designer as the above concerns of filter design are all, in one form or another, linked to DCR. If multiple filter sections are required the voltage drop savings will be further compounded.

A key requirement of automotive electronics is avoiding or eliminating EMI and electromagnetic radiation and its negative effects on electrical circuitry without excessive reduction in operating voltages. Current often has to travel over cables of appreciable length to the car’s electrical control units (ECUs) so voltage drop in the cable and the EMI filter can be a concern. An EMI filter and cable with combined resistance of 200 mΩ with 10 A of current would cause a voltage drop of 2 V.

DC/DC Converters

A Discussion on rated current

The most prevalent use for the IHLP style of inductor is in non-isolated dc-to-dc converters. In today’s and tomorrow’s power supplies, power handling capability and size are becoming the driving forces. To meet these requirements designers need to increase the operating frequency. Increasing frequency allows the use of smaller components, but the downside to this strategy is an increase in losses.

Dc-to-dc converters are also being asked to operate at higher ambient temperatures. This in turn requires the inductor to operate at the higher temperature in addition to its own temperature rise incurred due to power losses. It is known that iron powder exhibits the effects of aging at higher temperatures in the form of increased core losses. These losses must be accounted for during the design process in order for a composite inductor to be used at component temperatures in excess of 125 °C. The effects of thermal aging can be minimized by simply limiting the maximum inductor temperature to 125 °C or less. This does not mean, however, they cannot be used in excess of 125 °C, all that is required is proper care in the design process.

Thermal Aging

Based on experimental observations by Vishay, it has been determined that aging, in the form of increased core loss, occurs above 125 °C as a function of time and temperature. The higher the temperature above 125 °C, the shorter time it takes for the core loss to increase to a given level. This aging occurs due to the fact that the electrical insulation between powder particles becomes more conductive. Testing has shown that a pure iron component with no binder or insulation has roughly the same resistivity as an aged fully insulated part with binders. The IHLP product line exhibits a plateau (see Fig. 2) after 2500 h to 9000 h in core loss at higher temperatures. The higher the temperature, the quicker this plateau is reached.

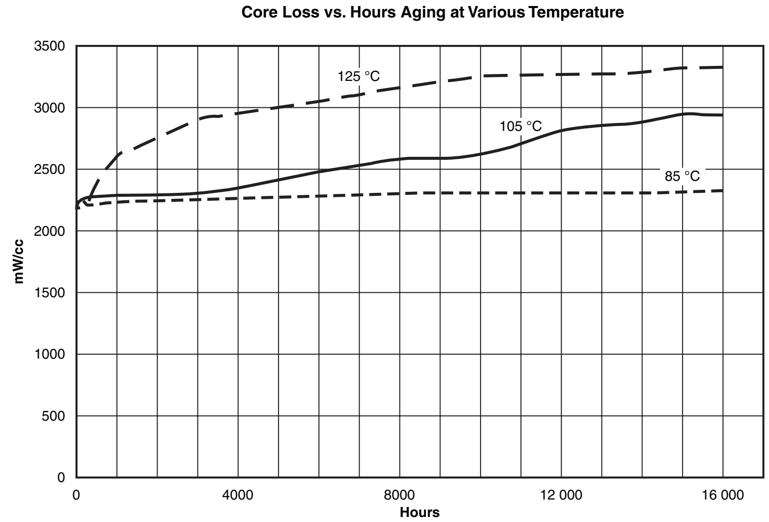

Figure 2.

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Thermal aging discussion

There is evidence that suggests that the insulating coating of the iron particles reacts in the presence of oxygen at elevated temperatures reducing its resistivity resulting in increased eddy currents and ultimately higher core losses.

Once this coating is used up, the degradation of the insulation layers ceases and the core loss stabilizes resulting in the "plateau" in the aging curve shown in Fig 2.

There has been much industry concern over the representation illustrated in Fig. 3 which would indicate a thermal runaway condition in a power inductor. In order for a thermal runaway condition to occur, an inductor application would have to be dominated by core loss. Vishay recommends that the core losses be roughly a third of the total losses, and that the combined ambient temperature, and temperature rise of the inductor due to core loss and copper loss be less than 125 °C. If operation in excess of 125 °C is required it is recommended that core losses be kept to 1/6 of total losses to mitigate the effects of thermal aging. Vishay further suggests that the total temperature rise of the inductor due to all loss factors (core loss, copper loss, proximity loss, skin effect) be kept to 40 °C or less regardless of the ambient temperature. If the core losses are a fraction of the total loss of inductor, any increases in core loss due to aging will have only a small effect on the final operating temperature of the inductor. To determine IHLP core losses please reference Vishay document number 34250, Selecting IHLP Composite Inductors for Non-Isolated Converters Utilizing Vishay's Application Sheet [2].

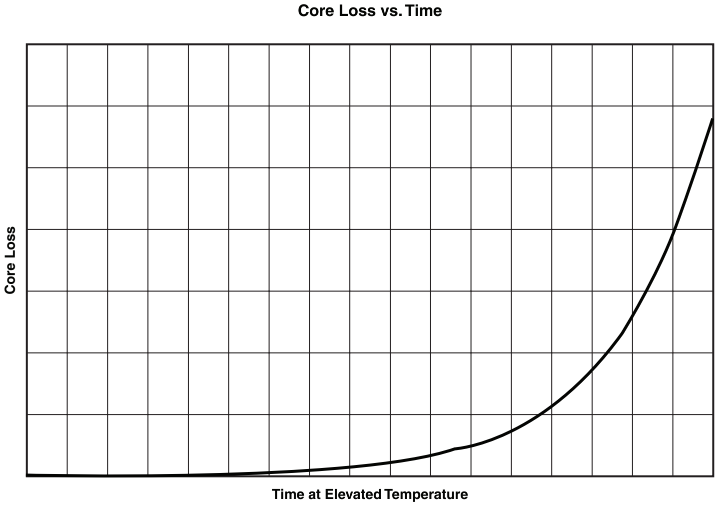

Figure 3.

As stated earlier, a thermal runaway condition will occur if the core loss is the dominant loss factor and only if the impedance of the inductor in the circuit controls the current limit in the inductor. As the core loss increases the effective inductance and energy storage ($1/2LI^2$) decreases. The scenario for thermal runaway would occur if the pulse width of the converter is increased in order to maintain regulation under load, this will increase current in the inductor. More current, more heat, etc. until runaway occurs.

However, if the circuit has current limiting on the switching transistor, then the regulator will shut down and thermal runaway will not occur. The inductor will still not support the energy storage due to aging, but a catastrophic heating will not occur if the current is limited. In addition, the losses of the powdered iron material cannot increase exponentially forever as the graph suggests. The losses can only increase to a point equivalent to that of the powdered iron since the magnetic characteristics of the base iron are not affected at these temperatures.

PCB Trace Size Concerns

In 1956 the National Bureau of Standards attempted to quantify the current carrying capacity of printed circuit board (PCB) traces. Their attempt fell short in being able to predict the temperature rise of PCB traces consistently. It was replaced in 1973 by MILSTD-275, since superseded in 1999 by IPC-2221, which also fell short in its attempt to set accurate standards for PCB trace design. While these documents were somewhat successful in predicting current carrying capacity they did not address surface mount components that utilize the PCB traces as heatsinks.

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Designers are increasingly being asked to design smaller and cheaper power supplies to meet market demand. To accomplish this task designers are often skimping on printed circuit board trace width, thickness or both. The end result of this practice is overheated parts, reduced efficiency, costly redesigns or product recalls. Contributing to the problem are power losses from surface mount components, in this case inductors, using the PCB traces as heatsinks.

Each power inductor manufacturer provides "Rated Current" numbers for their products. These ratings are usually based on temperature rise or saturation. In most cases, manufactures have adopted temperature rise as the deciding factor for rated current. Many times, the rated current is the amount of DC current that results in a temperature rise of 40 °C due to the DCR or self heating due to the resistance of the copper coil in the inductor. This current rating is performed under DC conditions only and does not take into account the self heating due to core losses. This is a topic for another paper. However, the rated current numbers do assume that the termination pads and copper traces on the designer's printed circuit board are adequate to carry the rated current and to carry away the heat produced by the copper winding. Many designers do not take into account the amount of copper necessary to handle the high currents that flow into the inductor and will experience more heat rise is indicated by the manufacturer's datasheet. While there are many factors that will affect a printed circuit board's ability to transmit heat, guidelines have been established to insure proper trace width to handle high currents.

TABLE 1 - RECOMMENDED EXTERNAL TRACE (1) CARRYING CAPACITY BASED ON TEMP. RISE

Temperature Rise	30 °C			40 °C			50 °C			60 °C			70 °C		
Trace Thickness (mm)	0.0175	0.035	0.07	0.0175	0.035	0.07	0.0175	0.035	0.07	0.0175	0.035	0.07	0.0175	0.035	0.07
Trace Width (mm)	Maximum Current (A)														
0.250	0.6	0.8	1.2	0.7	0.9	1.4	0.7	1.0	1.5	0.8	1.1	1.6	0.8	1.2	1.8
0.500	1.0	1.4	2.1	1.1	1.6	2.4	1.3	1.8	2.6	1.4	2.0	2.8	1.5	2.1	3.0
0.750	1.4	2.0	2.9	1.6	2.3	3.3	1.7	2.5	3.6	1.9	2.7	3.9	2.0	2.9	4.2
1.000	1.7	2.5	3.6	2.0	2.8	4.1	2.2	3.1	4.5	2.4	3.4	4.9	2.5	3.6	5.3
1.250	2.1	3.0	4.3	2.3	3.4	4.9	2.6	3.7	5.4	2.8	4.1	5.9	3.0	4.4	6.3
1.500	2.4	3.4	5.0	2.7	3.9	5.6	3.0	4.3	6.2	3.2	4.7	6.8	3.5	5.0	7.3
1.750	2.7	3.9	5.6	3.1	4.4	6.4	3.4	4.9	7.0	3.7	5.3	7.6	3.9	5.7	8.2
2.000	3.0	4.3	6.2	3.4	4.9	7.1	3.8	5.4	7.8	4.1	5.9	8.5	4.4	6.3	9.1
2.250	3.3	4.7	6.8	3.7	5.4	7.8	4.1	6.0	8.6	4.5	6.5	9.3	4.8	6.9	10.0
2.500	3.6	5.1	7.4	4.1	5.9	8.4	4.5	6.5	9.3	4.9	7.0	10.1	5.2	7.5	10.9
2.750	3.8	5.5	8.0	4.4	6.3	9.1	4.8	7.0	10.1	5.2	7.6	10.9	5.6	8.1	11.7
3.000	4.1	5.9	8.6	4.7	6.8	9.8	5.2	7.5	10.8	5.6	8.1	11.7	6.0	8.7	12.5
3.250	4.4	6.3	9.1	5.0	7.2	10.4	5.5	8.0	11.5	6.0	8.6	12.5	6.4	9.3	13.4
3.500	4.6	6.7	9.7	5.3	7.6	11.0	5.8	8.4	12.2	6.3	9.2	13.2	6.8	9.8	14.2
3.750	4.9	7.1	10.2	5.6	8.1	11.6	6.2	8.9	12.9	6.7	9.7	14.0	7.2	10.4	15.0
4.000	5.2	7.5	10.8	5.9	8.5	12.2	6.5	9.4	13.5	7.0	10.2	14.7	7.6	10.9	15.8
4.250	5.4	7.8	11.3	6.2	8.9	12.8	6.8	9.8	14.2	7.4	10.7	15.4	7.9	11.4	16.5
4.500	5.7	8.2	11.8	6.4	9.3	13.4	7.1	10.3	14.9	7.7	11.2	16.1	8.3	12.0	17.3
4.750	5.9	8.5	12.3	6.7	9.7	14.0	7.4	10.7	15.5	8.1	11.7	16.8	8.7	12.5	18.0
5.000	6.2	8.9	12.8	7.0	10.1	14.6	7.7	11.2	16.1	8.4	12.1	17.5	9.0	13.0	18.8

Note

1. Derate maximum current by 50 % for internal traces

Table 1 summarizes the recommended maximum current for a PCB trace based on trace width and thickness. These recommendations were developed using the following model: (1)

$$I = 3.188 \times \Delta T^{0.45} \times W^{0.79} \times Th^{0.53} \qquad (1)$$

The model uses ΔT in °C and width (W) and thickness (Th) in millimeters. The 3.188 is a constant based on a common thermodynamics model that has been converted to SI units.

If these guidelines for circuit board traces are followed, the designer should experience thermal performance very similar to that listed on the IHLP datasheet.

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Moving Forward

As the electronics content increases in automobiles and more systems become electrical instead of mechanical, large amounts of current need to be properly regulated and filtered. The advantages of the IHLP including its low DCR and high current handling capacity make it an excellent choice for dc-to-dc converters or EMI filters. With proper design techniques the IHLP style of inductor can safely be used by and be of great benefit to automotive electronic designers now and in the future.

References

[1] John Vandersleen, "Printed Wiring Board Manufacturing Advances", Power Electronics Technology, September 2004, pp. 40 to 43.

[2] Selecting IHLP Composite Inductors for Non-Isolated Converters Utilizing Vishay's Application Sheet, available on the Vishay Intertechnology, Inc. website: http://www.vishay.com