Review of Non-Standard Applications in Soft Ferrites

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Putting Maxwell's Laws to Work for You

Abstract:

Ferrite materials are used in numerous non-standard applications. The versatility of ferrites in its range of magnetic properties and forming techniques gives engineers a magnetic solution to complex problems. This paper will show by example the range of physical size and dynamic response available to solve engineering problems.

Introduction:

The use of ferrites for non standard applications is often assumed to be an expensive and impractical solution. Often the engineer is unable to find a catalogue core suitable to his requirement and either abandons the project or compromises his design without taking advantage of the machinability of ferrite to create a custom core. Several examples will be presented in this paper which demonstrate the versatility of ferrites as solutions to technical problems and the advantage of these solutions. When considering ferrites for non standard applications the engineer is often concerned with the perceived cost, tooling and lead time, and determines that a solution using ferrites is not available.

We will show by example that ferrites are readily available and by the use of standard ceramic grinding techniques can easily be formed into complex geometries. The example presented will cover ferrites used in instrumentation to measure thickness, as shielding and as probes. Examples where they are used as coupling devices for signal and power, and examples where they are used as pulse shaping elements and for commutation. We will attempt in each example to follow a standard format of first stating the problem, then showing how ferrite were implement to arrive at a working solution. A non rigorous use of key equations will demonstrate what key properties were employed and how other mechanical or physical properties assisted in the solution.

Problems:

A) Problem. Create a high voltage, fast rise time voltage pulse.
Solution. Use coaxial cable and ferrite cores.

In a distributed system an inductor on a coax cable will look like an open circuit to a fast pulse. If a fast rise time pulse, $t_r < 100$ nsec, is applied to a transmission line with an inductor inserted over the center conductor, then at t = 0 the voltage developed at the inductor is

$V_1 = 2*Vin$

The current flow through the toroid is $V*e^{\wedge}-(Z_0/L\ t)/Z_0$

Z_0 = impedance of the transmission line
Z_1 = impedance of the inductor

If one assume Z_1 to be ∞ at t = 0, changing to 0 at t+ϵ then the voltage applied to the next segment of transmission line is 2*Vin if the inductance Z_1 saturates. NiZn ferrite is a good compromise for this requirement. It has sufficient perm, 1500, 10^8 ohm cm resistivity, adequate saturation.

The applied pulse has characteristics as follows:
A) Amplitude = 10,000 volts, current of 200 amps.
B) Rise time of 100 nsec.
C) Pulse width of 1000 nsec.

Given these conditions one can size the ferrite toroid. To offer an infinite Z to the rise time for 100 nsec the core needs an area defined by

v = - N A dB/dt * 10^-8

For rise time of 100 nsec: v = (10^4 / 10^-7) * t

given Bsat = 3500 gauss
then A = 10^19 * t * $\Delta t/\Delta B$
A = 30 cm

The toroid is assumed to saturate with 5 Oersteds

If the path length = π * Dia = .4 * π I / H
Dia = 20 cm
Then the OD = 25 cm, I.D. = 15 cm, T = 3.3 cm
and L = 5 uH

Because a NiZn material was used where the DC resistivity is high one can assume the leakage currents through the ferrite core are low simplifying the insulations requirements.

The several properties of ferrite used in this example are:

1) Easy to saturate.
2) High permeability to a fast pulse.
3) Availability of core; ie, easy to fabricate.
4) High DC resistivity, > 10^8 Ω cm.

B) Problem. Limits the turn on current in a switch.
Solution. Insert a ferrite toroid in the anode circuit.

During the turn on of a semiconductor or vacuum tube switch, the device has a period of time where the element is operating in the linear mode and the power loss is excessive. If a ferrite core is put in the anode circuit then the core will reduce the current allowing the element to saturate with reduced losses. As shown in the example above a ferrite core will look like an open circuit to a fast rise time pulse. In this example the core needs to be sized to achieve a delay before saturation sufficient for the switch to reach a full on state. Both MnZn and NiZn materials can be used either alone or together to achieve the necessary current flow delay. To design a core the example above can be used as a guide.

The key equations are:

$$v = - N A \, dB/dt * 10^{-8}$$
$$H = .4 \pi N I / L$$

The ferrite characteristics used to accomplish this are:
For MnZn materials one uses the high saturation properties Bsat > 4500 gauss, permeability > 2500 and easy saturation < 5 Oersteds. The NiZn material offers response to the fastest transient as well as assisting the current delay. The requirements of the switch will determine which material will offer the best protection and improved power loss efficiency.

C) Problem. Measure the thickness of an abrasive material during manufacturing to control thickness.
Solution. Use a variable reluctance transformer fabricated from ferrite material.

In the manufacture of paper it is necessary to monitor the thickness, range from 0.002 to 0.005", and through feedback use this information to control the process to maintain thickness to tolerances of 0.000005". The abrasive nature of paper, traveling at 30 feet per second, with the probe moving across the paper, 10' wide, subjects the probe to a high wear rate. The probe must sandwich the paper and not damage it. The ambient temperature can vary from room temperature to > 175 °C.

The effective permeability of a gapped core is given by the equation

$$\mu_e = 1 / (1/\mu + lg / lm)$$

If μ = 5000, lm = 1.5", lg = 0.004 it can be observed that

$$\mu_e \approx lm / lg$$

Since μ_e is inversely proportional to the gap this can be used to control the resonance frequency of an oscillator. From this point it is a trivial solution to convert this information into a controlling element.

If a hot isostatically pressed ferrite, porosity free, is selected which is capable of a high degree of polishing, one can take advantage of the ferrites hardness for endurance to the abrasive environment. Surfaces finishes with these ferrites can be obtained to better than 50 Å. Both MnZn and NiZn can be used. The NiZn offers better wear and strength properties with a reduction in sensitivity associated with lower permeability.

The variations in permeability with temperature will introduce an error. This can be minimized by selection of a ferrite with a low variation in initial permeability with temperature. Selection of an material with as high a permeability as possible, consistent with the abrasive nature of the paper and temperature extremes will minimize these effects.

The properties of the ferrites used in these probes include the high density achieved by hot isostatically pressing the material for improved wear, the high initial permeability of MnZn and NiZn material for extreme conditions.

D) Problem. Couple to a rotating platform from a stationary platform.
Solution. Use a ferrite rotating transformer.

In the measurement of a continuous extrusion of plastic pipe for carrying gas, it is necessary to rotate a piezoelectric probe around the pipe while pulsing the probe with a 200 volt pulse and detecting the return echo, 20 mv. The time delay of the echo allows the determination of the pipe thickness. The transformer will be mounted in a steel housing. The transformer must act as a shield, couple signals of wide dynamic range and containing a high frequency components. The OD of the rotating shaft is 8", ID of the housing is 8.25". NiZn ferrite with a 1500 initial permeability, 3500 gauss is a potential solution. The mechanical stiffness will limits the radial displacement to < 0.002".

There are three concerns with this problems:

1) Saturation with the 200 volt, 10usec wide, 1 μsec rise time pulse.
2) Bandwidth limitations on the return echo.
3) Mechanical stability in an industrial environment.

For the flux level

$$v = - N * A \, dB/dt * 10^{-8}$$
$$N * A = 50 \text{ turns cm}^2$$

For inductance

$$L = 2 * N^2 * \mu_e * h * \ln(OD/ID) * 10^{-9}$$

$$\mu_e = 1 / (1/\mu + lg/lm)$$

For easy first order approximation the rotating transformer could be looked at as a toroid with an OD = the circumference around the cross section of the core, the ID = to the inside circumference, the length = π * diameter of the rotor. If the axial length of the transformer is 1.000", winding window of 0.500" X 0.030". OD of the rotor = 8.25". In the equation for L, h = π * 8.125", OD = 1" +1" + 0.25" + 0.25", ID = 0.5" + 0.5" + 0.060" + 0.060".

Therefore

$$\text{Area} = A = \pi/4 * (8.09^2 - 8.00^2) = 9.3 \text{ cm}^2$$
$$N = 6$$
$$\mu_e = 1 / (0.006 + 0.010 / 2.5) = 100$$
$$L = 375 \, \mu H$$

This value of L would yield a Z at 1 MHZ of approximately 2500 Ohms. This Z is the effect of the mutual inductance and is sufficient to accommodate the dynamic impedance of the transducer and not load the drive and sense amplifier. The leakage inductance was measured and was less than 10 μH. Testing confirmed that this value would not limit the required high frequency response.

The solution to this problem took advantage of the wide dynamic response of ferrite, the ease of high precision forming by grinding and the mechanical stability of ferrite in an industrial environment. The mechanical solution required a core structure machined to 0.001 tolerance, with a gap of 0.005 to accommodate the vibration associated with the mechanical system.

Conclusion:

It was the intention of the author to show by example the wide range of applications in which ferrites have been used . It is not an attempt to be inclusive of all potential applications, but to stimulate the engineer to seek solutions to technical problems using ferrite materials in innovative ways. In all cases the example above are reflective of real technical problems where the required ferrite were fabricated by machining. In some cases the tolerances were held to 0.0001". In most cases the cost of implementation of the solution was insignificant when one considered the information obtained or the protection offered in the real world.