The Dynamics of Orthogonal Coil Conditioning of VTA Magnets

By Barry Beasley:

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In an attempt to ease the task of replicating the VTA work of the late Floyd Sweet, I decided that as a first step, a better understanding of the dynamics of the orthogonal conditioning process was desirable.

The Past

To begin to understand the thought processes employed by the late Floyd Sweet, it is necessary to review the past, in particular the area of magnetics research carried out over last 40 years or so, in related subjects.

Transductors (Variable Inductors)

Transductors are generally considered to be a forgotten technology. The general concept is simple, namely the means of altering the inductance of a cored coil and therefore the ability of the magnetic material to support flux, by virtue of DC bias field applied either to a parallel or orthogonal winding.

This is how transductors operate..

For that portion of the material whose magnetic poles are parallel with the DC bias field, the flux moves along the hysteresis curve towards saturation. As the flux approaches saturation, the permeability of the material decreases but the AC component of the flux becomes non-symmetrical, which is how saturable cores are used for frequency multipliers.
For that portion of the material whose magnetic poles are 90 degrees to the DC bias field, the poles become progressively saturated, causing the hysteresis curve to shear, or rather flatten, which causes the permeability to decrease. The AC component of the flux remains symmetrical.

Some Transductor Terms…

Incremental Current:
The DC bias current flowing through the inductor which causes an inductance drop of 5% from the initial zero DC bias inductance value. This current level indicates where the inductance can be expected to drop significantly if the DC bias current is increased further. This applies mostly to ferrite cores in lieu of powdered iron. Powdered iron cores exhibit "soft" saturation characteristics. This means their inductance drop from higher DC levels is much more gradual than ferrite cores. The rate at which the inductance will drop is also a function of the core shape, i.e. air gap.

Saturation Current:
The DC bias current flowing through the inductor which causes the inductance to drop by a specified amount from the initial zero DC bias inductance value. Common specified inductance drop percentages include 10% and 20%. It is useful to use the 10% inductance drop value for ferrite cores and 20% for powdered iron cores in energy storage applications.
The cause of the inductance to drop due to the DC bias current is related to the magnetic properties of the core. The core, and some of the space around the core, can only store a given amount of magnetic ~ density. Beyond the maximum flux density point, the permeability of the core is reduced. Thus, the inductance is caused to drop. Core saturation does not apply to 'air-core' inductors.

Normal Permeability:
The ratio of the normal induction to the corresponding magnetizing force.
In the cgs system, the flux density in a vacuum is numerically equal to the magnetizing force and, consequently, the magnetic permeability is numerically equal to the ratio of the flux density to the magnetizing force. Thus:
$\mu = B/H$
Note: In a non-isotropic (anisotropic) medium the permeability is a function of the orientation of the medium, since, in general, the magnetizing force and the magnetic flux are not parallel.

Incremental Permeability:
The ratio of change in magnetic flux density to change in magnetic field (magnetizing force).
μ_{inc} = (1/μo)DB/DH in MKSA units
μ_{inc} = DB/DH in CGS units
The magnetic field variations are small or “incremental” and can be in addition to a steady (DC) bias field. For magnetic powder core data, “permeability” is incremental permeability unless otherwise noted. Because of the distributed air gap in powder cores, the initial permeability and incremental permeability, without bias, are essentially the same.

With small parallel bias, μ_{inc} decreases with increasing orthogonal bias. At higher parallel bias, μ_{inc} increases from an initial value to a peak value and then decreases. Behaviour of magnetic material under an AC exciting field while simultaneously under the action of a DC bias field may be mathematically modelled.

In this the permeability along the direction of the field H_a is:

$$\mu(H_0, H_a) = \frac{\mu(0, H_a)}{\sqrt{1 + \left(\frac{H_0}{H_a}\right)^2}}$$

where H_o is the orthogonal field strength and H_a is the applied field strength along the direction that is measured.

Initial Permeability:
The limit of incremental permeability as a changing unbiased magnetizing force approaches zero. Note: Because of the distributed gap in powder cores, the initial permeability and incremental permeability without bias are essentially the same.

Orthogonal magnetization in soft magnetic material:

Some of the effects of orthogonal magnetization in soft magnetic material are described in the U.S. patent No 4,210,859 titled Inductive Device Having Orthogonal Windings, Meretsky et al July 1, 1980.

I decided to replicate one of the hardware configurations necessary to observe the effects described in the above mentioned patent. A design utilising a ferrite pot core was chosen for ease of manufacture and repeatability, the main aim being to achieve flux levels that would partially saturate the core material, so better to observe the changes of permeability when orthogonal fields were applied.

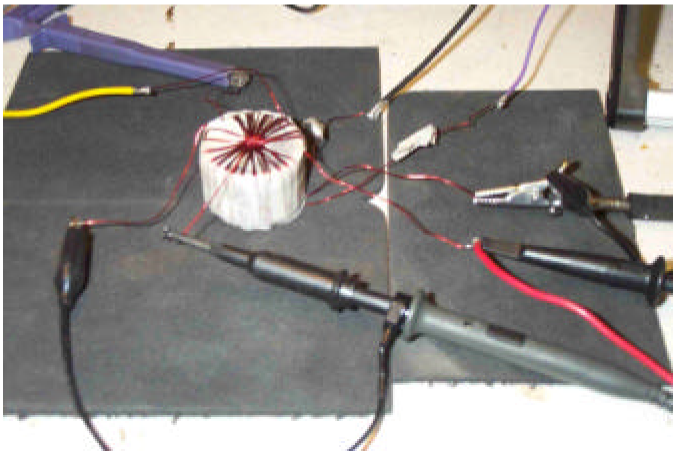

Fig 1. Pot Core With Two Sets of Orthogonal Windings

Fig1 shows a 30mm diameter pot core, wound with two sets of windings on the enclosed bobbin, designated ‘B’ windings and two sets of windings at 90 degrees though the center hole and around the outside of the core designated ‘A’ windings. During all of the tests the applied signal is 40V Pk-Pk @20KHz (approx), unless otherwise noted. Input and output windings consist of 30 turns 1mm wire. In the initial setup, DC is applied to both orthogonal windings from two isolated and de-coupled sources. As the DC windings have only 30 turns of 1mm wire, to achieve partial saturation, 2A was applied. With more turns on the winding, current could be reduced. DC has to be applied to both orthogonal windings for any appreciable coupling of the input signal to the output. Typically electrostatic coupling is less than 2%.

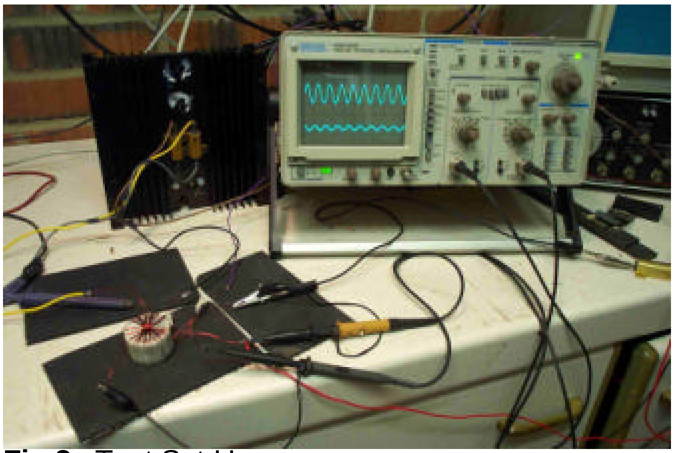

Fig 2. Test Set-Up

Fig 2 shows the test set-up. The DC to each orthogonal winding is supplied via two 22 ohm current limiting resistors mounted on the large heat-sink. The DC lines are also de-coupled with inductors at the respective power supplies, to ensure that any AC signal that may be present on the windings, is not cross coupled in any way. The input ‘B’ winding and output ‘A’ winding amplitudes are monitored on the scope.

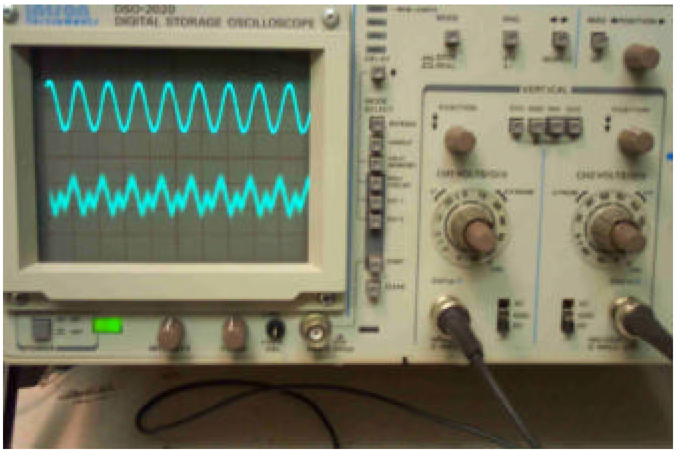

Fig 3. No A & No B DC Field. 40Vp-p In 20mVp-p Out

Fig 3 shows the small amplitude residual electrostatic coupling present between the orthogonal input (top trace) and output (bottom trace) windings.

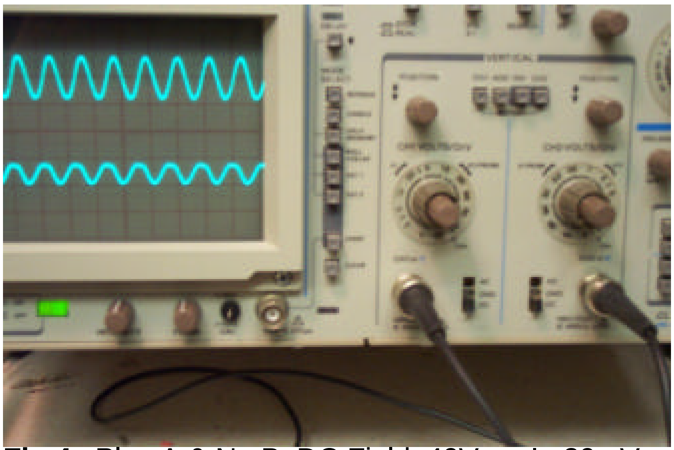

Fig 4. Plus A & No B DC Field. 40Vp-p In 20mVp-p Out

Fig 4 shows only a very small amplitude signal at the output (bottom trace), with only the 'A' DC field (60A/T) present.

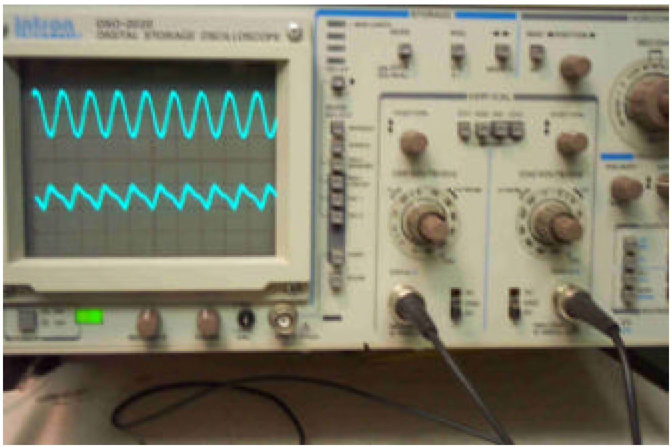

Fig 5. No A & Plus B DC Field. 40Vp-p In 500mVp-p Out

Fig 5 shows a slightly larger but still small amplitude signal at the output (bottom trace), with only the 'B' DC field (60A/T) present.

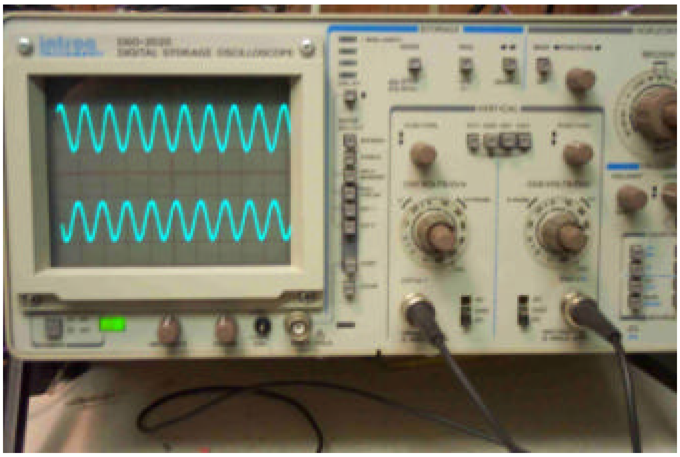

Fig 6. Plus A & Plus B DC Field. 40Vp-p In 38Vp-p Out

Fig 6 shows the coupling of almost all the input signal (top trace) to the output winding (bottom trace), when both 'A' & 'B' fields (60A/T) are applied. **This is quite remarkable and appears to contradict conventional theory that orthogonal fields do not couple.** Most engineer's are not aware of the Meretsky patent and I have found that those that I have directed towards the patent, are noticeably silent after reading it.
The output level is proportional to the DC bias through both 'A' and 'B' windings, although the 'B' winding has greater amplitude control for the same range of DC.

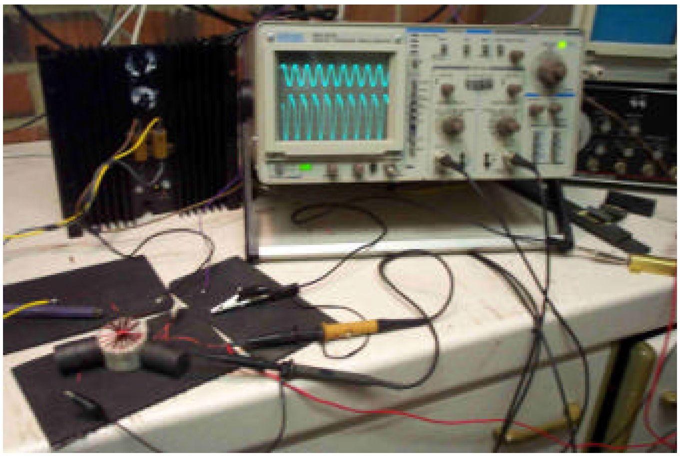

Fig 7. Plus B DC field, 'A' Field Provided by Permanent Magnets

Fig 7 shows 500mV of output from the 'A' winding, with the 'A' field provided by external magnets (bottom trace). In this case because of the construction of the pot core, it is not possible to apply the flux from the magnets into the circular 'A' winding plane, however enough flux was coupled in a radial direction to illustrate that permanent magnets could provide the biasing field substituting the DC field supplied via the orthogonal coils. The distortion to the wave form is caused by the uneven distribution of flux from the magnet.

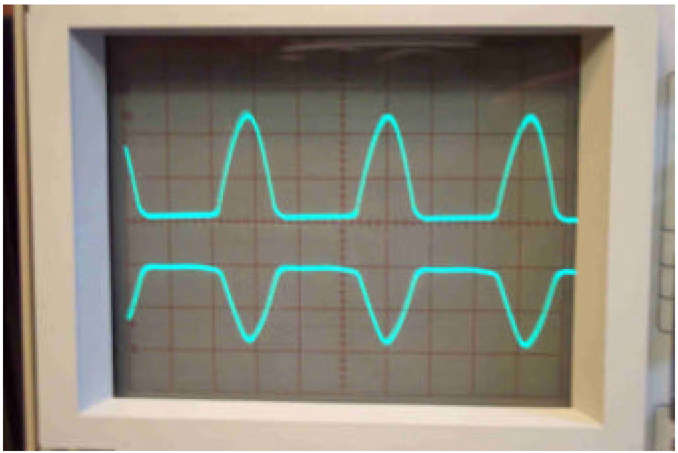

Fig 8. 2KHz Half Sine Wave Coupled to Orthogonal Coil

Fig 8 shows a half sine wave applied to a ‘B’ winding (top trace). It is not necessary to apply DC bias to the second ‘B’ winding, because as the half sine wave only traverses the 1st & 2nd quadrants, the signal effectively provides it’s own bias to allow the half sine wave to couple to the ‘A’ winding. The second ‘A’ winding still needs a DC bias to allow coupling. Note that the signal induced in the ‘A’ winding is in anti-phase (bottom trace).

If a second half sine wave is applied to an ‘A’ winding, once again with no DC bias on the second ‘A’ winding, this signal is also cross-coupled to the ‘B’ winding. If the A & B windings have the same polarity then the signal undergoes partial cancellation due to both cross coupled components being anti-phase to the applied signal. If one winding polarity is reversed then the signal is reinforced as then the cross-coupled components will be in phase with the applied signal.

Due to the architecture of the pot core, it is not possible to apply a third orthogonal field however, from the data presented in the Meretsky patent, it is clear that a block core will support three orthogonal fields, and a the third field may be used to modulate the other two, assuming a DC bias field is present in the third plane.

Conclusion:
Contrary to popular belief, it is possible to couple signals between orthogonal coils as demonstrated in this document. The exact mechanism of coupling is still unknown, but it is likely to be a second order effect i.e. permeability modulation. The next logical step is to try and verify if any of the effects observable in soft magnetic material described above , were observable in hard magnetic material. In the meantime, some postulation follows..

Orthogonal magnetization in hard (permanent) magnetic material:

Anisotropy:
In a non-isotropic (anisotropic) permanent magnetic materials the permeability is a function of the orientation of the material, therefore resistance to magnetization in directions orthogonal to the easy axis may be extremely high. For example, the coercive force required to completely magnetize a particular ceramic ferrite in the preferred direction is about 10,000 G. The same material when exposed to a field of 20,000 G in an orthogonal direction may not effect it at all and some materials reportedly require 100,000 G to magnetize it in that direction.
It is postulated that this changes when simultaneous magnetization of the material in two or three orthogonal planes occurs. The applied magnetizing force in one plane alters the permeability of the magnetic material in the orthogonal planes, therefore when a magnetizing

force is applied to two orthogonal planes, the flux levels generated are much higher in each plane respectively, for a given magnetizing force, compared to the same magnetizing force applied in one plane. The ferrite pot core setup demonstrates that the two applied half sine waves add constructively if the phase of one winding is reversed.

In the case of a block anisotropic magnet that is magnetized through the easy axis, the remanence provides the bias field, required for the 60Hz sine wave to modulate the two orthogonal planes which at the same time have magnetizing pulses (half sine waves) applied via coils.

It is postulated that permeability of the other two planes is modulated during the magnetization pulse period, by the 60Hz sine wave. Timing is important because the conditions where all three fields couple, is only present during the magnetization pulse period, after which the bias field provided by the remanence in the anisotropic plane disappears or is highly modified by the orthogonal magnetization. A full cycle of the 60Hz sine wave has to be completed during the magnetization pulse, as this is the only time it can influence the orthogonal fields. Sweet found that the 60Hz sine wave peak (voltage) or zero crossing (current), has to coincide with the start of the magnetizing pulse. The application of the three signals simultaneously, allows the formation of a highly stressed three dimensional domain pattern related to the 60Hz signal applied waveform.
It is this pattern that we know can be stimulated by a small external ‘tickler’ signal at the ‘programmed’ frequency, to produce large flux variations external to the magnetic block. This is the point at which over unity becomes possible.

I hope this document will prove to be stimulating and help sponsor further activity within the group. I believe the research now needs to be extended to determine why and how certain magnetic materials will support domain patterns.