A NOTE ON LOSSES IN 'EVANS'-TYPE TRANSFORMER CORES

The well known 'transformer equation' relates the peak magnetic flux density in a ferromagnetic core to the cross-sectional area of that core, the number of turns in the exciting coil and the voltage and frequency of the supply:

$$E_{rms} = (2\pi/\sqrt{2}) \,.\, f \,.\, N \,.\, B_{max} \,.\, A \quad \ldots\ldots\ldots\ldots \quad (1)$$

where E is the applied (sinusoidal) voltage (V)
F is the supply frequency (Hz)
N is the number of turns in the exciting winding
B_{max} is the peak core flux density (T) and
A is the net cross-sectional area of the core (m^2)

Note: $2\pi/\sqrt{2} = 4.44$

In a single phase transformer of the 'core'-type, the magnetic flux density is reasonably uniform across the cross-section of the core, and the total core losses may be estimated by multiplying the specific core loss (W/kg) at the design peak flux density (calculated from the above equation) by the mass of the core.

This is not the case, however, for 'Evans'-type cores, of the type shown in Figure 1:

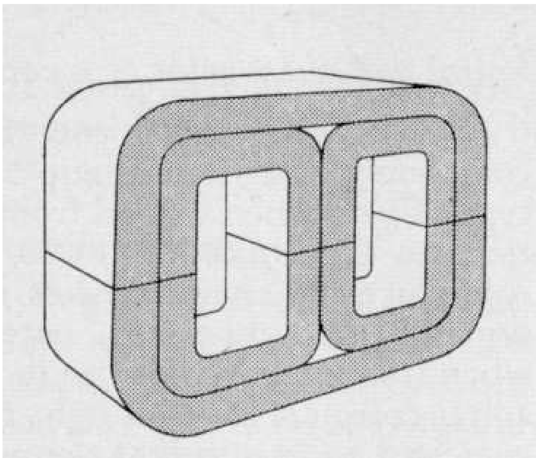

Figure 1: An 'Evans'-type core

The magnetic conditions in the Evans core are most easily understood by considering the 'delta'-core as shown in Figure 2:

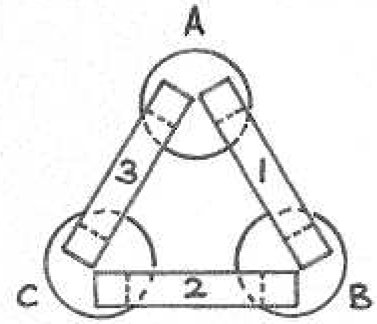

Figure 2: A 'delta'-core

If the core arrangement as shown above is provided with three identical exciting coils and these are connected to a balanced three phase voltage supply, the individual core loops each experience alternating fluxes, the phasor sums of which satisfy the transformer equation under each coil. These equations must, however be *simultaneously* satisfied for each of the three coils, and this is only possible if the fluxes in the two cores which link a given coil are out of phase with each other by 60°. These two flux components then add, in phasor fashion, to provide the net core flux required to satisfy the transformer equation for each coil.

Because of this phase difference, the flux magnitudes in the individual core loops must each be more than 50% of the net effective flux linking each of the coils.

Figure 3, below, shows how the fluxes in the individual core loops add to provide the necessary flux linking each of the exciting coils.

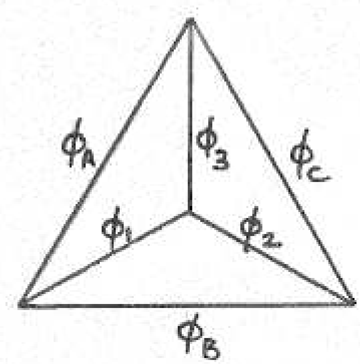

Figure 3: Flux phasor diagram

Analysis of the relations shown in Figure 3 shows that an individual core carries flux which is 1/√3 = 57.7% of the net flux required to link any given coil.

The flux density in all loops is thus 57.7/50 = 115.4% of the flux density which might be expected from the transformer equation.

Thus if the peak flux density required in the cores of a transformer of the type shown in Figure 2 is not to exceed (say) 1.7 T, then the peak flux density substituted into equation 1 for each coil must be 1.7/1.154 = 1.47 T.

The Evans core is very similar to the delta-core arrangement discussed above: It requires only that two of the three loops be smaller in mean path length, and that these then be fitted inside the third, larger loop. The result is an Evans core, (as shown in Figure 1) having three 'legs' of equal cross-sectional area.

Because of the phase difference between the two flux components which combine to produce the net flux linking each winding, and the fact that each of these components has a peak value which is up to 15.4% greater than that which would be expected in a corresponding single-phase transformer, the core losses incurred are those associated with this increased peak flux density. Thus although the peak flux density used in the transformer equation (1) might be 1.5 T, the core will exhibit losses associated with the significantly higher value of 1.7 T. Note that core losses are not linearly related to peak flux density, (at a fixed frequency) but increase more rapidly, according to the Steinmetz exponent, in the range 1.6 to 1.8. To calculate the expected core losses, the actual exponent for the particular core material (or manufacturer's data) should be used.

The Evans core does, in fact, allow a little 'mixing' of the fluxes from the individual loops, but establishment of any flux across the individual lamination strips is difficult because of the high reluctance of the effective 'air-gaps' between individual laminations. The above analysis represents, therefore, a 'worst case'.

In practice, the distribution of flux between the 3 component loops may be determined by winding three 'search coils' as shown in Figure 4.

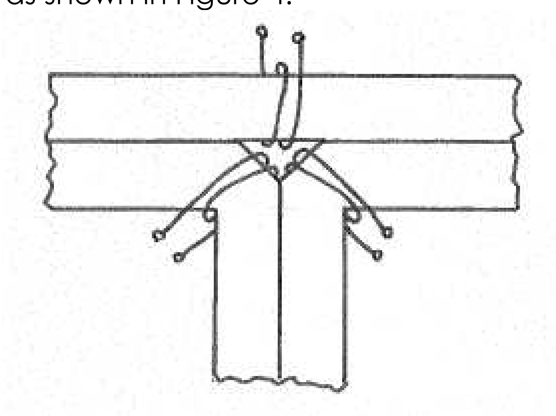

Figure 4: The use of search coils to determine the magnitudes and phase relations between individual Evans core loops.

A voltmeter connected across such a winding allows the actual peak flux density to be determined (by substituting into the transformer equation as above) and the phase difference between the fluxes may be observed and measured using an oscilloscope, with the signals from search coils displayed against each other.

Note that the phenomenon described above is a function of the shape and geometry of the core only and is not related to the quality of the material with which the core is made, nor by the process with which that material is formed into the 'Evans' shape. The phenomenon is therefore found in cores of this type manufactured by, for example, the 'C-core' or 'Unicore' processes.