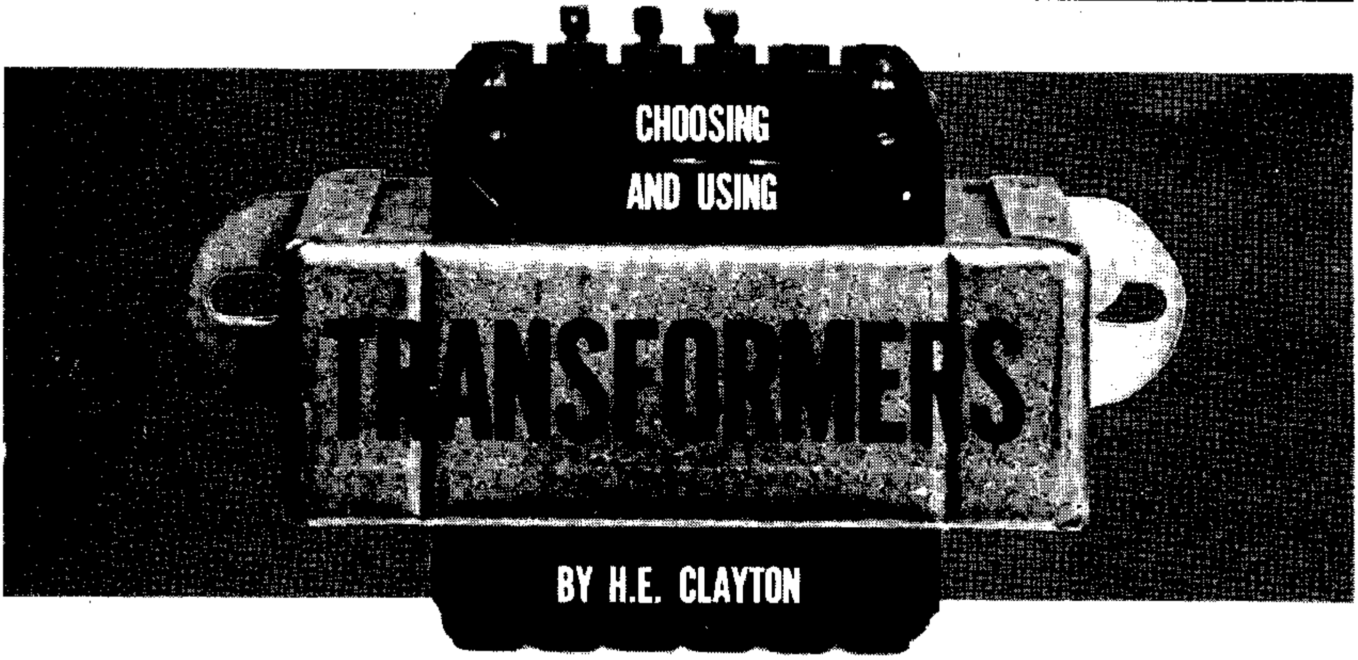
A mains transformer is often the single most expensive item in a project — H. E. Clayton of Reading Windings takes a close look at this often neglected item.



TRANSFORMERS ARE USED to increase or decrease either an AC voltage or an AC current level.

All transformers change both AC current and voltage levels simultaneously, but no transformer significantly changes power levels, as the input power equals the output power plus losses which are in general, negligible. Transformers can also be used to transform impedance from one level (in the primary circuit) to another level in the secondary circuit, the impedance transfer ratio being the square of the transformer turns ratio.

It is often possible to use transformers in the opposite mode to that for which they were designed e.g. by feeding into the secondary of a step down transformer and using it to step up in voltage. This will, however, usually give an output voltage below the rated value because the turns ratio is normally made less than the rated transformation ratio to compensate for voltage drops in the windings.

Power transformers can usually be operated at frequencies higher than that for which they were designed, e.g. a 50Hz transformer can be used at 60Hz, but not vice versa.

What we want is . . .

Before deciding on a transformer for a particular application, it is helpful to list one's requirements and to have some idea of what options there are it is hoped that the following outline will help.

RMS input voltages and supply frequency: In addition to the nominal input voltage the maximum value to which this can rise should also be considered. Most transformers will operate satisfactorily at about 6% overvoltage for short periods of time but if it expected to exceed this figure it is advisable to increase the rated input voltage. Primary windings can be tapped to cater for several voltages but this adds considerably to the cost of the transformer and may detract from performance. Twin series — parallel windings on the other hand, although adding a little to the cost, do not substantially interfere with efficiency as all of the winding is in use for both series and parallel connections. They are however limited to dual input voltage applications where one voltage is twice the other e.g. 240/120V.

Output Currents and Voltages: Unless otherwise agreed, the nominal or rated output voltage is that at full load output current based on resistive load. Again, several voltages can be provided by tapping and, unlike the primary taps, several secondary tappings can be used simultaneously to supply a number of loads. If, however, there is a significant difference between the load currents at different tappings, it may be preferable to have separate windings.

NB: The information above is the minimum which must be decided by the user, all the following requirements may remain unspecified unless circumstances demand otherwise, always remembering that special features can add considerably to a transformer's cost.

Regulation (usually Maximum Value): The regulation is defined as the difference between a secondary terminal voltage on open circuit and the secondary terminal voltage at rated full load current.

Maximum permissible Temperature rise: This is often decided by the manufacturer rather than the user as it may depend on the materials used. Higher standard temperature rises are associated with lower ambient temperatures.

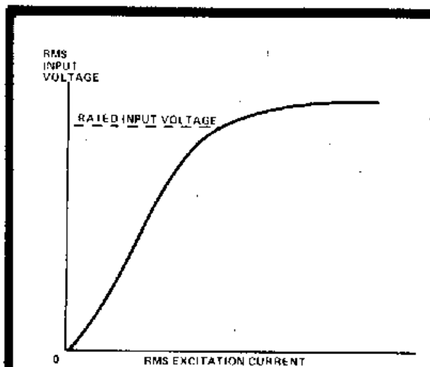


Fig. 1. Plot of excitation currents vs. RMS input voltage for typical transformer. The transformer should not be operated for long periods above the 'knee' of this curve.

Input Current (or Excitation or Magnetising Current): The no load input characteristic is shaped as in Fig. 1 and care should be taken not to use the transformer for long periods with voltages much higher than the "knee" of the curve.

Electrical requirements: Limitations to distortion of secondary waveform, any special phasing requirements etc.

Insulation requirements: The basic standard requirement is for a 2kV RMS test between the input and output windings and between any winding and the core if accessible.

Impregnation etc: Transformers without hygroscopic materials (those that absorb moisture) are often varnish dipped while those using absorbent materials such as paper are varnish impregnated. Both of these processes are effective for minimising lamination vibration and sealing against ingress of moisture.

Dimensions: Any limiting dimensions and/or fixing centres.

Construction: Some of the common alternatives are described below.

What Core

Interleaved laminations are widely used for small power transformers, the most common shape being the no-waste 'E' and 'I' in which the 'I's are cut from the 'E's (see Fig. 2) and the coils assembled over the centre limb (shell type construction). These are available in .50mm and .355mm thickness in various grades of hot rolled silicon iron and in 0.355 mm grain-orientated silicon iron.

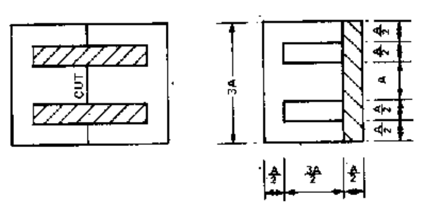


Fig. 2. No-waste E and I construction of transformer laminations.

Toroids and 'C' cores are made of 0.355 and 0.10 mm thickness, the thicker material being used in the 50-60Hz devices. Toroids have a highly efficient magnetic circuit and by virtue of their circular shape, low leakage flux. They are sometimes chosen because they can be used to make a "low profile" i.e. low height transformer.

Because the cost of toroidal transformers can be three times that of an E and I laminated transformer, a compromise between the two which is sometimes used for low profile units uses U and I laminations with the coils on the long limbs of the 'U'. (Core type construction).

Winding Things Up

Moulded bobbins are widely used for smaller transformers. They have the advantage that they can be wound on high speed machines. Insulation thickness between windings and core and between windings can be assured. The winding space factor (ratio of area occupied by active copper and total winding area) is high and terminal tags can be mounted on the bobbin cheeks. Certain bobbins may be fitted with shrouds encasing the windings and giving good mechanical and electrical protection.

Ending It All

The cheapest terminations are solder tags on the bobbin cheeks. For applications where solder connections are not convenient terminal blocks can be mounted on the transformer. For larger transformers terminal panels with turret lugs or bolted connections are used.

Mounting Up

Mounting brackets are available for the range of standard no-waste E and I laminations. They take the form of 'U' clamps with two hole fixing which are crimpled on to the smaller sizes (up to about 50VA) and flanged and frames secured to the larger transformers with core bolts and providing four fixing slots on each of their four sides (universal mounting). At the small end of the range (up to about 5VA) pin terminations can be used for PCB mounting.

Electrical Performance

In its simplest form a transformer consists of an input and output winding magnetically coupled with an iron core. The windings represent an impedance in series with the load and the core can be considered to be an impedance shunting the load. The winding impedances cause voltage drops proportional to the load current and a watts (copper) loss proportional to the square of the load current. The core impedance does not directly produce a voltage drop but is associated with an energy (iron) loss approximately proportional to the square of the volts per turn for a fixed supply frequency. The total losses (copper and iron) determine the operating temperature rise of the transformer which is usually the most important factor limiting the use of the transformer.

Watts A VA

Although the transformer total losses depend on both voltage and current, they are independent of the phase factor. For this reason transformers are rated in maximum VA and not in watts although with resistive loads VA = watts.

Transformer windings also have "self inductance" which can be thought of as a reactance in series with the winding resistance and the load and is usually referred to as the "leakage reactance". This does not usually effect the performance of small power transformers (below about 100 VA size) particularly when used with resistive loads.

Physical Performance

As transformers increase in VA rating and physical size, the working flux density and the winding current density are reduced, but even over a relatively large range of sizes, the variation is small enough to assume that they are constant.

With this premise, it is interesting to consider the effect on various parameters of change in physical size for the same overall shape.

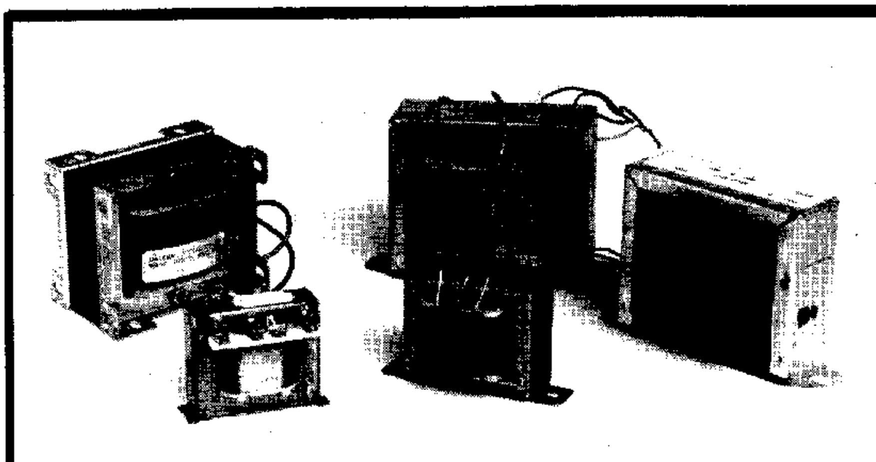


Fig. 3. A collection of some of the more common transformer types. Some of the wide variety of constructions and terminations available can be seen in this photograph.

TRANSFORMERS

We can show that

1) The regulation of small transformers with resistive loads decreases in inverse ratio to the increase in any linear dimension and
2) The reactive voltage drop increases while the resistive drop decreases linearly with dimensions.

Figure 4 shows the relationship between transformer VA rating, volume (or weight) and regulations. The volume here is the length × width × height, not the displacement. This is based on mains transformers using E and I no waste laminations and operating at 50 Hz.

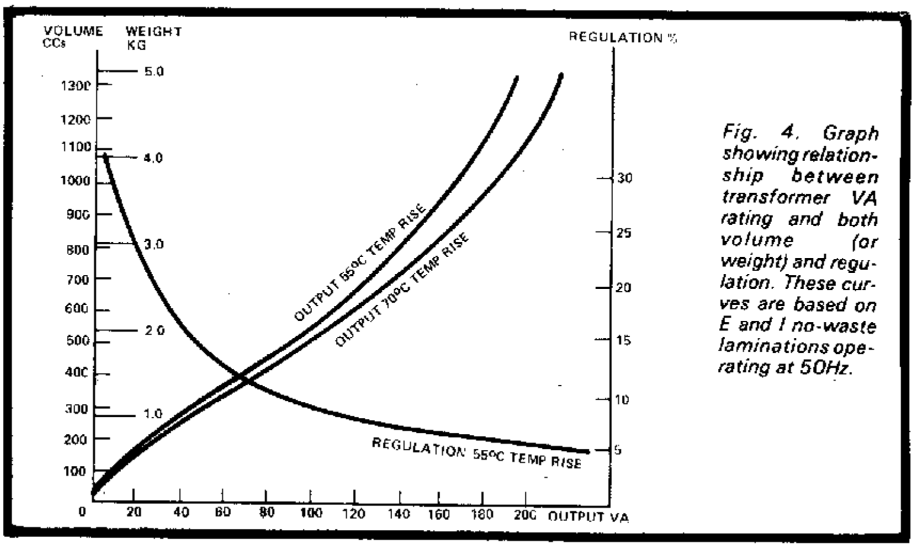


Fig. 4. Graph showing relationship between transformer VA rating and both volume (or weight) and regulation. These curves are based on E and I no-waste laminations operating at 50Hz.

It is often possible to increase the output current of a power transformer beyond the rated value if one can accept a temperature rise higher than the designed value. Overloading the transformer in this way will, however, cause the output voltage to fall because of the increased voltage drops in the windings.

Trying Time

The following tests can be used to establish basic transformer characteristics.

Turns Ratio: Apply a known voltage, less than the rated value, to the primary winding and measure the secondary voltage. Care should be taken, especially with transformers below about 20VA rating, that the instrument used does not impose a significant load on the transformer.

Excitation Characteristic Connect as in Fig. 5 and apply the rated input voltage to primary terminals and measure input current and voltage.

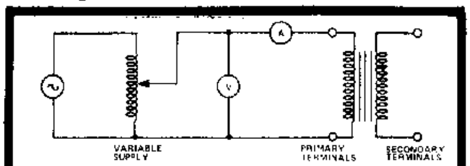


Fig. 5. Connections for the excitation or open-circuit test. The rated input voltage is applied to the primary and the excitation current is shown by A.

Winding Resistance Measure the primary and secondary DC winding resistances with a multimeter or Wheatstone bridge.

Phasing. Where windings can be interconnected e.g. with series/parallel designs, it is important to establish the relative polarity of terminations. This can be done by connecting the windings concerned in series, applying an alternating voltage to one and measuring the overall voltage (Fig. 6). If this measured voltage is greater than the applied voltage, then the windings are in phase. Conversely, if the measured voltage represents the difference of the two winding voltages the connection is in anti-phase.

It Takes All Sorts

Transformers Feeding Rectifiers. A common application for small transformers is to supply full wave rectifier circuits including capacitor input filters. The most common are the bridge amd bi-phase circuits shown in Fig. 7.

For the same power rating, the transformer for the bi-phase circuit will be larger than that for the bridge circuit because its secondary produces twice the voltage and carries current during each half cycle only. Ideally the secondary winding for the bi-phase transformer occupies $\sqrt{2}$ times the space of the primary winding. Although transformer cost is higher, rectifier costs are lower for the bi-phase circuit.

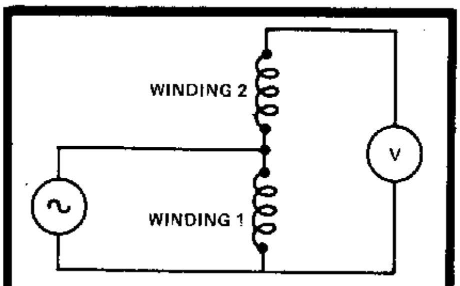


Fig. 6. Connections for the relative polarity test.

The relationship between the average DC voltage and the RMS secondary voltage is complex and is dependent on the smoothing capacitance, the supply frequency, the transformer series impedance and the load impedance. Curves illustrating this and other relevant relationships are published by rectifier manufacturers but neglect the effect of transformer leakage reactance which may be significant on some larger transformers. Because the waveform of the transformer current is very 'peaky' the effective reactive volt drop is greater than may be expected by considering RMS values.

Autotransformers have a single tapped winding to provide both input and output circuits. With transformation ratios near unity, autotransformers can be much smal-

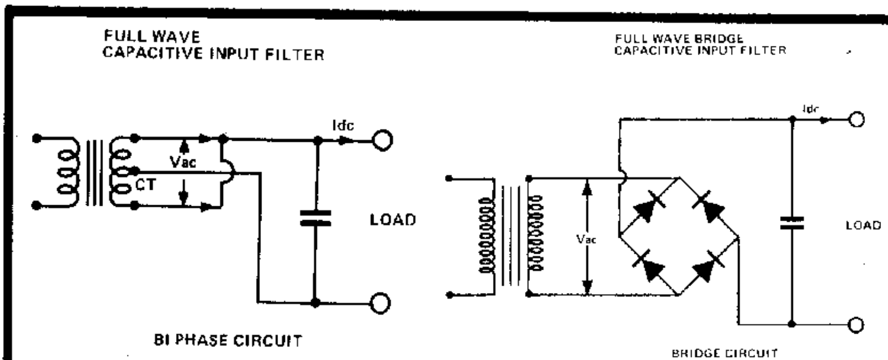


Fig. 7. Two of the most common rectifier circuits for use with capacitive input filters.

ler than similarly rated double-wound transformers

A disadvantage of autotransformers is that there is a direct electrical connection between primary and secondary circuits so that both circuits share a common relationship to earth.

Isolating Transformers usually have a 1:1 transformation ratio and are provided specifically to electrically isolate the secondary circuit from any earth connection in the primary circuit e.g. 'mains' circuits.

Inverter Transformers (e.g. for switched mode power supplies). These usually operate in the kilohertz range of frequencies and are supplied with square wave-form voltages.

High Impedance Transformers are used for a variety of purposes a few of which are mentioned below.

Short-Circuit Proof transformers are designed to continue in operation without damage when the secondary terminals are short-circuited. Small transformers (below about 5VA size) are sometimes made with sufficiently high winding resistances to restrict the short circuit current but with larger transformers an adjacent winding structure is used with an intermediate magnetic shunt. This gives an output characteristic as shown in figure 8 when used with resistive loads.

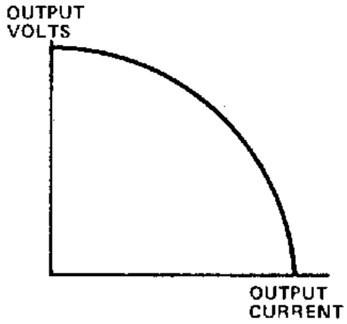


Fig. 8. Relationship between output current and output volts of high reactance transformer with resistive load.

High Frequency Transformers.

The foregoing is concerned with transformers operating only at a constant supply frequency and with sinusoidal waveforms. Transformers used in communication circuits are required to handle a wide range of frequencies and waveforms, although any repetitive waveform can be expressed as a series of sine wave components. Such transformers are often used in an *impedance matching* role. It is well known that to transfer the maximum amount of energy into a load from a voltage source the load impedance should equal the source of impedance.

SCREENING

Stray magnetic fields produced by power transformers can cause hum in high gain amplifiers in the same locality. Screening around the power transformer is not normal because a large percentage of the stray flux, which is emitted in all directions, would strike the screen at right angles and pass through it rather than be diverted. On the other hand input (e.g. microphased transformers are often enclosed in a screen of magnetic material to reduce pick-up).

PRODUCTION METHODS

Coil winding techniques and machinery have improved immensely in recent years. Unfortunately it is not always possible to make the best use of these improvements which are mainly geared to high volume production of standard products. Although some degree of standardisation in small transformers has been achieved equipment designers still expect transformers to be tailor-made, often in small quantities, to their particular electrical and dimensional requirements.

Summarising, before seeking a special transformer, consider first if readily available standard transformers can be used. It will often be cheaper to use two or more standard transformers than one special unit. ●