and secondary currents and potential differences at the same instant, these quantities are connected by the equations

\*\*\*\*<⅛-Rλ+SN⅛ ⅛=SNj^2-R2⅛.

Hence, if *b*1 = *b*2, and if R1*i*1 is negligible in comparison with SN1*db*/*dt* and *i=*0*,* that is, if the secondary circuit is open, then *e*1/*e*2=N1/N2, or the transformation ratio is simply the ratio of the windings. This, however, is not the case if *b*1 and *b*2 have not the same value; in other words, if there is magnetic leakage. If the magnetic leakage can be neglected, then the resultant magnetizing force, and therefore the iron core loss, is constant at all loads. Accordingly, the relation between the primary current (*i*1), the secondary current (*i*2) and the magnetizing current (*i*), or primary current at no load, is given by the equation N1*i*1-N2*i*2 = N1*i*. Then, writing *b* for the instantaneous value of the flux-density in the core, everywhere supposed to be the same, we arrive at the identity

*e*1*i*1=*e*2*i*2+ (R1*i*12+R2*i*2)+S*db*/*dt*(N1*i*1—N2*i*2).

This equation merely expresses the fact that the power put into the transformer at any instant is equal to the power given out on the secondary side together with the power dissipated by the copper losses and the constant iron core loss.

The efficiency of a transformer at any load is the ratio of the mean value, during the period, of the product *e*1*i*1 to that of the product *e*2*i*2. The efficiency of an alternating current transformer is a function of the form of the primary electromotive force curve. Experiment has shown@@l that if a transformer is tested for efficiency on various alternators having electromotive force curves of different forms, the efficiency values found at the same secondary load are not identical, those being highest which belong to the alternator with the most peaked curve of electromotive force, that is, the curve having the largest *form factor.* This is a consequence of the fact that the hysteresis loss in the iron depends upon the manner in which the magnetization (or what here comes to the same thing, the flux-density in the core) is allowed to change. If the primary electromotive force curve has the form of a high peak, or runs up suddenly to a large maximum value, the flux-density curve will be more square-shouldered than when the voltage curve has a lower form factor. The hysteresis loss in the iron is less when the magnetization changes its sign somewhat suddenly than when it does so more gradually. In other words, a diminution in the form factor of the core flux-density curve implies a diminished hysteresis loss. The variation in core loss in transformers when tested on various forms of commercial alternator may amount to as much as 10%. Hence, in recording the results of efficiency tests of alternating current transformers, it is always necessary to specify the form of the curve of primary electromotive force. The power factor of the transformer or ratio of the true power absorption at no load, to the product of the R.M.S. values of the primary current and voltage, and also the secondary drop of the transformer, vary with the form factor of the primary voltage curve, being also both increased by increasing the form factor. Hence there is a slight advantage in working alternating current transformers off an alternator giving a rather peaked or high maximum value electro- motive force curve. This, however is disadvantageous in other ways, as it puts a greater strain upon the insulation of the trans- former and cables. At one time a controversy arose as to the relative merits of closed and open magnetic circuit transformers. It was, however, shown by tests made by Fleming and by Ayrton on Swinburne’s “ Hedgehog ” transformers, having a straight core of iron wires bristling out at each end, that for equal secondary outputs, as regards efficiency, open as compared with closed mag­netic circuit transformers had no advantage, whilst, owing to the smaller power factor and consequent large R.M.S. value of the magnetizing current, the former type had many disadvantages (see Fleming, “ Experimental Researches on Alternate Current Transformers,’’ *Journ. Inst. Elec. Eng.,* 1892).

The discussion of the theory of the transformer is not quite so simple when magnetic leakage is taken into account. In all cases a certain proportion of the magnetic flux linked with the primary circuit is not linked with the secondary circuit, and the difference is called the magnetic leakage. This magnetic leakage constitutes a wasted flux which is non- effective in producing secondary electromotive force. It increases with the secondary current, and can be delineated by a curve on the transformer diagram in the following manner. The curves of primary and secondary electromotive force, or terminal potential difference and current, are determined experimentally, and then two curves are plotted on the same diagram which represent the variation of (*e*1-R1*i*1)/N1 and (*e*2-R2*i*2)/N2; these will represent the time differentials of the total magnetic fluxes S*b*1 and S*b*2 linked respectively with the primary and secondary circuits. The above curves are then progressively integrated, starting from the time

point through which passes the ordinate bisecting the area of each half wave, and the resulting curves plotted to express by their ordinates S*b*1 and S*b*2. A curve is then plotted whose ordinates are the differences S*b*1-S*b*2 and this is the curve of magnetic leakage.

The existence of magnetic leakage can be proved experimentally by a method due to Mordey, by placing a pair of thermometers, one of mercury and the other of alcohol, in the centre of the core aperture. If there is a magnetic leakage, the mercury bulb is heated not only by radiant heat, but by eddy currents set up in the mercury, and its rise is therefore greater than that of the alcohol thermometer. The leakage is also determined by observing the secondary voltage drop between full load and no load, and deducting from it the part due to copper resistance; the remainder is the drop due to leakage. Thus if V2 is the secondary voltage on open circuit, and V21 that when a current A2 is taken out of the transformer, the leakage drop *υ* is given by the equation

*v* = (V2 - V21) -{R2A2+R1A2(N2/N1)2}.

The term in the large bracket expresses the drop in secondary voltage due to the copper resistance of the primary and secondary circuits.

In drawing up a specification for an alternating current trans­former, it is necessary to specify that the maximum secondary drop between full and no load to be allowed shall not exceed a certain value, say 2 % of the no-load secondary voltage ; also that the iron core loss as a percentage of the full secondary output shall not exceed a value, say, of 1 % after six months’ normal work.

In the design of large transformers one of the chief points for attention is the arrangement for dissipating the heat generated in their mass by the copper and iron losses. For every watt expended in the core and circuit, a surface of 3 to 4 sq. in. must be allowed, so that the heat may be dissipated. In large transformers it is usual to employ some means of producing a current of air through the core to ventilate it. In these, called *air-blast transformers,* apertures are left in the core by means of λvhich the cooling air can reach the interior portions. This air is driven through the core by a fan actuated by an alternating current motor, which does not, however, take up power to a greater extent than about ¼ or 1/10% of the full output of the transformer, and well repays the outlay.

In some cases transformers are *oil-insulated,* that is to say, in- cluded in a cast-iron box which is filled in with a heavy insulating oil. For this purpose an oil must be selected free from mineral acids and water: it should be heated to a high temperature before use, and tested for dielectric strength by observing the voltage required to create a spark between metal balls immersed

|  |  |  |  |
| --- | --- | --- | --- |
| Material. | Dielectric strength in kilowatts per centimetre. | Material. | Dielectric strength in kilowatts per centimetre. |
| Glass. | 285 | Lubricating oil | 83 |
| Ebonite | 538 | Linseed oil | 67 |
| Indiarubber | 492 | Cotton-seed oil | 57 |
| Mica | 2000 | Air film -02 cm. |  |
| Micanite | 4000 | thick | 27 |
| American linen paper paraffined | 540 | Air film 1∙6 cm.  thick | 48 |

in it at a distance of 1 millimetre apart. Oils, however, are inferior in dielectric strength or spark-resisting power to solid dielectrics, such as micanite, ebonite, &c., as shown by the above table of dielectric strengths (see T. Gray, *Phys. Rev.,* 1898, p. 199)∙

*Polyphase Transformers* are appliances of similar construction to the single-phase trans­formers already described, but modified so as to enable them to transform two or more phase-related primary alternating currents into similar secondary currents. Thus, a three-phase transformer may be constructed with a core, as shown in fig. 8. Each core leg is surrounded with a primary coil, and these are joined up either in star or delta fashion, and connected to the three or four line wires. The secondary circuits are then connected in a similar fashion to three or four secondary lines. In the case of two- phase transmission with two separate pairs of leads, single-phase transformers may be

@@@i See Dr G. Roessler, *Electrician* (1895), xxxvi. 150; Beeton,

Taylor and Barr, *Journ. Inst. Elec. Eng.* xxv. 474; also J. A. Fleming, *Electrician* (1894), xxxiii. 580.