High Power Audio Transformers

A brief outline of the essential characteristics of high power audio transformers for class B amplification (tubes connected in push-pull fashion with their grid voltages of such value that the anode current is zero when there is no signal) is given here together with a brief description of the units used in the third and fourth stages of radiobroadcast station WLW.

By
J. F. PETERS
FELLOW A.I.E.E.

Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.

HIGH POWER audio transformers do not differ materially from large transformers for converting power at 60 cycles. They differ principally in physical proportions of copper and iron, and require greater care in minimizing the internal distributed capacitance.

Since an audio transformer must operate over a wide range of frequencies and be capable of handling the full output at any one frequency or any combination of frequencies, the problem of obtaining sufficiently low leakage reactance and sufficiently low magnetizing current is the reason for making the proportions different from those of transformers for use at commercial power frequencies. The leakage reactance must be made sufficiently low to give good performance at high frequency, and the magnetizing current must be made sufficiently low to give good performance at the low frequency end of the range. To produce sufficiently low reactance to give satisfactory operation at high frequencies requires using a small number of turns for a given voltage, which results in a magnetic circuit of relatively large cross section. To obtain sufficiently low magnetizing current at low frequencies still further increases the cross section of the magnetic circuit.

These transformers are supplied by tubes that pass current in only one direction, and generally it is not possible to maintain a perfect balance between the 2 tubes supplying the alternate half cycles. This results in the equivalent of a direct current flowing through the primary winding. In order to prevent the unbalance of current from producing a heavy biased magnetic flux in the core, air gaps were provided in the units described later in this paper. Although air gaps in the core increase the alternating magnetizing current, they make it possible to design the core and coils so that the iron does not become saturated and produce harmonics in the magnetizing current.

The effective resistance of the windings of these transformers is low, first, because of the relatively small number of turns resulting in a small number of ampere-turns and therefore low-density leakage magnetic field cutting the conductors; and second, because the conductors are made of small dimensions in the direction at right angles to the flux lines, thus resulting in a low ratio between high frequency resistance and low frequency resistance.

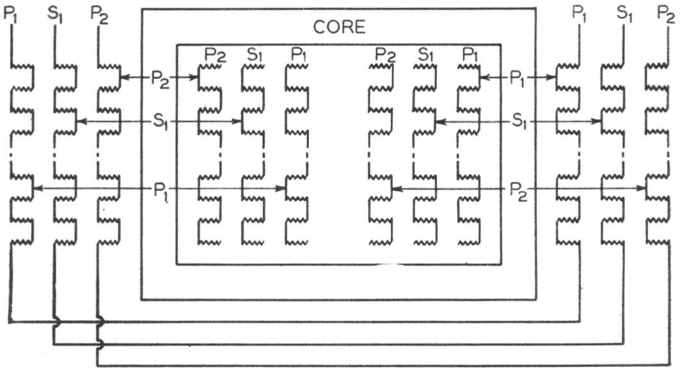

Fig. 1. Schematic diagram showing arrangement of windings in 180 kw fourth stage transformers

P and *S* designate primary and secondary windings, respectively

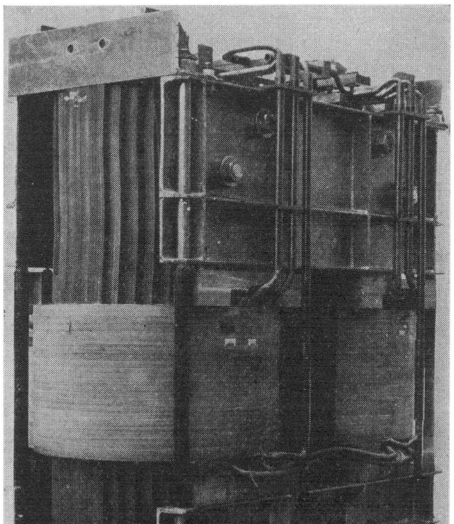

Fig. 2. One of the 180 kw fourth stage transformers out of its case

In producing the total output for radiobroadcast station *WLW*, 4 stages of amplification are required. Only the last 2 stages are described here, the first 2 stages being of quite small output. In determining the maximum permissible reactance for each of the last 2 stages, the total permissible value was determined and it then was proportioned between the 2 units in the manner that would meet most easily the maximum permissible value.

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It is desirable to have the output of the combined amplifying stages reproduce accurately all input frequencies in their relative magnitudes. It is of course not practical to accomplish this. Freedom from distortion is more important in certain parts of the frequency range than in others. Distortion in frequencies below 100 cycles and above 10,000 cycles, if not excessive, does not alter seriously the quality of reproduction. When designing the audio transformers for station *WLW*, the quality desired necessitated limiting the distortion to 5 per cent

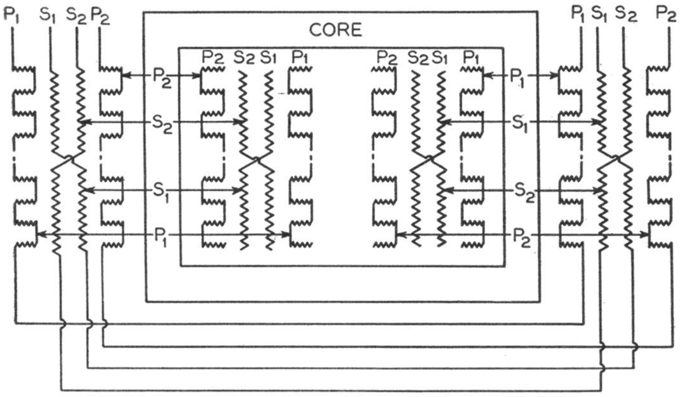

Fig. 3. Schematic diagram showing arrangement of windings in $7^1/_2$ kw third stage transformers

P and *S* designate primary and secondary windings, respectively

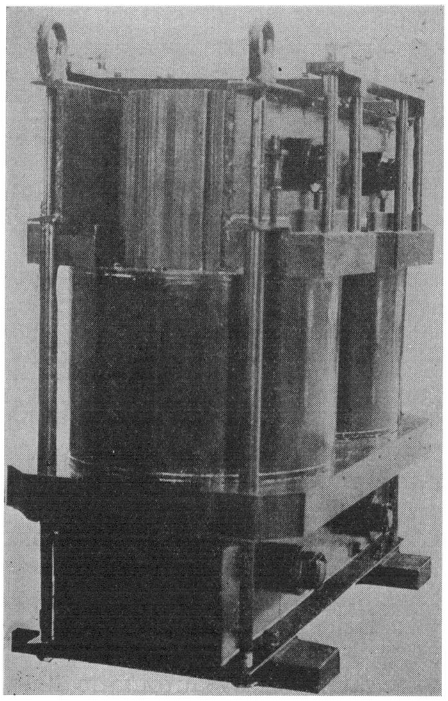

Fig. 4. A complete $7^1/_2$ kw third stage transformer

between 100 and 5,000 cycles and to 22 per cent at 30 cycles and at 10,000 cycles.

The requirements of reproducibility at the high frequency end of the range have more influence on the design of the transformers than do those at the low frequency end. The leakage reactance in the units, which is proportional to frequency, reduces the amplitude of delivered voltage. The load on the transformers is made up of various frequencies superimposed; but by limiting the reactance to such a value that the distortion will not exceed 22 per cent when supplying full load at 10,000 cycles, then when the load consists of a combination of frequencies, none of any appreciable magnitude exceeding 10,000 cycles, the required performance specifications will be met.

The circuits that the transformers feed into have the characteristics of a resistance; therefore, they supply loads at unity power factor. The regulation of the units as calculated for unity power factor at their rated loads then is a measure of their amplitude performance.

The total regulation at 22 per cent at 10,000 cycles was split arbitrarily 13 per cent for the fourth stage and 9 per cent for the third stage. The maximum permissible reactance for the fourth stage then was square root of $[100^2 - (100 - 13)^2]$ or 49 per cent and for the third stage 41 per cent, when delivering the full output of the units at 10,000 cycles. It was found when designing the units that the 49 per cent on the large unit could be appreciably lower, with the result that the combined errors of the 2 stages at 10,000 cycles should not exceed 14 per cent.

Performance tests were not made on individual transformers. Tests on the complete combination of all stages including the transformers and tubes indicated excellent results.

The fourth stage audio transformer for station *WLW* has a nominal rating of 180 kw. This unit has 2 input or primary windings each for 10,200 volts (crest) and one secondary or output winding of 6,000 volts (crest). The arrangement of the windings is indicated by figure 1, and the unit out of its tank is shown in figure 2. Since the 2 primary windings are supplied by separate tubes and therefore receive current on alternate half cycles, it was necessary to interlace these 2 windings symmetrically with the secondary winding. All 3 windings consist of circular pancake coils. Each primary winding consists of a stack of coils on each leg of the transformer as shown by figure 1. The stack of coils having the larger diameter on one leg is connected in series with the stack having the smaller diameter on the other leg, the secondary winding being between the inner and outer primary windings. All 3 windings are made of thin copper ribbon. The individual primary coils consist of 2 turns each, and the secondary coils of 3 turns each.

The assembled unit as shown in figure 2 weighs 27,000 pounds. Some idea of the proportion of copper and iron can be obtained from the fact that of the 27,000 pounds, the magnetic circuit contains 25,700 pounds of sheet steel. This transformer is placed in a boiler-iron tank and operates in oil.

The third stage transformers have a nominal rating of $7^1/_2$ kw each, 2 of these units being required for this stage. Each of these transformers has 2 primary and 2 secondary windings. The 2 primary windings are supplied from separate tubes, and the 2 secondary windings supply the grid voltage to the tubes for the fourth stage. The 2 primary windings receive current in alternate half cycles and must feed into each of the secondary windings; therefore, it was necessary to interlace all 4 windings. The arrangement of the windings is shown by figure 3.

The secondary windings are made up of single-layer helical coils. The coils are broken in the center and cross-connected so that on each leg the average coupling to the primary windings is the same for both windings. The 2 primary windings are made up of pancake coils. One of these units is shown in figure 4. They are air insulated and are not placed in a container. Their total weight is 4,200 pounds each.

Electrical Equipment for Waterworks Systems

The application of supervisory control equipment and electric pump drive to municipal waterworks systems results not only in greatly improved operation, but also in a reduction in operating costs. Existing waterworks systems may be modernized and many improvements secured by the application of various types of electrical equipment. As an illustration of the benefits which may be obtained, a description is given of the modernization of the waterworks system of the city of Pittsburgh, where electric operation of pumps, together with supervisory control, remote metering, and remote indication, are now used.

By
S. A. CANARIIS
MEMBER A.I.E.E.

Bureau of Water, City of Pittsburgh, Pa.

THE first known developments in waterworks engineering are recorded by the ancient nations as the digging of wells for obtaining a supply of water. Probably the most famous of these is Joseph's well in Cairo, Egypt, not only on account of its depth of 297 feet through solid rock, but also because it was pumped by means of endless chain buckets operated by mule power. Later developments brought the building of storage reservoirs and aqueducts, of which there are well preserved examples dating from before the birth of Christ. The Romans had an organized water department in charge of a water commissioner, and developed many phases of waterworks practice which are used today.

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During the middle ages the art declined, until the "Black Death" plague, taking a toll of over 40,000,000 lives, aroused the nations to the necessity of improved sanitary conditions. The developments were extremely slow, and it was not until steam engine driven pumps and cast iron pipe were available for general use, that the modern waterworks systems began to take form. Filtration of water was known and practiced in Europe in the early part of the 19th century, but was not generally accepted in this country until about 1900. Today, practically every urban community in the United States has an adequate supply of water, properly treated, and delivered at satisfactory pressures and in sufficient quantities to meet all demands of health hygiene and fire protection. There are now in this country approximately 9,000 municipally owned and operated water supplies.

Recent Developments

One of the most evident features of private plant modernization is the use of labor saving devices, with the replacement of manually operated equipment by automatically controlled equipment. This move is not only one of economy, but is often essential in order to eliminate errors and faults in operation and production which are results of the uncertainty of manual control. While no claim is made for perfection in machinery, equipment, and control for waterworks purposes, there is no doubt that the equipment which can be purchased today has been developed to such a degree of simplicity, efficiency, reliability, and safety that no water company, be it private or municipal, can afford to overlook the economic advantages offered by its use in modernization of its plants.

An example of this may be found in the development of the centrifugal pump, where improved design has increased the efficiency of certain sizes by more than 20 per cent during the past 10 years. Not only has the initial efficiency been increased, but much progress has been made in maintaining the efficiency for a reasonable length of time. The improved construction of bearings, with use of temperature relays, and also the use of metallic packing for glands, has made continuous attendance unnecessary, and after the initial running-in period, a weekly inspection is all that is required.

Another marked improvement in waterworks equipment is the development of the rotary cone type valve to serve as a combination of check and gate valve. Operated at adjustable speed by electric or hydraulic motor, and controlled hydraulically or electrically, it can operate entirely automatically as required for proper pump and pipe line protection. The development of this type of valve, has, more than any other equipment, made the electrically driven centrifugal pump practical for waterworks use and particularly for automatic station application, as it provides a protection in case of power failure or automatic shut-down which was impossible to obtain with the old type of check valve. That this protection is necessary can be realized when it is considered that the surge wave in pipe may reach veloci-