CONDENSER SHUNT FOR MEASUREMENT OF HIGH-FREQUENCY CURRENTS OF LARGE MAGNITUDE

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CONDENSER SHUNT FOR MEASUREMENT OF HIGH-FREQUENCY CURRENTS OF LARGE MAGNITUDE

By

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Summary—*The necessity for an accurate ammeter for large high-frequency currents is pointed out. A new device consisting of a large condenser in parallel with a small condenser, and the latter carrying the current to a small thermo-couple ammeter, is described.*

A device of this nature can be made very accurate; in fact, comparable in accuracy to any available standards.

The construction of the device includes provisions for reducing and restricting the electrostatic and electromagnetic field, due to large current, the reduction of distributed inductance and capacity, and a provision to prevent the resonance effect of high harmonics of the operating current. Provisions are also made for locating the measuring instrument at a distance from the circuit. Large ratings are possible by connecting a number of condenser units in parallel.

THE use of large broadcasting stations and other continuous-wave, high-power installations has created a demand for accurate means of measuring high-frequency current of large magnitude.

The methods so far in use are all limited in one particular or another. The use of the hot-wire expansion type instruments is not feasible for values above 10 amperes, as the size of heating element becomes excessively large and the skin effect does not allow the subdivision of hot wire into parallel elements.

The direct thermocouple type has been used with satisfactory results up to currents of 100 amperes, but the heating element of the higher ranges becomes bulky and expensive to build on account of the large-sized conductors and careful workmanship required. Also the skin effect becomes appreciable at the higher frequencies.

An iron core transformer for reducing the high-frequency current so that it can be applied directly to a small instrument gives satisfactory results for frequencies up to 500 kc. For higher frequencies, the heating of the iron parts of the transformer becomes quite appreciable and is the greatest drawback. At 2,000 kc. and above, it is difficult to use such a transformer; the heating of parts, the influence of stray fields, and the distributed capacity of windings become quite objectionable.

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This article describes a novel arrangement which will permit the limits of operation to be extended as far as the present art of radio transmission requires.

The advantage of the new condenser type of ammeter for large currents lies in its accuracy and simplicity, combined with

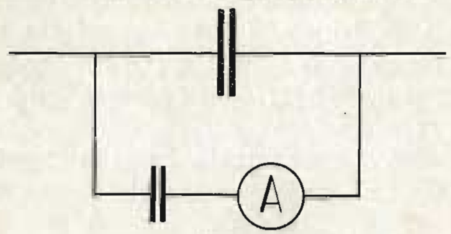

Fig. 1

its comparatively low cost, even for the highest of frequencies.

Fig. 1 illustrates the method by which currents of large magnitude and high frequency can be satisfactorily measured. It consists in general of two condensers in parallel; a large one

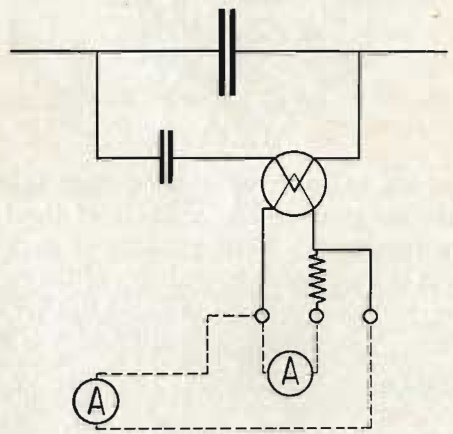

Fig. 2

which carries the greater portion of the current to be measured; without appreciable voltage drop, and so constructed that it can pass large current at high frequency without appreciable losses, and one considerably smaller, designed to shunt off a predetermined fraction of the total current through a small ammeter, either of the hot-wire or the thermocouple type. In the latter case, the meter may be located at a distance from the main circuit, as illustrated in Fig. 2.

A device of this nature, if properly designed, will give satisfactory measurements of current at frequencies as high as 60,000 kc., which is practically the limit of the present-day operations of radio stations. It can be designed for higher frequencies. The error due to the resistance of the thermocouple element is practically negligible, even at the highest frequencies used. Thus, if the condenser has a capacity of 0.001 μfd. and the thermocouple element has a resistance of 2.6 ohms, the error becomes one-half of one per cent at 6,000 kc. (50-meter wavelength). For shorter waves, smaller capacity would be used.

The only source of error actually found in operation is due to the fact that the two condensers and the thermocouple form a

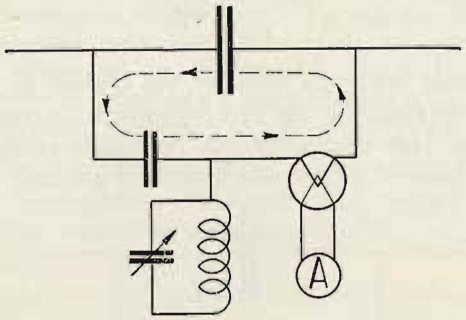

Fig. 3

closed circuit which has a resonant frequency that sometimes comes within the range of some harmonic of the frequency of operation of the instrument. The presence of such a condition becomes apparent in an obvious irregularity of the meter reading. Fig. 3 shows a very evident method to avoid this error due to the resonant frequency. An auxiliary circuit which is tuned to the resonant frequency of the closed circuit referred to is connected to some point of the condenser shunt and actually absorbs the power of the harmonic from this circuit and in this way eliminates this error. Since this tuned circuit is connected only at one point, its effect at all other frequencies is entirely negligible.

It is worthy of notice that the accuracy of this instrument cannot really be checked by any available standards of high-frequency current. Probably the most accurate fundamental method of measuring high-frequency current is by means of the calorimeter ammeter in which the heating due to the current registers the value of that current in terms of the resistance of

the heating element. Even this method, however, is subject to two errors which are difficult to eliminate. One is the actual value of resistance at the high frequency and the second is the distributed capacity of the heating elements and the calorimeter apparatus.

If it is remembered that the capacity values used in condenser shunt are considerably in excess of any distributed capacity, and moreover, with a properly constructed mica condenser, these values are constant at all frequencies, and if it is further realized

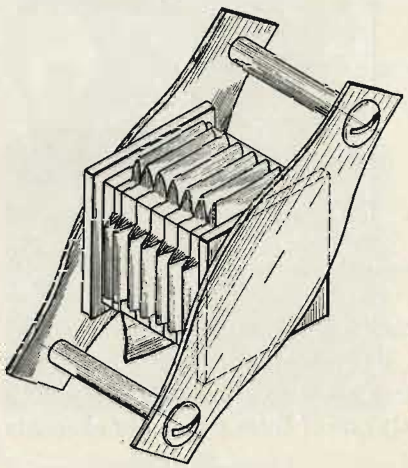

Fig. 4

that the distributed inductance and resistance of leads are really negligible, the accuracy of this method becomes self-evident; it establishes a standard of large high-frequency current measurement determined only by the accuracy of the meter element in series with the small condenser.

Fig. 4 illustrates an early design of condenser element which was found suitable for this apparatus. It is a unitary structure with a powerful clamp and two capacity elements, both within this clamp. One element consists of a number of metal foils in parallel, and gives the large capacity, while one extra foil brought out as a separate lead gives a small capacity. It is evident that the construction is made so symmetrical that there is no chance of one capacity changing relatively to the other. It will also be seen that the incoming and outgoing leads of this condenser are on the same side of the clamp. There is therefore no magnetic loop around the path of the current, and consequently an important cause of the losses is eliminated.

Fig. 5 is an illustration of a meter of this type constructed for operating with a current of 100 amperes. It will be seen that there

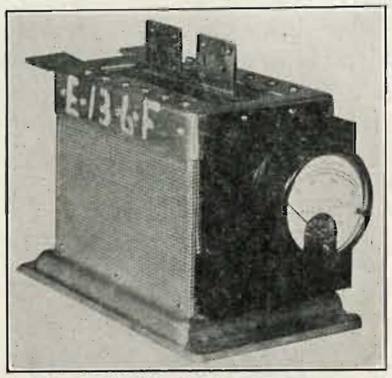

Fig. 5—External Appearance of an Early Model of Condenser Shunt.

are two leads coming out through the cover which can be connected in parallel or individually, depending on the current to be measured. There are two condenser elements corresponding to these leads. Only one of these condenser elements contains a small

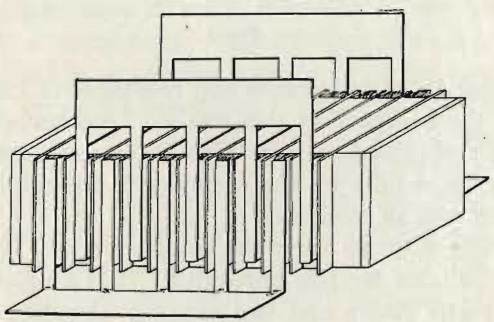

Fig. 6

capacity in series with the meter, that is, the element closest to the meter end. If this element alone is used, the reading is 50 amperes. If the second element is also connected, the reading becomes 100 amperes, and the meter readings must be multiplied by 2 without affecting the calibration of the instrument.

It is a well-known fact that a large current flowing at very high frequency causes considerable losses, and the heavier the current the more the relative losses. The cause of these losses was thoroughly analyzed and it was found that the probable reason for them is in the electro-magnetic field surrounding any path carrying large values of current. Such a magnetic field at very high frequency undoubtedly sets up an electro-static field through the body of the insulation and this electro-static field in turn causes dielectric losses. The problem therefore reduces to elimination of the magnetic field so as to eliminate the consequent electro-static field.

Fig. 6 shows diagrammatically a construction of a condenser where this electro-magnetic effect is practically entirely eliminated.

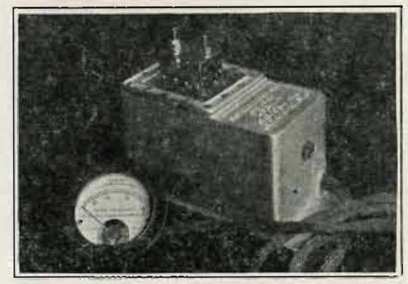

Fig. 7—Recent Model of Condenser Shunt with Shielded Lead and Panel Type Instrument

It will be seen that the condenser consists of a number of rather narrow sections interleaved with each other and so connected that the current through the body of the condenser has two opposite paths, each carrying an equal amount of current. Thus, the magnetic effects of the two paths cancel each other and the resulting electro-magnetic field is confined to the immediate vicinity of the conductors in each individual section. It was found by actual experiment that the losses by this construction were tremendously decreased so that a condenser which was previously giving a temperature rise of 15 or 20 deg. C. would with the new construction give an inappreciable temperature rise of 2 or 3 deg.

It will be further seen that this type of construction permits the use of a simple clamp surrounding the condenser, with leads coming out on both sides. Since the current now forms two loops in opposite directions, there will be no magnetizing effect on the clamp. If, further, bronze springs and brass clamping rods are used, the losses in the clamp are practically eliminated. As before, the small capacity is introduced by an extra foil in the condenser. It was found desirable to split this condenser into two parallel sections so that when a smaller current rating is required from the condenser shunt, half of the capacity may be used, giving full scale rating on the meter at one-half the current.

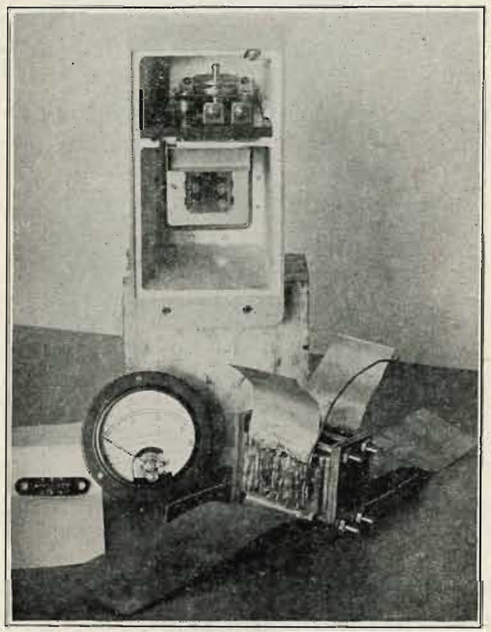

Fig. 8—Constructional Details of Condenser Shunt.

A typical example for a condenser to operate at 50 amperes is as follows. The shunt element is 0.199 μfds. and the part constituting the small condenser is 0.001 μfd. At 6,000 kc., the potential across this condenser will be only 6.6 volts. With this condenser a ratio of current is obtained of 200-to-1, so that with a 50-ampere condenser shunt the thermocouple will carry one-quarter of an ampere. If one-half of this condenser is used, as described above, to get the 25-ampere rating, the ratio is 100-to-1, giving again a current of one-quarter ampere for 25 ampere through the condenser shunt.

Fig. 7 illustrates a condenser of this type as it appears from the outside. In this case it was found more advantageous for commercial reasons to mount the instrument itself at a distance from

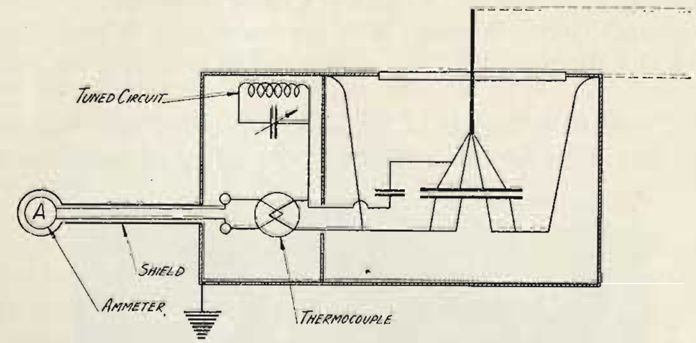

Fig. 9

the condenser shunt, and provide a shielded lead between the instrument and the condenser.

A split terminal is brought out on the top with a paralleling strap between the two halves. For currents more than 50 amperes,

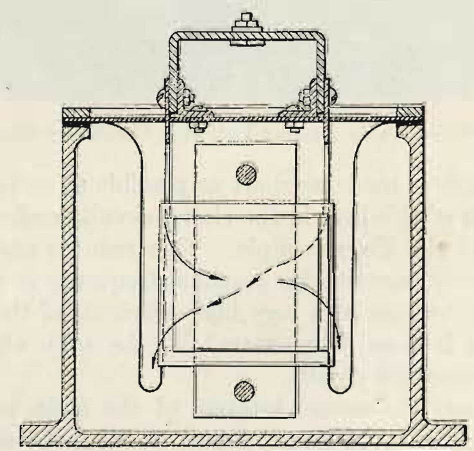

Fig. 10

a number of such condenser units may be paralleled, but of course only one instrument will be required. In that case it is evident that the ratio would be multiplied by the number of condenser units used.

Fig. 8 shows the inside appearance of this structure with a condenser element as described above in one compartment, and the small resonant circuit with the thermocouple in another compartment. A hole for bringing in a screw driver and adjusting the resonant circuit is sealed after the instrument is assembled, while a new thermocouple may be replaced by removing the lower cover.

Fig. 9 shows a diagram of connections inside of the condenser shunt. It will be seen that the lead from the small condenser to

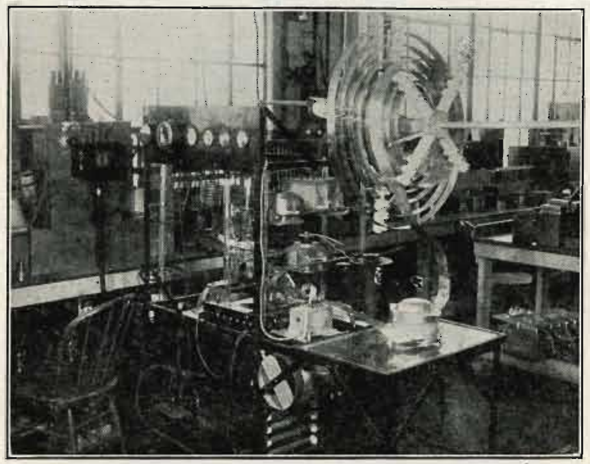

Fig. 11—Short Wave Radio Testing Set with Condenser Shunt Installed

the thermocouple is made as short as possible so as to avoid the inductive effect of this lead in the closed circuit consisting of two condensers and the thermocouple. This reduces one inductive effect and thereby increasse the resonant frequency of that circuit until it is effective only at a very high harmonic of the operating current. This is then compensated by the tank effect of the compensating resonant circuit.

Fig. 10 shows the actual location of the main leads in the condenser element. Attention is drawn to the fact that by interlacing the condenser sections and by arranging ingoing and outgoing connections through two parallel leads the magnetic effect of the current outside of the condenser element is almost entirely eliminated and to further avoid this magnetic effect on the thermocouple the condenser element is enclosed in a metal partitioned compartment.

Fig. 11 illustrates the location of this instrument on a radio transmitting set. The condenser shunt is mounted in a convenient location next to the ground lead, while the instrument is located on the instrument panel, with a shielded lead between the instrument and the condenser. In this particular set, which was designed for the purpose of testing condensers, and is capable of operating on a wide range of frequencies from 1000 meters to 20 meters, the condenser shunt was found to give correct readings for the full range and for currents in excess of 50 amperes an additional parallel unit could be applied.

A meter similar to the one described above has been in continual use for over two years on a testing set where the frequencies have ranged from 100 kc. to 6,000 kc., and the current values have ranged up to 120 amperes. It has been found that the meter indications are consistent and reliable at all these values. In fact, its accuracy has been such that it was possible to measure the voltage in a circuit by connecting such an ammeter in series with a known condenser, and determining the voltage drop in the condenser by calculation.

For developing a special thermocouple ammeter used in connection with the condenser shunt, an acknowledgment is due the Weston Electrical Instrument Corporation of Newark, New Jersey.