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The Influence of Power Factor and Capacity on Filtering Efficiency

PART 2

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IN the last issue of the "Research Worker," the influence of power factor on filtering efficiency was discussed. In this, the second part, it is proposed to determine the importance of the right capacity for filters and the effect on the hum when decreasing capacity, will be computed. In order to do this it will be necessary to discuss briefly the working of a filter, its design and finally the effect of smaller condensers.

HOW A FILTER WORKS

Let us consider two types of filters in common use (see Figure 1). The filter shown at a has what is called "condenser input" and is the more common of the two, while the filter at b has "choke input." Confining our attention at first to the filter shown at a.

The rectifier, at each half cycle passes current and permits the condenser to be charged to the peak voltage of the transformer secondary. Meanwhile the condenser discharges relatively slowly through the rest of the filter and the load. If there were no chokes but resistances, the voltage across C1 would decrease logarithmically until the rising transformer voltage becomes larger and permits the condenser to be charged anew. So the condenser charges only during a relatively small part of each half cycle and the charging current must necessarily be far higher than the load current. When designing filters this must be taken into consideration for the mercury vapor rectifier has a definite limit beyond which the current should not increase. If this were to happen the cathode (filament) will be bombarded by ions and soon be destroyed. In such cases one uses the filter of Figure 1b. But sticking with condenser input a little longer, the effect of capacity on residual hum is given by the equation

$$\Delta E_1 = \frac{1}{RfC_1}$$

Where $\Delta E1$ is the ripple voltage across C1, expressed in percent of the transformer voltage, R is the load resistance and f is the frequency of the rectified wave.

This equation teaches three things. First, when C1 and f are kept constant, the ripple voltage is inversely proportional to the load resistance or increases with the total current drawn. Second, when load and C1 are kept the same, the ripple voltage is inversely proportional to the frequency, hence, a lower frequency requires a better filter. Third, keeping frequency and load constant, the ripple voltage is inversely proportional to the capacity of C1. Figure 2 shows this effect in graphical form. This curve was made by taking f=120 cycles and R=44000 ohms (220 volts, 50 ma.). It will be seen that the improvement of filtering efficiency first increases rapidly with increased capacity but when about 8 mfd. has been reached a further increase in capacity does not give any appreciable return in hum reduction. Therefore, this condenser is less important from the standpoint of hum, but it performs another function: it affects the output voltage. This is easily seen from the well known equation of the discharge of a condenser through a resistor

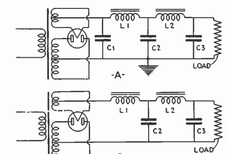

Fig. 1

$$E = E_0 \xi^{-\frac{t}{rc}}$$

E=instantaneous voltage, E_0=voltage before discharge, t=time in seconds, ξ=2.728.

The greater R and C, the slower will the voltage across C1 drop between charges and the higher the average voltage. The choice of C1 is a compromise between the requirements of high capacity to keep the voltage up and a relatively low one from a filtering efficiency standpoint.

The equation also shows that the voltage will drop with a lower load resistance, so this type of filter has poor regulation.

Turning now to Figure 1b, this filter has a choke input with a resultant lower voltages but better regulation and a lower peak current. For certain purposes this is preferred.

RATINGS OF CONDENSERS AND RECTIFIERS

In the case of Figure 1a, the condenser-input filter, it was shown that the voltage across it may rise to the peak of the transformer secondary voltage. Thus, the rating should be generous enough to allow for that and leave some leeway for surges. The rating should be at least 1.4 times the applied voltage .

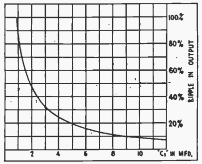

Fig. 2

What about the rating of the rectifier? One of the ratings of the rectifier has to do with "inverse peak voltage." This is the maximum potential difference permissible between filament and plate during the cycle that the plate is negative with respect to the filament. A little thought will

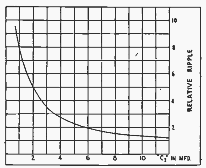

Fig. 3

bring out that at that moment the potential difference is equal to the transformer peak voltage plus the voltage across the filter. With a condenser-input filter, the inverse peak voltage may attain twice the value of the transformer peak voltage or 2.8 times the transformer rms rating. When a choke input is used, the inverse peak voltage may be even higher due to the induced counter e.m.f. of the choke.

The ripple voltage across the second condenser, C2, is given by the equation

$$\Delta E_2 = \frac{1}{1+\left[\frac{\omega L\ (1+R\omega C_2)}{R}\right]}$$

where ΔE_2 is the percentage of ripple across C2 (percent of ΔE_1), $\omega=2\pi f$, L inductance of the choke in henries, C2 is the capacity in farads and R is the load resistance in ohms. The curve of Figure 3 shows the influence of capacity on the remaining ripple. The curve has the same general shape as the one in Figure 2 (a hyperbola) and it is evident that the hum voltage is nearly proportional to the capacity; hence, half the capacity, double the hum.

The same is also shown by the method employed last month, by calculating the ratio between Z and the impedance of the condenser for an 8 mfd., 20 percent power factor condenser and another one of 4 microfarad, zero power factor. We shall return to this later.

DESIGN OF RECTIFIER FILTERS

It is the task of the rectifier filter to smooth out the rectifier current to something approaching direct current. The type of filter required for this work is known as a low-pass filter. It is not possible at this time to go into all the intricacies of filter design, but some fundamentals shall be given.

The standard equations for low-pass filters can be applied to the filter shown in Figure 4 and then we have

$$C = \frac{1}{2\pi f_c R} = \frac{.3183}{f_c R}\ \text{farads} = \frac{31813}{f_c R}\ \text{mfds.}$$

$$L = \frac{R}{\pi f_c} = \frac{.3183R}{f_c}\ \text{henries}$$

Where f_c is the cut-off frequency and R is the load resistance. Given a certain load resistance, the cut-off frequency can be chosen as low as prac-

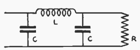

Fig. 4

tical and the values of L and C are easy to calculate. It is shown here once more that for a given load resistance, the larger the condenser, the lower the cut-off frequency and consequently the greater the attenuation of hum. ..

TUNED FILTERS

A greater amount of attenuation with less equipment can be obtained by tuning the filter, making the series arm of infinite impedance for the hum frequency or making the shunt arm of zero reactance at the hum frequency. Two of these filters are shown in Figures 5a and 5b. The former has a tuned series arm and the latter a tuned shunt arm. Equations for these filters will not be given here. Those who are interested can find them in the Radio Engineering Handbook by Keith Henney. The value of C1 in both of these filters is critical and replacement by a different capacity value will change the tuning with consequent decrease in efficiency.

Also, due to the effect of the tuned circuit; the voltage across C1 may rise

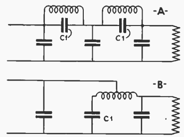

Fig. 5

far higher than the impressed voltage. A good condenser with high voltage rating is needed here.

EFFECT OF LOWERING CAPACITY

Let us come back to the original task and determine what will happen when 8 mfd., electrolytic condensers are replaced by 4 mfd. paper condensers in a typical filter (Figure 6) having three 8 mfd. condensers and two 30 henry chokes.

The examples of last month have been worked out laboriously just to show that the total impedance of the circuit does not change much by adding the resistance of the electrolytic condenser. It would then not cause any appreciable error if we consider that this value Z will be the same be-

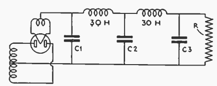

Fig. 6

fore and after replacement and we need not bother calculating how large it may be. From this, one comes to the conclusion that the hum voltage across the condenser whether it be in series with the tube or a choke, will be proportional to the impedance of it.

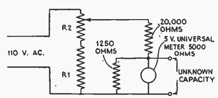

Fig. 7

The impedance of an 8 mfd. electrolytic condenser having a 20 percent pow-

er factor is 169.3 ohms. The impedance of a paper condenser (assuming zero power factor) of 4 microfarads is found by the old reliable equation

$$X_c = \frac{1}{2\pi f C} = \frac{1000000}{377} = 332\ \text{ohms}$$

Replacing an electrolytic of 8 mfd. with 4 mfd. paper condenser will then result in an increase of impedance of 169.3/332 or practically 2. This amounts to 6 db. which is easily noticed. But that is only the result of replacing one condenser. If all three are replaced, the hum will increase 6 db. for each condenser or a total of 18 db. This will result in a very annoying hum.

SUMMARY

By the foregoing it was shown that:

1. The residual hum voltage in a filter is practically proportional to the impedance of the condenser, all other factors remaining the same.

2. The power factor of the condenser has only a small effect on the filtering efficiency due to the vectorial addition of resistance and reactance. The increase in hum due to a power factor of 20 percent is only 2 percent or .017 db. for each condenser having such a power factor.

3. The filtering efficiency in each section is nearly proportional to the impedance and therefore inversely proportionately to the capacity. The replacement of a condenser by another of half the capacity will increase the hum voltage 2 times or 6 db. for each condenser so replaced.

A SIMPLE CAPACITY CHECKER

This article has shown the importance of knowing the capacity of replacement condensers. If all electrolytic condensers are replaced by paper ones of the same capacity, all is well and there will be a slight improvement but if the capacity is lower the hum will increase.

A handy device for quickly measuring the capacity of paper condensers greater than 1 mfd., is shown in Figure 7. The meter employed is the old familiar universal meter with a rectifier. The 5 volt range is used for several reasons.

This meter could have been used in series with the unknown condenser and its proper multipliers in the conventional circuit but then the scale will be too crowded for large condensers. In order to spread the scale properly, the condenser could be shunted across the meter itself. The current will then divide between the condenser and the meter inversely proportional to their impedance. Then the scale will still not be spread enough because the impedance of the condenser is so much less than that of the meter that practically no current flows through the meter, the difference between a shunt of 5 microfarads and 10 microfarads would be too small. This can be improved by shunting the meter so that the total impedance of meter plus resistor comes down to 1000 ohms.

Resistor R1 can be a fixed 4000 ohm resistor and R2 a 1000 ohm potentiometer, or if necessary it can be a semi adjustable resistor of 5000 ohms to replace both R1 and R2. However, the first arrangement is to be preferred.

HOW TO USE IT

The measuring instrument is connected across the 110 volts a.c. line and the potentiometer is adjusted until the meter reads exactly full scale. This adjustment is provided to compensate for fluctuations in line voltage. The unknown condenser is now connected across the test terminals and the meter needle will go down. The more it goes down, the higher the capacity. The meter readings may be converted into capacity readings by calculation or calibration. Figure 8 shows a curve of meter readings plotted against capacity which was calculated for the convenience of our readers.

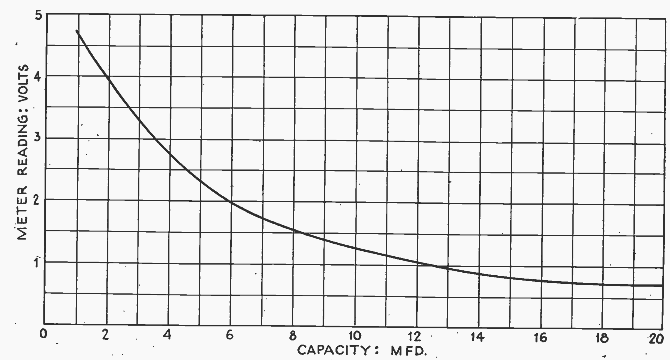

Fig. 8