

Jan. 26, 1943.

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2,309,586

STATIC FREQUENCY CHANGING SYSTEM

Filed Feb. 24, 1942

2 Sheets-Sheet 1

FIG. 1

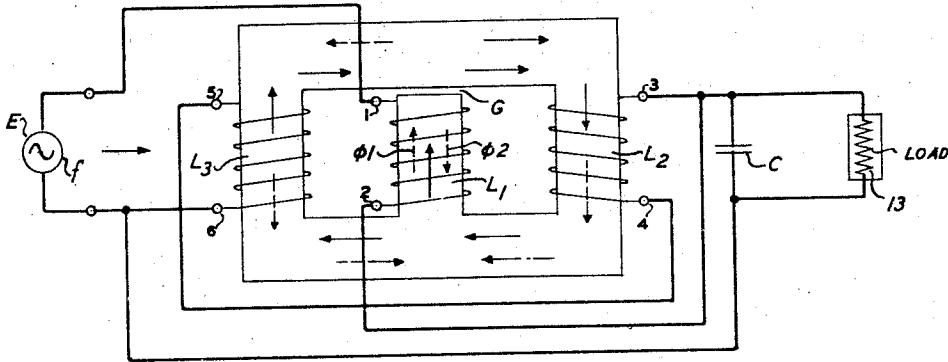


FIG. 2

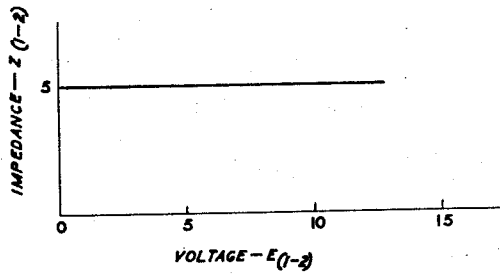
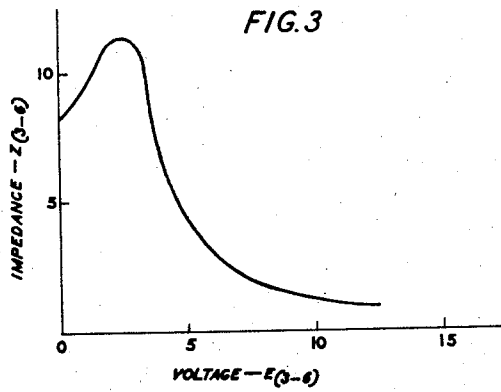


FIG. 3



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FIG. 4

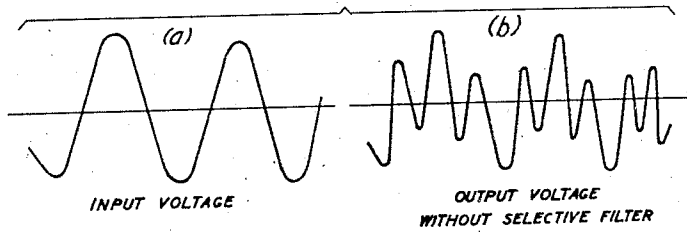
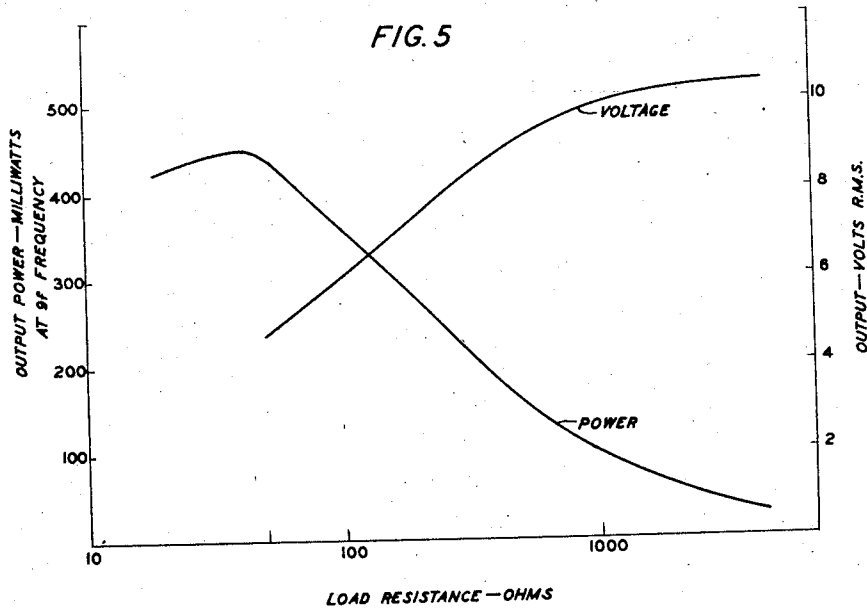


FIG. 5



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STATIC FREQUENCY CHANGING SYSTEM

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Application February 24, 1942, Serial No. 432,157

4 Claims. (Cl. 172-281)

The invention relates to static frequency changing systems, that is, systems for obtaining waves of one or more frequencies from a wave of a different frequency without the use of movable elements.

The invention particularly relates to static frequency changing systems of the type employing non-linear coils or transformers having saturable magnetic cores, operating to generate waves of frequencies having a harmonic relation to the frequency of the applied power wave. In certain systems of this type in the prior art, the input circuit consists of a linear impedance device, that is, one having an impedance which is constant over the working range of the applied current or voltage, in series with a non-linear coil, that is, one having an impedance which varies rapidly with applied current or voltage due to the magnetic characteristic and saturation of its saturable magnetic core. The linear impedance device may consist of a capacitor, an inductance coil or a combination of capacitor and coil having the desired linear characteristic. When a sinusoidal wave of voltage is applied to this input circuit, a non-sinusoidal voltage appears across the non-linear coil due to the distribution of the voltage between the two impedance elements over the cycle. The current passing through a secondary circuit connected across the non-linear coil, therefore, is proportional to the voltage of the non-linear coil and is also non-sinusoidal, containing odd harmonics of the fundamental input frequency. In certain circuits of this type in the prior art, a series or a shunt capacitor is added to the secondary circuit for the purpose of making the amplitudes of the harmonic components uniform over a wide frequency range. One such circuit is disclosed in the patent to L. R. Wrathall, No. 2,117,752, issued May 17, 1938.

An object of the invention is to construct, combine and arrange the various impedance elements in such a frequency changing system so as to provide advantages from the standpoint of reduction in size, weight and cost; increased output power; increased efficiency; improved regulation; and simplified control of variations in manufacture.

This object is attained in accordance with the invention by combining the functions of the linear and non-linear impedance elements of such a system in a single transformer having a three-legged core structure in the manner to be described.

Other objects and various features of the in-

vention will be brought out in the following detailed description when read in conjunction with the accompanying drawings, in which:

Fig. 1 shows schematically one embodiment of the system of the invention; and

Figs. 2 to 5 show characteristic curves illustrating the operation of that system.

As shown in Fig. 1, the frequency changing transformer of the invention utilizes a three-legged shell-type core structure of an easily saturable laminated magnetic material, with an appreciable air-gap G in the center leg L_1 and a continuous magnetic circuit for the outer legs L_2 and L_3 . The proportions of the outer legs L_2 and L_3 and of the window spaces of the core are not critical except that the two outer legs should have equal cross-section areas.

A winding identified as (1-2) is applied to the center leg L_1 , and the air-gap G in that leg is so proportioned that the impedance $Z_{(1-2)}$ of the winding (1-2) will be constant for variations of the impressed voltage $E_{(1-2)}$, as shown in the curve of Fig. 2. Windings identified as (3-4) and (5-6) having an equal number of turns are applied to the two outer legs L_2 and L_3 of the core and are connected in series-aiding as shown. At any given instant let ϕ_1 represent the flux in the center leg L_1 due to the current in the winding (3-4) on leg L_2 and let ϕ_2 represent the flux in the center leg L_1 due to the current in winding (5-6) on outer leg L_3 , as indicated by the dotted arrows in the center leg. Since windings (3-4) and (5-6) have equal turns and equal cross-section areas of core, $\phi_1 = \phi_2$. Hence these fluxes neutralize each other at any instant since they are in opposite directions. By proper selection of core material and interleaving of laminations in the outer sections of the core, the impedance $Z_{(3-6)}$ of the two windings (3-4) and (5-6) on the outer legs of the core can be made to vary with the impressed voltage $E_{(3-6)}$ in the manner shown by the curve of Fig. 3.

Now, if the windings (1-2), (3-4), and (5-6) are connected in series across a source of sinusoidal alternating current voltage E of the fundamental frequency f , as shown, it will be apparent that there will be no voltage interaction between windings (1-2) and (3-6) for the following reasons:

1. The flux set up by the current in winding (1-2) induces voltages of equal magnitude in windings (3-4) and (5-6). Due to the method of connecting the two windings, however, the voltage in winding (3-4) due to the source E is

180 degrees out of phase with that induced in winding (5-6) from the same source. Hence, the total voltage induced in the combined windings (3-6) due to current in winding (1-2) is zero;

2. Since, as seen above, the flux in the center leg L_1 of the core, due to current in the combined windings (3-6) is neutralized, there will be no voltage induced in winding (1-2) due to current in windings (3-6).

With the transformer windings connected in the manner specified above as shown in Fig. 1, the impedance of winding (1-2) functions as a linear element and that of windings (3-4) and (5-6) as a non-linear element. Consequently, when a sinusoidal wave shape of voltage E of the frequency f is applied across the input of the transformer, as shown, a non-sinusoidal voltage is induced across windings (3-4) and (5-6), containing odd harmonics of the input frequency f . The wave containing these odd harmonics may be taken off in a load circuit connected across the two windings in series or across either of the two windings and may be separately selected by tuned circuits or filters (not shown). The two windings in series are used for optimum conditions. If the output circuit works into a resistance load, or into a resistance load shunted by or in series with a suitable capacitor C , the amplitudes of harmonics will be appreciable. The load circuit and capacitor may be so selected that the amplitudes of the harmonics will be uniform over a wide frequency range or may be more pronounced at one particular harmonic.

Two important features of this arrangement are the following:

1. A large part of the transformer core structure is common to both linear and non-linear windings thus reducing the physical size required;

2. Apparently the flux due to the current in the linear winding (1-2) produces a saturation effect and a flux distortion in the outer legs of the core which tend to increase the harmonic components of the voltage induced in the output windings on the outer legs, and also to decrease the impedance of the transformer at the harmonic frequencies by decreasing the effective permeabilities at these frequencies. Since the harmonic power produced is directly proportional to E^2/Z the harmonic output power is increased and improved output voltage regulation with load is obtained.

Some of the advantages which may be obtained in the frequency generating system of the invention are the following:

1. For a given amount of output harmonic power, a considerable reduction in size, weight and cost may be obtained due to the replacement of the two elements by a single element which should be smaller in size than either of the original elements.

In one frequency changing transformer of this type which has been built and tested, the core structure was made up of a $\frac{1}{2}$ -inch pile-up of silicon steel L laminations, the over-all dimensions of this transformer with its windings being approximately $3\frac{1}{4}$ inches x $2\frac{3}{4}$ inches x 1 inch and the weight approximately 14 ounces;

2. For a given physical size of frequency generator, a considerable increase in output harmonic power may be obtained.

Tests have been made on a transformer as described above, operating from a 60-cycle sup-

ply with the output working into a resistive load of different values, with and without a secondary capacitor. Figs. 4(a) and (b) show oscillograph pictures of the input and voltage wave forms, and Fig. 5 curves showing the variations of the output voltage and output power obtained with variations in load resistance for the former case. For each of these cases, it was found that the output power is increased in the order of ten times that of a similar frequency changer of even larger physical size employing linear and non-linear impedance elements mounted on separate cores.

3. An appreciable increase in efficiency is obtained by the use of the frequency changing transformer of the invention used as either a high tone or low tone generator, over frequency changing systems employing the same arrangement of linear and non-linear impedance elements mounted on separate cores, and also a considerable improvement in output regulation;

Tests made on the transformer described above indicated that an improvement in efficiency of 500 per cent and in regulation of 1300 per cent over similar frequency changers of equivalent output employing linear and non-linear elements on separate cores was obtained.

4. In the manufacture of static type frequency generators, one of the most important problems is the control of manufacturing variations of the elements so that uniformity of quality and quantity of output can be obtained commercially. In the usual form of frequency generator, the output is a function of the characteristics of two or more independent elements, each of which has individual commercial variations. In the harmonic generating transformer of the invention, the harmonic power is controlled in a single element which may be advantageous from the standpoint of reducing or adjusting for manufacturing variations.

Various modifications of the frequency changing system which has been illustrated and described which are within the spirit and scope of the invention, will be apparent to persons skilled in the art.

What is claimed is:

1. A frequency changer including a source of sinusoidal voltage waves of a given fundamental frequency, a non-linear inductance, a linear inductance, an input circuit including said non-linear inductance and said linear inductance in series, connected across said source and an output circuit connected across said non-linear inductance, the linear and non-linear inductances being combined in a single transformer consisting of a shell-type magnetic core structure having a central branch and two outer branches of equal cross-section area in shunt with said central branch, equal inductive windings on the respective outer branches, connected in series-aiding relation, a third inductive winding on said central branch, connected in series with the windings on said outer branches across said source, said central core branch being such as to maintain the effective impedance of said third winding substantially constant for variations in the impressed voltage, to form said linear inductance, said outer core branches being such as to make the combined impedance of said equal windings thereon vary non-linearly with the impressed voltage, to provide said non-linear inductance, said output circuit being connected across said equal windings in series.

2. The frequency changer of claim 1 in which said core structure is laminated, said central core branch includes one or more air-gaps proportioned with respect to the magnetic material in that branch to provide the desired constant impedance for said third winding with variations in impressed voltage, and the desired non-linear variation of the combined impedance of the windings on said outer core branches is obtained by proper selection of the magnetic core material and interleaving of the laminations in these branches.

3. A harmonic producer including a source of sinusoidal voltage waves of a given fundamental frequency, a shell-type laminated magnetic core structure comprising two outer branches of equal cross-section area forming a continuous magnetic circuit, and an intermediate core branch including an air-gap, two equal inductive windings connected in series-aiding, wound on said outer core branches, one on each branch, a third

winding on said intermediate branch, connected in series with the first two windings across said source, the air-gap in said intermediate branch being proportioned with respect to the magnetic material therein to make said third winding with its core function as a linear impedance, the material in the outer core branches being selected and the laminations therein being interleaved so that the material passes through saturation in response to the voltage impressed on the windings of these branches, to make the latter two windings with their cores function in combination as a non-linear impedance, and an output circuit connected across the said latter two windings for taking off the wave produced therein including harmonics of said fundamental frequency.

4. The harmonic producer of claim 3, in which said output circuit includes a capacitor and a resistive impedance.

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