May 17, 1938. L. R. WRATHALL 2,117,752

HARMONIC PRODUCER

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FIG. 1

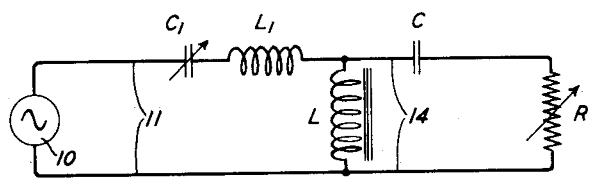

FIG. 2

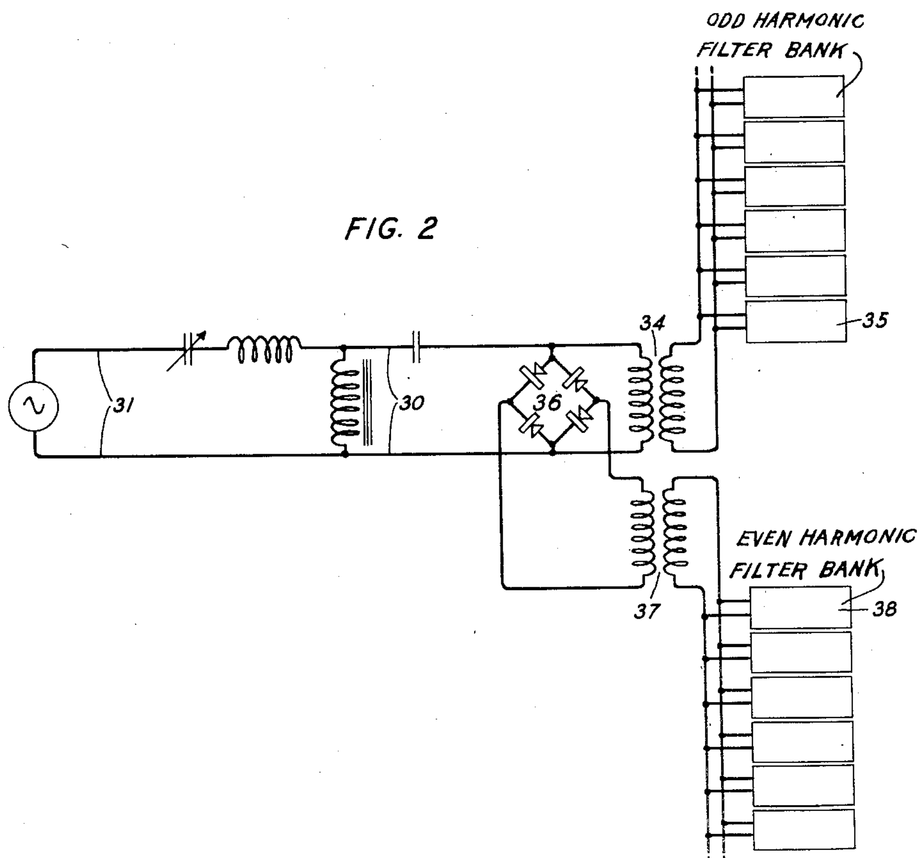

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FIG. 5

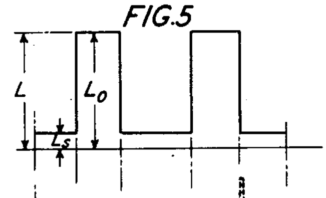

FIG. 3

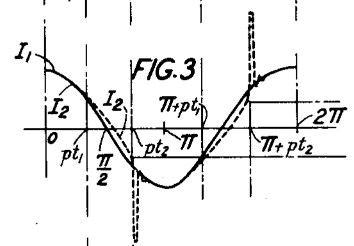

FIG. 4

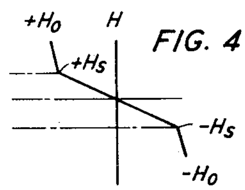

FIG. 6

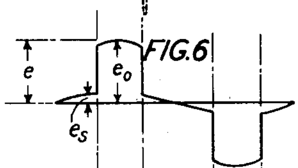

FIG. 8

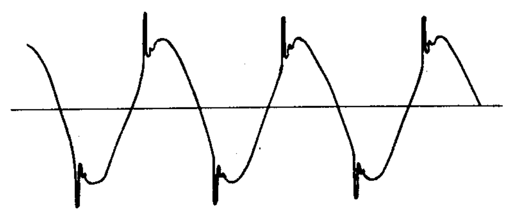

FIG. 7

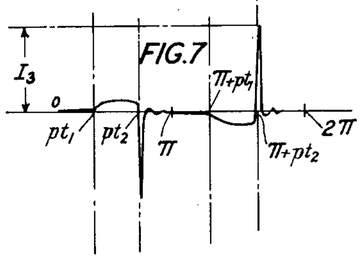

FIG. 9

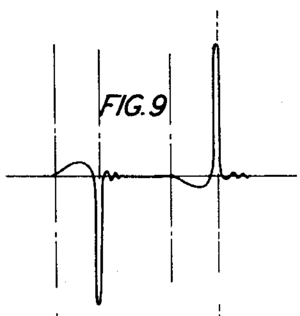

FIG. 10

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UNITED STATES PATENT OFFICE

2,117,752

HARMONIC PRODUCER

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Application May 5, 1936, Serial No. 77,989

9 Claims. (Cl. 172—281)

This invention relates to a generation of alternating current waves, and more particularly to a circuit arrangement for producing a group of harmonic frequencies having a uniformly large amplitude.

Heretofore, it has been found desirable in transmission systems requiring a large number of alternating waves of different frequencies such, for example, as the carrier waves for the several channels of a multiplex carrier telephone, to simultaneously provide the different frequencies by distorting a fundamental frequency of an alternating current wave by use of a single wave distorting device, such, for example, as a thermionic vacuum tube, or a saturating magnetic-core coil. From the output of each wave distorting device, the desired harmonic frequencies were selected by suitable circuits, or filters. In the above systems, it is known that the amplitude of the harmonic frequencies decreases very rapidly as the positions of the latter advance in the harmonic scale.

It is an object of this invention to produce from a base frequency wave a group of harmonic frequency waves of more nearly a uniform amplitude distributed over a desired range of frequencies.

In accordance with the invention, the object is attained by employing a particular circuit arrangement in combination with a magnetic-core coil of the unpolarized type. In the preferred embodiment, a fundamental frequency wave impressed on the coil connected in a resonant circuit produces a desired group of odd harmonic frequency waves. An output circuit for the coil includes a condenser connected in series with a load which may be a highly resistive impedance such as a bank of filters. The constants of the output circuit effects in the odd harmonics a uniformly large amplitude distributed over the desired frequency range.

An additional feature of the invention is a use of a copper-oxide bridge rectifier connected across the output circuit to separate a desired group of even harmonic frequency waves having a uniformly large amplitude distributed over the desired frequency range.

Fig. 1 is a diagrammatic circuit illustrating the preferred embodiment of the invention;

Fig. 2 is a diagrammatic circuit delineating a modification of Fig. 1; and

Figs. 3, 4, 5, 6, 7, 8, 9, and 10 are curves showing operating characteristics of the circuits shown in Figs. 1 and 2.

In the preferred embodiment of the invention shown in Fig. 1, an alternating current source **10** generates a fundamental frequency wave, preferably 4 kilocycles, which is impressed on a primary circuit **11** comprising in series an inductance L_1, a condenser C_1, and a non-linear inductance L. The primary circuit **11** is resonant, or nearly so, to the fundamental frequency wave so that the latter is caused to follow a substantially sine wave form. The inductance L embodying a non-linear magnetic core of a suitable structure such, for example, as the laminated or spiralled tape type produces a desired group of odd harmonics of the fundamental frequency in a well-known manner. The inductance L is preferably formed with a comparatively small diameter so as to provide high magnetizing forces in response to relatively small magnetizing currents thereby enabling an operation within its saturation region. The primary circuit **11** is designed to obviate reactance to the fundamental frequency and, in addition, to provide a high impedance to the desired range of odd harmonic frequencies. The inductance of L_1 is large as compared with that of L.

A secondary, or output circuit **14** comprises a highly resistive impedance load R and condenser C, both of which are connected in series with the inductance L.

To facilitate a description of the operation of the circuit shown in Fig. 1, I_1 represents the sinusoidal current flowing at any instant from the alternating source **10** through the primary circuit **11**; I_2 represents the current flowing at any instant in the inductance L; and I_3 represents the current flowing at any instant through the output circuit **14**.

The operation of Fig. 1 may be more readily comprehended by following the electromagnetic features of the circuit through one cycle of the fundamental frequency. Accordingly, it is assumed that the current I_1 is a sinusoidal wave represented by the equation

$$I_1 = I_0 \cos pt$$

the curve of which is shown in Fig. 3.

It is well known that a potential developed across an inductance, neglecting the potential due to the copper losses, is represented by the equation.

$$e = nA10^8 \cdot \frac{dB}{dt} = nA10^8 \cdot \frac{dB}{dH} \cdot \frac{dH}{dt} \text{ volts}$$

the inductance is represented by the equation

$$L = \frac{4n^2A}{d} \cdot \frac{dB}{dH} \times 10^{-9} \textit{ henries}$$

and the magnetizing force is represented by the equation

$$H=\frac{.4nI_2}{d}$$

where n is the number of turns; and A is the cross-sectional area and d is the mean diameter of the magnetic path. The B—H relationship of the coil is shown in Fig. 4.

Assuming I_1 at its maximum positive value in Fig. 3, then the magnetizing force of the inductance L has a value $(+)H_0$ which, as seen in Fig. 4, is larger than the saturating magnetizing force Hs. At this point, $pt=0$,

$$\frac{dH}{dt}$$

is substantially zero, and

$$\frac{dB}{dH}$$

is very small due to the fact that the value of H is larger than (+)Hs. As I_1 decreases but remains above the saturating magnetizing force (+)Hs, the impedance of the inductance L is negligible and consists mainly of the copper loss in its windings. Accordingly, for values of I_1 between $(+)H_0$ and (+)Hs a relatively small potential will be developed across the inductance L; I_3 flowing in the output circuit 14 will have a negligible value; and I_1 and I_2 will be substantially equal. In Fig. 4, it is seen that a change in H above (+)Hs effects very small changes in B. For the above values of current, the inductance L will have a relatively small value L_s as seen in Fig. 4.

When I_1 decreases to a value such that H falls below (+)Hs but remains within the positive and negative saturating magnetizing values, (+)Hs and (—)Hs, respectively,

$$\frac{dB}{dH}$$

becomes relatively large so that the values of the potential e and the inductance L in the above equations are abruptly increased by the relatively large factors of e_0 and L_0, respectively, of Figs. 5 and 6. During this interval,

$$\frac{dH}{dt}$$

attains its maximum value. In consequence of this flux-variation, a potential is developed in the inductance L to effect a current I_3 in the output circuit 14. The current I_3 charges condenser C but due to the relatively large value L_0 of the inductance L, it charges slowly. The charging current I_3 for the values e_0 and L_0 is shown lying between pt_1 and pt_2 in Fig. 7.

Between the saturating values (+)Hs and (—)Hs, the current I_2 flowing in the inductance L will have a value less than I_3, that is

$$I_2=I_1-I_3$$

The current I_2 is seen in the broken curve of Fig. 3. As I_2 decreases below the negative saturation value (—)Hs,

$$\frac{dB}{dH}$$

becomes relatively small so that the values of the voltage e and the inductance L decrease abruptly to the comparatively small values shown in Figs. 5 and 6. This terminates the charging of condenser C which then proceeds to discharge through the load R and the inductance L to produce a current I_3 in the output circuit 14. Due to the relatively small value L_s of the inductance L, the condenser C discharges in the form of an extremely sharp pulse as seen in Fig. 7.

It will be understood that, during the discharge of the condenser C, the inductance L possesses a relatively small impedance so that the I_3 pulse is limited largely by the impedance of the load R. As a result, the discharge current rises sharply to its maximum value and then drops sharply toward its minimum value and thereafter decreases in a substantially exponential manner until the charge on condenser C is entirely dissipated. At this time, the current I_2 is again substantially equal to the current I_1 as seen in Fig. 3. The above action is then repeated in the opposite direction during which I_1 attains values whereby the inductance L is caused to manifest a change in value. As a consequence thereof, the aforementioned values of I_2 and I_3 are repeated in the opposite direction, as shown in Figs. 3 and 7.

The sharp pulse of I_3 resulting from the discharge of the condenser C effects a uniformly large amplitude in the desired group of odd harmonics produced, as hereinbefore described, in the load R. The form of the I_3 curve is determined by the values of the impedance R and the condenser C of the output circuit, and also by the relatively small inductance of L during the discharge interval of the condenser C. These values may be preselected to provide a desired performance or constant, of the circuit.

Referring to Fig. 7, the curve of current I_3 indicates the following; first, that during each I_1 cycle, the current I_3 is divided into two isolated pulses in a manner that relatively small values of I_3 are interposed therebetween; and second, that each pulse is sharply divided into two stages. In connection with the latter, the first stage, pt_1 to pt_2, resembles a slow growth of current in response to a potential impressed on a circuit containing a relatively large inductance; and the second stage, pt_2 to $\pi+pt_1$ resembles the discharge of a condenser through a relatively small inductance and a resistance.

The non-linear inductance L may also be considered as having two distinct values of inductance, one for each of the two stages of I_3 extending from pt_1 to $\pi+pt_1$ in Fig. 7. As seen previously, one of the inductances is relatively smaller than the other. Therefore, the smaller value of inductance must be so small that the fundamental potential impressed thereacross would be negligibly small to account for the absence of an appreciable steady-state fundamental current during this time. In addition, the discharge of condenser C must be sharply effected to account for the negligible portion of I_3 flowing during this interval.

Accordingly, it is seen in Fig. 7 that for each sharp pulse of I_3, the condenser C is charged and discharged in less than a half-cycle of the fundamental current wave.

The larger value L_0 would seem to be associated with the initial permeability of the magnetic core of the inductance L while the value L_s would seem to be associated with the saturation permeability of the magnetic core.

Figs. 8 and 9 are oscillographic representations of the currents I_2 and I_3, respectively, obtained by a circuit similar to the circuit described above.

Fig. 2 is a modification of the circuit shown in

Fig. 1 and differs therefrom only with respect to its output circuit. In Fig. 2 the output circuit 30 is designed to provide odd and even harmonics both of which may be used for cable carrier and coaxial channel terminals. The output circuit 30 of Fig. 2 is connected to the primary winding of a transformer 34 having its secondary winding connected to a bank of filters 35 comprising six in number (by way of example) and arranged for parallel operation to pass only the desired group of odd harmonics. To provide a desired group of even harmonic frequencies, there is employed a copper-oxide bridge rectifier 36 comprising one pair of the conjugate bridge terminals connected across the secondary circuit 30 and a second pair of output bridge terminals connected to the primary winding of a transformer 37. The secondary winding of the latter is connected to a bank of filters 38 comprising six in number and arranged for parallel operation to pass only the desired groups of even harmonic frequencies.

The arms of the rectifying bridge are so poled that alternate pulses of I_3 are reversed thereby causing current to always flow in the same direction through the primary winding of the transformer 37. As a consequence thereof, only the even harmonics are provided with a uniformly large amplitude distributed over a desired frequency range.

When the banks of filters 35 and 38 cover a wide range of harmonic frequencies so as to provide a substantially uniform impedance, the operation of the secondary circuit 30 of Fig. 2 approximates closely the operation of the resistive secondary circuit 14, therefore the form of I_3 effected by the output current 30 of Fig. 2 would be substantially identical with the form of I_3 effected by the circuit of Fig. 1 as shown in Fig. 9. Accordingly, a uniformly large amplitude distributed over the desired frequency range of the produced odd harmonics would be effected in the output circuit of Fig. 2.

When the operation of secondary circuit 30 tends to vary substantially from the above, one of the following adjustments thereto may be adopted; first, the banks of filters may be flanked by high- and low-pass filters so as to provide a sufficiently uniform impedance over the entire desired frequency range; second, a condenser may be shunted across either transformer 34 or 37, or both; and third, a transformer having a sufficiently large shunt capacity associated with its winding may be substituted for either transformer 34 or 37. It will be observed, however, that a use of the above shunting elements alters the form of I_3 so as to include an extra loop as illustrated in Fig. 10, and, in addition, that the distribution of I_3 remains uniform although the amplitude of the produced harmonics is slightly increased. Fig. 10 is an oscillographic record made from an output circuit embodying the above shunting elements.

It is to be understood that the invention is capable of other modifications by those skilled in the art, and is to be limited only by the scope of the appended claims.

What is claimed is:

1. A harmonic producing circuit comprising an alternating current generator of fundamental frequency, a circuit connected across the generator and comprising in series an air-core induction coil, a capacity, and an induction coil having a saturable magnetic core tuned to the fundamental frequency; the magnetic-core coil producing a desired group of odd harmonics of the fundamental frequency and the inductance of the air-core coil being large compared with the inductance of the magnetic-core coil, and an output circuit for effecting a uniformly large amplitude in the produced harmonics comprising a second capacity and a highly resistive load circuit connected in series with the magnetic-core coil.

2. A harmonic producing system comprising an induction coil having a saturable magnetic core, means for impressing sufficient alternating current energy of a base frequency on the coil to cause saturation of its core so as to produce odd harmonics of the base frequency in the coil, and an output circuit for the coil including means for making certain that the produced harmonics will have a uniformly large amplitude over a desired frequency range, the means in the output circuit comprising a capacity and resistance in series with the induction coil, said resistance being sufficiently high to render said output circuit non-oscillatory within the range of utilized harmonics.

3. A harmonic producing circuit comprising a generator of fundamental frequency, an induction coil having a saturable magnetic core for producing harmonics of the fundamental frequency, a circuit coupling the generator across the coil and including an air-core induction coil and a capacity in series tuned to the fundamental current, the inductance of the second-mentioned coil being large compared with that of the first-mentioned coil, an output circuit for the first-mentioned coil comprising a capacity and a load in series therewith, the values of the second-mentioned capacity, the effective resistance of the load, and the smallest inductance of the first-mentioned coil being so chosen as to make the output circuit substantially aperiodic whereby harmonics are produced within a desired frequency range of a uniformly large amplitude; and means associated with the output circuit for selecting certain of the harmonics within the desired frequency range.

4. A harmonic producing system comprising an induction coil having a saturable magnetic core, means for impressing alternating current energy of a fundamental frequency on the coil to produce odd harmonics of the fundamental frequency therein, an output circuit for the coil comprising a capacity in series with a highly resistive impedance; the values of the capacity, the impedance and the smallest inductance of the coil being selected to make the harmonics within a given frequency band of a uniformly large amplitude; and means in the output circuit for selecting certain of the odd harmonics in the desired frequency range.

5. In a system for producing harmonics, an induction coil having a saturable magnetic core, means for impressing alternating current energy of a fundamental frequency on the coil to cause saturation of its core so as to produce a desired group of odd harmonics of the fundamental frequency on the coil, an output circuit for the coil comprising a capacity and resistance in series therewith, the total resistance being sufficiently large to confine the condenser discharge current principally to a single short sharp impulse in each half cycle of the fundamental wave to cause the generated odd harmonics to have a uniformly large amplitude distributed over the desired frequency range, said total resistance including a copper-oxide rectifier bridge connected across the

output circuit for rectifying a portion of the odd harmonic energy, and a circuit connected across the conjugate points of the bridge for taking off even harmonics of the fundamental frequency.

6. In a system for producing harmonics, an induction coil having a saturable magnetic core, means for impressing alternating current energy of a fundamental frequency on the coil to cause saturation of its core so as to produce odd harmonics of the fundamental frequency in the coil, an output circuit for the coil comprising a capacity in series with a highly resistive impedance; the values of the capacity, the impedance, and the smallest inductance of the induction coil being selected to confine the condenser discharge current principally to a single short sharp impulse in each half cycle of the fundamental wave to effect a uniformly large amplitude in the generated odd harmonics distributed over the desired frequency range; means connected across the output circuit for selecting certain of the odd harmonics in the desired frequency range, a copper-oxide rectifier bridge connected across the output circuit for rectifying a portion of the odd harmonic energy, and a circuit connected across the conjugate points of the bridge for taking off even harmonics of the fundamental frequency, said copper oxide rectifier comprising a part of the highly resistive impedance of the output circuit.

7. In a system for producing harmonics, an alternating current generator, an induction coil having a saturable magnetic core, a circuit coupling the generator across the coil and including an air-core induction coil and a capacity in series therewith, the circuit being tuned to the fundamental frequency of the generator for producing odd harmonics of the fundamental frequency in the magnetic-core coil, the inductance of the air-core coil being relatively large as compared with the inductance of the magnetic-core coil, a load circuit including a capacity connected across the magnetic-core coil; the value of the last-mentioned capacity, the effective resistance of the load circuit, and the smallest inductance of the magnetic-core coil being selected to confine the condenser discharge current principally to a single short sharp impulse in each half cycle of the fundamental wave to effect over the desired frequency range a uniformly large amplitude in the produced odd harmonics; means connected across the load circuit for selecting certain of the odd harmonics within the desired frequency range, a copper-oxide rectifier bridge connected across the output circuit for rectifying a portion of the odd harmonic energy, and a circuit connected across the conjugate points of the bridge for taking off even harmonics of the fundamental frequency, said copper oxide rectifier comprising a part of the highly resistive impedance of the output circuit.

8. In combination, a saturable core inductance, an exciting circuit producing substantially sinusoidal current flow through said inductance of sufficient amplitude to produce saturation in said core, and an output circuit including in series a winding on said core and a condenser and a highly resistive load, said output circuit containing sufficient resistance to render it substantially aperiodic whereby a broad range of harmonic frequency currents are produced in said load.

9. A harmonic frequency producing system comprising a saturable core inductance, a circuit for applying base frequency current thereto of sufficient amplitude to saturate said core, an output circuit connected across a winding on said core and including a condenser and a highly resistive load in series, the time constant of said output circuit being proportioned to permit said condenser to become substantially fully charged during the portion of the cycle throughout which said inductance has its maximum value and to discharge through said load when said inductance has substantially its minimum value, the resistance of said output circuit being so high as to render the output circuit highly damped.

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