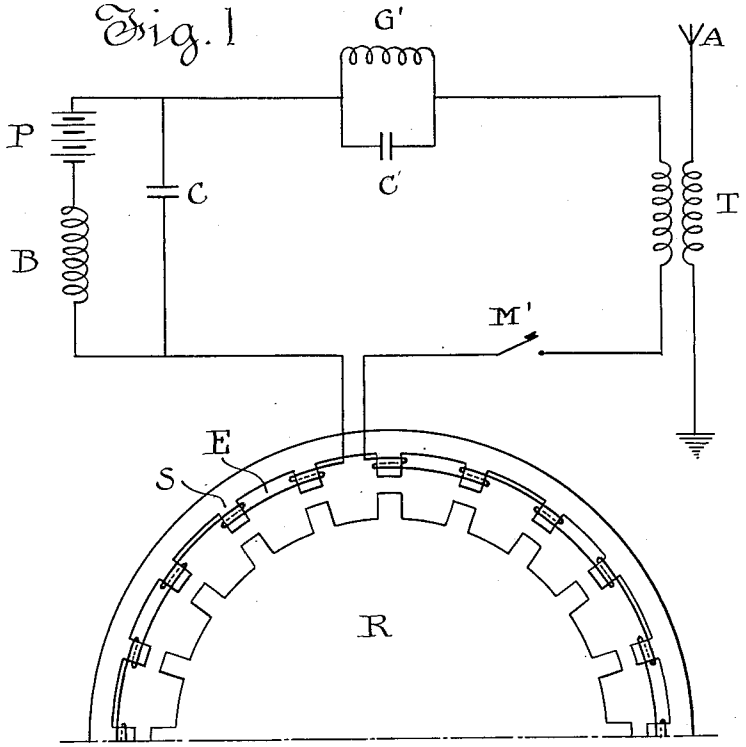
Jan. 21, 1930. J. BETHENOD ET AL 1,744,609

HIGH FREQUENCY ALTERNATOR

Filed Aug. 29, 1921 2 Sheets-Sheet 1

Fig. 1



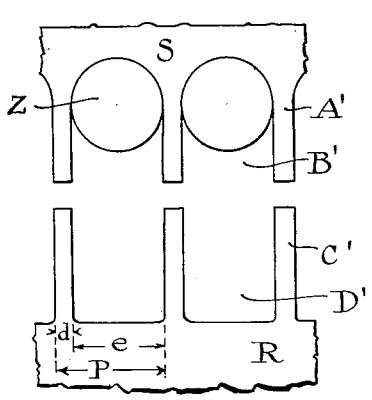


Fig. 2

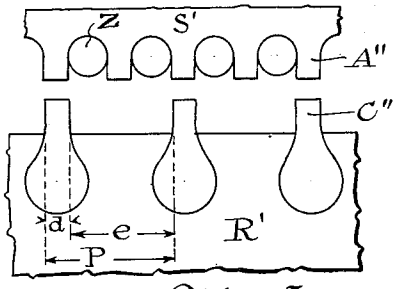
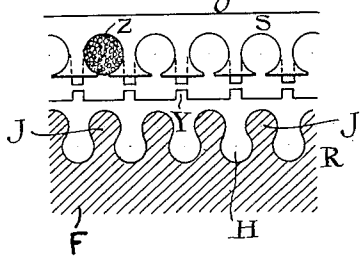


Fig. 5

Fig. 4



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HIGH FREQUENCY ALTERNATOR

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Fig. 3

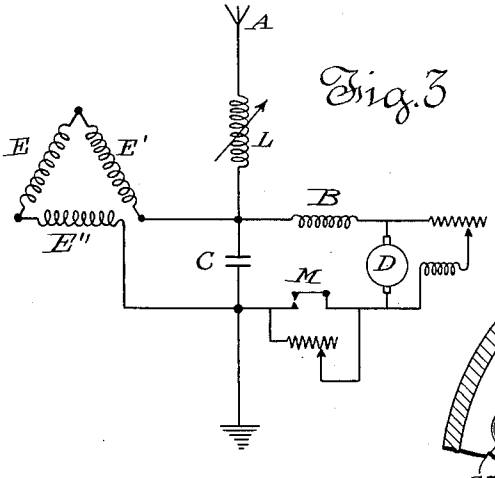
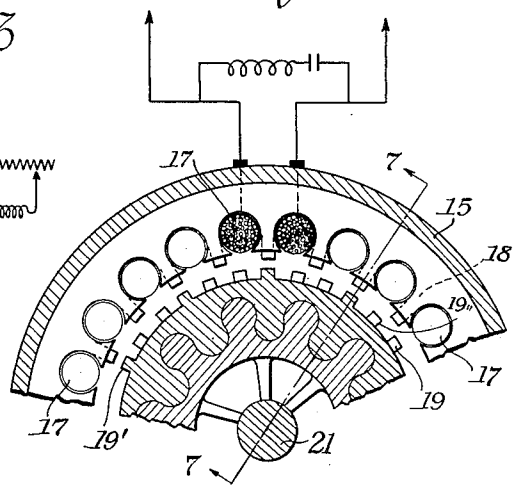


Fig. 6



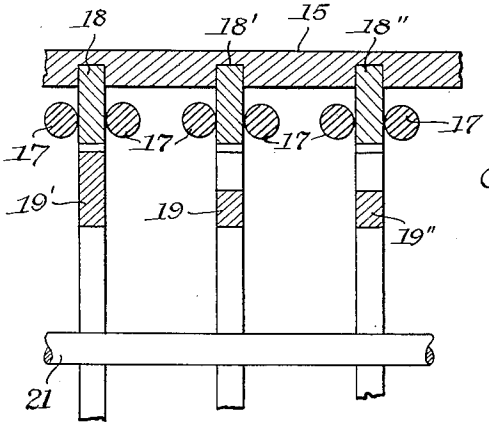


Fig. 7

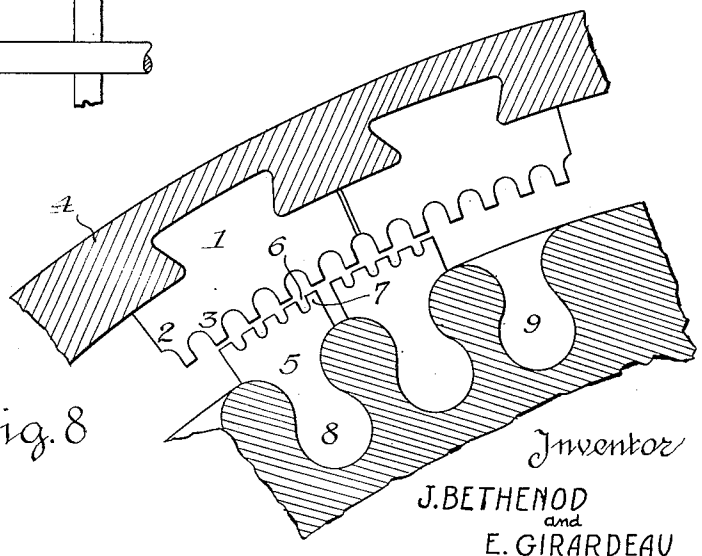


Fig. 8

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UNITED STATES PATENT OFFICE

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HIGH-FREQUENCY ALTERNATOR

Application filed August 29, 1921. Serial No. 496,552, and in France August 10, 1915.

We have filed applications as follows: France, filed Aug. 10th, 1915, granted No. 492,414; France, filed Jan. 30th, 1919, granted No. 21,730; Germany, filed Mar. 3rd, 1921; Great Britain, filed July 26th, 1916, granted No. 101,148; Great Britain, filed July 26th, 1916, granted No. 103,657; Great Britain, filed July 26th, 1916, granted No. 103,658; Belgium, filed May 15th, 1920, granted No. 287,154; Brazil, filed June 14th, 1920; China (custom house, Shanghai), filed Aug. 16th, 1920, No. of registration 21,041; Belgian Congoland, filed May 17th, 1920, granted No. 590; Denmark, filed Jan. 10th, 1920; Spain, filed Dec. 20th, 1919, granted No. 71,809; Netherlands, filed May 6th, 1920; Italy, filed Apr. 15th, 1920, granted No. 184,033; Morocco, filed April 19th, 1920, granted No. 144; Norway, filed Jan. 17th, 1920, granted No. 37,309; Poland, filed July 6th 1920; Portugal, filed May 11th, 1920, granted No. 11,434; Rumania, filed July 3rd, 1920, granted No. 5,310; Sweden, filed Dec. 31st, 1919, granted No. 54,909; Switzerland, filed Dec. 8th, 1919, granted No. 94,335; Czechoslovakia, filed May 4th, 1920; Tunisien Protectorate, filed Apr. 30th, 1920, granted No. 1,704.

This invention relates to apparatus for use in wireless telegraphy and wireless telephony and particularly to a high frequency alternator for use in connection therewith.

An object of our invention is to provide a high frequency alternator of simple construction, reliable operation and substantially lower speed than those now in use for the same frequency.

A further object of our invention is to provide a high frequency alternator in which a harmonic of the fundamental frequency of the wave of the machine is utilized to raise the frequency of the output.

A further object of our invention is to provide an alternator in which the amplitude of a harmonic of the fundamental frequency is increased at the expense of the amplitude of the fundamental, thereby raising the frequency of the output of the alternator.

A further object of our invention is to provide a high frequency alternator in which certain harmonics of the wave form are accentuated and the fundamental is suppressed.

A further object of our invention is to provide a high frequency alternator in which a certain harmonic of the wave form is accentuated and the fundamental is suppressed by judiciously choosing the width and pitch of the teeth of the rotor and stator.

Our invention is particularly adapted to alternators of the variable impedance type but is not limited to such machines, being adapted also to alternators of the homopolar type. It will be described hereinafter as applied to both types.

For a detailed description reference is made to the accompanying drawing in which

Fig. 1 is a system employing a high frequency alternator conforming to our invention,

Fig. 2 is a diagrammatic showing of the rotor and stator teeth of an alternator of the variable impedance type conforming to the invention,

Fig. 3 is a connection diagram illustrating a plurality of alternators connected in cascade to feed the same antenna,

Fig. 4 is a detailed view illustrating a method of holding the stator windings in their slots,

Fig. 5 is a diagrammatic showing similar to Figure 2, but illustrating our invention as applied to an alternator of the homopolar type.

Figs. 6 and 7 are sectional views, at right angles to each other, illustrating a plurality of alternators mounted on a common shaft according to the invention and

Fig. 8 is a detail view showing the rotor and stator teeth of a homopolar alternator conforming to the invention and comprising a composite rotor.

The attempts hitherto made to produce directly the high frequency oscillations that are necessary for the transmission of wireless telegraphic and telephonic signals consisting in the use of machines comprising rotors or moving members have given rise to the establishment of high frequency generators, the construction of which involves very heavy expense and results in serious technical difficulties.

Among the technical difficulties existing in previous installations the following may be enumerated.

1. Those met with in the use of cascade alternators comprising a wound rotor

Since the peripheral velocity is always considerable, even with the cascade arrangement, and since moreover the useful periphery of the rotors should consist of segments of extra thin sheet iron (having regard to the impossibility of manufacturing with a thickness less than $\frac{1}{10}$ of a millimetre, sheet iron plates of dimensions sufficiently large to enable the rings necessary for a high power machine to be cut out therefrom in one piece), these alternators are very costly to construct and always present very great mechanical risks. In fact the incongruous collection of segments of extra thin sheet iron held by dovetailing, of cables forming the winding of the rotor, and of insulating material, possesses none of the qualities required for resisting with sufficient safety the effects of centrifugal force.

2. Those met with in the use of static frequency transformers

It has been suggested that by the use of frequency changing apparatus, such as static frequency transformers, a relatively lower frequency generator may be utilized for feeding the same which generator may be better adapted to stand the strains incident to use. However, such an arrangement is not fully satisfactory because of the indifferent output of such apparatus and because of the technical difficulties, both practical and theoretical, that their construction involves as well as other complications they introduce into the installation.

It is to be observed, morever, that the solutions recalled under headings Nos. 1 and 2, which in spite of their defects are the only ones that appear up to the present moment to have been carried into practice on a large scale, necessitate the use of exceedingly powerful cooling methods or devices which can only be effected with difficulty.

Our invention will first be described in connection with a high frequency machine of the variable impedance type, without windings on the rotor, the fundamental frequency of which is of the order of 5,000 to 15,000 alternations per second. The frequency which we obtain from the machine however is much higher than this fundamental frequency as we make use of one of the harmonics of the wave of the machine thereby multiplying the fundamental frequency by 3, 5, 7 or some other factor depending on the harmonic which is utilized.

The installation hereinafter described and forming the subject of the present invention employs an alternator of a new or improved type, the rotor of which has no winding, that is to say, which is free of such criticism as referred to in relation to cascade machines.

Furthermore the multiplication of frequency operates in the machine itself, that is to say, under conditions of efficiency and simplicity incomparably superior to those obtained by separate static transformers.

Variable-impedance machines are already known that do not comprise any windings on the rotor, see J. Bethenod, Bulletin de la Societe Internationale des Electriciens, Third Series, Volume IV, No. 36, 1914.

In such machines as therein stated, the rotor consists of a toothed disc of sheet iron, having as many slots as possible; round this rotor is placed a stator having the same number of teeth as the rotor and provided with a single winding so wound on the teeth that they, considered successively, are of alternate polarity.

Under these conditions, if the current from a continuous-current source is sent into this winding, there is obviously produced in the winding an alternating current that is superposed on the continuous exciting current, and which is capable of feeding for example a radio-telegraphic antenna through a transformer or if desired an inductance or a capacity or both may obviously be used for the antenna connection.

The machine just described was proposed by Joseph Bethenod in 1907 for radiotelegraphy. He pointed out at that time that the fundamental frequency of such a machine is given by the formula: (1) $f=mn$ where n equals the number of revolutions per second and m the number of teeth of the stator (in this case of the rotor also).

If m be regarded strictly as the number of stator teeth then m teeth only form in reality m poles, and the machine in question furnishes, under equal conditions, double the fundamental frequency obtained with an alternator of the type ordinarily employed for low frequency, i. e. an alternator wherein the number of pole windings on the rotor is equal to the number of stator poles, whereby the frequency equals the number of revolutions multiplied by the number of pole pairs, or with an undulating flux machine having two armature cores arranged on the stator and separated by an inductor, the cores and inductor being magnetized by a field coil, also fixed, concentric with the axis of rotation, each armature or stator core having double the number of inductor teeth. See the Alexanderson machine shown on page 402 of the Transactions of the American Institute of Electrical Engineers, Vol. XXVIII (1909), and referred to by Bethenod in the above cited bulletin.

The above described Bethenod machine possesses two defects:

(1) in spite of the advantage pointed out

above relative to the high frequency obtained, the latter cannot be raised sufficiently high to correspond to a wave length of 10,000 metres unless excessive peripheral velocities are adopted; a supplementary multiplication of frequency is therefore imposed in the majority of cases.

(2) The rotor should obviously be of thin laminated sheet iron, although it is not provided with windings, which presents advantages (particularly for a rotor constructed in several segments) over the Goldschmidt machines and cascade machines.

According to the present invention, the first defect has been remedied in the following manner.

Referring now to Figs. 1 and 2 of the drawing, which illustrate the application of our invention to machines of the variable impedance type, S represents the stator with teeth A′ and slots B′ and R represents the rotor with teeth C′ and slots D′. On the stator S is the winding Z which is wound oppositely on each successive tooth thereby causing the stator teeth to become alternately north and south poles when the winding is energized with direct current. It will be noted that, whereas, in the older type of machine, described above, the teeth and intervening slots were of equal peripheral width on both the stator and rotor, in our machine the slots on both the stator and rotor are considerably wider than the teeth. In the machine shown in Figs. 1 and 2 the width of the rotor teeth is equal to the width of the stator teeth and the width of the rotor grooves is equal to the width of the stator grooves.

The older type of machine does not give a sinusoidal E. M. F. curve of frequency f (Formula 1); for that it would be necessary that the flux variation produced by the displacement of the rotor should be simple harmonic, which is not the case in practice.

An E. M. F. is therefore obtained, the expression for which, developed according to the Fourier series, contains harmonic terms in $2^f, 3^f$, etc.

The mathematical analysis of this series shows that the relative amplitude of any term depends on the ratio between the width d of the teeth (Figure 2) of the stator S or of the rotor R, to the common pitch p of the teeth (this pitch being equal to d plus e the width of slot), and that the harmonic of rank q will reach its maximum amplitude when the relation (2) $d=\frac{p}{2q}$ is realized or in other words the ratio of tooth width to pitch of the teeth is equal to $\frac{1}{2q}$.

Of course d will in practice be the actual magnetic breadth, i. e. the circumferential width, at the air gap, of the extremity of the tooth, plus the effective width of the fringe formed by the flux at its exit from the tooth.

This harmonic, which is in this way rendered very marked, is utilized, according to the present invention, for the direct feeding of the antenna. Most often $q=2$ or $q=3$ will be chosen; doubling or trebling of the fundamental frequency f will then be obtained, and this choice leads in practice to a machine without excessive magnetic leakage into the slots or notches, the teeth however being mechanically of ample dimensions when the wave-length of the antenna is of the order of 10,000 metres, (as employed in large modern stations).

In order to eliminate from the external circuit every current of fundamental frequency, as well as the unused harmonics, it is possible:

(*a*) Either to arrange in series in the electric circuits actual "dams" for the currents of a particular frequency, to this end systems will be used that are formed for example by putting an inductance and a capacity in parallel, the whole so constituted being damped as little as possible, and being syntonised with the frequency of the currents to be eliminated.

(*b*) Or to create short circuits for the stray electro-motive forces; this may be attained by means of resonators formed by putting a capacity and an inductance in series, the whole so constituted being again damped as little as possible, and being syntonised with the frequency of the E. M. F.'s to be eliminated, and shunted to the armature winding of the generator.

It will be noted that the fundamental frequency of the machine is a function of the number of teeth on the rotor and the speed of the machine in accordance with the equation $f=mn$ (1), this relation, of course applying to our improved machine as well as the older type. However by dimensioning the relative widths of the teeth and slots in accordance with the relation $d=\frac{p}{2q}$ in which q represents the order of the harmonic which is to be utilized, the amplitude of this harmonic will be much increased and the machine can therefore be used as a source of energy of a frequency several times its fundamental frequency.

In Fig. 1 the alternator is shown connected to an antenna to serve as a high frequency source of energy. The winding E is connected to a source of direct current represented by a battery P, an inductance B being connected in the battery circuit to prevent the high frequency current from the alternator from reaching the battery. The winding E is thus energized and causes the stator teeth to become magnetized to form alternate north and south poles. It is obvious that as the rotor teeth sweep past the stator teeth there will be changes in the impedance of the winding and these changes cause an alternating current to be induced in the winding E, this

current being superimposed on the energizing direct current. The frequency of this current as stated above is equal to the number of rotor teeth multiplied by the speed of rotation of the rotor in revolutions per second. This is the fundamental frequency of the machine. Owing to the spacing and width of the stator and rotor teeth the amplitude of the fundamental wave is very small as compared to the amplitude of one of its harmonics. The particular harmonic which is thus accentuated is determined by the spacing and width of the teeth as determined by the formula $d=\frac{p}{2q}$ given above.

The alternator in Fig. 1 is shown connected to an antenna through a transformer T, a condenser C being connected in the circuit. An impedance G′ and condenser C′ in parallel with each other are also connected in the circuit to eliminate the currents of the fundamental frequency of the alternator but to freely permit the passage of currents of the chosen harmonic. By manipulating the key M′, waves of several times the fundamental frequency of the alternator can be sent from the antenna.

Finally, by connecting in series q machines mechanically coupled in such a way that they possess a regular electrical phase-displacement of $\frac{2\pi}{q}$ every current is eliminated the frequency of which is not a multiple of q. An arrangement of this nature is shown diagrammatically in Figures 6 and 7 in which 21 is a common shaft supporting three sets of rotor teeth namely, 19′, 19 and 19″ which are so supported on the shaft as to be electrically displaced from each other in phase by $\frac{2\pi}{3}$. Each set of rotor teeth co-operates with a separate stator 18, 18′, and 18″, respectively, which are identical with each other and in the present case are shown as mounted on a common member 15 in alignment axially of the shaft 21. The several stators are energized by suitable windings 17 located and conveniently supported in slots between the stator teeth. This structure comprises substantially three separate alternators mechanically coupled so that there is a regular phase displaced between their output currents.

Figure 3 shows a circuit arrangement for such a connection for $q=3$, the windings E, E′, E″ representing respectively the windings of three different machines having a phase-displacement of $\frac{2\pi}{3}$; the capacity C here forms the connection with the antenna, a variable inductance L permitting of the regulation of the antenna circuit, the emission of the signals has been assumed to be effected by operating with the key M on the excitation current supplied by the dynamo D, but these details may be varied without departing from the nature of the present invention.

Instead of providing q separate machines, the same elimination may be arrived at by using on the rotor q times as many teeth as on the stator, the breadth common to the stator and rotor teeth always being determined by formula (2) and p being then the pitch of the stator teeth only. This solution is in general suitable only for low frequencies.

The second mechanical defect referred to in the introduction, is completely eliminated in accordance with the present invention. The section of Fig. 4 shows the details of a machine of this new type, and the great security obtained by means of this machine will be obvious from an examination of this figure. The rotor R (shown open the same way as the stator S) comprises segments of sheet-iron cut out like Y, and separated from each other by means of joints J. J. These segments are held in place on the massive ferrule F (or on a drum forming a unitary structure with the shaft of the machine) by means of tenons H provided in the grooves on the same side. An important feature of the invention to be noted is that, on account of the relatively small width of the teeth with respect to their pitch (the drawing corresponds to $q=3$, whereby $d=\frac{p}{6}$) as many tenons H are provided as there are teeth, and the sheet-iron bridges connecting the teeth are only of such a slight height as is necessary for the passage of the flux. Each tooth is thus individually anchored to the shaft without the necessity of subjecting the bridges to appreciable strain. In order to avoid the multiplication of the magnetic joints J, the teeth provided with their tenons are not separately stamped out. The shape of these tenons constitutes also a characteristic feature of the invention. Its advantages over the usual dove-tailing consists in that it has progressive curves of great radius, i. e. does not form any weak spot in the profile herein adopted. As well-known, the small radius curvatures of the dove-tails cause quite often local strains that may bring about the splitting of the whole assembly. The conductors Z may be maintained in their slots by any convenient means, one very good method being illustrated in Fig. 4. In order to locate the conductors Z as near as possible to the air-gap, and preferably they should be located in this manner for obtaining the maximum variation of useful flux, the following arrangement may be adopted; at certain distances in the sheet iron structure of the rotor, cut out in accordance with Fig. 4, non-magnetic sheets are inserted and are provided with half-closed notches. These non-magnetic sheets will maintain the stator windings due to the shape of the notches

provided in these sheets, and the teeth of the sheets of non-magnetic material, the ends of which are shown pointed, would be of the minimum length that is necessary for preventing contact between the stator winding and the rotor. It should be noted that, the circular section of the conductors of the stator shown in Fig. 4 is not indispensable, and a section of any suitable shape may be adopted in each individual case.

In the preceding description provision is made for the application of the devices previously described in connection with variable impedance machines, to homopolar machines having energizing windings concentric with the shaft.

Such a machine is illustrated diagrammatically in Fig. 5. The teeth C'' in this figure are all magnetized to the same polarity by any convenient means (not shown). In a homopolar machine it is of course necessary for a rotor tooth to sweep past two complete stator teeth to induce a complete alternation in the stator winding and therefore there must be twice as many stator teeth for a given number of rotor teeth in the homopolar type as in the variable impedance type. This is shown in Fig. 5 in which there are shown two stator teeth for each rotor tooth. By dimensioning and spacing the rotor teeth in the same way as in the variable impedance type, that is in accordance with the equation $d=\frac{p}{2q}$, any desired harmonic represented by q can be accentuated in the same way as in the variable impedance type. The frequency of the output of the homopolar type can therefore be made a multiple of its fundamental frequency.

As in the case of the variable impedance type q machines may be connected in series. The machines possess an electrical phase-displacement of $\frac{2\pi}{q}$ for the purpose of eliminating all currents, the frequency of which is not a multiple of q. The dimensions of the machines are chosen in a manner whereby they possess a harmonic of the multiple q which is very marked. As before, these machines can be combined into a single machine in which the same stator acts for all the rotors. The combined rotor however represents in reality a plurality of rotors having the teeth for the several machines all mounted on a common drum and having the teeth of the several machines displaced in accordance with the formula $\frac{2\pi}{q}$ in which q is the number of machines combined. In such a combined machine it is clear that the number of stator teeth will be very much reduced over the number of rotor teeth owing to the fact that each pair of stator serves for a plurality of sets of rotor teeth. For one of the odd harmonics, which are found to be better suited for this purpose, the number of stator teeth is only $\frac{2}{2n+1}$ of the number of rotor teeth, in which n is an integer depending on the harmonic to be accentuated. This relationship can best be explained by a concrete example and in Figure 8 a combined machine designed to accentuate the third harmonic is shown. In this case $n=1$. By referring to Fig. 8 it will be noted that there are three rotor teeth, representing three machines for each pair of stator teeth. Preferably, the profile of the teeth and the notches described previously for variable inductance machines, should be preserved, and the periphery of the rotor should be composed of thin sheet-iron, fitted into the massive core by means of tenons having round contours, as already described.

The width of the rotor teeth at the air gap should be preferably equal to the width of the stator teeth.

The sheets composing the stator are formed by the segments 1 provided with open notches 2 and teeth 3. These may, for instance be dove-tailed into the stator frame 4. The rotor segments 5 are provided with notches 6 and teeth 7, and are attached to the massive drum of the rotor by means of tenons 8 of progressive curvature and provided in the channels 9.

These channels are distributed over the circumference at an arbitrary pitch p, and in any desired relation to the polar pitch of the rotor teeth.

The width of the teeth 7 is the same as that of the teeth 3, and the width of the notches 2 is double the width of the teeth. In the present case, the width of the notches 6 is the same as that of the teeth 7 in accordance with the general principles previously explained.

As shown in the drawing, the pitch p should be preferably chosen in such a manner that, two consecutive segments 5 are separated by a distance equal to the width of the teeth 7. In this manner, economy will be made in the sheet iron, because the interval between the segments performs the function of a notch in the rotor. Furthermore, by means of this arrangement, each segment of the sheet iron will be made mechanically independent.

All these arrangements may be readily applied to the case when $n=1$.

The above described arrangement may also be applied to machines having fields with alternating poles of the usual industrial type. The purpose of such application is to reduce the number of notches in the armature.

Having described our invention what we claim is:

1. A variable impedance high frequency alternator having a rotor and a stator where-

by a fundamental frequency is determined for said alternator by the speed of the rotor, said rotor and stator each having teeth of equal width, and the width of said teeth being equal to $\frac{1}{2q}$ times the tooth pitch of the rotor where q is an integer representing the harmonic to be strengthened, the ratio of the number of rotor teeth to stator teeth at least being unity.

2. A variable impedance high frequency generator comprising a plurality of alternators, each alternator having a rotor and stator whereby a fundamental frequency is determined for said generator by the speed of said rotors, each of said rotors and stators having teeth, the width of said teeth being equal to $\frac{1}{2q}$ times the tooth pitch of said rotors, where q is an integer greater than unity and representing the harmonic to be strengthened, said rotors being mechanically coupled and electrically displaced by $\frac{2\pi}{q}$ whereby the chosen harmonic will be strengthened and the fundamental will be substantially eliminated.

3. In a variable impedance high frequency generator, in combination, a single stator and q rotors mechanically coupled on one same shaft and electrically displaced by $\frac{2\pi}{q}$, said stator and rotors having teeth of equal width whereby a fundamental frequency is determined for said generator by the speed of the rotors, the number of teeth on each rotor being greater than the number of stator teeth, the width of the teeth being equal to $\frac{1}{2q}$ times the tooth pitch of each rotor, where q is an integer greater than unity and representing the harmonic to be strengthened, and means including the mechanically coupled rotors for insuring the elimination of the fundamental frequency of all harmonics to be used.

4. In a variable impedance high frequency generator, in combination, a stator and a rotor each having open slots and having also teeth of equal width thereon whereby a fundamental frequency is determined for said generator by the speed of the rotor, said rotor comprising q teeth sets electrically displaced by $\frac{2\pi}{q}$, the number of teeth on each rotor set being greater than the number of stator teeth and the width of the teeth being equal to $\frac{1}{2q}$ times the tooth pitch of the rotor sets, where q is an integer greater than unity and representing the harmonic to be strengthened, and means including the q teeth sets for insuring the elimination of the fundamental frequency of all harmonics.

5. A variable impedance high frequency generator having open slots and having teeth of equal width on rotor and stator whereby a fundamental frequency is determined for said generator by the speed of the rotor, the number of rotor teeth being greater than the number of stator teeth and the width of all the teeth being equal to $\frac{1}{2q}$ times the tooth pitch of the rotor, where q is an integer greater than unity and representing the harmonic to be strengthened, and the magnetic parts of the rotor being formed of segments of thin plate provided with teeth and secured in position by means of tenons, the radius of the incurved portions of said tenons being large with respect to the height of the teeth forming the polar projections, and the number of tenons being independent of the number of teeth.

6. A variable impedance high frequency alternator having open slots and having teeth of equal width on rotor and stator, whereby a fundamental frequency is determined for said alternator by the speed of the rotor, the number of rotor teeth being equal to $\frac{1}{2q}$ times the tooth pitch of the rotor, where q is an integer greater than unity and representing the harmonic to be strengthened, the stator being provided with non-magnetic material inserted at intervals between the active laminations of the stator and the said material being provided with notches which are partially closed to maintain the windings of the stator on the armature.

7. A high frequency alternator having teeth of equal width on its rotor and stator and the width of the teeth being equal to $\frac{1}{2q}$ times the tooth pitch of the rotor where q is an integer greater than unity and represents the harmonic desired to be generated, the ratio of the number of rotor teeth to stator teeth at least being unity.

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