May 15, 1956 J. A. MAS 2,745,999

VIBRATOR

Filed Aug. 10, 1951 3 Sheets-Sheet 1

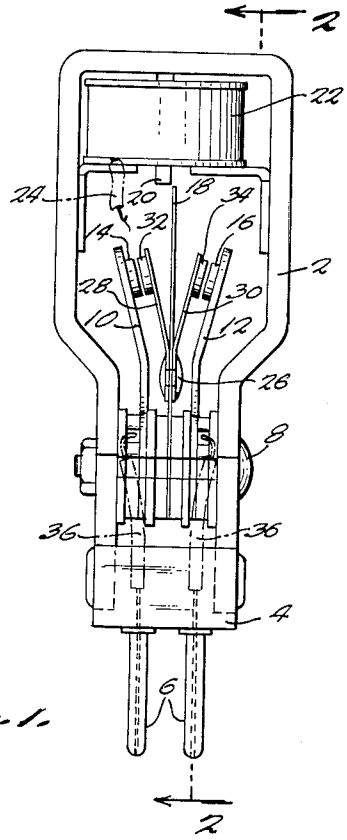


Fig. 1.

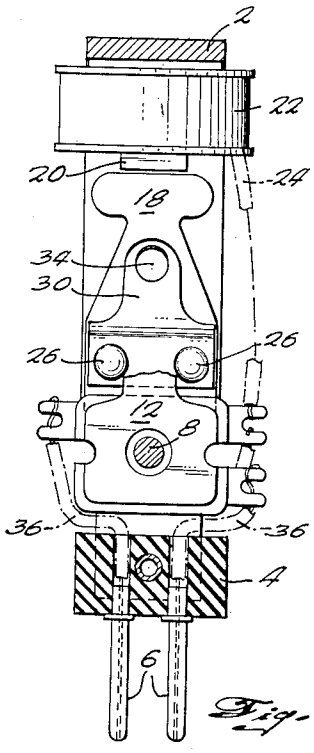


Fig. 2.

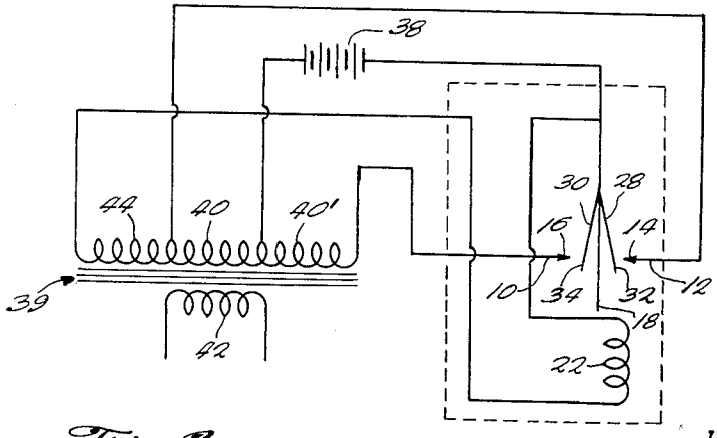


Fig. 3.

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VIBRATOR

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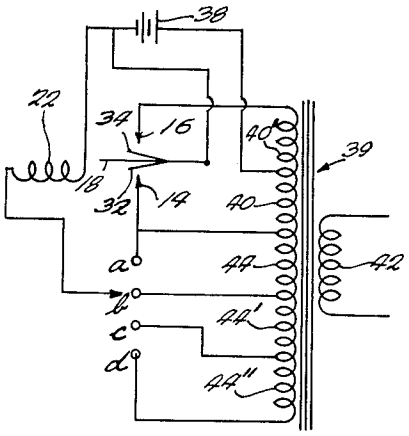


Fig. 4.

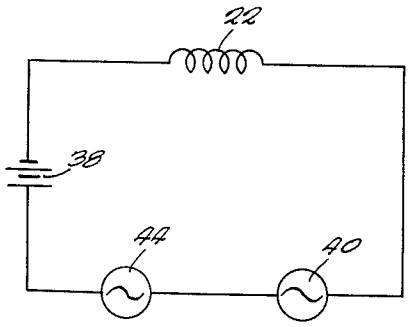


Fig. 5.

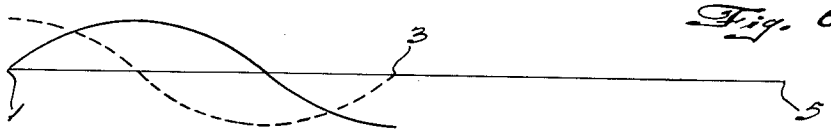


Fig. 6.

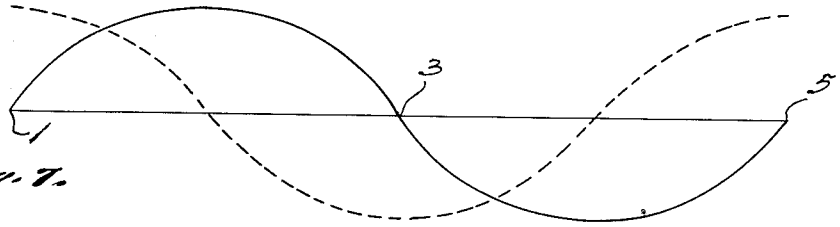


Fig. 7.

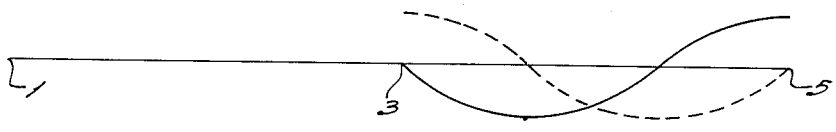


Fig. 8.

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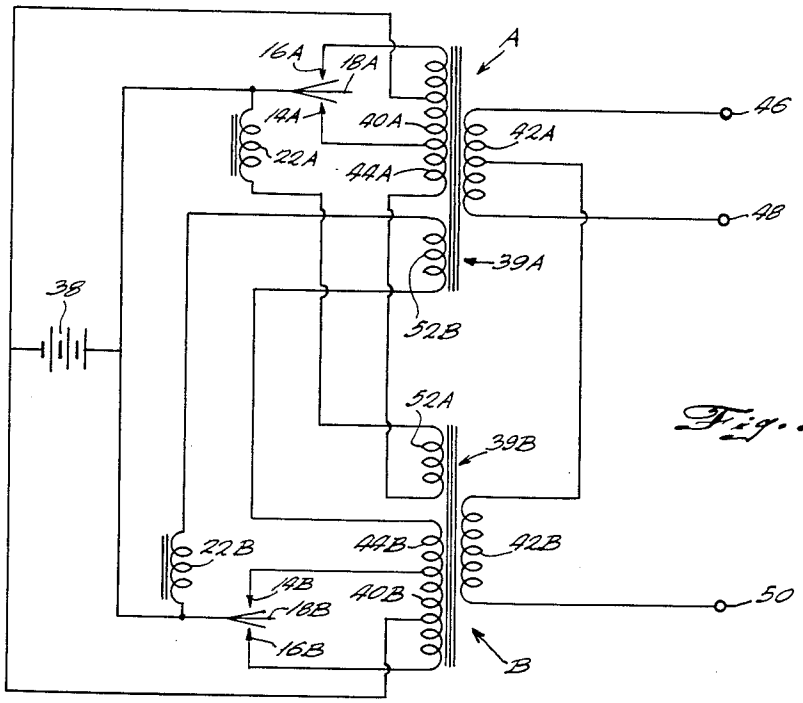


Fig. 9.

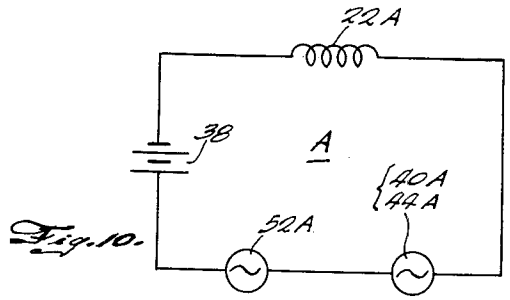


Fig. 10.

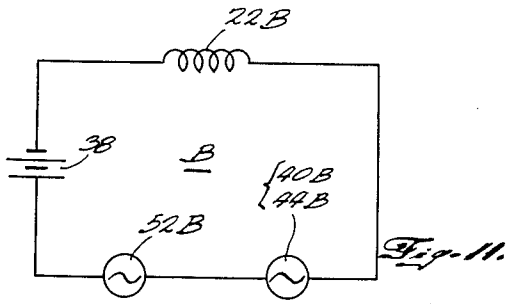


Fig. 11.

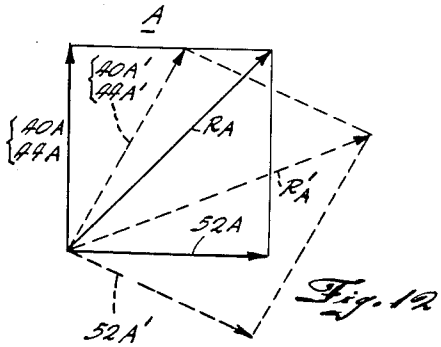


Fig. 12

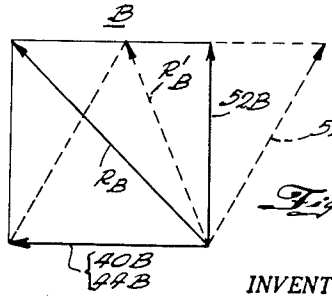


Fig. 13.

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United States Patent Office 2,745,999 Patented May 15, 1956

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VIBRATOR

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Application August 10, 1951, Serial No. 241,363

17 Claims. (Cl. 318—124)

The present invention relates to a vibrator, and particularly to the construction of the vibratile portions thereof and the means employed for causing those portions to vibrate.

Vibrators of various designs have been in comparatively widespread use, both to change direct to alternating current and to step up the voltage of a direct current source. While many problems are involved in their design, two of the most basic difficulties, each having much to do with the life of the vibrator, revolve about the efficiency or power consumption of the unit and the manner in which contact is made and broken between the relatively movable contact members which form a part of the vibrator. While efficiency or power consumption are not always prime factors in the design of units of this type, they have become exceedingly important when vibrators are used in special installations, particularly for the military, where battery power supplies are of limited capacity, where size and weight are often very formidable factors, or where the unit must operate in an enclosed space and at a comparatively high ambient temperature, so that heat losses in the unit itself cannot be neglected. When space considerations are a prime factor, and when therefore the unit must have as small dimensions as possible, problems of contact making and breaking become accentuated, because massive contact elements which could withstand appreciable mechanical and electrical abuse can no longer be employed.

When to these complicated factors is added the requirement that the vibrator should operate at a much higher frequency than has heretofore been common, such as on the order of 400 cycles per second, either to increase the voltage step-up or to produce a fluctuating or alternating current having a greater frequency, problems of design become exceedingly complicated. The production of a small, light, high frequency vibrator capable of operation without breakdown over a long period of time and using so little power that a standard direct current source can be used without difficulty, has heretofore eluded the art.

By a series of design changes based upon a careful analytical study of the nature of operation of vibrators of the type under discussion, I have been able to produce a specialized vibrator of the type above described which is as simple in structure as currently available vibrators which do not meet its operating characteristics, and which is as inexpensive as or in some cases even more inexpensive than standard commercial vibrators.

The improved operation of the vibrator of my invention derives from various improvements in the design thereof which act combinatively as well as individually and aggregatively. One such improvement is directed specifically to the contact structure, that structure including, as is conventional, a substantially rigid fixed contact member and a cooperating movable contact member secured to a central vibratile member. I have discovered that one of the important reasons for rapid breakdown of these contact members, through which an appreciable

current must be made and broken many time a second, is that the impact of the movable contact member on the stationary contact member at the moment when those members engage is often so great that bouncing occurs, giving rise to arcing which in turn causes very rapid deterioration of the contact members. In order to minimize this effect to as great a degree as possible I mount the movable contact member on the central vibratile member via a second vibratile member which has a natural frequency of vibration X.5 times the natural frequency of vibration of the central vibratile member, X being an odd integer. Consequently, at the moment when the motion of the central vibratile member causes the movable contact member to engage the fixed contact member, said movable contact member, although positioned all the way toward the fixed contact member relative to the central vibratile member so as to facilitate engagement with the fixed contact member, has no appreciable velocity relative to the central vibratile member. Thus contact engagement is made with a comparatively low relative velocity between the contacts, the tendency of the movable contact to move with respect to the central vibratile member is such as to minimize or cushion the impact between the contact members, and consequently bouncing of the contact members is avoided or minimized, a firm, instantaneous and non-arcing engagement taking place.

The tendency in the past, where a high frequency vibrator was to be designed, was to increase the thickness of the central vibratile member, thus increasing its natural frequency of vibration by increasing its stiffness. When space, weight, efficiency and power consumption were not important factors this expedient was not too unsatisfactory. However, with a stiffer or less compliant central vibratile member, more force is required to displace that vibratile member. This means that a larger driving coil must be employed, which in turn means that more power is consumed in driving the vibrator and more heat is generated within the driving coil, which heat must be dissipated.

I have found that the old approach to the problem of designing a high speed vibrator is engineeringly unsound. By departing radically from the old teachings—by maintaining the compliance at a low value and decreasing the mass of the central vibratile member—I find that a vibrator is produced which can function at a high speed without self-destruction, in an exceedingly efficient manner, and without excessive power consumption. Because the central vibratile member is light and flexible, only a small driving coil is needed. Hence the physical dimensions of the unit may be minimized, power consumption is less, and the production of heat by the vibrator is minimized.

Shunt energization of the driving coil is common in vibrators. However, for a given vibrator design this prior art method of energization is highly inefficient, since the fluctuations of magnetic attraction exerted by the driving coil on the central vibratile member by reason of the connection of the driving coil in shunt with one of the energizing coils of the vibrator are not as great as they might theoretically be. The alternating current component in the driving coil which causes the central vibratile member to vibrate never completely overcomes the direct current component in that coil, so that the coil always attracts the central vibratile member to an appreciable degree. Hence it is impossible, with conventional connections to the driving coil, to obtain proper amplitude of vibration of the central vibratile member while using a driving coil of minimal size. I have found that when an additional increment of alternating voltage is applied to the driving coil, that additional increment being generated inductively in an additional coil by

the generating coil of the vibrator, a greater amplitude of vibration of the central vibratile member can be achieved even at comparatively high frequencies. This result is attained not only without an increase in power consumption, but indeed with a small but nevertheless appreciable decrease in power consumption, the current flowing through the driving coil with the circuit of my invention being somewhat less than that which would flow through it were it conventionally connected.

The use of added increments of alternating voltage applied to the driving coil of a vibrator permits the attainment of another very desirable objective, to wit, the synchronization of a plurality of vibrators so that their outputs will bear a fixed phase relationship to one another. As here specifically disclosed, a pair of vibrators may be connected so that the driving coil of each vibrator has applied thereto an alternating voltage increment derived inductively from the generating coil of the other vibrator. These incremental alternating voltages are applied to the driving coils of the two vibrators in different senses with respect to the voltages with which they are inductively associated, and as a result the two vibrators, designed to operate at the same frequency, will have outputs which vary in phase by a fixed amount, the electrical hook-up so controlling the energization of the vibrators that any tendency on the part of one to change its fixed phase relationship with respect to the other will be compensated for instantaneously and automatically.

To the accomplishment of the above, and to the attainment of such other objects as may hereinafter appear, the present invention relates to a vibrator structure and to the manner in which various electrical connections are made, all as defined in the accompanying claims and as described in this specification, taken together with the accompanying drawings in which:

Fig. 1 is a front elevational view of a vibrator constructed according to the present invention;

Fig. 2 is a side cross-sectional view thereof taken along the line 2—2 of Fig. 1;

Fig. 3 is a circuit diagram illustrating a preferred circuit arrangement for energizing the driving coil;

Fig. 4 is a circuit diagram similar to Fig. 3 and illustrating an experimental set-up hereinafter described;

Fig. 5 is a schematic representation of the circuit of Fig. 3;

Figs. 6 7 and 8 are graphical representations of the motions of the various vibratile members which form a part of the vibrator, Figs. 6 and 8 representing the motion of outer vibratile members carrying movable contacts and mounted on opposite sides of said central vibratile member, said motion being with respect to said central vibratile member, Fig. 7 representing the motion of the central vibratile member;

Fig. 9 is a circuit diagram illustrating a manner in which two vibrators may be connected for vibration in fixed phase relationship;

Figs. 10 and 11 are equivalent circuit representations showing the circuits of the driving coils of the two vibrators of Fig. 9; and

Figs. 12 and 13 are vectoral representations of voltage relationships in the circuits of Figs. 10 and 11 respectively.

Insofar as basic structural details are concerned, vibrators of the present invention may take a variety of forms. Only one such form is here specifically disclosed, that form being similar to many standard vibrators now in wide-spread use. A frame member **2** is employed the ends of which are mounted in base **4** from which prongs **6** depend. Toward the bottom of the frame member **2** a bolt **8** is provided upon which are mounted fixed plates **10** and **12** bearing fixed contacts **14** and **16** respectively, the central vibratile member **18** being mounted at one end on the bolt **8** between the plates **10** and **12**, the other end of the central vibratile member **18** being free to vibrate and positioned close to and to one side of armature **20** depending from the top of the frame member and

surrounded by the driving coil **22**. Wires **24** extend down from the driving coil **22** to appropriate prongs **6**. Rivets or eyelets **26** secure lateral vibratile members **28** and **30** to the opposite sides of the vibratile member **18**, each of the lateral vibratile members **28** and **30** bearing movable contact members **32** and **34** respectively positioned opposite the fixed contact members **14** and **16** respectively and movable into and out of engagement therewith as the central vibratile member **18** flexes from side to side as viewed in Fig. 1. Wires **36** electrically connected to the fixed contacts **14** and **16** and to the movable contacts **32** and **34** also lead to appropriate prongs **6**. Insulating and conductive spacers are employed on the bolt **8**, as is conventional in the art. The central vibratile member **18** is made of electrically conductive material, as are the lateral vibratile members **28**, **30** and the fixed plates **10** and **12**. In addition, the central vibratile member **18** is of magnetizable material, so that it can be attracted by the armature **20** and thus be deflected from its normal central position when the driving coil **22** is energized. It is particularly to be noted that each of the vibratile members **18**, **28**, **30** are defined substantially completely by thin sheets of appropriate resilient material dimensioned and shaped to impart to them desired vibratile characteristics as determined by the design of the equipment and the frequency at which it is to operate.

Having reference now to Fig. 3, in which the dotted line encloses those elements which form a part of the vibrator unit illustrated in Figs. 1 and 2, a source of direct current such as the battery **38** has one end connected directly to the central vibratile member **18** and thus, via the lateral vibratile members **28** and **30**, to the movable contacts **32** and **34**. The other end of the battery **38** is connected to the center tap of the primary of a transformer **39**, said primary being defined by generating coils **40** and **40'**, the outer ends of the coils **40** and **40'** being connected respectively to the fixed contacts **14** and **16**. These coils are inductively associated with secondary coil **42** in which the output of the vibrator is induced. One end of the driving coil **22** is connected directly to one end of the battery **38**, the other end of the driving coil **22** being connected to the other end of the battery **38** via a second generating coil **44** and the first generating coil **40**, the coil **44** being inductively related to the coil **40** so that alternating voltages generated in the coil **40** through the making and breaking of the contact pair **14**, **32** will induce an alternating voltage in the coil **44**. While the coil **44** is here shown on the primary side of the transformer, it is to be understood that this is merely a conventional mode of representation.

The action of the vibrator insofar as the generating coils **40** and **40'** are concerned is conventional. As each contact pair **14**, **32** and **16**, **34** are alternately made and broken while the central vibratile member **18** vibrates, currents will be built up and interrupted in the generating coils **40** and **40'**, and corresponding voltages will be induced in the coils **42** and **44**. It is the circuit in which the driving coil **22** is connected which is unconventional, and a study of its operation appears to be in order.

So long as the vibrator is energized a direct current component will flow through the coil **22**, that component being equal to the voltage of the direct current source **38** divided by the combined resistances of the driving coil **22**, the generating coil **40** and the second generating coil **44**. When the vibrator is first energized, this direct current causes a magnetic field to act through the armature **20** so as to attract the central vibratile member **18** thereto, thus closing the contact pair **14**, **32**. A current will then flow through the contact pair **14**, **32**, the driving coil **22** being thereby partially shunted from across the battery **38**. The current through the coil **22** will therefore decrease, the central vibratile member **18** will be less strongly attracted toward the armature **20**, the vibratile member **18** will move back, and the contact pair **14**, **32** will be

opened. In effect, the generating coil **40** may be viewed as a source of alternating voltage which superimposes itself upon the D. C. source 38 insofar as the driving coil **22** is concerned.

Disregarding losses for purposes of simplification, the greatest alternating voltage which could be induced in the generating coil **40** is equal to the voltage of the D. C. source 38. However, since the circuit is primarily inductive its inductive reactance is much greater than its resistance at the frequencies here involved. Consequently the maximum magnitude of the component of alternating current which is superimposed on the direct current flowing through the driving coil **22** is necessarily considerably less than the magnitude of the direct curent. Therefore there is always some direct current flowing through the coil **22**. From this it follows that the coil **22** is always attracting the central vibratile member **18**, although with a fluctuating intensity. The amplitude of the central vibratile member **18** will be determined by the magnitude of the fluctuations of the current in the driving coil **22**, the greater those fluctuations, the greater the amplitude of vibration.

In order to maximize the amplitude of vibration I have employed the second generating coil **44** which, because it is inductively associated with the coil **40**, adds an increment of alternating voltage to the driving coil **22**. The generating coils **40** and **44** may conveniently be considered as separate but related sources of alternating current voltage in phase and connected in series (see Fig. 5). The added increment of alternating voltage derived from the second generating coil **44** increases the current fluctuations in the driving coil **22**, and thus increases the amplitude of vibration of the central vibratile member **18**. The optimum condition arises when the maximum amplitude of the alternating current component in the driving coil **22** just equals the direct current component therein. This may be represented by the formulas

$$I_{ac}=I_{dc}=\frac{E_{ac}}{X}=\frac{E_{dc}}{R}$$

hence

$$\frac{E_{ac}}{E_{dc}}=\frac{X}{R}$$

Simple circuit analysis and measurement will determine the actual circuit parameters which, in a given installation, will produce the above optimum result.

Fig. 4 represents an experimental set-up to demonstrate the effect of the added alternating voltage component on a vibrator operating at approximately 400 cycles per second. Connections were made to points *a*, *b*, *c*, and *d* respectively, point *a* shorting out all of the auxiliary generating coils **40**, **40'** and **40''** and thus corresponding to the normal shunt connection, and points *b*, *c* and *d* connecting one and then another of auxiliary generating coils **44**, **44'** and **44''** into the circuit so as to progressively increase the alternating voltage component applied to the driving coil **22**. Experimental results are indicated in the following tabulation, the alternating current components being indicated in their proportion to the direct current voltages.

Connection Point	AC/DC Ratio	R. M. S. Current in Driving Coil	Amplitude of Vibration of Member 18
		ma.	*in.*
a	1	95	.032
b	2	92	.062
c	3	90	.094
d	4	88	.156

It will be noted that as the alternating voltage component was increased, the amplitude of vibration of the central vibratile member **18** increased correspondingly. It will also be noted that a slight decrease in current passing through the driving coil **22** resulted. This is apparently due to the increased impedance presented in the circuit by the auxiliary generating coils **44**, **44'** and **44''**. Whatever the reason, it is noteworthy that increased amplitude of vibration resulted with an actual decrease in current flow.

Thus far only the amplitude of vibration of the central vibratile member **18** has been considered. Its frequency of vibration will be determined by its physical configuration according to the well known formula

$$f=\frac{1}{2\pi\sqrt{MC}}$$

where M is the mass of the member and C is its compliance, being defined as deflection per unit force. Compliance may be computed from the following formula:

$$C=\frac{4l^3}{Ebh^3}$$

where l is the effective length of the vibratile member, b is its effective width, h is its effective thickness and E is its modulus of elasticity.

From the above formula it is apparent that one way in which higher frequency could be obtained is by increasing the thickness of the member. While this will tend to increase the mass of the member proportionately to the increase in thickness, it will tend to decrease the compliance according to the cube of the thickness so that the overall result will be a greater frequency of vibration. However, because the compliance is decreased the deflection per unit of attractive force exerted by the driving coil **22** will also be decreased, and hence increased frequency of vibration is obtained only at the expense of decreased amplitude of vibration. In order to produce adequate amplitude of vibration it has therefore been necessary to employ a large and powerful driving coil **22**.

When considerations of size, space and weight are controlling, as is now becoming more and more prevalent, particularly in military applications, this approach is not feasible. I have found that the mass of the vibratile member may be decreased, while its compliance is retained at a normal high value, so as to obtain the desired high frequency of vibration, on the order of 400 cycles per second, even when a very small driving coil **22** is used. By way of example, standard commercial vibrators having a natural frequency of vibration on the order of 100 cycles per second have a central vibratile member **18** consisting of a thin shaped plate of resilient material to the end of which a weight is secured in order to add mass to the vibratile member and give it its proper frequency of vibration. So revolutionary is my concept, as above expressed, that I can produce a 400-cycle vibrator merely by removing the mass at the end of the central vibratile member of a conventional 100-cycle vibrator. This is in marked contrast to the prior art, which tended toward special units of difficult construction and requiring appreciable power consumption. Moreover, when connections to the driving coil are made as outlined above, a much smaller driving coil **22** can be used without sacrificing amplitude of vibration.

The higher the frequency at which the central vibratile member **18** vibrates, and for a given amplitude of vibration thereof, the greater is the maximum velocity of the movable contacts **32**, **34**. The velocity of these movable contacts at the moment when they engage their respective fixed contacts **14**, **16** is of great significance insofar as the life of the vibrator is concerned. All other things being constant, the greater the velocity of impact of the movable contact on the fixed contact, the greater is the tendency of the former to bounce. This bouncing gives rise to arcing and consequent rapid destruction of both the fixed and movable contacts. When a vibrator of high frequency is involved, the tendency to bounce is greatly accentuated, not only because the frequency of the central vibratile member **18** is increased but also because,

along the lines of the discussion immediately above, the mass of the central vibratile member is minimized by holding its thickness to as low a magnitude as practical. It follows that the movable contacts carried by the central vibratile member **18** must therefore be comparatively light, and as such they are more likely to bounce and are less able to withstand the destrictive action of the arcing which results from bouncing.

The prior art has taught that, when the movable contacts **32**, **34** are mounted on the central vibratile member **18** by means of second vibratile members **28** and **30** respectively, the natural frequency of vibration of the second vibratile members **28** and **30** should be three times that of the central vibratile member **18**. However, I have found that this relationship or ratio between the natural frequency of vibration of the various vibratile members is not optimum, because the nature of that relationship is such that at the moment of impact the movable contact has a maximal velocity relative to the fixed contact, that maximal velocity being the sum of the velocities of the central vibratile member **18** as it moves toward the fixed contact and of the appropriate movable contact relative to the central vibratile member **18** by which it is carried. With a frequency relationship of the type called for in the prior art, and bearing in mind that contact is usually made very close to the mid-point of travel of the central vibratile member **18**, the velocity of the central vibratile member **18** is a maximum at the mid-point of its vibration and, when the central vibratile member **18** is at its mid-point and moving with its maximum velocity, the second vibratile member **28** or **30** upon which the movable contact **32** or **34** is mounted will be at the mid-point of its travel relative to the central vibratile member **18**, and consequently will also be moving at its own individual maximum velocity.

I have found that the proper ratio of natural frequencies of vibration of the central vibratile member **18** with respect to the second vibratile members **28** or **30** should be 1:X.5, where X is any odd integer, and in high-frequency vibrators is preferably 1. The effect of this improved frequency relationship can be seen from a study of Figs. 6, 7 and 8, in each of which the solid lines represent displacement and the broken lines represent velocity. Fig. 7 represents the motion of the central vibratile member **18**. At point 1, at the left-hand edge of Fig. 7, the vibratile member **18** is moving away from the fixed contact **14** and toward the fixed contact **16**. In so moving the movable contact **34**, whose motion is represented by Fig. 8, engages the fixed contact **16** and therefore does not vibrate with respect to the central vibratile member **18**. At the same time the movable contact **32** is moved away from the fixed contact **14**, the second vibratile member **30** thus being free to vibrate with respect to the central vibratile member **18**. Its motion relative to the central vibratile member **18** is represented by Fig. 6. When the central vibratile member **18** has moved through half a cycle and again passes through the midpoint of its travel, as at point 3, the movable contact **32** which heretofore has been free to vibrate is brought into engagement with the fixed contact **14** and its free vibration is thus stopped. As can be seen from Fig. 6, at that instant the second vibratile member **30** is extended from the central vibratile member **18** to its full amplitude of vibration toward the fixed contact **14**, and at that instant the velocity of the movable contact **32** relative to the central vibratile member **18** is zero. Thus the engagement between the contacts **14** and **32** is made at the proper instant, and solely with the velocity of the central vibratile member **18**, the relationship of natural frequencies of vibration being such that the second vibratile member **30** adds no component of velocity thereto. During the next half of the cycle of vibration of the central vibratile member **18**, to the point 5, exactly the same effect obtains with respect to the movable contact **34** and the second vibratile member **28**, as illustrated in Fig. 8.

The above defined ratio of natural frequencies of vibration permit the use of light vibratile elements of small mass and high compliance and the use of small movable contact members **32**, **34** without adversely affecting the life of the vibrator. Engagement between fixed and movable contacts is made at the proper instant and in a firm and positive manner, with as low a velocity as is possible consistent with proper operation. Bouncing does not appreciably occur, not only because the velocity of impact is minimized but also because, substantially at the instant that engagement between contacts is made, the second vibratile member **30** or **28** would normally be tending to approach the central vibratile member **18** as that central vibratile member **18** continues to move toward the fixed contact in question. Thus the second vibratile members **28** or **30**, as the case may be, act to cushion the impact in the course of their normal and respective vibratory patterns, snuffing out any tendency toward bouncing which might be present despite the minimized velocity of impact.

In many installations a three-phase power output is required. It is conventional to produce three-phase alternating current from two-phase alternating current in which the phases are 90 degrees apart, this being accomplished through a Scott or **T** connection. However, no practical way of operating two vibrators has heretofore been available with any assurance that their outputs will constantly have a 90 degree phase relationship. The concept, as set forth above, of utilizing an inductively generated alternating voltage increment over and above that generated in the usual primary coil of the vibrator to energize the driving coil **22** permits the attainment of this very desirable objective in a simple and foolproof manner. This is illustrated in Fig. 9, where two vibrators generally designated A and B are employed, the secondary coils **42A** and **42B** of those vibrators being connected in a conventional **T** network so that three-phase alternating current is produced at the output points **46**, **48** and **50**. The energizing circuits for the driving coils **22A** and **22B** are substantially the same as those disclosed in Fig. 3, with the exception that an additional generating coil **52A** and **52B** is inserted in series with the driving coils **22A** and **22B** respectively. The generating coil **52A** is inductively connected to the generating coils **40B** and **44B** of the vibrator B, while the generating coil **52B** is inductively connected to the coils **40A** and **44A** of the vibrator A. The coils **44A** and **44B** are included in the circuit because they have the advantageous effects described above, but they could be dispensed with insofar as the application under discussion is concerned, although with a consequent loss of the advantages which they represent. The generating coils **52A** and **52B** are connected in their respective energizing circuits in opposite senses with respect to the coils with which they are inductively associated. In Fig. 9 this effect is obtained by crossing the leads to the coil **52A**, the leads to the coil **52B** not being crossed. A single direct current source **38** is employed. Figs. 10 and 11 illustrate schematically the energizing circuits for the driving coils **22A** and **22B** respectively, the circuit for the coil **22A** including the direct current source **38**, an alternating current source defined by the coils **40A** and **44A**, and another alternating current source defined by the coil **52A**. The energizing circuit for the driving coil **22B** correspondingly consists of the direct current source **38**, an alternating source consisting of the coils **40B** and **44B**, and another alternating source derived from the coil **52B**.

The alternating voltages involved are graphically represented in Figs. 12 and 13, Fig. 12 representing vibrator A and Fig. 13 representing vibrator B. The solid line vectors represent the normal situation, with the voltage derived from the coils **40A** and **44A** leading the voltages derived from the coils **40B** and **44B**, the coils **52A** and **52B** being wound and connected so that the voltage from

coil 52B is in phase with the voltage 40A, 44A with which it is inductively associated, and the voltage from said coil 52A is 180° out of phase with the voltage from coils 40B, 44B. The resultant voltages are R_A and R_B which will be seen to be 90 degrees out of phase. These resultants represent the effective alternating voltages in the driving coils 22A and 22B respectively, and hence the central vibratile members 18 of those vibrators will be caused to vibrate at their natural frequency of vibration, that natural frequency being the same for both vibrators, but 90 degrees out of phase. In Figs. 12 and 13 the voltages derived in the coils 52A and 52B are shown as being equal in magnitude to those derived from the coils 40A and 44A, 40B and 44B respectively, but this is not essential, a 90 degree phase relationship between R_A and R_B being achievable so long as voltage 52A equals voltage 52B in magnitude and voltage 40A, 44A equals 40B, 44B in magnitude.

The above described circuit connection ensures that the two vibrators A and B, once started, will continue to vibrate in their desired phase relationship. The broken line vectors in Figs. 11 and 12 illustrate an instantaneous situation which might occur if the central vibratile member 18 of the vibrator A started to move in advance of its normal phase relationship with respect to the vibratile member 18 of the vibrator B. The voltage produced by coils 40A and 44A will thus advance in phase, as represented by the vector 40A', 44A'. The voltage generated in coil 52B will therefore also advance in phase, as represented by vector 52B'. The effect of the voltage 52B' on the driving coil 22B when combined with the voltage 40B, 44B, is represented by the vector R'_B. This vector leads R_B, thus indicating that the vibrator B will speed up, thus advancing the voltage 40B, 44B in phase. This will in turn cause the voltage 52A to advance in phase, as represented by the vector 52A'. When the voltage 52A' combines with the voltage 40A', 44A', a resultant voltage R'_A is produced which in advance of R_A and which will, after sufficient time for interaction between the two vibrators, become once again 90 degrees out of phase with respect to the vector R'_B. In other words, while the two vibrators A and B will have substantially the same frequency of vibration, one of these vibrators will take control and the other will accommodate itself exactly to the frequency of vibration of the first and will vibrate in such a manner as to produce an output voltage 90 degrees out of phase with respect to the output voltage of the controlling vibrator.

The features of design above set forth all cooperate to produce a vibrator particularly adapted for high speed operation which may be inexpensively produced, which may be small and light in construction so that it may be employed in special installations where those features are significant, which will consume only small amounts of power, and the life of which will compare favorably with, and in most cases even exceed, the life of standard vibrators which are much larger, heavier and less efficient than the vibrator of the instant iinvention. By reducing the thickness of the vibratile members so that their natural frequencies of vibration increase because of reduced mass and without sacrifice of compliance, high frequencies are attained and proper amplitudes of vibration are produced with consumption of a minimal amount of power in the driving coils. Positiveness of operation is increased by adding an increment of alternating current to the driving coils over and above that normally produced by shunt connection of such coils. By properly relating the natural frequencies of the vibratile members which directly carry the movable contacts to the natural frequency of vibration of the central vibratile member on which they are mounted, proper contact engagement is produced, bouncing and arcing are minimized or eliminated, and the life of the contacts, and hence of the vibrator, is greatly extended. If incremental alternating voltages applied to the driving coil are derived from the generating coils of other vibrators, and if those increments are properly related in phase with respect to the other alternating voltages applied to the respective driving coils, a plurality of vibrators may be electrically linked together so as to vibrate, and hence produce alternating or fluctuating voltage outputs, having a predetermined, constant, and automatically maintained phase relationship.

While but a single vibrator structure has been here disclosed, and the embodiments have been specifically described with respect to that structure, it will be apparent that many variations may be made in the vibrator structure, and in the manner in which the various elements thereof coact, all within the spirit of the present invention as defined in the following claims.

I claim:

1. In a vibrator comprising a fixed contact, a first vibratile member having a natural frequency of vibration, means for causing said first vibratile member to vibrate, and a movable contact periodically engageable with and disengageable from said fixed contact and mounted on said first vibratile member via a second vibratile member having a different natural frequency of vibration; the improvement which comprises the natural frequencies of vibration of said first and second vibratile members being in the ratio of 1:X.5, where X is any odd integer.

2. In a vibrator comprising a fixed contact, a first vibratile member having a natural frequency of vibration, means for causing said first vibratile member to vibrate, and a movable contact periodically engageable with and disengageable from said fixed contact and mounted on said first vibratile member via a second vibratile member having a different natural frequency of vibration; the improvement which comprises the natural frequency of vibration of said first and second vibratile members being in the ratio of 1:1.5.

3. A high speed, low power vibrator comprising a fixed contact, a vibratile member carrying a movable contact engageable with said fixed contact and having a comparatively high natural frequency of vibration, and electromagnetic means controlled by engagement and disengagement of said fixed and movable contacts for vibrating said member, said member having high compliance and low mass, said movable contact being mounted on said vibratile member via a second vibratile member having a natural frequency of vibration X.5 times the natural frequency of vibration of said first mentioned vibratile member, where X is any odd integer.

4. A high speed, low power vibrator comprising a fixed contact, a vibratile member carrying a movable contact engageable with said fixed contact and having a comparatively high natural frequency of vibration, and electromagnetic means controlled by engagement and disengagement of said fixed and movable contacts for vibrating said member, said member being substantially completely defined by a thin resilient sheet having high compliance and low mass, said movable contact being mounted on said vibratile member via a second vibratile member having a natural frequency of vibration X.5 times the natural frequency of vibration of said first mentioned vibratile member, where X is any odd integer.

5. A high speed, low power vibrator comprising a fixed contact, a vibratile member carrying a movable contact engageable with said fixed contact and having a comparatively high natural frequency of vibration, and electromagnetic means controlled by engagement and disengagement of said fixed and movable contacts for vibrating said member, said member being substantially completely defined by a thin resilient sheet having high compliance and low mass, said movable contact being mounted on said member via a second vibratile member substantially completely defined by a thin resilient sheet having a natural frequency of vibration X.5 times the natural frequency of vibration of said first mentioned vibratile member, where X is any odd integer.

6. In a vibrator having a vibratile member and a driving coil active upon said member so as to make it vibrate at a predetermined frequency, said driving coil being energized by a D. C. source upon which is superimposed an A. C. voltage the frequency of which is controlled by the vibration of said member; the improvement which comprises having the A. C. voltage greater than the D. C. voltage.

7. In a vibrator having a vibratile member and a driving coil active upon said member so as to make it vibrate at a predetermined frequency, said driving coil being energized by a D. C. source upon which is superimposed an A. C. source the frequency of which is controlled by the vibration of said member; the improvement which comprises having the A. C. voltage greater than the D. C. voltage substantially by the ratio between the reactance of said driving coil at said predetermined frequency and its resistance.

8. A vibrator comprising a fixed contact, a driving coil, a vibratile member acted upon by said driving coil so as to vibrate at a predetermined frequency and carrying a movable contact engageable with said fixed contact, a D. C. voltage source, a first generating coil connected to said D. C. voltage source via said contacts, a second generating coil inductively connected to said first generating coil, and fixed electrical connections between said D. C. source, said driving coil and said generating coils so that said coils and source are connected in series independently of said contacts, said second generating coil adding an increment of alternating voltage to said driving coil in addition to that derived from said first generating coil.

9. The vibrator of claim 8 in which the maximum instantaneous value of the sum of the alternating voltages produced in said generating coils is related to the value of said direct voltage substantially as the ratio between the reactance of said driving coil at said predetermined frequency and its resistance.

10. The vibrator of claim 8 in which said movable contact is mounted on said vibratile member via a second vibratile member, said first and second vibratile members having natural frequencies of vibration in the ratio of 1:X.5, where X is any odd integer.

11. The vibrator of claim 8 in which the maximum instantaneous value of the sum of the alternating voltages produced in said generating coils is related to the value of said direct voltage substantially as the ratio between the reactance of said driving coil at said predetermined frequency and its resistance and in which said movable contact is mounted on said vibratile member via a second vibratile member, said first and second vibratile members having natural frequencies of vibration in the ratio of 1:X.5, where X is any odd integer.

12. The vibrator of claim 8 in which said vibratile member is substantially completely defined by a thin resilient sheet having high compliance and low mass.

13. The vibrator of claim 8 in which said vibratile member is substantially completely defined by a thin resilient sheet having high compliance and low mass and in which said movable contact is mounted on said vibratile member via a second vibratile member, said first and second vibratile members having natural frequencies of vibration in the ratio of 1:X.5, where X is any odd integer.

14. The vibrator of claim 8 in which said vibratile member is substantially completely defined by a thin resilient sheet having high compliance and low mass, in which said movable contact is mounted on said vibratile member via a second vibratile member, said first and second vibratile members having natural frequencies of vibration in the ratio of 1:1.5, and in which the maximum instantaneous value of the sum of the alternating voltages produced in said generating coils is related to the value of said direct voltage substantially as the ratio between the reactance of said driving coil at said predetermined frequency and its resistance.

15. First and second synchronized vibrators, each having a vibratile member, a driving coil active on said member to cause it to vibrate, relatively movable contacts controlled by said member, a source of D. C. power connected via said contacts to a first generating coil, and an energizing circuit for said driving coil including said D. C. source, said first generating coil and a second generating coil inductively connected to the first generating coil of said other vibrator, one of said second generating coils being oriented in its circuit in a different sense from the other with respect to the first generating coils with which they are respectively inductively associated whereby the voltages generated in said first generating coils of said first and second vibrators maintain a fixed phase relationship.

16. First and second synchronized vibrators, each having a vibratile member, a driving coil active on said member to cause it to vibrate, relatively movable contacts controlled by said member, a source of D. C. power connected via said contacts to a first generating coil, and an energizing circuit for said driving coil including said D. C. source, said first generating coil and a second generating coil inductively connected to the first generating coil of said other vibrator, one of said second generating coils being oriented in its circuit in a different sense from the other with respect to the first generating coils with which they are respectively inductively associated, whereby the voltages generated in said first generating coils of said first and second vibrators maintain a fixed phase relationship and the magnitudes of the voltages generated in the first and second generating coils of said first vibrator being equal respectively to the magnitudes of the voltages generated in the first and second generating coils of said second vibrator, whereby the voltages generated in said first generating coils of said first and second vibrators maintain a 90 degree phase relationship.

17. The synchronized vibrator of claim 15, in which the energizing circuit for each of said vibrators includes an auxiliary generating coil inductively connected to said first generating coil of the vibrator in question and adding an increment of alternating voltage to the driving coil thereof, in addition to and in phase with that derived from said first generating coil.

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