May 25, 1948. C. HUETTEN 2,442,270

VIBRATOR

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Fig. 1

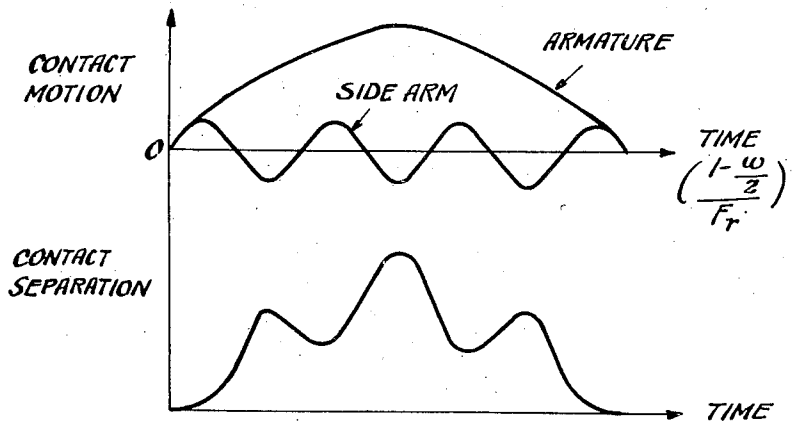
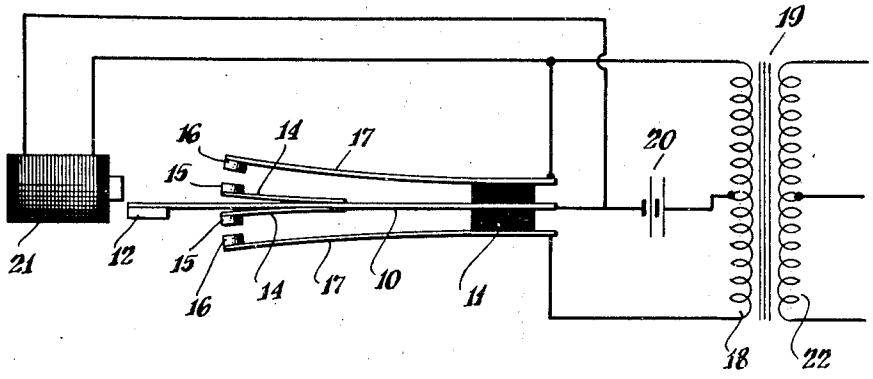


Fig. 2



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VIBRATOR

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8 Claims. (Cl. 172—126)

1

The present invention relates to vibrators, and, more particularly, to vibratory electromagnetic interrupters of novel and improved character.

As those skilled in the art know, vibratory interrupters may be considered to be vibratory systems in which damped forced vibrations are set up. For very low frequencies the damping is also very low so that the forcing power input may be likewise quite low. For higher frequencies the damping becomes greater and more power input to the system is required unless the system is modified to keep the damping low. Damping has the further effect of reducing the frequency of the vibratory system below its natural frequency as determined by its masses and compliances.

The simplest and most economical vibrator is the one having a single driver coil. This results, however, in an asymmetrical effect due to the unequal distribution of the magnetic driving force over a cycle of the vibrator armature. Therefore, if damping can be kept low, the power input and its accompanying asymmetry may be reduced and the frequency may be increased by virtue of the low damping itself.

The major portion of damping in a vibrator results from one contact striking another. This produces spurious high-frequency vibrations resulting in contact chatter and reflects vibrations into other parts of the vibratory system. Since the contacts must come together during the normal operation of the vibrator, they will do so with a finite velocity and it cannot be expected to completely eliminate this effect. The lost energy may be represented by the expression $\frac{1}{2}MV^2$, where M is the mass of the contacts and associated parts and V is their velocity at "make." M may be somewhat reduced by reducing the mass of the contacts but very little improvement may be expected in this direction as a reasonable length of vibrator life is predicated upon the provision of satisfactory contacts. On the other hand, V may be reduced without detrimental effects, and, as a matter of fact, such reduction of V is desirable because the loss of energy is proportional with the square of V.

Another factor determining damping is the sliding of one contact surface against another during the time the contacts are together. Unless this contact sliding is minimized, variation of contact surfaces with life causes asymmetrical effects and considerable damping.

At the present time, the best method of obtaining a low V at make is to tune the reed arms so that the natural frequency of each of said

2

arms is equal to N times the natural frequency of the reed, where N is an odd integer. This principle and its practical applications to a vibratory interrupter are disclosed in U. S. Patent No. 2,197,607 to Harold J. Brown, issued on April 16, 1940. Although this principle has provided excellent results and permitted the manufacture of vibrators having superior operational characteristics, certain difficulties have been experienced in manufacturing such vibrators on a quantity production scale. As the synchronization of the tuned reed arms depended upon the perfect selection and accurate relation of the masses and compliances of the several parts and since parts and dies must have certain practical tolerances and the selection of parts also requires tolerances, perfect synchronization was difficult to attain and to maintain from day to day in large scale production without a relatively great expenditure of time and labor.

It is an object of the present invention to provide a solution for the outstanding problem and to eliminate the foregoing difficulties experienced in the manufacture of vibrators of the described type.

It is another object of the present invention to provide a vibrator of novel and improved character in which the advantages of frequency correlation of the several vibratory parts, including reduction of the velocity of contact "make," may be obtained without critical parts selection and with reasonable manufacturing tolerances which may be considerably higher than heretofore possible.

It is a further object of the invention to provide a vibratory interrupter in which not only the reed or contact arms but also the side arms are tuned to frequencies in predetermined harmonic relation to the reed frequency with attendant reduction in the velocity of contact "make" and increase in the operational efficiency of the vibrator.

It is also within the contemplation of the invention to provide a vibrator in which both the reed arms and the side arms are tuned so that tuning of each tunable part is attained at different points and the vibrator may be properly adjusted somewhere between the tunable points of the component parts, thus permitting reasonable manufacturing tolerances.

The invention also contemplates a vibratory interrupter with reed, reed arms, and side arms tuned to harmonically related frequencies which combines high operational efficiency with simplicity of construction and manufacture.

Other and further objects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawing, in which:

Fig. 1 illustrates a graph representing the contact separation during the "off-contact" time in a vibrator; and

Fig. 2 depicts a circuit diagram of one type of circuit in which the vibrator of the invention may be used.

While a preferred embodiment of the invention is described herein, it is contemplated that considerable variation may be made in the method of procedure and the construction of parts without departing from the spirit of the invention. In the following description and in the claims, parts will be identified by specific names, for convenience, but they are intended to be as generic in their application to similar parts as the art will permit.

Referring now more particularly to Fig. 2 of the drawing, the vibrator of the invention is shown in a diagrammatic manner in a conventional circuit organization. The vibrator essentially comprises a vibratory reed 10 clamped in a stack 11 at one end thereof and carrying an armature or weight 12 at the other end thereof. Reed 10 has a pair of reed or contact arms 14 secured to an intermediate portion thereof, carrying at their ends vibratory contacts 15. The said vibratory contacts cooperate with relatively stationary contacts 16, mounted at the ends of side springs 17, which are likewise clamped in stack 11. The two side springs are connected to the two ends of primary winding 18 of a transformer 19, a source of low voltage direct current 20 being connected between reed 10 and the center tap of the primary winding. A driver coil 21 is connected between reed 10 and one of side springs 17. As those skilled in the art know, in a circuit of the described type reed 10 will be maintained in continuous vibration and current from the source will be alternately passed in opposite directions through the two halves of the primary winding in a manner well understood. A high alternating voltage will be induced in secondary winding 22 of the transformer, and such voltage may be rectified in any conventional manner, such as by means of rectifier tubes or by means of a set of synchronous rectifier contacts carried by the reed.

Broadly stated, the preferred procedure for obtaining a low velocity V of contact "make" is to tune the reed arms to a frequency harmonically related to the reed frequency. In such case, the frequency of the tuned vibratory member may be represented by the equation:

$$F_h = \frac{F_r(N+.5)}{1-\frac{W}{2}}$$

where F_h is the frequency of the oscillating member during "off contact" time, F_r is the reed or armature frequency, N is an integer, and W is the vibrator "time efficiency."

The application of the above equation to the described vibrator structure may be better understood in the light of the following description. Assuming that the vibrator is functioning, each operating cycle consists of a period when the upper set of contacts 15, 16 is closed, a period during which the lower set of contacts 15, 16 is closed, and an interval when both sets of contacts are open. The vibrator "time efficiency" W expresses the percentage of each cycle during

which one or the other set of contacts is closed. As a result, the symbol

$$\frac{W}{2}$$

denotes the percentage of each cycle during which any one individual set of contacts is closed. Accordingly, the expression

$$1-\frac{W}{2}$$

represents the percentage of each cycle when any one individual set of contacts is open.

According to one aspect of the invention, it is desired that the upper reed arm 17 and contact 16, for example, shall vibrate through an odd number of half cycles during each open contact period. That is to say, the unit consisting of upper reed arm 17 and contact 16 must make (N+.5) vibrations during each open contact period, the length of which, as previously stated, may be represented by the expression

$$1-\frac{W}{2}$$

This factor multiplied by the reed frequency F_r obviously yields the necessary tuned frequency F_h of the vibrating unit to cause it to vibrate through an odd number of half cycles during each open contact period. The desired relation is shown by the upper part of the graph in Figure 1 wherein it will be noted that the side arm vibrates through seven half cycles during a single open contact period, the length of which is represented by the abscissa of the "armature" curve.

If the oscillation of the tuned side arm is plotted during the off-contact interval and the effective armature motion on the mating contacts is subtracted therefrom, a graph indicating the contact separation during the "off-contact" time is obtained, as this is indicated in Fig. 1. It will be noted from this figure that the contact separation changes slowly at time

$$\frac{1-\frac{W}{2}}{F_r}$$

in other words V is small at the time the contacts make. The graph of Fig. 1 has been obtained by making N equal to 3, but similar conditions will result for other integer values of N. However, for any value of N it will be found that the vibrators can stand a limited variation in their various compliances and masses and still may utilize this effect to advantage. The necessary limits are difficult to hold in production because of the peaked resonance characteristics of a mechanical vibratory system of low damping.

In accordance with the invention, the problems arising from the aforesaid peaked resonance characteristics are eliminated or substantially minimized by selecting the natural frequencies of both the reed arms and the side arms in accordance with the aforementioned formula and in accordance with the principles now to be explained. For convenience, when the frequency relationship established by the formula exists between the reed arms or side arms and the reed, that is when the reed arms or side arms vibrate through an odd number of half cycles during each open contact period, the reed arms or side arms will be said to be in synchronism with the reed or to have maximum tuning. It has been found that when the side arms are adjusted so that they are in synchronism at a frequency slightly

above the frequency of the vibrator and the reed arms are in synchronism at a frequency slightly lower than that of the vibrator, the problem of peaked resonance characteristics is substantially eliminated but the advantages of the invention in reducing the velocity of contact making and breaking are nevertheless obtained. This also holds true when the reed arms are in synchronism at a frequency slightly higher than that of the vibrator and the side arms are in synchronism at a frequency slightly lower than that of the vibrator.

It will be understood also that, when the reed arms are adjusted, according to the formula, to have a predetermined natural frequency, there will be several reed frequencies, herein referred to as synchronously related reed frequencies, at which the condition of synchronism or maximum tuning will occur. Likewise, for a given predetermined natural frequency of the side arms, there will be several reed frequencies at which synchronism will occur. At any of these reed frequencies, the advantages of the invention resulting from decreased velocity of contact making and breaking are obtained. These facts may be better understood by reference to Figure 1 wherein it will be seen that the side arms are in synchronism since they pass through seven half cycles during each open contact period, the length of said open contact period being defined by the abscissa of the "armature" curve. It will be apparent that the side arms will also be in synchronism with the reed at a synchronously related reed frequency such that the armature curve includes only five half cycles of the side arm curve. Similar conditions will prevail when the reed frequency is such that the armature curve includes nine or any other odd number of half cycles of the side arm curve. At each of the synchronously related reed frequencies determined by the above conditions, the problem arising from peaked resonance characteristics may be eliminated by insuring that the reed arms are in synchronism at a frequency slightly higher than that of the vibrator while the side arms are in synchronism at a frequency slightly lower than that of the vibrator, or vice versa. Alternatively, good results may be obtained by adjusting the reed arms for maximum tuning at two synchronously related reed frequencies in the manner just described and adjusting the side arms for maximum tuning at an intermediate frequency between said synchronously related frequencies. Obviously, the side arms may be adjusted for maximum tuning at two synchronously related reed frequencies and the reed arms adjusted to the intermediate frequency, if desired. While the improved damping qualities and advantages resulting from decreased contact velocity are not to pronounced in this case as in the examples previously discussed, considerable improvement over conventional vibrators is nevertheless obtained. The last modification has the additional advantage that it is not at all critical as to frequency but, instead, gives improved results over a large band of vibrator frequencies.

In order to give those skilled in the art a better understanding of the invention, the following numerical example may be given:

Let it be assumed that a vibrator is required to have a frequency of 250 cycles per second, plus or minus 10 cycles per second. In accordance with the invention, the reed arms would have maximum tuning at 240 cycles per second, and the side arms would have maximum tuning at 260

cycles per second reed frequency. In this case let N equal 3 and the vibrator time efficiency W equal 90%. The reed arm compliance and the associated contact mass should be such that the resonant frequency will be:

$$F_h=\frac{F_r.(N+.5)}{1-\frac{W}{2}}=\frac{240(3.5)}{1-\frac{.90}{2}}=1526 \text{ cycles/sec.}$$

At the same time the side arm compliance and the associated contact mass should be so selected that its resonant frequency will be:

$$F_h=\frac{F_r.(N+.5)}{1-\frac{W}{2}}=\frac{260(3.5)}{1-\frac{.90}{2}}=1654 \text{ cycles/sec.}$$

When the reed arm and side arm frequencies are approximately as given in the foregoing equations, then the closer the vibrator frequency is to 240 cycles per second, the more aptly the reed arms will tend to assume maximum tuning and the closer the vibrator frequency comes to 260 cycles per second, the closer the side arms will come to assuming maximum tuning action. In other words, with a wider variation of compliances and masses, the vibrator will still be properly tuned for best operation.

Considering the foregoing specific example in a more general way, let it be further assumed that the production tolerances were such that it was necessary to have an even greater range of frequency and that a certain number of vibrators would operate at less than 240 cycles per second. Of course, the resonant frequencies of the contact bearing members would be substantially the same as with the higher frequency units. In this case, the side arms would come into synchronization but instead of oscillating 3.5 cycles during the off-contact interval, the side arms would oscillate 4.5 cycles during the same interval. The frequency for perfect synchronization would be:

$$F_r=\frac{F_h\left(1+\frac{W}{2}\right)}{N+.5}=\frac{1654(.55)}{4.5}=202 \text{ cycles/sec.}$$

In this numerical example, the frequency of the side arms is 1654 cycles per second, that is, "suitable" for N=3 and N=4. By "suitable," it is meant that the selection of N is restricted by the design and by the general characteristics of the vibrator. For example, N could not be much greater than 4, because otherwise the amplitude of harmonic motion would be too small. On the other hand, if N were too small, the harmonic motion amplitude might be too great for this particular design. In general, in the instant case, the side arms will all have the same resonant frequency such as 1654 cycles per second, and the reed arms will likewise all have the same resonant frequency, such as 1526 cycles per second.

There are a number of variables which determine the vibrator frequency, some of all of which may vary from unit to unit. These variables include not only the masses and compliances of the system, but also the contact spacing, air gap spacings, voltage range, etc. Let us take cases where the weights (one of the variables), are such as to give reed frequencies in the range of 202 cycles per second to 260 cycles per second.

In a 202 cycle vibrator (heaviest weight), the side arms will oscillate harmonically at maximum amplitude.

In a vibrator whose frequency is greater than 202 cycles per second but less than 240 cycles per second (heavy weight), the side arms and reed arms will both oscillate but at less than maximum amplitude.

In a 240 cycle vibrator (medium weight), the reed arms will oscillate harmonically at maximum amplitude.

In a vibrator whose frequency is greater than 240 cycles per second but less than 260 cycles per second (light weight), the side arms and reed arms will both oscillate but at less than maximum amplitude.

In a 260 cycle vibrator (lightest weight), the side arms will oscillate harmonically at maximum amplitude.

In each of these cases, the mating contacts will experience the desired harmonic motion due to the motion of the reed arms, the side arms, or both. In other words, the advantages of the invention, such as the low velocity contact "make," are readily and positively obtained for a very wide range of vibrator frequencies.

In self-rectifying vibrators in which the rectifier contact time efficiencies are lower than the interrupter contact time efficiencies, the optimum rectifier side arms resonant frequency will be slightly lower, as calculated by the equation.

While the present invention, as to its objects and advantages, has been described herein as carried out in specific embodiments thereof, it is not desired to be limited thereby but it is intended to cover the invention broadly within the spirit and scope of the appended claims.

What is claimed is:

1. A vibratory interrupter comprising in combination a vibratory reed the frequency of which may vary between F_1 and F_2 clamped at one end thereof and having an armature mounted on the other end thereof, a tuned reed arm for each side of said reed having one end secured to the reed and bearing a vibratory contact at its other end, a tuned side arm for each reed arm clamped at one end and bearing a relatively stationary contact at its other end adapted to cooperate with the respective vibratory contact, and electromagnetic driver means under the control of said contacts to maintain the reed in vibration, the frequency of said tuned reed arms during off-contact time being harmonically related to F_1 and the frequency of said tuned side arms during off-contact time being harmonically related to F_2 whereby a low contact-making velocity of said cooperating contacts is obtained throughout the frequency range of the vibratory reed.

2. A vibratory interrupter comprising in combination a vibratory reed the frequency of which is in the range F_1 to F_2, a first set of contacts supported by said reed and having a resonant frequency of about

$$F_1\frac{(N+.5)}{1-\frac{W}{2}}$$

a second set of contacts adapted to cooperate with said first set supported independently of said reed and having a resonant frequency of about

$$F_2\frac{(N+.5)}{1-\frac{W}{2}}$$

wherein N is an integer and

$$1-\frac{W}{2}$$

is the fractional part of the period of a cycle during which no contact engagement exists, and electromagnetic driving means under the control of said contacts to maintain the reed in vibration.

3. A vibratory interrupter comprising in combination a vibratory reed the frequency of which is in the range of F_1 to F_2, a tuned reed arm for each side of said reed having one end fixed thereon and supporting a contact for vibration at its other end, a tuned side arm for each reed arm fixed at one end and supporting a contact for vibration and cooperation with a reed arm contact at its other end, and a driver electromagnet under the control of said contacts for maintaining the reed in vibration, the resonant frequency of said reed arms being approximately

$$F_1\frac{(N+.5)}{1-\frac{W}{2}}$$

and the resonant frequency of said side arms being approximately

$$F_2\frac{(N+.5)}{1-\frac{W}{2}}$$

wherein N is an integer and

$$1-\frac{W}{2}$$

is the fractional part of the period of a cycle during which no contact engagement exists.

4. A vibratory interrupter comprising in combination, a vibratory reed, a set of reed arms mounted on said reed, a vibratory contact carried by each of said reed arms, a relatively fixed contact adapted to cooperate with each of said vibratory contacts, a set of side arms, one for supporting each of said fixed contacts, and electromagnetic driving means under the control of said reed to maintain the reed in vibration, one of said sets of arms being tuned to synchronism at a frequency slightly higher than that of the reed, the other set of arms being tuned to synchronism at a frequency slightly lower than that of the reed.

5. A vibratory interrupter comprising, in combination, a vibratory reed the frequency of which may be between two predetermined values clamped at one end thereof and carrying an armature at the other end thereof, a set of reed arms, one of which is mounted on each side of said reed, a vibratory contact at the end of each of said reed arms, a relatively fixed cooperating contact for each vibratory contact, a set of side arms for supporting the respective fixed contacts, and a driver coil under the control of said reed to apply deflecting force to said armature thereby to maintain the reed in vibration, one of said sets of arms being tuned to synchronism with the reed at the higher of said two predetermined frequency values, the other of said sets of arms being tuned to synchronism with the reed at the lower of said two predetermined frequency values.

6. A vibratory interrupter comprising, in combination, a vibratory reed the frequency of which may be between F_1, and F_2 clamped at one end thereof and having an armature at the other end thereof, a set of arms, one of which is mounted on each side of said reed, a vibratory contact at the end of each of said reed arms, a relatively fixed cooperating contact for each of said vibratory contacts, a set of side arms supporting the respective fixed contacts, and a driver electromagnet adapted to be energized under the control

of said contacts to apply deflecting force to said armature and to maintain the reed in vibration, one of said sets of arms being tuned to vibrate through an odd number of half cycles during each open contact period when the reed is vibrating at frequency F_1, the other of said sets of arms being tuned to vibrate through an odd number of half cycles during each open contact period when the reed is vibrating at frequency F_2 whereby a low contact-making velocity of said cooperating contacts is obtained.

7. A vibratory interrupter comprising in combination a vibratory reed, a tuned reed arm for each side of said reed having one end secured thereto and supporting a contact for vibration at its other end, a tuned side arm for each reed arm clamped at one end and supporting a contact for vibration and for cooperation with a reed arm contact at its other end, and electromagnetic driver means under the control of said reed to maintain the reed in vibration, the compliance of and the contact mass carried by one set of said arms being so determined that said set of arms is in synchronism with the reed at two synchronously related reed frequencies, the compliance of and the contact mass carried by the other set of said arms being so determined that said set of arms is in synchronism at an intermediate frequency between said synchronously related frequencies.

8. A vibratory electromagnetic interrupter

comprising in combination a vibratory reed clamped at one end thereof and having a ferromagnetic weight at the other end thereof, a tuned reed arm for each side of said reed having one end fixed on the reed and supporting a contact for vibration at its other end, a tuned side arm for each reed arm fixed at one end and supporting a contact for vibration and cooperation with a reed arm contact at its other end, and a driver electromagnet asymmetrically mounted with respect to the reed adapted to apply deflecting force under the control of said contacts to said weight and to maintain the reed in vibration, one set of arms being tuned for synchronism with the reed at two synchronously related reed frequencies, the other set of arms being tuned for synchronism with the reed at an intermediate frequency between said synchronously related reed frequencies.

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