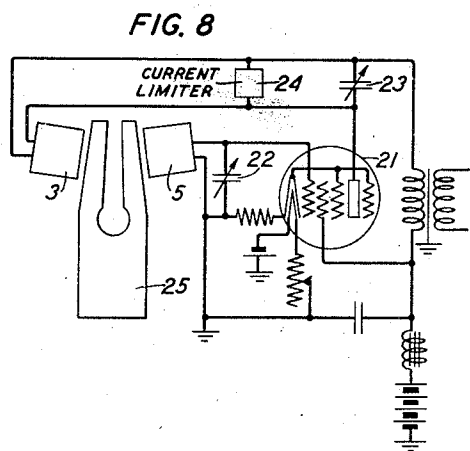
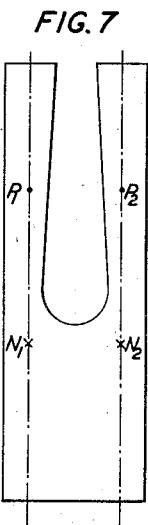
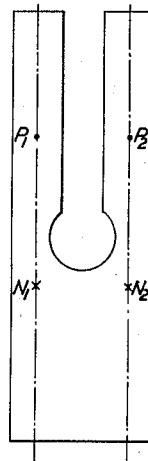


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INVENTOR
S.E. MICHAELS
BY E. V. Griggs
ATTORNEY

UNITED STATES PATENT OFFICE

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TUNING FORK

Simon Eugene Michaels, Woodhaven, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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8 Claims. (Cl. 84-409)

This invention relates to mechanically vibrating devices and more particularly to tuning forks.

An object of the invention is to reduce the effect upon the frequency of an electrically driven tuning fork introduced by its mechanical supports so that the vibrating frequency of the fork may remain substantially unchanged when the fork is removed from its support and again replaced therein.

Another object of the invention is to reduce the coupling between the longitudinal vibration of the stem of the fork and the lateral vibration of the tines.

The vibration of tuning forks is rather complex. As the tines flex laterally toward and away from the central longitudinal axis of the fork the effect of their masses may be viewed as equivalent to that of the same masses concentrated at their respective centers of mass and vibrating in similar fashion. Experimental studies show that for each tine this vibration is in the nature of an arcuate oscillation about a corresponding nodal point in the stem of the fork. The arcuate motion may be resolved into two components, one of which is lateral or transverse to the longitudinal central axis of the fork and the other of which is parallel to that axis. The parallel or longitudinal component tends to cause displacement of a portion of the stem and its support and thus to couple with the lateral vibration of the tines a longitudinal vibration of masses extending down into the stem portion of the fork which may give rise to considerable energy dissipation thus lowering the selective characteristic of the fork. Moreover, any change in the mounting of the fork, such as inevitably occurs when the fork is removed from its support and replaced, will be reflected as a change in the longitudinal vibration effect and, hence, in the frequency at which the fork vibrates.

In accordance with the invention, the coupling between the longitudinal vibration of the mass of a tuning fork and particularly that of its stem and its clamping support to the lateral vibration of the tines is reduced to a minimum by so designing the fork that the center of mass of a tine is longitudinally aligned with the corresponding nodal point of the fork. Under these conditions, the arcuate motion of the tine viewed as concentrated at its center of mass becomes, for the small excursions involved, almost purely transverse motion and the longitudinal component is enormously reduced or substantially eliminated. Thus, the effects of the mass of the stem and the mounting or other constraints to which

the stem of the fork is subjected are substantially eliminated. Such a design may be attained in a number of ways. For example, the tines of an ordinary tuning fork which customarily have a center of mass more remote from the central axis of the fork than the nodal point about which the tine vibrates may be bent inwardly until, in the rest position of the fork, the mass center of each tine has been moved toward the central axis just sufficiently to bring it into longitudinal alignment with the corresponding nodal point of that tine. An alternative expedient is to taper the cross-section of the tine from its stem toward the free end in such manner that the outer or the inner longitudinal margin of the tine is inclined inwardly at the free end of the fork toward the central longitudinal axis of the fork. In an alternative structure the tuning fork formed by slotting a rectangular parallelepiped may have an enlarged opening at the base or at some other point of the slot which has the effect of moving the nodal point outwardly into longitudinal alignment with the centers of mass of their corresponding tines.

In the drawing:

Fig. 1 discloses an apparatus for exploring the vibrations which occur in a mechanical vibrating member such as a tuning fork;

Fig. 2 portrays the nodal lines of transverse and of longitudinal vibration of an ordinary type of tuning fork as ascertained by use of the apparatus of Fig. 1;

Fig. 3 discloses one form of the invention in which the tines of a tuning fork are bent inwardly just sufficiently to bring the centers of mass of the tines into alignment with the nodal points;

Fig. 4 is an alternative form of the invention in which the same general result is attained by tapering of the tines of the fork;

Fig. 5 is another embodiment of the invention in which the slot of the fork is so formed as to displace the nodal points outwardly;

Fig. 6 is a still different modification embodying a combination of the features of Figs. 3, 4 and 5;

Fig. 7 is an additional modification in which the fork employs tapered tines; and

Fig. 8 discloses a schematic diagram of a vacuum tube oscillator the frequency of which is controlled by a tuning fork of the type disclosed in Fig. 6.

A difficulty that has beset operation of systems involving electrically driven tuning forks is the abrupt change in frequency experienced by such

a fork when it is removed from its mounting and replaced. Frequency changes of one hundred parts in a million are not uncommon under these circumstances. Since the material of which present-day tuning forks are constructed may readily be made to have temperature coefficients of frequency less than three or four parts in a million per degree centigrade, and fork-controlled vacuum tube oscillators may be constructed to hold within frequency limitations of the same order, the large change resulting from removal and replacement of the fork from its supports is most undesirable.

Experience indicates that the frequency aberrations which are experienced in replacing a fork in its mounting are occasioned by longitudinal vibration of the base portion of the fork. With the fork constrained to vibrate as a whole while clamped to a mass constituting the mounting, some energy is dissipated in the mounting, the quantity of the energy so dissipated depending upon the efficacy of clamping, the mass and the rigidity of the mounting and the character of the contact surfaces between the stem of the fork and the mounting. Expedients for reducing the energy dissipation of tuning forks are disclosed and claimed in the copending application of C. H. Rumpel, Serial No. 268,659, filed April 19, 1939, for Vibratory frequency controlling devices, to which reference may be made for a disclosure of the form of fork mounting and pick-up and driving element assembly which is preferred in the exercise of the principles of the present invention.

A system used to study the vibration of tuning forks is illustrated in Fig. 1 in which an oscillator 1 having a variable output amplitude control which may comprise a potentiometer 2 or other equivalent expedient of well-known type is connected to a driving unit 3 preferably of the electromagnetic type disclosed in the application of C. H. Rumpel. The driving unit 3 is associated with one tine of the tuning fork 4 to be studied. A pick-up unit 5 which may be of the type disclosed in the Rumpel application may be associated with the other tine of the tuning fork to respond to vibrations of the fork. Connected to the output terminals of the pick-up unit in sequence are an amplifier 6, a thermocouple 7 for converting the alternating current output of the amplifier 6 to a unidirectional electromotive force and a milliammeter 8. Also associated with the tuning fork is a microphone 9 preferably of the well-known piezoelectric type having an exploring needle 11. The output of the microphone 9 is connected to a circuit including in tandem a variable attenuator 12, an amplifier 13 and the current measuring or indicating instrument 14.

In the operation of the apparatus of Fig. 1, the oscillator 1 is tuned to substantially the frequency of the tuning fork 4. The fork is preferably supported by pieces 15 of medium hard rubber pressed fairly lightly against the sides of the stem at the base by means of adjustable mounting plates 16 and 17 attached to a support or foundation not shown. The fork is thus permitted to vibrate naturally with no appreciable constraint. The pick-up unit 5, amplifier 6, thermocouple 7 and measuring instrument 8 serve to maintain a constant check upon the amplitude of the oscillations of the fork 4 to insure that during the study the excitation remains constant, thus making comparable the results of observations on vibration of various

points of the fork. The piezoelectric microphone 9 is of the laterally operated phonograph type which is sensitive to vibration or motion in one direction only and substantially insensitive to motion or vibration in other directions. This apparatus is characterized by a low needle pressure, a high sensitivity and a very high directional response. Vibrations, at a particular point P_0 on which the tip of the needle 11 lightly rests and in the direction capable of causing the microphone to respond, excite the piezoelectric microphone to produce electromotive forces of corresponding frequency and wave form and of proportional magnitude which, after amplification by the amplifier 13, are indicated by the instrument 14. It is, therefore, possible while the fork 4 is maintained in vibration at constant amplitude by the oscillator 1 to explore the surfaces of the fork point by point for vibrations in a particular direction and to ascertain and plot the contour lines of equal vibration intensity for such vibrations.

The microphone 9 may first be positioned to record vibrations in the transverse direction, that is, in a direction perpendicular to the central longitudinal axis LL. In a study so made of a standard rectangular parallelepiped fork of the type illustrated in Fig. 2, the contour lines for equal vibration intensities in the transverse direction were ascertained and plotted. The contour lines at which zero transverse vibration occurred and which are, therefore, the loci of nodes for transverse vibration are represented in Fig. 2 by T_1T_1 and T_2T_2 . After readjustment of the position of the piezoelectric microphone 9 to cause it to record only longitudinal vibrations, the loci L_1L_1 and L_2L_2 of nodal points for longitudinal vibration were obtained and plotted. The intersections of these loci, namely N_1 and N_2 are, therefore, nodal points at which there are no vibrations in any direction. The centers of mass of the tines are indicated by points P_1 and P_2 respectively. It will be observed that the broken lines 18, 18 and 19, 19 passing through the centers of mass P_1 and P_2 , respectively, and parallel to the central longitudinal axis LL pass outside of the nodal points N_1N_2 . It will be apparent, therefore, that as the mass of the left-hand tine of the fork as centered at P_1 vibrates about the nodal point N_1 its motion may be resolved into two components, the principal one of which is lateral and the smaller one of which is longitudinal. As the tines flex outwardly about the nodal points N_1 and N_2 , the mass of material of the central portion of the stem will tend to rise toward the slot between the tines. Accordingly, the transverse vibration of the tines is coupled to a longitudinal vibration of the mass of the central stem. At the same time the mass of the outermost portions of the stem, that is, those portions remote from the central longitudinal axis LL, tends to move downwardly. The resulting vibrational characteristic of the tuning fork when its tines are set in transverse vibration is, accordingly, a function of a number of factors including the mass of the stem portion of the fork and of the mounting upon which it is based and by which it is constrained.

Fig. 3 discloses an improved tuning fork embodying the principles of the present invention in which a fork originally formed like that of Fig. 2 has had its tines bent inwardly so that the points P_1 and P_2 representing their respective centers of mass fall in the same longitudinal lines with the nodal points N_1N_2 respectively. With this

construction the transverse vibration of the mass centered at points P_1 and P_2 is accompanied by a negligible coupling to longitudinal vibration. In practice it has been found that the changes in frequency occurring when a fork of the form of Fig. 3 is taken from its mounting and replaced even by an inexperienced operator is very small, indeed, compared with the best result which would be obtained with the fork of Fig. 2 adjusted under most satisfactory conditions attainable.

Fig. 4 discloses an alternative embodiment of the invention in which the centers of mass P_1 and P_2 are brought into longitudinal alignment with the nodal points N_1N_2 by tapering the cross-section of the tines so that the outer marginal surfaces 20 converge from the end of the tine adjacent the stem toward the free end of the tine.

In the structure of Fig. 5, the slot between the tines is formed with an enlarged circular opening 19 at the inner end of the slot. This has the effect of moving the nodal points N_1 and N_2 outwardly from their positions in Fig. 2, to bring them into longitudinal alignment with the centers of mass P_1 and P_2 of their respective tines. The enlarged opening need not be circular but it should be symmetrical with respect to the central axis. Moreover, it may be located at any point along the central axis.

It will be appreciated that the principle involved in the invention, namely, bringing the centers of mass of the vibrating tines and the nodal points into longitudinal alignment requires that the bending or tapering of the prongs or the enlargement of the base of the slot be made such as to nicely achieve the alignment. If, for example, the tines be bent inwardly too far their centers of mass will be carried to points inside the nodal points in which case there will be the same difficulty as was present in the original fork of Fig. 2.

It is not necessary to obtain the entire adjustment of position of the centers of mass by a single one of the expedients which have been described. It is possible to employ any two of these or all of them or, in fact, any system of conformation or loading whatever which will cause the centers of mass of the tines to be aligned longitudinally with their respective nodal points. For example, in Fig. 6, there is disclosed a structure in which the base of the slot has been enlarged and the tines have been tapered in cross-section and also have been bent inwardly to bring the centers of mass into longitudinal alignment with the nodal points. For the purpose of illustration these factors have been somewhat exaggerated in the drawing. It is only necessary that taken together they operate in conformance with the general principle which has been presented.

In Fig. 7 the tines of the tuning fork are tapered on their inner sides to displace their centers of mass inwardly into line with the nodal points.

Fig. 8 illustrates a vacuum tube oscillator comprising an electron discharge device 21 of the usual screen grid type. The output circuit of the device 21 is connected to an electromagnetic driving unit 3 associated with the tuning fork 25 of the general type disclosed in Fig. 6. An electromagnetic pick-up unit 5 associated with the tuning fork is connected to the input circuit of the discharge device 21 to maintain oscillations in well-known manner. In order to obtain

proper phase relations between the output alternating current of the discharge device 21 and the input electromotive force impressed thereon by the pick-up device 5, phase adjusting variable condensers 22 and 23 are provided in shunt respectively to the input and output circuits of the electron discharge device 21. A current limiter 24 of well-known type is also connected across the output circuit of the electron discharge device in the manner described in connection with the application of C. H. Rumpel to which reference has previously been made.

Tuning forks embodying the principles of this invention may be mounted in any desired manner and no specific operating mounting for such forks other than of the test apparatus of Fig. 1 are illustrated herein. It is to be understood, however, that preferably the mountings will be constructed in accordance with the disclosure of the Rumpel application, Serial No. 268,659, to which reference has been previously made. Such mountings will additionally reduce any remanent effect of mass of the stem and its constraining supports upon the transverse vibration of the tuning fork.

It will be appreciated, therefore, that the net result of the invention is to reduce the complex mechanically vibrating system more nearly to a mechanical system having a single degree of freedom with little or substantially no coupling to extraneous mechanical systems with which it may be mechanically connected.

What is claimed is:

1. A tuning fork having a stem portion and two integral tines of similar conformation symmetrically positioned with respect to the central longitudinal axis of the stem, characterized in this, that the lines connecting the centers of mass of the tines with the respective nodal points about which the tines oscillate in their vibration are substantially parallel with the longitudinal axis of the fork.

2. A mechanical vibrator comprising a body of elastic material symmetrical about a longitudinal axis and having two integral extensions of similar conformation and symmetrically positioned with respect to the longitudinal axis, the nodal points of said body for lateral vibrations of the extensions lying in lines extending through the centers of mass of the respectively adjacent extensions which lines are substantially parallel to the longitudinal axis.

3. A tuning fork comprising a stem member and a pair of symmetrical tines extending from one end thereof, the mass of each tine having an effective center which lies in a line extending through a nodal point of the fork and approximately parallel to the central longitudinal axis of the stem whereby the longitudinal component of vibration of the fork tines is substantially eliminated.

4. A tuning fork comprising a block of metallic material in the form of a long rectangular parallelepiped, an opening therethrough centered at a point in the longitudinal axis of the block and a longitudinal slot extending from the opening to an end of the body to form two tines, the longitudinal axis of the slot coinciding with that of the block and the width of the slot being sufficiently less than the diameter of the opening that the line connecting the center of mass of a tine at one side of the slot with the nodal point in the unslotted portion of the block which is nearest the respective tine is substantially parallel with the longitudinal axis of the fork.

5. A tuning fork comprising a stem member and a pair of symmetrical tines extending from one end thereof, each of the tines having a center of mass which is displaced inwardly toward the other tine with respect to the center of area of the base of the tine adjacent the stem, the center of mass of each tine being so located with respect to a nodal point of the fork for transverse and longitudinal vibration that a line extending through the center of mass and the nodal point is substantially parallel to the central longitudinal axis of the stem.

6. A tuning fork comprising a stem member and a pair of symmetrical tines extending from one end thereof and inclined toward each other toward their free ends to such an extent as to bring the line connecting the center of mass of each tine with its respective nodal point of the fork into parallelism with the longitudinal axis of the fork.

7. A tuning fork having a stem and a pair of tines extending from one end thereof, corresponding margins of the tines being inclined inwardly toward the free ends of the tines to such a degree as to bring the lines connecting the center of mass of each tine with the intersections of the respective nodal lines of transverse and of longitudinal vibration of the fork into parallelism with the longitudinal axis of the fork.

8. A mechanical resonance device comprising a stem having two projections each tapering from the stem toward its free end, the conformation of the projections being such as to cause lines extending through their respective centers of mass and the most nearly adjacent of the nodal points of the device for lateral vibrations of the projections to be parallel to the central longitudinal axis of the device.

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SIMON EUGENE MICHAELS.