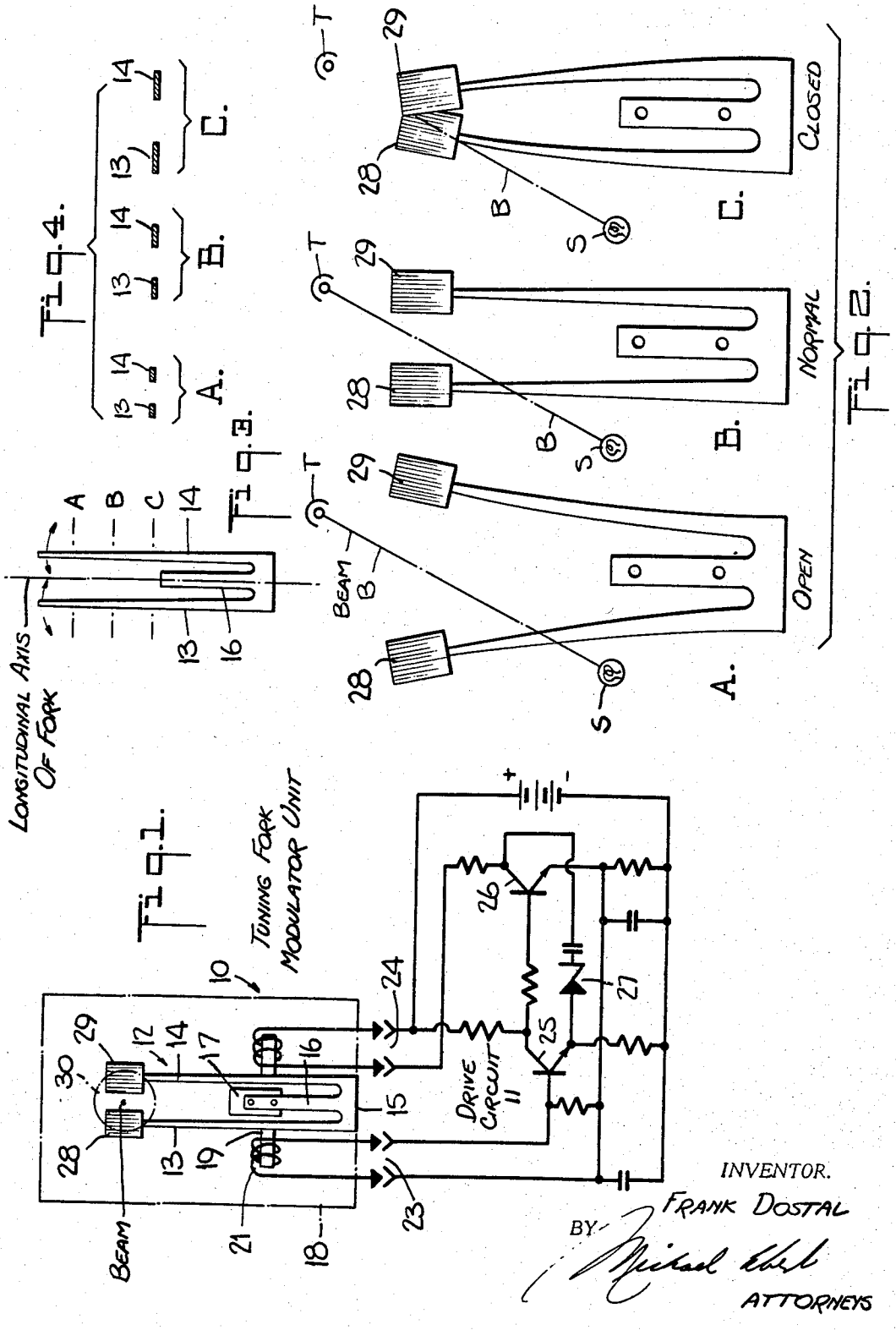
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TUNING FORK STRUCTURES

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TUNING FORK STRUCTURES

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U.S. Cl. 350—269 2 Claims

ABSTRACT OF THE DISCLOSURE

A tuning fork for actuating an optical shutter or other vibrating device and having a prolonged life. The fork is constituted by a pair of tines each of which is tapered to impart a progressively decreasing cross-sectional dimension thereto from the base to the tip to effect a distribution of bending along the length of the tine causing an incremental deflection which is substantially uniform per increment of length.

This invention relates generally to tuning-fork oscillators, and more particularly to tuning-fork structures whose tines have a configuration resulting in an increased swing whereby relatively small forks may be used to drive optical choppers and other devices, whose operation depends not only on fork frequency, but also on the amplitude of swing. This application is a continuation-in-part of my copending application Serial No. 313,004, filed October 1, 1963, entitled "Optical Modulators," now abandoned.

Tuning-fork oscillators have many practical applications and are currently used as frequency standards, in inertial guidance systems, and in geophysical instruments, as well as driving elements in optical modulators and in timing devices. The operating frequency of a vibratory fork is determined by the tine dimensions, the frequency being directly proportional to the thickness of the tines and inversely proportional to the square of their length.

The vibration of a tuning fork is a complex phenomenon. As the tines flex laterally toward and away from the longitudinal mid-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 a similar fashion. For each tine, this vibration is in the nature of an arcuate oscillation about a corresponding nodal point in the stem on the fork.

In my copending application, above-identified, there is disclosed an electromagnetically-actuated tuning-fork oscillator for driving optical elements mounted on the tines of the fork. These elements are constituted by a pair of shutter vanes which are arranged to swing in parallel planes. As the tines vibrate laterally in phase opposition, in the course of each vibratory cycle the two vanes move away from each other to define the maximum aperture, and toward each other to close the aperture. By projecting a beam of radiant energy through the aperture, the beam is chopped at a rate depending on the frequency of the fork.

The maximum size of the optical aperture depends on the amplitude of tine deflection, and in order to obtain large apertures it has heretofore been necessary to employ larger forks. However, with the increasing demand for compact and miniaturized equipment, the use of larger forks is undesirable. With smaller forks, larger apertures are attainable by raising the amount of power applied to actuate the fork electromagnetically, but quite apart from the increased power requirement, there are other serious drawbacks incident to this approach.

In a conventional fork, most of the bending takes place near the base of the fork, as a result of which metallurgical fatigue and the strain imposed on the fork metal is concentrated in this region. It has been found that tuning forks operating at extremely high amplitudes undergo a fatiguing process leading to increasing losses tantamount to a reduction in Q or figure of merit by 10 to 1 or more culminating in failure. Consequently, while it is possible to step up the power actuating the tines to thereby increase the swing thereof, the augmented stress on the tines has a deleterious effect on the fork properties.

Accordingly, it is the main object of the present invention to provide a tuning-fork structure having a tine configuration in which a greater degree of total deflection is possible with less stress near the base.

A significant advantage of the invention is that in the context of light choppers and other devices exploiting the swing of the fork, one may now use relatively small forks with a high degree of efficiency to accomplish the functions heretofore feasible only with large forks and greater power expenditure.

More specifically, it is an object of the invention to provide a tuning-fork structure whose tines have a linear taper from the base to the tip thereof, acting to distribute the bending along the length of the fork whereby the incremental deflection of each tine for incremental length is substantially uniform. A logarithmic taper is also suitable.

Also an object of the invention is to provide a tuning-fork structure of the above-described type having a higher Q than conventional fork configurations, a lesser degree of aging, and hence a longer effective life.

The invention is of particular advantage in the context of light choppers, for it makes possible exceptionally large optical apertures using relatively small forks driven at low power.

Briefly stated, these objects are accomplished in a tuning-fork oscillator including a tuning fork having a pair of tines extending from a common base, the tines being electromagnetically actuated and having an optical element mounted on at least one of the tines to vibrate therewith. Each tine is tapered to impart a progressively decreasing cross-sectional dimension thereto from the base to the tip to effect a distribution of bending along the length of the tine causing an incremental deflection which is substantially uniform per increment of length.

For a better understanding of the invention, as well as other objects and further features thereof, reference is made to the following detailed description to be read in conjunction with the accompanying drawing, wherein:

FIG. 1 is a schematic diagram of an optical modulator including a tuning-fork structure in accordance with the invention;

FIG. 2A, 2B, and 2C illustrate three different positions of the shutter vanes on the tuning-fork structure;

FIG. 3 separately illustrates in elevation the tuning-fork structure; and

FIGS. 4A, 4B, and 4C are transverse sections taken in the planes indicated by letters A, B and C, in FIG. 3.

THE STRUCTURE OF THE OSCILLATOR

Referring now to the drawing, and more particularly to FIG. 1, there is shown an optical chopper including a tuning-fork oscillator, generally designated by numeral **10**, and a drive circuit therefor, generally designated by numeral **11**. While the tuning-fork structure in accordance with the invention is described in the context of an optical chopper, it is to be understood that the fork is also useful with other forms of electro-optical systems wherein mirrors, lenses and other elements not necessarily of an optical nature are mounted on the tines of the fork.

The tuning-fork oscillator **10** includes a tuning-fork structure having a pair of flexible tines **13** and **14** interconnected by a relatively inflexible base **15**. Extending upwardly from the base is a stem **16** which is disposed midway between the tines and is attached to a supporting plate **17** within a casing **18**. The fork is preferably formed of a metal such as "Ni-Span C," "Elinvar" or "Vibralloy," having a low temperature coefficient of elasticity to render the fork substantially insensitive to changes in ambient temperature.

The stem mounting of the fork is located at the center of gravity, thus rendering the fork less sensitive to shock and vibration. The re-entrant fork stem also conserves space, as compared to the usual arrangement in which the stem projects below the base.

Attached to tines **13** and **14** are small permanent-magnet rods **19** and **20**, respectively, the rods reciprocating within fixed coils **21** and **22**. Each coil and rod combination acts as a transducer, coil **22** being a drive coil and coil **21**, a sensing or pickup coil. The coils are connected through plug-in pins **23** and **24**, to the electronic drive circuit **11**, pickup coil **21** going to the base input circuit of a first transistor **25** and drive coil **22** to the output collector circuit of a second transistor **26** of a two-stage battery-energized amplifier.

The arrangement of transistor **25** and **26** provides a positive feedback between the two coils, whereby the vibration of rod **19** induces an A-C voltages in pickup coil **21**, this voltage being amplified and applied to drive coil **22** to actuate rod **20** and thereby excite the fork into motion. The circuit is stabilized by a negative feedback circuit including a Zener diode **27**, whereby the fork oscillations are maintained at a constant amplitude and frequency.

The drive means shown herein is merely by way of example, and forms no part of the invention. Thus the fork itself may be of magnetic material operating in conjunction with a fixed electromagnetic transducer.

Attached to the free ends of tines **13** and **14** are a pair of shutter vanes **28** and **29** which are arranged to swing opposition, the two vanes alternately move toward and in parallel planes. As the tines vibrate laterally in phase away from each other in the course of each vibratory cycle. A window **30** is formed in casing **18** and is dimensioned to expose adjacent portions of the two vanes to a beam of radiant energy which may be in the form of light or ultraviolet rays.

OPERATION OF THE OSCILLATOR

In operation, as shown in FIG. 2A, a beam B of radiant energy is projected through the window along an axis symmetrically disposed with respect to the two vanes. Thus, as shown in FIG. 2B, when vanes **28** and **29** occupy their static or normal position, they are separated to permit the beam to pass linearly from a source S to a pickup sensor or target T. In the course of a vibratory cycle, the tines move away from each other, as shown in FIG. 2A, further separating the vanes, and the beam continues to pass, but in the remaining period the tines move toward each other, causing the vanes to overlap, as shown in FIG. 2C, and the path of beam B is then blocked.

The maximum size of the optical aperture or opening is determined by the swing of the tines. Obviously, if the swing is very small, the initial opening between the vanes in the static condition shown in FIG. 2B, must be similarly small, otherwise the vanes will not overlap to close the aperture as shown in FIG. 2C. In a modified arrangement the vanes are designed to just meet in the static position, thus when vibrating, the open and shut tines are exactly equal, which is useful in some applications. While, as pointed out previously, the swing can be increased by the use of a larger fork or greater drive power, neither solution is desirable.

FORK CONFIGURATION

In accordance with the invention, a fork whose structure inherently produces a greater swing without entailing a rise in excitation power, is produced by the use of tines **13** and **14** having a linear taper from the base to the tip thereof, such that most of the bending and the stress resulting therefrom, is distributed along the length of the fork rather than being concentrated in the region of the base, as in the usual structure. By distributing the bending along the length of the fork tine, the incremental deflection of the tine per incremental length, is made substantially uniform, and internal losses in the tine are diminished.

The benefits of the invention will now be illustrated by comparison with a conventional straight fork having an operating frequency of 200 cycles, the fork having a length of 2⅝", with tines uniformly of .10" thickness and .09" in width. The width of the tine is the dimension in the direction of lateral movement. This conventional fork is cut or otherwise tapered so that the width remains .09" at the base, but is reduced to 0.3" at the tip. Thus the taper progressively decreases the height dimension to an extent that the ultimate dimension at the tip is one-third that at the base.

As a result of the tapering, the fork frequency goes from 200 to 250 cycles, which is to be expected, since frequency is a direct function of the cross-sectional dimensions of the tines and inversely proportional to the square of their length. The unexpected result obtained from the taper, is that the amplitude of the straight fork is .120 peak to peak, whereas the same fork when tapered now has an amplitude of .250 peak to peak, thereby more than doubling the swing. In this example, the drive power is the same in both instances.

If the original straight fork tines are dimensioned uniformly throughout their cross-section to operate at 250 cycles, it is found that the amplitude is reduced to .08 peak to peak. Thus the invention makes possible, for a given operating frequency, a smaller fork with a substantially increased swing or amplitude.

Ideally the progressive taper is made a logarithmic rather than an arithmetic function, although in practice a logarithmic taper is more difficult to execute. Thus the sections in the tines of the fork taken in planes A, B and C, as shown in FIG. 4, are of progressively increasing width, moving away from the tips but of constant thickness.

The benefits which accrue from the invention, namely longer life and reduced losses become significant factors in the case of very high fork amplitudes. Such benefits are not as appreciable in forks operating at normal, low-amplitudes. The explanation for this is that in a non-tapered fork operating at low amplitudes, losses due to the damping constant of the fork material are very low for such amplitudes, even if the flexure is confined to a short increment near the base. But at higher amplitudes the losses and stresses begin to increase much more than linear with amplitude. Tapering the width acts to distribute the bending over more increments of length, thereby keeping the losses and the stresses per increment small.

Tests on forks tapered in thickness have the advantages in varying degrees of the fork tapered in width, except that the proportions required are not practical. For instance, a fork equivalent to the fork described above would require a thickness of .9" tapered to .1". This arises because, in the direction of bending, the stiffness varies as the square of width but only directly as the thickness.

While in the embodiment disclosed, the ultimate dimension at the tip is one-third that at the base, this ratio is not critical. If the fork as described were increased fifty per cent in length, the .03 dimension would be reduced to .02 and the ratio would go from one-third to two-ninths. In addition, the ratio may be changed substantially according to the mass to be vibrated.

What I claim is:

1. An optical modulator having a prolonged working life and comprising a tuning fork having a pair of tines extending from a common base, and optical elements mounted on said tines and vibrating therewith, said tines being tapered in width only to impart a progressively decreasing cross-sectional dimension thereto from the base to the tip of the tine to increase the swing thereof and to effect a distribution of bending along the length of the tine causing the incremental deflection of the tine per incremental length to be substantially uniform, said taper being substantially a logarithmic function and means to drive said fork to maintain the tines in vibration.

2. A modulator as set forth in claim 1, wherein an optical element in the form of a shutter vane is mounted at the end of each tine, the vanes being disposed in parallel planes and being caused to produce a relatively large aperture therebetween when the tines are outwardly deflected.

References Cited

UNITED STATES PATENTS

329,090	10/1885	Segrove	84—409
465,832	12/1891	Cassagnes	84—457 X
1,631,021	5/1927	Dowling	350—269 X
1,958,071	5/1934	Scofield	315—337
2,349,125	5/1944	Turner	350—269
2,581,963	1/1952	Langloys	84—403
3,093,743	6/1963	Inderwiesen	250—232
3,178,579	4/1965	Zuckerbraun	250—232 X
3,192,701	7/1965	Tanaka et al.	84—457 X
3,350,667	10/1967	Shreve	84—409 X

FOREIGN PATENTS

446,444	1/1948	Canada.

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U.S. Cl. X.R.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,493,292 Dated February 3, 1970

Inventor(s) Frank Dostal

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, lines 41,42 and 43 should read as follows:

--in parallel planes. As the tines vibrate laterally in phase opposition, the two vanes alternately move toward and away from each other in the course of each vibratory --

Column 4, line 22, "0.3" " , should read -- .03" -- ;
line 58, change "linear" to -- linearly --

SIGNED AND
SEALED
JUL 21 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents