

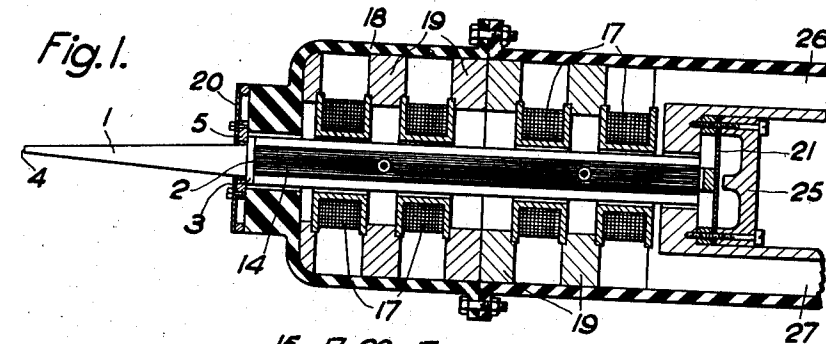
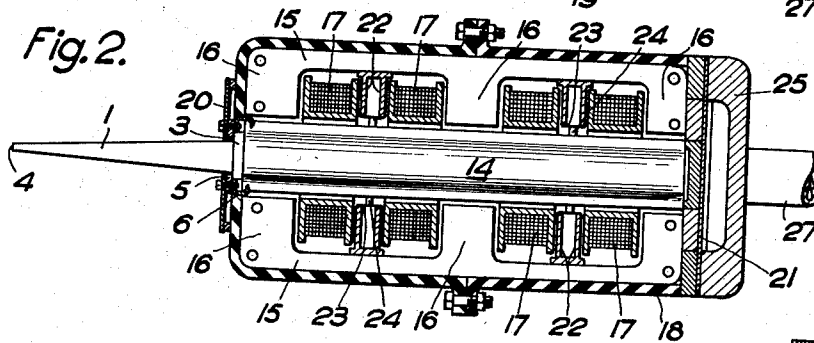
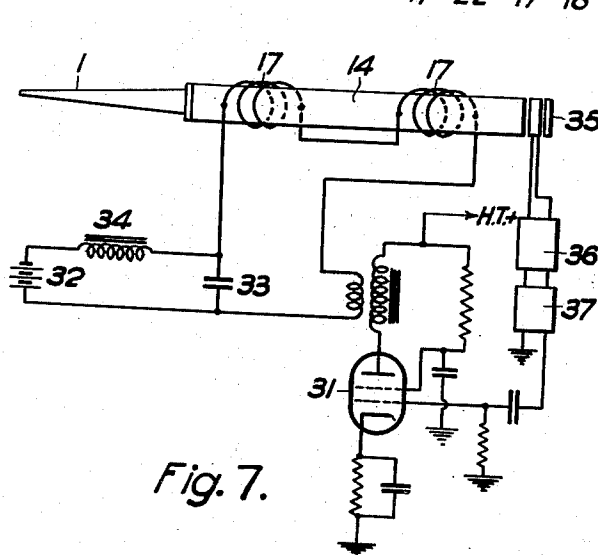
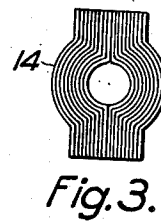
Sept. 17, 1957

G. BRADFELD
VIBRATORY TOOLS

2,806,328

Filed Jan. 29, 1953

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

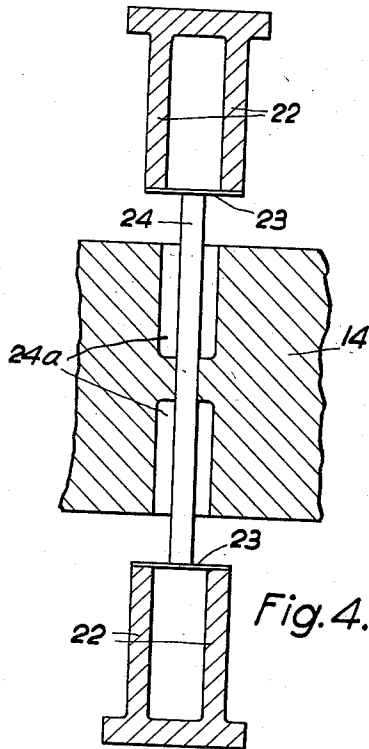


Fig. 4.

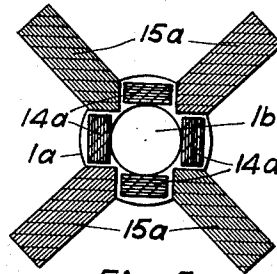


Fig. 5.

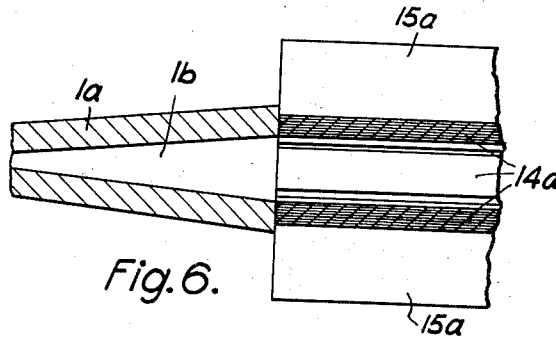


Fig. 6.

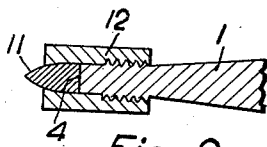


Fig. 8.

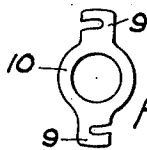


Fig. 10.

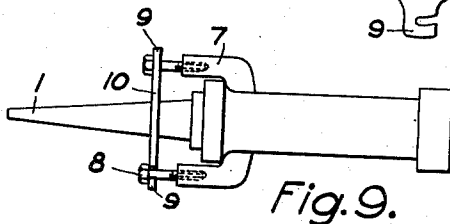


Fig. 9.

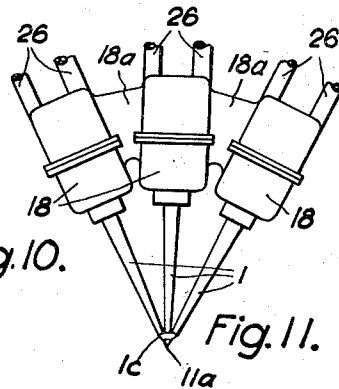


Fig. 11.

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2,806,328

VIBRATORY TOOLS

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Claims priority, application Great Britain January 31, 1952

9 Claims. (Cl. 51—59)

This invention relates to supersonic oscillators or transducers and to vibratory tools such as dental drills and engraving tools incorporating such oscillators.

A transducer according to the invention comprises a bar member of magnetostrictive material, the length of which is an integral odd multiple, including a unit multiple, of one half wavelength at the frequency at which the transducer is to be operated, helical windings around said bar member, a magnetic yoke, spaced pole pieces around said yoke co-operating with said bar member, and means anchoring said bar member longitudinally in relation to said unit at the nodes of vibration without substantially hindering the transverse expansion and contraction of said bar member while it is in vibration. The bar member may be a solid block of magnetostrictive material such as a ferrite, if it is substantially non-conductive so that substantially no eddy currents flow, or it may be of laminated structure if the material is conductive. To constitute a vibratory tool the transducer may be provided with a tapering shank of a material of low internal damping, e. g. steel, secured at its larger end to one end of the transducer bar member and carrying or constituting an abrading tip at its smaller end, and the overall length of the tool and frequency being such that having regard to the material of the shank if any and of the oscillator, the tool as a whole vibrates in substantially free-free mode, in which case the abrasive tip end is a vibration anti-node. This last condition may be ensured by making the length of the shank effectively equal to one half wave length of the operating frequency (or an odd integral multiple thereof). If, however, the material of the shank and of the oscillator are matched as to characteristic impedance and Poisson's ratio, rigid adherence to the foregoing length requirement is not essential; it being then merely necessary to adjust the overall length of the tool to provide vibration anti-nodes at the extremities of the assembly. To enable the abrading tip to be exchanged, a face-to-face joint with seating surfaces having a surface finish such that irregularities are of the order of a few microns or less may be provided at a suitable point between the transducer bar member and the abrading tip conveniently at the large end of the tapering shank, thus giving a large area for the transmission of energy. An oil or a material such as a wax, resin or low temperature solder is used at the joint to ensure satisfactory transmission of energy.

The abrasive tip itself may seat on carefully prepared surfaces as described above, and may then be secured in or clamped by a metal sleeve which screws on to the shank or oscillator. The tip may be of abrasive material, e. g., diamond, or the action of the abrading tip enhanced by the use of powdered abrasive suspended in oil or other liquid between the tip and the work. In general such a practice permits the use of points which are made of some relatively soft material (i. e., readily fabricated) such as mild steel. The tip can take the form of the desired peripheral shape of the hole, i. e., square tube to trepan a square hole, an oval tube to cut an oval

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hole and the like. This is of especial value when soft tips are used since these can readily be fabricated in the desired form.

It is preferable to set the transducer in excitation using feed back from a separate or built-in electrode mechanical transducer actuated by the mechanical motion. Such feed back transducer may be attached to the transducer bar member at the opposite end to the tapering section leading to the abrasive tip.

The invention will be further described with reference to the accompanying drawings, in which:

Fig. 1 is a longitudinal section of an example of the invention embodying a magnetostrictive transducer;

Fig. 2 is a longitudinal section taken at right angles to Fig. 1;

Fig. 3 is a detail cross section;

Figure 4 is a detail of Figure 2 on an enlarged scale with the bar member in section.

Fig. 5 is a diagrammatic cross section of a modification of magnetostrictive transducer;

Fig. 6 is a detail longitudinal section corresponding to Fig. 5;

Fig. 7 is a diagram illustrating a preferred mode of excitation of the magnetostrictive type of transducer.

Fig. 8 is a detail showing one way of securing the abrasive tip;

Figs. 9 and 10 are details showing a quick action clamp;

Figure 11 is a diagrammatic view of another modification for applying greater mechanical forces at one point.

In the example shown in Figs. 1 to 4, a separate tapering section 1 is used, for example of steel tapering from a transverse seating 2 at the larger end, which may conveniently be flanged as at 3, down to a small transverse seating 4 at the other end. The base of the section 1 is held to the exciting means by the aid of a clamping ring 5 or the like, which bears against the flange 3 and carries a split clamp 6 or the like which engages a flange on the exciter. The ring 5 conveniently carries the clamp 6 by screws, enabling the clamping pressure to be applied and varied. It will be understood that the seating surfaces are highly finished and make good contact over a large area so that satisfactory transmission of the vibrations through the surfaces takes place.

In the alternative attachment shown in Figs. 9 and 10, a split clamp or the like 7 engaging a flange or groove of the exciter carries screws 8 under the heads of which can engage hook arms 9 on a ring 10 which fits over the tapering section 1. This is a quickly releasable clamp which enables the tapering section and its abrasive tip to be changed rapidly.

Where the abrasive tip is of hard material, such as a diamond, it may be mounted as shown in Fig. 8 in which the tip 11 is held down by a sleeve 12 which screws on to the end of the tapering shank 1 and holds the tip 11 against the seating 4. The seating 4 and the base of the tip 11 must be highly finished and contact over a large area.

The exciter operates by magnetostriction; and in Figs. 1 to 4 its magnetic circuit is made up of a bar 14 and two external yokes 15 having three polar projections 16. The polar projections are spaced half a wave length apart, so that in the illustrated example the bar 14 consists of two half wave length sections, but the invention is not limited to this and any desired number of half wave length sections can be used. Excitation is effected by the aid of windings 17 which surround the bar 14 helically, these windings carrying a direct polarising current as well as driving alternating current. The form of the magnetic circuit is such that very high field strength can be used. Both the bar 14 and the yokes 15 are laminated in the plane of Fig. 1, i. e., the plane wherein

the most serious eddy currents would circulate. The lamination of the bar 14 is visible in Figure 1 but the yokes 15 which are similarly laminated are hidden in this figure.

Depending on the material used the laminations of the bar 14 may be flat in cross-section or they may be curved as shown in Fig. 3. Thus, if the laminations are of nickel or Permendur (an alloy of very high magnetic saturation, composition 49% cobalt, 49% iron, 2% vanadium) the curved section of Fig. 3 is to be preferred. Alternatively solid ferrite may be used, ferrite being a double oxide of the $\alpha\text{AO} \cdot b\text{BO} \cdot \text{Fe}$ type wherein A and B are certain divalent metals and a and b are proportions, a typical example being (90% NiO, 10% ZnO). Fe_2O_3 —see Philips Res. Rep. 8 91—132, 1953.

The yokes 15 are mounted in an outer housing 18 of insulating material, e. g., moulded synthetic resin and the housing is made in parts to allow for assembly and to clamp the windings 17 and the yokes 15 in place. Spacers 19 assist in locating and clamping the windings. Spiders 20, 21, at opposite ends of the bar 14 maintain the air gaps in the magnetic circuit constant without imposing longitudinal constraint sufficient to interfere with the longitudinal vibrations.

The bar 14 is anchored longitudinally in relation to the yokes 15 and the outer housing 18, at the vibration nodes in such a way as not to constrain the transverse expansion and contraction of the bar while it is vibrating longitudinally, arising from the Poisson effect. This anchoring is effected by the aid of forks 22 anchored through the yokes 15 to the main housing 18 and carrying at their ends flat springs 23 parallel to the length of the bar. Central lugs 24 on these springs engage the bar. These lugs may in fact as shown in Fig. 4 be cross bars passing right through the bar 14, being a tight fit in a short part of the bore at the centre of the bar 14, the bar elsewhere being counterbored as at 24a to clear the cross bars.

The construction shown in Figs. 1 to 4 is completed by an end cover 25 incorporating air ducts 26, 27, by which cooling air blast is led in and away. The yokes 15 restrict movement of the air from the inlet to the outlet and this restriction is desirably graded to keep the cooling constant along the whole length of the transducer.

Figs. 5 and 6 show how greater power can be obtained within substantially no greater compass by the use of multiple elements. Here there are four bar members 14a and four yoke members 15a. The yoke members are arranged radially and the bar members so that each extends between two adjacent yoke members. Corresponding with the disposition of the bar members a tapering shank 1a is used which has a central conical cavity 1b so that its end corresponds as nearly as may be with the ends of the bar members. Manifestly the construction shown in Figs. 5 and 6 is only one example of an arrangement in which there is a plurality of pairs of yoke bars distributed round the circle and a corresponding number of bar members arranged between adjacent yoke members.

Fig. 7 shows schematically how the device of Figs. 1 to 4 is preferably excited. A power valve 31 is used as the source of alternating current and its anode circuit is transformer coupled to the windings 17 on the bar member 14. Polarising current is supplied to the same circuit by a battery 32, a condenser 33 being provided to carry the alternating current and a choke 34 to prevent the alternating current passing through the battery. The valve 31 is maintained in oscillation by back feed to its grid from an electro-mechanical transducer 35, mechanically coupled, i. e., clamped to the opposite end of the bar member 14 to the shank 1. This transducer 35 is coupled through a phasing unit 36 and an amplifier 37 to the grid of the valve 31. The transducer 35 could itself be of magnetostrictive type or electromagnetic but

is preferably of piezo-electric type using a barium titanate crystal.

Figs. 5 and 6 described above show one way in which increased activity of the abrading tip can be achieved for a given bulk of tool. Another possibility is to couple together mechanically several tapered sections 1 conveying the mechanical waves at or near the abrading tip. An example is illustrated in Figure 11, which shows three transducers each of which is of the structure shown in Figures 1 to 4 or it might be as in Figures 5 and 6. The outer casings 18 are united by webs 18a while the outer ends of their tapered shanks 1 are united by a member 1c which carries the abrading tool 11a. The resulting structure is fan-shaped in two dimensions if the axes of the shanks 1 all lie in the same plane and in three dimensions if the axes of the shanks 1 do not lie in the same plane. Lateral mutual coupling or constraint between elements must be light.

It should be mentioned that if the load at the point of a tool according to the invention is reactive so that in effect there is compliance at the working point, the resonant frequency of the tool will be modified. As the length of the tool cannot be altered to restore its resonant frequency to the desired value, the condition is met by adjusting the frequency of the exciting current.

Another point of importance which should be mentioned is that in any very high frequency device used for cutting by substantially vertical motion of the cutting end driven by a tapered member the force on the cutting edge is rarely anything like sinusoidal. It is therefore an advantage to have a high stored vibratory energy in the device. One way of achieving this is to employ a magnetostrictive device with low damping. The devices above-described with reference to Figs. 1 to 6 have been designed to keep the damping low. The damping arises from several sources. For instance, a laminated structure is necessary to eliminate eddy currents, but this gives rise to distortional damping due to the motion of some of the laminations being non-parallel to their own planes. This is reduced by cementing the laminations firmly together with no air bubbles, e. g., with shellac or by cementing them together at the edges in the case of the construction of Fig. 3, leaving the central parts adjacent but not in actual contact. Or the damping may be reduced by curving the laminations in a plane normal to their longitudinal motion. A further component of damping arises from the magnetostrictively developed eddy currents in the interior of the laminations themselves which occurs during mechanical vibration. This component can be reduced by operating the material near to magnetic saturation when the Q will be high and the damping low. The excitation is then somewhat pulse-like so that the lamination stays in the high damping condition for a relatively short part of the vibratory period.

An alternative construction of exciter to those above-described is one of the Ferroxcube (a commercial ferrite of British origin), Ferrosphenel (a commercial ferrite of U. S. A. origin), Magnetite (magnetic iron or ferrosferric oxide $\text{FeO} \cdot \text{Fe}_2\text{O}_3$) type i. e., using the magnetostrictive material in solid block form. The principle of high stored energy can also be extended by making the material of the tapering section 1 a heavy but very strong material such as tungsten carbide or tungsten.

In the latter case, as the material is more dense than that of the transducer itself, the junction is desirably matched as follows. The taper section will taper uniformly for

$$\frac{3\lambda}{8} \text{ or } \frac{7\lambda}{8}$$

etc., back from the cutting edge to a part at which its radius

$$R' = R \sqrt{\frac{\rho_e}{\rho_h}}$$

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where R is the radius of the transducer end or its equivalent radius, which in the case of a rectangular transducer of sides ab , such that $\pi R^2 = ab$. This diameter part of the tapering section will be

$$\frac{\lambda}{8}$$

from the end of the transducer and the intervening part has a profile formed by a common tangent to a circle radius R at the end of the transducer, and another circle of long radius formed at the large end of the uniform taper above referred to. λ is the wave length, ρ_e the density of the transducer, and ρ_h the density of the taper section. In the above formula for R' the longitudinal velocities of the waves in the materials has been ignored as usually they do not differ very much. More correctly however

$$R' = R \sqrt{\frac{\rho_e}{\rho_h} \times \frac{C_l}{C_h}}$$

where C_l is the longitudinal velocity in the transducer material and C_h is the longitudinal velocity in the dense material.

I claim:

1. An electromechanical transducer comprising a bar member of magnetostrictive material, the length of which is an integral odd multiple, including a unit multiple of one half wavelength at the frequency at which the transducer is to be operated, helical windings around said bar member, a magnetic yoke, spaced pole pieces on said yoke co-operating with said bar member, and means anchoring said bar member longitudinally in relation to said yoke at the nodes of vibration without substantially hindering the transverse expansion and contraction of said bar member while it is in vibration.

2. An electromechanical transducer as set forth in claim 1 wherein said anchoring means includes flat springs set parallel with the length of said bar member, secured by their ends axially in relation to said yoke and by their centres axially in relation to the bar at the nodes of vibration.

3. An electromechanical transducer as set forth in claim 1 also comprising spiders mounted at the ends of the yokes and bar member whereby the bar member is centred in the air gaps of the yoke without substantially hindering the longitudinal vibrations of the bar member.

4. An electromechanical transducer as set forth in claim 1 also comprising an outer shell fitting closely over the outer edges of said yokes so that the yokes extend inwardly therefrom, a cover closing an end of said shell and entry and outlet connections for a supply of cooling fluid in said cover, said connections being respectively on opposite sides of said yokes so that the yokes are in the path of the flow of fluid.

5. An electromechanical transducer comprising a laminated bar member of magnetostrictive material, the length of which is an integral odd multiple including a unit

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multiple of one half wave length at the frequency at which the transducer is to be operated, helical windings around said bar member, a magnetic yoke, spaced pole pieces on said yoke co-operating with said bar member and means anchoring said bar member longitudinally in relation to said yoke at the nodes of vibration without substantially hindering the transverse expansion and contraction of said bar member while it is in vibration.

6. An electromechanical transducer as set forth in claim 5 wherein the laminations of which said bar member is composed are of curved cross section arranged adjacent but out of contact with one another, the structure also including cement securing the laminations together along their edges.

7. An electromechanical transducer comprising a plurality of bar members of magnetostrictive material, the length of which is an integral odd multiple of one half wave-length at the frequency at which the transducer is to be operated, helical windings located to set up longitudinal fields in said bar members, a plurality of magnetic yokes, spaced pole pieces on said yokes each co-operating with two adjacent bar members and means anchoring said bar members longitudinally in relation to said yokes at the nodes of vibration without substantially constraining said bar members transversely.

8. An electromechanical transducer as set forth in claim 7 wherein said bar members are of laminated construction.

9. A vibratory tool comprising a combination of a plurality of transducers each as set forth in claim 1, means securing the yokes of said transducers together with the axes of their bar members directed substantially towards a common point, a tapering shank of vibration-transmitting material of low damping, secured at its larger end to the end of the bar member of each transducer nearer said point, and a member uniting the smaller ends of said shanks and serving to carry an abrading tool tip, the overall length of each transducer and shank being such as to provide a vibration anti-node at the location of said uniting member at the frequency at which the transducers are to be operated.

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