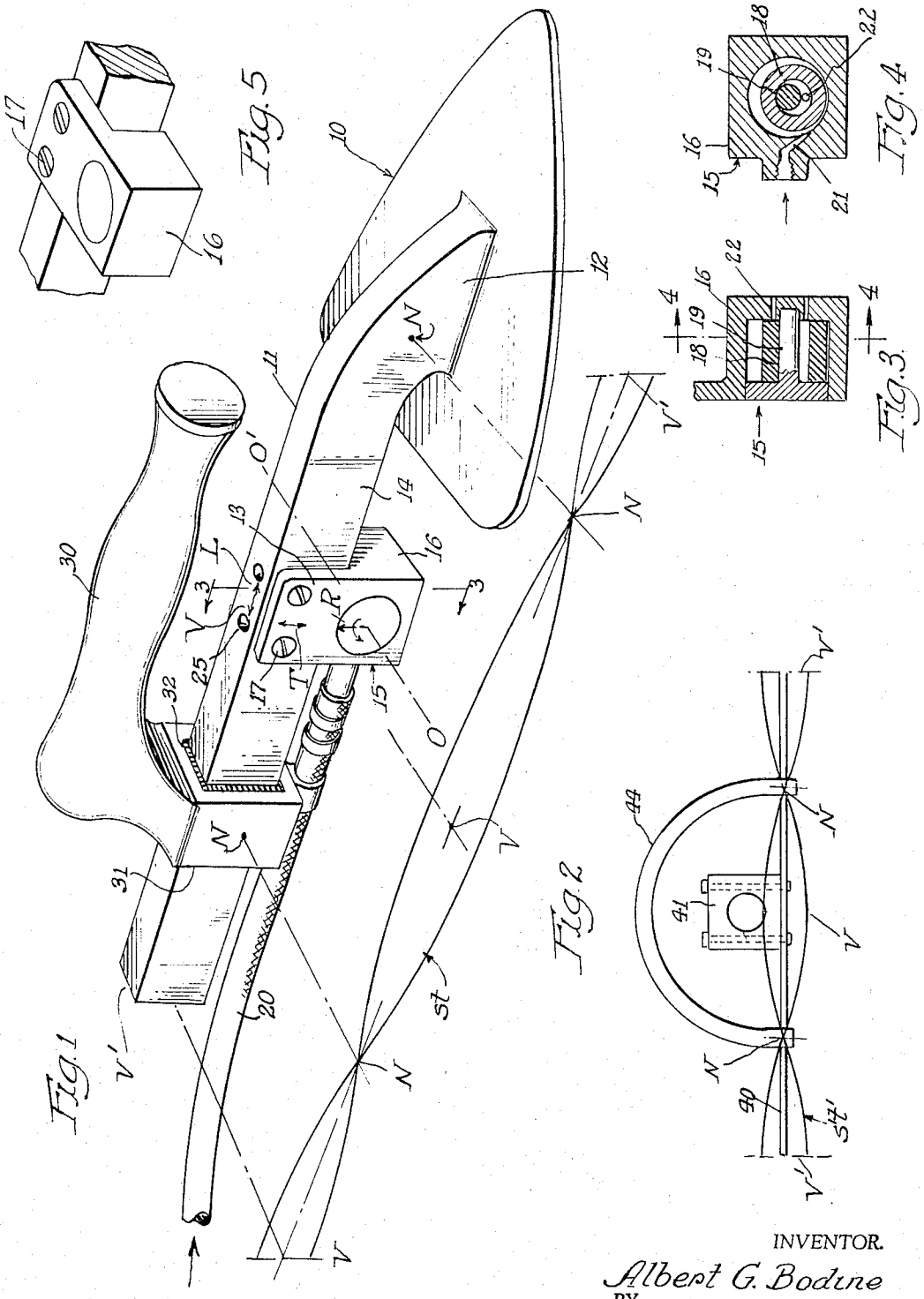
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SONIC TROWEL

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SONIC TROWEL

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ABSTRACT OF THE DISCLOSURE

A sonic vibration generator is coupled to a resonant elastic vibration system including a trowel blade to cause high level resonant vibration thereof. In one embodiment, the vibration system includes an elastic bar member on which the vibration generator is mounted and to which the trowel blade is attached. In another embodiment, the vibration generator is attached directly to the trowel blade and directly elastically vibrates such blade. The sonic energy imparted to the trowel blade facilities the movement thereof over the material being worked and provides significant benefits in the working of such material.

This invention is directed toward a sonically vibratory tool in the nature of a trowel which can be used for shaping a plastic or cementitious form, much in the manner of a conventional stone mason's or cement or plastic worker's trowel, but equipped additionally with means for applying sonic energy at the interface between the trowel and the work. Such a trowel has a number of advantages, one of which is improved facility of moving the tool over the surface to be formed or troweled by virtue of reduction in static and sliding friction when sonic energy is applied to the trowel surface.

The trowel of the invention has other benefits arising out of the radiation of sonic energy into the work media and these of course depend upon the particular nature of the work in hand.

The object of the invention is accordingly the provision of a trowel having means whereby sonic energy is applied to its working or troweling surface, for such purposes as facilitating the moving of the trowel over the surface to be formed, improvement in the finish of the formed material, and, in certain cases, contributing to the setting up and hardening of the work material.

With certain types of plastic media, radiation of sonic energy from the trowel into the media can contribute importantly and even critically to the hardening of the material. Examples to be mentioned are plastics of the thermosetting resin type, where sonic energy applied to the material is effective in activating the chemical reaction involved in setting and hardening, and thermoplastic resins, where thermal heating owing to conversion of sonic energy to heat is relied upon to do the necessary heating of the resin. In the case of the thermosetting resins, the trowel has the double function of forming the part into the shape desired while at the same time activating the exothermal reaction which is involved in the thermosetting process. This facilitates the use of materials that normally would require a considerable set-up time after the form is shaped. With the sonic trowel, the set-up time is greatly reduced because the chemical reaction is initiated and accelerated by the sonic energy from the trowel itself.

The sonic trowel of the invention is broadly applicable to the troweling of ceramic and cementitious materials, as in forming cement sidewalks, etc., where the troweling action is greatly aided by the sonic activity which facilitates the sliding movement of the trowel over the surface being formed. In this field of use, the sonic action is useful for working up bubbles of air out of the cement and accomplishing a more uniform compaction and wetting of the various aggregates by the cement material

itself. The sonic vibratory activity of the trowel results in a fluidization of the material it is working, making it possible to work with materials which are stiffer and dryer than usual. The tendency of sonically vibratory action to cause a fluidization of granular types of materials is a known phenomenon and is referred to in some of my prior patents. Under sonic activation, dry granular materials move and flow almost like a liquid. This tendency towards sonic fluidization is of course not lessened by the presence of moisture, as in cements in condition to be troweled. This fluidization effect is especially beneficial in troweling cement, because dryer mixes can be used to advantage, while still having adequate flowability, resulting in a stronger piece, and one having a minimum of voids, or in other words, having maximum strength. The sonic energy also warms up the cement, to accelerate the setting up of the material.

In a simple and illustrative form, the tool comprises a sonic vibration generator or oscillator operating a resonant elastically vibratory member or resonator which includes a trowel blade. In another form, the invention embodies a resonant elastically vibratory member or resonator which consists entirely or largely of the flat trowel member or blade which is brought into contact with the surface to be worked. In the presently preferred form of the invention, there is provided an elastically vibratory shank or bar member, in combination with a trowel member or blade, and this assembly of elastically vibratory member and blade is elastically vibratory in a resonant standing wave pattern, preferably of a lateral type. Acoustically coupled to the combination is a sonic vibration generator for generating vibrations at resonance in the assembly.

In its preferred form, the trowel of my invention employs an orbiting mass vibration generator or oscillator coupled into the resonant system. Examples are given in my prior patents and applications as follows: Patent No. 2,960,314, and applications Ser. Nos. 112,897 (now Patent No. 3,191,911) and 402,530 (now Patent No. 3,229,961). This orbiting mass oscillator has the highly advantageous characteristic that it adjusts its frequency, its phase angle, its power factor, and its impedance output in relation to the changing load of the work material as it goes through the hardening process while the trowel is drawn across it. Moreover, the sonic device keeps the trowel in resonant operation even when lifted off the work, the resonant vibration being maintained at a powerful level when the trowel is brought into contact with the work because the orbiting mass oscillator or generator inherently has this accommodating characteristic.

In order to facilitate the comprehension of the operation of the device of the invention, it is helpful to make an analogy between an electrical resonant circuit and a mechanical resonant circuit. This type of an analogy is well known to those skilled in the art and is described, for example, in Chapter 2 of Sonics by Hueter and Bolt, published in 1955 by John Wiley & Sons. In making such an analogy, force, F, is equated with electrical voltage, E; velocity of vibration, u, is equated with electrical current, i; mechanical compliance, C_m, is equated with electrical capacitance, C_e; mass, M, is equated with electrical inductance, L; mechanical resistance (such as friction), R_m, is equated with electrical resistance, R; mechanical impedance, Z_m, is equated with electrical impedance, Z_e. Thus, it can be shown that if a member is elastically vibrated by a sinusoidal force, $F_o \sin \omega t$, ω being equal to 2π times the frequency of vibration, that

$$Z_m = R_m + j\left(\omega M - \frac{1}{\omega C_m}\right) = \frac{F_o \sin \omega t}{u} \quad (1)$$

Where ωM is equal to $1/\omega C_m$, a resonant condition exists, and the effective mechanical impedance, Z_m, is

equal to the mechanical resistance, R_m, the reactive impedance components, ωM and $1/\omega C_m$, cancelling each other out. Under such a resonant condition, velocity of vibration, u, is at a maximum, effective power factor is unity, and energy is most efficiently delivered to the object being vibrated. It is such a high efficiency resonant condition in the elastic system being driven that is preferably utilized in the device of this invention to achieve the desired end results.

The invention will be further understood by now referring to the following detailed description of several illustrative embodiments thereof, reference for this purpose being had to the accompanying drawings, in which:

FIG. 1 is a perspective view of an embodiment of the invention, including also a standing wave diagram representative of the vibratory performance of the device;

FIG. 2 is a side elevational view of a modification of the system of FIG. 1;

FIG. 3 is a vertical medial section through the vibration generator of FIG. 1, in accordance with section line 3—3 on FIG. 1, and showing a simple form of orbiting mass generator;

FIG. 4 is a section on line 4—4 of FIG. 3; and

FIG. 5 is a perspective view illustrating an alternative mounting of the vibration generator utilized in the device of the invention.

With reference now to FIG. 1, numeral **10** designates a flat trowel blade of generally triangular configuration, having the usual point at its front end, as illustrated. Attached to this blade **10**, at about the center thereof, as by welding, is one end of an elastic bar or shank **11** which may be fabricated of steel and which extends rearwardly from the pointed blade **10** along a longitudinal direction line which is spaced above and parallel to the plane of the blade. The bar **11** thus extends along a direction line which is parallel with the plane of the blade **10** for the greater part of its length, but has a curved forward end portion **12** which meets and is attached to the blade.

Secured to the bar **11**, as by an attachment plate **13** engaging against one of its flat sides **14**, is a vibration generator or oscillator **15**, preferably of an air-driven orbiting-mass type, a number of examples of which are disclosed in my aforesaid Patent No. 2,960,314, and applications Ser. Nos. 112,897 and 402,530, now Patent Nos. 3,191,911 and 3,229,961 respectively. The attachment plate **13** extends upwardly from the generator housing **16** and may be a part of the housing **16**, which latter underlies and engages the lower side of the bar **11**, as illustrated. In the present instance, the generator is secured to the bar **11** by screws **17** extending through attachment plate **13** into the side of bar **11**; and, as illustrated, the generator is attached to the bar **11** close to the longitudinal mid-point of the latter. The illustrative generators of the aforesaid patent and pending applications are of two general types, one involving an inertia roller driven in a circular or orbital path in a circular raceway formed in a generator housing by a jet of air introduced under pressure and so oriented as to impinge on the roller tangentially to the raceway and thus drive it in its orbital path. The other type involves an inertia ring spinning on a fixed pin or axle set into a circular chamber in the generator housing, and again driven by tangentially injected air. The ring spins or gyrates in an orbital path about the pin, after the manner of a hoop on a stick. In the case of the roller traveling orbitally in the raceway in the generator housing, the centrifugal force of the orbital roller produces a gyratory force vector which is effective against the oscillator housing and therefore to whatever the oscillator housing is attached.

In the case of a ring spinning on a pin, such a gyratory or rotating force vector is exerted, by centrifugal force, on the pin, and therefore on the generator housing, and thence to whatever the housing may be attached to. The detailed arrangements of said generators form no part of the present invention, though for convenience I have

shown a simple ring and pin type, involving a ring **18** on a pin or axle **19**, driven by air supplied via an air hose **20** connected to housing **16** to feed one or more tangential air nozzles **21** directed against the orbitally traveling or spinning ring **18**. Spent air escapes via passages **22**. The air supply hose **20** will be understood to lead from any suitable controllable source of pressurized air, not shown. With either this ring and pin generator, or the ball and raceway type mounted to the sonic bar **11** as illustrated in FIG. 1, the generator housing delivers gyratory or rotating force, which is effective as a force vector R turning about the axis represented at O–O' in FIG. 1.

Now, it will be seen that the rotating force vector R will apply to the mid-section of the bar **11** to which the generator housing **16** is secured, a component of alternating force T which is oriented transversely of the bar **11**, and a component of alternating force L which is oriented longitudinally of the bar **11**. Now, if one of these components of alternating force corresponds to a resonant frequency of the bar for a mode of standing wave vibration, and if the pattern of standing wave vibration has an antinodal region near to the point of application of the force, the bar will be set into such a mode of standing wave vibration.

The tool of FIG. 1 has a possible one-wavelength mode of lateral standing wave vibration, as diagrammed at *st* in FIG. 1, where the height of the diagram, between the two curved lines, represents the amplitude of vibration along the length of the bar **11**. It will be seen from the diagram that the vibration amplitude is substantially zero at two nodal points N spaced a fractional percent of the length of the bar from each of its ends (this percentage depending upon lumped constant effects), and that there is an antinode V (region of maximized vibration amplitude), at the mid-point of the diagram, and antinodes V' at the two ends thereof. These nodes and antinodes N, V and V' are also marked on the appropriate portions of the vibratory bar **11** in FIG. 1.

It will be understood that the standing wave performance of the bar **11** involves alternating upward and downward elastic bowing of the portion of the bar **11** between the nodes N, accompanied always by opposed bending or flexure of the two end portions of the bar **11** outward of the nodes N. The masses and vibration amplitudes of the different sections of the bar separated by nodes are such as to maintain the bar **11** always in a counterbalanced condition. It will be clear that the blade **10** on the forward extremity of the bar **11** moves alternately upwards and downwards as represented by the velocity antinode V' in the standing wave diagram of FIG. 1. It is of course realized that the standing wave diagram of said figure is greatly magnified for clarity of illustration. The true amplitude of vibration of the forward extremity of the bar **11**, and of the trowel plate or blade **10**, is relatively minute—a small fraction of an inch.

It has been mentioned that the transverse component of vibration T derived from the gyratory force vector R delivered to the mid-point of the bar from the generator **15** is responsible for the lateral standing wave pattern and the performance as just described. The longitudinal component L delivered to the mid-point of the bar does not correspond at any frequency to any longitudinal standing wave pattern in the bar, and therefore does not produce any substantial amplitude of vibration.

Returning to a consideration of the lateral standing wave pattern set up in the bar **11**, it will be clear that the bar **11** undergoes transverse elastic bending in its participation in this mode of vibration. Assuming the blade **10** to be made also of an elastic material, as steel, the standing wave pattern may be extended to some extent in the blade beyond the plane of attachment between the bar **11** and the blade. For the most part, however, the blade **10** will ordinarily behave primarily as a lumped mass, without large wave action or pattern, and the tendency thereof is primarily to modify the idealized

standing wave pattern by shifting of the node N a little closer to the blade **10**, with an accompanying small reduction in vibration amplitude, and increase of impedance, at the blade.

The trowel is provided with a handle **30**, which is fixed at one end to a mounting frame **31** that surrounds the bar **11** at its rearward nodal region N, this being, as will be recalled, a region of minimized standing wave vibration amplitude. Between the handle frame **31** and the bar **11** is fitted a resilient rubber gasket **32**, which acts to isolate remaining vibration in the bar from the handle. The gasketed handle frame **31** is placed on the bar **11** with a snug fit, and because of the nodal point location, as well as the vibration isolation gasket **32**, handle vibration is minimized, and of no bother to the workman.

The trowel may be used much as an ordinary hand trowel, forming and smoothing the cement, plaster, or other material to be formed by sliding the blade **10** along the surface of the work. As mentioned preliminarily, the vibratory action of the blade **10**, which in this instance is substantially perpendicular to the work, applies sonic energy to the interface between the blade **10** and the work, and thereby reduces friction, both static and sliding, and thereby facilitates and eases the sliding of the blade over the work. In addition it radiates the sonic energy into the work material. In use, it is necessary to regulate the pressure of the air fed to the vibration generator until the orbiting mass rotor of the generator approximates the frequency of the desired resonant standing wave. Resonance can be readily recognized by peaking vibration amplitude in the region of resonance. The manifestations of resonance are very unique and can not be missed. Vibration amplitude suddenly rises markedly with only small increase in air pressure, and peaks as the resonant frequency is attained at an amplitude many times higher than that obtainable either just below or just above the resonant frequency. As a merely ilustrative example, without intention of limitation, the vibration amplitude of the blade to and from the work may, below resonance, be of the order of, for example, a few thousandths of an inch. At the resonance frequency, this may be magnified by many times, for example, of the order of ten times. At resonance, of course, output energy and power are greatly magnified, and large sonic energy is radiated from the surface of the blade into the work.

It is of interest that, when the trowel is driven to operate a resonance, the mass and compliance reactances of the resonator, inclusive of the blade, and of the oscillator, and also of any coupled-in reactive loading factor from the plastic body being formed, tend to counteract one another, such that the force consuming characteristics of these reactances are eliminated or tuned out. In this connection, it will of course be seen that the trowel blade vibrating against a plastic body is subjected to or encounters whatever mass or compliance reactance is presented by the particular body being troweled. The present tool is capable of adjusting its frequency automatically so that the reactance of the media is cancelled at the operating frequency.

As mentioned earlier, the sonic vibrations radiated into the work by the trowel can be effective in several ways to improve, facilitate, or even control the progress of the hardening process. For example, in the case of thermoplastic resins, the sonic energy thus radiated into the work may be utilized to generate the heat within the resin which is necessary to reduce it to its plastic state, wherein it can be readily formed by the trowel. In the case of thermosetting plastics, on the other hand, the sonic energy radiated into the resin can be utilized to excite or activate the exothermal reaction undergone in the thermosetting process.

The trowel of FIG. 1 may also be operated with the standing wave pattern in the plane of the blade rather than perpendicular thereto. For this purpose, the generator **15** is removed from the bar **11** by taking out the screws **17**, and reattached, on top of the bar **11**, by use of the tapped screw holes **25** to receive the generator fastening screws **17** as illustrated in FIG. 5. In this case, the same gyratory force is applied to the bar **11** at the center region thereof, but the plane of rotation of the gyratory force R is parallel to the blade **10**. In this case, a standing wave pattern such as shown at *st* in FIG. 1 is set up in the bar **11**, but in a plane parallel to the upper edge of the bar **11**, so now the bar **11** bends in a horizontal plane instead of vertically. In this case, the blade **10** participates in the standing wave vibration, but vibrates laterally rather than up and down, and therefore in the plane of the work rather than perpendicular thereto. Frictions are reduced by this sonic vibratory activity, again facilitating movement of the trowel over the work. Radiation of sonic energy perpendicularly into the work, however, is replaced in this instance by a shear type of acoustic coupling. Depending upon the nature of the material, considerable sonic energy can thus again be transmitted into the work, for any purpose desired.

A second embodiment of the invention is shown in FIG. 2, and comprises a long trowel blade **40**, composed of elastic material, such as steel, and it will be understood that this trowel blade **40**, as seen in plan, would normally have a point at the front and be somewhat wider at the rear. In other words, it may be of a flat-iron shape, or it might be, alternatively, of any elongate form such as a relatively long and narrow rectangle. Mounted at the center of this blade **40** is a vibration generator **41**, which may be exactly of the same type as the generator **15** mentioned hereinabove in connection with FIG. 1. This generator **41**, when driven at the resonant frequency of the blade **40** for a mode of lateral standing wave vibration, sets up such a lateral standing wave pattern within the blade itself, such as diagrammed at *s't'* in FIG. 2, with a velocity antinode V at the mid-point (at the location of the vibration generator), nodes N at points spaced typically twenty percent or so of the length of the blade inward from each of its ends, and further velocity antinodes V' at each of the ends of the blade. It will be appreciated that in this case the blade itself alternately bows downward and then upward, about the nodal points as points of minimized movement.

A bail type of handle **44** is attached to the blade, in any suitable or desired manner, at the nodes N, so as to minimize vibration in the handle.

The embodiment of FIG. 2, in common with that of FIG. 1, has the advantages of reduction of friction, for working with any troweling operation, and radiation of sonic energy into the substance in cases where such is desirable, as in case of heat to soften a plastic substance to permit it to be formed, or to start the exothermal reaction in case of a thermosetting process.

It will be understood that the embodiments now described and illustrated in the drawings are illustrative only, and that various changes in design, structure and arrangement may be made without departing from the spirit of the invention or of the appended claims.

I claim:

1. A sonic trowel for working material comprising:

a resilient sonic resonator bar structure including a trowel blade adapted to be placed in direct surface contact with said material,

a sonic oscillator attached to said resonator bar structure,

the vibrational output of said oscillator being coupled to said resonator bar structure, and

means for driving said oscillator at a frequency such as to cause resonant elastic vibration of said resonator bar structure thereby setting up a standing wave pattern therein, said material acting as a load on said resonator and receiving vibrational energy from said trowel blade.

2. The trowel as recited in claim **1** and additionally including a handle, said handle being attached to said

trowel blade at at least one region thereof where said standing wave pattern exhibits minimum vibration velocity.

3. A sonic trowel for working material comprising:

a sonic resonator including a trowel blade placed in contact with said material and an elastic bar attached at one end thereof to said blade,

a sonic oscillator mounted on said bar, the vibrational output of said oscillator being coupled to said resonator, and

means for driving said oscillator at a frequency such as to cause resonant elastic vibration of said resonator thereby setting up a standing wave pattern therein, said material acting as a load on said resonator and receiving vibrational energy from said trowel blade.

4. The trowel as recited in claim 3 wherein the broad surfaces of said blade lie in a plane substantially parallel to the longitudinal axis of said bar.

5. The trowel as recited in claim 4 wherein said oscillator is oriented with respect to said bar so as to generate a standing wave pattern in said trowel blade in a plane normal to the broad surfaces thereof.

6. The trowel as recited in claim 4 wherein said oscillator is oriented with respect to said bar so as to generate a standing wave pattern in said trowel blade in a plane parallel to the broad surfaces thereof.

7. The trowel as recited in claim 4 and further including a handle connected to said bar at a region thereof where said standing wave pattern exhibits minimum vibration velocity.

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