THE ULTRASONIC HAMMER TRANSDUCER

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Abstract – A new high power ultrasonic transducer is described. This transducer consists of a front mass and rear mass and two piezoelectric drivers on either side of a center mass which is also the dominating resonance mass. The characteristics of the transducer resemble a force transducer combined with the small signal characteristics of a sandwich transducer. Several variations can be achieved by manipulating the mechanical coupling as well as the electrical connections. The transducer is suitable for driving high mass loads such as the contents of pipes.

I. INTRODUCTION

Conventional Langevin or sandwich transducers [1] (Figure 1) are well known and are widely used in high power piezoelectric sonar and ultrasonic applications. These transducers are usually characterized by a relatively narrow resonant frequency bandwidth (or a relatively high Q) and a resonant characteristic that is coupled to the load i.e. its resonance is affected by changes in the medium. Most conventional ultrasonic systems account for this variation by employing various frequency and motional locking schemes to insure that the load is optimally driven within the limits of the transducer and the energy supply [2].

In spite of the popularity of the Langevin transducer, these transducers cannot effectively drive certain loads such as those contained within thick-walled pipes. This is due the load mass being directly connected to the front oscillating mass and thereby introducing an additional order of complexity into the system as well as an increase in lumped element mass. This problem has become more prevalent as many emerging applications such as sonochemistry or high pressure cleaning [3], require ultrasonic energy to be transmitted through thick walled vessels.

A separate problem with conventional ultrasonic cleaning and liquid processing systems is that one generally requires a uniform coverage over the treatment vessel. Since the transducers used have of relatively narrow resonant characteristics, standing waves usually form. Many systems make use of some frequency sweeping, amplitude modulation or a combination of different transducers to reduce this effect. However, this usually results in some compromise on the transducer efficiency. Increasing the transducer system frequency response would therefore have the potential to couple energy into the load without the formation of standing waves, but this is not practical with conventional sandwich transducer systems.

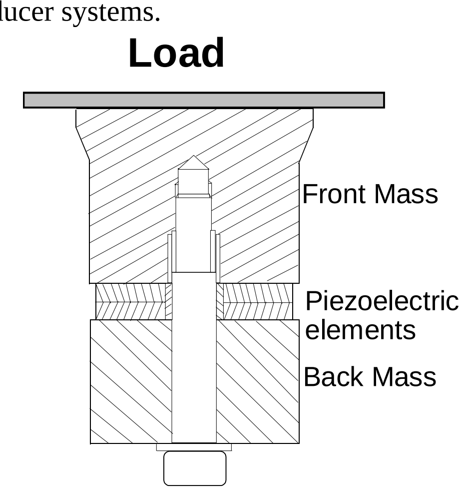

Figure 1 : Conventional Langevin transducer. The front mass is coupled to the back mass via a tensional bolt and the piezoelectric ring elements in the middle of the transducer. The load is coupled to the front mass and therefore influences the resonance response.

This paper presents a novel configuration that we have termed the hammer transducer [4]. The transducer has a resonant mass element that is independent of the acoustic load and, in certain circumstances, this configuration has a multi-resonant characteristic that is well suited to multi-frequency driving (over a significant bandwidth).

II. THE HAMMER TRANSDUCER

This transducer uses a minimum of two series driven piezoelectric elements to drive a fixed resonator mass element that is clamped between the piezoelectric rings. The piezoelectric elements are in turn sandwiched between a front and back mass and held together by a central bolt (which is also used to pretension the piezoelectric elements) as shown in Figure 2.

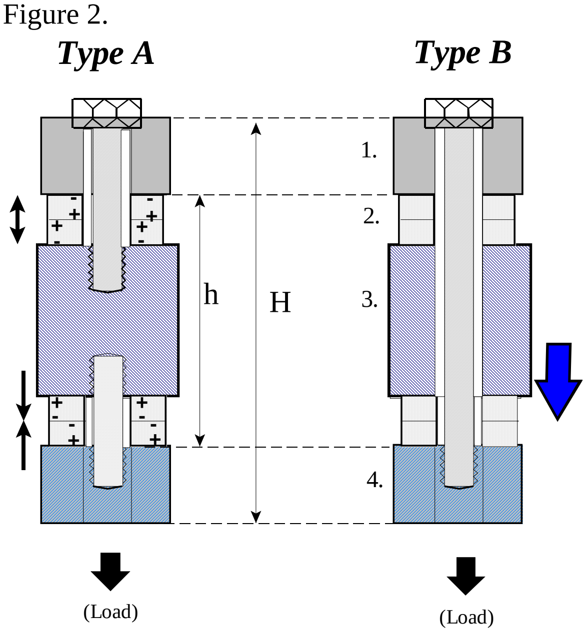

Figure 2 : Schematic of the Hammer transducer showing 1) tail mass, 2) four piezoelectric rings, 3) hammer mass and 4) front mass that is usually coupled to the load. Two configurations are possible: *Type A* - Center mass connected directly to bolt and *Type B* - Center mass moves independently of the bolt.

Although the construction of the transducer is similar to a conventional sandwich transducer, the operation is different as the central mass is usually designed to be the predominant resonant mechanism. This mass is in turn forced in one direction and then the other as a consequence of the piezoelectric elements being driven in series – as one disk contracts the other expands (in thickness mode). We have termed this type of transducer a "hammer transducer" as the central mass "hammers" the front and back masses [4].

Two different constructions are possible; firstly *Type A* the central bolt mechanically connects all masses and participates as an important (spring and mass) element of the total mechanical oscillating circuit (all three masses are oscillating) and secondly, *Type B* where the middle mass is not mechanically (directly) connected to the central bolt and central bolt can be approximately considered as the rigid connection between two end metal masses (only the middle mass is oscillating).

III. TRANSDUCER OPERATION

An approximate mechanical-equivalent oscillating circuit demonstrating the different hammer transducers configurations is shown in Figure 3. Mechanical excitation is symbolically represented as a mechanical generator/s, e_m(F,V), where *F* and *V* are the force and the velocity respectively.

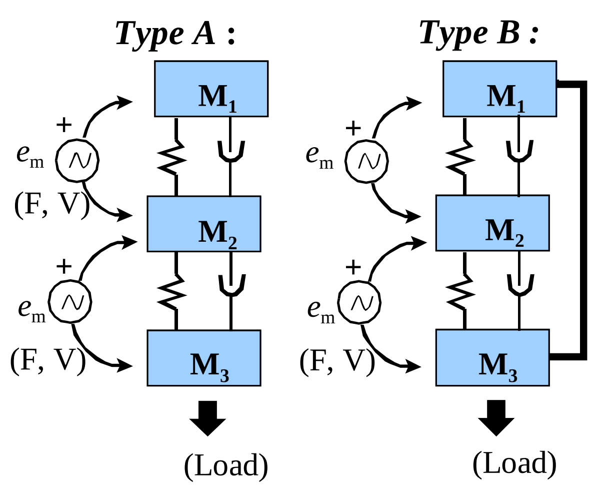

Figure 3 : Simplified equivalent oscillation system for the Hammer transducer options.

In the *Type A* resonator, we create a double resonant, 3 degree of freedom system. This can be rather complex to analyze (especially if the load interacts with M_3). This configuration is similar to a hybrid magnetorestrictive / piezoelectric combinational transducer that has been reported to be capable of achieving a significantly greater bandwidth than conventional tonpilz type transducers [5].

In *Type B* we have a hammer-mode where we can assume that only the middle metal mass is moving (in piston-mode with the end masses confined by the central bolt). With suitable parameter selection, *Type A* resonators can be designed with a dominant central mass, also approximating hammer-mode resonance. In this case, the end-masses are also oscillating, but significantly less (power-wise) than the middle-mass.

Hammer-mode resonance :

The total length of the active transducer stack *h* (the length of the central mass and two piezo-ceramic layers, without counting the end metal) remains approximately constant and fixed by the bolt. This is because the two piezo-ceramic layers are mechanically identical and are in opposite electrical polarization (and equally driven). When the first piezo-ceramic layer is contracting, the second one is extending by the same displacement (and vice versa) mutually compensating the total displacement of the active middle-stack length. Of course, the total transducer length, including both end-masses will not stay absolutely constant, except in case/s of fully symmetrical hammer transducer structure where upper and lower end-masses, and piezo-ceramic layers are identical.

An unusual property of the hammer transducer is that the dynamic center of mass, or center of inertia also oscillates. This is in contrast with conventional transducers where the center of mass will remain in a stable position.

The overall hammer-mode vibration is as a force transducer as opposed to a displacement transducer. This property means that the transducer will require a coupling to a load (such as a cavity resonator), but the characteristics of the load will not necessarily affect the resonance of the hammer.

Electrical driving options :

There are two basic configurations in which the hammer transducers electrical terminals can be connected; piezoelectric elements series driven and piezoelectric parallel driven. This is demonstrated by drawing the system in the format of a two-port network [6]. This is shown for the case of a hammer *Type B* with piezoelectric elements driven in series in Figure 4 and for parallel driving in Figure 5.

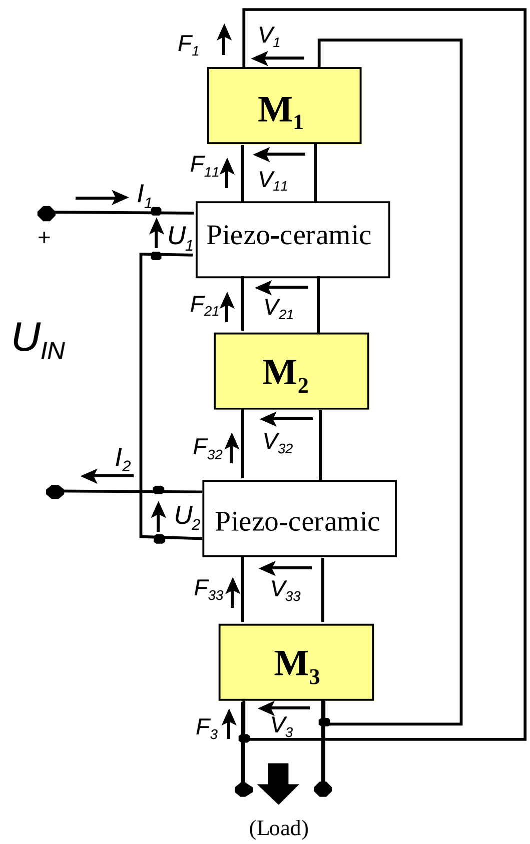

Figure 4 : Two-port system representation [6] showing piezoelectric elements driven in series. In this case, $F_1 \approx F_3$, $V_1 \approx V_3$, $F_{21}=F_{32}$, $V_{21}=V_{32}$, $I_1=I_2$ and $U_1=U_2=0.5U_{in}$

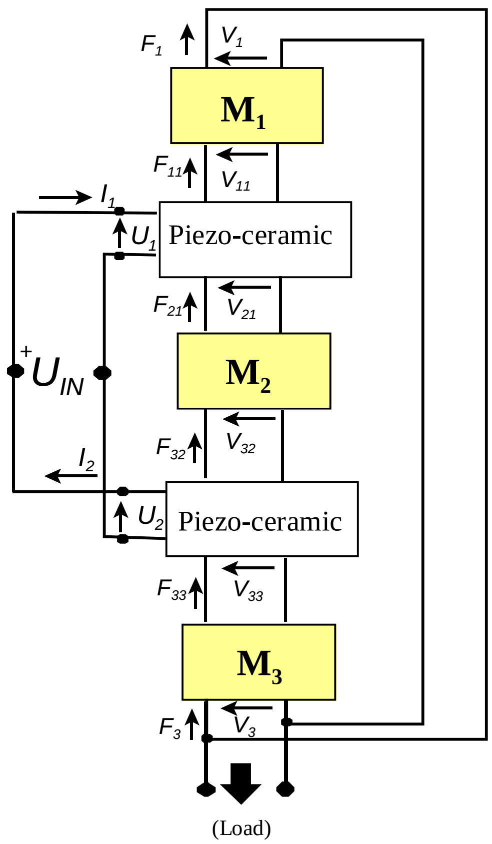

Figure 5 : Two-port system representation of a Type B hammer transducer [6] showing piezoelectric elements driven in parallel. In this case, $F_1 \approx F_3$, $V_1 \approx V_3$, $F_{21}=F_{32}$, $V_{21}=V_{32}$ and $U_1=U_2=U_{in}$

The two electrical configurations shown in Figure 4 and 5 allow for various driving options (including motional current and motional voltage). A complete analysis however, must take into account the transmission line characteristics of the components (including the load).

IV. EXPERIMENTAL RESULTS

Hammer transducers have been tested in various metal stamping, forging and high pressure cleaning [3] applications. Coupling from the hammer transducer to the load was via an aluminum or steel bar and in the case of high pressure cleaning, an additional acoustical coupling ring (round the exterior of the liquid filled pipe).

Variations in the load have very little effect on the operation of this transducer. Further the drive frequency can be modulated in a much wider frequency interval than in the case of traditional two-mass transducers (sometimes up to ±30% around central operating frequency), without dropping mechanical quality factor.

V. CONCLUSIONS

Several configurations of a force transducer, termed the hammer transducer have been presented. A central mass is the dominant resonant mechanism and the transducer has several advantages; namely a certain degree of isolation from the load, a transducer capable of generating large forces in an attached work-piece (even of high mass) and the potential of driving over a wide power bandwidth. Two electrical configurations are possible, each resulting in a complex system filter characteristic that cannot be accurately represented as a lumped equivalent circuit.

VI. REFERENCES

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