THE USE OF SIMULATION TO DETERMINE OPTIMAL VOLTAGE CORRECTION FOR A UNIMORPH TRANSDUCER

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1 INTRODUCTION

Most transducers used to produce sound are intended to operate by vibrating in a particular mode. However it is likely that at certain frequencies or subject to environmental conditions, such as a nearby reflecting surface, other modes may be excited causing undesirable resonances and antiresonances in the frequency response. This may occur as cone breakup in a loudspeaker or headflap in a piston transducer, used in underwater acoustics. If a transducer has a second, auxiliary motor, with a different form of excitation, then potentially this could be used judiciously to suppress unwanted modes. For efficiency, such a secondary motor should be light.

In some audio applications it would be convenient to have a flat piston radiator. However a flat diaphragm, being light for efficiency, will almost inevitability have low bending stiffness and suffer badly from breakup modes. Recently it has been suggested by Griffiths[1] that a simple piezoelectric disk could be used as a corrective motor to eliminate undesirable diaphragm modes. This paper considers modal-based methods to determine an appropriate voltage excitation.

2 THEORY

2.1 Modal Contribution Factors

Finite element analysis[2] is a well-established method for analysing the dynamics of mechanical systems, both computing modes and frequencies, and for forced response in frequency or time domains.

Let $\left[M\right]$ be the system mass matrix $\left[K\right]$ the system stiffness matrix.
Then the (r)th mode satisfies

$$\left[K\right]\left\{U_r\right\}=\omega_r^{\,2}\left[M\right]\left\{U_r\right\} \tag{1}$$

The modes are orthogonal with respect to the stiffness matrix, and after scaling, are orthonormal with respect to the mass matrix, thus

$$\left\{U_r\right\}^T\left[M\right]\left\{U_s\right\}=\begin{cases}1 & \text{if } r=s\\ 0 & \text{if } r\neq s\end{cases} \tag{2}$$

The full set of modes form a basis for the vector space of permissible displacements. Thus an arbitrary displacement vector can be expressed, uniquely, as a linear combination of modes,

$$\left\{u\right\}=\alpha_1\left\{U_1\right\}+\alpha_2\left\{U_2\right\}+\alpha_3\left\{U_3\right\}+\ldots \tag{3}$$

The α_r's are the modal contribution factors. They can be determined using the orthonormal property of the modes as

$$\alpha_r = \{U_r\}^T [M]\{u\} \tag{4}$$

2.2 Supressing a Mode

Suppose a vibrating device is excited at frequency f by a primary motor producing response $\{u(f)\}$ which is expanded as in equation (3). Assume mode 1 is the intended radiating mode and mode 2 is undesirable. If there is a secondary motor, which when driven with unit input has response $\{v(f)\}$, which is expanded as

$$\{v(f)\} = \beta_1\{U_1\} + \beta_2\{U_2\} + \beta_3\{U_3\} + \ldots \tag{5}$$

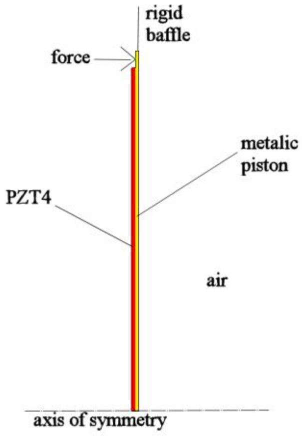
then if the secondary motor is driven with excitation $\frac{-\alpha_2}{\beta_2}$ then the combined response eliminates mode 2. The modal contribution factors are frequency dependent and so need to re-evaluated at each frequency. Note that it is necessary that the secondary motor excites mode 2, and $\beta_2 << \alpha_2$, i.e. the secondary motor only weakly excites mode 2, then this approach will be inefficient.

The above methodology could be applied over the entire frequency range, or over a narrow range where mode 2 needs suppression. It is easy to extend the method so that if there are n auxiliary motors, then n modes can be simultaneously supressed.

The piezoelectric effect can be used as an excitation mechanism. The finite element method can model piezoelectric materials. It is necessary to have the same mechanical and electrical constraints in both the eigenmode analysis and the forced response.

3 A SIMPLE EXAMPLE

A simple example, comprising of a steel disk with a PZT4 backing plate, is shown in figure 1.

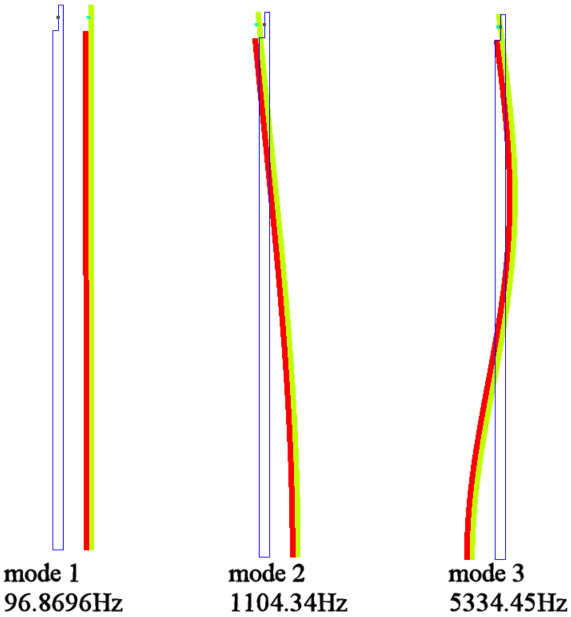


The metalic diaphragm has radius 21mm and thickness 0.205mm. The front face of the steel disk is flush with an infinite rigid baffle and radiates into a half space. The ceramic disk has radius 20mm and thickness 0.215mm and is axially polarized PZT4. The face in contact with the diaphragm is earthed and the back face is constrained to be at constant voltage. Excitation is by an axial force at radius 20.5mm. A simple representation of a voicecoil and suspension is included as a mass 0.005kg, an earthed spring with stiffness 3500N/m and a dashpot with damping constant 2.5Ns/m at the point of excitation.

Figure 1: simple, piezo-controlled piston radiator

This was analysed with an axisymmetric finite element model. All simulation results in this paper were produced with the PAFEC VibroAcoustics program[3].

The first 3 undamped natural modes are shown in figure 2.



Mode 1, pure axial motion, is the intended mode for radiation. Mode 2 is the first diaphragm breakup mode and mode 3 is a higher order diaphragm breakup.

Both steel and PZT4 are only lightly damped; it is therefore likely that the breakup modes will be excited significantly at the natural frequency.

Figure 2: modes of vibration

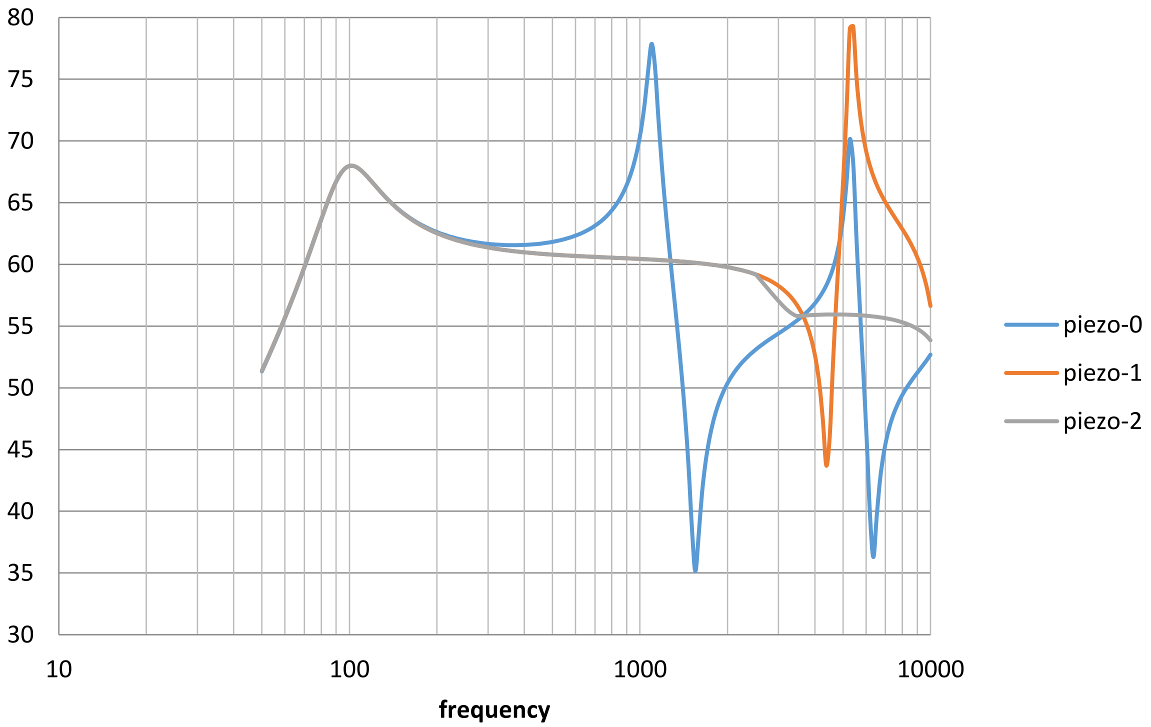


Figure 3: SPL at 1m in front of piston radiator

The radiation of the piston into the half space was analysed from 40Hz to 10kHz, using acoustic BEM & FEM[4] to model the air in the half space. Figure 3 compares the SPL at 1m in front of the axis of symmetry. Job piezo-0 is with no correction; modes 2 and 3 are strongly excited. Job piezo-1 is with suppression of mode 2 over the entire frequency range; this is very successful, although mode 3 is more strongly excited. Job piezo-2 is with suppression of mode 2 up to 2.5kHz, suppression of mode 3 above 3.5kHz and a transition region between.

4 A REALISTIC CASE

A more realistic case is shown in figure 2. This has a surround, former and voicecoil explicitly included. Again mode 1 is the intended radiating mode. Mode 2 has diaphragm bending and should ideally be suppressed. Mode 3 is a surround mode and hence only weakly coupled to the piezoelectric disk.

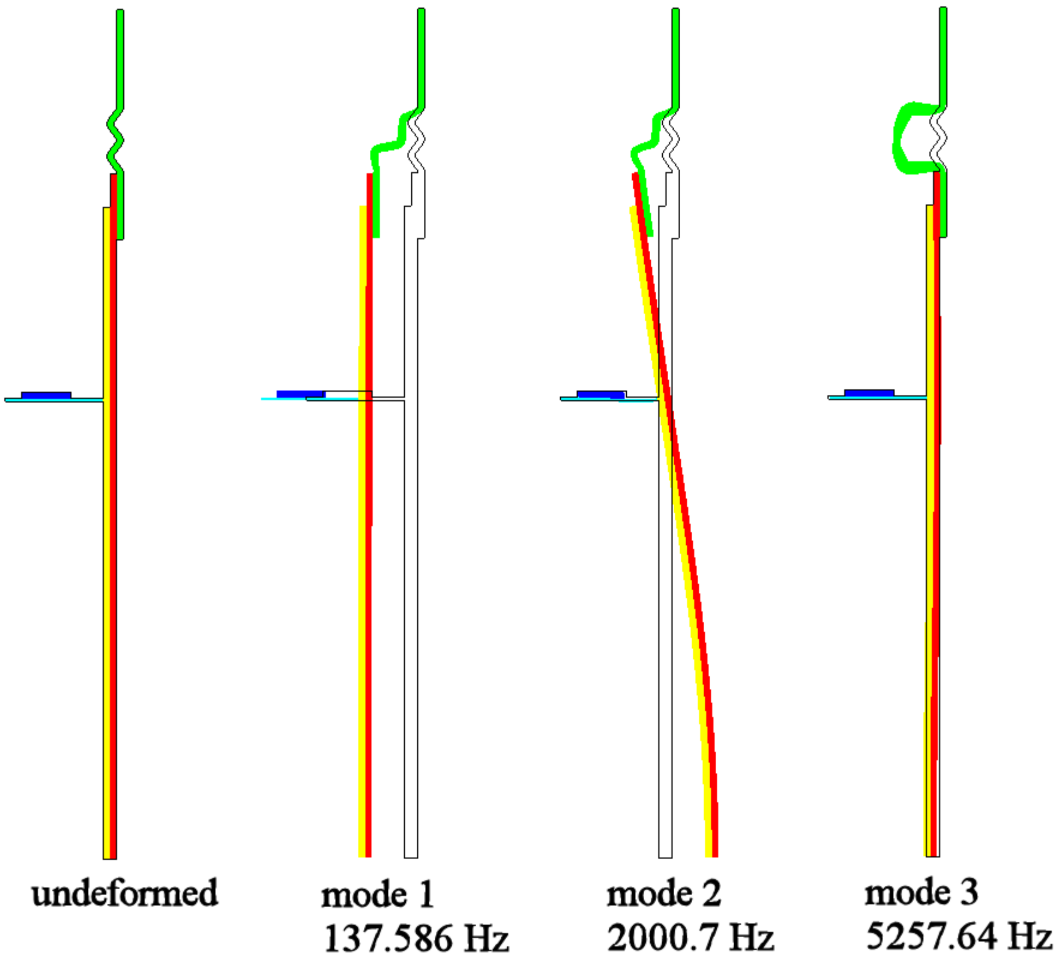


Figure 4: Piston radiator model with first three modes

The same procedure was followed to eliminate mode 2 from the response. A comparison of the SPL on axis for case with pure voicecoil excitation (piston-0) and voicecoil + piezoelectroic (piston-1) is shown in figure 5. Mode 2 is seen to be effectively eliminated.

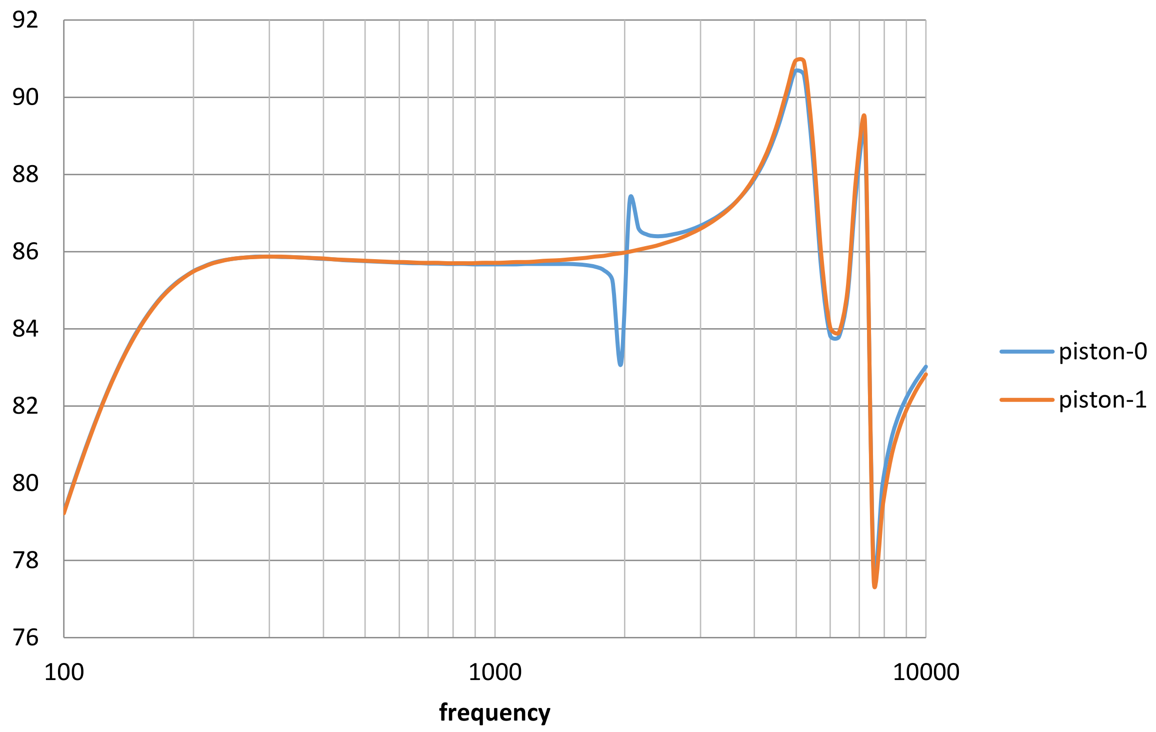


Figure 4: SPL at 0.25m in front of piston radiator

5 CONCLUSIONS

It has been shown that breakup modes of a piston radiator can be suppressed by use of a piezoelectric disk. It is likely that the method can be made more efficient by splitting the disk into an inner disk and outer annulus which are driven independently, and can probably couple more efficiently to the undesired moe(s).

6 REFERENCES

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