DESIGN OF A NEW HIGH-QUALITY TWEETER USING FINITE ELEMENT ANALYSIS

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Abstract

This paper describes the contribution of Finite Element Analysis to the accelerated development of a new high-frequency tweeter. A new technique, Wavefront Analysis, is introduced.

1. INTRODUCTION

Until recently the Finite Element Analysis (FEA) technique for simulating mechano-acoustical systems has been confined to research projects by a combination of high computational demand and lack of user friendliness. Both of these aspects have lately been subjects of close scrutiny and the result is a significantly more accessible design tool.

In traditional loudspeaker design it is often the case that the engineer uses 'off the shelf' parts, unable to take the risk of tooling new parts only to find that they do not perform as required. This means that drive unit design has become a very gradual evolution, each new unit being a small variant upon the last. In theory FEA allows the designer to experiment with different mechano-acoustical structures without making, in terms of lead-time and tooling cost, expensive mistakes.

This paper focuses on the use of FEA in the mechano-acoustical design of the tweeter for a new, high quality coincident source array. This is a strong challenge, requiring the combined facilities of coupled mechano-acoustical behaviour, structural vibration analysis and acoustic wavefront propagation. The FEA results are compared to the measured frequency responses (up to 40kHz) and laser scans (up to 25kHz) of actual tweeters and show encouraging correlation.

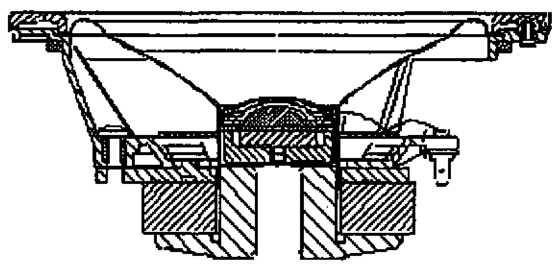

Figure 1. Existing coincident source array.

2. THE TASK

Our goal is to produce a coincident source array having a frequency response that extends beyond 30kHz. In order to tackle this problem it is broken down into three well defined stages.

1) development of a mechanically optimised tweeter
2) acoustic integration of this tweeter into a waveguide
3) structural optimisation of a midrange driver which does not adversely affect the tweeter performance

The first two are discussed here.

3. MECHANICAL DESIGN OF THE TWEETER

Based on the design goal, our definition of a mechanically optimised tweeter is one that has the first bending mode above 30kHz. As a starting point we considered a very good 25 mm titanium dome tweeter (fig. 2).

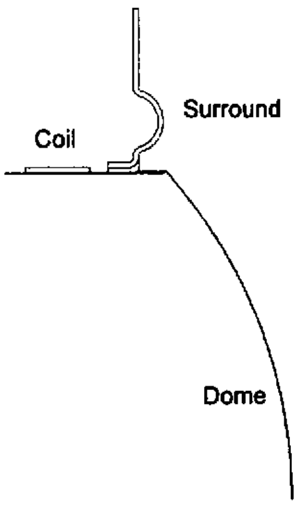

Figure 2. Original tweeter (radial section).

The first break-up in the existing dome occurs at 22kHz. On the laser scan (fig. 3) , the periphery of the dome is seen to be flexing.

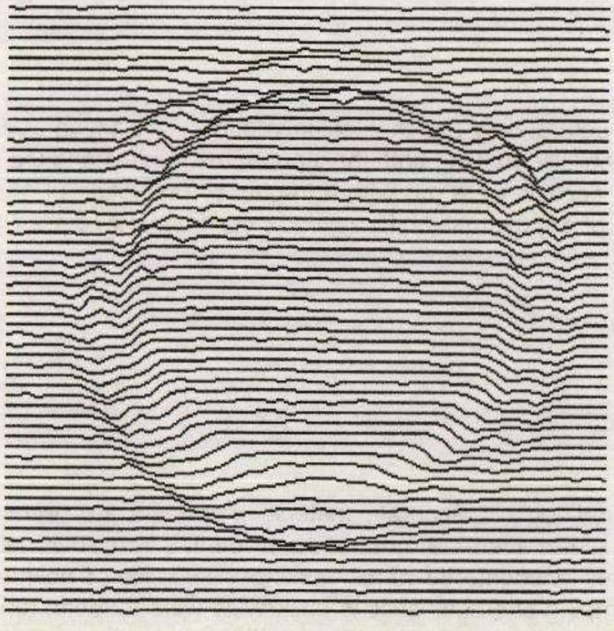

Figure 3. Laser scan of original tweeter, 22kHz.

The effect of this bending mode is seen very markedly as a high 'Q' peak in the frequency response curve (fig. 4) - no surprise to loudspeaker designers familiar with hard dome tweeters.

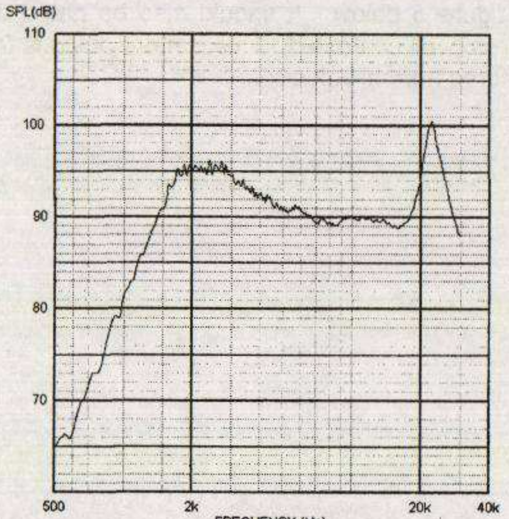

Figure 4. Frequency response of original tweeter in infinite baffle.

This bending is the first weakness in the dome's behaviour, so we need to know how to address the problem. In order to do this we can construct a FEA model to analyse the behaviour and allow us to methodically modify the structure to achieve the desired result.

4. THE FEA MODEL

Our first models were structural only (mechanical in vacuo). The advantage over fully acoustically coupled models is the simplicity, making both the input of the models and their solutions faster. The models presented in this section were run with a frequency resolution of 12 or 24 frequencies per octave and ran at a rate of approximately 12 seconds per frequency on a PII 233MHz PC with 96 Mb of RAM.

The basic FEA inputs required are
1) geometry
2) material properties
3) element size
4) solution type

The geometry is easily defined but accurate material properties are generally difficult to obtain. Those who have tried to glean even the most basic properties from material suppliers will be very familiar with the difficulties encountered here - asking a supplier of polypropylene sheet for the frequency dependent damping characteristics is unlikely to yield a useful result! But, to produce a good FEA model it is of paramount importance that representative material properties are used.

Choosing the correct element size and solution type is dependent upon the high frequency limit required from the model. The reader is referred to references [1], [2] and [3] for further information about defining FEA models accurately.

The tweeter shown in figure 2 was the first to be modelled and the FEA model clearly demonstrates the same bending mode, in figure 5 below. It should also be noted that the movements of the surround and former are far from well controlled. This is more obvious from the FEA than the laser scan, because the laser measures normal velocities.

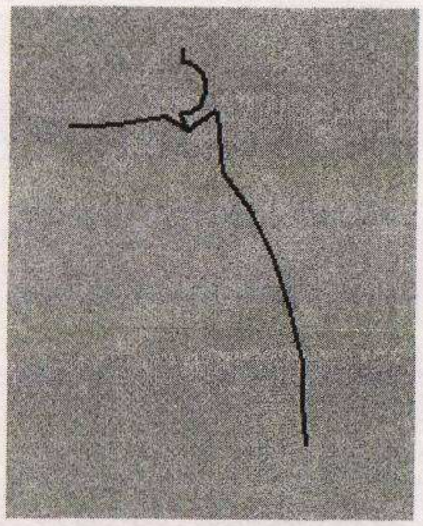

Fig 5. Sectional plot of original tweeter in breakup, 22kHz (coarse model).

Our first task was to address this bending mode. It is intuitive that increasing the mechanical stiffness where the dome bends will shift the mode higher in frequency and we are able to approach this from different directions.

1) Change the dome
2) Change the surround
3) Move the coil

Changing the dome and surround geometry and materials are intuitive, but less obvious is the fact that the inherent stiffness (or 'barrel strength') of the coil can also be of benefit. On the current assembly, the coil is wound onto a separate former, fabricated from a loop of polyimide film. This is in turn bonded to the dome. If instead the coil is wound directly onto the skirt of the dome, close to the shoulder, the stiffness of the whole assembly is usefully increased.

Modifying the dome profile by adding a radius to the shoulder (fig. 6) demonstrates how this improves the behaviour, shifting the bending mode to 24kHz as seen in figure 7a.

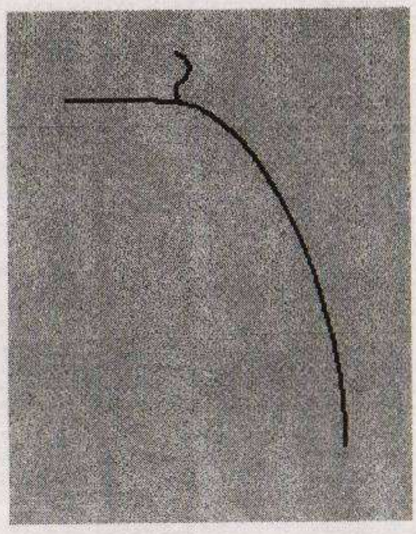

Figure 6. Geometry showing radius in shoulder

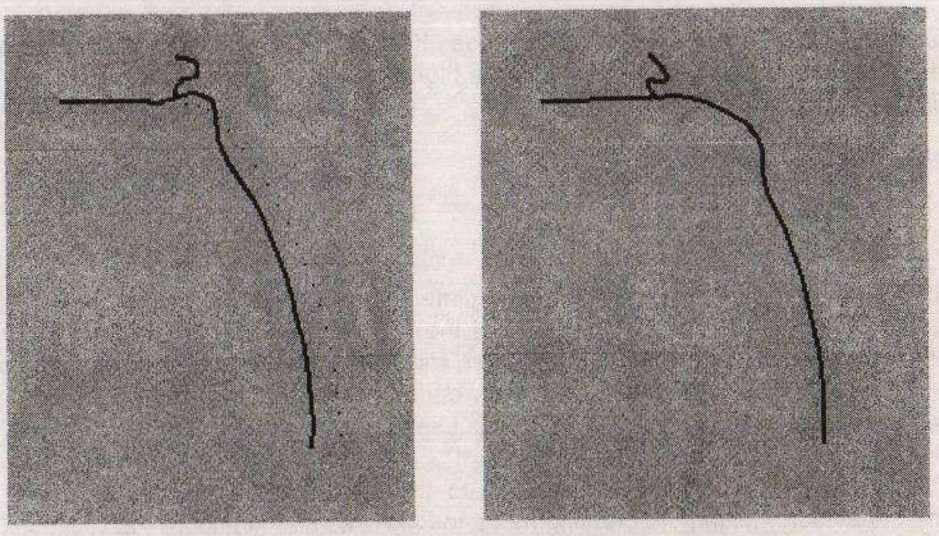

Figure 7. Flexure of shoulder, (a) 24kHz, (b) 28kHz.

Note that the bending is shifted towards the apex of the dome. We tried gradually increasing radii and found that the bending mode gradually shifted higher in frequency and further up the dome (fig. 7b), leading us to the idea of a continuously varying radius - i.e. an *ellipse*. The pure ellipse shaped dome demonstrates very controlled breakup, with a peak at 31kHz (fig. 8). The uncontrolled behaviour of the surround has been improved by reducing its size and forming it from a stiffer material. This also reduces the radiating area of the surround and hence the contribution to the acoustic output of the tweeter.

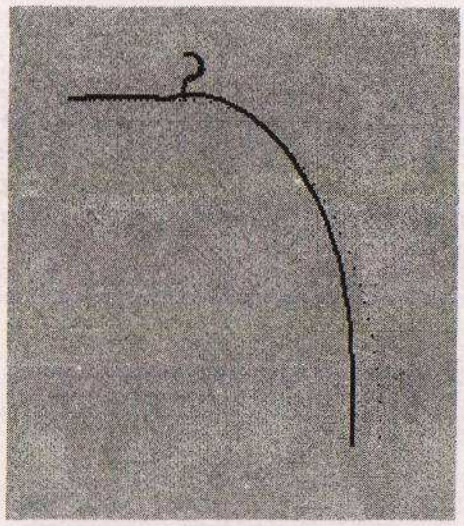

Figure 8. First breakup of elliptical dome, 31kHz

The laser scan of the prototype unit confirms the piston-like behaviour of the dome at 22 kHz, and the plot can be seen below in figure 9.

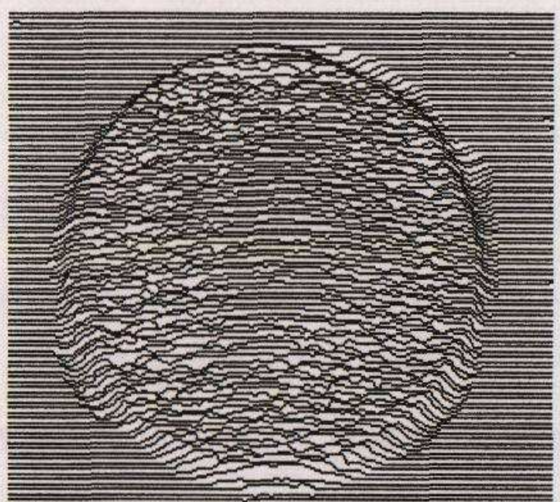

Figure 9. Laser scan of the elliptical dome, 22kHz.

4.1 Adding The Air

The mechanical models offer a great insight into the problem but a frequency response is required to check the acoustic performance of the tweeter. In order to see the frequency response of the final tweeter air is added to the model. This makes the equations considerably more difficult to solve, increasing the solution time to approximately 14 minutes per frequency. The frequency response plot from the elliptical dome model is compared with a measurement (normalised for constant-force input) of the prototype tweeter in figure 10.

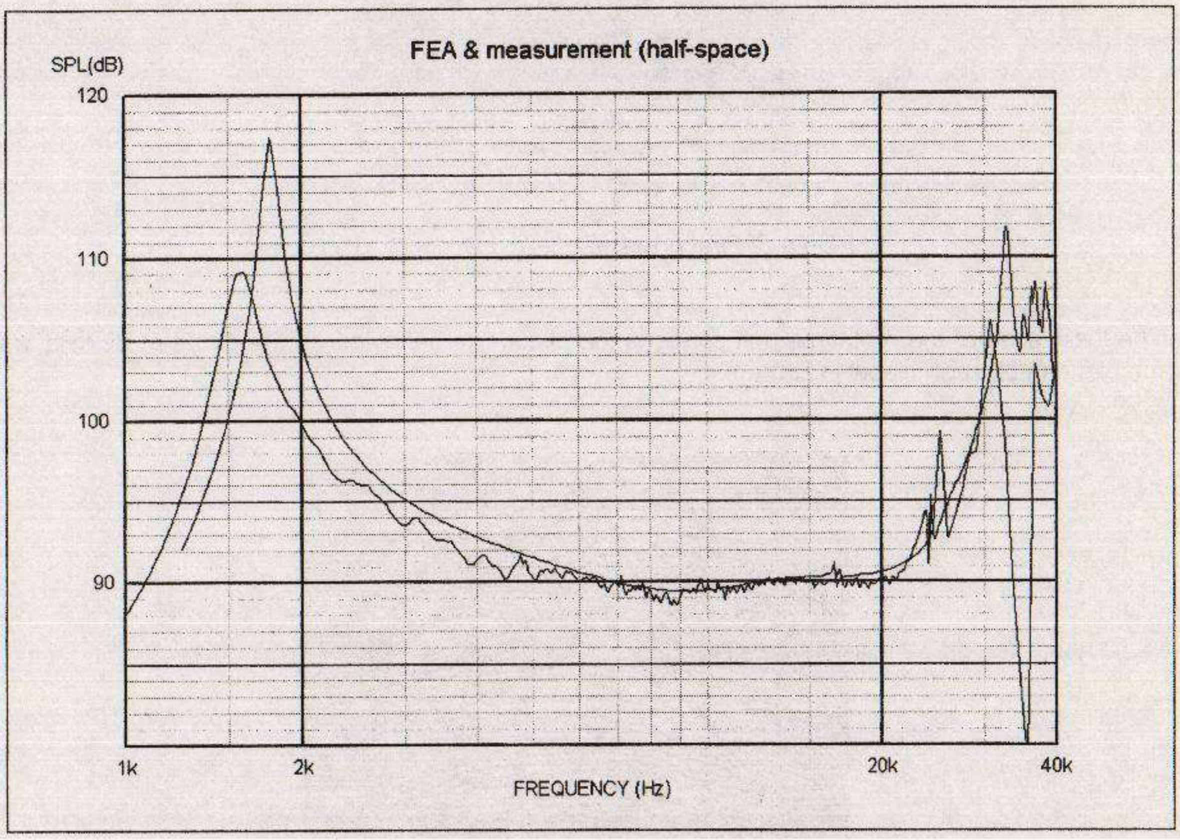

Figure 10. Comparison of FEA simulation with measurement.

The correlation between measurement and simulation is very encouraging. The errors around the fundamental mass-stiffness resonance of the moving system and the first break-up mode of the dome are largely due to the use of frequency-independent material properties. Improvements will be gained by allowing these properties to vary with frequency. In the passband the agreement is very good. A small disturbance can be seen at 16.6kHz, which is due to acoustic reflection from the metalwork behind the dome.

4.2 Wavefront Analysis

Once we have air in the model we can do much more than just plot the frequency response. It is possible to look at the sound propagation via the technique of Wavefront Analysis. This technique, described in [4] is an animated visualisation of the acoustic wavefronts and can be usefully described as a 'virtual ripple tank'. This tool which gives a view of the acoustics of a problem is invaluable when waveguides are to be designed. Looking at the wavefronts produced from the tweeter on a flat baffle (fig.11) it can be seen that at low frequencies (5kHz) the tweeter behaves as an omni-directional source and as the frequency increases the tweeter begins to beam due to it's finite size.

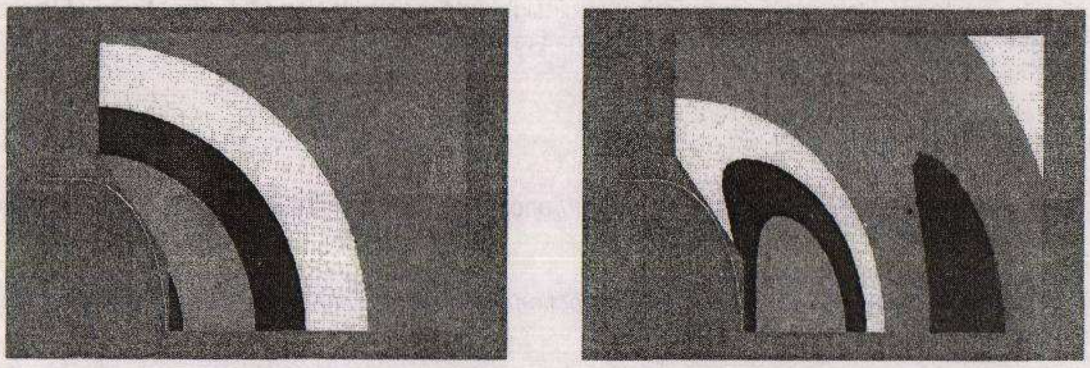

Figure 11. Wavefronts at (a) 5kHz (b) 14kHz, infinite baffle.

For this simple case there are no big surprises, but once a waveguide is added the problem becomes much more interesting (read complicated!).

The acoustic behaviour has some interesting features which can be investigated with Wavefront Analysis (fig.12). These will be addressed in a future paper.

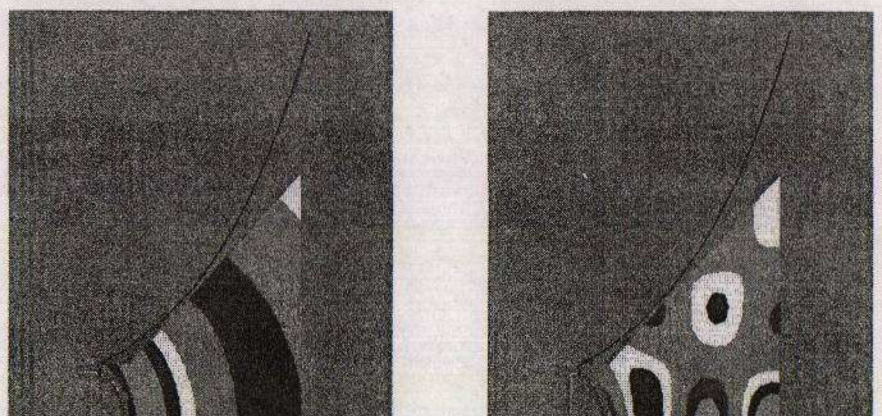

Figure 12. Wavefronts at (a) 5kHz (b) 14kHz, in waveguide.

5. CONCLUSION

This paper has discussed the design stages for a tweeter which is a significant evolution from an existing design. The FEA has allowed a very thorough and in-depth design process to take place in a short timescale. 20 'virtual' prototypes were 'built and tested' in 7 days. The results presented here demonstrated very promising correlation with early physical prototypes, so good that further physical prototyping was not necessary.

As different materials and processes become available FEA will allow the engineer to efficiently examine more radical designs for performance improvements. FEA is a very useful tool that gives the loudspeaker design engineer an excellent insight into a new design at the front end of the cycle - the point at which the most important decisions are made.

6. REFERENCES

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3. J.R.Wright, *Radiation Impedance Calculation by Finite Element Analysis*, Inst. Acoust. Bulletin, 19 (6), 1994.

4. J.R.Wright, *Seeing Sound*, Proc. Inst. Acoust., 20 (5), 1998.