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A NEW COMPRESSION DRIVE UNIT

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1. INTRODUCTION.

Compression drive units have evolved over more than half a century, used with a horn they provide high efficiency reproduction in midrange and high frequency bands. Modern pressure drive units not only are extremely efficient, but also have high power handling. Compared to a 1" direct radiating dome with 90dB/W sensitivity and a 10W power handling, a 1" pressure driver is 20dB more sensitive and has 5dB more power handling giving a maximum SPL approximately 25dB higher.

Until recently the tools available for design have involved either crude lumped models or incomplete analytic solutions, the results from which are combined with a large amount of empirical work. The acoustics of pressure drive units is especially difficult to work with in practice because of the complex geometry of the cavities surrounding the diaphragm and the extreme difficulty of measuring pressures in these volumes. The magnetic behaviour is similarly difficult to work with, in this case because the flux in the gap must be very high and the magnetic poles behave in a very non-linear manner. Traditional lumped analyses of magnets cannot cope with this non linearity and a 'cut it and see' approach was until recently the only way to refine a design. Bearing in mind the close spacing of the diaphragm to the phase plug, the difficulties of forming diaphragms and fabricating phaseplugs together with the tight tolerances required for the magnetic gap makes evolution an expensive process.

More recently numerical techniques such as Finite Element Analysis (FEA) and Boundary Element Analyses (BEA) have become accessible to loudspeaker designers. Such techniques may be applied to sound and vibration as well as thermal and magnetic domains. Given the correct material properties and boundary conditions, as well as the dimensions of a structure, these methods may be used to model this structure and thus predict some aspects of its behaviour. This paper focuses on the application of FEA to the magnetic and vibro-acoustic design of a compression driver.

2. PRESSURE DRIVERS-AN OVERVIEW.

Pressure drive units are drivers which are designed to work in conjunction with a horn. The movement of the diaphragm causes air pressure which rather than radiating freely into space produces a wave with both its rate of expansion and shape controlled by a horn. The throat of the horn usually has a much smaller area than the diaphragm, this combined with the horn produces a large acoustic load on the diaphragm which results in a high efficiency. It is this junction between diaphragm and horn which makes the design of pressure drivers 'different' and allows large diaphragms to be successfully used to reproduce relatively high frequencies without interference between the radiation from different parts of the diaphragm.

This paper discusses the development of a pressure driver which radiates from the concave side of the diaphragm through the pole (see figure 1). While sound and magnetic field must both be squeezed through the centre pole the resulting phaseplug geometry readily lends itself to producing the standard exit sizes traditionally used for horns.

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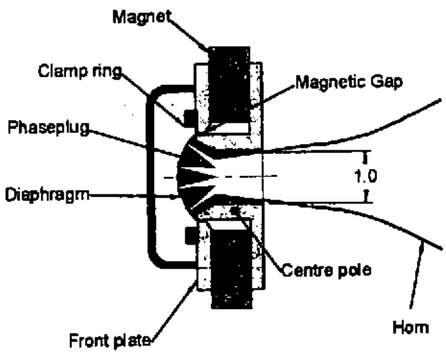


Figure 1. Diagram of a compression driver.

3. MAGNETIC DESIGN.

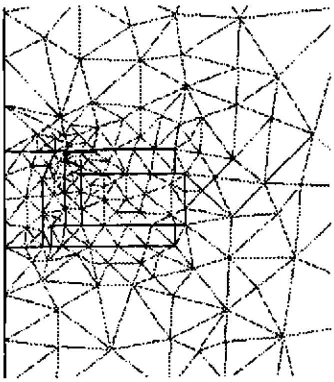
The magnet is an expensive and heavy component. We required the strongest possible field in the magnetic gap for the lowest cost, size and weight. The high gap flux leads to magnetic saturation the iron poles which cannot be accommodated using lumped element analyses, consequently FEA was used throughout the design to model the magnet behaviour. FEA is able to model the non-linear behaviour of the iron and magnet materials producing a good estimation of the flux density throughout the magnet.

3.1 FEA Modelling.

Producing an FEA model involves a process which takes the geometry of the device to be modelled as a starting point. Each region of material is broken up into a number of 'elements' the nodes of which are the points at which the calculations are made. The element type must first be selected then the elements must be given material properties, boundary conditions set up, and a driving force applied. Some problems may be simplified by considering symmetry, this can greatly reduce the number of elements required and thus the solution time. Both acoustic and magnetic models discussed in this paper have axisymmetric symmetry and use a 'half section' to define geometry which can then be meshed with axisymmetric elements.

3.2 Magnet Design.

In a loudspeaker magnet the two main areas of interest are the magnitude of the radial flux in the gap and the magnitude of the flux density in the iron poles. It is interesting to note that the flux within the poles cannot be measured directly and the FEA simulation is providing 'new' information.



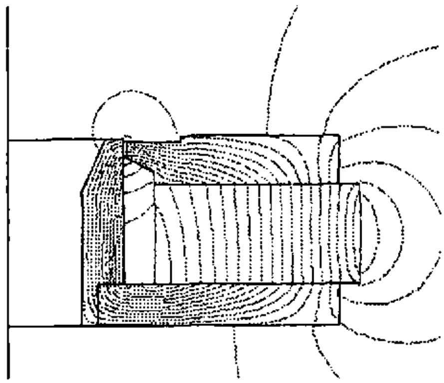


Figure 2. Outline of magnet and FEA mesh. Figure 3. Outline of magnet and lines of flux.

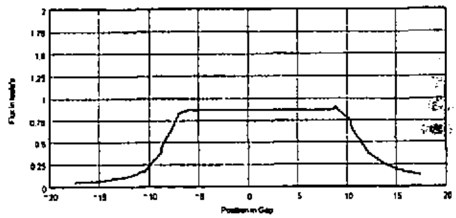


Figure 4. Flux profile in magnetic gap.

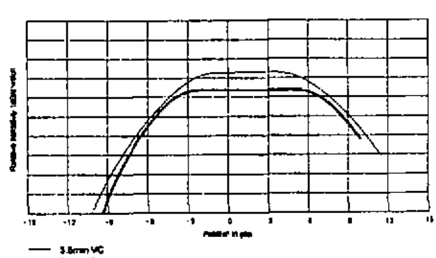


Figure 5. Relative sensitivity of two coils in the simulated gap.

Initially the two 'industry standard' sizes were modelled using Magnet[1]. The mesh used for the analysis is shown in figure 2. Figure 3 shows the calculated flux, colour contour plots (not illustrated) proved especially effective for observing pole saturation. To evaluate the effect of the gap flux on the loudspeaker performance of various gap sizes variations of voicecoil properties such as mass, height and wire length should be taken into account. Any change in coil diameter is usually reflected in the gap dimensions, these are generally adjusted to keep the clearance to the minimum achievable value. Consequently in-house software was produced to convolve the flux density profile with various voice coils. By taking into account the various coil masses and combining them with the diaphragm mass a graph of 'normalised sensitivity' against gap position was produced. This allows different gap and coil geometries to be analysed in respect to sensitivity variation with position. Figure 4 shows the radial flux in the gap as a function of position, figure 5 shows the resulting sensitivity profile calculated for two different voice coils. These results pointed the way to a more efficient design using an intermediate sized magnet of 120mm OD to achieve the same gap flux produced by the original model with the larger 140mm OD magnet.

4.0 ACOUSTIC DESIGN.

4.1 Lumped Element Analyses.

The acoustical behaviour of the driver may be represented by an analogous or equivalent electrical circuit in almost the same way as a direct radiating driver, the difference being that the radiation resistance may not be neglected. Unlike a direct radiating driver the airload affects the diaphragm displacement significantly and is crucial in determining the driver performance. To include its effect on diaphragm displacement it is usual to calculate the acoustic impedance at the diaphragm and use this frequency dependant impedance as part of a lumped element model.

4.2 Modelling The Acoustic Load.

The acoustic load consists firstly of the cavity between the diaphragm and phaseplug. This cavity is joined to the 'horn stub' and then to the horn by the phaseplug slots. Where lumped element analysis is to be applied it is common practice to assume that the cavity is small compared to a wavelength, while this is clearly not the case there is much to be learned from this approach.

Most commonly the acoustic load on the diaphragm would be calculated for the combined slots, stub and horn using single parameter techniques[2 3]. This basic model is very useful for quick calculation of the driver power output with a particular horn since it is a fast and reliable method of calculating the acoustic impedance of the horn and driver for an arbitrary flare rate. One complication with this method is that the area of the wave depends on the wavefront shape which is most often assumed to be planar. In fact the wavefront shape depends on the shape of the horn and the frequency being considered, in practice the best approach is to use known cases to deduce an approximate wavefront.

To extend the model to predict the on-axis SPL would require knowledge of the horn directivity. While some approximate attempts have been made to do this using an assumed spherical-cap shaped wavefront of constant amplitude these approximations do not produce good results for most horn shapes within their working bands. This is important since most loudspeaker manufacturers cannot measure power output and checking a models validity is a necessary stage of its use.

Consequently the approach made in much of this work was to model and measure the results of a driver initially without the horn and later mounted on a planewave tube.[4]

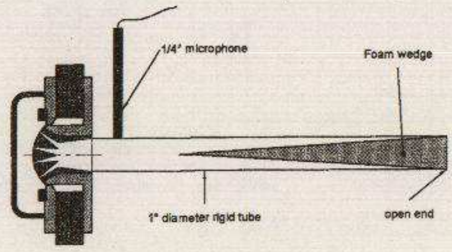


Figure 6 Planewave tube

The results from a simulation of the driver using AkAbak[5] is shown in figure 7. This response curve shows evidence of longitudinal modes in the driver, horn stub and phaseplug slots. When compared to the measured result shown in figure 8, this curve shows suprisingly good agreement with this relatively crude model.

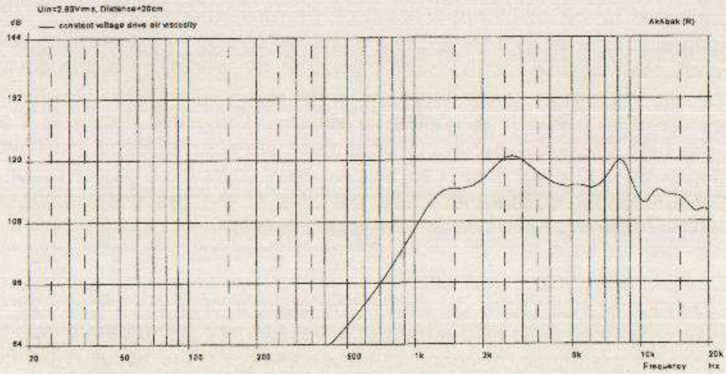


Figure 7. AkAbak calculated lumped element response.

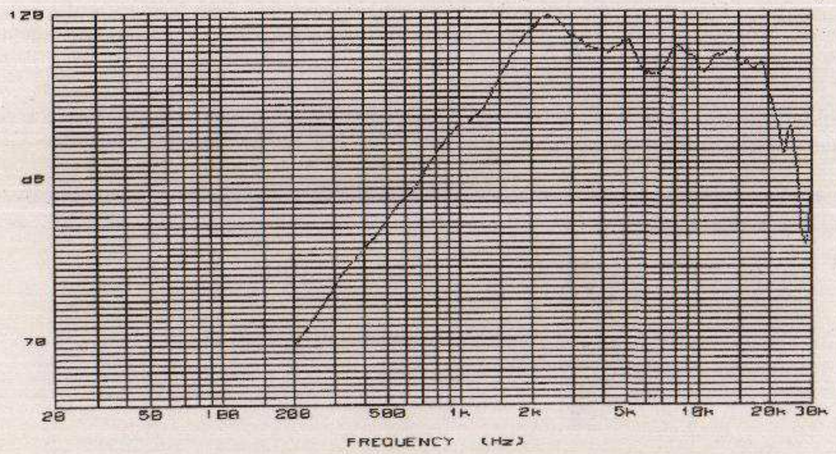


Figure 8. Measured response of driver without horn.

4.3 Analytic Approach To Phaseplug Diaphragm Cavity.

To allow an analytic approach the cavity shape may approximated to a cylindrical cavity[6] and the diaphragm approximated to a rigid piston. This approach is very useful since it illustrates how the resonances in the cavity are a result of the radial modes which are excited by the radial displacement of the air as it flows into the phaseplug slots. The resulting response dips may be controlled by suitable slot position. However the geometry of the cavity is a poor approximation and the lack of modal behaviour in the diaphragm means that the results from this analyses are only useful in a qualitative sense. The same theory is also useful in considering the high frequency behaviour of a plane wave tube, since the driver does not produce a plane wave but a 'spherical cap' shaped wave transverse modes occur in the tube. Similarly at these modal frequencies there are dips in the response simply due to the mismatch between wavefront and waveguide. See animation.

4.4 FEA And BEA Applied To A Pressure Driver.

The flexibility of FEA and BEA to model almost any shape is of crucial importance. Not only is it possible to observe the sound field within the driver for changes of parameters but also it is possible to observe the impact of changing the geometry on the acoustic behaviour of the design. For example the effect of altering the shape and dimensions of the phaseplug slots may be investigated. An FEA model may include the complete geometry with little need for approximation, however like any modelling technique it has it's shortcomings. These are firstly the time and effort it takes to produce and solve the model, secondly it is difficult to model the thermal and viscose properties of air, thirdly the model does not include the complete transducer, in this case the diaphragm will have a constant force imposed on it.

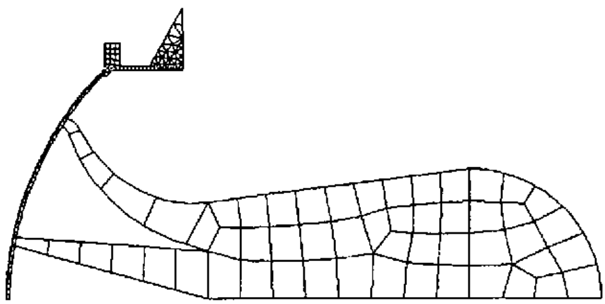


Figure 9. Axisymmetric FEA mesh used to calculate SPL at 0.2m.

The consequences of these approximations are that even FEA does not give a full prediction of the behaviour of the pressure drive unit. The model can however be made to predict the behaviour of a pressure drive unit driven by a constant current source without the effects of air damping. In practice, the large amounts of damping in the arrow slots greatly reduce the magnitude of predicted acoustic resonances. Pafec [7] was used to generate and solve an FEA model of this driver. The mesh used is illustrated in figure 9, it includes all of the air cavities on the concave side of the diaphragm as well as a flexible diaphragm, former and voice coil. The results from this model, shown in figure10 revealed that the acoustic path past the coil through the voice coil gap turns out to play a significant part in the acoustic behaviour of the driver. This result led initially to an alteration to the lumped element model which led eventually to a design alterations to control the effect of these cavities on the driver performance.

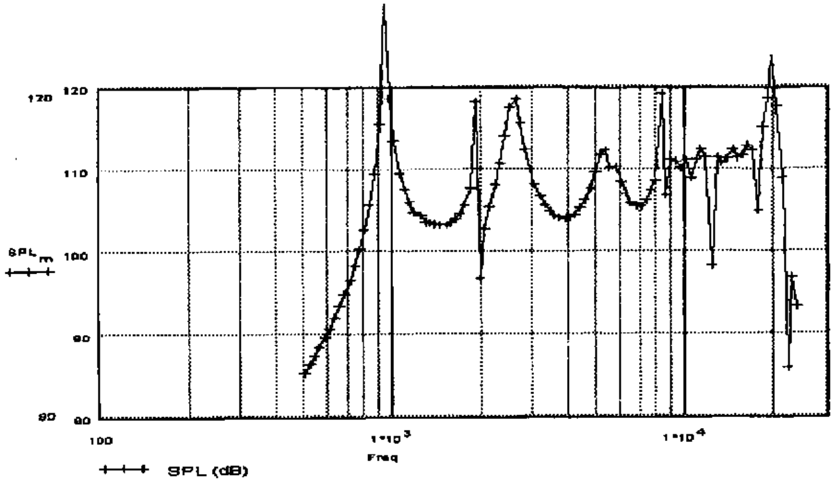


Figure 10. SPL at 0.2m calculated with FEA/BEA. Level uncalibrated PETP diaphragm.

To allow comparison of the FEA and final lumped element model, the lumped element model had all air losses removed and was driven via a 1Mohm resistor to give a constant current source. These results shown in figure 11 show a clear similarity, although the FEA results show the presence of additional modes not modelled in the lumped element analysis. These modes were studied, the vibrational modes by observing the deformed structure, and the acoustic modes by considering colour contour plots of the instantaneous pressure magnitude. As a direct result of this work the high frequency response of the driver was made both smoother and more extended.

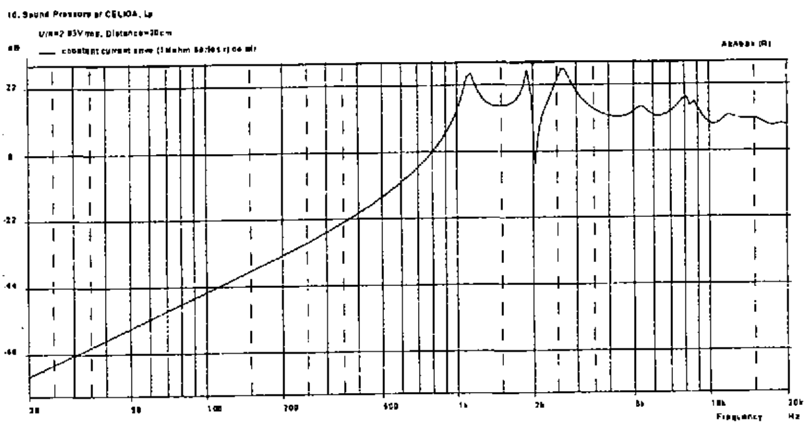


Figure 11. AkAbak model with constant current drive and viscous losses removed.

The measured planewave response of the driver as shown in figure 12, this may be compared the results in figure 13. These are from a lumped element model terminated by a 2m lossy tube. It is interesting to note the difference in the frequency of the first longitudinal mode of the tube. The predicted response appears to come from a shorter tube than the real tube. It is suspected that this error is due to the foam in the planewave tube reducing the speed of sound by making some of the air behave in an isothermal manner.

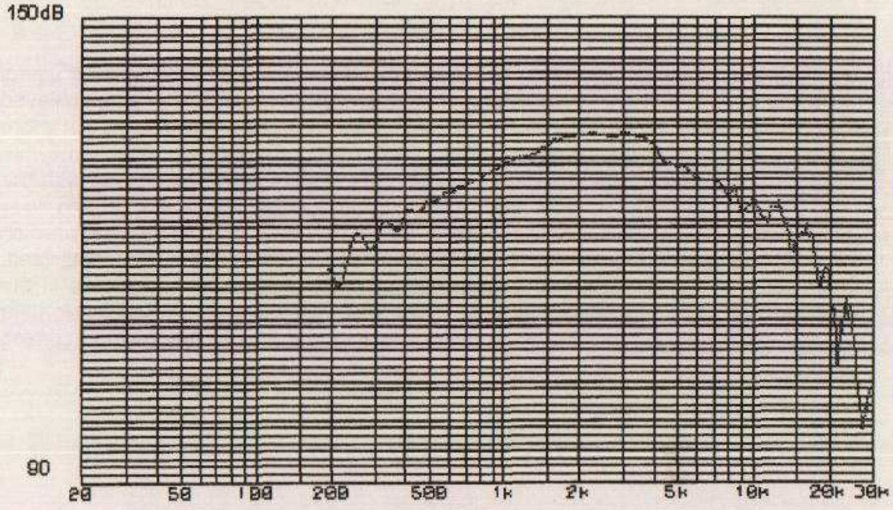


Figure 12. Measurement of final driver on planewave tube.

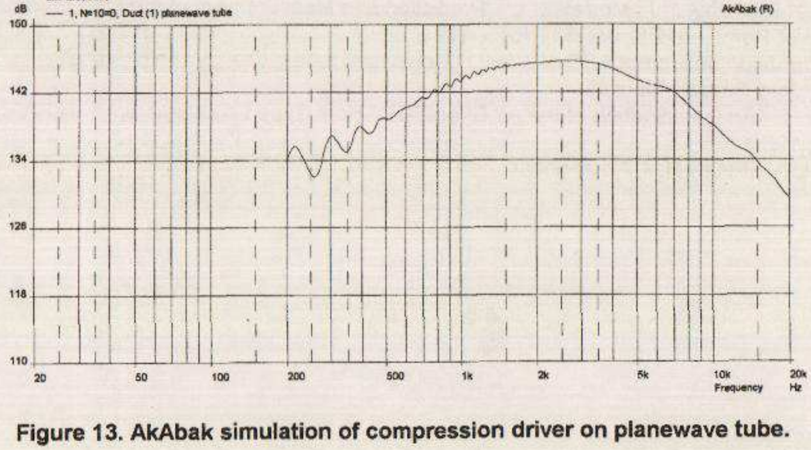


Figure 13. AkAbak simulation of compression driver on planewave tube.

5. CONCLUSION

The advanced computer techniques used to develop this compression driver all proved useful in producing actual performance improvements. The reduction in magnet size was achieved by a relatively flexible and simple process. Obtaining the response imp required a more sophisticated approach due to the limitations of the FEA model, which produced a somewhat abstract result. The lumped element approach gives quick results which agree well with the measured results of a well behaved drive unit. However, the lumped element approach does not predict the interaction and resonances of the diaphragm and phaseplug cavity which cause large response deviations unless these aspects of the design are well optimised. The time and cost that the use of these programmes involves proved well worthwhile in the case of this drive unit. It seems likely that given faster computers and more accessible user interfaces these techniques will become even more effective and thus widely used in coming years.

6. REFERENCES

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