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AN APPLICATION OF BOB SMITH'S PHASING PLUG

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The war of the phasing plugs still rages after more than 25 years. Compression driver phasing plugs have vascillated between annular rings, salt shakers, tear drops, and now radial slots again. When Bob Smith provided simple design criteria for optimization of the annular ring type, little did he realize how studiously he would be ignored. His design is now incorporated into a large compression driver capable of operating to the high frequencies where this design is important.

INTRODUCTION

Phasing plugs have been with us for most of this century, but there is still less than perfect agreement as to what they should look like. The very simplest means for coupling a moving piston to an acoustic medium is to place the former in the latter and turn it on. Under the assumption that louder is better, pistons grew larger and moved further, but practical limitations soon made themselves felt. By 1924 Hanna and Slepian [1] were referring to pistons mounted in the ends of tubes (Figure 1) as simple sound radiating systems.

Naturally the straight tube must be replaced by a horn having a throat diameter equal to the tube diameter. However, with either a tube or a horn, phasing plugs are unnecessary. However, the high output impedance of the piston is not yet matched to the input impedance of the tube. The most efficient match is illustrated in Figure 2 and may be attained under the condition [2].

$$\frac{S_D}{S_T} = \frac{\beta^2 \ell^2}{\rho c R_c S_D} \qquad (1)$$

It is instructive to note that for the case of a 0.1 metre diaphragm driven by an 8 Ω voice coil under electro-mechanical coupling efficient ($\beta\ell$) of 19, the ratio of these areas is 13.8. More commonly this ratio is closer to 10 to increase the bandwidth. At this point the phasing plug becomes necessary.

The functions of the phasing plug are to (1) bring all portions of a wave generated by a large piston into phase coherence at the smaller horn throat, and (2) minimize the volume of the air chamber between itself and the piston.

Figure 3 shows a tear drop design produced by Bell Laboratories [3] during the 1920's. Another variation, described verbally in a class on acoustic fundamentals [4], is shown in Figure 4. This has some advantages for large pistons but we have not been able to find it in the literature, although a simple version of it can be found in [5].

Today the most common phasing plugs are concentric rings, Figure 5 [6]; Salt shaker, Figure 6; and more recently a fully developed radial type, Figure 7 [7]. Each of these plugs is designed to radiate through the magnet.

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BOB SMITH'S CONCENTRIC RING DESIGN - [6]

Smith considers a disk shaped air chamber as shown in Figure 2. One wall and the edges are solid and the other wall, the diaphragm, moves in response to a voice coil signal. Assigning these boundary conditions, and an arbitrary function to define the axial component of velocity at the far wall, $f(r)$, to the wave equation he obtains his equation (2) for the potential and equation (3) to approximate the pressure. These equations are elegant, but not necessary to this review.

The first case analyzed is the case wherein the horn throat connects to the center of the chamber as shown in Figure 2. Under this condition the function $f(r)$ may be defined as:

$$
\begin{aligned}
f(r) &= u_r = P_r/\rho c && 0 \leq r \leq a_1 \\
&= 0 && a_1 < r \leq a
\end{aligned}
$$

The result is a family of radial standing waves in the chamber such that $k_n a$ is a root of the Bessel function of the first kind of order one (J_1) as n varies from 1 to ∞. You may see Smith's equation (7) for all the gory details. This standing wave pattern, as illustrated in Figure 2, produces a pressure null in the horn throat resulting in a null in the output of the entire transducer. The resonant frequencies are given for the first few modes for a 5×10^{4} m spacing as:

$$
\begin{aligned}
&f_1 = 176/a \qquad f_2 = 338/a \qquad f_3 = 518/a \\
&f_2 = 724/a, \text{ for } a \text{ in metres}
\end{aligned}
\tag{2}
$$

These frequencies have been corrected for air viscosity, but more recent measurements of viscosity reduce these frequencies approximately 1% lower.