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IRONLESS LOW FREQUENCY LOUDSPEAKER WORKING UNDER ITS RESONANCE FREQUENCY

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A soon achieved low frequency loudspeaker (10 Hz to 100 Hz) is described. To suppress the non-linearities and the drawbacks due to the motor, its structure is totally ironless. The large flat diaphragm and the high force factor of the loudspeaker lead to its high efficiency. Efforts have been made for reducing the non-linearities of the loudspeaker for a more accurate sound reproduction. Especially we have developed a motor totally made of permanent magnets, which create a uniform induction across the entire intended displacement of the coil. The motor linearity and the high force factor of the loudspeaker make it possible to work under its resonance frequency. This functioning needs the use of a DSP to raise the 12 dB/octave slope of the pressure response of the loudspeaker under its resonance frequency and to protect the moving pieces from large displacements. Results presented here are to be completed as soon as the loudspeaker will be achieved.

Keywords: flat diaphragm, ironless motor, under resonance frequency functioning.

1. Introduction: functioning of the loudspeaker

Nowadays most woofers manufacturers are confronted with the problem of decreasing their mechanical resonance frequency, to extend the bandwidth of the woofer. Since a suspension whose stiffness tends to be null does not exist, the widening of this bandwidth implies an increase in the mobile mass, at the expense of the efficiency of the woofer. It is also met loudspeakers whose bandwidth comprises this resonance, despising phase problems among other things.

For these reasons it has been decided to make up a loudspeaker (Fig. 1) working under its resonance frequency. In this bandwidth, supplying current, tension and displacements of the diaphragm and are in phase. Moreover, this way of functioning means a coherent work on making the mobile mass be light, to increase the bandwidth of the woofer at the same time as to increase its efficiency.

Yet, let's remind that, in a simple way, the pressure radiated by a loudspeaker can be assimilated to a high-pass filter for the radiated pressure (Fig. 2). This means that an

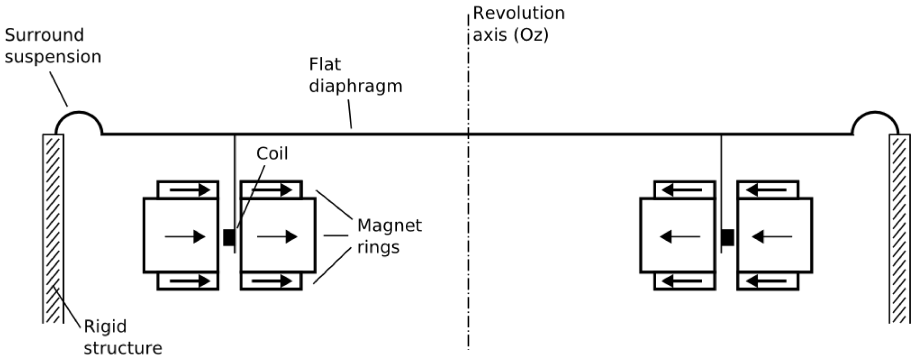

Fig. 1. Composition of the ironless flat loudspeaker.

embedded electronics (DSP) is necessary to raise the 12 dB/octave slope of the pressure response of the loudspeaker under its resonance frequency f_0. In order to protect each piece of the loudspeaker, the DSP is also used to restrain the displacements of the mobile mass at very low frequencies.

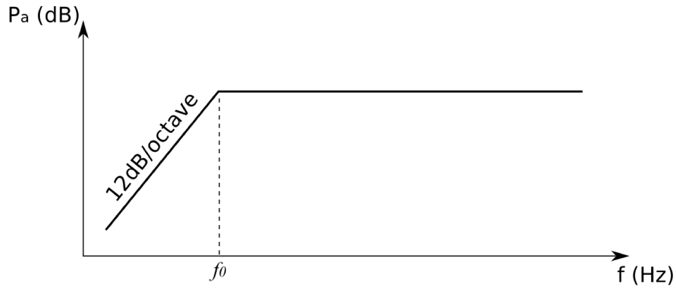

Fig. 2. Behaviour of the pressure response of a loudspeaker vs. frequency.

To conserve all advantages of working under the resonance frequency of the woofer, it is important to make it efficient as well as the most possible linear. Efforts have been made to ideally conceive the motor and the diaphragm of the woofer.

2. Ironless and linear motor

The drawbacks due to the iron in classical loudspeakers have already been described [5, 10]. Iron is the source of reluctant effect and Eddy currents, and is the origin of a magnetic field that is a function of the axial position in the airgap. Accordingly, the iron is a major source of non-linearities and as a result of harmonic distortion. That is why, in addition to considering or reducing these effects, it is important to try to remove them.

The first step of this research is the use of a motor entirely made of magnets, i.e. the removal of iron. The benefits of these whole magnet structures have been demonstrated [5] and some manufacturers have already used this technology [4, 6]. But all presented structures are aimed to create an intense magnetic induction; this induction still varies with the axial position in the airgap.

Searching for a uniform induction, analytical calculations of the magnetic field created by permanent magnets have been made using the Coulombian model [1–3, 8, 9]. Associated to an algorithm of rotation, this model can be applied to every permanent magnet, whatever is their shape.

The structure we find uses two sets of three superimposed rings whose radial magnetization differs in order to give the intended shape to the observed induction. The space between the two sets defines the airgap where the coil moves. Figure 3 shows an example of the contribution of each ring and the resulting induction. The dimensions of the magnets are arbitrary chosen to show clearly the contributions of the three rings and their effect on the result.

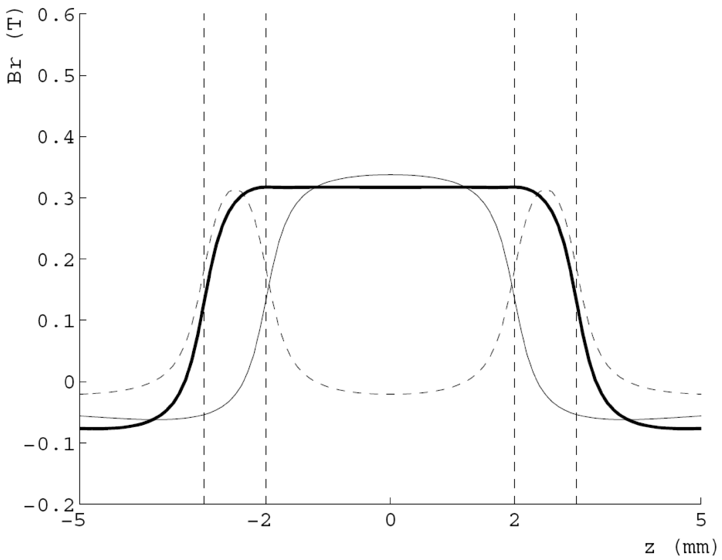

Fig. 3. Radial magnetic induction, Br (T), created by the three rings structure (bold line), by its central ring (full line) and by its two external rings (dashed line). The vertical dashed lines reflect the heights of the three rings.

When ideal set of dimensions and magnetizations are found, this assembly of three rings creates a uniform induction across the entire height of the central ring. The structure we use for our first speaker is not optimized in terms of uniformity because we have to use a low volume of magnet. Nevertheless we reach a quite uniform induction whose intensity is 0.58 T across a 40 mm height, while the total height of the magnetic structure is 52 mm (Fig. 4). Today the force factor *Bl* reaches 35 N·m, but it could be optimized to reach 45 N·m and more.

The structure allows large and linear displacements, while being quite flattened. The reduced height is an advantage for the use of a cylindrical support of coil whose height is also reduced. Eigen modes are then moved to high frequencies.

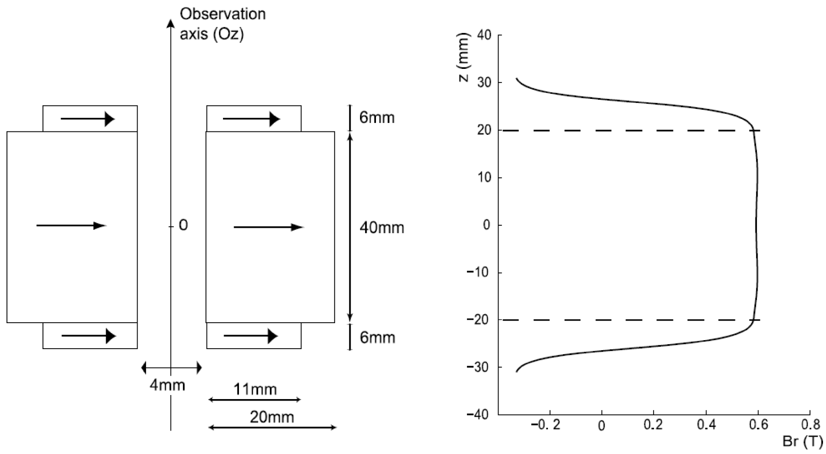

Fig. 4. Magnetic structure used in our first woofer and its created radial magnetic induction, Br (T), along the observation axis.

3. Circular flat diaphragm

The march in material research gives rise to increasingly rigid and light materials. This progress makes possible the use of a flat diaphragm instead of using a classical cone-shaped diaphragm for the loudspeaker. A circular flat diaphragm is easier to manufacture than a conical one. It is also in agreement with the radiation model of a flat piston, and analytical calculations of its radiation and its eigenmodes can be lead. And finally, it allows a more faithful reproduction of sound through the elimination of interference phenomena which are subject conical shapes [7].

3.1. Considering the support of coil

The diaphragm of the first prototype speaker has a diameter $a = 20''$; it is 3 mm thick and is made up of a composite honeycomb sandwich whose flexural modulus is higher than 2 GPa and whose density is less than 400 g/m^2. The first modes of this diaphragm alone appear at frequencies lower than 100 Hz, i.e. in the intended bandwidth of the woofer.

Because the diaphragm is flat, we can stiffen it using a well sized cylindrical support of coil. To study its influence, the support is assumed to be rigid. Figure 5 shows that the frequency of the first appearing eigenmode is maximal when the ratio b/a equals 0.7. That is why the diameter of our support of coil equals $14''$. With this support, the first eigenfrequency of the diaphragm with its previous characteristics reaches about 80 Hz.

Figure 6 gives the shape of the first three eigenmodes of the diaphragm when fixed to the support of the coil. Here the modal deformation of the first mode corresponds to the modal deformation of the second mode of the diaphragm without support. To stiffen the diaphragm, a diametrical reinforcement could be used and would make the first eigenfrequency increase.

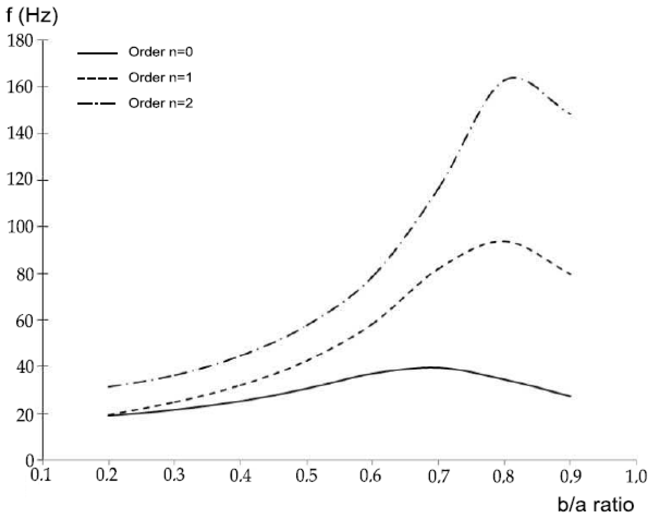

Fig. 5. Evolution of the eigenfrequencies of an arbitrary circular plate (diameter a), when fixed to a circular support whose diameter b varies.

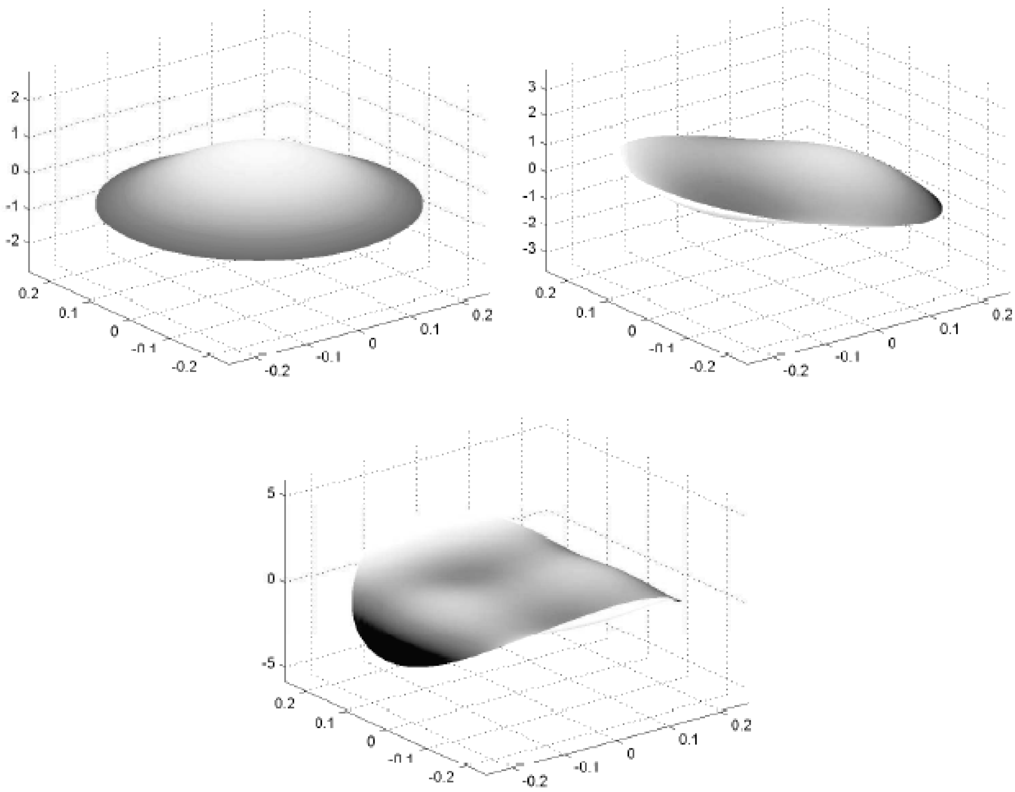

Fig. 6. First three modal deformations of the diaphragm in free-supported conditions.

3.2. Considering the suspension

The surround suspension brings also an additional stiffness to the diaphragm. Given the material used for this suspension, eigenfrequencies of the diaphragm should then become higher, especially if a suspension that does not allow rotation is used. We have not estimated yet a vibration model including a suspension. But when the contact between the diaphragm and the suspension is considered as a clumping, the first eigenfrequency reaches 220 Hz. So in reality, considering the previous results, the first eigenfrequency of the diaphragm can be expected to be higher than 100 Hz.

4. Conclusion

First calculations and measurements are quite promising for the conception of an efficient and accurate woofer. Its coming assembly will lead to new measurements that will give us the definitive values of the loudspeaker parameters.

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