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# New structure of loudspeaker

Guy Lemarquand

## Abstract

We present a new structure of loudspeaker: the motor is ironless, the suspension is ferrofluidic, the moving part is piston like, with a concave dome. The absence of iron guarantees a small and constant inductance of the moving coil, as well as the absence of Eddy currents. The motor includes two circular joints, one on each side of the moving coil. These joints are ferrofluidic. They fulfil the guidance and centring function and the air tightness function. This structure is quite rigid. As there is no traditional suspension in this structure, the related non-linearities and hysteresis disappear.

## I. THE NON LINEARITIES OF THE CLASSICAL STRUCTURE

Classical loudspeaker motors present well-known non linearities, which are drawbacks of the transducer. Numerous authors, such as Dobrucki [1][2], Gander [3][4], Kaizer [5], Klippel [6][7], Mills [8], Noris [9], and Olsen [10] described and studied these non linearities, and tried to reduce their effects. The most important of them are following: the variation of the force factor,  $Bl$ , along the  $Ox$  axis, the hysteresis, the asymetry and the compliance variation of the suspension, the variation of the inductance with the coil's position. A reluctance effect and the presence of Eddy currents were studied by Vanderkooy [11]. These two effects are caused by the iron in the motor.

## II. NEW STRUCTURES

### A. The loudspeaker

We present new structures of loudspeakers (Fig.1) to get rid of these drawbacks. The motor is ironless and constituted by stacked rings of permanent magnets. These structures are studied with the use of the Coulomb's model of permanent magnets, that allows analytical calculations. The aim is to achieve a highly constant force factor along the  $Ox$  axis. The design can thus be optimized to create a uniform and high

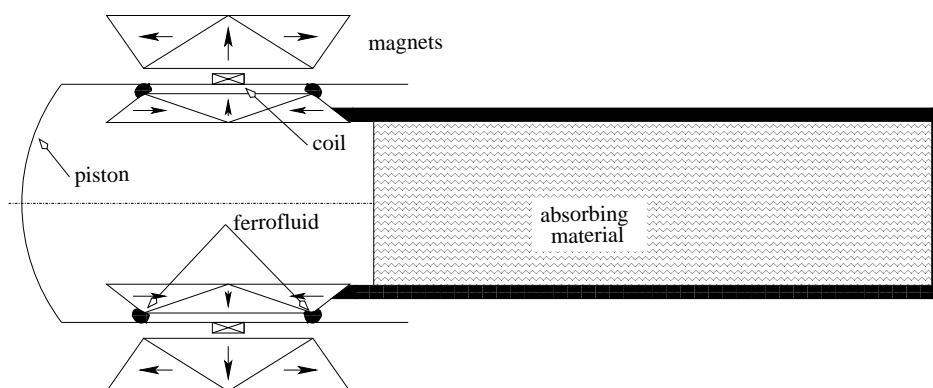


Fig. 1. Full structure geometry.

level induction in the space where the coil moves. It also permits to work on the induction map so as to fix the ferrofluidic joints where they have to be.

The first consequence of the absence of iron in the structure is a very low and constant inductance of the coil. The second consequence is the absence of the reluctance effect and a great decrease of the Eddy currents, depending on the electrical conductivity of the permanent magnets' material. The third consequence is the increase of the magnetic induction and the decrease of the magnetic leakage, that leads to a good efficiency of the loudspeaker. The major goal is to create a very uniform induction in the space of the moving coil to cancel the harmonic distortion. The maximum excursion of the coil is limited in the presented structures by the inversion of the magnetic field in the areas outside the nominal displacement, which constitutes a good protection to limit the travel of the moving set when a peak of power is applied to the voice coil motor.

These structures are not very difficult to realize with the use of plastic bonded magnets. The motor includes two circular joints, one on each side of the moving coil. These joints are ferrofluidic. They therefore play an interesting part. They centre the moving set as a radial bearing. Indeed, the radial stiffness is high, while the axial one is low. The stiffnesses are independent from each other. As a consequence, the centring is good, and the axial resonance frequency is very low, with regard to a classical structure. These joints fulfil the air tightness function between the front acoustical pressure and the rear one. They also are an easy way for the thermal flow coming from the moving coil. The classical suspension has disappeared as well as its related drawbacks. Another peculiarity of the structure is the shape of the moving set. It is cylindrical, piston-like, and the transduction is done by a concave dome. This mechanical structure has high frequency vibration modes.

#### B. The loudspeaker cabinet

The cabinet associated to this loudspeaker is non conventional. As there is no motor in the center of the diaphragm, the whole rear surface is active and it generates a plane wave. The cabinet is in fact a cylindrical pipe that has the same diameter as the piston and behaves like a waveguide [12]. The pipe is filled with an absorbing material.

### III. PROTOTYPE

A prototype has been built, with the means of a lab -and not of an industrial group-. Of course, this first prototype shows some imperfections.

The piston diameter is 50 mm wide and it weights 5.1 g. The coil section is 2 mm x 2 mm. The force factor,  $Bl$ , is 5.85 N/A. The coil is shorter than the area of uniform induction along the  $Ox$  axis. The volume,  $V_{cab}$ , of the "pipe cabinet" is 0.82 l.

#### A. Electrical properties

We use the equivalent electrical circuit proposed by Thiele and Small [13] and the corresponding notations for the parameters. The electrical resistance,  $r_e$ , of the coil is 4.20  $\Omega$ . Its inductance,  $l_e$ , is 210  $\mu H$ . As there is no iron in the motor, this inductance is constant whatever the position of the moving set is. When the coil is wound on a capton stay, no Eddy currents appear, neither on the stator, nor on the moving set: the inductance and the resistance remain constant even at high frequencies. The value of the  $R_{ms}$  parameter is 5.6 kg/s. This value is important because it results of the damping effect of the ferrofluidic joints. The mobile mass,  $M_{ms}$ , is 5.1  $10^{-3}$  kg. The usual parameter  $C_{ms}$  does not appear because the suspension stiffness is zero and so, the compliance is infinite. As the moving part is exactly a flat circular piston, the impedance  $Z_{ar}$  is given by the Rayleigh formula in Eq.1.

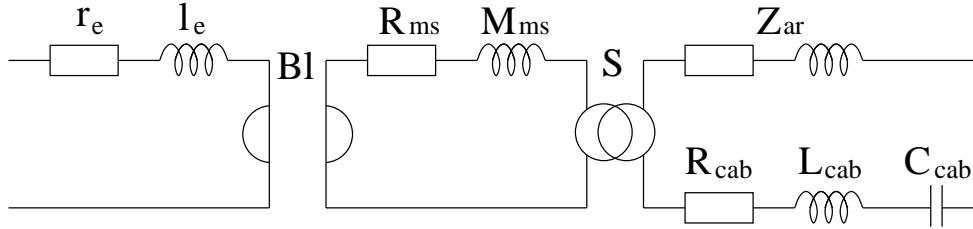


Fig. 2. Equivalent electrical circuit.

$$Z_{ar} = \frac{\rho c}{S} \left( \frac{(kr)^2}{2} + j \frac{8}{3\pi} (kr) \right) \quad (1)$$

The impedance of the “pipe cabinet” is given by Eq.2.

$$Z_{cab} = R_{cab} + j\omega L_{cab} + \frac{1}{j\omega C_{cab}} \quad (2)$$

where the compliance,  $C_{cab}$ , is :

$$C_{cab} = \frac{V_{cab}}{\rho c^2} = 5.4 \cdot 10^{-9} \text{ m}^4 \text{ kg}^{-1} \text{ s}^2 \quad (3)$$

The equivalent electrical circuit is shown in Fig.2. Fig.3 and Fig.4 show the motion impedance versus the frequency. The first resonance, observed at 55 Hz, is caused by the compliance of the cabinet,  $C_{cab}$ . This resonance is highly damped by the effect of the ferrofluidic joint,  $R_{ms}$ . The second resonance, at 162 Hz, corresponds to the reflection at the end of the pipe. The third resonance, at 7700 Hz, is the dome proper mode. The phase of the impedance tends towards  $90^\circ$ : the impedance is a pure inductance at high frequencies, which demonstrates the absence of Eddy currents.

#### B. Near-field acoustic radiation

Fig.5 shows the near field response. This 50 mm diameter loudspeaker is a medium range one. The major imperfection appears clearly to be the resonance of the dome (7700 Hz). Three other structural resonances appear at 4470 Hz, 10 kHz and 14 kHz.

#### C. Advantages

The great advantage of this structure is its high linearity with regard to the displacement amplitude. All the responses are proportionnal to the excitation level. As a consequence, the sound has a high definition and seems very clear and crisp.

### IV. CONCLUSION

The structure of this loudspeaker is a new concept that has to be studied further. The major non linearities have been suppressed. Thanks to the original magnetic circuit of the motor, the force factor is perfectly constant for large displacements of the moving part. As the motor is ironless, the electrical inductance is low and independent of the coil's position as well as of the frequency, because no Eddy currents appear. The absence of a traditional suspension makes the compliance depend only on the closed-box. So, the compliance is constant. The built prototype is quite promissive, in spite of its large mechanical resonance.

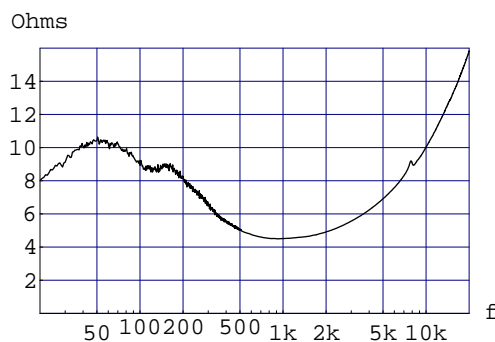


Fig. 3. Modulus of the motion impedance.

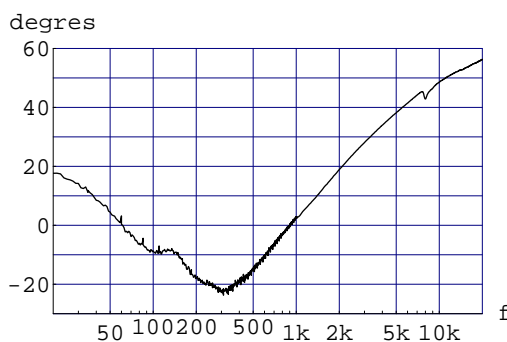


Fig. 4. Phase of the motion impedance.

## V. ACKNOWLEDGEMENTS

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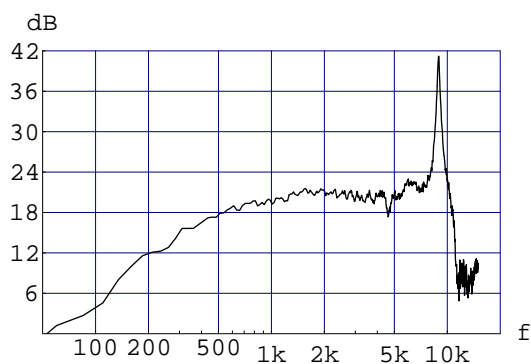


Fig. 5. Acoustical response.

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