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An ironless low frequency subwoofer functioning under its resonance frequency.

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Abstract

A low frequency loudspeaker (10Hz-100Hz) is described. Its structure is totally ironless in order to avoid nonlinear effects due to the presence of iron. The large 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. In particular 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 this flat loudspeaker make it possible to function under its resonance frequency with a great accuracy.

1 INTRODUCTION

In sound reproducing systems, the bass range is important because it contributes more to the feeling of power and quality than any other part of the sound spectrum: when the bass is solid and realistic the resultant sound is usually perceived as being very good to excellent. However problems to reproduce tight, clean, and realistic sound in the bass range are not trivial. This paper presents a loudspeaker bound to produce low and very low frequencies, the particularity coming from the fact that the proposed loudspeaker works under its resonance frequency. This type of subwoofer has more demands regarding its designing than traditional ones, with the aim of being very accurate and efficient.

2 WORKING UNDER THE RESONANCE FREQUENCY

When looking at its pressure response, a loudspeaker acts like a high-pass driver (Fig.1). Since

every frequencies have to be reproduced ideally with the same level, a classical loudspeaker works above its critical resonance frequency f_0 where its pressure response is relatively flat. Thus, the major problem when manufacturing subwoofers is to decrease their mechanical resonance frequency to extend their bandwidth towards the low frequencies. When mounted in a closed enclosure, the resonance frequency of the loudspeaker is proportional to the square root of the total mechanical stiffness of the mounted loudspeaker over the total moving mass of the loudspeaker. Therefore to extend the bandwidth of a subwoofer towards low frequencies, ones has to decrease the stiffness while increasing the moving mass, at the expense of the efficiency of the subwoofer. Since a suspension whose stiffness tends to be null does not exist, the widening of this bandwidth also gives rise to large closed enclosures. It is also met subwoofers used on a frequency range that comprises their mechanical resonance, despising all spoiling risks and phase reversals.

Numerous theories and ideas have led to designs which have significantly improved low frequency response of such loudspeakers [1],[2],[3],[4]. Unfortunately these methods deteriorate the phase

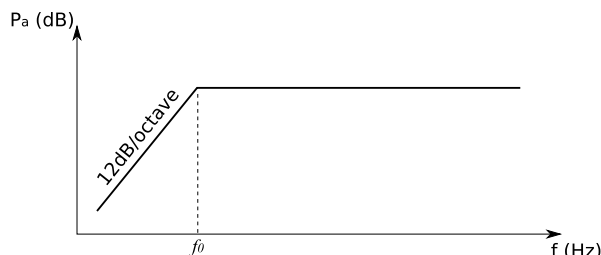


Figure 1: Behaviour of the pressure response of a loudspeaker vs. frequency.

response and the consequent smearing of the arrival times of these now audible low frequency sound components. However phase distortion is well known to be a critical criterion for the quality and accuracy of the response of a loudspeaker [5].

In this paper a subwoofer working under its resonance frequency, in the bandwidth $10Hz-100Hz$, is investigated. The first advantage is that the behavior of the loudspeaker is really well known and well modeled in this frequency range: supplying tension, current and displacement of the diaphragm are in phase. The phase of the diaphragm velocity is almost constant which is an important point when searching for coherent response of the loudspeaker. Let's remind that under the resonance frequency, the pressure response of the loudspeaker falls at a rate of 12dB per octave as the frequency is decreased. This means that an embedded electronics using a double integrator is necessary to raise this slope and to flatten the pressure response of the loudspeaker under its resonance frequency. The integrator is also used to perfectly correct phase variations of the pressure response of the loudspeaker, at the same time as to filter the highest frequencies, in contemplation of a good agreement with a bass or bass-medium loudspeaker. Long *et al.* have also worked on a necessary electronics to protect each piece of the loudspeaker from large displacements at very low frequencies [6]. And it appears that a custom-built loudspeaker is necessary to well fit the functioning under the resonance frequency.

Therefore, with regard to the subwoofer itself, a coherent work leads to make a light moving mass to increase the bandwidth of the subwoofer at the same time as to increase its efficiency. Efficiency of this subwoofer also represents an important work to compensate for the drawback of the 12dB/octave slope under the resonance frequency, and to make

this subwoofer be very dynamic with sharper time response.

3 STRUCTURE OF THE LOUDSPEAKER

The structure of the loudspeaker designed for a better adaptation to the functioning under its resonance frequency is shown Figure 2. It is made of a flat diaphragm, only centered thanks to the surround suspension. The former coil and the voice-coil are located in the airgap between two sets of three annular radially magnetized permanent magnets. The following presents the design proposed to make the subwoofer be very performant at low and very low frequencies with really reduced nonlinearities.

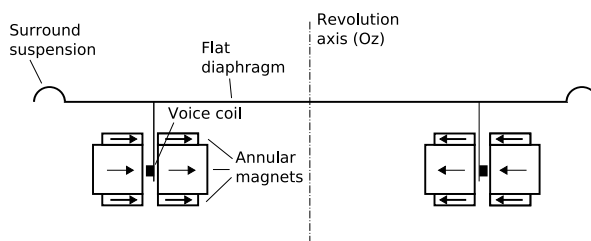


Figure 2: Composition of the ironless subwoofer.

3.1 The loudspeaker motor

The drawbacks due to the iron in classical loudspeakers are really well known [7],[8],[9]. Iron is the source of Eddy currents and reluctant effects, especially at low frequencies, and is the origin of a magnetic field that is a function of the axial position in the airgap. Some solutions have been proposed based on specific design of ironless motor structures [10],[11]. However, since their created magnetic induction highly depends on the position in the airgap, these assemblies are only suitable to small voice-coil displacement and thus to medium or high frequency loudspeakers. Indeed bass loudspeakers also require the most uniform magnetic induction possible over the whole displacement of the voice-coil.

When only using magnets, analytical calculations of the magnetic field created by different

magnetic structures are now usable [12],[13]. The knowledge of analytical solutions makes possible the fast optimization of conceivable structures made of magnets, and searching for linear motors, leads finally to the magnetic structure of the presented loudspeaker. It uses two sets of three stacked annular radially magnetized permanent magnets. In one set, the two external rings are used to make the radial component of the magnetic induction created by the central ring become constant along the total height of this central ring (Fig.3). For eco-

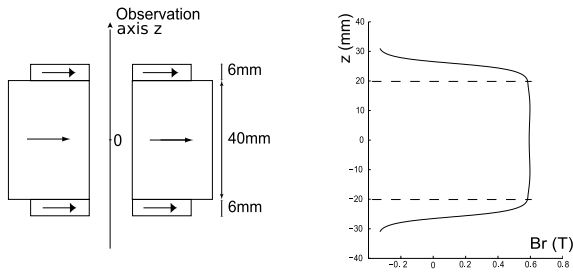


Figure 3: Magnetic structure used in the subwoofer and its created radial magnetic induction, $Br(T)$, along the observation axis.

nomical reasons, the chosen dimensions and magnetizations of each ring of the presented structure are not optimal. Nevertheless Figure 3 shows that the created induction is really quite uniform. In an underhung configuration, this structure makes possible a constant force factor along the entire displacement of the voice-coil up around $\pm 20mm$. First attempts lead to a constant force factor of $35N.m$ along the $40mm$ height of the central rings, for an electrical resistance of 5Ω . By optimizing the magnets and the wire used in the voice-coil, it may be reached more significant values of this force factor.

Thus, a very linear motor has been designed, even for large displacements of the voice-coil. We are nevertheless conscious that this structure is subject to magnetic flux leakages. The use of the three radially magnetized rings represents a considerable reduction of the total height of the magnetic structure, in prevision of reduced dimensions of the former coil to increase its resonance frequencies.

3.2 The moving part of the loudspeaker

In addition to be ironless, the loudspeaker has the characteristic to have a flat circular diaphragm. This choice enables to fit as well as possible the approximation of circular piston used in the models, and is reinforced by the conclusions of Quaegebeur's work [14]. Interferences, diffraction phenomena and cavity effects caused by the conical shape usually given to the loudspeaker diaphragm are thus removed [15]. The use of a flat diaphragm intrinsically makes possible to use a voice-coil whose diameter is larger than usual. The former coil diameter is calculated with the aim of pushing back the first resonances of the diaphragm towards the high frequencies. Figure 4 shows that the optimal diameter of the voice-coil is 0.7 times the diameter of the diaphragm, when the coil and its support are considered rigid. The 20" diameter flat diaphragm possesses two resonance frequencies in its wanted working bandwidth, measured at $38Hz$ and $61Hz$. In presence of the former coil, the first resonance of the diaphragm occurs at $83Hz$.

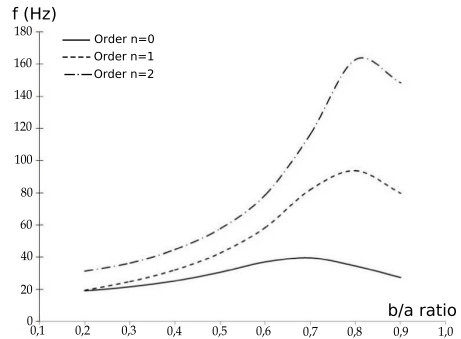


Figure 4: Evolution of the resonance frequencies of an arbitrary circular plate (diameter a), when fixed to a circular support whose diameter b varies.

Moreover, thanks to the previously described motor, the total height of the moving part of the loudspeaker is low compared to the radius of the diaphragm; the gravity centre of the moving element is thus rather close to the diaphragm so that only the external suspension is necessary to centre and control the motion of the moving part. The removal of the spider represents a consequent decrease of the excursion non-linearities. Since a high mechanical resonance frequency is reached, a low volume box is

used to enclose the loudspeaker and provides 50% of the total stiffness. The total needed stiffness implies the use of a material with high modulus for the surround suspension: the suspension brings a non-negligible boundary condition. Note that in the case of a clamped boundary condition, first resonance of the diaphragm with the former coil is predicted at $135Hz$; with the surround suspension, the first resonance frequency is then expected up to $100Hz$.

4 Conclusion

An ironless loudspeaker well suitable to a functioning under its mechanical resonance frequency has been described. First calculations and measurements are quite promising for its conception and its improvement. The perfectly constant force factor, the removal of the iron and the flat diaphragm are the basis of a really expected accurate, clear and dynamic low frequency subwoofer.

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