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Subwoofer design with Moving Magnet Linear Motor

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ABSTRACT

A new electro-dynamic transducer has been studied, based on a moving magnet linear motor instead of a traditional moving coil, and it has been carefully described into a recently presented paper from Claudio Lastrucci. This moving magnet motor could considerably improve the conversion efficiency and the sound quality at the lowest frequency range. It has been developed around a fully balanced and symmetrical moving magnet motor geometry and it can reduce the distortion, in the lowest range, to a fraction if compared to that of a conventional moving coil loudspeaker in the same range. It also offers a considerably higher power handling and overall robustness thus being able of reproducing the lowest range on bass spectrum with an unprecedented level of quality and output. The novel motor design also shows a considerable high acceleration that makes it suitable for the application also in the upper bass region. This paper proposes a review of the methodology that can be pursued in subwoofer design while using this motor technology. The new motor technology will require a different approach to subwoofer design. Several aspects that are in common with conventional loudspeakers will be outlined while also described those characteristics that differs significantly. The application of the technology and relative results will be shown through examples of practical applications and with measurement results.

1. INTRODUCTION

Moving Magnet Transducers systems have remained very little explored for long time. One of the main reasons for this is the limited availability, up to some years ago, of magnetic materials capable of concentrating high magnetization energy in a limited volume and mass. Then the inherent simplicity of the moving coil transducer realization has still kept showing several advantages in low frequency transducer system.
In fact, although the theoretical concept of a moving magnet transducer was already valid also with lower grade magnetic materials, the developing of the idea has become more interesting and effective with the recent availability of high-grade neodymium magnets that allow for concentrating a very high magnetic field in a relatively limited mass and volume, at a reasonable cost. This is a crucial aspect for a moving magnet linear motor because it allows reducing the moving mass to a reasonable value, thus obtaining acceleration values that could be comparable or even higher than standard designs.
This new motor has been developed around a fully balanced and symmetrical geometry. This characteristic allows for considerable large amount of very linear excursion with a lower distortion figures if compared to conventional moving coil design. In addition to this, the balanced symmetrical geometry is inherently stabilized and self-retained within the boundaries of the magnetic field.

2. THE MOTOR

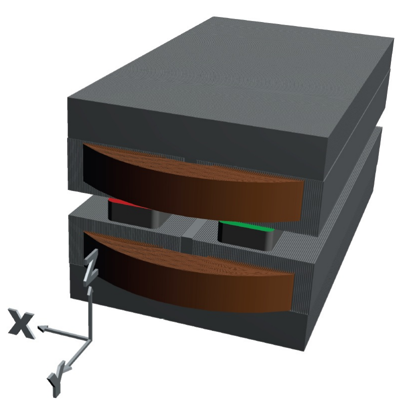

Figure 1 - Simplified drawing of the Moving Magnet Motor

This novel motor design has been designed around a very simple mechanical structure. As already mentioned, it represents a symmetrical fully balanced driving structure that is very linear and is able to achieve significant reduction in distortion, especially at the lowest frequencies and at highest excursion. Moreover, this novel motor geometry allows for a very good inherent self-protection from any possible over excursion, nevertheless, because of its symmetry and its linearity, it is virtually free from the DC component that usually affects low frequency transducers at large excursion.

The active magnetic portion of the device is based on two parallel bars of Nd-Fe-B magnets of the same size, facing to a common plane but with opposed magnetic field orientation (orthogonally to the plane XY in Figure 1).

Two coils are placed facing the bars of magnet, one coil for each side, creating a “sandwich” structure that holds the magnet within the coils.

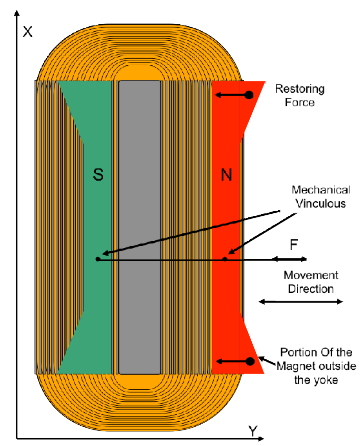

Figure 2 - Schematic drawing of the magnet bars and coil arrangement

The coils are wound using a ribbon of solid conductor, forming a winding of rectangular shape. The magnetic field generated by the magnets is forced to cross the conductor of the coils. Once the coils are subjected to current, a relative force between the coils and the magnet bars will be generated. This force will depend linearly on the intensity of the field generated by the magnets and the current flowing into the coil.

To maintain a very low reluctance path for the magnetic field generated by the permanent magnets, a mix of conductive material such as copper or aluminum and ferromagnetic material such as Silicon Iron have been incorporated into the exciting coils. The ribbon of conductor has been interleaved with properly shaped sheets of low losses Fe-Si, in a way to create a high permeability path across the coil turns.

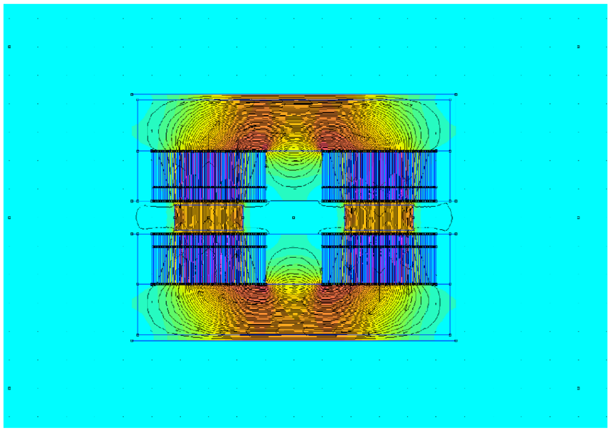

Figure 3 - Section view of the magnetic field generated by the magnets and the relative distribution inside the ferromagnetic structure, with no coil current excitation

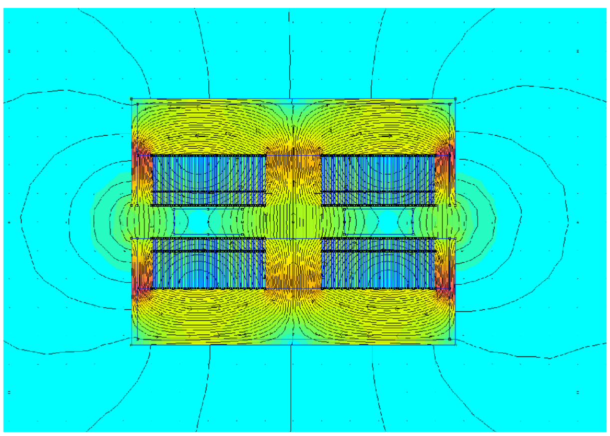

Figure 4 -Section view of the magnetic field generated by the coils excited by a current of 150A and the relative distribution inside the iron path.

Noteworthy coils arranged in such way they present a very anisotropic magnetic behavior:

The particular arrangement described so far, in fact, allows for high permeability through the coil plane (XY) and a very low relative permeability along transversal conductor direction. An outer ferromagnetic shell has been implemented to allow easy circulation of the steady field generated by the magnet bars and to create a defined path for the variable flux produced by the current flowing in the coils.

The magnets are positioned on a frame of composite material that provide a mechanical connection to the radiating part of the complete acoustical transducer.

Due to the natural symmetry of the device, this can be considered a push pull device, where both magnet bars and coils work completely symmetrical in respect to the axial displacement and each portion of the conductors provide either push or pull action on one magnet bar in a complementary fashion to the other specular portion of the motor.

Being symmetrical in the X and Z directions, the resulting pulling forces from the magnets to the steady ferromagnetic structures are nulled out and, with proper magnet bar shaping, it is possible to achieve magnetic centering of the moving parts without the need of springs or suspension.

3. FEATURES OF THE MOTOR STRUCTURE

One of the most evident features of a moving magnet design is the absence of conductors in the moving portion of the motor. The forces are provided by the interaction of the field that is generated by the steady coils and the field generated by the magnets that do not need to be energized by any connection. With proper design, no eddy currents flows inside the magnets and the heat generated in the motor is due only the losses in the coils conductor. Furthermore, the absence of flexible conductors connected to the moving parts improves reliability during the transducer operation, even with extreme acceleration and displacement.

The stationary coils of this motor design are built with very large cross section conductors, not having any constraints other than the cost of the conductor material and weight of the motor. These coils can dissipate more easily the heat and have at least one surface facing towards outside of the device, allowing very low thermal to ambient resistance. Moreover, being built on large cross section and compounded with thermal filler, the motor does not have a specific thermal hot spot. The thermal model is very simple and based on thermal capacity and thermal resistance of the entire device, and is much higher than that of a high power moving coil design, up to two orders of magnitude.