

Title:

Compact Magnetic Suspension Transducer.

Abstract:

The role of compliant parts in the operation of loudspeaker drivers is discussed, and a new method of construction employing a magnetic suspension system is presented. Audio transducers require a complex interaction between moving and non-moving structures, placing conflicting demands on the compliant parts typically employed to interface between them. The limitations of current materials and of manufacturing technology both suggest that replacing flexible and compliant mechanical parts with a system based on magnetic forces might yield several benefits. Such a system, which utilizes a moving magnet balanced between repulsive static forces, is discussed conceptually, analytically and experimentally. Proposed advantages include increased linear excursion, convenient form-factor, reduced wear and fatigue, and the simplification of certain production processes.

Précis:

The task of designing and constructing loudspeaker soft-parts is not trivial, as the mechanical system must meet a wide range of sometimes mutually exclusive engineering goals. Vibrating elements within the transducer have to be free to move along one axis, yet accurately constrained in all other directions. A restoring force must also be provided, one which remains as linear as possible over a target range of displacement, but which increases at the extremes of excursion so as to avoid damage and high-order distortion from excessive input. The engineering difficulty is exacerbated by ever-increasing demands for improved excursion and power handling, at reduced size.

In a practical sense, some elements of the transducer are constrained to remain at rest with respect to the listener's frame of reference, so that the device can be usefully assembled into other structures. At the same time, the moving elements which are used to excite vibrations either directly in the surrounding air, or in some interposing structure, travel over a distance defined by the required extremes of frequency and output level. Conventionally, flexible or compliant parts are employed to allow the necessary range of motion while positioning the moving parts properly within their containing structures. However, mechanical considerations make it almost impossible to design a small driver that is capable of long linear excursion and which has a low resonant frequency. Part of the problem is the geometry of the flexible materials, and part are the characteristics of the materials themselves. Highly compliant materials may allow a good range of motion and extended low frequency response, but they are subject to wear and fatigue, and are difficult to handle on a high-volume production line. Conversely, stiffer materials limit linear excursion and bass extension, and sometimes introduce undesirable structural resonances.

In order to overcome the limitations of mechanical suspensions, a few magnetic suspension approaches have been developed by the industry over the last several years. The majority of these are relatively large and most suitable to low frequency application. The primary attention of the present research has been focused on very compact transducers, ($<15 \text{ cm}^3$), which are capable of covering a substantial portion of the audible frequency range at moderate levels. Applications for these transducers include direct radiators, vibration actuators and headphones. The fundamental operating principle employed is the electrodynamic interaction between a fixed coil and a moving magnet. The magnet, which weights approximately 5 g, travels along the inside of a tubular enclosure, centered by two "skates" of ferromagnetic liquid. The shape of the magnet concentrates the fluid into two rings, which surround either end of the slug providing an

extremely stable and low friction bearing. The containment tube supports one or two solenoidal coil sections, which present an impedance and sensitivity essentially similar to a conventional electrodynamic speaker.

In order to improve upon the performance of compliant suspensions, various fixed magnet configurations were explored. The goal was to develop a force vs. displacement profile that is sufficiently linear and which automatically creates a stable rest position for the moving parts. Initial approaches attempted to use magnets or ferromagnetic materials located at the midpoint of the housing, which serve to attract the moving magnet. These efforts proved less than ideal, since the inherent non-linearity of the magnetic forces as a function of distance led to signal distortion, and since the restoring force is rapidly diminished towards the excursion extremes.

The most successful design utilizes two small, fixed magnets, one at each end of the tube, both oriented so as to repel the moving magnetic element. As the repulsive forces balance, the moving slug is forced towards the center of the tube. The theoretical and measured results are very satisfactory, since the push-pull configuration reduces distortion, and the increase in repulsive force towards the displacement maxima provides a natural, progressive limiting function. Transducers with a natural resonance below 5 Hz and a high frequency corner above 10 kHz are easy to obtain in a volume of well under 10 cm³. Typically, mid-band sensitivity is several dB below that of transducers based on more concentrated magnetic forces, but it is considered easily adequate for commercial application.