Application Brief

Moving-Coil Loudspeakers

A moving-coil loudspeaker is the most common type of loudspeaker, also called an (electro) dynamic loudspeaker. The device is an electro-acoustic transducer that consists of a voice coil that moves in a steady magnetic field to produce the sound in response to electrical audio signal input. ANSYS Maxwell software can be used to effectively analyze various important design aspects of moving-coil loudspeakers.

Keywords

Moving-coil loudspeaker, electrodynamic loudspeaker, voice coil, magnetic field, finite element analysis

Products Used

ANSYS® Maxwell® 16.0, ANSYS Optimetrics™

Background

In contrast to other types of loudspeakers (such as piezoelectric, electrostatic or magnetostrictive), moving-coil loudspeakers work on the Lorentz force principle. According to this principle, the force acts on a current-carrying coil of wire in a magnetic field. In a moving-coil loudspeaker, the magnetic field is almost always generated by permanent magnets. The moving coil (or voice coil) is attached to a cone, which is connected to a rigid basket (frame) through a flexible suspension called the spider. The spider restricts coil movement to axial direction inside a cylindrical magnetic gap. By driving a current through the voice coil, a mechanical force is generated, which moves the coil as well as the attached cone, thereby reproducing sound under the control of the applied electrical signal coming from the amplifier. Individual transducers (called drivers) are used to reproduce different frequency ranges. To adequately reproduce a wide range of frequencies, most loudspeaker systems employ more than one driver (subwoofer, woofer, mid-range driver, tweeter), particularly for higher sound pressure levels.

Description

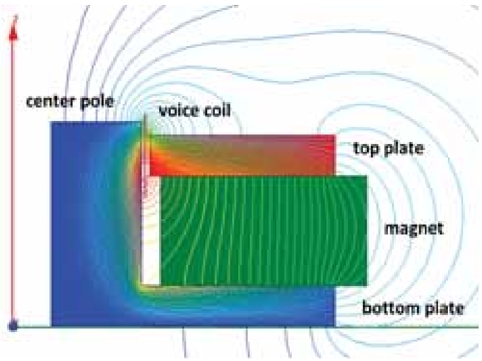

Figure 1. Typical axisymmetrical geometry of moving-coil loudspeaker magnet assembly together with flux lines plot

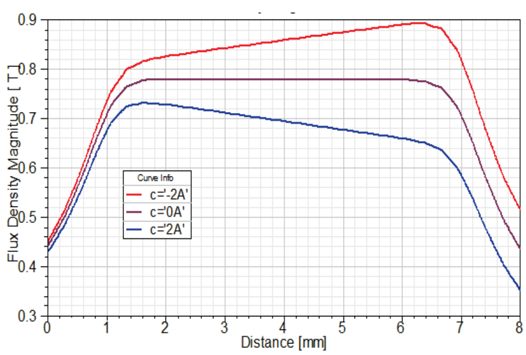

Figure 2. Flux density magnitude along line in center of air gap as a function of various coil currents

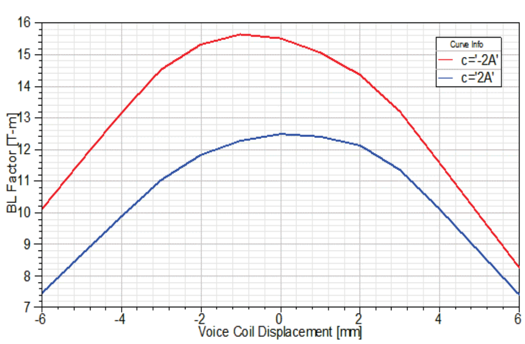

Figure 3. BL-factor, also called force factor, as a function of voice coil displacement for coil current of same magnitude but opposite polarities

Various important design characteristics of moving-coil loudspeakers can be easily predicted by the ANSYS Maxwell electromagnetic field simulator. These include flux modulation, BL-factor, losses and impedance of a loudspeaker.

As these devices feature mostly rotational symmetry, they are typically analyzed using a 2-D axisymmetrical solver. Figure 1 shows a typical magnet assembly of a moving-coil loudspeaker together with the magnetic flux lines plot, with the z-axis being the axis of rotational symmetry. The top plate, bottom plate and center pole are made from magnetic steel material. These parts shape and drive the magnetic flux generated by the magnet.

The voice coil is made of several copper turns and is located in the air gap. Figure 2 shows the variation of the flux density magnitude along the line in the center of the air gap. This variation is shown for three different values of the current assumed in the coil. This graph clearly shows how the main flux in the air gap generated by the magnet is modulated by the flux produced by the current in the coil.

Beyond studying magnitude, it is equally important to analyze different current polarities, as they have different effects on the flux in the air gap. Figure 3 depicts another important parameter: BL-factor or force factor. It describes the coupling between mechanical and electrical sides of a loudspeaker and is defined as the integral value of the flux density B over voice coil length L. The BL-factor is shown as a function of the voice coil displacement for the voice coil current of opposite polarities.

A designer of a loudspeaker also needs to know the frequency dependence of the stationary coil impedance. This characteristic is derived using the transient solver of ANSYS Maxwell, applying a sinusoidal input voltage signal to the coil at different frequencies, while keeping the coil stationary. The simulation includes the eddy currents induced in the steel parts and magnet, which have the effect of generating power loss and, thus, reducing the voice coil impedance.

The distribution of the power loss density for the modeled loudspeaker at the frequency of 500 Hz is shown in Figure 4. The skin depth can be easily observed, as the losses are mainly located on the surface of the steel parts and magnet. The skin depth in the steel parts is smaller than in the magnet, largely because steel permeability is much higher.

The transient simulations at different frequencies and for different coil

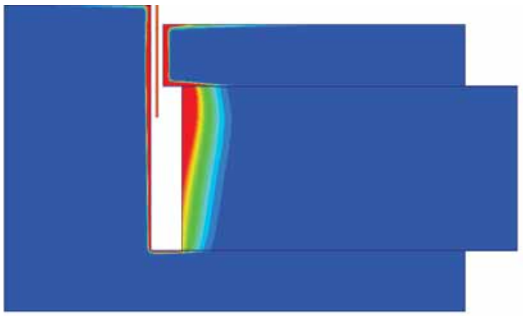

Figure 4. Distribution of power loss density in magnet assembly of modeled loudspeaker as obtained from transient simulation at 500 Hz frequency using ANSYS Maxwell

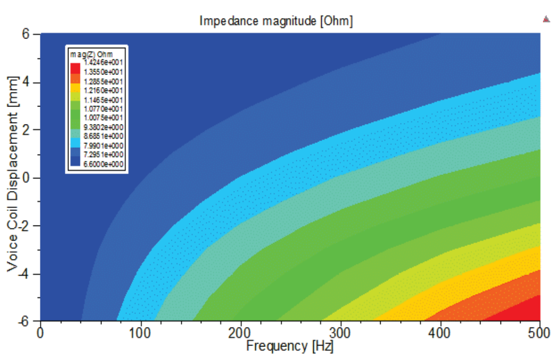

Figure 5. Stationary impedance magnitude as function of frequency and displacement of coil as obtained from transient simulations using ANSYS Maxwell

positions can be run automatically using ANSYS Optimetrics. The result is depicted in Figure 5, in which the stationary coil impedance magnitude is shown as a function of frequency and displacement of the coil. The influence of the displacement of the coil on the impedance is clearly visible, as the shaded areas representing the equal impedance are divided by curved contours. If there was no influence of the displacement on the impedance, the contours would be straight vertical lines.

Conclusion

There are various challenges connected with designing moving-coil loudspeakers, which can be comfortably addressed by ANSYS Maxwell. Starting with magnetostatic analysis, a designer can predict important parameters like inductance, force, BL-factor and magnetic field distribution and assess the level of saturation. The influence of flux modulation on these parameters can be studied as well. Time-stepping analysis in Maxwell's transient solver allows determination of the dynamic performance of the loudspeaker, predicting parameters like impedance and losses at different frequencies of the input voice coil signal. In addition to conducting the pure electromagnetic analysis in time domain, Maxwell can include the equation of motion to the set of unknowns, thereby enabling study of real electromechanical interactions in a moving-coil loudspeaker. The design parameters can be automatically determined for different variations of geometry, coil position, coil current and material properties using ANSYS Optimetrics. This allows generation of an equivalent circuit model of the voice coil, which can be included in a systems-level simulation model of ANSYS Simplorer®. Thus, the performance of the whole system can be modeled and assessed, making sure that the entire system meets defined design requirements.

Author

Julius Saitz, julius.saitz@ansys.com

ANSYS, Inc.
Southpointe
275 Technology Drive
Canonsburg, PA 15317
U.S.A.

724.746.3304
ansysinfo@ansys.com