Loudspeaker Motional Feedback Using A Piezoelectric Accelerometer

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The principle of active control of a loudspeaker cone has been known for many years, and has been commercialized by many audio manufacturers (perhaps most notably by Philips in the mid-1970's). In recent years, the blending of high-end audio and video reproduction has created a fast-growing market in "home theater systems". Movie soundtracks can contain a variety of sounds not normally encountered in conventional music recordings, most significant at the lower end of the audio spectrum. Thus the use of servo-control or motional feedback principles, especially for sub-woofers, is experiencing a resurgence. One example is the new "Komri" active speaker system from Linn Products Ltd of Waterfoot, Glasgow, UK.

An ideal speaker will exhibit flat frequency response characteristics extending down to the limits of the audio band, and in the case of home theater, the low frequency limit may be set as low as 15 Hz. In addition, to maintain good audio reproduction, the distortion level must also be kept low - this means that a pure sine wave reproduced at a given frequency should create an acoustic pressure wave of identical shape, without harmonic components or non-linearity. Given that the motion of the speaker is created by magnetic effects that may become non-linear at high amplitudes, eliminating distortion is perhaps the most challenging task demanded of a high quality sub-woofer.

Use of a sensor mounted on the moving element of the loudspeaker itself allows both control over distortion level, and extension of the low frequency response, if the sensor's output is fed back to an active control network.

It can be shown that the sound pressure level created by the cone (as a function of applied drive current) is proportional to the acceleration of the cone. Therefore, an accelerometer is the ideal sensor for this job. The device should be lightweight for practical purposes, and have a dynamic range suitable for operation up to about +/- 150 g. The sensor should introduce minimal electrical noise into the control loop, especially at very low frequencies. It should be immune to external influences other than pure acceleration (in other words, electrical, magnetic or pressure fields). Finally, it should be easy to assemble and install, and, of course, be cost-effective for production. The ACH-01-03 piezoelectric accelerometer from Measurement Specialties, Inc, was found to meet these requirements well, with 10 mV/g sensitivity, a noise floor of <200 µg/√Hz at 10 Hz, mass of 4 grams, and a selling price of <$20 in one-off quantity.

The device has a flat mounting base suitable for adhesive mounting onto Linn's custom-built driver assembly. The accelerometer has built-in impedance-matching circuitry, and an integral shielded cable is simply brought through the cone and taken to the amplifier and control electronics. Although
the sensor has a bandwidth which extends beyond the upper limit of the audio band, the control
signal is primarily of use at low frequencies only, so the response is rolled off at around 200 Hz.
Appropriate gain and phase response within the loop allows the sound pressure level to show flat
frequency response down to 15 Hz (-3 dB).

![ACH-01 magnitude response](image)

![ACH-01 phase response](image)

(Caption: author's measurements of ACH-01 sensitivity at low frequencies are shown above)

To achieve adequate peak levels, the sub-woofer can deliver a maximum excursion of +/- 0.5”, and
the peak drive current from the controlled power amplifier is around 20 A (meaning 1,400 W peak
power delivery).

In practical terms, the perceived sound quality of the complete system is superlative, as is expected
from a market leader. What is really remarkable is simply to touch the cone before and after the
control loop is enabled. Without active control, the cone deflects inwards easily, and recovers position
in a "relaxed" way when finger pressure is released. With the control loop active, the cone feels like a
brick wall, pushing back with surprising force.

The Komri will be released mid-June 2001.

About the companies:

Linn Products Limited is an independent precision-engineering company specialising in top
performance sound reproduction, founded in 1972, with reputation as the sound technology leader in
the world of specialist hi-fi and specialist multi-channel sound for their recording and reproduction
expertise. Linn pursues the very best and most accurate sound quality through uncompromising,
innovative design and precision engineering (http://www.linn.co.uk)

Measurement Specialties, Inc., designs, develops, produces, and sells electronic sensors and sensor-
based systems. They produce a wide variety of pressure, force, vibration, flow, and ultrasonic
sensors. By leveraging core Microfused sensor, ASIC, piezoelectric film technology, and low-cost
manufacturing expertise, they provide their global customer base with an excellent price-value
relationship (http://www.meas-spec.com/ NASDAQ:MEAS)