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THE APPLICABILITY OF PID-CONTROLLERS TO THE LOUDSPEAKERS WITH AN ELECTROMECHANICAL FEEDBACK

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О ПРИМЕНИМОСТИ ПИД-КОНТРОЛЛЕРОВ К ГРОМКОГОВОРИТЕЛЯХ С ЭЛЕКТРОМЕХАНИЧЕСКОЙ ОБРАТНОЙ СВЯЗЬЮ

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Abstract. *In this paper, a preliminary analysis of the possibilities of application of PID controllers for management under coverage loudspeaker electromechanical feedback (MFB). It is shown that for certain classes of MFB use PID corrector does not allow for good governance in force nonzero error control in the steady state. In addition, for certain classes of MFB shown that the use of optimal PID controller can not provide stability of the system as a whole.*

Аннотация. *В статье проведен предварительный анализ возможностей применения ПИД-контроллеров для организации управления при охвате громкоговорителя электромеханической обратной связью (ЭМОС). Показано, что для некоторых классов ЭМОС использование ПИД-корректора не позволяет обеспечить качественного управления в силу ненулевой ошибки управления в установившемся режиме. Кроме того, для некоторых классов ЭМОС показано, что использование оптимального ПИД-контроллера не позволяет обеспечить устойчивость системы в целом.*

PREFACE

Modern loudspeakers are low efficiency electroacoustic transducers. In comparison with other parts of the audio systems they exhibit a high level of linear and nonlinear distortions, particularly significant at low frequencies. Improve the conversion efficiency and reduce distortion to some extent contribute to the rational design of acoustic enclosures (boxes) and use of modern technologies in the production of loudspeakers and their drivers.

On the other hand, in cybernetics it is known the method of negative feedback, that can significantly improve the parameters of the system, including the loudspeaker, through judicious redeployment of input energy [1].

Despite the apparent simplicity and numerous attempts to use feedback in loudspeakers, which is called motional feedback (MFB), it is not widely spread, and the number of industrial designs with the use of this technology is still insignificant.

In [2] are discussed general and specific difficulties encountered in MFB applied for loudspeakers. It is shown that most of the existing methods of MFB is characterized by tendency to self-oscillating behavior in a particular frequency range, due to the instability of the loudspeaker with feedback.

Due to the fact that MFB is a special case of control methods, all known in cybernetics methods for sustainability are acceptable in a varying degree. One of those methods is to use corrective circuits - electrical circuits with specific frequency characteristics. The inclusion of correcting circuit in feedback loop that provides a change in the overall transfer function of the loudspeaker so as to ensure its stability in the case of the initial instability, or increase the amount of feedback and its uniformity in the target frequency range.

For loudspeaker with MFB know two basic variants of use correcting circuits: in a straight chain (Fig. 1, a) and in the feedback chain (Fig. 1, b). Generally in practice is required to use of pre-correctors outside of the feedback loop.

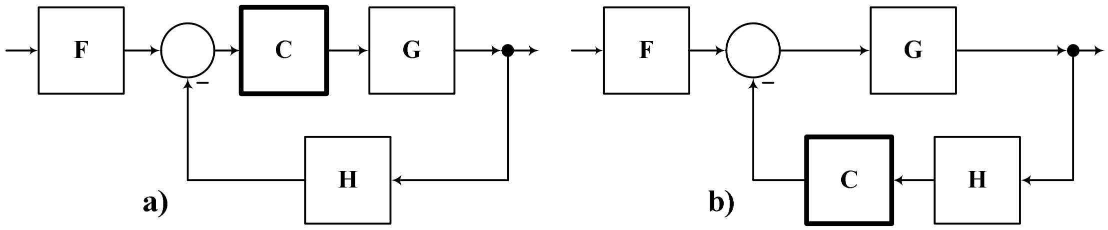


Figure 1 – Variations of MFB in loudspeakers:

a) with corrective circuit in a straight chain; b) with corrective circuit in a straight chain in a feedback chain; F – pre-corrector or equalizer; C – MFB corrective circuit (control unit); G – loudspeaker (plant); H – sensor (mechanoelectrical transducer)

It should consider changing the overall transfer function of the loudspeaker when the corrector transfer function calculation is produced. With try-and-error method and iterative calculations the desired all-over characteristics of the loudspeaker and required for its maintenance characteristics of corrector are selected. With help of modern CAD tools such as SISO Design of Matlab®, all characteristics of the system can be dynamically controlled with respect to any changes of characteristics each chain. In addition, with model of an appropriate controlled object (plant), this CAD allows the use of a variety of different methods and techniques of control theory to calculate the correction and control systems of the plant.

The aim of this work is to analyze the possibility of using such a common method of correction in feedback circuits as the use of PID - correctors for loudspeakers with MFB. This method is notable for relatively inexpensive integrated circuits that implement a proportional- integral-differentiated management, sufficient for many cases, the quality of control, the relative ease of configuration parameters PID corrector. However, it should be noted that the use of the PID is not always possible to ensure stability of the system as a whole and requires a series of experiments or iterative calculations. Also control with PID-corrector in most cases is far from optimal [3].

CLASSICAL TYPES OF MFB WITHOUT CORRECTION

Difficulties getting correct feedback signal, uniquely representing the electrical equivalent of the measured sound pressure in the output of loudspeaker, is inherently mechanical parameter, leads to use of several types for MFB, represented in [2]. The MFB cases, when feedback signal is proportional to the acceleration, velocity, or displacement of the movable unit of loudspeaker, are classical. Loudspeaker with MFB based on acceleration tend to instability in the frequency range below the resonance frequency. The instability of displacement MFB is observed in range above resonance. And velocity MFB is always stable (Fig. 2, a). In any of these cases, the depth of the feedback is frequency-dependent. This behavior means undesirable different error-correcting capability of MFB. In addition each of the classes of MFB produce all-over transfer function changes of loudspeaker (Fig. 2, b). The original approximated expressions for transfer function of closed-box loudspeaker with a single emitter, has the form (1):

$$W_0(s) = K_0(s) \cdot s^2 \cdot w_0^{-2} \cdot \frac{1}{s^2 \cdot w_0^{-2} + s \cdot w_0^{-1} \cdot Q^{-1} + 1} \tag{1}$$

where $K_0(s)$ – the complex frequency response of the power audio amplifier;

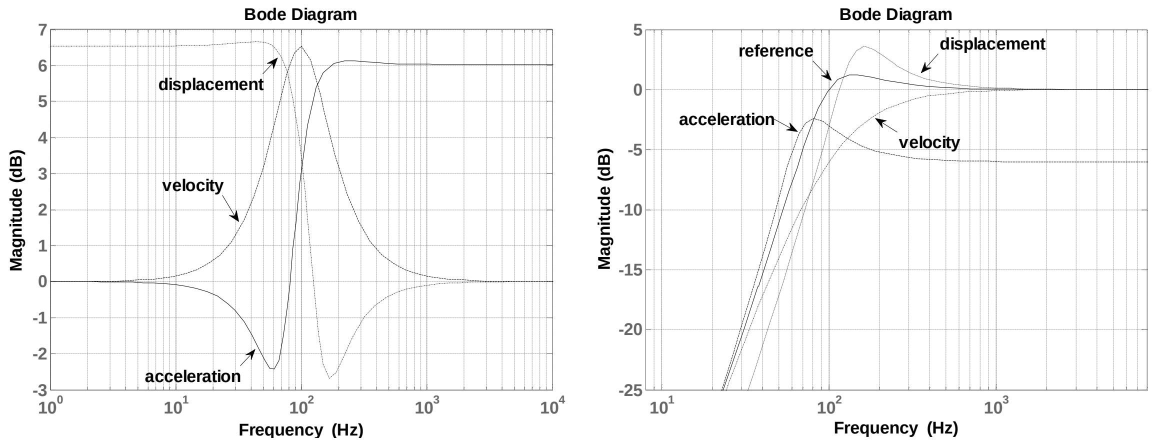
w_0 – cyclic resonance frequency;

Q – full quality factor of loudspeaker;

$s = j \cdot w$ – complex frequency.

Thus loudspeaker with MFB can be viewed as a concatenation of the oscillating link and two differentiators covered feedback. In this case, in the feedback circuit, depending on the feedback sensor, may be one or other processing circuitry, consisting of integrators or differentiators.

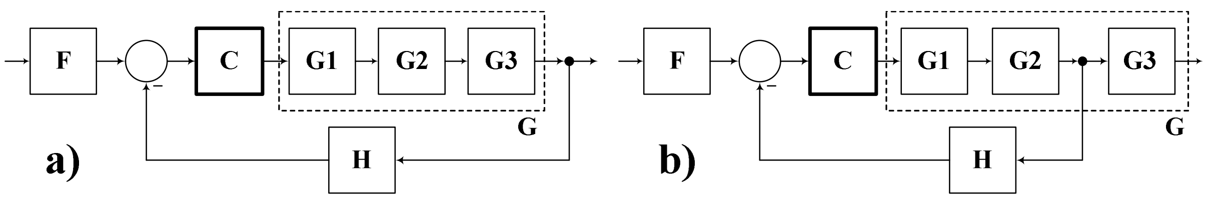
Due to the fact that between the acceleration, velocity, displacement, there is a unique mathematical relationship, each of the MFB classes can lead to other by equivalent transformations of circuits and their transfer functions. In this case the feedback loop will not cover all series connection with transfer function (1), but only part of it. Variants of MFB equivalent circuits by acceleration, velocity and displacement for the common case of forcing the feedback signal using the accelerometer and a main correction circuit in a straight chain of the loop is shown in Fig. 3.

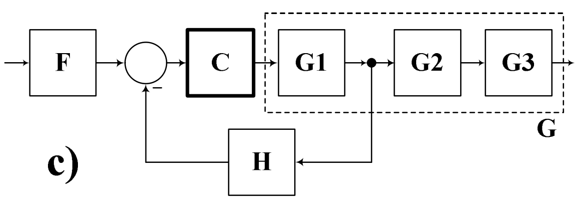


a) b)

Figure 2 – The classic version of MFB for loudspeaker with Q=1 and f_0 = 100 Hz:

a) Bode plot for depth of feedback; b) Bode plot for transfer function of loudspeaker with MFB; acc. – MFB by acceleration; vel. – by velocity; dis. – by displacement.





$$G1 = \frac{1}{s^2 \cdot w_0^{-2} + s \cdot w_0^{-1} \cdot Q^{-1} + 1}$$

$$G2 = G3 = s \cdot w_0^{-1}$$

Figure 3 - Equivalent circuits for classical types of MFB with an acceleration sensor as a feedback signal transducer:

a) MFB by acceleration; b) MFB by velocity; c) MFB by displacement

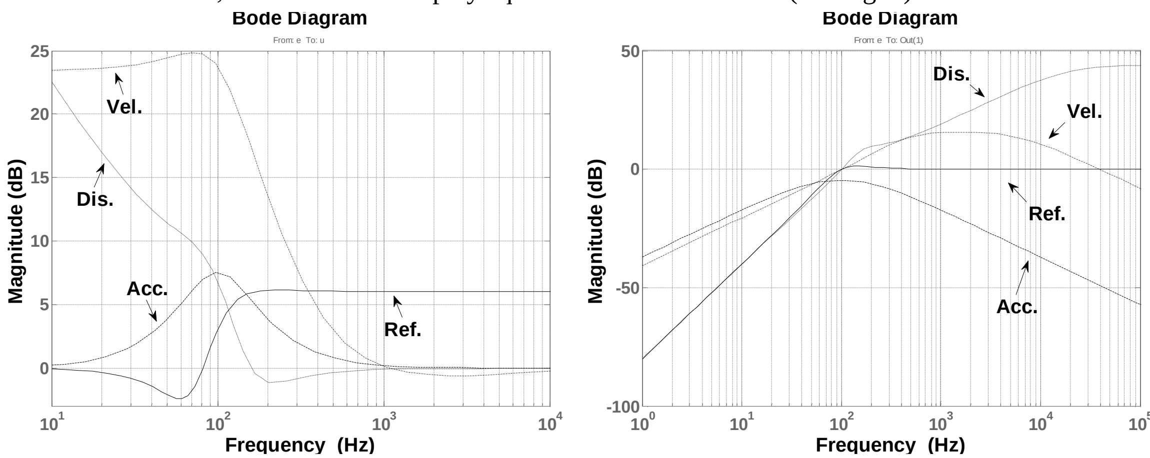
As follows from Fig. 3, MFB which feedback signal is proportional to the displacement of loudspeaker's cone, involves only oscillating part of loudspeaker in feedback loop. MFB by velocity also included in the loop one of the conditional differentiators. And the MFB by acceleration produce full loudspeaker coverage by feedback loop.

USING OF PID CONTROLLER IN LOUDSPEAKERS WITH MFB

PID - regulators, being relatively simple and provide good quality control, widespread as correction circuits in the control systems. Application management using the same PID in the system with MFB difficult complexity of obtaining astatic system, ie having a zero error in the steady state behavior.

Equation (1) confirms the existence of root (zero) of the function at the point $s = 0$, that can be attributed to the loudspeaker conditionally stable or neutral systems. This plant property, also known in control theory like «statism», can not be eliminated by using of PID corrective circuits [4]. Specified root be shown in the case of MFB by acceleration, and for the case of MFB by velocity. Initial expressions of transfer functions, which can explain this cases, presented in [1]. For case of displacement MFB zero of transfer function is out of feedback loop, the plant in loop is astatic, and the transfer function of the plant can be described by first multiplier in (1). In this case PID-corrector can eliminate error in steady-state mode.

Effect of PID corrector on the resulting characteristics of the loudspeaker with MFB shown in Fig. 4. In this case the initial parameters of PID corrector determined automatically using Matlab® mechanism «PID Tuner». Note that the Bode diagrams for feedback depth is depicted only for that part of loudspeaker, which included into the feedback loop. Over-all transfer function depicted for whole system with considering the influence of chains, excluded from loop by equivalent transformations (see Fig. 3).



a) **b)**

Figure 4 - Loudspeaker with MFB and PID corrector in the forward chain of feedback loop: a) Bode plot for depth of feedback (Ref. – without PID); b) Bode plot for transfer function of loudspeaker with MFB (Ref. – reference transfer function of loudspeakers); Acc. – MFB by acceleration; Vel. – by velocity; Dis. – by displacement

CONCLUSIONS

1 Application of PID-correctors for loudspeaker with MFB is, on the first view, ineffective. In the case of acceleration feedback PID-controller ensures the stability of the loudspeaker with MFB, but leads to a large non-uniformity of its frequency response, which should be adjusted by prefilter (equalizer) . The feedback is also uneven. Loudspeaker with MFB by acceleration and PID controller is approaching its properties to a loudspeaker with velocity MFB, which is characterized by good resonance damping.

2 PID-controller in velocity MFB tends to equalize the amount of feedback depth in the low frequency range, however, may cause self-oscillation at high frequencies. As well as for the case of acceleration MFB the use of equalization to ensure a uniform frequency response is necessary.

3 Using PID for displacement MFB can not be considered appropriate previously, because frequency independent of over-all transfer function and uniform depth feedback is not provided. Furthermore persists propensity to self-oscillation in the low frequency region.

4 Despite the contradictions, should conduct a more detailed analysis of the applicability of PID control to the loudspeakers with MFB. In particular interest is the potential for PID in the loudspeaker with acceleration MFB, because this method of control can provide stability. Item PID in velocity MFB increases uniformity of feedback depth and hence the error-correcting capability. Also useful to examine separately the PID application to the combined types of feedback.

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