



Parameterization and optimisation of EMC balances based on the frequency response of the impedance



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ABSTRACT

In this paper, a method for deriving significant parameters for the description of the dynamic behaviour of electromagnetic force compensated load cells (EMC) from its frequency response of the impedance is presented. With these parameters, the dynamic behaviour of a load cell can be described and classified near its main resonance frequency. By going the inverse way the load cell can be designed based on the favored parameters to fulfil certain criteria concerning the dynamic behaviour. This method is based on the estimation of parameters characterising the behaviour of electrodynamic speakers, called Thiele–Small parameters, which is state of the art for designing loudspeakers. It will be demonstrated that the controller design for EMC load cells can be based on the derived parameters.

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1. Introduction

Concerning uncertainty of measurement and achievable resolution, balances based on the principle of electromagnetic force compensation represent the state of the art.

In Fig. 1, the schematic setup of an EMC balance is depicted.

When a weight is applied to the weighing pan (1), it moves down, guided by the parallel lever system (5). The motion is transferred by the transmission lever (3) with a specific ratio. A position detector (7) detects the displacement x of the transmission lever. The position signal is the input of the controller, which outputs a current I through the coil of the electrodynamic actuator (8). The resulting electromagnetic force compensates the

weightforce. The current in the steady state ($\dot{x} = 0$) is an accurate measure for the mass to be determined.

Due to many applications of these systems in industry and research, there is a strong interest in improving their performance in terms of speed and accuracy, especially for dynamic purposes. In order to simplify the design process of a load cell to reach the desired global characteristics in the best and fastest way, a small set of parameters describing the main dynamic properties is needed. This set of parameters may also be used to characterise existing load cells in terms of applicability for dynamic purposes and to determine controller parameters. From the area of acoustics and sound engineering, a method for describing the dynamic behaviour of electrodynamic speakers with a set of parameters, called Thiele–Small parameters (TSP) is known [1–3]. These parameters can be derived from the characteristic curve of the frequency response of the impedance of an electrodynamic speaker. They give information on the mechanical and the electrodynamic behaviour. By interpreting the TSP, the speakers can be classified in their applicability as woofer (low frequency)

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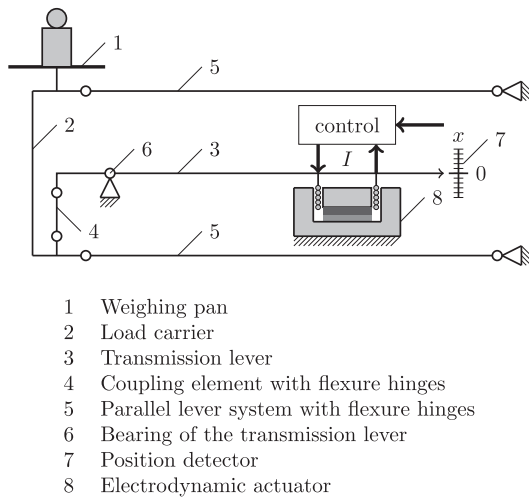


Fig. 1. Schematic setup of an EMC balance.

or tweeter (high frequency), the mechanical, electrical and total quality factors are given, and a suitable form for a loudspeaker box can be defined. The model applied to determine the TSP reduces an electrodynamic speaker without box to a mechanical system of spring, mass and damper coupled to an electrical series circuit of ohmic resistance and inductance. We show that an EMC load cell may be reduced to a model of the same kind. Thus a set of similar parameters describing the dynamic behaviour of an EMC load cell can be found from its frequency response of the impedance.

2. Thiele–Small parameters

Thiele–Small parameters describe the dynamic behaviour of an electrodynamic speaker near its resonance frequency. In Table 1 the parameters and the corresponding units are described.

For load cells, the parameters V_{as} , S_d , V_d and X_{max} can be neglected, as the moved air volume is very small. The mechanical parameters f_s , M_{ms} , R_{ms} and C_{ms} and the electrical parameters R and lB are coupled to each other through the quality factors with Eq. (1) [2].

Table 1

List of Thiele–Small parameters [1–3].

Symbol	Unit	Explanation
Q_{ms}	1	Mechanical quality factor of the speaker at f_s
Q_{es}	1	Electrical quality factor of the speaker at f_s
Q_{ts}	1	Overall quality factor of the speaker at f_s
f_s	Hz	Resonant frequency of the driver
R	Ω	DC resistance of the voice coil
L	H	Voice coil inductance
lB	Tm	Coupling factor – product of B-field strength in air gap and length of coil wire in B-field
M_{ms}	kg	Moved mass
R_{ms}	kg/s	Mechanical resistance of speaker suspension
C_{ms}	m/N	Compliance of speaker suspension
V_{as}	m^3	Equivalent compliance volume
S_d	m^2	Projected area of speaker diaphragm
V_d	m^3	Peak displacement volume
X_{max}	m	Maximum linear peak excursion

$$Q_{es} = \frac{R}{(lB)^2} \sqrt{\frac{M_{ms}}{C_{ms}}}, \quad Q_{ms} = \frac{1}{R_{ms}} \sqrt{\frac{M_{ms}}{C_{ms}}}, \quad Q_{ts} = \frac{Q_{ms} Q_{es}}{Q_{ms} + Q_{es}} \quad (1)$$

3. Model description

An EMC load cell can be modelled as a system of masses, springs and dampers, as done in [4]. By reducing the model order, a simple model consisting of just one mass M_{ms} , spring C_{ms} and damper R_{ms} can be obtained [5], (Fig. 2a). This model will of course provide no detail about higher order resonances of the system. By applying an electromechanical analogy [2], the system of mass, spring and damper, driven by the velocity can be transformed to an electrical circuit of inductance, capacitance and ohmic resistance. The mechanical system is bilaterally coupled to the electrodynamic actuator via the force F acting on the mechanics by applying a current I to the coil and the voltage induced U_{ind} in the coil due to the velocity v of the lever:

$$F = lIB \quad \text{and} \quad U_{ind} = -vIB \quad (2)$$

The coupling factor lB represents the strength of the electrodynamic actuator. The bilateral coupling of mechanical and electrical system can be reduced to this coupling factor in terms of an electromechanical analogy as an ideal transformer with a turns ratio equal to lB . The electrodynamic actuator can be reduced to a series circuit of ohmic resistance and inductance [6], (see Fig. 2b). In this model, the acoustical parameters which appear for speakers were completely cancelled as the influence of air on the dynamic behaviour of an EMC load cell is negligible. This conclusion was drawn from a series of experiments under different pressures and vacuum where no change in the dynamic characteristics of the balances was observed.

Most EMC load cells are set up with a lever (see Fig. 1). On one side the weighing pan is mechanically coupled to the lever and on the other side the voice coil is fixed. The masses of each side of the lever can be concentrated to the point masses m_1 and m_2 . Masses applied to the weighing pan can be considered as Δm (cf. Fig. 3).

In order to concentrate the distributed masses to a single point mass as in [5], the geometry of the balance has to be taken into account. As the dynamic properties of the balance should be retained after the transformation of the masses, the moment of inertia J has to be considered:

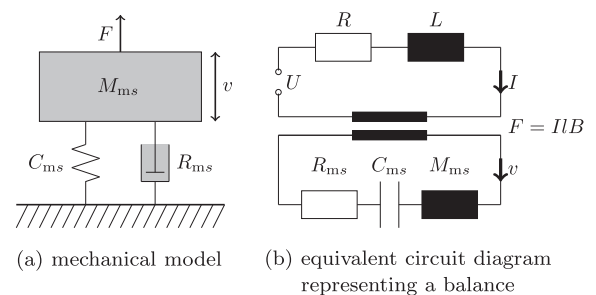


Fig. 2. Reduced model for EMC load cell.

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