

Modelling of Moving Magnet Actuators for Haptic Sensing Applications

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Summary:

Haptic feedback is a key component of human interface devices as it allows for intuitive interaction. A common way to give haptic feedback is via vibrations, depending on either the user's inputs or the state of the device. One difficulty of such devices, vibration actuators in particular, is the influence of the outside environment on the actuator's performance. In this work, we show a way to model how the coupling of the outside environment affects the impedance response of a moving magnet actuator for haptic vibrational feedback and to, in turn, extract the properties of the actuator's surroundings. To achieve this, we derived an electrical equivalent circuit from a linear two-degree-of-freedom mechanical model and calculated the resulting electrical impedance of the actuation coil. After calibration, impedance spectra were measured in different user scenarios, and the contributions to the impedance which are related to the environment (e.g., the user's hands) were extracted, showing the possibility to measure the characteristics of a surrounding system via the impedance spectrum.

Keywords: haptic sensors, resonance, modelling, equivalent electrical circuit

Introduction

Integrating haptic feedback into electronic interfaces supports intuitive interaction between user and device [1,2]. In particular, so-called Moving Magnet Actuators (MMAs), which utilize the electromagnetic actuation of vibrating permanent magnets, enable such feedback to the user [3]. MMAs have different designs, most of which can be described as a magnet suspended by springs inside a housing comprising a coil for electro-magnetic actuation, as shown in Fig. 1.

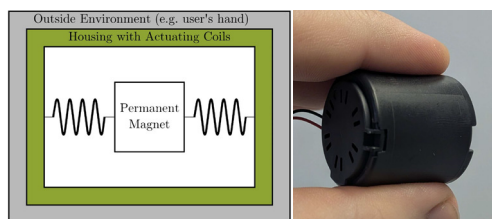


Fig. 1 Simplified sketch of the inner structure of an MMA (left) and a picture of an MMA held in the user's hand (right).

Interaction with the external environment remains an issue for all types of mechanical oscillators, including MMAs, resulting in changes in resonance frequency in particular. In MMAs, the interaction causes a change in vibration amplitude depending on the way a user holds the device, resulting in a measurable change in electrical impedance [4].

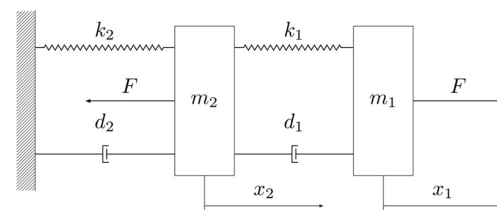


Fig. 2 Mechanical model of a MMA using two degrees of freedom x_1 and x_2 . The Mass m_1 , with the spring k_1 and damper d_1 represent the magnet and the spring connecting it to the housing with Mass m_2 . The components k_2 and d_2 model the user's hand or materials surrounding the MMA.

This effect can be considered to be spurious, but it could also be utilized for sensing and possibly controlling the vibration amplitude in various environments and handling situations. Hence, a mechanical model is devised, which can be further translated into an equivalent circuit for the actuation coil's impedance.

Mechanical and Electrical Model

Based on the linear two-degree-of-freedom mechanical model shown in Fig. 2, a transformer model coupling the electrical and mechanical quantities at the actuation coil via a constant coupling factor $a = \frac{F}{i} = \frac{u_{\text{ind}}}{\dot{x}}$ and by introducing mechanical admittances connecting velocity and applied force $Y_{\text{mech}} = \frac{v}{F}$, an equivalent circuit was derived as shown in Fig. 3.

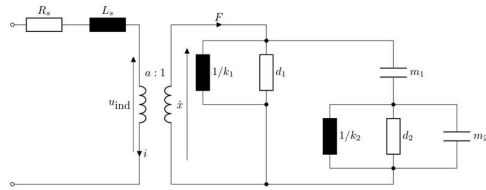


Fig. 3. Equivalent circuit representing the mechanical system together with the ohmic resistance R_s and self-inductance L_s of the coil yielding the impedance of the actuation coil.

Measurements

As described in our previous work [4], the electrical impedances of multiple MMAs in different baseline and user scenarios were measured using an impedance analyzer. These spectra in Fig. 4 (solid) show that holding or clutching an MMA with different forces leads to strongly varying resonances.

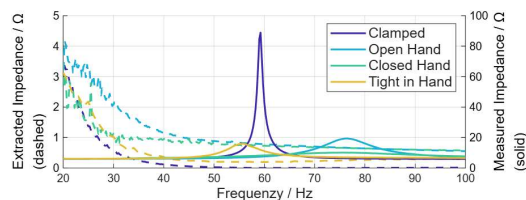


Fig. 4. Measured (solid) and extracted (dashed) impedance spectra of multiple user scenarios of the MMA shown in Fig. 1.

Using calibrated system parameters as well as the aforementioned model, the characteristics of the “outer” system, represented by k_2 , d_2 and m_2 , can be extracted as shown in Fig. 4 (dashed; impedance) and Fig. 5 (admittance). These spectra represent the properties of the surrounding environment (e.g., a user’s hand).

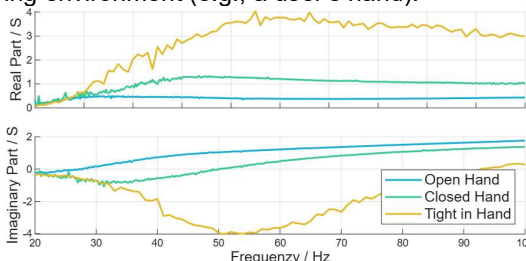


Fig. 5. Real and Imaginary parts of the extracted admittances of the “outer” system.

The parameters d_2 and k_2 , responsible for the plateau in the real part and the shape of the imaginary part in Fig. 5, respectively, show a clear increase over the increase in grip strength. The increase in stiffness k_2 from 100 N/m (closed hand) to 300 N/m (tight in hand) is also consistent with reported similar observations [5], indicating that these parameters are well suited to be used as measurement metrics for the grip strength, thus enabling sensor functionality of these actuators.

Observed Challenges

The desired parameters are nested within the rather complex impedance spectrum of the whole system, and consequently, inaccuracies during the calibration process lead to significant errors in the extracted “outer” impedance. Additionally, many MMAs are constructed without any magnetic field guides, resulting in a coupling factor a that is dependent on the position of the inner magnet, which results in a significant variation of the impedance spectrum depending on the displacement amplitude, in addition to various other non-linearities that can be encountered.

Conclusion

This work illustrates the modeling of an MMA for haptic applications. From a linear mechanical two-degrees-of-freedom model, a model for the observed electrical impedance, as well as an electrical equivalent circuit are derived. This model, with additional calibration measurements, can be used to extract the characteristics of the surrounding environment (e.g., a user’s skin tissue), which would enable sensing associated parameters in the environment. This can, in turn, allow for active control of the vibration amplitude of haptic feedback elements.

Acknowledgment

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