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# A generalised multiple-mass based method for the determination of the live mass of a force transducer

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ABSTRACT

Many applications in Experimental Modal Analysis (EMA) require that the sensors' masses are known. This is because the added mass from sensors will affect the structural mode shapes, and in particular its natural frequencies. EMA requires the measurement of the exciting forces at given coordinates, which is often made using piezoelectric force transducers. In such a case, the live mass of the force transducer, i.e. the mass as 'seen' by the structure in perpendicular directions must be measured somehow, so that compensation methods like mass cancelation can be performed. This however presents a problem on how to obtain an accurate measurement for the live mass. If the system is perfectly calibrated, then a reasonably accurate estimate can be made using a straightforward method available in most classical textbooks based on Newton's second law. However, this is often not the case (for example when the transducer's sensitivity changed over time, when it is unknown or when the connection influences the transmission of the force). In a self-calibrating iterative method, both the live mass and calibration factor are determined, but this paper shows that the problem may be ill-conditioned, producing misleading results if certain conditions are not met. Therefore, a more robust method is presented and discussed in this paper, reducing the ill-conditioning problems and the need to know the calibration factors beforehand. The three methods will be compared and discussed through numerical and experimental examples, showing that classical EMA still is a field of research that deserves the attention from scientists and engineers.


## 1. Introduction

Piezoelectric force transducers operate with the principle that when a piezoelectric crystal is deformed by the action of a force, a charge output (proportional to the rate of change of the force acting on the crystal) is produced. As with piezoelectric accelerometers, force transducers can either be of the type 'charge' or IEPE (Integrated Electronics Piezo-Electric), depending if they bring built-in pre-amplifiers or not. IEPE transducers have built-in pre-amplifiers and thus do not need a charge amplifier in the measurement chain, as charge transducers do.

One example where force transducers are used is in the measurement of the Frequency Response Function (FRF) of a structure. The FRF contains information about the natural frequencies, modal damping factors and mode shapes of a structure. For harmonic (sinusoidal) excitation, the FRF is the relationship between the response and the force. If an

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accelerometer is used, and as long as the excitation is harmonic, the amplitude of the FRF at a given frequency $\omega$ is:

$$H(\omega) = \frac{a(\omega)}{f(\omega)} \quad (1)$$

where $a(\omega)$ is the amplitude of the acceleration response to the amplitude of input force $f(\omega)$. Because this is a representation of the FRF that makes use of the acceleration, it is called "accelerance". For other types of excitation, auto-correlation functions may have to be used [1].

When measuring FRF data, one is concerned with the ratio of motion to force and not the individual values of any of these quantities [1]. Thus, it is possible to generate an excitation function, where force is transmitted to the structure using a shaker (Fig. 1). These excitation functions can be "Random", "Pseudo-Random", "Sweep-Sine", "Multi-Sine" or "Stepped-Sine" [1,2]. The push-rod shown (often also referred to as the "stinger" or "drive rod") is used to apply the excitation force from the shaker to the structure. The objective is to transmit controlled excitation to the structure in a given direction and, at the same time, to impose as little constraint on the structure as possible in all the other directions. The effects of the push-rod on EMA have been previously discussed, for example in [1,3–6].

Force transducers have a sandwich construction: a piezoelectric crystal is placed between a base case and a top case. Note that one side of the transducer may be lighter than the other. In a conventional force transducer setup and according to, e.g., [1,5], the transducer is placed with the lighter side (called the "base side") towards the structure and the heavy side (called the "top side") away from the structure (Fig. 2(a)). This is done to avoid as much mass modification to the structure as possible. The mass of the side that is attached to the structure is also called "live mass" [1,5]. This mass is 'seen' by the structure in the sensing direction. However, at perpendicular directions, the structure will 'see' the total mass of the force transducer. For example, these masses have been recorded as 3 g and 18 g on the different sides of a conventional force

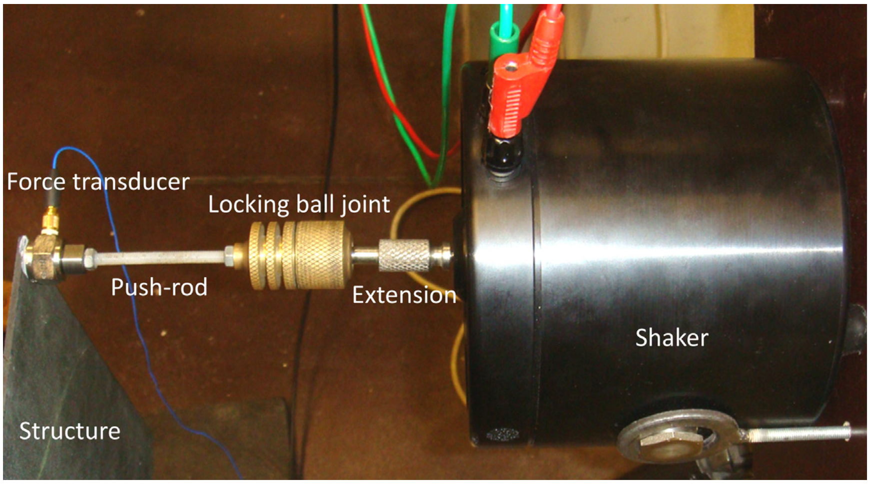


**Fig. 1.** Push-rod connection between a shaker and a force transducer [8].

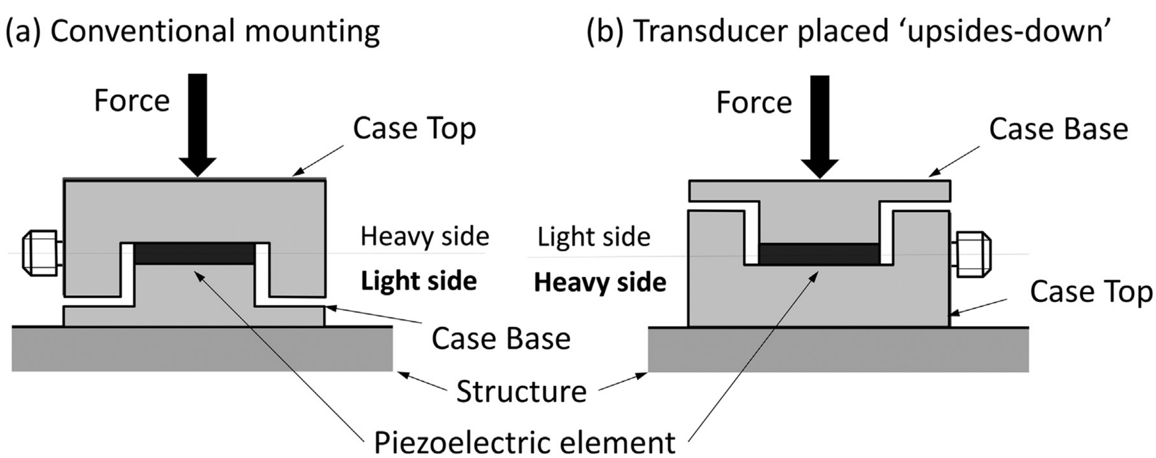


**Fig. 2.** Schematic cross-sectional view of a piezoelectric force transducer: (a) conventional mounting and (b) 'upsides-down' mounting.