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Toward dynamic force calibration

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ABSTRACT

Ways of establishing dynamic calibration methods are discussed. Three methods for evaluating the dynamic response of force transducers against varying force are described. In all methods, the inertial force of a mass is used as the known dynamic force, and this reference force is applied to a force transducer under test. The inertial force is measured highly accurately as the product of the mass and the acceleration. An aerostatic linear bearing is used to obtain linear motion with sufficiently small friction acting on the mass (i.e., the moving part of the bearing). Three experimental setups were built for the dynamic calibration against an impact force, an oscillation force and a step force. The present status and the future prospects of dynamic force calibration are discussed.

1. Introduction

Recently, the need for measuring dynamic forces have increased in various industrial and research applications such as process monitoring, material testing, motion control and crash testing. However, only static methods, in which transducers are calibrated with static weights under static conditions, are widely available at present. Methods for dynamic calibration of force transducers are important to fulfill these needs. The required uncertainty of a dynamic calibration method should be approximately 0.1% at the best, considering the fact that commercial force measuring systems are usually statically calibrated with the uncertainty of approximately 0.1% or worse. However, the establishment of a dynamic calibration method with an uncertainty level of a few percent will be a significant contribution to the field of force measurement.

Although procedures for dynamic calibration of force transducers are not yet well established, there have been a few attempts to develop dynamic calibration methods for force transducers. These attempts can be divided into three categories, namely, methods for calibrating transducers against an impact force, methods for calibrating transducers against an oscillation force, and methods for calibrating transducers against a step force.

As for the procedure for calibrating transducers against an impact force, the author has proposed and developed a method [1–6]. Bruns and Kobusch have also recently developed a similar method for calibrating transducers by using an impact force [7]. This method was first proposed [1] as an impulse response evaluation method for force transducers; a mass was made to collide with a force transducer and the impulse, i.e., the time integration of the impact force, was measured highly accurately as a change in the momentum of the mass. To obtain linear motion, with sufficiently small friction acting on the mass, a pneumatic linear bearing [2,3] was used, and the velocity of the mass (i.e., the moving part of the bearing) was measured

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using an optical interferometer. This method was subsequently improved [4] as a method for determining the instantaneous value of the impact force in the impulse. In this case, the instantaneous value of the impact force was measured as the inertial force acting on the mass, by means of measuring the instantaneous acceleration of the mass. This method was also improved [5] as a method for determining the response against a steep impulse with a half value width of approximately 1 ms. The author has discussed the possible applications and importance of this method in force measurement [6]. The impact response of a force transducer embedded inside an impact hammer has been evaluated [7].

As for the trials for calibrating transducers against an oscillation force, Kumme has proposed and developed a method, in which the inertial force of a mass attached to a force transducer is used [8–10]. In this method, both the mass and the transducer are shaken at a single frequency using a shaker, and the inertial force of the mass is applied to the transducer. The inertial force of part of the transducer itself must be taken into account, to evaluate the characteristics of the transducer under typical conditions in which it is fixed to a stable base. Park et al. use this method for dynamic investigation of multi-component force-moment sensors [11,12]. The author has also proposed a method for calibrating force transducers against an oscillation force, in which the force transducer under test is firmly fixed to a stable base [13].

As for the trials for calibrating transducers using a step force, the author first proposed a method in reference [14]. In the method, the reference force, which is suddenly applied to the force transducer under test, is the combined gravitational and inertial force acting on the object. At the beginning of the evaluation, the object is suspended just above the transducer with the use of a wire; then the object is allowed to fall on to the transducer by cutting the wire. To realize perpendicular motion with sufficiently small friction, a pneumatic linear bearing is used. The inertial force acting on the object is measured highly accurately by measuring the velocity of the mass using an optical interferometer. On the other hand, the step force response of force transducers has recently become a topic of much interest. For example, there is research dealing with the dynamic characteristics of force transducers under step load [15]. In this method, the real force is approximately estimated from the output signal without the known reference force. Strictly speaking, there are no other dynamic calibration methods using a step force, in which a known step force is used as the reference, except the method proposed by the author.

Summarizing the present situation, dynamic calibration methods for force transducers are not yet established and are still being developed. The author has proposed all three types of dynamic calibration methods that are for the impact response calibration, the oscillation response calibration and the step response calibration. Proposing a method integrating the different calibration methods and proposing an appropriate set of parameters for describing the dynamic characteristics of general transducers will be very important in the next stage.

All the three methods proposed by the author are based on the Levitation Mass Method (LMM). In this paper, the present status and the future prospects of the LMM as the dynamic force calibration method are discussed.

2. The levitation mass method (LMM)

The principle of the proposed methods is shown in Fig. 1. In the Levitation Mass Method, the inertial force of a mass is used as the known dynamic force and this reference force is applied to a force transducer under test. The inertial force is measured as the product of the mass and the acceleration. The acceleration of the mass is accurately measured using an optical interferometer. An aerostatic linear bearing is used to obtain linear motion with negligible friction acting on the mass, i.e., the moving part of the bearing.

Recently, a pendulum mechanism for use as a substitute of an aerostatic linear bearing has been developed [16]. An algorithm of evaluating the frequency fro the waveform recorded using a digitizer has also been proposed [17]. By introducing a pendulum mechanism instead of the expensive aerostatic linear bearing and a low cost digitizer instead of the expensive electronic frequency counter, a low cost instrument based on the LMM can be developed.

The LMM has also been applied to the field of small force measurement [18] and the field of material testing [19,20].

In this paper, the methods for evaluating the dynamic response of force transducers against a varying force are described, and ways for integrating the three different methods are discussed.

3. Calibration methods for typical dynamic forces

The three types of dynamic calibration methods based on the LMM, which are for the impact response calibration [1,4,5], the oscillation response calibration [12] and the step response calibration [13], are described here.

3.1. Impact response calibration method

Fig. 2 shows the experimental setup for measuring the impact force applied to the force transducer being tested. An impulse is generated and applied to the transducer by

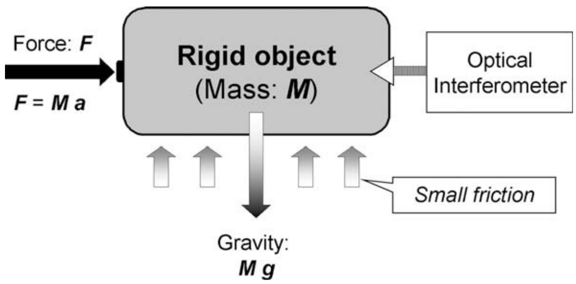

Fig. 1. Principle of the Levitation Mass Method (LMM).