Measurement 82 (2016) 432–438

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Force balanced transducer based on electromagnetic lever with improved linearity

Qiuxiao Wang [a,*], Pan Jiang [b], Lijian Shen [b]

[a] *State Key Laboratory of Mechanical Transmission, Chongqing Univ., Chongqing 400044, China*
[b] *School of Mechanical Eng., Chongqing Univ., Chongqing 400044, China*

ARTICLE INFO

Article history:
Received 29 July 2015
Received in revised form 7 January 2016
Accepted 11 January 2016
Available online 14 January 2016

Keywords:
Force transducer
Linearity
Signal–noise ratio
Electromagnetic force

ABSTRACT

The elastically sensitive element nonlinearity and the signal–noise ratio are the limitation of the traditional force transducer, which makes the precision is rarely higher than 0.02%. This study proposes a force transducer with electromagnetic force balance lever structure. The transducer utilized a controllable electromagnet that generated the controllable electromagnetic force to offset the load while the load value is obtained by the coil voltage, which solves the signal–noise ratio problem. Analyzing the electromagnetic force curves under different temperatures by the piecewise linearization method acquires the high linearity electromagnetic force, which solves the nonlinearity problem. Test results indicated that the transducer linearity was 0.001%, and its precision was 0.003%.

1. Introduction

The force transducer is a very important part in force measurement field [1,2]. The traditional force transducer is usually based on the elastic sensitive element and Wheatstone bridge configuration, which change physical parameters to obtain force value [3–6]. Firstly, the element is fixed on a cantilever beam or a simply supported beam [5–7]. Then the beam is deformed with the force applied. Its elasticity modulus and rotational-inertia changes as long as the force is large enough. The structure itself has a nonlinearity problem. Secondly, the transducer precision is affected by the signal–noise ratio. For example, the precision of a S2M high precision force sensor from HBM is 0.02% and its sensitivity is 2 mV/V. The minimum output voltage is 4 μV at a 10 V excitation voltage. In order to improve the precision, the output voltage must reach nV-level, which is much lower than the electronic noise (the low noise amplifier noise from Texas Instruments (TI) is 50 μV). In this case, the signal will be covered by the noise. In general, the nonlinearity error and signal–noise ratio of the transducer are the two major problems in designing the force transducer.

Many studies have reported to resolve the nonlinearity problem. Marco et al. proposed that the large deflection of the diaphragm and the unbalanced stress among piezoresistors in the Wheatstone bridge are the two major nonlinearity error sources for the diaphragm type piezoresistive pressure transducer with a Wheatstone bridge configuration [8,9]. To solve this problem, a stiffening structure is usually used [10–12], which is an effective method to reduce the nonlinearity error. Nonlinear compensation also reduces the nonlinearity error, and Multi-linear regression and curve fitting are traditional nonlinearity compensations [13,14]. There are also many studies on solving the signal–noise ratio problem. Sariyildiz presented that the majority noise comes from the amplifier [15,16]. Using a low-pass-filter (LPF) or the Kalman filtering method removes the noise [15,16]. Besides, self-adapting filtering fairly well resolves the random noise and the pulse noise existing in the electronic system [17,18]

* Corresponding author. Tel.: +86 23 65429037.
E-mail address: wqxiao1963@163.com (Q. Wang).

http://dx.doi.org/10.1016/j.measurement.2016.01.019
0263-2241/

Compared with the traditional force transducer, the force balance transducer has obvious advantages, such as a wide range of available capacities, highest accuracy, and the most optional features [19]. It is widely used as an electromagnetic force balance transducer [6,20,21] and an electric analysis balance [22–24]. Nevertheless, these transducer and electronic balance were for low-force range [6,20–24].

In this paper, a novel force balance transducer based on an electromagnetic force balance lever structure for a normal range is proposed. The proposed structure replaced the principle of the traditional transducer. In the following sections, Finite Element Method (FEM) analysis was performed on the electromagnet, and the relationship between coil voltage and electromagnetic force is obtained. The linearity influence on the electromagnetic force is discussed in detail, and the high linearity electromagnetic force is obtained by a piecewise linear fitting method. Finally, the force balance transducer was tested and demonstrated with a three-point measurement device, which is used in the mass measuring instrument.

2. The transducer principle

Fig. 1 illustrates the electromagnetic force transducer principle, and Fig. 2 illustrates the electromagnetic force transducer schematic. If a force is applied on the weighing pan (1), the lever (2) deflects. An armature (3) is attached to the lever that is above an electromagnet (4). The lever position is measured by an position sensor (5). A closed-loop control system (6) controls the lever position by setting the voltage of the electromagnet coil, generating an electromagnetic force. Fig. 3 shows the mechanical relationship, and according to the moment balance theory, the equilibrium between the applied force F_1 and the electromagnetic force F is

$$F_1 = \frac{x_2}{x_1} F \tag{1}$$

If the lever regains the initial position, then the voltage is proportional to the force applied on the weighing pan. Additionally the signal–noise ratio improves because the voltage is usually higher than the electronic noise. A temperature sensor (7) is used, which can send feedback information to the control loop by monitoring, because an electromagnet is easily influenced by the temperature.

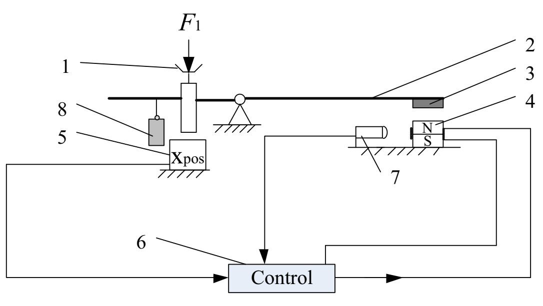

Fig. 1. Principle of electromagnetic force transducer.

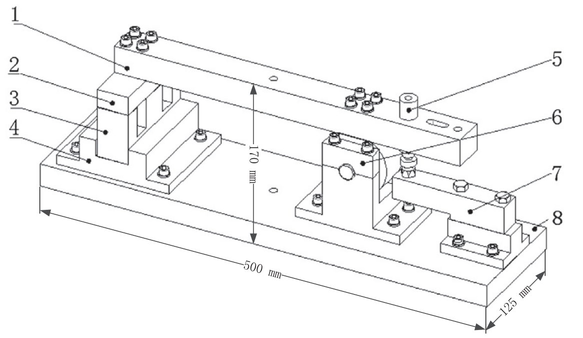

Fig. 2. Schematic of electromagnetic force transducer (1) lever, (2) armature, (3) electromagnet, (4) electromagnet stents, (5) support pillar, (6) rotary mechanism, (7) lever balance detection device and (8) bottom plate.

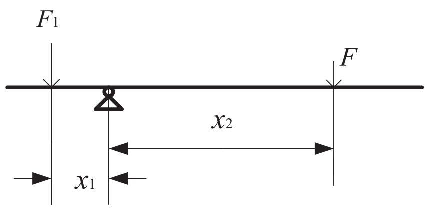

Fig. 3. Mechanics model of the lever.

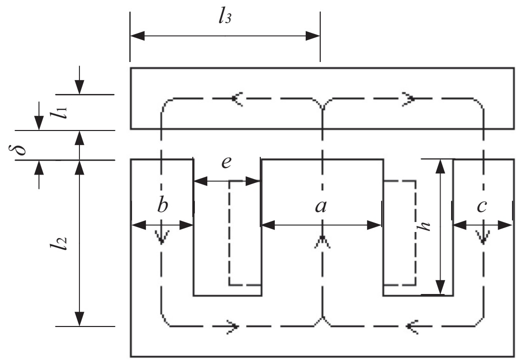

Fig. 4. The dimensions of the E-type magnet.

3. Analysis and the electromagnetic force nonlinearity correction

3.1. The device for generating magnetic force

The E-type direct current-electromagnet produces the magnetic force, which is a direct-acting magnet. Compared with other magnets, this magnet can generate higher electromagnet force with a smaller air gap. The materials of the iron core and the armature are pure iron and nodular cast iron respectively, and the coil is made of enameled.

Fig. 4 shows the dimensions of the E-type magnet. The middle core limb width is $a = 35.0$ mm, while the others are $b = 17.5$ mm and $c = 17.5$ mm. The distance between the middle core limb and the edge is $e = 19.5$ mm. The core limb height is $h = 38.0$ mm. The magnet thickness is