Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Sensors and Actuators A 136 (2007) 137–143
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

Signal modeling of electromagnetic flowmeter under sine wave excitation using two-stage fitting method

Ke-Jun Xu [a,b,*], Xiao-Fen Wang [a]

[a] Institute of Automation, Hefei University of Technology, Hefei 230009, PR China
[b] Department of Engineering Science, Oxford University, Parks Road, Oxford OX1 3PJ, UK

Received 22 June 2006; received in revised form 11 October 2006; accepted 13 October 2006

Abstract

The current signal models of electromagnetic flowmeter under sinusoidal excitation cannot describe quantitatively the relationship among the sensor output, flow rate and exciting signal. A two-stage fitting method is proposed to build up the accurate signal model based on experimental data. The first step of the method is to approximate the relationship between the sensor output and the flow rate, and the second one is to fit the relationship between the model coefficients and the frequency or amplitude of exciting current. This method can determine the terms and coefficients of signal model, and reflect the effects of transformer and eddy current.

Keywords: Electromagnetic flowmeter; Signal model; Fitting method; Experiment

1. Introduction

The electromagnetic flowmeter has been widely used in the process industries due to its many features. However, it is still difficult to measure the following fluids: (1) low-conductive fluids; (2) low-speed fluids; (3) high-concentration slurry fluids containing solids and (4) adhesive fluids [1]. One effective way of solving these problems is to improve the signal processing method so as to enhance the capacity of extracting information from noisy signal. In order to select the suitable signal processing algorithm and evaluate its effectiveness, the signal models need to be built up firstly. Since the coils of magnetic flowmeter can be energized by a sine waveform or rectangular waveform, the signal models are not the same for different excitations. This paper studies the signal modeling under the sine wave excitation. The sinusoidal excitation is readily affected by commercial frequency noise. However, this problem can be solved by a high-frequency exciting method. The high-frequency exciting method is resistant to $1/f$ noise such as electrochemical noise or spike noise, where f is the exciting frequency. The effect of transformer in the sensor output under sine wave excitation results in a large zero offset. The demodulation technique can reduce this action. In addition, this exciting mode can improve the dynamic response and make a flow rate signal quickly follow a change in flow rate [2–4].

The electromagnetic flowmeter operates on Faraday's law, in which a voltage is induced in a conductor moving relative to the magnetic field [5,6]. The coils surrounding the flow pipe create the magnetic field; electrodes, on the opposite sides of the pipe walls, sense the induced voltage. The moving fluid in the pipe acts as a conductor and the induced voltage is directly proportional to the flow rate. The signal model of magmeter under sine wave excitation has been studied by researchers [7–9]. The magnetic field is of the form $B\sin\omega t$, and the sensor output of electromagnetic flowmeter is

$$u(t) = e_{\mathrm{ab}} + c_2\frac{\mathrm{d}B}{\mathrm{d}t} = c_1 qB\,\sin\omega t + c_2\omega B\,\cos\omega t \qquad (1)$$

where e_{ab} is the inter-electrode potential; B the magnetic flux density; $\mathrm{d}B/\mathrm{d}t$ the transformer voltage, which is the time rate of change of flux in electrode wiring loops, earth loops and in the conducting medium both inside and outside the flowmeter head; q the flow rate, c_1 and c_2 the constants; and ω is the exciting angular frequency.

---

[*] Corresponding author. Tel.: +86 551 2901412; fax: +86 551 2904435.
E-mail addresses: dsplab@hfut.edu.cn, xukejun@mail.hf.ah.cn (K.-J. Xu).

0924-4247/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2006.10.029

Since the magnetic flux density is proportional to the exciting current, Eq. (1) becomes

$$u(t) = c_3 qI \sin \omega t + c_4 \omega I \cos \omega t \tag{2}$$

where I is the amplitude of exciting current, and c_3 and c_4 are constants.

There are problems in this signal model. The first one is that the effects of some factors are not been considered, for example the effect of eddy current that is induced in the body of the flowmeter or adjacent structure. The second one is that the quantitative relationship among the sensor output, flow rate and exciting signal cannot be present, and the values of model coefficients cannot be determined. This is because we only carry out the qualitative analysis according to Faraday's law and some assumptions. We cannot obtain an accurate signal model because in practice the interaction between the electromagnetic field and the fluid field is complex. Therefore the signal modeling has to be based on both Faraday's law and the experimental data, and at the same time some calculation methods must be employed. In this paper, a two-step fitting technique is proposed to determine the terms and coefficients of signal model according to the experimental data. The first step of the two-stage fitting method is to approximate the relationship between the sensor output and the flow rate. The second one is to fit the relationship between the coefficients and the exciting frequency, or between the coefficients and the current amplitude.

2. Experiments

The experiments are the foundation of modeling. The experiments were performed by first author at the Invensys University Technology Centre for Advanced Instrumentation (UTC), Department of Engineering Science, University of Oxford in UK. The experimental facility consists mainly of a flow rig, a dSPACE system that is a data acquisition system and made by dSPACE Inc. in Germany, an electromagnetic flowmeter, and other equipment, which are shown in Fig. 1.

The centrifugal pumps with a 6-blade impeller were controlled by the variable-speed drives to control the flow rate in the flow rig. A Foxboro's Coriolis mass flowmeter with accuracy of 0.1% was as the standard meter to detect the flow rate and display the measurement value. A Foxboro electromagnetic flow tube of 2 in. diameter (9320A flowmeter) was associated with the drive and sensor circuits developed by the UTC. A HP 33120A 15 MHz Function/Arbitrary Waveform Generator produced the sinusoidal signal with various frequencies and amplitudes, and send it to the input of power amplifier in the drive circuit. The drive circuit generated the sinusoidal current to excite the coils in electromagnetic flowmeter. The exciting current and sensor output of electromagnetic flowmeter were collected by the dSPACE system, and experimental data were sent to PC. At the same time a HP 3478A Multimeter was employed to test the exciting current through the coils of electromagnetic flowmeter. During experiments five flow rate points were selected in the certain range of flow rate, that is, from 0 L/s to 2 L/s. At each flow rate point, the frequency and amplitude of exciting current were altered, respectively. For each flow rate, exciting frequency and current, 10 sets of experimental data were logged so as to perform averaging processing.

3. Signal modeling

According to the operating principle of electromagnetic flowmeter with sine wave excitation, the sensor output consists of two parts. One is the in-phase component, and the other is the quadrature component. We have

$$u(t) = k_1 \sin \omega t + k_2 \cos \omega t \tag{3}$$

where k_1 and k_2 are coefficients, but are not constants. They reflect actions of the flow rate, frequency and amplitude of exciting current.

We employ the exciting current $i(t) = I \sin \omega t$ as a reference signal to demodulate the sensor output, and obtain the in-phase and quadrature components, respectively. Before demodulation the amplitude of reference signal is normalized, that is,

$$i_1(t) = \sin \omega t \tag{4}$$

First, the sensor output is multiplied by the normalized reference signal, and the in-phase component is

$$\begin{aligned} u_{\mathrm{d}i}(t) &= u(t) i_1(t) = (k_1 \sin \omega t + k_2 \cos \omega t) \sin \omega t \\ &= \tfrac{1}{2} k_1 - \tfrac{1}{2} k_1 \cos \omega t + \tfrac{1}{2} k_2 \sin \omega t \end{aligned} \tag{5}$$

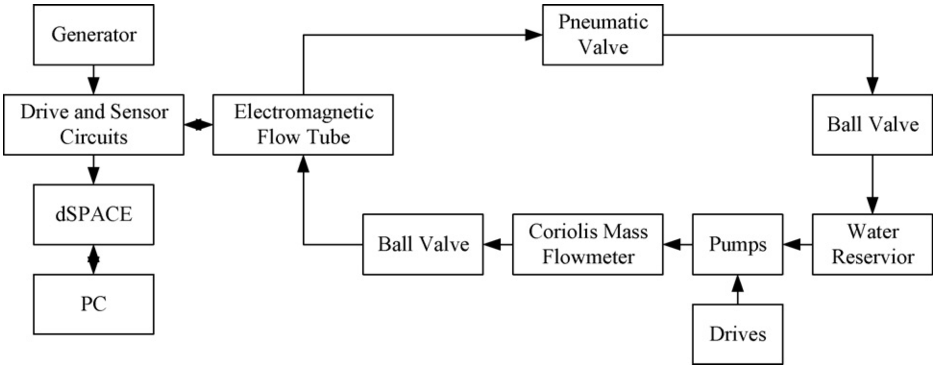

Fig. 1. Scheme of flow rig and data collection.