Available online at www.sciencedirect.com

ScienceDirect

Applied Acoustics 69 (2008) 891–900

applied acoustics

www.elsevier.com/locate/apacoust

A new nondestructive technique for measuring pressure in vessels by surface waves

Hongjian Zhang [a,*], Qing He [a], Yong Yan [b]

[a] *National Laboratory of Industrial Control Technology, Institute of Automation Instrumentation, Zhejiang University, Hangzhou 310027, Zhejiang Province, China*

[b] *Department of Electronics, University of Kent, Canterbury, Kent CT2 7NT, UK*

Received 22 October 2006; received in revised form 27 May 2007; accepted 29 May 2007
Available online 29 October 2007

Abstract

Thin-walled pressure vessels are widely used in modern industry. It is important to measure pressure of the vessels. It has been proved that the velocity of ultrasonic propagation in the material could be affected by the stresses applied to it. The pressure measurement should consider the effect of temperature as the velocity of ultrasonic is affected by the temperature and thermo-stress is produced in the vessels wall. Furthermore, the propagation distance of ultrasonic is influenced by thermal deformation due to temperature changes. In consideration of these influencing factors, a modified model of pressure measurement has been developed, and according to this model, a reference method for the temperature compensation is presented. The relationship between the time delay and pressure was established through this method. The correlative time estimation method based on Hilbert–Huang Transform is presented to estimate the time delay. Therefore, a new method for measuring the pressure of thin-walled vessels nondestructively is presented. Two vessels made of different kinds of materials were used as specimens in our experiments. The results obtain from the tests are used to validate the modified model and demonstrate that the reference method is effective.

© 2007 Elsevier Ltd. All rights reserved.

Keywords: Pressure measurement; Rayleigh waves; Temperature influence; Reference method; Hilbert–Huang Transform

1. Introduction

Pressure vessels are widely used in modern industry. In order to ensure that vessels work safely, it is important to monitor the pressure in vessels. Conventional methods for measuring the pressure require drilling a hole in the wall of vessels, which not only induce local stress concentration but also bring many safety problems. Ultrasonic waves, as a medium, have been used in the nondestructive measurement. Through the measurement of velocity of the ultrasonic waves, some information can be deduced about the material's texture, thickness, quality of surface treatments and the residual or applied stress [1–4]. The main effect of stress on the propagation of Rayleigh waves in the material is the variation of wave velocity. Generally, the relative change of wave velocity is proportional to the applied stress and the proportion coefficients are material-dependent parameters named acoustoelastic coefficient. Based on these theories, the relationship between the time delay and the pressure of vessels was deduced [5,6], and considering the influence of strain caused by stress, this measurement method was modified [7]. However, this kind of measurement model has not taken temperature influences into account. The velocity of ultrasonic wave is strongly influenced by temperature. Through experimentation, we found that the time delay due to 1 °C temperature change is close to 1 MPa pressure change. Therefore, the influence of temperature should be taken into account in pressure measurement.

---

[*] Corresponding author. Tel.: +86 571 87952253; fax: +86 571 87951219.
E-mail addresses: hjzhang@iipc.zju.edu.cn, jerryhq78@163.com (H. Zhang).

0003-682X/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apacoust.2007.05.011

The temperature effect on the measurement is very complicated. In addition to the ultrasonic velocity, the thermo-stress and length of ultrasonic propagation will also be influenced by temperature. Considering these temperature influences, the improved model of pressure measurement is derived and a reference method for temperature compensation is presented based on the modified model. This method establishes the relationship between the time delay and the pressure to be measured. It is crucial to estimate the time delay of two ultrasonic pulses. To improve the accuracy in time delay estimation and the capability of anti-interference, cross-correlation techniques based on Hilbert–Huang Transform was adopted in this paper. The reference method was applied to two different kinds of vessels and the results of the experiments demonstrated that this method is suitable.

2. Temperature modified model

Rayleigh wave propagates along the surface of the material between the transmitter and receiver, even if the surface is curved. Its energy is concentrated within a layer of about one wavelength thickness under the surface, without radiation loss, in contrast to the surface skimming L-waves and SV waves. Some studies have shown the sensitivity of Rayleigh waves to stresses in different materials, such as iron and aluminium [8,9]. The use of Rayleigh waves for applied stress and residual stress measurements has been reported [10,11]. These studies have evidenced the higher sensitivity of the acoustoelastic effect of Rayleigh waves to measure surface stresses. The main effect of stresses on the propagation of Rayleigh waves in the material is the variation of wave velocity. Generally, the relative change of wave velocity is proportional to the applied stress [8] and the proportional coefficients are material-dependent parameters known as the acoustoelastic coefficient. But the direct measurement of ultrasonic velocity is not straightforward. It is noticed that the Rayleigh wave should propagate in the material, and the velocity changes of Rayleigh wave due to stress could be substituted by the transit time change, which can be measured directly. The transit time is equal to distance divided by velocity, and both the velocity and distance are changes with pressure and temperature. Therefore, the change of both velocity and propagation distance should be considered in order to establish the relationship between the transit time and the pressure applied on the vessels.

2.1. Alteration of surface velocity

2.1.1. Influence of stresses

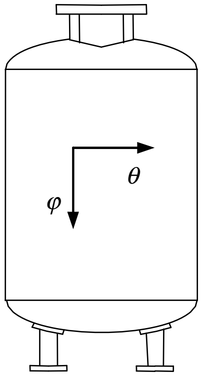

Fig. 1. Schematic diagram of vessel stress.

The low or middle pressure cylindrical vessels, as shown in Fig. 1, most of them are thin-walled vessels whose ratio of thickness of the wall to the outer diameter is not greater than 0.05. Based on the thin-shell theory [12,13], the stresses of vessel's wall caused by applied pressure may be expressed as:

$$\sigma^{p}_{\varphi} = \frac{pR}{2\delta} \tag{1}$$

$$\sigma^{p}_{\theta} = \frac{pR}{\delta} = 2\sigma^{P}_{\varphi} \tag{2}$$

where p is the pressure applied on the vessel, R is the outer radius, δ is the thickness of the wall, σ_{θ} is the stress on vessel surface in the “θ” (circumferential) direction, and σ_{ϕ} is that in the “ϕ” (axial) direction. The stresses in the vessel's wall are comprised of not only the stress caused by the applied pressure, as shown in the Eqs. (1) and (2), but also the thermal stress [12,13]

$$\sigma^{T}_{\theta} = \sigma^{T}_{\varphi} = -\frac{\beta E \Delta t_{\mathrm{w}}}{2(1-\mu)} \tag{3}$$

where σ^{T}_{θ} is the thermal stress in the circumferential direction and σ^{T}_{φ} is that in the axial direction, β is the linear expansion factor, $\Delta t_{\mathrm{w}} = t_{\mathrm{w1}} - t_{\mathrm{w2}}$, t_{w1} and t_{w2} denote the temperature of inner surface and external surface of the vessel's wall, E and μ denote Young's modulus and Poisson's ratio of the material. Supposing a Rayleigh wave propagating on the surface of a homogeneous, elastic material under uniform static deformation, when the displacement due to the propagation of the wave is infinitesimal, the relative variation of the velocity [8–10] could be expressed in terms of static stresses as:

$$\frac{\Delta v_{\varphi}}{v^{\mathrm{o}}_{\varphi}} = A^{\varphi}_{R\varphi}\sigma_{\varphi} + A^{\theta}_{R\varphi}\sigma_{\theta} \tag{4}$$

$$\frac{\Delta v_{\theta}}{v^{\mathrm{o}}_{\theta}} = A^{\varphi}_{R\theta}\sigma_{\varphi} + A^{\theta}_{R\theta}\sigma_{\theta} \tag{5}$$

where v^{o}_{φ} is the velocity of the Rayleigh wave propagating along the “ϕ” (axial) direction under the initial state, v^{o}_{θ} is the velocity of the Rayleigh wave propagating along the “θ” (circumferential) direction, the superscript “o” denotes the initial state that the vessel is unstressed and the temperature remains constant, $\Delta v_{\varphi} = v^{\sigma}_{\varphi} - v^{\mathrm{o}}_{\varphi}$, $\Delta v_{\theta} = v^{\sigma}_{\theta} - v^{\mathrm{o}}_{\theta}$, v^{σ}_{φ} and v^{σ}_{θ} denote the velocity of the Rayleigh wave propagation along the axial and circumferential directions under stressed state, respectively, $A^{\varphi}_{R\varphi}$, $A^{\theta}_{R\varphi}$, $A^{\varphi}_{R\theta}$, $A^{\theta}_{R\theta}$ are the Rayleigh wave acoustoelastic coefficients, which depend not only on the propagation and polarization directions of the wave but also on the stress direction, σ_{ϕ} and σ_{θ}

Download English Version:

https://daneshyari.com/en/article/755260

Download Persian Version:

https://daneshyari.com/article/755260

Daneshyari.com