46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE 2019-6774

MODELING FLAW PULSE-ECHO SIGNALS IN CYLINDRICAL COMPONENTS USING AN ULTRASONIC LINE FOCUSED TRANSDUCER

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ABSTRACT

This work provides an ultrasonic measurement model using line focused transducers to predict flaw responses in cylindrical components for evaluating the detection ability of this kind of transducer. The wave beams in cylindrical components radiated by line focused transducers are modeled using a multi-Gaussian beam model with consideration of effects of wave mode conversion and curvatures. Such a model is developed by combining the system function, the wave beam model and a Kirchhoff approximation flaw scattering model. The system function with a line focused transducer is characterized using reference signals by taken into account for the effects of diffraction and attenuation. One advantage of the proposed method is that the system function can be calibrated at different distances. The proposed model is certified from good agreement between the experimental and predicted signals of side drilled holes. In addition, the discussions on the effects of curvatures and wave mode conversion are helpful for guidance of nondestructive test cylindrical components using line focused transducers in practical application.

Keywords: Ultrasonic measurement model, Line focused transducer, Multi-Gaussian beam model, Wave mode conversion, Cylindrical component

1. INTRODUCTION

Ultrasonic testing provides an effective technique to nondestructively test and evaluate material properties. When a cylindrical component is tested using the ultrasonic method, line focused transducers can concentrate acoustic energy in a line through cylindrical interface, which is helpful for detecting flaws; in addition, such transducers have higher sensitivity and signal-to-noise ratio than planar transducers while have larger scanning area than point focused transducers [1]. Therefore, line focused transducers are very suitable for nondestructively testing cylindrical components, and it is essential to research on their testing ability for guidance of their practical applications.

2. MATERIALS AND METHODS

The ultrasonic measurement model for predicting the responses of the SDH in pulse-echo mode as

$$V_0(\omega)=\beta(\omega)\int_L \left(V_T^{\gamma}(\mathbf{x},\omega)\right)^2 dl\,\frac{A(\omega)}{L}\left[\frac{4\pi\rho_2 c_{\gamma 2}}{-ik_{\gamma 2}S_R\rho_1 c_{p1}}\right] \tag{1}$$

It can be seen from Eq. (1) that the UMM for predicting signals from a SDH contains the system function, the ultrasonic wave beam model, and the flaw scattering model. In order to predict the flaw responses, we still need to calibrate the inspection system function using a line focused transducer and calculate the wave beams over the flaw surface radiated by the line focused transducer. These two parts will be discussed in the following sections.

3. RESULTS AND DISCUSSION

When the system function is obtained, the wave beams over the center of the SDH are simulated, and the Kirchhoff scattering approximation for a SDH is employed, the pulse-echo signals reflected from the SDH can be predicted by using the ultrasonic measurement model, Eq. (1). In these predictions, the wave beam will be focused at the center of the SDH. We treat the theoretical focal plane as the actual focal point since they are very close at the frequency of 10 MHz. Here, we will focus on the results obtained using longitudinal waves. The predicted maximum pulse-echo signals at three samples versus incident angles are shown in Fig. 1. It can be found through these simulations that with the increasing of the inclination angles and curvatures, the amplitudes of predicted flaw signals become smaller.

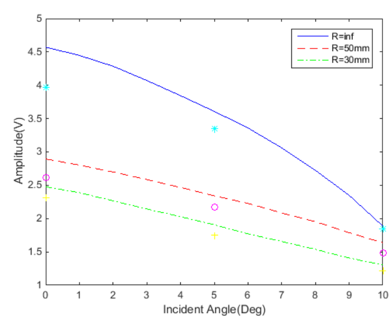

Fig. 1. Comparison of wave magnitude results between predictions (lines) and measurements (triangles) using longitudinal waves when the curvatures and incidence angle vary.

We then compare the predicted and measured flaw signals in detail. Fig. 2 shows the comparison results at different samples when the incidence angles are $\theta_{p1} = 10^\circ$. It is observed that the phase characteristics of these signals agree well.

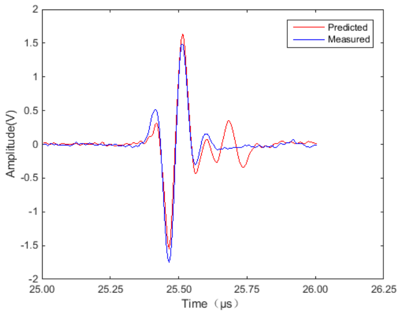

Fig. 2. Comparisons of the flaw signals between predictions and measurements at incidence angle of $\theta_{p1} = 10^\circ$ when the curvature is R = 50mm

Fig. 3 shows the predicted maximum flaw signals in the samples with different curvatures. Note that in this incidence angle range, only shear waves exist in the sample and these wave beams can be focused at the center of the SDH in each sample. A similar behavior to the results predicted using longitudinal waves is observed from this figure: the magnitudes of these flaw responses decrease as the incidence angles and curvature increase.

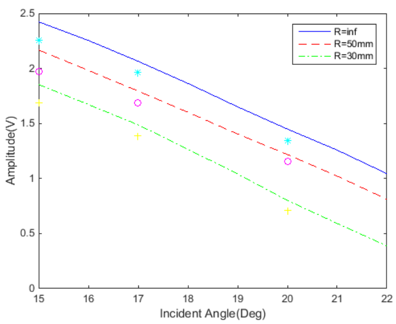

Fig. 3. Comparison of wave magnitude results between the predictions and measurement using mode-converted shear waves when the curvatures and incidence angle vary.

Fig. 4 compares the model predicted signals and experimental measurement results of the SDHs in these samples using shear waves when the incident angle is 20°. It can be seen from these comparisons that both the wave shapes and magnitudes agree well with each other. These agreements verify the proposed model to predict flaw signals using line focused transducers and shear waves.

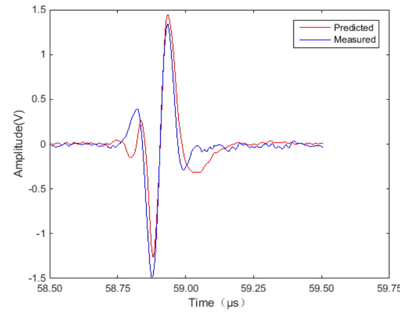

Fig. 4. Comparisons of the flaw signals between predictions and measurements at incidence angle of $\theta_{p1} = 20^\circ$ when the curvature is R = inf

4. CONCLUSION

In this work, we proposed an ultrasonic measurement model for line focused transducers to predict flaw responses in cylinder components. The MGB model with transfer matrices are employed to calculate the propagating wave beams in cylinder components generated by line focused transducers. This model has high efficiency, and can be used to help analyze wave propagation properties due to component curvatures and mode conversion. The system function is calibrated using reference signals and MGB model-based transfer functions. One advantage of this calibration method is that measurement distances do not affect this calibration result. The system function, flaw scattering model and wave beam model are combined to develop the ultrasonic measurement model for line focused transducers, and flaw responses from side drilled holes are predicted using this model. Good agreement between the predictions and experiments validates the proposed work. The results also show that in the same measurement condition, the amplitudes of flaw signals will reduce as the curvature increases; and the flaw can be effectively detected by shear waves from mode conversion. This work will benefit the application of line focused transducers in nondestructive evaluation.

ACKNOWLEDGEMENTS

This work is support by National Key R&D Program of China (Grant No. 2017YFB1201201).

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