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A Numerical Simulation of Linear and Nonlinear Normal Interfacial Stiffness in Dry Rough Contact Measured with Longitudinal Ultrasonic Wave

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When the rough surfaces create a dry contact, the interface consists of the asperity contact regions and air gaps. As the contact load increases, the interfacial stiffness increases and is therefore nonlinear. Both the linear and nonlinear interfacial stiffness can be measured using the response of a longitudinal ultrasonic wave. In this study, a numerical simulation with Abaqus was used to investigate the effect of surface roughness as well as the amplitude of longitudinal ultrasonic wave and contact pressure on the linear and nonlinear interfacial stiffness. The results showed that as the surfaces become smoother, the interfacial stiffness increases.
Keywords (from 3 to 5 max): tribology, numerical simulation analysis, contact acoustic nonlinearity, interfacial stiffness.

1. Introduction

When the rough surfaces in a component touch there is contact at asperity peaks. The interface consists of these solid contact regions and air gaps. The interface is then a region of reduced stiffness. This can be important in situations where low deflection is required such as precision instruments, or machine stool spindles. The stiffness of a rough surface contact is nonlinear as the load increases more contact is made and the joint becomes stiffer. Linear and nonlinear normal interfacial stiffness of a joint can be measured using a longitudinal ultrasonic wave. A reflected/transmitted ultrasonic wave from/through an imperfect contact causes a tiny distortion. If the wave is powerful enough it can also cause opening and closing of the interface gaps. This leads to nonlinearity being generated in the waves and higher order frequencies are observed. This study aims to measure the linear and nonlinear interfacial stiffness by simulating a frictional imperfect contact subjected to longitudinal ultrasonic wave with Abaqus. The effect of surface roughness, nominal contact pressure as well as amplitude of incident ultrasonic wave are studied.

2. Methods

Figure 1a shows the simulated test. Two cylindrical aluminum blocks with different surface roughness profile were simulated to create a dry frictional joint. Three piezoelectric longitudinal transducers were bonded on the back surface of the aluminum blocks (two transducers on the top body and the third on the bottom body). One of the transducers on the top body generated the incident wave and the second transducer received the signal reflected from the interface. The third transducer received the signal transmitted through the interface. High power signals with center frequencies of 0.5, 1, 2, and 10MHz was emitted to the interface. The interface was subjected to a nominal contact pressure from 0 to 200MPa. The reflected and transmitted signal were time domain, so some signal processing methods such as a window function, zero padding and Fast Fourier Transform (FFT) were employed to convert the signals to frequency domain in order to distinguish the amplitude of fundamental and 2nd harmonics. The linear and nonlinear interfacial stiffness are given by [1]:

$$K_1 = \frac{\rho c \omega}{2} \frac{\sqrt{1-R^2}}{R} \qquad (1)$$

$$K_2 = \gamma\, \rho c \omega \sqrt{1 + (K_1/\rho c \omega)^2} \qquad (2)$$

where ρ and c are density and speed of sound in the aluminum block respectively, ω is angular frequency of the transducer, R is the reflection coefficient and γ is the second order nonlinear parameter for the reflected ultrasound from the interface.

(a) (b)

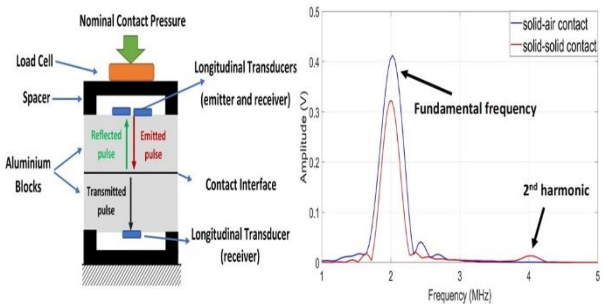

Figure1. (a) Simulated apparatuse, (b) Amplitude of frequency spectrum of the reflected signal from solid-air and solid-solid contact.

3. Result and Discussion

Figure 1b shows frequency domain of the signal reflected from solid-air and solid-solid contact interface. Although, reflected signal from solid-air contact only contains fundamental frequency, higher order harmonics were generated in the reflected signal from solid-solid contact. The results were substituted into Eqs.1 and 2 to measure the linear and nonlinear interfacial stiffness. The results showed that as the surfaces become smoother, the interfacial stiffness increases.

4. References

[1] S. Biwa, et. al, "On the Acoustic Nonlinearity of Solid-Solid Contact With Pressure-Dependent Interface Stiffness," *J. Appl. Mech.*, vol. 71, no. 4, pp. 508–515, 2004.