

# In-Situ Measurement of Linear and Nonlinear Normal Interfacial Stiffness in Dry Rough Surface Contact using Longitudinal Ultrasonic Wave

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Real contact of mating solid surfaces occurs at the asperity peaks. Asperity contacts can be modelled as an equivalent spring with a prescribed interfacial stiffness. The spring stiffness, both the first order linear stiffness and the second order nonlinear stiffness, can be determined by reflection of a finite amplitude ultrasonic wave that induces non-linear deformation. In this study, the variation of both linear and nonlinear interfacial stiffnesses were measured as the nominal contact pressure was increased. In both cases these were integrated to deduce the contact pressure-surface separation relationships. The relationships derived from linear and nonlinear measurements were similar, indicating the accuracy of the presented methods.

**Keywords (from 3 to 5 max):** tribology, contact acoustic nonlinearity, interfacial stiffness.

$$K_2 = \gamma \rho c \omega \sqrt{1 + (K_1/\rho c \omega)^2} \quad (4)$$

## 1. Introduction

When two solid surfaces come into contact, it is their asperity peaks that touch. The asperity has an interfacial stiffness which can be modeled as an equivalent spring. The interfacial stiffness is important in tribology because it affects machine element deflection, wear, and friction. Machining accuracy, for example, depends on the stiffness of the joints in the machine tool assembly. Biwa et al.[1] used the concept of Contact Acoustic Nonlinearity (CAN) with the aid of a second order Taylor series to define a linear and nonlinear interfacial stiffnesses:

$$K_1 = -\frac{dp_0}{dY} \quad (1)$$

$$K_2 = \frac{1}{2} \frac{d^2 p_0}{dY^2} \quad (2)$$

where  $p_0$  is the nominal contact pressure,  $Y$  is the relative displacement of the mean line of contacting surfaces.

This study aims to evaluate the linear and nonlinear interfacial stiffness and to demonstrate that they are both based on the same fundamental contact pressure-surface separation relationship.

## 2. Methods

Figure 1a shows the experimental apparatus. Two cylindrical aluminum blocks were machined, and the contacting surfaces were polished to create a dry frictional joint. Two piezoelectric longitudinal transducers with center frequency 2 MHz were bonded on the back surface of one of the aluminum blocks. One of the transducers generated the incident wave, the other transducer received the signal reflected from the interface. The emitted signal was amplified using a high-power amplifier (RITEC RAM-5000) and stored by a digital oscilloscope. The interface was subjected to nominal contact pressure from 0 to 4 MPa. The reflected pulses 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 2<sup>nd</sup> harmonics. The linear and nonlinear interfacial stiffnesses are given by [1]:

$$K_1 = \frac{\rho c \omega}{2} \frac{\sqrt{1 - R^2}}{R} \quad (3)$$

where  $\rho$  and  $c$  are density and speed of sound in the aluminum block respectively,  $\omega$  is angular frequency of the transducer,  $R$  is the reflection coefficient and  $\gamma$  is the second order nonlinear parameter for the reflected ultrasound from the interface.

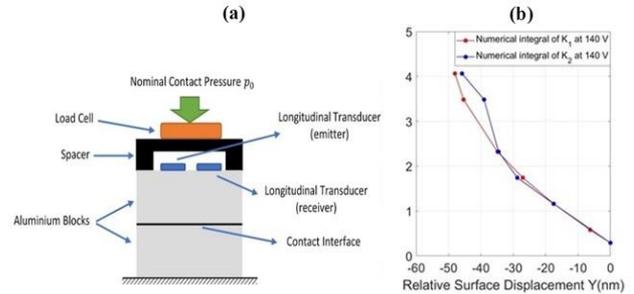


Figure 1. (a) Schematic diagram of the apparatus; (b) comparison of the nominal contact pressure determined from linear and nonlinear interfacial stiffness.

## 3. Result and Discussion

Linear and nonlinear interfacial stiffness are functions of the nominal contact pressure. Since the interfacial stiffness was defined nonlinearly with the aid of a second order Taylor series, integrals of the linear and nonlinear interfacial stiffness were used:

$$p_0(Y) = f^{-1} \left\{ \int_0^{p_0} [K_1]^{-1} dp_0 \right\} \quad (5)$$

$$p_0(Y) = f^{-1} \left\{ \int_0^{p_0} [K_2]^{-1} dp_0 \right\}^{\frac{1}{2}} \quad (6)$$

where  $f^{-1}$  is inverse function. Figure 1b shows the nominal contact pressure from Eqs. (5) and (6) result in the same applied nominal pressure. It can be concluded Eqs. (3) and (4) can be used to determine the linear and nonlinear interfacial stiffnesses.

## 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, 4, pp. 508–515, 2004.