Force sensing by electrical contact impedance between conductive ceramics

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Abstract

The electrical contact impedance at stiff interfaces is essential to the development of touch sensors for *in-situ* force and pressure measurements. The electrical contact impedance can be affected by a number of factors, including surface roughness, loading levels, measurement signals, and materials properties of contacting solids. This work examines systematically the relationship between the electrical contact impedance and the applied normal contact load between two spheres of silicon carbide. Through the combination of numerical simulations and experimental measurements, we meaningfully locate the linearity between the electrical contact impedance and the contact load, for various measurement conditions. Results indicate that the electrical contact impedance, for slight normal compression, is strongly affected by voltage amplitude, measurement time, and the generally existing surface roughness at the submicron scale, presenting significant nonlinearity and nonrepeatability. However, these dependencies vanish as the normal compression increases. Additionally, the characteristic frequency of the interfacial impedance is found to follow a stretched power-law function with respect to the normal load, which can be considered as a linear relationship for a certain load range. This study advances our understanding of electro-mechanical mechanisms at conductive interfaces, providing insights into the development of touch sensors for *in-situ* force and pressure measurements.

1 Introduction

Currently existing contact-type force sensors are sometimes required to be connected in series within the testing system in accomplishing force and pressure monitoring. Significant deformation can occur due to the compliance of the sensing elements, thus bringing about influences in the system properties and responses. Stiff contacts formed between two conductive ceramics can be widely observed in different applications, such as high-precision actuators, sealing processes, and advanced bearings [1]. The dependence of electrical contact impedance on contact pressure, extensively reported in the literature [2], pointed out a promising approach for direct *in-situ* force estimation. Previous experiments indicate that surface roughness, material properties, and testing conditions can largely influence the interfacial impedance at contacting ceramics [3], presenting nonlinearity and nonrepeatability. Therefore, we make efforts in figuring out the relationship between the electrical contact impedance, and normal load, measurement signals, through both numerical modeling and experiments.

2 Theory

Roughness generally exists for both natural and engineering surfaces, resulting in microcontacts and microvoids at the interface. The effective electrical resistance at two contacting conductive ceramics can be integrated by micro-resistors at microcontacts in parallel, while the overall capacitance can be considered to be contributed by both the microcontacts and microvoids, as illustrated in Fig. 1. The complex electric potential distribution at conducting rough surfaces is governed by Maxwell's equations and boundary conditions [4]. For simplicity, we develop the statistical model based on Greenwood and Williamson [5]. For individual microcontact, the contact resistance is approximately given

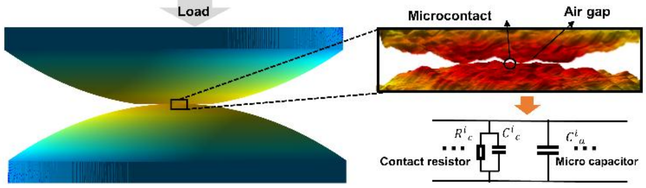

Fig. 1: Schematic diagram of rough interface electrical contact impedance

$$R^i{}_c = \frac{\sqrt{\pi}\rho}{2\sqrt{a}} \tag{1}$$

where ρ is resistivity, a is the microcontact area, respectively. The capacitance of microvoids is contributed by $C_{non} = \sum_i C^i{}_{non} = \varepsilon_a A_n (1 - A_r/A_n)\langle 1/2t \rangle$, where ε_a is air dielectric constant, t is the dielectric thickness, A_r and A_n are total real area and apparent area, $\langle 1/2t \rangle$ is the statistical average of the inverse separation.

3 Result

For a typical contact pair of silicon carbide spheres with a roughness of R_{rms} (18.865 μm), under the compression load ranging from 10 to 30 N, the electrical contact impedance demonstrates a power-law decay with the increasing normal load, as shown in Fig. 2A, for both numerical simulations and experimental observations. At the measurement frequency of 100 Hz, the effect of voltage amplitude (Fig. 2B) on the measured impedance can be ignored for the considered range of normal loads.

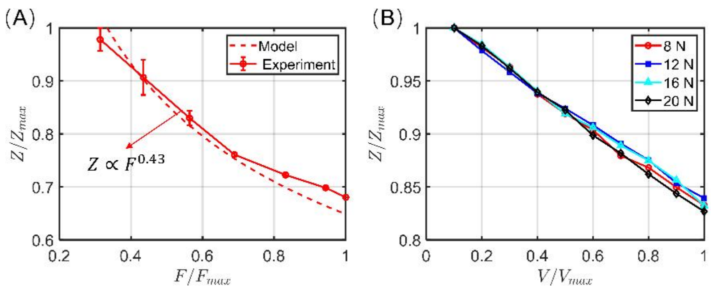

Fig. 2: The relationship between impedance, load, and voltage.

4 Conclusion

We investigate the relationship between electrical contact impedance and the normal contact load applied between two silicon carbide spheres. For selected measurement signals, range of normal load, results show the electrical contact impedance monotonically decreases with the normal load. Our findings provide a roadmap for establishing an *in-situ* measurement method of contact force based on electrical impedance.

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