SINGLE POINT CONTACT MEASUREMENTS OF MECHANICAL RESONANCES

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ABSTRACT

In this paper we present a novel technique for measuring the material properties of spherical objects. The technique is also capable of detecting the presence of surface defects in these objects. We excite resonances of spheres at both low and high frequencies. Resonances are generated by forming a one-point Hertzian contact between the sphere and a spherical depression in a buffer rod with a transducer. The resonance spectrum is detected from the opposite pole of excitation using a Heterodyne interferometer. At low frequencies, bulk resonances of the sphere are excited and material properties are determined. At high frequencies, surface wave resonances of the sphere are excited and the dispersion relation of the waves is measured. The measured dispersion relation of the sphere is correlated to the surface wave velocity on the sphere and to the presence of surface defects.

INTRODUCTION

Ceramic material retains high strength under high temperature and nonlubricative environments. However, because ceramics are brittle, it is very important to inspect ceramic parts for the existence of small (1-10 μm) surface defects. We have developed a contact-contact resonance technique[1,2,3] to perform nondestructive testing on spherical objects. The schematic of the contact-contact technique is shown in Fig. 1. The sphere is held mechanically between two transducers. The two transducers are mounted on flexible supports. The bottom transducer excites resonances on the sphere. The upper transducer, in turn, detects the resonances on the sphere. The received signal is sent to an electronic system to generate the amplitude and phase of the transmitted signal. By sweeping over a designated range of frequencies, a resonant spectrum is generated. We have used this technique to successfully measure the longitudinal and shear wave velocities of silicon nitride with an accuracy of one in 10^4. We have also been able to identify a decrease in the quality factor (Q) of surface wave resonance with an increase of surface defects for ceramic bearing balls. Table I shows the results of such a measurement at low frequencies. Table II shows the inverse relationship between surface resonance quality factors (Q) and crack sizes. The experiment is conducted on three Si_3N_4 ceramic bearing balls with the same diameter of 1/2 inch. Ball A is a perfect sphere. Ball B and Ball C have cracks made by a Knoop indenter with 10g and 50g loads, respectively.

The contact-contact technique has its limitations at high frequencies and for the inspection of small spheres. This is because of the difficulties in the alignment of the two transducers and in controlling the contacting load between the transducers and the sphere. These problems can be circumvented by the following one-point-contact interferometric measurement technique.

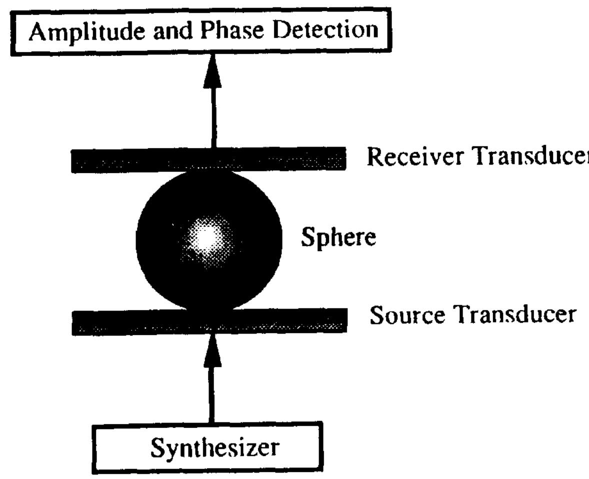

Fig. 1. Schematic of the contact-contact resonance technique.

Table I

CALCULATION OF MATERIAL PROPERTIES FROM LOW-FREQUENCY SPECTRUM

Ball A: a perfect ball with no cracks.
Ball B: has a series of cracks made with a 10 g load on a Knoop indenter.
Ball C: has a series of cracks made with a 50 g load on a Knoop indenter.

	Ball A	Ball B	Ball C
T_{11} mode f(KHz)	905.80	905.74	905.50
S_{01} mode f(KHz)	720.41	724.42	721.40
V_s (m/s)	6270.5	6270.1	6268.4
V_l (m/s)	11081.	11100.	11082.
V_R (m/s)	5779.9	5780.8	5778.8
ν	0.26447	0.26573	0.26522

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Table II

COMPARISON OF SURFACE RESONANCE Q FOR BALLS WITH DIFFERENT DEFECTS. WE SEE A DECREASE IN Q AS CRACK SIZE INCREASE.

	Ball A		Ball B		Ball C	
$2\pi r/\lambda_R$	f (MHz)	Q	f (MHz)	Q	f (MHz)	Q
98	14.1964	10810	14.2090	7905	14.1790	3655
99	14.3409	11321	14.3547	7998	14.3252	4348
100	14.4855	9573	14.4988	8546	14.4677	4607

ONE-POINT-CONTACT INTERFEROMETRIC MEASUREMENT TECHNIQUE

The schematic of the one-point-contact technique is shown in Fig. 2. The sphere is placed on a spherical depression (lens) in a buffer rod with a piezoelectric transducer on the other end. The transducer is excited by a synthesizer that sweeps over a designated frequency range. The curvature of the lens is less than that of the sphere such that the sphere will reach a stationary point in the lens. The vertical displacement associated with the resonances of the sphere is measured using a Heterodyne interferometer that is focused on the pole opposite the excitation pole. The output of the interferometer is the resonant spectrum of the sphere.

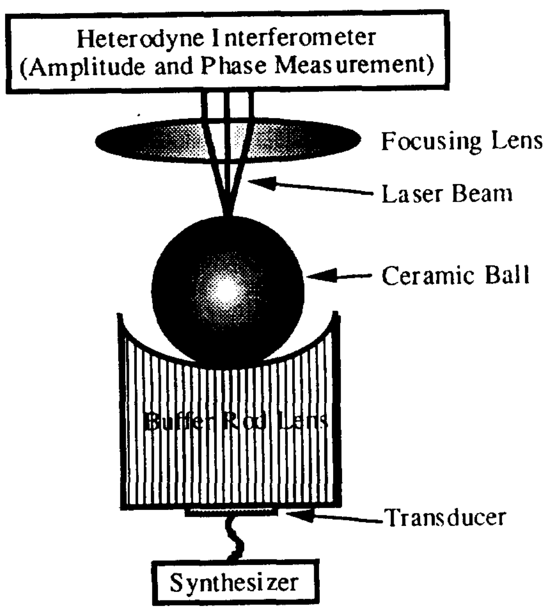

Fig. 2. Schematic of the one-point contact interferometric measurement technique.

This technique has several advantages over earlier techniques. The only contact between the sphere and the external environment is a single Hertzian contact. The contact area is determined by the weight of the sphere, the curvatures and Young's moduli of the sphere, and the concave buffer rod lens. Thus, the contacting load and area are fixed for a set of transducer and sphere, implying a reproducible result. For most of the spheres of interest, the contacting radius is less than 1/100 of the wavelength and has little effect on the resonance spectrum. Also, because the sphere is located on the stationary point of the concave lens, alignment of the measurement system for different spheres of identical diameters becomes trivial. Finally, there is no limit to the frequency range over which the measurement can be made.

EXPERIMENTAL RESULTS

We measured three Si_3N_4 ceramic bearing balls, all with diameters of 1/4 inch. One ball is perfect, one has small cracks, and the third has large cracks. We see in Fig. 3 that, as the crack size increases, the resonance energy is scattered, leading to a decrease in resonance amplitude. Figure 4 shows a scrambling effect in the higher frequency range due to surface cracks. New resonances appear at off frequencies. In this frequency range, surface cracks act like secondary sources of propagation of surface waves. The primary wave, generated by the transducer, and the secondary wave, generated by surface cracks, interfere with each other, producing the scrambling effect observed.

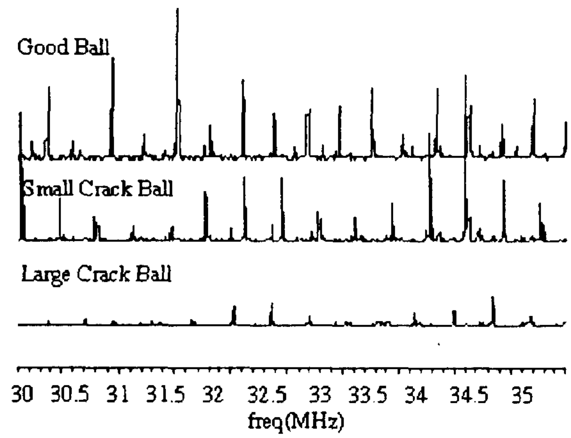

Fig. 3. Amplitude variation with crack size of surface wave resonant modes. Samples are three Si_3N_4 ceramic bearing balls. Diameter=1/4 inch.

We also demonstrated the capability of this technique on small bearing balls. We measured, from 100 KHz to 70 MHz, the resonance spectrum of a Si_3N_4 bearing ball with a diameter of 1 mm. In the low frequency spectrum, where we can identify resonant frequencies with bulk resonant modes (torsional or spheroidal), we see that this technique, unlike the contact technique, excites only spheroidal modes. This is because there is only one point of contact and the excitation direction is in the normal direction of the contact. This also shows the alignment difficulty for the contact-contact technique where we did observe torsional modes. We chose two high Q spheroidal modes to calculate material properties of the 1 mm diameter sphere. The results are shown in Table III. The calculated values of longitudinal and shear wave velocities were then used to calculate the dispersion relation of surface waves. This calculated surface wave dispersion curve is then compared to the measured surface wave resonances, as seen in Fig. 5. We see that for ka larger than 40, the apparent surface wave velocity asymptotically approaches a constant--surface wave velocity on a planar surface.

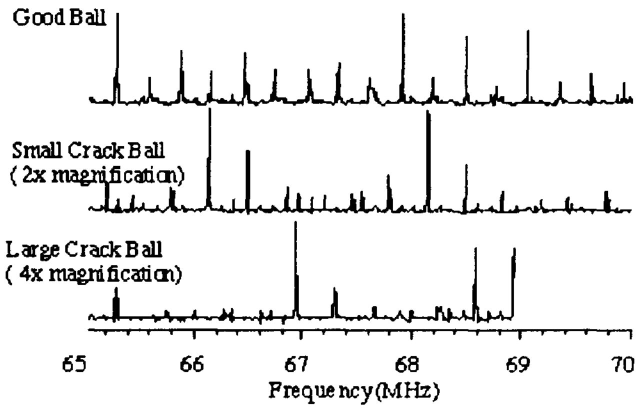

Fig. 4. Scrambling effect of surface wave resonant modes at high frequency range. The interference of primary and secondary waves is apparent.

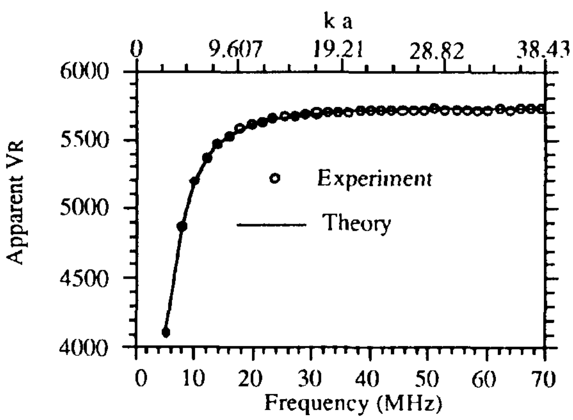

Fig. 5. Dispersion relation of surface waves on a sphere. k: surface wave number. A: radius of the sphere.

CONCLUSIONS

We have developed and demonstrated a new technique capable of measuring the material properties of spherical objects and of inspecting them for the presence of surface defects. The technique uses a single point contact to excite resonances in the object and an optical interferometer to measure these resonances. The measurements are reproducible, and the technique is capable of measuring material properties, and of detecting the existence of surface defects. The measurement can be made on spherical objects of any size and over an unlimited frequency range. We also showed, for the first time, the good agreement between theory and experiment of the dispersion relation of surface waves on a sphere. This technique has the potential of inspecting nonmetallic spheres, or spheres with coatings, and cylindrical objects. It can also be applied to objects of uncommon geometries.

ACKNOWLEDGMENT

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