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Investigating Ultrasonic Diffraction Grating Spectroscopy and Reflection Techniques for Characterizing Slurry Properties

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Research Objectives

The particle size of a slurry and the viscosity of a liquid or slurry are both difficult to measure on-line and in real time. The objectives of this research are to develop the following methods for such measurements: 1) ultrasonic diffraction grating spectroscopy (UDGS) to measure the particle size and concentration of a slurry, 2) develop theoretical models and computer codes to describe the passage of ultrasound through a grating surface in order to increase the sensitivity of the particle size measurement.

Research Progress and Implications

This report summarizes research in the second year of a two-year EMSP renewal project, (following the three-year EMSP project that was completed on September 30, 2004). The results show that the reflection of ultrasound from the grating surface depends upon the particle size of the slurry in contact with the grating. These results are the *first observation* of such effects using ultrasonics.

During the past year, a new data acquisition system was developed in which a chirp signal was sent to the transducer. A chirp signal corresponds to a long signal, 36 microseconds long, in which the frequency of the sine wave changes continuously and, thus, the signal contains a large range of frequencies. This system shortened considerably the time for data acquisition. Data were obtained for polystyrene spheres having the following diameters: 45, 71, 98, 134, 215, 222, 275, 363, and 467 microns. Slurries of polystyrene spheres in water were used with concentrations ranging up to a volume fraction of 0.2 and data were obtained for over 10 different concentrations for each particle size. Data were obtained using the following gratings: 1) aluminum grating have a grating spacing of 484 microns, 2) stainless steel grating with a grating spacing of 240 microns, and 3) aluminum grating with a grating spacing of 120 microns. The data for all data sets have been analyzed, but the data from the first one will be presented here.

The aluminum grating (#1) with a grating spacing of 484 microns has a critical frequency of 3.5 MHz for $m = 1$ and a critical frequency of 7.0 MHz for $m = 2$. When the ultrasound traveling in the aluminum at an angle of 30° strikes the grating surface, some of the ultrasound is reflected and some is transmitted into the slurry. The order $m = 0$ corresponds to the ordinary refracted ray that would occur even if the surface were flat. Beams also are produced for orders $m = 1$ and $m = 2$ and are due to the constructive interference. As the frequency of the ultrasound is reduced, the angle of the $m = 1$ (and 2) becomes larger. The frequency at which it reaches 90° is called the critical frequency.

The interaction with the particles in the slurry occurs at this critical frequency. The m = 1 and m = 2 waves cannot exist in the slurry at a frequency smaller than the critical frequency. When these waves "disappear," their energy is redistributed to other waves, including that reflected by the grating, and which is observed in our experiments. Thus, a peak appears in the receive transducer for m = 1 and another for m = 2. Further, the height of this peak is dependent upon the interaction with the particles at the critical frequency. Thus, the data consist of the peak height and the critical frequency where the peak occurs. Also, the velocity of sound in the slurry is determined from the critical frequency. This is a unique method for measuring the velocity of sound in which a time of flight through the slurry is *not* required. Fig. 1 and Fig 2 present the data for m = 1 and m = 2, respectively, for the natural logarithm of the peak height observed in the receive transducer versus the volume fraction of the slurry. The lines both figures are obtained from the theory of Atkinson and Kytomaa [1]: for the upper and lower limits of the particle size distribution in Fig. 1 and for the average value of the particle size in Fig. 2.

The particle size and the volume fraction of an unknown sample can be determined from the peak heights for m = 1 and m = 2 as well the velocity of sound in the slurry determined from a measurement of the critical frequency. Since the critical frequency is dependent upon the volume fraction and the particle size, the velocity of sound can be determined as a function of volume fraction for a given particle size.

The results show that a sensor for the measurement of particle size and concentration show that an on-line sensor can be designed to serve the needs of the DOE.

The effect of viscosity has been studied using aluminum grating #1 and suspending polystyrene spheres in sugar water solutions having a weight percentage of 11%, 20%, and 30%. These results are compared with the theory of Atkinson and Kytomaa and Harker and Temple [2]. A paper on these results will be presented at the International Congress on Ultrasonics in April, 2007.

Basic physics about the interaction with ultrasound with particles in a slurry is obtained from these studies. For example, the theory of Atkinson and Kytomaa indicates that, as the particle size decreases, the interaction or attenuation of ultrasound increases. The data do demonstrate this for particle sizes ranging from about 100 microns to 500 microns, as shown in Fig. 1 and

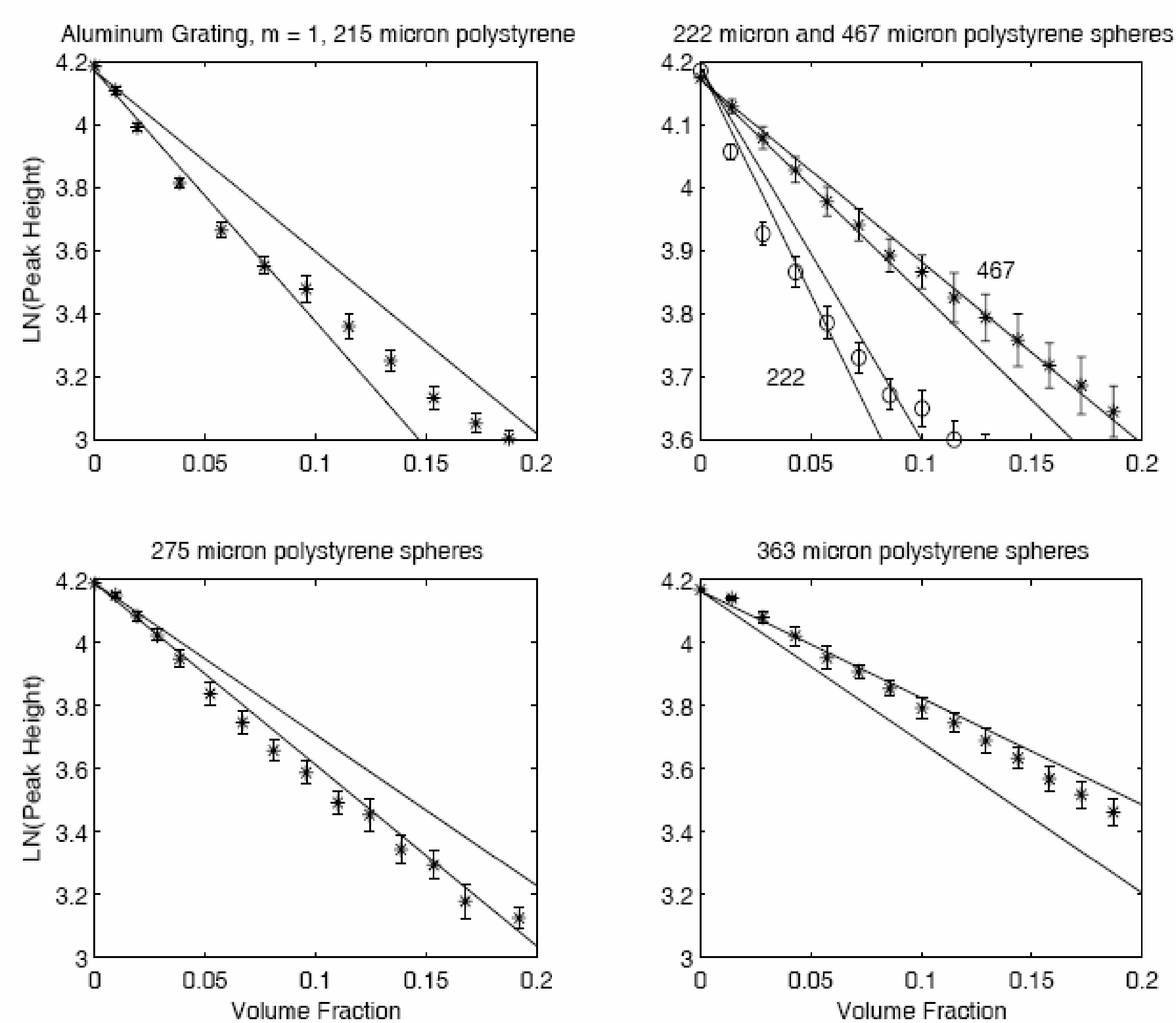

Figure 1.

Fig. 2. However, for particle sizes smaller than 100 micron, the data for the aluminum grating show that the interaction decreases as the particle size decreases, which shows that the Atkinson and Kytomaa theory is not applicable for the smaller size range at the frequencies of 3.5 MHz and 7 MHz. An alternate interaction mechanism is currently being investigated. The other aluminum grating (#3) with a groove spacing of 120 microns has a critical frequency of 13 MHz. The data from this grating shows an increased sensitivity to smaller diameter polystyrene spheres.

The data from the stainless steel grating with a grating spacing of 240 microns (#2) has a critical frequency of 7.0 MHz. Since this grating has a smaller transducer than grating #1, the results will show the effect of the transducer size on the sensitivity of the measurement of particle size. This information will aid in the development of a sensor.

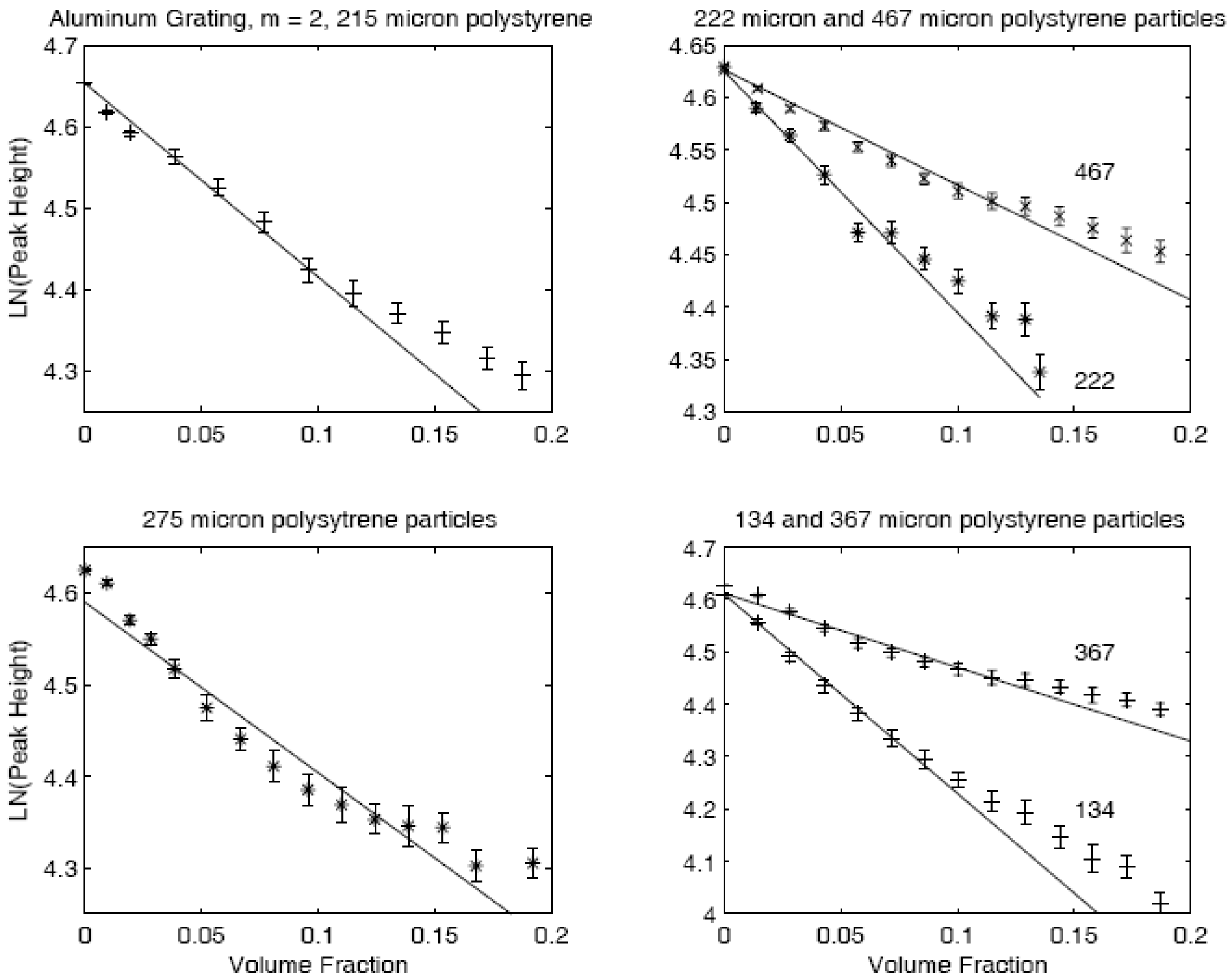

Figure 2.

The passage of ultrasound through a grating surface has been studied theoretically using the Elastodynamic Finite Integration Technique (EFIT) [3,4,5] and a code developed for modeling. The code was tested using a planar surface first and then a grating surface was treated. Fig. 3 shows the normalized ultrasonic signal received by a transducer after reflection from a finite-length periodic surface with triangular grooves. The incident beam is generated by a 0.94 cm wide two-dimensional transducer and the angle of incidence is 30°. The incident ultrasonic field was generated by an 8-cycle toneburst launched into the aluminum block at a distance of 8 cm from the interface. The period of the symmetric triangular grooves is 483 microns and the height of each groove is 418 microns (included angle of 60°) The theoretical first critical frequency of 3.47 MHz compares well with the computational results.

The computational tool we have developed can be used to study the effect of angle of incidence, shape, and the depth of the periodic surface. Therefore, the numerical predictor can be used to design an optimum grating surface and incidence angle combination that produces a large signal at the critical frequency.

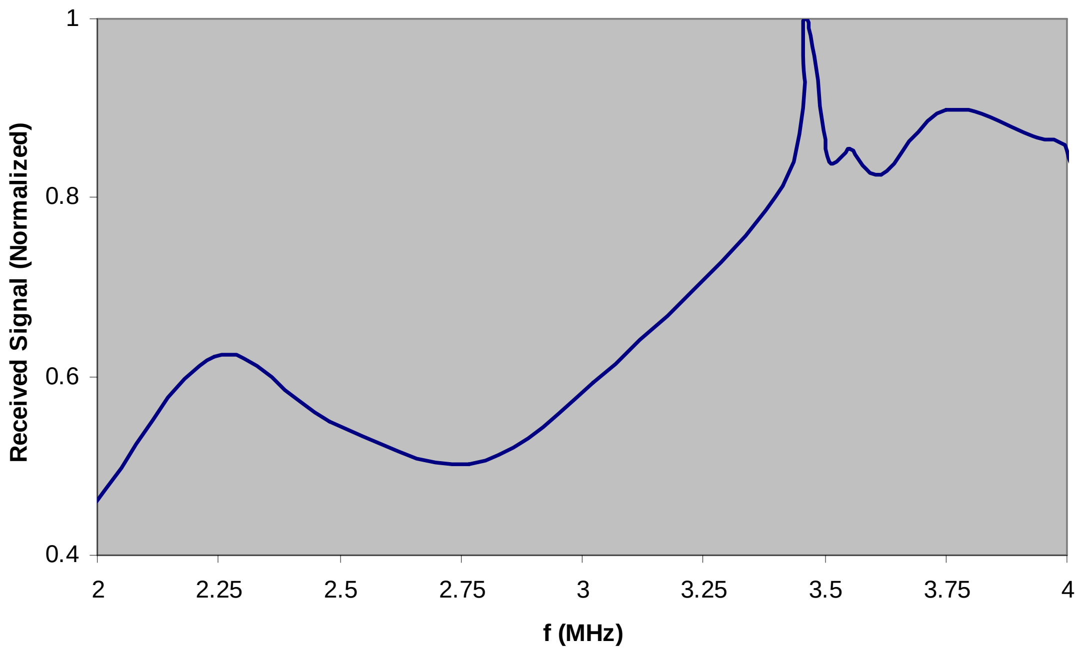

Figure 3.

Planned Activities

Activities planned for this year include designing a grating unit where the critical frequency is about 20 MHz. The objective is to extend the particle size measurement to smaller diameter particles. All of the measurements so far have been made using polystyrene spheres. Such measurements will be extended to include more dense particles, such as glass spheres. Experiments will also be designed to compare the data with theoretical calculations.

References

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