§1. Introduction Resonant ultrasound spectroscopy (RUS) involves scanning the resonance structure of a compact specimen such as a cube, parallelepiped, sphere or short cylinder with the aim of determining mechanical properties. Typically, a sample is supported by piezoelectric ultrasonic transducers, one a transmitter, and one a receiver, at opposite corners in the case of a cube or at opposite edges for a short cylinder. Corners provide elastically weak coupling to the transducers, hence minimal perturbation to the vibration, minimal shift in resonant frequency, and minimum parasitic damping. The RUS approach has the advantage of simplicity in that no gluing, clamping, or painstaking alignment of the specimen is required since it is held by contact force.

One can obtain all the elastic moduli C_{ijkl} of a single specimen of an anisotropic material at ultrasonic frequency. The complexity of the usual RUS method enters in the data reduction procedure, which makes use of fast computers to infer elastic moduli from the resonant frequencies.

It is much simpler to obtain the shear modulus from the fundamental frequency, and the mechanical damping tan δ from the width of the resonance curve as described in the attached sheet. One can also obtain Poisson's ratio graphically using plots of normalized mode frequency vs. Poisson's ratio obtained numerically.

§1.1.1 Preparation. Prior to the lab, read the article on RUS by Maynard, published in Physics Today, and available in the RUS links on the class web site. Read the accompanying sheet on RUS methods and interpretation.

§2 Testing.

§2.0 Set up and overview First, measure the dimensions and mass of each specimen. Prior to testing, mount the specimen between the ultrasonic transducers by its corners (if a cube) or by its edges (if a cylinder). Use the minimum possible contact force; use the fine micrometer adjustment. Keep in mind that shear transducers are polarized. Weak electrical output signals can be amplified using an available amplifier module.

Do a preliminary calculation of the expected frequency range in which the fundamental is expected. Sweep through this range. Explore a range of frequency at least a factor of two below the lowest apparent mode frequency to confirm that you have indeed identified the fundamental. The fundamental mode is torsion in cubes and cylinders. For cylinders, the polarization of the shear transducers can be used as a consistency check: rotate the cylinder around the contacts. Response should decrease for the orthogonal orientation.

§2.1 PMMA test Determine the response amplitude of the cylinder from 10 kHz to 100 kHz using the shear transducers. Use the oscilloscope to compare drive and response signals. To locate the fundamental frequency, perform a slow sweep with the SRS function generator, and observe the scope. Take sufficient data points from the scope to plot the resonance curves and to determine the full width at half maximum of the fundamental mode. Noisy signals can be averaged by the digital scope: quick menu, acquisition, avg 16 rather than sample.

§2.2 Zinc, brass, aluminum alloy test Again take sufficient data to determine shear modulus, tan δ and Poisson's ratio.

For metals, the resonant modes may be sharp. To find such modes it may be necessary to perform a slow sweep with the SRS function generator to find where these modes are; then sweep over a narrower frequency range to zoom in on the natural frequency. Some metal specimens, particularly if extruded, can exhibit a slight anisotropy due to orientation of grains.

If there is a baseline signal off resonance, there may be electrical conduction of signal through the metal. Put a small piece of paper between metal and transducer to eliminate this feed through.

§2.3 Further tests (Optional) For the ball bearing, determine Young's modulus and Poisson's ratio. Do they agree with your expectations for steel? For the rectangular piece of graphite epoxy, determine effective shear modulus (it is anisotropic) and damping. Discuss. The fundamental frequency here will depend on several modulus elements.

§3 Analysis and discussion.

§3.1 Determine the shear modulus G and mechanical damping tan δ of each specimen studied. Discuss how you identified the fundamental. Illustrate damping with plots of detected amplitude vs. frequency.

§3.2 Determine Poisson's ratio as follows. Compare the mode structure observed in your detailed measured spectrum with the theoretical mode structure given in the accompanying sheets (also available on the web) of normalized frequency vs. Poisson's ratio.

§3.3 Compare results obtained via RUS with results obtained via wave transmission ultrasound. Keep in mind the brass composition may not be the same as that of the piece studied earlier. The aluminum alloy (type 6061) pieces are the same. Discuss.

§3.4 If you choose to try numerical methods for a project, download software in binary format. Input file needs carriage returns, not squares.

§4 Questions.

(i) The function generator has a precision of one micro Hz and an accuracy of 5 parts per million. What limits the precision of your final results? Compare with that of wave ultrasound.

(ii) What might limit your ability to measure specimens 1 mm in size or below?