

Optimization of a Dynamic Magnetostrictive Material Property Testing Capability

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This report highlights results of an on-going effort to experimentally measure the pertinent material properties of rare earth magnetostrictive Terfenol-D. A Terfenol-D transducer is used to measure the material properties under varied operating conditions, including various load, temperature, and amplitude of the drive signal. The transducer used in the experiment houses a two inch long, quarter inch diameter Terfenol-D rod. The rod is placed within two collocated wire coils, the drive coil which provides the magnetic field, and the pick up coil, which is used to measure the response of the Terfenol-D sample. A bolt in the base of the transducer applies a constant prestress to the rod, a necessary condition when using the highly brittle Terfenol-D in a push-pull transducer. Measurements are obtained by running a swept sine test to excite the transducer with a constant current amplitude at sequential frequencies ranging from 20 Hz to about 10 kHz. The drive signal is provided by a Tektronics 2630 Fourier Analyzer and fed through a Techron 7520 power supply amplifier. The amplifier operates in current control mode so that it supplies an AC current, which follows the input voltage from the Tektronics, to the drive coil. An AC current through the solenoid coil produces an alternating magnetic field which polarizes the magnetic domains in the Terfenol-D rod causing the rod's length to oscillate. The output from the transducer is measured with a low mass Kistler accelerometer. In addition the voltage and current across the drive coil and the voltage across the pick up coil are measured. The electrical impedance function (V/I) is determined from the drive coil voltage over the current and from the pick up coil voltage over the current. The electrical admittance function, the inverse of the electrical impedance function, is determined from the current over the pick up coil voltage. Vector impedance and admittance analysis is used to determine the resonant, anti-resonant, and half power point frequencies. These frequencies are found graphically on the mobility loops in the Nyquist plot of the impedance and admittance functions. The material properties of a Terfenol-D sample used in the transducer, including Young's moduli, permeabilities, magnetomechanical coupling factor, and the axial strain coefficient (d_{33}), can then be calculated from a model of low signal, linear, magnetostriction, the linear transduction equations for a transducer, and a one degree of freedom mechanical model of the transducer. The quality of a given test and therefore the resulting material properties can be estimated based on the shape of the mobility loops, which, for a good test, should be circles. The sensitivity of the mobility to spurious resonances, noise, and poor testing conditions requires careful attention to testing details on the part of the tester. With experience four testers have been able to perform reliable tests with four identical transducers. This variety of testers and transducers along with a large number of rods allows us to perform a good statistical study of the material properties of Terfenol-D.

Many factors were considered prior to using magnetostrictive transducers to make reliable measurements of material properties. First, the design of the transducers was meticulously examined to maximize bandwidth and output, and to minimize spurious resonances. Small parts, which resulted in low internal masses and were less likely to cause undue resonances, were

extremely sensitive to the assembly process. Particular concern needed to be taken with the orientation and loading of a pair of diaphragms, which provided lateral support to the motion output thus reducing the chance of applying a moment to the Terfenol-D rod. The difficulties in getting useful results from a single transducer are compounded by experimental design requirement of four identical transducers. The next consideration was the effect of the rod prestress on the tests and the Terfenol-D rod properties. As the prestress applied to the rod increases the acceleration (or displacement) of the transducer increases to a peak value and then falls off steadily. Tests are run with the rod prestressed to provide the largest output (acceleration) at resonance. The fundamental resonance of the transducer increases dramatically as the prestress on the rod is increased. Finally, on the electrical side of the equation, good signal to noise ratio are needed to provide a good drive signal for the transducer and to ensure that good data can be recorded. Grounding problems, which produced horrendous noise levels, were overcome by tying together the grounds of the Tektronics, the reference signal source and data acquisition system, the Techron amplifier, and the circuitry.

Plots of the relative strain (ϵ) vs applied magnetic field (H) ("butterfly" curves) are a powerful tool for designing the test parameters. Successful efforts have been made to precisely quantify the relative strain using a photonic sensor MTI-1000. The fact that this piece of equipment is highly sensitive to the reflectivity of the surface of interest ("target") complicates its use; however, this problem was overcome using a reflecting tape over the surface. The displacement signal from the MTI 1000 and the current monitored from the Techron are used to make the butterfly plots. A butterfly curve for a typical transducer test is shown in Fig. 1. From these plots the total magnetic bias and the allowable drive levels can be determined for each transducer. The optimal magnetic bias (due to the permanent magnet and a constant DC current applied to the drive coil) is found by centering the peak to peak magnetic drive level in the steepest linear region of the butterfly curve. The magnetic drive level amplitude is calculated to avoid clipping and saturation of the output. For most purposes, however, some saturation is allowed and so the maximum peak to peak drive level is determined between points A (DC bias point) and B (90% maximum strain point).

Initially, it was thought that the position of the DC bias point should be fixed for a given transducer driven with different drive levels. In this case the DC bias would be produced solely by the permanent magnet. But experiments show that the position of A could vary with the drive level for a given frequency. Work is in progress to collect evidence that this DC bias shift follows a definite trend. Early experimentation indicates that higher drive levels produce larger DC bias. In other words, driving the transducer with higher current amplitudes produces more negative DC shifts.