

# Verification of the ELF for Dynamic Mechanical Characterization of Materials

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## Abstract

The ELeCtroForce™ (ELF™) Series of material test systems is the result of significant advances in linear motor design from the product development teams of Bose® Corporation and EnduraTEC Systems Corporation. This paper presents data on a variety of elastic and visco-elastic materials that shows the ELF 3200 is an excellent instrument for dynamic mechanical characterization (DMC) of viscoelastic materials up to 200 hz and provides a wide range of benefits over traditional test instruments.

## Overview

The ELeCtroForce™ (ELF™) Series of material test instruments is the result of significant advances in linear motor design from the product development teams of Bose® Corporation and EnduraTEC Systems Corporation. This paper presents data on a variety of elastic and visco-elastic materials that shows the ELF 3200 is an excellent instrument for dynamic mechanical characterization (DMC) of viscoelastic materials up to 200 hz and provides a wide range of benefits over traditional test instruments

## Historical Perspective

Historically, there have been three test instrument choices for measuring dynamic properties of viscoelastic materials and components:

- Torsional motor driven instruments
- Linear instruments driven by voice coil motors
- Linear test systems driven by servohydraulic actuators

The torsional motor driven systems have low frequency capability due to the high rotary inertia of the motors and bearing systems. They also only measure the shear behavior of the material. The voice coil driven linear systems have low force output (typically less than 20N) and small displacement (+/-1.5mm maximum). This limits the size of the samples that can be tested. Servohydraulically driven systems provide high force (10,000N) and large displacement (+/-50mm), however, they do not provide adequate resolution for soft specimens and smaller samples. In addition the infrastructure requirements for servohydraulic systems is substantial requiring input power and cooling in the 10 to 100KW range. The associated maintenance for servohydraulic systems is also quite high.

The ELeCtroForce Series of material test instruments can generate data at higher frequencies than torsional instruments while testing both the normal and shear material properties. The ELF provides higher force and displacement than voice coil driven linear instruments while offering better performance, resolution and efficiency than servohydraulic test systems. Engineering sized samples can now be tested without the mess, maintenance and expense of servohydraulic test systems.

The use of larger samples minimizes the anomalies associated with end effects and provides information that is more indicative of how the material will behave in a structure. Use of ELF generated material properties in Finite Element Analysis (FEA) models provides a more accurate prediction of component behavior. The exceptional performance range of the ELF also enables it to recreate test conditions provided by torsional and voice coil driven systems. Using this approach, correlations to existing material properties generated with those instruments can be made.

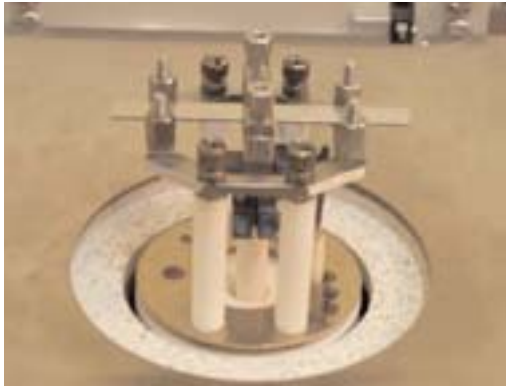
The ELF features a patented electromagnetic linear motor design. The design utilizes a fixed winding and moving magnet assembly coupled with a flexure support guidance system that eliminates the friction associated with traditional bearing/seal assemblies. This new design provides unmatched performance, fidelity and durability. The result is a high performance, precision test instrument that has cleaner and quieter operation, and a predicted maintenance-free life of more than 10 billion cycles.

## Evaluation

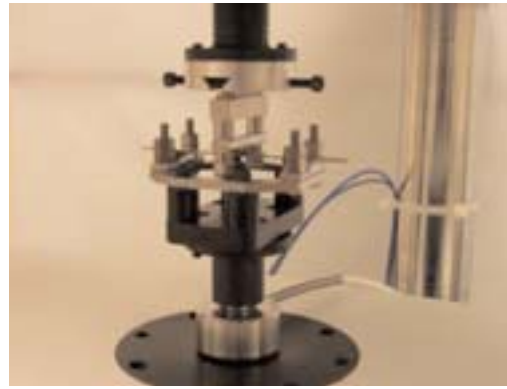
This paper presents an evaluation of the ELF's capabilities for dynamic characterization of viscoelastic materials. First, test data was taken on a linear-elastic metal beam sample to verify that the measured modulus and phase angle were accurate. Then visco-elastic data acquired with an ELF 3200 was compared with data from a Rheometrics DMTA 3E with identical fixtures and specimen geometries. Finally, data taken on the same material but with larger samples using a tensile grip designed specifically for DMC by EnduraTEC was compared to the results of the earlier testing on small samples. This data shows that the use of larger specimens provides materials properties that are consistent with expectations for less constrained samples.

## Phase Verification Using Steel Sample

Tests were conducted using the Rheometrics three point bend fixture and a metal beam as a specimen over a frequency range of 1 Hz to 200 Hz at an amplitude of 0.1 mm peak-peak on the ELF system.

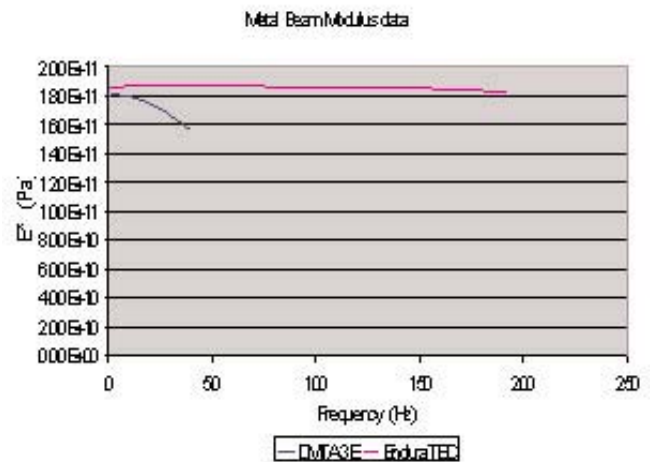
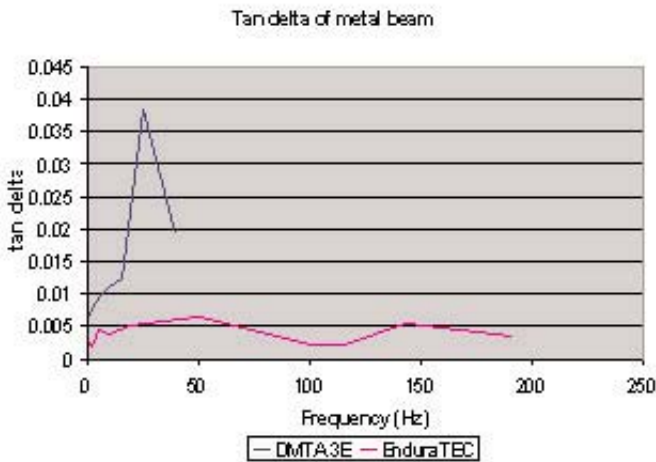


3pt bend sample in  
Rheometrics DMTA 3E



3 pt bend sample in  
ELF 3200

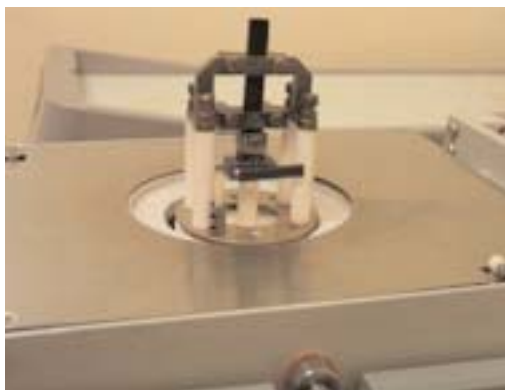
The ELF 3200 readings were captured using the WinTest Controller provided with the instrument. The raw data showed a phase measurement between force and displacement that increased linearly with frequency. This linear relationship was attributed to transducer and data acquisition channel phase differences. A single linear correction factor was applied and implemented in the acquisition and analysis software and the results are shown in the phase and modulus graphs below. The Rheometrics DMTA 3E data collection and analysis was done using the control system and software supplied with the instrument. Those results are also shown in the graphs below.



The graph of modulus as a function of frequency for the ELF 3200 shows less than 2% variation in measured stiffness from 1 Hz to 200 Hz, and the modulus value of 186 GPa correlates closely with published static data for 302 Stainless Steel. The large variation in tan delta and drop in elastic modulus shown for the DMTA 3E was caused by a beam resonance. Any data from the DMTA 3E taken at or above the resonance frequency (~20 Hz) is not valid.

#### Correlation to Rheometrics Axial Data

Tests were run on a thermoset elastomer sheet sample, 6.48 mm wide by 2 mm thick by 6 mm gage length, using the Rheometrics tensile fixture on the DMTA 3E at room temperature over a range of frequencies from 1 to 200 Hz at a strain of 1%.

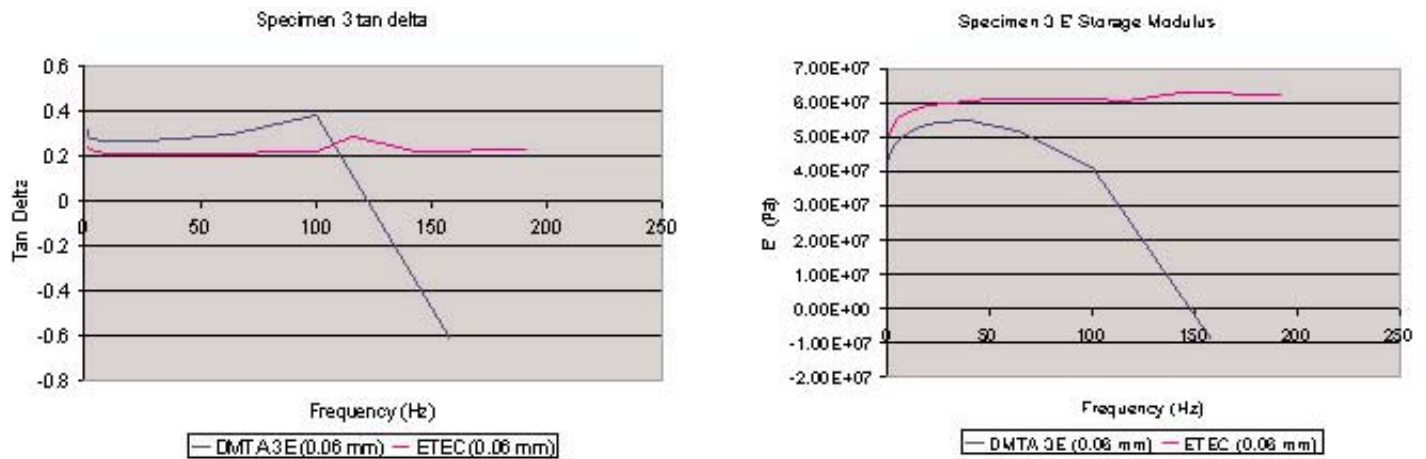


Tensile sample in  
Rheometrics DMTA 3E



Tensile sample in  
ELF 3200

These tests were then recreated on the ELF using the same fixtures and specimens. The following is a comparison of that data.



The tan delta values differ by 0.078 at 1 hz and the difference becomes slightly larger with increasing frequency. At frequencies above 100 hz the tan delta measured by the DMTA 3E is negative, indicating a system resonance. The modulus measured on the DMTA 3E at 1 hz is 13% less than the modulus measured on the ELF system. Considering the differences in the test systems, including the structural stiffness of the reaction frames, the methodology of force measurement (load cell for ELF 3200 versus motor current for DMTA 3E), and the number of cycles applied prior to data being collected (less for ELF 3200), the moduli and tan delta agree fairly closely.

### Larger Specimen Evaluation

Test were conducted using the EnduraTEC DMC tensile grip. The samples used were of the same material with the same width and thickness used in the correlation to the Rheometrics DMTA 3E described above. The only difference was that a longer gage length was used. Two specimens were tested in each instrument under the same conditions.



EnduraTEC DMC Tensile Grip  
In ELF 3200 with Chamber

The modulus of the material as measured by the DMTA 3E and ELF 3200 (longer gage length) was very similar between both sample sizes and fixtures. However, the tan delta reported was significantly lower for the longer gage length (ELF 3200) samples. Although the data is not conclusive, there is evidence to suggest that the shorter sample (DMTA 3E) may be constrained due to end effects. The use of the material properties from the short samples in FEA models to predict component behavior could produce inaccurate estimates of damping and heat generation. Additional testing using a wider variety of sample lengths and strain levels is being conducted to confirm this behavior.

### Conclusions

The EnduraTEC ELF test system accurately measured modulus and phase angle for a linear-elastic metal beam sample. It has also been shown to agree well with an established test system, the Rheometrics DMTA 3E when test conditions and specimen geometry and fixtures are held constant. It has also been used to show that specimens with higher aspect ratios behave differently than those with low aspect ratios. The capabilities of the ELF permit testing at amplitudes and frequencies much higher than those available with traditional voice coil driven test instruments. Engineering sized samples can now be tested without the mess, maintenance and expense of the larger servohydraulic test systems.