TA Instruments

Thermal Analysis & Rheology

DYNAMIC MECHANICAL ANALYZERS: HOW DO THEY WORK?

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Dynamic mechanical analysis (DMA) is an analytical technique which measures the modulus (stiffness) and damping (energy dissipation) properties of materials as those materials are deformed under periodic (oscillatory) stress. There are several components which are critical to the design and resultant performance of a dynamic mechanical analyzer. These components are the drive motor (which supplies the sinusoidal deformation force to the sample material), the drive shaft support and guidance system (which transfers the force from the drive motor to the clamps which hold the sample), the displacement sensor (which measures the sample deformation [oscillation amplitude] that occurs under the applied force), the temperature control system (furnace), and the sample clamps.

The TA Instruments DMA 2980 is based on a unique patent-pending design which optimizes the combination of these critical components. Figures 1 and 2 show the schematic diagrams of these components for the DMA 2980 and a "traditional" DMA respectively. The following sections highlight the advantages of the DMA 2980 design.

Figure 1 DMA 2980: Key Design Elements

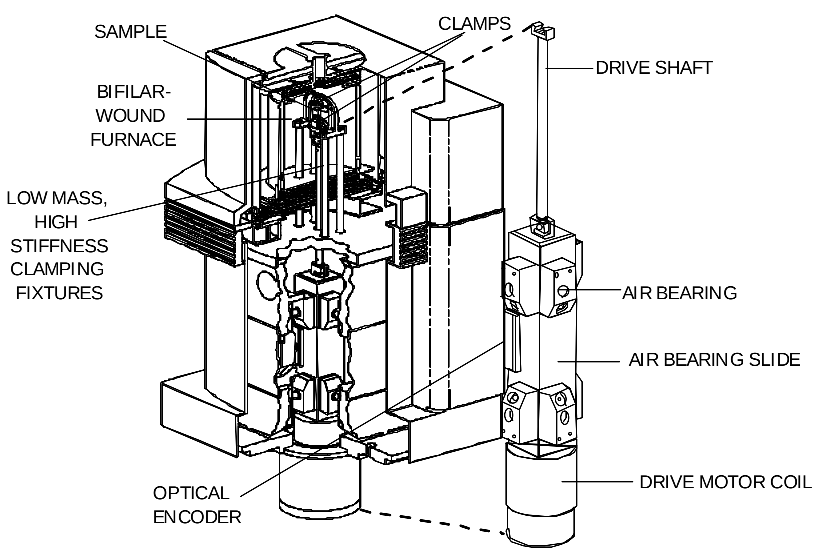
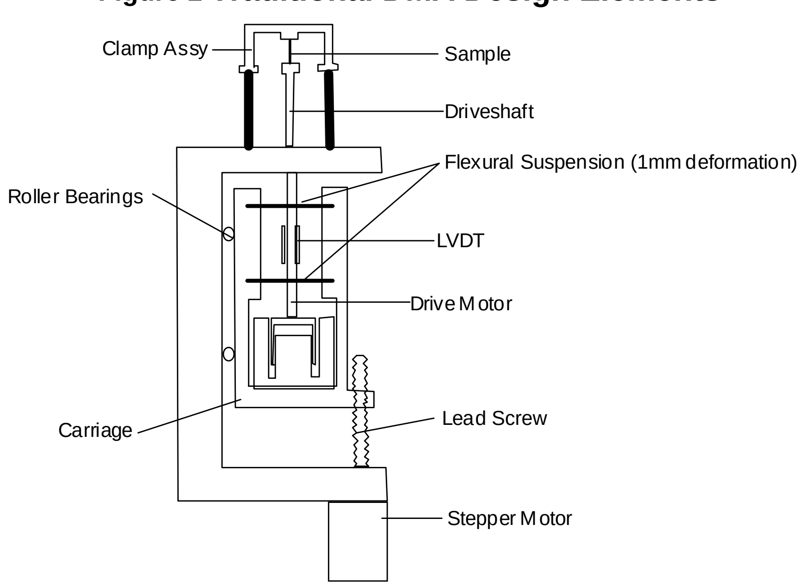


Figure 2 Traditional DMA Design Elements



Drive Shaft Support/Guidance System

In traditional DMA's, the drive shaft is supported and guided by mechanical springs which flex to deliver the sinusoidal force from the drive motor to the sample. This approach has two limitations. First, the springs have a finite stiffness which interferes with the measurement. Although this spring contribution can be calibrated and hence eliminated from the calculations of sample modulus, the spring contribution does limit the accuracy and precision when measuring materials whose stiffness approaches or is less than that of the spring. This situation is most likely to occur with low modulus materials (e.g., elastomers) but could occur even with high modulus materials depending on the sample dimensions.

More importantly, the mechanical spring has a limited range of travel, typically 1mm or less. In order to evaluate larger samples and/or larger deformations, therefore, it is necessary to adjust the position of the drive shaft during the experiment using a stepper motor and lead screw. However, the resultant curves are not smooth and continuous, so that subtle transitions are hard to detect.

On the other hand, the DMA 2980 drive shaft is supported by the drive motor and guided by eight air bearings grouped into two sets of four each near the top and bottom of a rectangular air bearing slide. Pressurized air or nitrogen flows through these bearings and creates a thin layer of air (an air cushion) between the surface of the bearings and the surface of the slide on which the slide "floats" without contact in a "friction-less" fashion. The slide moves smoothly and freely vertically but lateral movement is prevented by the high resistance of the thin air layer to compression. Furthermore, the unique rectangular design of the slide eliminates any possibility for "torquing" (sideways twisting) of the slide, which could occur if the slide were circular. The range of continuous vertical travel in the DMA 2980 is 25 mm which means that even large samples (e.g., fibers as long as 30 mm can be evaluated in the tension mode) or large displacements (oscillation amplitudes to 10,000 µm) for determination of the linear viscoelastic region or for fatigue testing can be accommodated. In addition, the inherent resistance of the air bearing to vertical movement is so low that even thin films and fibers can be evaluated.

The air bearings in the DMA 2980 are made from porous graphite and are designed for low air consumption as well as low susceptibility to contamination. The bearings can be operated using "house air" or air generated by an optional compact compressor.

Drive Motor

The DMA 2980 uses a non-contact, direct drive motor to provide the oscillatory force which deforms the sample materials. The motor is built from high performance composites and other materials which ensure low system compliance and allow the motor to deliver reproducible forces over a wide dynamic range 0.0001 to 18 N. The motor is thermostated to eliminate heat build-up even when using large oscillation amplitudes in combination with high deformation forces. Furthermore, the electronics associated with the motor enable the current to the motor to be rapidly adjusted in small increments so that measurements at amplitudes as small as 0.5 µm can be made.

Optical Encoder

In traditional DMA's, the displacement sensor is a linear variable differential transformer (LVDT) which measures small displacements based on the relative position of a metal core between two secondary coils. Displacement sensitivity (resolution) for an LVDT can be as good as 1 nm, but only over a limited range of displacement. (Typically the resolution of an LVDT is 1 part in 200,000, which means that to obtain 1 nanometer resolution the maximum range of displacement is 200 µm without a stepper motor and lead screw. In addition, LVDT's generally become nonlinear at the extremes of travel of the core which further reduces the range.) LVDT's are also susceptible to outside interference from other sources such as the drive motor.

The DMA 2980 uses an optical encoder to measure displacement. Based on diffraction patterns of light through gratings (one movable and one stationary), optical encoders provide a much higher resolution than LVDT's. The resolution of the DMA 2980 optical encoder is 1 nm over the whole displacement range (25 mm), or 1 part in 25,000,000. This high resolution of oscillation amplitude means that both E' and E" precision (1%) as well as tan delta (δ) sensitivity (0.0001) are excellent. Another benefit of high displacement resolution is the ability to evaluate high modulus materials where, even with the high drive force of the DMA 2980 motor, it is possible to sustain only very small oscillation amplitudes.

Other DMA Components

There are several other components which are important to the design of a quality DMA, including:

- **Temperature Control Components**
  The DMA 2980 incorporates a bifilar wound furnace complemented by a Gas Cooling Accessory (GCA) to cover a broad range of temperature (-145 to 600°C) with excellent temperature precision for transitions (±1°C). The furnace also features automated “swing-away” movement for easy access to the sample area without increasing the DMA 2980’s “foot-print” on the bench, as well as automated air cooling between experiments for rapid turnaround time (increased productivity).

- **Sample Clamps**
  The versatility of a specific DMA design to a large extent is dependent on the variety of sample clamping and deformation modes available. The DMA 2980 offers a broad range of deformation modes (single/dual cantilever, 3 point bend, shear sandwich, compression, and tension), as well as a variety of clamp sizes so that sample materials ranging from 0.57 tex (5 denier) single fibers to films as thin as 1 µm to test bars (50 x 15 x 5 mm) can be accommodated. Table 1 summarizes the options available.

  These DMA 2980 clamps offer two other important features:

  (1) they are designed using “finite element analysis” to provide high stiffness (minimizes clamp compliance) yet low mass (ensures rapid temperature equilibrium).

  (2) they are designed for easy loading (assures clamping consistency for reproducible results) and easy adjustment (reduces time and effort to change and recalibrate).

Table 1 DMA 2980 Clamp Configurations

3-POINT BENDING	5, 10, 15 mm long; up to 15mm wide and 7 mm thick
	20 and 50 mm long; up to 15 mm wide and 7 mm thick
TENSION	(Film) 5 to 30 mm long; up to 8 mm wide and 2 mm thick
	(Fiber) 5 to 30 mm long; 0.57 tex (5 denier) to 0.8mm diameter (single fibers or fiber bundles)
SINGLE/DUAL CANTILEVER	4 mm long (single); 8 mm long (dual); up to 15 mm wide and 5 mm thick
	10 mm long (single); 20 mm long (dual); up to 15 mm wide and 5 mm thick
	17.5 mm long (single); 35 mm long (dual); up to 15 mm wide and 5 mm thick
SHEAR SANDWICH	10 mm x 10 mm; up to 4 mm thick each side
COMPRESSION	15 mm diameter; up to 10 mm thick
	40 mm diameter; up to 10 mm thick

See TA Instruments DMA 2980 Brochure (Ref. No. TA 212) for further details on the DMA 2980 and its application.

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