Dynamic Mechanical Analysis
Basic Theory & Applications Training
Part 1
Course outline

Part 1
- Basic Theories of Dynamic Mechanical Analysis
- DMA Instrumentation and Clamps
- Introduction to DMA Experiments
  - Dynamic tests
  - Transient tests
- Appendix: Screenshots from the instrument control software

Part 2
- Recap of Part 1
- DMA Applications and data interpretation
- Troubleshooting experimental Issues
- Time-temperature superposition (TTS)
Basic Theories of Dynamic Mechanical Analysis
DMA definitions

- A Dynamic Mechanical Analyzer (DMA) measures the mechanical/rheological properties of a material as a function of time, frequency, temperature, stress and strain.

- Typical materials tested on a DMA
  - Thermal plastic and thermosets
  - Elastomers/ rubbers
  - Gels
  - Foams
  - More....
Working principle of a DMA

- Apply a **force** or a **deformation** to a sample, then measure sample’s response, which will be a deformation or a force.
- All mechanical parameters (stress, strain, modulus, stiffness et al) are calculated from these 2 raw signals

\[
\text{Stress (Pa)} = \frac{\text{Force (N)}}{\text{Area (m}^2\text{)}}
\]

\[
\text{Strain} = \frac{\text{Deformation (m)}}{\text{Length (m)}}
\]

\[
\text{Modulus (Pa)} = \frac{\text{Stress (Pa)}}{\text{Strain}}
\]
Hooke’s Law of Elasticity

- For a purely Elastic Solid, Stress and Strain have a constant proportionality
- The slope of stress over strain is the Young’s modulus of the material

\[ \sigma = E' \varepsilon \]
Newton’s Law of Viscosity

- For a purely Viscous Liquid, Stress is proportional to Strain Rate $\frac{d\varepsilon}{dt}$

- The slope of stress over strain rate is the viscosity of the material

\[ \sigma = \eta \cdot \frac{d\varepsilon}{dt} \]
Viscous  
Viscoelastic  
Elastic
In tensile testing of viscoelastic materials, the rate of extension will give different results

- the stress depends on both the strain, and the strain rate

\[ \sigma = E^*\varepsilon + \eta^*\frac{d\varepsilon}{dt} \]
Time-dependent viscoelastic behavior

- Long deformation time: pitch behaves like a highly viscous liquid
  - 9th drop fell July 2013
- Short deformation time: pitch behaves like a solid

Started in 1927 by Thomas Parnell in Queensland, Australia

Let’s take another common example – silly putty

When we pull on silly putty slowly, it is flowy and stretchy like a liquid.

However, if we pull on it quickly, it snaps and breaks like a solid.
Time-dependent viscoelastic behavior (silly putty)

Time-period of deformation is short (high frequency)  
Time-period of deformation is long (low frequency)
Dynamic Mechanical Testing

- An oscillatory (sinusoidal) deformation (stress or strain) is applied to a sample.

- The material response (strain or stress) is measured.

- The phase angle $\delta$, or phase shift, between the deformation and response is also measured.
Phase angle response in dynamic mechanical tests

**Purely Elastic Response** (Hookean Solid)
\[ \delta = 0^\circ \]

**Purely Viscous Response** (Newtonian Liquid)
\[ \delta = 90^\circ \]

**Viscoelastic Response** (Most materials)
Phase angle \( 0^\circ < \delta < 90^\circ \)
Viscoelastic parameters obtained from DMA tests

**Complex Modulus:** Measure of materials overall resistance to deformation.

**The Elastic (Storage) Modulus:** Measure of elasticity of material. The ability of the material to store energy.

\[ E' = \left( \frac{\sigma}{\gamma} \right) \cos \delta \]

**The Viscous (loss) Modulus:** The ability of the material to dissipate energy. Energy lost as heat.

\[ E'' = \left( \frac{\sigma}{\gamma} \right) \sin \delta \]

**Tan Delta:**
Measure of material damping. Increasing tan \( \delta \) implies a greater potential for energy dissipation and lower elasticity, and vice-versa. Measure of viscous property while having the appropriate level of stiffness.

\[ \tan \delta = \left( \frac{E''}{E'} \right) \]
Storage and Loss of a Viscoelastic Material
Viscoelastic spectrum for a typical amorphous polymer

- Glassy Region
- Transition Region
- Rubbery Plateau Region
- Terminal Region

Storage Modulus (\(E'\) or \(G'\))
Loss Modulus (\(E''\) or \(G''\))

DMA Applications Range
DMA results can correlate to:

**Molecular Structures**
- Stress
- Strain
- Stiffness
- Damping factor
- Transition temperatures
- Modulus (E, G) / Compliance (J)

**Product Properties**

**Processing Conditions**
DMA Instrumentation and Clamps
DMA instrumentation

RSA G2

Discovery DMA850

Electroforce series (high load frame, fatigue)
DMA instrumentation

**RSA G2**

*Separate Motor & Transducer*

- Actuator Applies deformation (Strain)
- Sample
- Force Rebalance Transducer (FRT) Measures Force (Stress)

**DMA850 and Q800**

*Combined Motor & Transducer*

- Sample
- Displacement Sensor Measures deformation (Strain)
- Motor Applies Force (Stress)
RSA G2: Schematic Dual Head Design

- Transducer
- Upper Geometry Mount
- Lower Geometry Mount
- Motor
DMA850: Schematic
DMA850 and Q800: Humidity Option
<table>
<thead>
<tr>
<th></th>
<th>RSA G2</th>
<th>DMA850</th>
<th>Q800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Force</td>
<td>35 N</td>
<td>18 N</td>
<td>18 N</td>
</tr>
<tr>
<td>Min Force</td>
<td>0.00005 N</td>
<td>0.0001 N</td>
<td>0.0001 N</td>
</tr>
<tr>
<td>Displacement</td>
<td>1 nm</td>
<td>0.1 nm</td>
<td>1 nm</td>
</tr>
<tr>
<td>Resolution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency Range</td>
<td>$2 \times 10^{-6}$ to 100 Hz</td>
<td>$1 \times 10^{-4}$ to 200 Hz</td>
<td>$1 \times 10^{-2}$ to 200 Hz</td>
</tr>
<tr>
<td>Dynamic Deformation Range</td>
<td>$\pm 5 \times 10^{-5}$ to 1.5 mm</td>
<td>$\pm 5 \times 10^{-6}$ to 10 mm</td>
<td>$\pm 5 \times 10^{-4}$ to 10 mm</td>
</tr>
<tr>
<td>Temperature range</td>
<td>-150 to 600°C</td>
<td>-150 to 600°C</td>
<td>-150 to 600°C</td>
</tr>
<tr>
<td>Isothermal Stability</td>
<td>± 0.1</td>
<td>± 0.1</td>
<td>± 0.1</td>
</tr>
<tr>
<td>Heating Rate</td>
<td>0.1°C to 60°C/min</td>
<td>0.1°C to 20°C/min</td>
<td>0.1°C to 20°C/min</td>
</tr>
<tr>
<td>Cooling Rate</td>
<td>0.1°C to 60°C/min</td>
<td>0.1°C to 10°C/min</td>
<td>0.1°C to 10°C/min</td>
</tr>
</tbody>
</table>
DMA Mode on DHR and ARES-G2

**ARES G2 and DHR DMA Mode**

*Strain control & dynamic test only*

- Force Rebalance Transducer (FRT) *(Measures Stress)*
- Servo control on Null position *(Strain)*
- Sample

For the ARES-G2, the bottom Actuator remains locked during DMA function.
### Specifications of the DHR-DMA and the ARES-G2 DMA

<table>
<thead>
<tr>
<th>Dynamic test only</th>
<th>DHR – DMA mode</th>
<th>ARES-G2 DMA mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Control</td>
<td>FRT</td>
<td>FRT</td>
</tr>
<tr>
<td>Minimum Force (N) Oscillation</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>Maximum Axial Force (N)</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Minimum Displacement (µm) Oscillation</td>
<td>0.01</td>
<td>0.5</td>
</tr>
<tr>
<td>Maximum Displacement (µm) Oscillation</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Axial Frequency Range (Hz)</td>
<td>$1 \times 10^{-5}$ to 16</td>
<td>$1 \times 10^{-5}$ to 16</td>
</tr>
</tbody>
</table>

• Dynamic test only
What samples can be measured on a DMA?

- By changing the clamp, we can test a range of different materials

- Elastomers
- Films
- Fibers
- Gels
- Plastics
- Foams
- Composites
Clamps for DMA850 and Q800

- S/D Cantilever
- Film/Fiber Tension
- 3-Point Bending
- Compression
- Shear Sandwich
- Submersible Tension
- Submersible Bending
- Submersible Compression
Clamps for RSA G2

- Film/Fiber Tension
- 3-Point Bending
- Shear Sandwich
- Compression
- S/D Cantilever
- Contact Lens
RSA G2 Immersion Clamps

- Immersion clamp kit offers 3 geometries with temperature control from -10 to 200 °C in the FCO.

**Tension**: Up to 25 mm long, 12.5 mm wide and 1.5 mm thick.

**Compression**: 15 mm in diameter; maximum sample thickness is 10 mm.

**Three Point Bending**: includes interchangeable spans for lengths of 10, 15, and 20 mm. Maximum sample width is 12.5 mm and maximum thickness is 5 mm.
Testing Solids on a Rheometer

Torsion (rotational) and DMA (axial) geometries allow solid samples to be characterized in a temperature controlled environment.

\[ E = 2G(1 + \nu) \]

\( \nu \): Poisson’s ratio

Shear Modulus: \( G', G^*, G^* \)
Young’s Modulus: \( E', E^*, E^* \)

Parallel plate
Rectangular and cylindrical torsion
3-point bending
Cantilever
Tension
Three fundamental modes of deformation

Young's Modulus

$$E = \frac{\sigma}{\varepsilon}$$

Shear Modulus

$$G = \frac{\tau}{\gamma}$$

Bulk Modulus

$$B = \frac{\sigma_{\text{hyd}}}{\Delta V/V_0}$$

Where

- Dashed lines indicate initial stressed state
- $\sigma$ = uniaxial tensile or compressive stress
- $\tau$ = shear stress
- $\sigma_{\text{hyd}}$ = hydrostatic tensile or compressive stress
- $\varepsilon$ = normal strain
- $\gamma$ = shear strain
- $\Delta V/V_0$ = fractional volume expansion or contraction
Poisson's Ratio

- Poisson's ratio, $\nu$, is the ratio of transverse to axial strain

$$\frac{l_y - l_{0y}}{2} = \frac{-\varepsilon_y}{2}$$

$$\frac{l_z - l_{0z}}{2} = \frac{-\varepsilon_y}{2}$$

$$\nu = \frac{-\varepsilon_y}{\varepsilon_z}$$
Elastic Isotropic materials are materials in which properties at a point are the same in all directions. Some examples of isotropic materials are unoriented amorphous polymers and annealed glasses [1].

If any of the two elastic constants of a homogenous (in which properties do not vary from point to point) isotropic material, the other two may be calculated [2].

\[ E = 2G(1 + \nu) = 3B(1 + 2\nu) \]

### Comparison of Moduli and Poisson’s Ratio

<table>
<thead>
<tr>
<th>Material</th>
<th>E (GPa)</th>
<th>$\nu$</th>
<th>G (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>220</td>
<td>0.28</td>
<td>85.9</td>
</tr>
<tr>
<td>Copper</td>
<td>120</td>
<td>0.35</td>
<td>44.4</td>
</tr>
<tr>
<td>Glass</td>
<td>60</td>
<td>0.23</td>
<td>24.4</td>
</tr>
<tr>
<td>Granite</td>
<td>30</td>
<td>0.30</td>
<td>15.5</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>34</td>
<td>0.33</td>
<td>12.8</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>24</td>
<td>0.38</td>
<td>8.7</td>
</tr>
<tr>
<td>Natural Rubber</td>
<td>0.02</td>
<td>0.49</td>
<td>0.0067</td>
</tr>
</tbody>
</table>

## Modulus calculations in DMA

### DMA850 and Q800

- **Stiffness (K)** = Force / Displacement
- **Modulus (E)** = \( K \times GF \)
- **GF**: Geometry factor. Clamp dependent. Can be found in online help manual.

### RSA G2

- **Stress (\( \sigma \))** = Force \( \times K_\sigma \)
- **Strain (\( \gamma \))** = Displacement \( \times K_\gamma \)
- **Modulus (E)** = \( \sigma / \gamma \)
- **\( K_\sigma \)**: Stress constant. **\( K_\gamma \)**: Strain constant. Clamp dependent. Can be found in online help manual.

\[
GF = \frac{K_\sigma}{K_\gamma}
\]
Choose the correct clamp for testing

- **Sample Dimension**
  - Films and fibers: tension clamps
  - Bars and cylinders: bending clamps
  - O-rings and tablets: compression and/or shear

- **Deformation Mode:**
  - E [tension, compression and bending]
  - G [shear]

- **Sample Stiffness:**
  - Machine range fixed: $10^2 - 10^7 \text{ N/m}$. Stiffness of sample related to its dimensions [L, w, t]. Stiffness may limit sample size to below clamp maximum.
Sample which are stiff with a well-defined geometry allowing for sample dimensions can be measured accurately.

- Precautions:
  - Soft samples (Tg < RT) with well-defined geometry such as elastomers may get pinched during clamping and cause errors in measurement.
  - Samples with high CTE can expand between the clamp faces and buckle, causing significant errors in measurement.

- Mechanical properties, secondary transitions, Tg of polymers (thermoplastics/thermosets)
  - Measurement of modulus and tan δ

- Typical sample length is 17.5 mm. Smaller sizes available.
- Use a consistent clamping torque (typically 10 in-lbs)
Modulus = Stiffness × Geometry Factor

\[ GF_{SC} = \frac{12l^3 \left[ 1 + \frac{12}{5} (1+\nu) \left( \frac{t}{l} \right)^2 \right]}{12wt^3} \]

If length/thickness > 10, the contribution of the term containing the Poisson’s Ratio can be approximated to be negligible.

\[ GF_{SC} = \frac{l^3}{wt^3} \]

w = sample width
l = sample length
t = sample thickness
Samples which are stiff with a well-defined geometry allowing for sample dimensions can be measured accurately.

- Precautions:
  - Soft samples (with Tg < RT) such as elastomers may get pinched during clamping and cause errors in measurement.
  - Samples with high CTE can expand between the clamp faces and buckle, causing significant errors in measurement.

- Tracking cure of thermosets/composites, mechanical properties, secondary transitions and Tg of polymers (thermoplastics/thermosets)
  - Measurement of modulus and tan δ

- Typical sample length is 35 mm. Smaller sizes available. Good for materials that require a larger sample size for homogeneity

- Use a consistent clamping torque (typically 10 in-lbs)
Modulus = Stiffness × Geometry Factor (GF)

\[ GF_{DC} = \frac{12l^3}{24wt^3} \left[ 1 + \frac{12}{5}(1+\nu)\left(\frac{t}{l}\right)^2 \right] \]

If length/thickness > 10, the contribution of the term containing the Poisson’s Ratio can be approximated to be negligible.

\[ GF_{DC} = \frac{l^3}{2wt^3} \]

w = sample width
l = sample length
t = sample thickness
DMA: 3 Point Bend Clamp

- Conforms with ASTM standard test method for bending
- Purest deformation mode since clamping effects are eliminated
- Samples which are stiff with a well-defined geometry allowing for sample dimensions can be measured accurately.
  - Precautions:
    - Samples that get soft around $T_g$ (typically unfilled thermoplastics) can sag and introduce errors in modulus measurements.
- Tracking cure of thermosets/composites, mechanical properties and $T_g$ of polymers that are stiff past the glass transition (filled thermoplastics/thermosets/elastomers)
  - Measurement of modulus and tan δ
- Typical sample lengths 50 mm and 20 mm. Smaller sizes available.
- Sample alignment along the stationary fulcrum is important.
Geometry Factor - 3 Point Bending Clamp

Modulus = Stiffness × Geometry Factor

\[ GF_{3PB} = \frac{3l^3}{12wlt^3} \]

If length/thickness > 10, the contribution of the term containing the Poisson’s Ratio can be approximated to be negligible.

\[ GF_{3PB} = \frac{l^3}{4wlt^3} \]

- \( w \) = sample width
- \( l \) = sample length
- \( t \) = sample thickness
Films and fibers need to have a well-defined geometry allowing for sample dimensions can be measured accurately. Sample length is calculated automatically by the instrument.

- Applications
  - Mechanical properties, Tg, secondary transitions (modulus and tan δ)
  - Creep and stress relaxation
  - Temperature controlled constant force or displacement tests to understand processing effects and shrinkage
  - Generation of stress-strain curves

- Sample alignment between the clamps is important.
- Use a consistent clamping torque (typically 3-5 in-lbs)
Modulus = Stiffness × Geometry Factor

\[ GF_{\text{Film}} = \frac{l}{wt} \]

- \( w = \text{sample width} \)
- \( l = \text{sample length} \)
- \( t = \text{sample thickness} \)
DMA: Compression Clamp

- Good mode for low to medium modulus materials (gels, elastomers) which are compressible throughout the test temperature range
  - Precautions:
    - Samples that are incompressible (typically below the $T_g$) are difficult to test under compression
    - Samples that are too soft and cannot support the load of the clamp need alterations in sample dimensions to get meaningful measurements
- Option for penetration measurements (no modulus information in penetration, only transitions and tan $\delta$)
- Applications:
  - Mechanical properties, $T_g$, secondary transitions (modulus and tan $\delta$)
  - Creep and stress relaxation
  - Temperature controlled constant force or displacement tests to understand processing effects
- Alignment of plates attached to the moveable and stationary clamps is important.
- Sample diameter <= plate diameter (15 mm and 40 mm options). Use exact sample diameter
Geometry Factor – Film/fiber/tension clamp

**Modulus = Stiffness × Geometry Factor**

\[
GF_{\text{Comp}} = \frac{\text{thickness}}{\text{sample surface area}} = \frac{t}{\pi r^2}
\]

- \( r \) = sample radius
- \( t \) = sample thickness, between clamp faces
DMA: Shear Sandwich Clamp

- Good for evaluating highly damped soft solids such as gels and adhesives & elastomers $> T_g$
  - Precautions:
    - Samples should be able to support their own weight under gravity (no flow through the test temperature)
    - Clamping between the plates need to be consistent
- Applications:
  - Mechanical properties, Tg, secondary transitions (modulus and tan $\delta$)

Sample size $\leq$ plate size
Operating Range of the Shear Sandwich Clamp

Modulus = Stiffness \times \text{Geometry Factor}

\[ \text{GF}_{\text{Shear}} = \frac{3t}{5wh} \]

- \( w \) = sample width, i.e. horizontal dimension
- \( h \) = sample height, i.e. vertical dimension
- \( t \) = sample thickness, between clamp faces
## Changing Sample Stiffness

<table>
<thead>
<tr>
<th>Clamp Type</th>
<th>To Increase Stiffness...</th>
<th>To Decrease Stiffness...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension Film</td>
<td>Decrease length or increase width. If possible increase thickness.</td>
<td>Increase length or decrease width. If possible decrease thickness.</td>
</tr>
<tr>
<td>Tension Fiber</td>
<td>Decrease length or increase diameter if possible.</td>
<td>Increase length or decrease diameter if possible.</td>
</tr>
</tbody>
</table>
| Dual/Single Cantilever      | Decrease length or increase width. If possible increase thickness.  
Note: L/T ≥ 10 | Increase length or decrease width., If possible decrease thickness.  
Note: L/T ≥ 10 |
| Three Point Bending         | Decrease length or increase width. If possible increase thickness. | Increase length or decrease width. If possible decrease thickness. |
| Compression – circular sample | Decrease thickness or Increase diameter.             | Increase thickness or decrease diameter.             |
| Shear Sandwich              | Decrease thickness or Increase length and width.      | Increase thickness or decrease length and width.      |
## DMA Clamping Guide

<table>
<thead>
<tr>
<th>Sample</th>
<th>Clamp</th>
<th>Sample Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High modulus materials and composites</td>
<td>3-point Bend Dual Cantilever Single Cantilever</td>
<td>L/T &gt; 10 if possible</td>
</tr>
<tr>
<td>Unreinforced thermoplastics or thermosets</td>
<td>Single Cantilever Dual cantilever</td>
<td>L/T &gt; 10 if possible</td>
</tr>
<tr>
<td>Brittle solid (ceramics)</td>
<td>3-point Bend</td>
<td>L/T &gt; 10 if possible</td>
</tr>
<tr>
<td>Elastomers</td>
<td>3-point bend Tension</td>
<td>L/T &gt; 10 if possible</td>
</tr>
<tr>
<td>Films/Fibers</td>
<td>Tension</td>
<td>L 10-20 mm</td>
</tr>
<tr>
<td>Supported Systems</td>
<td>8 mm Dual Cantilever</td>
<td>minimize sample, put foil on clamps</td>
</tr>
</tbody>
</table>
Instrument calibration
DMA850 Flow Chart of Calibration Procedures

- Follow the online help manual
- The stability verification is performed at installation
- Instrument calibration includes 2 steps: force and phase
- Clamp calibration: perform when newly attached.
- Position calibration from touchscreen

See also: https://www.youtube.com/user/TATechTips
Q800 Flow Chart of Calibration Procedures

- Instrument calibration includes 3 steps: Electronics, Force, and Dynamic
- Position calibration: calibrate the absolute position of the drive shaft. Perform this calibration when DMA is moved, reset, or powered down.
- Clamp calibration: perform when newly attached.

See also: https://www.youtube.com/user/TATechTips
RSA G2 Flow Chart of Calibration Procedures

- Follow the online help manual
- Instrument calibration: force and phase angle check
- Clamp calibration: mass (perform when newly attached)

**Calibration Tasks and Recommended Intervals**

<table>
<thead>
<tr>
<th>Calibration Task</th>
<th>Calibration Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Fixture Mass Calibration</td>
<td>Mandatory: During geometry creation (is a part of geometry configuration)</td>
</tr>
<tr>
<td>Phase Angle and Modulus Check</td>
<td>Suggested: Monthly. Mandatory: Following actuator or transducer replacement</td>
</tr>
<tr>
<td>Gap Temperature Compensation</td>
<td>Suggested: As required by the experiment</td>
</tr>
<tr>
<td>Temperature Offset Table Calibration</td>
<td>Suggested: As needed</td>
</tr>
</tbody>
</table>

See also: [https://www.youtube.com/user/TATechTips](https://www.youtube.com/user/TATechTips)
Available DMA Experiments

(1) Dynamic Tests
Dynamic (Oscillatory) Testing

Available oscillatory test modes

• Strain (stress) Sweep
• Time Sweep
• Frequency Sweep
• Temperature Ramp
• Temperature Step (Sweep) (TTS)
• Others
Some Clamps Require Offset (static) Force!

Clamps **without** static force:
- Single Cantilever
- Dual Cantilever
- Shear Sandwich

Clamps **with** static force:
- Tension Film
- Tension: Fiber
- 3-Point Bend
- Compression
- Penetration

A = Oscillation (dynamic) force
SF = static force

Force/Time Curves
Preload force in tension

- Preload force continues to act.
- Length is measured and updated automatically.
Net forces acting during oscillation (tension)
static force > oscillation force

Fixed clamp

Pre-stretched sample

Half-cycle down

F_{static} + F_{osc.}

F_{static} > F_{osc.}

Sample remains taut

Half-cycle up

F_{static} - F_{osc.}

F_{static} > F_{osc.}

F_{static} - F_{osc.}
Net forces acting during oscillation (tension)
static force < osc. force

Fixed clamp

Half-cycle down

Fixed clamp

Half-cycle up

Fixed clamp

Waveform on buckling

Pre-stretched sample

F_{static} < F_{osc.}
Sample becomes slack on half-cycle up due to net upwards force
Preload force in compression, 3-point bending

**COMPRESSION**

- Preload force continues to act.
- Thickness is measured and sample information is updated automatically.

**3-POINT BENDING**

- Sample dimensions are entered manually prior to start of experiment (no automatic update of thickness)
- Preload force continues to act.
Net forces acting during oscillation (compression and 3PB) static force > osc. force

Fixed clamp maintains contact with sample at all times due to net downward force
Net forces acting during oscillation (compression)

static force < osc. force

\[ F_{\text{static}} + F_{\text{osc.}} \]

**Half-cycle down**

- Moveable clamp
- Fixed clamp

**Half-cycle up**

- Moveable clamp
- Fixed clamp

\[ F_{\text{osc.}} > F_{\text{static}} \]

Moveable clamp loses contact with sample on half-cycle up due to net upwards force.
Recap: Desired situation for all clamps is that $F_{\text{static}} > F_{\text{osc}}$

- Force track = \( \frac{F_{\text{static}}}{F_{\text{osc}}} \)
- If \( \frac{F_{\text{static}}}{F_{\text{osc}}} > 1 \), then \( F_{\text{static}} > F_{\text{osc}} \)
- Force track ratio is expressed as a percentage
  - On 850 and 800, Force track = \( \frac{F_{\text{static}}}{F_{\text{osc}}} \times 100\% \)
  - On RSA-G2, Force track = \( (\frac{F_{\text{static}}}{F_{\text{osc}}} - 1) \times 100\% \)
Benefits of using force track

- Force track ensures that static force exceeds oscillation force throughout the experiment.
- Values from 125-150% (850/Q800) or 25-50% (RSA-G2) is a good starting point for most samples.
- **Decreases static force in proportion to sample modulus** in "Tension clamps" to reduce stretching as specimen weakens on increasing temperature.
- Constant (or static) force can be used as long as static force > oscillation force throughout the entire experiment.
  - Stiff samples in 3-point bending (thermosets)
Q800 uses the term “Dynamic Force” to denote oscillation force ($F_{osc}$). Static Force tracks Dynamic Force throughout Temperature Ramp to prevent over-stretching.
### Choosing Force Track Parameters

<table>
<thead>
<tr>
<th>Clamp Type</th>
<th>Static Force</th>
<th>Force Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension Film</td>
<td>0.01 N</td>
<td>120 to 150%</td>
</tr>
<tr>
<td>Tension Fiber</td>
<td>0.001 N</td>
<td>120%</td>
</tr>
<tr>
<td>Compression</td>
<td>0.001 to 0.01 N</td>
<td>125%</td>
</tr>
<tr>
<td>Three Point Bending</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermoplastic Sample</td>
<td>1 N</td>
<td>125 to 150%</td>
</tr>
<tr>
<td>Three Point Bending</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stiff Thermoset Sample</td>
<td>1 N</td>
<td>150 to 200%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can use constant static force</td>
</tr>
</tbody>
</table>

- **Note:**Constant (or static) force can be used as long as static force > dynamic force throughout the entire experiment.
- **Refer to appendix for screenshots of setting force track parameters for your respective instrument**
The material response to increasing deformation amplitude is monitored at a constant frequency and temperature.

**USES**
- Identify Linear Viscoelastic Region
- Resilience/elasticity
Dynamic Strain Sweep: Material Response

Results depend on strain in the non-linear viscoelastic region. Results are independent of strain in the linear viscoelastic region. The critical strain $\gamma_c$ is marked.
Rubber: Effect of Filler Content in Tire Rubber (NR)

- Instrument: TA Instruments ElectroForce DMA 3200 with FCO and ACS-3
- Samples: Cured Natural Rubber Compound with Two Filler Levels (40 & 60 PHR)
- Clamp: Tension
- Method: Strain Sweep at 10Hz
Dynamic Time Sweep

The material response is monitored at a constant frequency, amplitude and temperature.

USES
- Curing studies
- Fatigue tests
- Stability against thermal degradation
Epoxy Curing on Glass Braid

Instrument: DMA850
Clamp: Dual cantilever
Sample: Epoxy coated on glass braid
Dynamic time sweep
Temperature: 35°C
Frequency: 1 Hz
Amplitude: 10 μm
**Frequency Sweep**

- The material response to increasing frequency (rate of deformation) is monitored at a constant amplitude and temperature.

**USES**
- Quick comparison on modulus and elasticity on solids
- Study polymer melt processing (shear sandwich).
- Estimate long term properties with extended frequency (time) range using TTS
Happy and sad balls vide

- Set of 2 black rubber balls used as demonstration of viscoelastic behavior.
  - When dropped, the Happy Ball bounces and the Sad Ball does not.

https://www.youtube.com/watch?v=lubaukB6B34
Dynamic Mechanical Properties: Tan Delta

![Graph showing the relationship between tan(δ) and frequency (Hz) for Happy Ball and Sad Ball. The graph indicates a logarithmic scale for both axes, with tan(δ) ranging from 10^-2 to 10^1 and frequency from 10^0 to 10^-1.]
Dynamic Mechanical Properties: Tan Delta

- **Tan δ**: Measure of material damping. Balancing viscous property while having the appropriate level of stiffness.

- Increasing Tan δ implies a greater potential for energy dissipation and lower elasticity, and vice-versa.

\[
\tan \delta = \left( \frac{E''}{E'} \right)
\]

- Sad ball has a much higher tan δ compared to the happy ball.
Frequency Sweep: Material Response

![Diagram showing different regions of a frequency sweep graph: Terminal Region, Rubbery Plateau Region, Transition Region, Glassy Region. The graph plots log E' (G') and E" (G'') against log Frequency (rad/s or Hz).]
Dynamic Temperature Ramp

- A linear heating rate is applied. The material response is monitored at a constant frequency and constant amplitude of deformation. Data is taken at user defined time intervals.

Recommend ramp rate for polymer testing: 1-5°C/min.
A step and hold temperature profile is applied. The material response is monitored at one, or over a range of frequencies, at constant amplitude of deformation.
Temperature Profile on Amorphous Polymers

- Glassy Region
- Transition Region
- Rubbery Plateau Region
- Terminal Region

Log $E'$ (G') and $E''$ (G'')

Storage Modulus ($E'$ or G')
Loss Modulus ($E''$ or G'')

DMA Applications Range

Temperature
DMA temperature ramp: Happy and sad balls

-56.2°
-6.8°
-47.5°
8.8°
Experimental Considerations

- Sample
  - Deformation Mode
  - Stiffness (sample size and shape)
  - Clamp Type (sample size and shape)

- Static Force/Force Track

- Amplitude (single/multiple)

- Frequency (Single/multiple)

- Heating Rate/Temperature Program
Selecting Appropriate Amplitude and Force

• Strain consideration
  ▪ Must be within the linear region

• Force consideration
  ▪ Maximum - 18 N on Q800, DMA850
  ▪ Maximum - 35 N on RSA G2

• Yielding /Creep
  ▪ If the force is too high the specimen may deform irreversibly
  ▪ Must consider behavior at all temperatures and frequencies

• Noise
  ▪ Higher amplitude = lower noise (generally)
  ▪ Trade off against yielding/creep behavior
Frequencies

• Single Frequency
  ▪ In a temperature ramp the most commonly used frequency is between 1 to 10 Hz (6.28 or 63 rad/sec)

• Multiple Frequencies
  ▪ For an ambient test the commonly used frequency range is from 0.1 – 10Hz.
  ▪ Frequency sweeps at multiple temperatures for Time-Temperature Superpositioning (TTS)
  ▪ Run from high to low frequencies for faster initial data acquisition (for DMA850 and Q800 users)

• Data Collection Rate
  ▪ Lower frequencies take longer time - control experiment
  ▪ More frequencies = longer experiment
Temperature Program

- Temp ramp
  - Commonly used heating rate: 1-5°C/min
  - Larger samples have more thermal lag
  - Use slower ramp rates for lower frequencies and frequency sweeps because these take more time

- Temp sweep
  - No thermal lag but time consuming
  - Commonly used for TTS testing, typical temp step: 5-10°C

- Multiple temp steps
  - Commonly used to mimic certain application temperature profile
Available DMA Experiments

(2) Transient Tests
Transient Testing

Available transient test modes

- Creep-Recovery
- Stress Relaxation
- Iso-strain Temperature Ramp
- Iso-force Temperature Ramp
- Stress-Strain Rate Tests
Creep recovery

• A stress is applied to sample instantaneously at $t_1$ and held constant for a specific period of time. The strain is monitored as a function of time ($\gamma(t)$ or $\varepsilon(t)$).

• The stress is reduced to zero at $t_2$ and the strain is monitored as a function of time ($\gamma(t)$ or $\varepsilon(t)$).
Creep recovery

Response of Classical Extremes

**Elastic**
- Stain for $t>t_1$ is constant
- Strain for $t > t_2$ is 0

**Viscous**
- Stain rate for $t>t_1$ is constant
- Strain for $t>t_1$ increase with time
- Strain rate for $t > t_2$ is 0
Creep recovery

Creep $\sigma > 0$

Recovery $\sigma = 0$ (after steady state)

Viscous

Visco-elastic

Elastic

Less Elastic

More Elastic

Strain

Creep Zone

Recovery Zone

t_1

t_2

time

$\sigma/\eta$
Creep recovery: Creep and Recoverable Compliance

Creep Zone

$J(t) = \frac{\gamma(t)}{\sigma}$

Creep Compliance

$J(t) = 1/\eta$

Recovery Zone

$J_r(t) = \frac{[\gamma_u - \gamma(t)]}{\sigma}$

Recoverable Compliance

Where $\gamma_u = \text{Strain at unloading}$
$\gamma(t) = \text{time dependent recoverable strain}$

Creep experiments report the material property Compliance which is in a sense the inverse of Modulus.
Creep-recovery test on PET Film

Stress: 5MPa

Instrument: Q800
Clamp: Tension
Temperature: 75°C
Stress: 5MPa

p/n: 984309.901
Creep: Material response

- Glassy Region
- Transition Region
- Rubbery Plateau Region
- Terminal Region

Log Creep Compliance, Jc vs. Log time
Stress relaxation experiment

- Strain is applied to sample instantaneously (in principle) and held constant with time.
- Stress is monitored as a function of time $\sigma(t)$. 

![Graph showing strain and time](image)
Stress relaxation experiment

Response of Classical Extremes

- **Elastic** (Hookean Solid): Stress for $t>0$ is constant.
- **Viscous** (Newtonian Fluid): Stress for $t>0$ is 0.
Stress relaxation experiment

Response of ViscoElastic Material

Stress decreases with time starting at some high value and decreasing to zero.

- For small deformations (strains within the linear region) the ratio of stress to strain is a function of time only.

- This function is a material property known as the STRESS RELAXATION MODULUS, $E(t)$

$$E(t) = \frac{\sigma(t)}{\gamma}$$
Stress Relaxation: Compression

![Graph showing the relationship between Modulus E(t) (Pa) and Step time t_s (s) for Happy Ball and Sad Ball]

- Happy Ball
- Sad Ball
Stress Relaxation: Material response

- Glassy Region
- Transition Region
- Rubbery Plateau Region
- Terminal Region

log Stress Relaxation Modulus $E(t)$ or $G(t)$ vs. log time
Iso-strain/Iso-stress Temperature Ramp

- The strain or stress is held at a constant value and a linear heating rate is applied.

- Valuable for assessing mechanical behavior under conditions of confined or fixed load (stress) or deformation (strain).

- Example: Measure sample shrinkage (length shrinkage or shrinking force)
Iso-Strain Temp Ramp: Measure Shrinking Force

Sample is held at a constant length; shrinkage force is measured

Strain = 0.05%
Iso-Force Temp Ramp: Measure Length Shrinkage

Sample is held at a constant force; shrinkage is measured

- Hold force at 0.05N
- Temperature: ambient to 120°C
- Ramp rate: 3°C/min
Stress-Strain Testing

- Sample is deformed under a constant linear strain rate, Hencky strain rate, force, or stress for generating more traditional stress-strain curves.
- Measure sample’s Young’s modulus, yield stress, strain hardening effect and sample fracture.
Polysaccharide Film Stress-Strain Test

Yield Point:
Stress: 2.58e7 Pa
Strain: 2.1 %

Fracture Point:
Stress: 3.80e7 Pa
Strain: 35.8 %

Young’s Modulus: 2.08e7 Pa
R²: 0.999662

Geometry: Tension
Temperature: 37°C
Rate: 10 μm/s
Summary of Part 1
Summary

- Introduction to Dynamic Mechanical Analysis Importance of mechanical analysis
  - Conventional (non-oscillatory) vs dynamic (oscillatory) mechanical analysis
  - Viscoelasticity
    • Definition and physical significance of viscoelastic parameters

- DMA Instrumentation and Clamps
  - DMAs offered by TA Instruments
    • Discovery DMA 850
    • RSA-G2
    • TA Electroforce series
  - Common clamp configurations
    • Use of stiffness as a guide to choose the appropriate clamp
Summary: DMA experiments

- Significance of pre-load force and force track
- Dynamic tests
  - Strain/amplitude sweep
  - Time sweep
  - Frequency sweep
  - Temperature ramp
  - Temperature sweep
- Transient tests
  - Creep-recovery
  - Stress-relaxation
  - Iso-strain temperature ramp
  - Iso-stress temperature ramp
  - Stress-strain tests
End of Part 1

See appendix in the subsequent slides for additional experimental setup details
Appendix
Instrument control software screenshots
Dynamic/oscillation experiments
Offset force and force track on DMA850

- **Constant static force**

- **Force track**
Offset force and force track on Q800

- **Constant static force**

- **Force track**
Offset force and force track on RSA G2

- **Constant static force**

- **Force track**
Dynamic Strain (Stress) Sweep

The material response to increasing deformation amplitude is monitored at a constant frequency and temperature.

USES
- Identify Linear Viscoelastic Region
- Resilience/elasticity
## Programming Strain Sweep on DMA850

### Sweep Mode
- **Sweep Mode:** Logarithmic
- **Strain:** 0.01% to 10.0%
- **Points per decade:** 5
- **Number of Sweeps:** 1

### Configuration
- **Temperature:** 25°C
- **Soak time:** 60.0 s
- **Frequency:** 1.0 Hz
- **Initial/preload force:** 0.1 N
- **Use Force Track:** 125.0%

### Buttons
- **Test Settings**
- **Post Test Conditions**
Programming Strain Sweep on Q800

Mode: DMA Multi-Strain

Material is held isothermally and deformed over a range of strains (amplitudes) at a single frequency.

- **Procedure Information**
  - Test: Strain Sweep
  - Notes: Material is held isothermally and deformed over a range of strains (amplitudes) at a single frequency.

**Strain Sweep**
- Frequency: 1.00 Hz
- Preload force: 0.0100 N
- Force track: 1.25

**Isothermal temperature:** 35.00 °C

**Soak time:** 5.00 min

**Number of sweeps:** 1

**Amplitude Table**
- Single
- Log
- Linear
- Discrete

- Amplitude: 0.100 to 100.000 μm
- Number of points: 13

- Table entries:
<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>100.000</td>
</tr>
<tr>
<td>5.65</td>
<td></td>
</tr>
<tr>
<td>11.20</td>
<td></td>
</tr>
<tr>
<td>16.75</td>
<td></td>
</tr>
<tr>
<td>22.30</td>
<td></td>
</tr>
<tr>
<td>27.95</td>
<td></td>
</tr>
<tr>
<td>33.40</td>
<td></td>
</tr>
</tbody>
</table>

117
Programming Strain Sweep on RSA G2

[Experiment 2]

- Sample: PET film LN2 only
- Geometry: Tension fixture (rectangle)

Procedure of 2 steps:
1. Conditioning Options Active, Enabled
2. Oscillation Amplitude

Environmental Control
- Temperature: 25 °C
- Soak time: 60.0 s

Test Parameters
- Frequency: 1.0 Hz

Logarithmic sweep
- Strain %: 0.01 to 10.0%
- Points per decade: 5

- Data acquisition
- Advanced
Dynamic Time Sweep

The material response is monitored at a constant frequency, amplitude and temperature.

USES
- Curing studies
- Fatigue tests
- Stability against thermal degradation
Programming Time Sweep/fatigue on DMA850

- Time sweep example

- Fatigue example
Programming Time Sweep on Q800

Mode: DMA Multi-Frequency-Strain

- **Test**: Custom
- **Name**: Frequency sweep

**Frequency Table**

<table>
<thead>
<tr>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

**Method**

- Amplitude: 20.0000 μm
- Strain: 0.0000%
- Preload force: 0.0100 N
- Force track: 125.%

**Procedure Information**

- Test: Custom
- Notes: 

**Frequency Table Editor**
Programming Time Sweep on RSA G2

- Time sweep example

- Fatigue example

**Procedure of 2 steps**

1. Conditioning Options Active, Enabled
2. Oscillation Cycle Sweep

**Environmental Control**
- Temperature: 50 °C
- Soak time: 300.0 s

**Test Parameters**
- Duration: 300.0 s
- Sampling interval: 10.0 s/p.t.
- Strain %: 0.5 %
- Single point
- Frequency: 1.0 Hz

**Total parameters**
- Total cycles: 10000.0 Cycles
- Total time: 02:46:40 hh:mm:ss
- Measure every: 2.0 Cycles
- Strain %: 2.0 %
- Frequency: 1.0 Hz
Frequency Sweep

- The material response to increasing frequency (rate of deformation) is monitored at a constant amplitude and temperature.

**USES**
- Quick comparison on modulus and elasticity on solids
- Study polymer melt processing (shear sandwich).
- Estimate long term properties with extended frequency (time) range using TTS
Programming Frequency Sweep on DMA850
Programming Frequency Sweep on Q800

Mode: DMA Multi-Frequency-Strain

- **Procedure Information**
  - **Test**: Isothermal Temp / Freq Sweep
  - **Notes**: Material is held isothermally at a user-specified temperature. Then it is deformed (oscillated) at a constant amplitude (strain) over one or more frequencies and the mechanical properties measured.

- **Frequency Sweep**
  - **Amplitude**: 25.0000 μm
  - **Strain**: 0.0000 %
  - **Preload force**: 0.0100 N
  - **Force track**: 125 %
  - **Isothermal temperature**: 35.00 °C
  - **Soak time**: 5.00 min
  - **Number of sweeps**: 1
  - **Frequency Table**
    - **Single**: Checked
    - **Log**: Checked
    - **Linear**: Checked
    - **Discrete**: Checked
    - **Frequency**: 0.10 to 10.00 Hz
    - **Points per decade**: 5

- **Method / Frequency Table**

---

125
Programming Frequency Sweep on RSA G2

[Experiment 2]

- Sample: PET film LN2 only
- Geometry: Tension fixture (rectangle)

Procedure of 2 steps:
1. Conditioning Options Active, Enabled
2. Oscillation Frequency

Environmental Control
- Temperature: 25 °C
- Soak time: 50.0 s
- Inherit set point
- Wait for temperature

Test Parameters
- Strain %: 0.5%

Logarithmic sweep
- Frequency: 0.1 to 50.0 Hz
- Points per decade: 5

Data acquisition
Advanced
Dynamic Temperature Ramp

• A linear heating rate is applied. The material response is monitored at a constant frequency and constant amplitude of deformation. Data is taken at user defined time intervals.

Recommend ramp rate for polymer testing: 1-5°C/min.
Temperature Step & Hold - Single / Multi-Frequency

- A step and hold temperature profile is applied. The material response is monitored at one, or over a range of frequencies, at constant amplitude of deformation.
Programming Temp Ramp/Sweep on DMA850

- Temp Ramp Example

- Temp Sweep Example

Note: Measurement can be done with single or multiple frequencies
Programming Temp Ramp/Step on Q800

Mode: DMA Multi-Frequency-Strain

- Temp Ramp Example
- Temp Sweep Example

Note: Measurement can be done with single or multiple frequencies
Programming Temp Ramp/Sweep on RSA G2

- **Temp Ramp Example**
  - Sample: PET film LN2 only
  - Geometry: Tension fixture (rectangle)
  - Procedure of 2 steps
    - 1: Conditioning Options Active, Enabled
    - 2: Oscillation Temperature Ramp

- **Temp Sweep Example**
  - Procedure of 2 steps
    - 1: Conditioning Options Active, Enabled
    - 2: Oscillation Temperature Sweep

  **Environmental Control**
  - Start temperature: -100 °C
  - Soak time: 300.0 s
  - Ramp rate: 3.0 °C/min
  - End temperature: 200 °C
  - Soak time after ramp: 0 s
  - Estimated time to complete: 01:40:00

  **Test Parameters**
  - Sampling interval: 10.0 s/pct
  - Strain %: 0.06
  - Single point
    - Frequency: 1.0 Hz

  **Note:** Measurement can be done with single or multiple frequencies
Transient experiments
Creep Recovery Experiment

- A stress is applied to sample instantaneously at $t_1$ and held constant for a specific period of time. The strain is monitored as a function of time ($\gamma(t)$ or $\varepsilon(t)$).

- The stress is reduced to zero at $t_2$ and the strain is monitored as a function of time ($\gamma(t)$ or $\varepsilon(t)$).
Programming Creep Recovery on a DMA850

[Experiment 1]

- Sample:
- Clamp: Film Clamp

**Stress Control**

- Creep Recovery

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>30 °C</td>
</tr>
<tr>
<td>Soak time</td>
<td>60.0 s</td>
</tr>
<tr>
<td>Preload force</td>
<td>0.01 N</td>
</tr>
<tr>
<td>Stress</td>
<td>500.0 Pa</td>
</tr>
<tr>
<td>Creep time</td>
<td>120.0 s</td>
</tr>
<tr>
<td>Recovery time</td>
<td>240.0 s</td>
</tr>
</tbody>
</table>

**Data sampling mode**
- Linear
- Log

**Sampling rate**
- 1.0 pts/s

**Test Settings**
**Post Test Conditions**
Programming Creep Recovery on a Q800

- **Preload force:** 0.0010 N
- **Stress:** 1.0000 MPa
- **Isothermal temperature:** 35.00 °C
- **Creep time:** 10.00 min
- **Recovery time:** 20.00 min
- **Running Segment Description:**
  1. Data storage Off
  2. Equilibrate at 35.00 °C
  3. Isothermal for 5.00 min
  4. Data storage On
  5. Displace 10.00 min recover 20.00 min
Programming Creep Recovery on a RSA-G2

• A pre-test is required to obtain sample information for the feedback loop
• Stress Control Pre-test: frequency sweep within LVR

1: Conditioning Stress Control

- Load Precomputed
- Run and Calculate

Environmental Control
- Temperature: 30°C
- Soak time: 60.0 s

Test Parameters
- Strain %: 0.05%

Save stress control PID file
- Stress control PID file path: W:\2011\creep.creep

Data acquisition

2: Step (Transient) Creep 25°C, 60s, 100Pa
Programming Creep Recovery on a RSA-G2

- Stress: needs to be in the linear region
- Creep time: until it reaches steady state
- Recovery time: until the compliance and strain reach plateau
Stress relaxation experiment

- Strain is applied to sample instantaneously (in principle) and held constant with time.
- Stress is monitored as a function of time $\sigma(t)$. 

![Graph showing stress relaxation experiment](image)
Programming Stress Relaxation on a DMA850
## Programming Stress Relaxation on a Q800

### Procedure Details

- **Mode:** DMA Stress Relaxation
- **Test:** Custom
- **Clamp:** Custom
- **Sample Shape:** Rectangular (L x W)
- **Dimensions:** 17.500 mm, 12.900 mm, 3.200 mm

### Stress Relaxation Parameters

- **Preload force:** 0.0010 N
- **Strain:** 0.1000 %
- **Isothermal temperature:** 35.00 °C
- **Soak time:** 5.00 min
- **Relaxation time:** 10.00 min
- **Recovery time:** 0.00 min

### Running Segment Description

1. Data storage Off
2. Equilibrate at 35.00 °C
3. Isothermal for 5.00 min
4. Data storage On
5. Displace 10.00 min, recover 0.00 min
Programming Stress Relaxation on a RSA-G2

2: Step (Transient) Stress Relaxation

Environmental Control
- Temperature: 50 °C
- Soak time: 120.0 s
- Inherit set point
- Wait for temperature

Test Parameters
- Duration: 300.0 s
- Tension
- Compression
- Strain %: 1.0 %
- Sampling
  - Linear
  - Log
- Number of points: 300
- Data acquisition
- Advanced
Iso-strain/Iso-stress Temperature Ramp

- The strain or stress is held at a constant value and a linear heating rate is applied.

- Valuable for assessing mechanical behavior under conditions of confined or fixed load (stress) or deformation (strain).

- Example: Measure sample shrinkage (length shrinkage or shrinking force)
Iso-Strain/Iso-Stress on a DMA850

- DMA Iso-strain
  - Hold strain constant and measure sample shrinking force

- DMA Iso-stress
  - Hold stress constant and measure sample dimension change
Iso-Strain/Iso-Stress on a Q800

- DMA Iso-strain
- Hold strain constant and measure sample shrinking force
- Only works with film-tension clamp on the Q800

- DMA Control force
- Hold force constant and measure sample dimension change
Iso-Strain/Iso-Stress on a RSA G2

- DMA Iso-strain
- Hold strain constant and measure sample shrinking force

- DMA Iso-force
- Hold stress constant and measure sample dimension change
Stress-Strain Testing

- Sample is deformed under a constant linear strain rate, Hencky strain rate, force, or stress for generating more traditional stress-strain curves.
- Measure sample’s Young’s modulus, yield stress, strain hardening effect and sample fracture
Strain/Stress Ramp on a DMA850

**Strain Ramp**

- Sample:
- Clamp: Film Clamp
- Rate Control: Strain Ramp
- Temperature: 25 °C
- Soak time: 300.0 s
- Preload force: 0.01 N
- Inherit starting displacement
- Ramp from: Inherited, Ramp to: 100.0 μm
- Ramp rate: 20.0 μm/min
- Data sampling mode: Linear, Sampling rate: 1.0 pts/s

**Stress Ramp**

- Sample:
- Clamp: Film Clamp
- Rate Control: Stress Ramp
- Temperature: 25 °C
- Soak time: 300.0 s
- Preload force: 0.01 N
- Inherit starting force
- Ramp from: Inherited, Ramp to: 5.0 N
- Ramp rate: 1.0 N/min
- Data sampling mode: Linear, Sampling rate: 1.0 pts/s
Strain/Stress Ramp on a Q800

- DMA strain rate mode
- Strain ramp
- Displacement ramp

- DMA control force mode
- Force ramp
Strain Ramp on a RSA G2

- **Linear strain rate**
- **Hencky strain rate**
Additional resources for experimental setup
Getting Started Manuals on your desktop

TA Instruments
Discovery DMA 850 Manuals

To view the desired manual using Acrobat Reader, click the name in the list below:

- DMA 850 Getting Started Guide
- DMA-PK Accessory Getting Started Guide
- Gas Cooling Assembly (DCA) Getting Started Guide
- Nitrogen/Purge Center (NPC) Getting Started Guide
- What’s New in TRIOS Software
- Installing TRIOS Software
- Configuring a New Geometry in TRIOS Software
- DMA Clamping Factors for Compression Clamps

Instrument & Accessory Documentation:
- DMA 850 Getting Started Guide
- DMA-PK Camera Kit Installation Guide
- DMA-PK LN2 Kit Installation Guide
- DMA-PK Chiller Panel Kit Installation Instructions
- DMA-PK Electric Accessory Getting Started Guide
- ACS Getting Started Guide

Software Documentation:
- What’s New in TRIOS Software
- Installing TRIOS Software
- Configuring a New Geometry in TRIOS Software

Miscellaneous Documentation:
- DMA-PK Site Preparation Guide

TA Instruments
RSA-G2 Manuals

To view the desired manual using Acrobat Reader, click the name in the list below:

- RSA-G2 Getting Started Guide
- RSA-G2 PK Camera Kit Installation Guide
- RSA-G2 LN2 Kit Installation Guide
- RSA-G2 Chiller Panel Kit Installation Instructions
- RSA-G2 Electric Accessory Getting Started Guide
- ACS Getting Started Guide

Software Documentation:
- What’s New in TRIOS Software
- Installing TRIOS Software
- Configuring a New Geometry in TRIOS Software

Miscellaneous Documentation:
- RSA-G2 Site Preparation Guide

TA Instruments
Q Series™ Manuals

To view the desired manual using Acrobat Reader, click the name in the list below:

- Q Series™ Instrument Control Getting Started Guide
- Universal Analysis Getting Started Guide
- Advantage Integrity™ Getting Started Guide
- Specialty Library Getting Started Guide
- RIM File Utilities

Software Manuals:
- Q Series™ Instrument Control Getting Started Guide
- Universal Analysis Getting Started Guide
- Advantage Integrity™ Getting Started Guide
- Specialty Library Getting Started Guide
- RIM File Utilities

Miscellaneous Documents:
- Installing/Updating Advantage™
- Updating Q Series™ Instrument Software
- New Features in Advantage Q Series™
- New Features in Advantage Integrity™
- TA Update

Issue: February 2019

Issue: December 2018

151
## Available DMA Tests

#### Express (Single Step) Tests
Select from the following test names for more information.

- **Oscillation: Temperature Sweep**
- **Oscillation: Frequency Sweep**
- **Oscillation: Temperature Ramp**
- **Oscillation: Strain Sweep**
- **Oscillation: Fatigue**
- **Oscillation: Temperature Sweep (Multifrequency)**
- **Oscillation: Temperature Ramp (Multifrequency)**
- **Oscillation: Time Swap**
- **Oscillation: Temperature Ramp (MultiStep)**

#### Unlimited (Multi-Step) Tests
Select from the following test names for more information.

- **Conditioning Temperature**
- **Conditioning Data**
- **Conditioning Other**
- **Conditioning Strain**
- **Conditioning Stress**
- **Conditioning Repeat**
- **Oscillation Temperature Rest**
Instructional Videos

- From [www.tainstruments.com](http://www.tainstruments.com) click on Videos, Support or Training

- Select Videos for TA Tech Tips, Webinars and Quick Start Courses

See also: [https://www.youtube.com/user/TATechTips](https://www.youtube.com/user/TATechTips)
Web based e-Training Courses

TA Instruments offers a variety of training opportunities via the Internet. e-Training opportunities include the following:

QUICKSTART e-TRAINING COURSES

QuickStart e-Training courses are designed to teach a new user how to set up and run samples on their analyzers. These 60-90 minute courses are available whenever you are. These pre-recorded courses are available to anyone at no charge. Typically these courses should be attended shortly after installation.

Contact Us for Web based e-Training Courses

https://www.tainstruments.com/videos/quick-start-guides/
Instructional Video Resources

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https://www.tainstruments.com/videos/quick-start-guides/
For additional questions:
• Email: rheologysupport@tainstruments.com
• Please put Online Training Questions in the subject line
• Link to download the presentation:
  https://www.tainstruments.com/online-training-course-downloads/