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

Day 1
- Basic Theories of Dynamic Mechanical Analysis
- DMA Instrumentation and Clamps
- Introduction to DMA Experiments
  - Dynamic tests
  - Transient tests

Day 2
- Recap of Day 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

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

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

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

$$\sigma = \eta \cdot d\varepsilon/dt$$
Time dependency of mechanical properties in viscoelastic materials

- 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

\[ \sigma = E \cdot \varepsilon + \eta \cdot d\varepsilon/dt \]
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

Time-dependent viscoelastic behavior

T is short [< 1 sec]

T is long [>2 hours]
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)
\[ \delta = 0° \]

Purely Viscous Response
(Newtonian Liquid)
\[ \delta = 90° \]

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

The Modulus: Measure of materials overall resistance to deformation.

\[ E^* = \frac{\text{stress amplitude } (\sigma)}{\text{strain amplitude } (\gamma)} \]

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

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

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

Temperature

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
DMA results can correlate to:

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

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

Force Rebalance Transducer (FRT) Measures Force (Stress)

Sample

Actuator Applies deformation (Strain)

DMA850 and Q800
Combined Motor & Transducer

Fixed

Sample

Displacement Sensor Measures deformation (Strain)

Motor Applies Force (Stress)
DMA850: Schematic
DMA850 and Q800: Humidity Option
## DMA Specifications

<table>
<thead>
<tr>
<th></th>
<th>RSA G2</th>
<th>DMA850</th>
<th>Q800</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Max Force</strong></td>
<td>35 N</td>
<td>18 N</td>
<td>18 N</td>
</tr>
<tr>
<td><strong>Min Force</strong></td>
<td>0.0005 N</td>
<td>0.0001 N</td>
<td>0.0001 N</td>
</tr>
<tr>
<td><strong>Displacement Resolution</strong></td>
<td>1 nm</td>
<td>0.1 nm</td>
<td>1 nm</td>
</tr>
<tr>
<td><strong>Frequency Range</strong></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><strong>Dynamic Deformation Range</strong></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><strong>Temperature range</strong></td>
<td>-150 to 600°C</td>
<td>-150 to 600°C</td>
<td>-150 to 600°C</td>
</tr>
<tr>
<td><strong>Isothermal Stability</strong></td>
<td>± 0.1</td>
<td>± 0.1</td>
<td>± 0.1</td>
</tr>
<tr>
<td><strong>Heating Rate</strong></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><strong>Cooling Rate</strong></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>0.1</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>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Maximum Displacement (μm) Oscillation</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Displacement Resolution (nm)</td>
<td>10</td>
<td>10</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>
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: \( E', E'', E^* \)
Three fundamental modes of deformation

Young’s Modulus

Shear Modulus

Bulk Modulus

\[ E = \frac{\sigma}{\varepsilon} \]

\[ G = \frac{\tau}{\gamma} \]

\[ B = \frac{\sigma_{\text{hyd}}}{\Delta V/V_o} \]

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
- \( \Delta V/V_o \) = fractional volume expansion or contraction
Poisson's Ratio

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

\[ \frac{I_z - I_{0z}}{2} = \frac{e_z}{2} \]

\[ \frac{I_y - I_{0y}}{2} = \frac{-e_y}{2} \]

\[ \nu = \frac{-e_y}{e_z} \]
Relationship between moduli and Poisson’s ratio for elastic isotropic materials

• 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].

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

Poisson’s Ratio

• If the volume of the specimen remains constant when deformed, $\nu = 0.5$.
  • Examples of constant volume materials are liquids and ideal rubbers.

• In general, there is an increase in volume given by $\frac{\Delta V}{V_0} = (1 - 2\nu)\varepsilon$ where $\Delta V$ = increase in initial volume $V_0$ caused by straining the sample.
Comparison of Moduli and Poisson’s Ratio

<table>
<thead>
<tr>
<th>Material</th>
<th>E (GPa)</th>
<th>ν</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

<table>
<thead>
<tr>
<th>DMA850 and Q800</th>
<th>RSA G2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness ((K)) = Force / Displacement</td>
<td>Stress ((\sigma)) = Force (\times K_\sigma)</td>
</tr>
<tr>
<td>Modulus ((E)) = (K \times GF)</td>
<td>Strain ((\gamma)) = Displacement (\times K_\gamma)</td>
</tr>
<tr>
<td>GF: Geometry factor. Clamp dependent Can be found in online help manual</td>
<td>Modulus ((E)) = (\frac{\sigma}{\gamma})</td>
</tr>
</tbody>
</table>

\[
GF = \frac{K_\sigma}{K_\gamma}
\]
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 ($T_g < RT$) 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, $T_g$ of polymers (thermoplastics/thermosets)
  - Measurement of modulus and $\tan \delta$

- Typical sample length is 17.5 mm. Smaller sizes available.

- Use a consistent clamping torque (typically 10 in-lbs)
Geometry Factor - Single Cantilever Clamp

Modulus = Stiffness × Geometry Factor

\[
GF_{sc} = \frac{12 \cdot l^3 \left[ 1 + \frac{12}{5} (1+v) \left( \frac{t}{l} \right)^2 \right]}{12 w t^3}
\]

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

\[
GF_{sc} = \frac{l^3}{w t^3}
\]

w  = sample width
l  = sample length
t  = sample thickness
DMA: Dual Cantilever Clamp

- 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 T_g 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)
Geometry Factor - Dual Cantilever Clamp

Modulus = Stiffness \times Geometry Factor (GF)

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

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}{2 w t^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 $\tan \delta$
- 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

\[ GF_{3PB} = \frac{3l^3}{12wt^3} \left[ 1 + \frac{6}{10}(1+\nu)\left(\frac{2t}{l}\right)^2 \right] \]

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

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

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)
Geometry Factor – Film/fiber/tension clamp

Modulus = Stiffness × Geometry Factor

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

w = sample width
l = sample length
t = 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 Tg) 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 δ)
- 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
- 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 $\times$ Geometry Factor

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

$r = \text{sample radius}$
$t = \text{sample thickness, between clamp faces}$
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, T_g, secondary transitions (modulus and tan δ)
- Sample size <= plate size
Operating Range of the Shear Sandwich Clamp

Modulus = Stiffness $\times$ Geometry Factor

$$GF_{\text{Shear}} = \frac{3t}{5wh}$$

- $w$ = 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>
<tr>
<td>Dual/Single Cantilever</td>
<td>Decrease length or increase width. If possible increase thickness. Note: L/T ≥ 10</td>
<td>Increase length or decrease width,, If possible decrease thickness. Note: L/T ≥ 10</td>
</tr>
<tr>
<td>Three Point Bending</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>Compression – circular sample</td>
<td>Decrease thickness or Increase diameter.</td>
<td>Increase thickness or decrease diameter.</td>
</tr>
<tr>
<td>Shear Sandwich</td>
<td>Decrease thickness or Increase length and width.</td>
<td>Increase thickness or decrease length and width.</td>
</tr>
</tbody>
</table>
# 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 T&lt;1 mm</td>
</tr>
<tr>
<td>Films/Fibers</td>
<td>Tension</td>
<td>L 10-20 mm T&lt;2 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>

- **L/T**: Length to Thickness ratio
- **T**: Thickness of the sample
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](https://www.youtube.com/user/TATechTips)
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)

See also: 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 > osc. force

Pre-stretched sample

Half-cycle down

Fixed clamp

Half-cycle up

Sample remains taut
Net forces acting during oscillation (tension)
static force < osc. force

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

$F_{\text{static}} > F_{\text{osc.}}$

Moveable clamp maintains contact with sample at all times due to net downward force
Net forces acting during oscillation (compression)
static force < osc. force

Half-cycle down

Half-cycle up

Moveable clamp loses contact with sample on half-cycle up due to net upwards force
Force track

- 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 through out the entire experiment.
  - Stiff samples in 3-point bending (thermosets)
Temperature Ramp with Force Track

- Q800 uses the term “Dynamic Force” to denote oscillation force ($F_{osc}$)
- Static Force tracks Dynamic Force throughout Temperature Ramp to prevent over-stretching
Offset Force on DMA850

- **Constant static force**

  - Clamp: Film Clamp
  - Oscillation
  - Temperature Ramp

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>20.0  μm</td>
</tr>
<tr>
<td>Frequency</td>
<td>1.0 Hz</td>
</tr>
<tr>
<td>Initial/preload force</td>
<td>2.0 N</td>
</tr>
<tr>
<td>Use Force Track</td>
<td>125.0 %</td>
</tr>
</tbody>
</table>

- **Force track**

  - Clamp: Film Clamp
  - Oscillation
  - Temperature Ramp

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</tr>
<tr>
<td>Frequency</td>
<td>1.0 Hz</td>
</tr>
<tr>
<td>Initial/preload force</td>
<td>0.1 N</td>
</tr>
<tr>
<td>Use Force Track</td>
<td>125.0 %</td>
</tr>
</tbody>
</table>

  - Use current temperature
  - Ramp from 35 °C to 150 °C
  - Ramp rate 3.0 °C/min
  - Soak times
    - at Start temperature 00:05:00 hh:mm:ss
    - at End temperature 00:00:00 hh:mm:ss
  - Estimated time to complete 00:38:20 hh:mm:ss

  Test Settings  Post Test Conditions
Offset Force on Q800

- **Constant static force**

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

- **Constant static force**

- **Force track**
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 Thermoplastic Sample</td>
<td>1 N</td>
<td>125 to 150%</td>
</tr>
<tr>
<td>Three Point Bending Stiff Thermoset Sample</td>
<td>1 N</td>
<td>150 to 200%</td>
</tr>
</tbody>
</table>

Note: Constant (or static) force can be used as long as static force > dynamic force throughout the entire experiment.
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
Dynamic Strain Sweep: Material Response

- **\( \gamma_c \)** = Critical Strain
- Linear viscoelastic region: Results independent of strain
- Constant Slope
- Oscillation strain \( \varepsilon \) (%)
- Storage modulus \( E' \) (Pa)
- Oscillation stress \( \sigma' \) (Pa)
Programming Strain Sweep on DMA850

Sample:

Clamp: Film Clamp

Oscillation

Strain Sweep

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

Sweep Mode
- Logarithmic
- Linear
- Discrete

Strain: 0.01% to 10.0%
Points per decade: 5
Number of Sweeps: 1

Test Settings
Post Test Conditions
Programming Strain Sweep on Q800

Mode: DMA Multi-Strain

Material is held isothermally and deformed over a range of strain amplitudes at a single frequency.

Strain Sweep

- Frequency: 1.00 Hz
- Preload force: 0.0100 N
- Force track: 125%

Isothermal temperature: 35.00 °C
Soak time: 5.00 min
Number of sweeps: 1

Amplitude Table

- Amplitude: 0.100 μm to 100.000 μm
- Number of points: 19
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
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
Programming Time Sweep/fatigue on DMA850

• Time sweep example

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>25 °C</td>
</tr>
<tr>
<td>Soak time</td>
<td>60.0 s</td>
</tr>
<tr>
<td>Strain</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Frequency</td>
<td>1.0 Hz</td>
</tr>
<tr>
<td>Duration</td>
<td>300.0 s</td>
</tr>
<tr>
<td>Initial/preload force</td>
<td>0.1 N</td>
</tr>
<tr>
<td>Use Force Track</td>
<td>✔️</td>
</tr>
<tr>
<td>%</td>
<td>125.0</td>
</tr>
</tbody>
</table>

Data sampling mode:
- seconds/pt
- Total points
  - Sampling interval: 10.0 s/pt

Test Settings | Post Test Conditions

• Fatigue example

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>25 °C</td>
</tr>
<tr>
<td>Soak time</td>
<td>00:05:00</td>
</tr>
<tr>
<td>Amplitude</td>
<td>20.0 µm</td>
</tr>
<tr>
<td>Frequency</td>
<td>1.0 Hz</td>
</tr>
<tr>
<td>Initial/preload force</td>
<td>0.01 N</td>
</tr>
<tr>
<td>Use Force Track</td>
<td>✔️</td>
</tr>
<tr>
<td>%</td>
<td>125.0</td>
</tr>
<tr>
<td>Total cycles</td>
<td>10000.0</td>
</tr>
</tbody>
</table>

Data sampling mode:
- seconds/pt
- cycles/pt
- Total points
  - Sampling interval: 10.0 s/pt

Test Settings | Post Test Conditions
Programming Time Sweep on Q800

Mode: DMA Multi-Frequency-Strain
Programming Time Sweep on RSA G2

- Time sweep example

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

- 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
  - Total cycles: 10000.0
  - Total time: 02:46:40
  - Measure every: 2.0
  - Strain %: 2.0
  - Frequency: 1.0 Hz

- Data acquisition
  - Advanced
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
What are Happy and Sad Balls?

- 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

- Happy Ball
- Sad Ball

Graph showing the relationship between Frequency $f$ (Hz) and $\tan(\delta)$, with logarithmic scales on both axes.
Dynamic Mechanical Properties: Tan Delta

- $\tan \delta$: Measure of material damping. Balancing viscous property while having the appropriate level of stiffness.

- Increasing $\tan \delta$ 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 $\tan \delta$ compared to the happy ball.
Frequency Sweep: Material Response

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

Log Frequency (rad/s or Hz)

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

Storage Modulus (E' or G')
Loss Modulus (E'' or G'')
Programming Frequency Sweep on DMA850

- Sample:
- Clamp: Film Clamp

Oscillation → Frequency Sweep

- Temperature: 25 °C
- Soak time: 60.0 s
- Strain: 0.5 %
- Initial/preload force: 0.1 N
- Use Force Track: 125.0 %

Sweep Mode:
- Logarithmic
- Linear
- Discrete

- Frequency: 0.1 Hz to 50.0 Hz
- Points per decade: 5
- Number of Sweeps: 1

Test Settings → Post Test Conditions
Programming Frequency Sweep on Q800

Mode: DMA Multi-Frequency-Strain

- **Procedure Information**
  - **Isothermal Temp / Freq Sweep**
  - 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 Parameters**
  - **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**
  - **Frequency**:
    - Single
    - Log
  - **Range**: 0.10 Hz to 10.00 Hz
  - **Points per decade**: 5

- **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.
Programming Frequency Sweep on RSA G2

- **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**: 60.0 s

**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.
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
DMA temperature ramp: Happy and sad balls
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

  **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/pt
  - Strain %: 0.06%
  - Frequency: 1.0 Hz

  **Data acquisition**
  - Advanced

- 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
  - End temperature: 200 °C
  - Temperature slew: 10 °C
  - Step soak time: 300.0 s

  **Test Parameters**
  - Strain %: 0.02%

  **Logarithmic sweep**
  - Frequency: 0.1 Hz to 10.0 Hz
  - Points per decade: 5

  **Data acquisition**
  - Advanced

Note: Measurement can be done with single or multiple frequencies
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 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 $\epsilon(t)$).

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

Response of Classical Extremes

**Elastic**
- Stain for t > t1 is constant
- Strain for t > t2 is 0

**Viscous**
- Stain rate for t > t1 is constant
- Strain for t > t1 increase with time
- Strain rate for t > t2 is 0
Creep Recovery Experiment

Creep $\sigma > 0$

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

Viscous

Visco-elastic

Elastic

Creep Zone

Recovery Zone

$\sigma/\eta$

t$_1$

t$_2$

time
Creep Recovery: Creep and Recoverable Compliance

**Creep Compliance**

\[ J(t) = \frac{\gamma(t)}{\sigma} \]

Creep experiments report the material property *Compliance* which is in a sense the inverse of Modulus.

**Recoverable Compliance**

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

Where \( \gamma_u \) = Strain at unloading
\( \gamma(t) \) = time dependent recoverable strain

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

Graph: Logarithmic plot of creep compliance ($J_c$) against log time.
Programming Creep Recovery on a DMA850

[Image of software interface showing settings for experiment 1, including:
- Sample
- Clamp: Film Clamp
- Stress Control
- Creep Recovery

Settings include:
- Temperature: 30 °C
- Soak time: 60.0 s
- Preload force: 0.01 N
- Stress: 500.0 Pa
- Creep time: 120.0 s
- Recovery time: 240.0 s

Data sampling mode options: Linear, Log
Sampling rate: 1.0 pts/s]
Programming Creep Recovery on a Q800

**Creep**
- **Preload force:** 0.0010 N
- **Stress:** 1.0000 MPa
- **Isothermal temperature:** 35.00 °C
- **Soak time:** 5.00 min
- **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 Environmental Control
  - Temperature: 30°C
  - Soak time: 60.0 s
- Run and Calculate
  - Strain %: 0.05%

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

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 $\sigma(t)$.
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 modulus $E(t)$ vs. step time $t_s$ (s) with lines for Happy Ball and Sad Ball.](image)

- Happy Ball
- Sad Ball
Stress Relaxation: Material Response

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

log Stress Relaxation Modulus $E(t)$ or $G(t)$

log time
Programming Stress Relaxation on a DMA850

Temperature: 50 °C
Soak time: 120.0 s
Preload force: 0.01 N
Strain: 1.0 %
Relaxation time: 600.0 s
Recovery time: 0.0 s

Data sampling mode: Linear
Sampling rate: 1.0 pts/s
Programming Stress Relaxation on a Q800

- Stress Relaxation
  - 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 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
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

---

### DMA Iso-strain

**Environmental Control**
- Start temperature: 20°C
- Soak time: 180.0 s
- Ramp rate: 3.0 °C/min
- End temperature: 200°C
- Soak time after ramp: 0 s
- Estimated time to complete: 01:00:00 h:mm:ss

**Test Parameters**
- Sampling rate: 1.0 pts/s
- Tension: 0.1 %
- Maximum force: 20.0 N

---

### DMA Iso-force

**Environmental Control**
- Start temperature: 20°C
- Soak time: 180.0 s
- Ramp rate: 3.0 °C/min
- End temperature: 200°C
- Soak time after ramp: 0 s
- Estimated time to complete: 01:00:00 h:mm:ss

**Test Parameters**
- Sampling rate: 1.0 pts/s
- Motor direction: Tension
- Constant axial force: 0.01 N

---

Data acquisition
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 %

Strain hardening

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

Young's Modulus: 2.08e7 Pa
$R^2$: 0.999662

Geometry: Tension
Temperature: 37°C
Rate: 10 μm/s
Strain/Stress Ramp on a DMA850

**Strain Ramp**

- Sample: [Image]
- 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 μm to 100.0 μm
- Ramp rate: 20.0 μm/min
- Data sampling mode: Linear
- Sampling rate: 1.0 pts/s

**Stress Ramp**

- Sample: [Image]
- 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 N to 5.0 N
- Ramp rate: 1.0 N/min
- Data sampling mode: Linear
- Sampling rate: 1.0 pts/s

Test Settings | Post Test Conditions
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**
  - Sample: PET film LN2 only
  - Geometry: Tension fixture (rectangle)
  - Procedure of 1 step: Other Axial
  - Environmental Control
    - Temperature: 30 °C
    - Soak time: 60.0 s
  - Test Parameters
    - Duration: 120.0 s
    - Motor direction: Tension
    - Constant linear rate: 1.0 mm/s
    - Maximum gap change: 15.0 mm
  - Sampling
    - Sampling rate: 1.0 pts/s

- **Hencky strain rate**
  - Sample: PET film LN2 only
  - Geometry: Tension fixture (rectangle)
  - Procedure of 1 step: Other Axial
  - Environmental Control
    - Temperature: 30 °C
    - Soak time: 60.0 s
  - Test Parameters
    - Duration: 120.0 s
    - Motor direction: Tension
    - Hencky strain rate: 1.0 1/s
    - Maximum gap change: 15.0 mm
  - Sampling
    - Sampling rate: 1.0 pts/s
Summary of Day 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
    - Clamp calibration routines
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
Getting Started Manuals on your desktop

**Discovery DMA 850 Manuals**
- To view the desired manual using Acrobat Reader, click the name in the list below:
  - TA Manual Supplement (Contains important information applicable to all manuals.)
- Instrument Documentation
  - Discovery DMA 850 Getting Started Guide
- Accessory Documentation
  - Air Chiller System (ACS) Getting Started Guide
  - DMA-Perp Accessory Getting Started Guide
  - Gas Cooling Assembly (DCCS) Getting Started Guide
  - Nitrogen Pump Cooler (NPC) Getting Started Guide
- Software Documentation
  - What's New in TRIOS Software
  - Installing TRIOS Software
- Site Preparation Guides and Installation Requirements
  - Discovery DMA 850 Site Preparation Guide
- Additional Information
  - DMA Clamping Factors for Compression Clamps

**RSA-G2 Manuals**
- To view the desired manual using Acrobat Reader, click the name in the list below:
  - TA Manual Supplement (Contains important information applicable to all manuals.)
- Instrument & Accessory Documentation
  - RSA-G2 Getting Started Guide
  - RSA-G2 PC01 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 - UPDATED
- 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

**Q Series™ Manuals**
- To view the desired manual using Acrobat Reader, click the name in the list below:
  - TA Manual Supplement (Contains important information applicable to all manuals.)
- Instrument & Accessory Manuals
  - TA Series™ Instrument Control Getting Started Guide
  - Universal Analysis Getting Started Guide
  - Advantage Integrity™ Getting Started Guide
  - Specialty Library Getting Started Guide
  - BMX 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
  - BMX File Utilities
- Miscellaneous Documents
  - Installing/Updating Advantage™
  - Updating Q Series™ Instrument Software
  - New Features in Advantage™
  - New Features in Advantage Integrity™
  - TA Update

**New Features in Advantage™**
- DMS DSC Getting Started Guide
- DCW Getting Started Guide
- QA Series™ Getting Started Guide
- DMA Scanning Guide
- DMAS Accessory Getting Started
- TGA™ Series™ Getting Started Guide
- TQ Series™ Getting Started Guide
- TA Update

**New Features in Advantage Integrity™**
- DMS DSC Getting Started Guide
- DCW Getting Started Guide
- QA Series™ Getting Started Guide
- DMA Scanning Guide
- DMAS Accessory Getting Started
- TGA™ Series™ Getting Started Guide
- TQ Series™ Getting Started Guide
- TA Update
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: Stress Sweep
- Oscillation: Temperature Sweep (Multifrequency)
- Oscillation: Temperature Ramp (Multifrequency)
- Oscillation: Time Sweep
- Oscillation: Temperature Ramp (Multifrequency)
- Rate Control: Strain Ramp
- Rate Control: Stress Ramp

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 Sweep

Trios and Advantage Help
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)
Instructional Video Resources

Quickstart e-Training Courses

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/
Need DMA HELP?!?

• Check the manuals, help and error help.
• Contact the TA Instruments Rheology Hotline
  ▪ Email rheologysupport@tainstruments.com
• Call the TA Instruments Service Hotline
  ▪ 302-427-4050  M-F  8-4:30 ET
• Call your local Technical or Service Representative
• Visit our Website www.tainstruments.com for training videos, TA Tech tips, application notes and much more!