Normal force control is an additional option for the AR500 & AR1000 and standard on the AR2000 series rheometers. This feature is important for many applications, from measuring samples in torsion to ensuring contact is maintained between the geometry and sample during testing. This brief will describe how normal force control operates, understanding normal force control parameters, and cite specific values to use when testing materials with normal force control.

**When should normal force control be used?**

Normal force control should be used when materials expand and/or contract during testing. If these changes in volume occur, the material will either cause a normal stress field within the material or shrink away from the testing geometry, either way inducing error into the results. Generally, volume changes within a material often occur by a change in temperature, solvent/moisture loss or when the material gels. In order to convey the use of normal force completely, the remainder of this paper will associate the volume change of a material with a change in temperature, or simply, its coefficient of expansion. The most widely used test mode to control normal force is oscillation and the procedure type is a temperature ramp.

**NOTE:** Normal Force Control is disabled when using a cone & plate type geometry, since correct rheological results depend on the truncation gap to remain constant when using this type of geometry.

**How does normal force control work?**

The air bearing system contains two thrust air bearings, which virtually eliminates upward movement of the drive shaft, allowing any volumetric change of the sample to be sensed by the normal force transducer. The normal force transducer is located below the bottom testing assembly, i.e. fixed Peltier Plate (AR1000 & AR500) or below the Smart Swap™ magnet (AR2000). When the material undergoes a change in volume, assuming the material is stiff enough to translate the resultant force, the normal force transducer will detect a change in normal force and the linear ball slide will increase or decrease the gap accordingly. This will result in the normal force conditions, set-up prior to the start of the procedure, to be maintained.

**NOTE:** During the oscillation normal force control is disabled. When the oscillation has completed, all data is collected and the normal force will be adjusted appropriately, if outside the chosen normal force conditions.
Controlling Normal Force

Normal force can be activated either on a global/macroscopic scale, maintaining the specified conditions prior to, during and after the testing, or microscopic scale, maintaining the specified conditions when the test is started.

Global/Macroscopic Control

In order to activate normal force control after loading the sample and prior to the start of the procedure, the user must either go to the main tool bar and choose Instrument>Normal Force>Control Normal Force or view the Instrument status page by choosing and then choosing the button. **NOTE:** This button is only active when the Instrument Status page is viewed.

Microscopic Control

The normal force control can be automatically turned on at the instant the procedure is started by activating it in the conditioning step under the Normal force tab, shown in Figure 1. In order for microscopic control to be activated, the box labeled ‘Use current instrument settings’ must be unchecked, and check the box ‘Active’.

Figure 1

Global/Macro to Micro Control

Another method to control normal force is to activate both the global/macro mode and the microscopic control with different parameters. This will automatically change the normal force settings from global/macro control to micro control.

Turning off Global/Macro Control when the test begins

The global/macro control can be automatically turned off when the procedure is started by de-selecting both the ‘Use current instrument setting’ and the ‘Active’ boxes located within the conditioning step of the procedure.
**Control Settings**

Upon performing either global/macro or micro control, the following choices will appear (Figure 2).

![Figure 2](image)

In order to activate the normal force control, the ‘Active’ box must be selected. The ‘Normal force’ box is where the user can set the value applied to the sample by the rheometer. The ‘Normal force tolerance’ is the amount of variability in the applied force without any adjustment of the instrument to correctly maintain the applied value set in the ‘Normal force’ box. The ‘Gap change limit down’ and ‘Gap change limit up’ is the amount, in micrometers, that the head will move to maintain the set force value. Once either of these limits is exceeded, normal force control will cease. To determine the allowable range that the instrument will travel to control normal force, one must add or subtract the up and down limits, respectively, to the gap value that is being measured when the normal force control is activated. If it is necessary to apply the ‘Normal force’ immediately before the test commences, check the box ‘Set initial value’. If unchecked, the normal force will be controlled within the tolerance window.

The section labeled ‘Action when outside the range’ maintains the normal force within the tolerance range during the time normal force control is activated. ‘Return to initial value’ maintains the value set in the ‘Normal force’ box at all times. The ‘Return to window’ selection allows the instrument to maintain a value of ‘Normal force’ plus or minus the ‘Normal force tolerance’ (this option is recommended to use). The last section shows an option to either control the normal force in ‘Tension’ or in ‘Compression’. This setting will apply the force either in an upward or downward direction, respectively. A negative force will signify a tensile force and a positive force signifies a compressive force, when viewed by the software.
**General Conditions for Different Materials**

Table 1: Recommended Values for Torsion (Tension Mode)*

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Normal Force</th>
<th>Normal Force Tolerance</th>
<th>Gap change (down)</th>
<th>Gap change (up)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft thermoplastic above Tg @ RT</td>
<td>2 N</td>
<td>1.75 N</td>
<td>2000 microns</td>
<td>5000 microns</td>
</tr>
<tr>
<td>Stiff thermoplastic below Tg @ RT</td>
<td>2 N</td>
<td>1.75 N</td>
<td>2000 microns</td>
<td>5000 microns</td>
</tr>
<tr>
<td>Elastomer above Tg @ RT</td>
<td>1 N</td>
<td>0.5 N</td>
<td>2000 microns</td>
<td>5000 microns</td>
</tr>
<tr>
<td>Stiff thermoset below Tg @ RT</td>
<td>5 N</td>
<td>4 N</td>
<td>1000 microns</td>
<td>5000 microns</td>
</tr>
</tbody>
</table>

Table 2: Recommended Values for Parallel Plate (Compression Mode)*

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Normal Force</th>
<th>Normal Force Tolerance</th>
<th>Gap change (down)</th>
<th>Gap change (up)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isothermal test</td>
<td>1 N</td>
<td>0.2 N</td>
<td>10 -15% gap</td>
<td>10 -15% gap</td>
</tr>
<tr>
<td>Cure (starts as solid)*</td>
<td>5 N</td>
<td>6 N</td>
<td>10 -15% gap</td>
<td>10 -15% gap</td>
</tr>
<tr>
<td>Cure (starts as liquid)*</td>
<td>0.5 N</td>
<td>2 N</td>
<td>10 -15% gap</td>
<td>10 -15% gap</td>
</tr>
<tr>
<td>PSA *</td>
<td>1 N</td>
<td>3 N</td>
<td>10 -15% gap</td>
<td>10 -15% gap</td>
</tr>
</tbody>
</table>

* NF conditions are shown as examples and may need adjustment based on the first set of results
* Set Initial value
* Do not set the initial value