



<b>SURFACE VEHICLE RECOMMENDED PRACTICE</b>	<b>J2964™</b>	<b>NOV2023</b>
	Issued	2018-01
	Revised	2023-11
Superseding J2964 JAN2018		
Low-Speed Continuous Slip SAE No. 2 $\mu$ PVT Procedure		

## RATIONALE

This document includes an updated reference to JASO, rewritten test parts installation, rewritten description of operation for better clarity, and additional figure for the Break-In phase.

### 1. SCOPE

This SAE Recommended Practice is intended as the definition of a standard test, which may be subject to frequent change to keep pace with experience and technical advances. This should be kept in mind when considering its use.

The SAE No. 2 friction test is used to evaluate the friction characteristics of automatic transmission plate clutches with automotive transmission fluid combinations.

The specific purpose of this document is to define a  $\mu$ PVT test for the evaluation of the variation of wet friction system low speed slip characteristics as a function of speed, temperature, and pressure. This procedure is intended as a suggested method for both suppliers and end users.

The only variables selected by the supplier or user of the friction system are:

- Friction material
- Fluid
- Reaction plates
- Oil flow (optional)

These four variables must be clearly identified when reporting the results of this test. If any of the test parameters or system hardware as described in this document are changed—other than the friction material, test fluid, or reaction plates—the data may not be reported as being obtained using this document.

This procedure is intended to evaluate ramped speed friction characteristics, also called sweeps, and can be used to demonstrate capacity changes that occur between the different levels of slip speed, applied pressure, and fluid temperature. The level of coefficient of friction, as well as the trends in torque capacity with speed, can be used to compare candidate materials or fluids.

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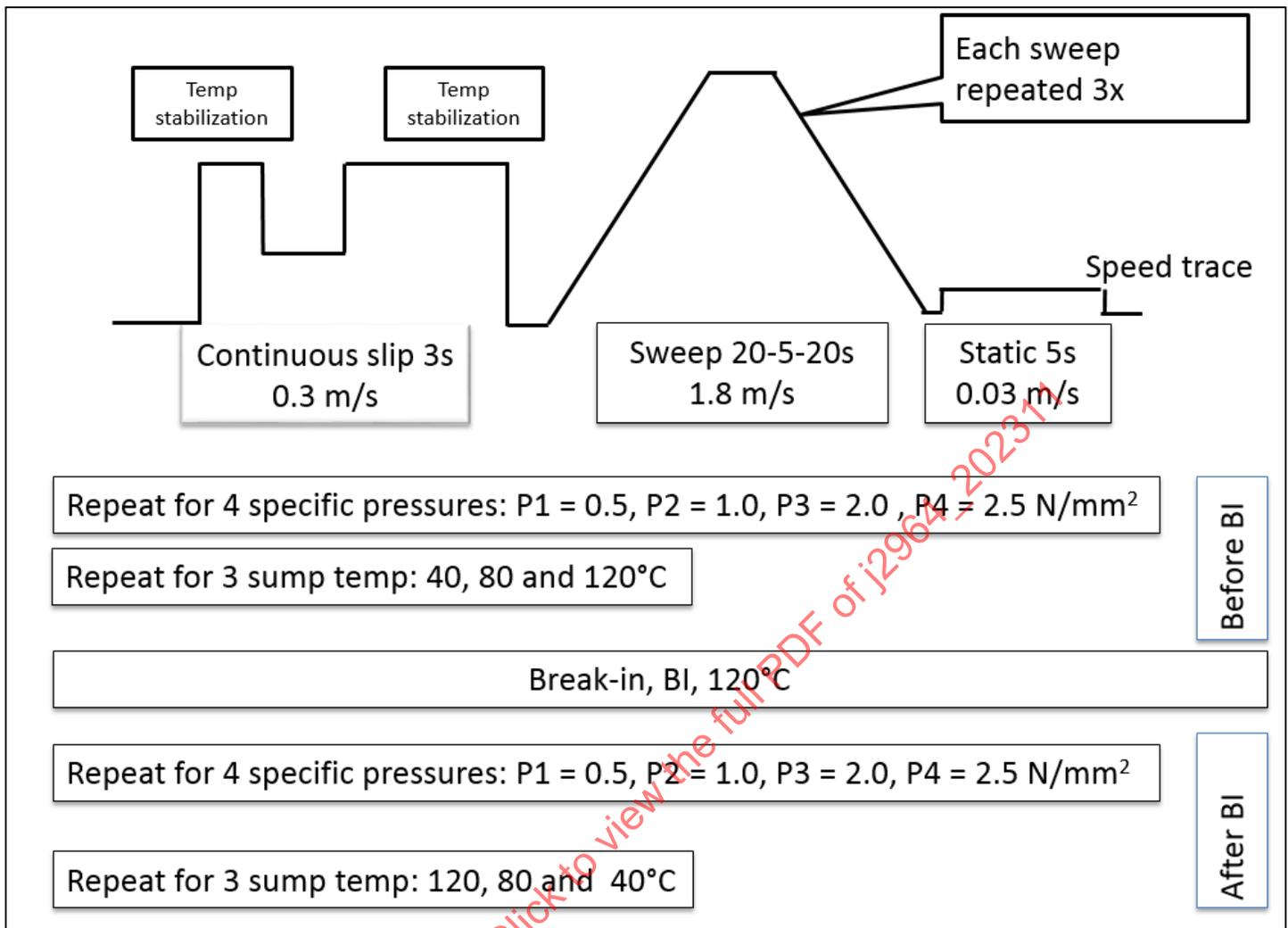


Figure 1 - Test events

Table 1 - Clutch data

Parameter	Symbol	Unit	Value
Lining outside diameter	OD	m	0.1460
Lining inside diameter	ID	m	0.1205
Lining mean diameter	Dm	m	0.13325
Lining mean radius	$r_e$	m	0.066625
Surface area	$A_g$	$\text{m}^2$	0.00534
Number of friction surfaces	$n_r$	#	2
Area of standard piston	$A_p$	$\text{m}^2$	0.0151
Assumed friction coefficient	$\mu$		0.13

Table 2 - Applied pressure

Parameter	Formula	Symbol	Unit	A	B	C	D
Applied air pressure		$P_p$	kPa	175	355	708	885
Axial load	$P_p \cdot A_p$	$F_A$	N	2643	5361	10691	13364
Specific gross (lining) pressure	$F_A / A_g$	$P_g$	MPa	0.50	1.00	2.00	2.50
Engagement torque	$n_r F_A \cdot \mu \cdot r_e$	$T$	N·m	45.9	93.1	185.8	232.2

**Table 3 - Speed conversion for  $D_m=0.13325\text{ m}$** 

Test Phase	rpm	m/s
Static	4.3	0.030
Continuous slip step	43	0.300
Speed ramp	258	1.800
Break-in	86	0.600
Reference	300	2.093

## 2. REFERENCES

### 2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

#### 2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

SAE J286 SAE No. 2 Clutch Friction Test Machine Guidelines

SAE J1646 Glossary of Terms - Lubricated Friction Systems

SAE J2490 SAE No. 2 Friction Test Machine  $\mu$ PVT Test

Morgan, C., Fewkes, R., McCombs, T., Tersigni, S. et al. (2004). *Low-speed carbon fiber torque capacity and frictional properties test for ATFs* (SAE Technical Report No. 2004-01-3026). 2004 Powertrain & Fluid Systems Conference & Exhibition. <https://doi.org/10.4271/2004-01-3026>.

### 2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

#### 2.2.1 JSAE Publications

Available from Society of Automotive Engineers of Japan (JSAE), 10-2 Gobancho, Chiyoda-Ku, 102-0076 Japan, Tel: +81-3-3262-8211 <https://www.jsae.or.jp/en/>.

JASO M349-2010 Test Method for Anti-Shudder Performance of Automatic Transmission Fluids

JASO M349-2012 Automatic Transmission Fluid Test Method for Anti-Shudder Performance

## 3. TEST EQUIPMENT

### 3.1 Test Machine

An SAE No. 2 friction test machine with low speed (300 rpm) drive or other test machine having adequate capabilities. Because machine design characteristics can have a significant effect on test results, users are advised to use caution when comparing results obtained on machines of different design. The standard test will be SAE No. 2 machine or equivalent with  $\varnothing 190\text{ mm}$  standard test head, piston area of  $0.0151\text{ m}^2$ . If a non-standard SAE No. 2 machine is used, the type shall be noted in the test report.

### 3.2 Data Acquisition

At not less than 1000 samples per second and storage system with at least six channels with response as follows:

- a. Torque channel: Bandwidth 500 Hz; accuracy shall be within  $\pm 0.5\%$  full range.
- b. Apply pressure channel: Bandwidth 500 Hz; accuracy shall be within  $\pm 0.5\%$  full range.
- c. Speed channel: Bandwidth 500 Hz; accuracy shall be within  $\pm 0.1\%$  full range.
- d. Test fluid temperature channel: Bandwidth 3 Hz; accuracy shall be within  $\pm 1\%$  full range.
- e. Front reaction plate temperature channel: Bandwidth 3 Hz; accuracy shall be within  $\pm 1\%$  full range.
- f. Rear reaction plate temperature channel: Bandwidth 3 Hz; accuracy shall be within  $\pm 1\%$  full range.

For digital data systems the data is to be recorded at a minimum of 1000 samples per second per channel using a 15 ms time constant RC filter.

### 3.3 Test Fluid System

Fixed fill 700 mL by filling oil up to the reservoir, or as appropriate for the machine being used. On machines so-equipped, fluid flow systems are permissible. The actual fluid volume and any flow system used shall be noted in the test report. Reference will be run at 1 L/min.

External flow (refer to Figure 7C in SAE J1646), this represents the configuration wherein an external pump supplies fluid at a specific flow rate through a line to the centerline of the shaft. A flowmeter shall be installed on the line to the cover to measure the flow supplied to the head. The reservoir is optional as a drain can be directly connected on the bottom of the test head, 5, 6, or 7 o'clock position.

### 3.4 Adapters and Reaction Plates

Adapters for an SAE No. 2 friction test machine including reaction plates, hub, retainer, and pressure plates and spacers are all described in Appendix A of SAE J2490. Other machines would use adapters suited to that machine.

### 3.5 Test Parts

The test requires one SAE No. 2 friction plate and two mating steel reaction plates.

The friction plate is described in item 6 of SAE J2490, Appendix A.

The steel reaction plates, also known as separator plates, are described in item 5 of SAE J2490, Appendix A. The orientation of the two steel plates is shown in Figure B3 in Appendix B. The coining side, rounded edge due to the stamping process shall face the front of the test head for both reaction plates.

Any modifications in plates orientation is permissible but it shall be documented in the final test report.

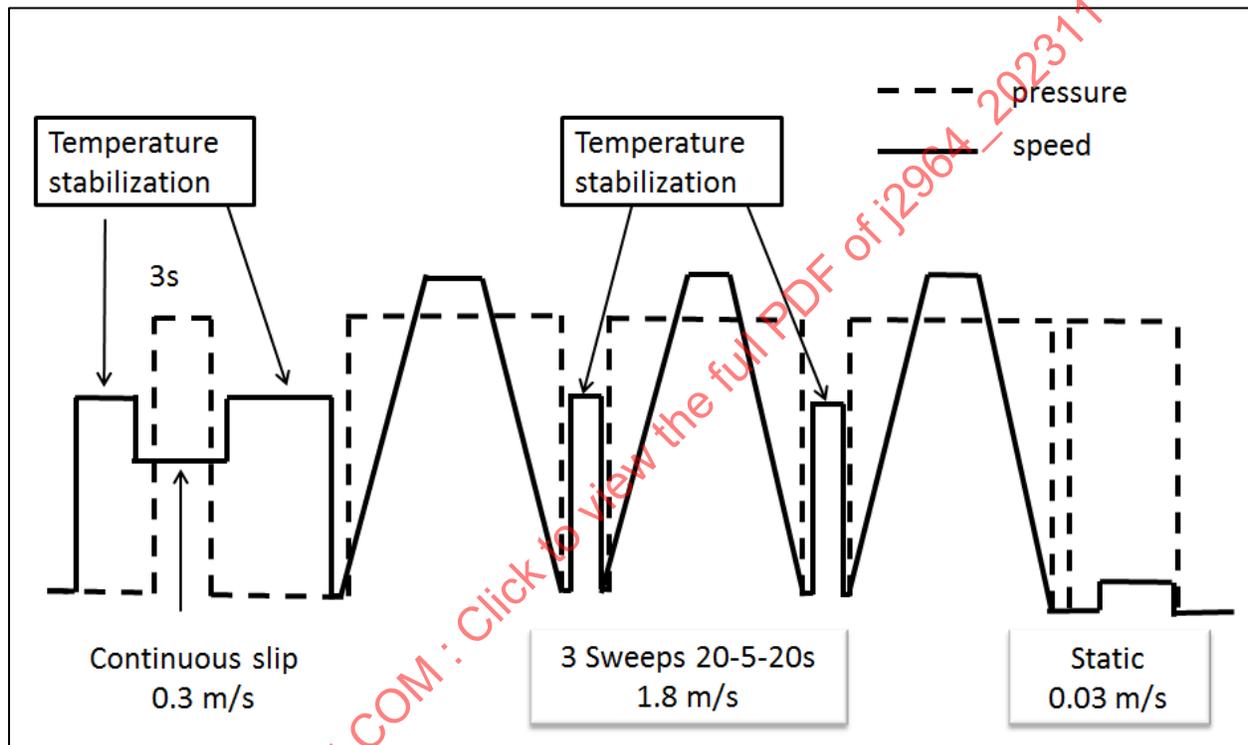
### 3.6 Apply Piston

A silicon compound seal is recommended for use with this high temperature fluid.

#### 4. OPERATING CONDITIONS AND TEST PARAMETERS

The test synopsis is given in Figure 1, and the test profile is described in Figure 2. The test profile is run for the four pressures P1 to P4 first at 40 °C. It is then repeated at 80 °C for the four pressures, and finally at 120 °C for the four pressures. This constitutes the before break-in (BBI) phase. A break-in phase is run at 120 °C (see 4.5). The test profile is then run at 120 °C for the four pressures and again for 80 °C and 40 °C. This constitutes the after break-in (ABI) phase. Temperature stabilization cycles are run between ramps to allow the bulk fluid and parts to regain temperature equilibrium. Fluid temperature for the second evaluation after break-in (ABI) is run from high to low temperature. The sweeps are repeated three times in order to improve repeatability.

Fluid temperature is the sump temperature measured at 7 o'clock with the sump thermocouple. A thermocouple is inserted in the middle thickness of each reaction plate and positioned in the middle point between two tabs (see Appendix B, Figure B2).



**Figure 2 - Test profile**

##### 4.1 Temperature Stabilization

- Heat the sump to the target specification (40, 80, or 120 °C).
- Maintain for 1 minute after attaining target temperature  $\pm 3$  °C.
- Speed 100 rpm.
- Surface pressure: 0 MPa (clutch open).

##### 4.2 Continuous Slip

- Change the rotational speed to 0.3 m/s (43 rpm  $\pm$  1 rpm per Table 3).
- Stabilize the speed during 1 second.
- Apply clutch with surface pressure: 0.5, 1.0, 2.0, and 2.5 MPa,  $\pm 3\%$  MPa.

- Duration 3 seconds  $\pm 0.05$  second speed step.
- Ramp rate to achieve pressure 0.2 to 0.25 second.
- Data recording: 1000 Hz.

#### 4.3 Ramp Cycles

Three consecutive sweeps which start after temperature stabilization.

- Initial/final motor speed: 0 m/s.
- Maximum part velocity: 1.80 m/s  $\pm 0.05$  m/s (258 rpm for plates per Table 3).
- Ramp up time: 20 seconds  $\pm 0.5$  second.
- Dwell (hold) time: 5 seconds  $\pm 0.5$  second.
- Ramp down time: 20 seconds  $\pm 0.5$  second.
- Surface pressure (gross): 0.5, 1.0, 2.0, and 2.5 MPa,  $\pm 3\%$  MPa.
- Data recording 100 Hz.

#### 4.4 Static Cycles

- This cycle should start immediately after the third sweep event with no temperature stabilization.
- Static motor speed: 0.03 m/s (4.3 rpm  $\pm 0.1$  rpm for plates per Table 3).
- Apply time: 5 seconds.
- Data recording 1000 Hz.

#### 4.5 Break-in

The break-in procedure is three 10-minute continuous slip cycles with 1 MPa surface pressure, 120 °C fluid temperature at 0.60 m/s sliding speed (86 rpm for plate per Table 1). Each continuous slip cycle is followed by 1 minute of pressure release at 0.6 m/s in order to cool and to refresh the fluid at the friction contact.

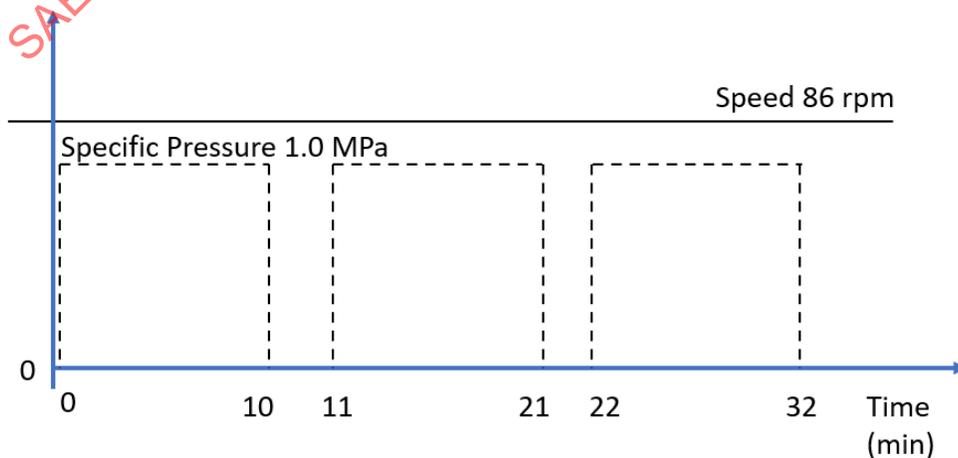


Figure 3 - Break-in profile

- Data recording 10 Hz.

#### 4.6 Pack Clearance

- 0.75 mm  $\pm$  0.15 mm.

### 5. GENERAL TEST INFORMATION

#### 5.1 Clean

Prior to each test the fixture and test cavity must be cleaned thoroughly and rinsed with solvent.

#### 5.2 Inspect

Inspect rotating shaft seals for deterioration and replace if necessary. If the seal is replaced, also replace the non-rotating lip seals on the apply piston.

#### 5.3 Soak

Soak friction element in the test fluid for at least 10 minutes at room temperature.

#### 5.4 Install clutch pack and check clearance per 4.6.

#### 5.5 Add fluid.

#### 5.6 Start test.

#### 5.7 Follow test summary schematic as in Figures 1 and 2 and Tables 1 through 3.

#### 5.8 Coefficient Calculations

Coefficient calculations are made per SAE J1646.

### 6. DATA REPORTING

#### 6.1 Data Tables

The data are reported for before break-in (BBI) and after break-in (ABI). The sweep data will be reported in function of time. It will include the traces for:

- Torque.
- Speed.
- Sump temperature.
- Reaction plate temperature (front and rear steel).

Since there are 12 sweeps BBI and 12 ABI, only the high temperature, 120 °C, ABI plots are needed. See Appendix A. Actual traces of the three repeats should be provided.

#### 6.2 Data Analysis for Ramps (Based on JASO M349:2010)

For the ramp down, the equation showing  $\mu$ -v characteristic shall be obtained from a 5th degree polynomial obtained by fitting the data of each sweeps using the least square method. The data should be sampled at 100 Hz starting from 0.1 m/s to the maximum speed 1.8 m/s.

Approximate  $\mu$ -v characteristic:

The  $\mu$  is approximated as:

$$\mu = a \cdot v^5 + b \cdot v^4 + c \cdot v^3 + d \cdot v^2 + e \cdot v + f \quad (\text{Eq. 1})$$

where  $v$  is the velocity and  $a$ ,  $b$ ,  $c$ ,  $d$ ,  $e$  and  $f$  the coefficient of the polynomial and  $\mu$  is unitless.

The slope is:

$$d\mu/dv = 5 \cdot a \cdot v^4 + 4 \cdot b \cdot v^3 + 3 \cdot c \cdot v^2 + 2 \cdot d \cdot v + e \quad (\text{Eq. 2})$$

The  $\mu$ - $v$  characteristics are plotted for each temperature for the four pressures ABI using the approximate expression. Values for  $\mu$  and  $d\mu/dv$  shall be reported for 0.3 and 0.9 m/s in Table 4. The  $d\mu/dv$  shall be multiplied by 1000 and reported to the first decimal (Table 5).  $d\mu/dv \cdot 1000$  unit is s/m.

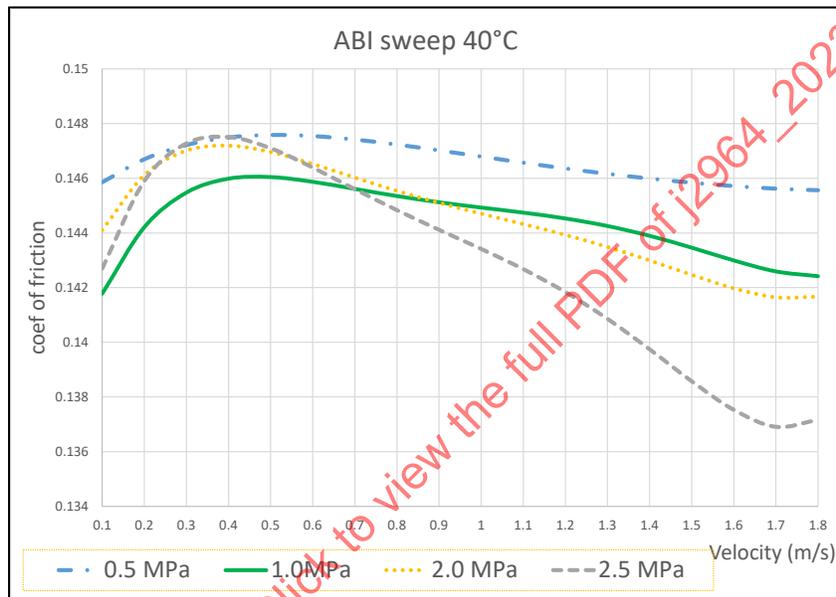


Figure 4 - Example  $\mu$ - $v$  plot

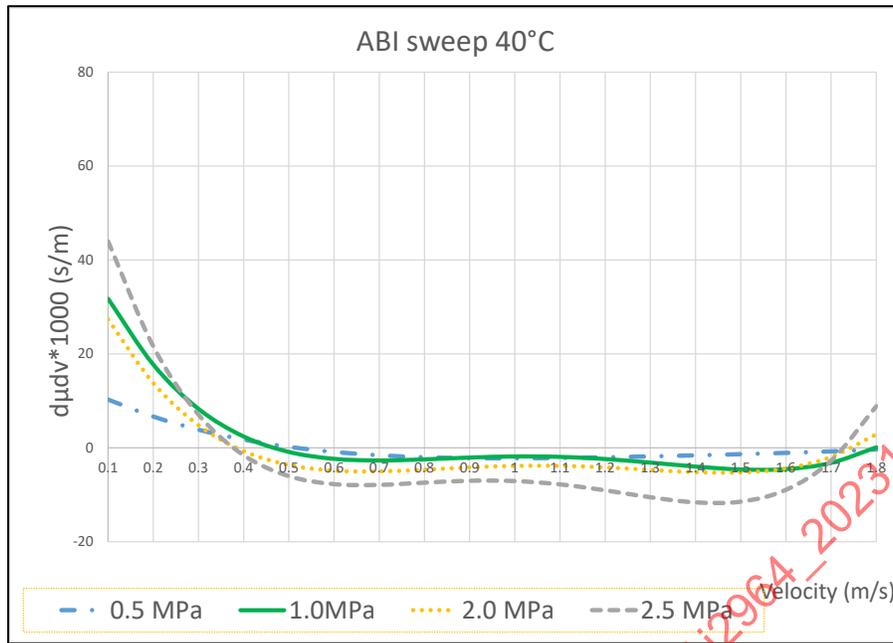


Figure 5 - Example  $d\mu/dv$  plot

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**Table 4 - Report table - sweep data  $\mu$  (ramp down) - coefficient of friction**

	Pressure	0.5 MPa		1.0 MPa		2.0 MPa		2.5 MPa	
	Speed Temp	0.3 m/s	0.9 m/s						
<b>BBI</b>	40 °C								
	80 °C								
	120 °C								
<b>ABI</b>	120 °C								
	80 °C								
	40 °C								

**Table 5 - Report table - sweep data  $d\mu/dv$  (ramp down) - slope \* 1000**

	Pressure	0.5 MPa		1.0 MPa		2.0 MPa		2.5 MPa	
	Speed Temp	0.3 m/s	0.9 m/s						
<b>BBI</b>	40 °C								
	80 °C								
	120 °C								
<b>ABI</b>	120 °C								
	80 °C								
	40 °C								

Per customer request:

- Upward ramp data may be required (optional).
- Tabular data for the  $\mu$ -v sweep may be required.
- Overlay of actual coefficient of friction with the polynomial curves, may be required.

### 6.3 Surface Condition of Friction Plate

At the end of the test, the steel plates and friction plates should be inspected. Any abnormalities as hot spot or cracks on the steel plate, heavy glazing, loss of material, heavy wear for the friction plates must be reported.

### 6.4 Continuous Slip Data

Report  $\mu$  at 2.9 seconds ( $\mu_{2.9}$  is the average of  $\mu$  over 17 ms centered at 2.9 seconds) for each temperature and pressure (see Table 6) to the third decimal.

### 6.5 Static Data

Report peak static measurement  $\mu_{s4.3}$  as average over 3 ms around the maximum of  $\mu$  after speed reach 0.03 m/s (dragging), and Torque,  $T > 5$  Nm.

Report static  $\mu_{t4.3}$ , average of 7 ms starting after 2 seconds from the dragging start ( $T > 5$  Nm) (see Figure 6). These static coefficients are reported for each pressure and each temperature (see Table 6), to the third decimal.

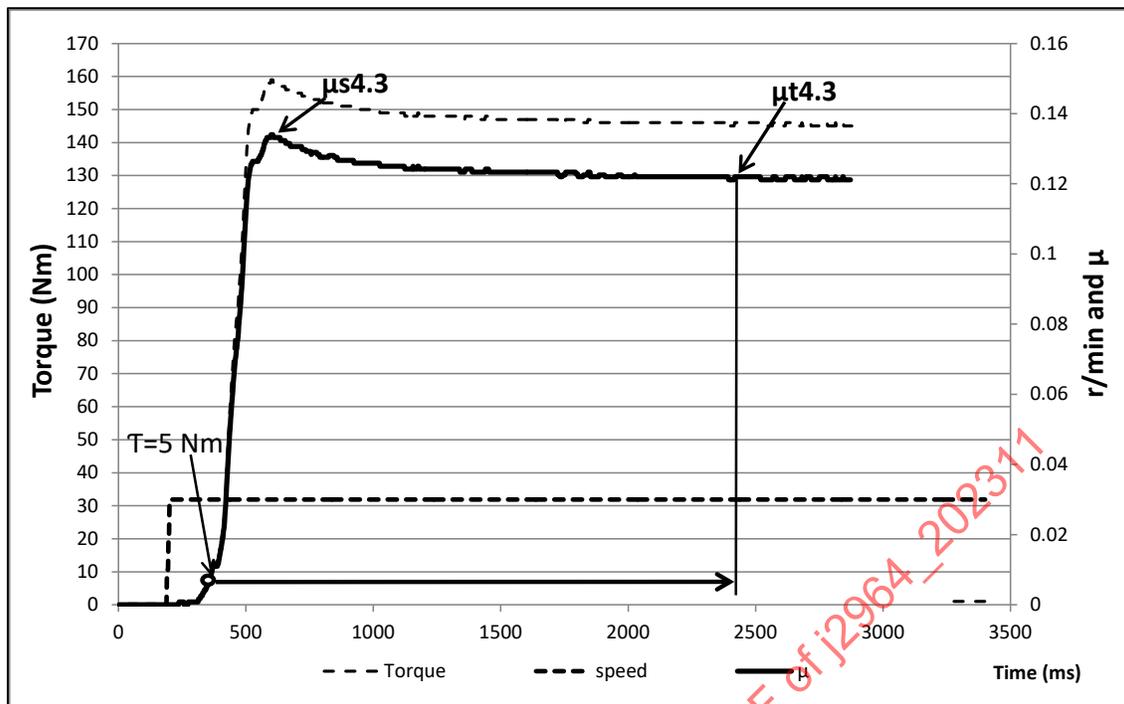


Figure 6 - Example of static trace

Table 6 - Continuous slip and static report table

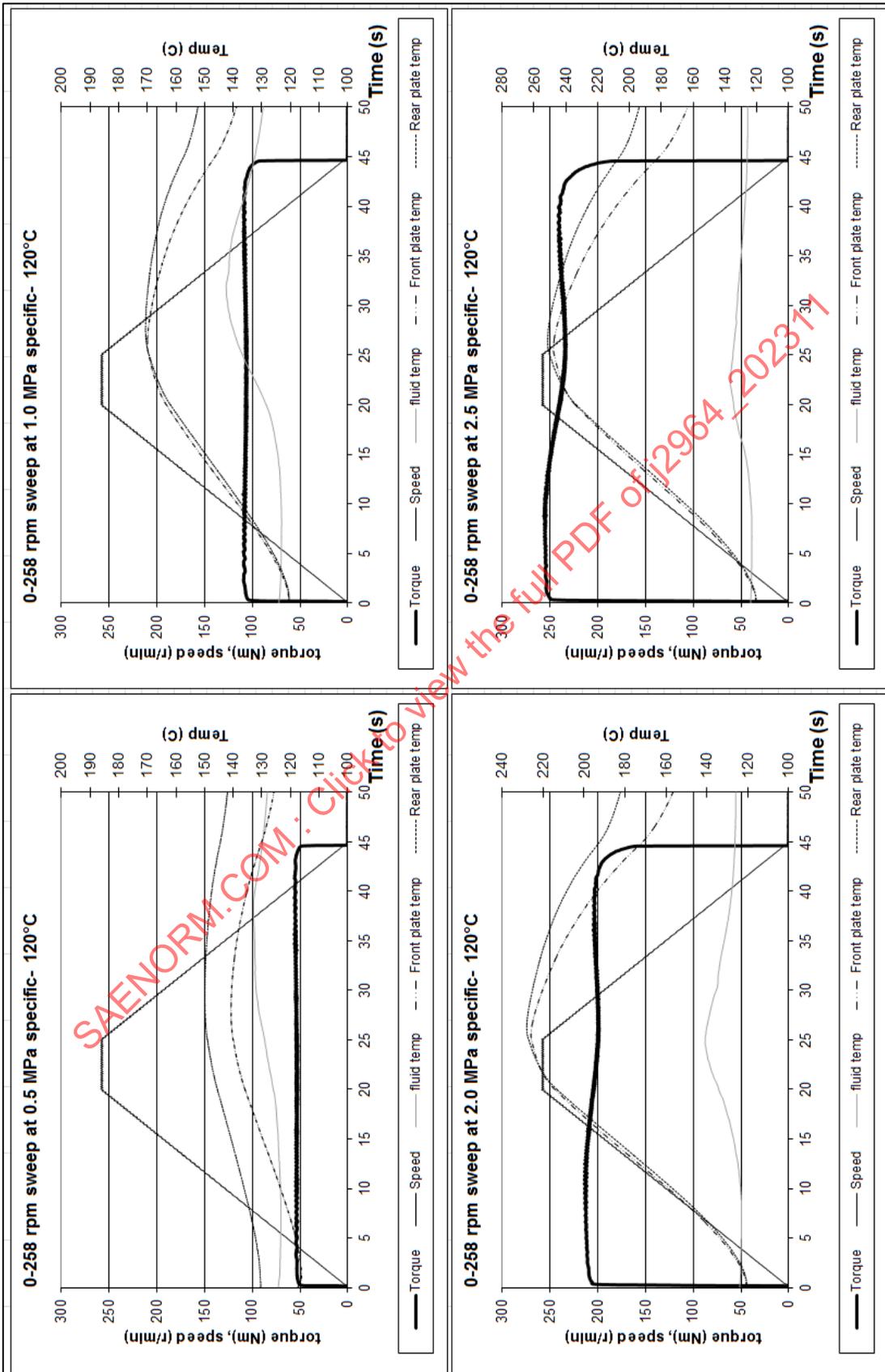
	Pressure Coefficient	0.5 MPa			1.0 MPa			2.0 MPa			2.5 MPa			
		Temp	μ2.9	μs	μt	μ2.9	μs	μt	μ2.9	μs	μt	μ2.9	μs	μt
BBI	40 °C													
	80 °C													
	120 °C													
ABI	120 °C													
	80 °C													
	40 °C													

7. NOTES

7.1 Revision Indicator

A change bar (|) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

APPENDIX A - REPORT PLOT EXAMPLES



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## APPENDIX B - THERMOCOUPLE INSTALLATION ON SAE PLATE

The thermocouple, TC, for sump temperature is inserted in the 7 o'clock position. Its tip is at 1 mm from the outside tab of the reaction plates.

The non-grounded thermocouple J type of diameter 0.5 mm (0.019 inch) is inserted in the middle of the thickness of the reaction plate, hole of diameter 0.6 mm (0.024 inch).



Figure B1 - Location of thermocouple, TC, within the test head

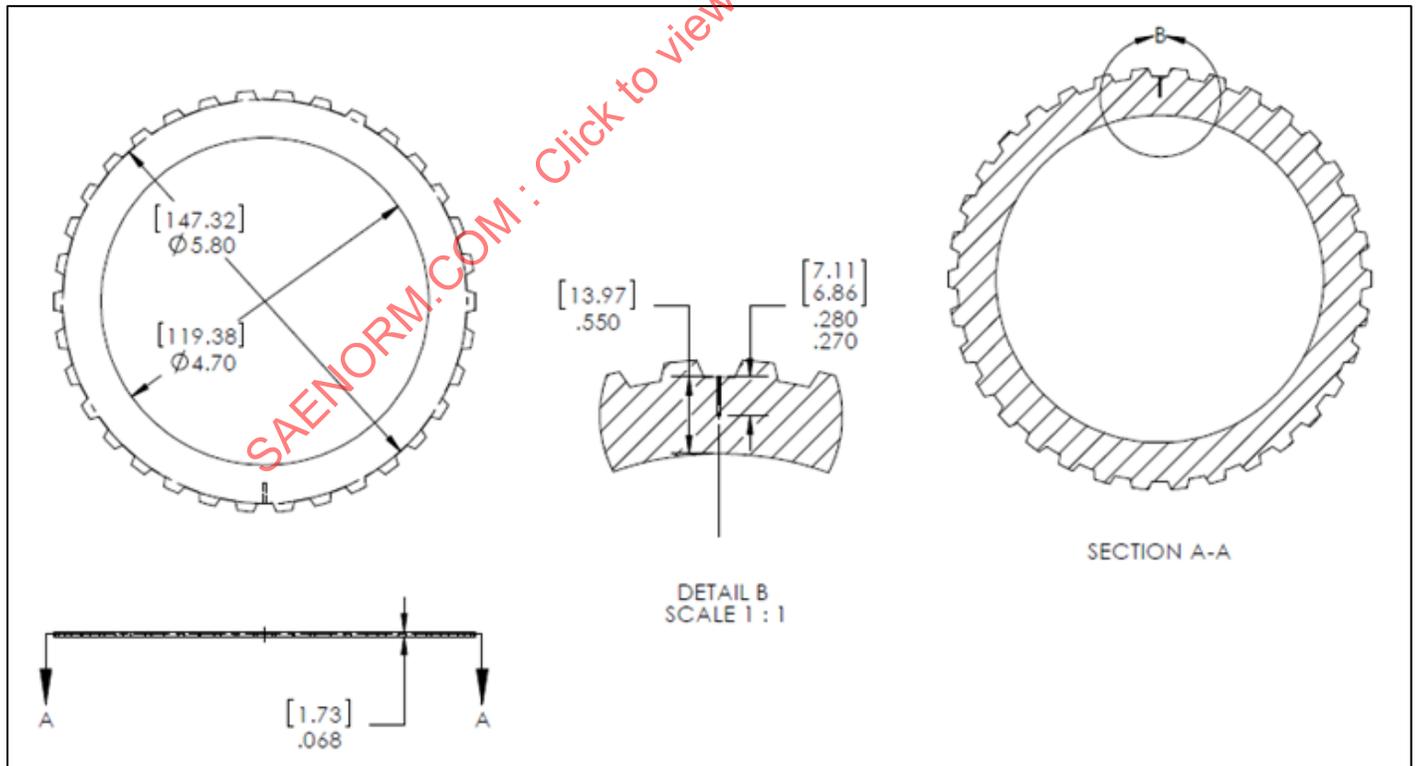
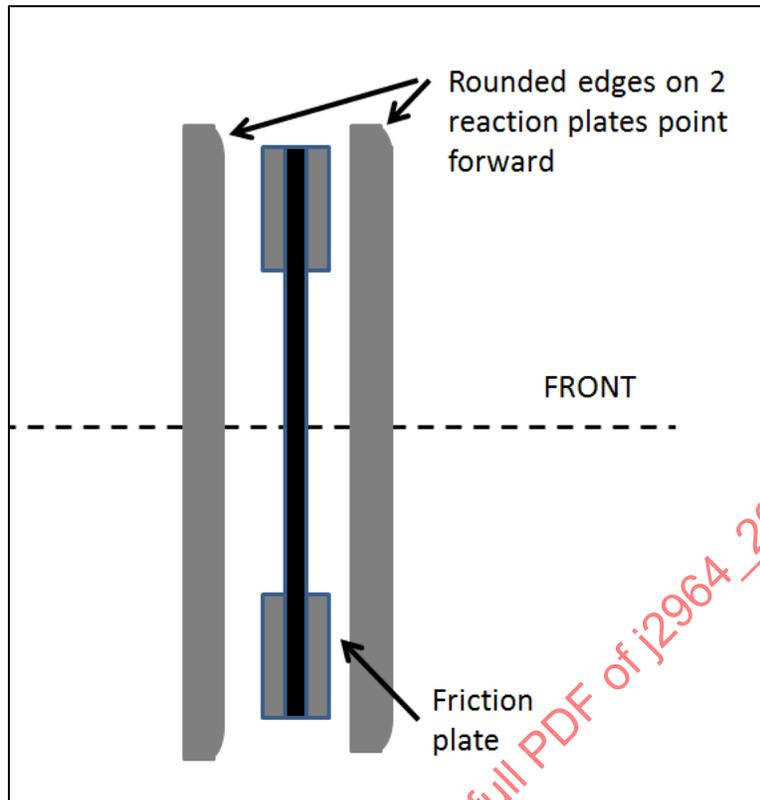


Figure B2 - Detail of thermocouple hole in the reaction plate



**Figure B3 - Plate orientation in test head**

NOTE: "Front" in Figure B3 is defined as looking at the machine from the test head (motor in the rear).

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## APPENDIX C - RESULTS OF THE ROUND ROBIN

A round robin was performed between three laboratories using the same fluid (Dex VI) and the same friction material (BW4329 GM racing batch 15985, steel batch SAE 12-14). Two additional tests were provided by Afton with batch 19711 to get more data for the statistical analysis.

The tests considered in the following statistical results are:

- Afton test run 8-1278- EOT 9/16/2016 - GM racing batch 15985
- Afton test run 8-1614- EOT 4/10/2017 - GM racing batch 19711
- Afton test run 8-1615- EOT 4/10/2017 - GM racing batch 19711
- Greening M39-004-10 report 166254-1 9/27/2016 - GM racing batch 15985
- Lubrizol test run 2012510085 12/13/2016 GM racing batch 15985

Hardware sourcing:

Kit GMPT-0506 (SAE No. 2 plate test, friction material BorgWarner type BW4329 and steel plate)  
TGI Direct  
5365 Hill 23 Dive  
Flint, MI 48507  
[Scott.Stap@tgidirect.com](mailto:Scott.Stap@tgidirect.com)

Lubricant sourcing:

Fluid: ATF Dexron VI  
From Afton Chemical Corporation  
500 Spring Street  
Richmond, VA23219  
Website: [aftonchemical.com](http://aftonchemical.com)

Laboratories participating in the round robin:

Afton Chemical Corporation  
500 Spring Street  
Richmond, VA23219  
Website: [aftonchemical.com](http://aftonchemical.com)

Lubrizol Corporation  
Wickliffe, Ohio  
Website: [lubrizol.com](http://lubrizol.com)

Greening Testing Laboratories  
19465 Mt Elliott St, Detroit, MI 48234  
Website: [greeninginc.com](http://greeninginc.com)

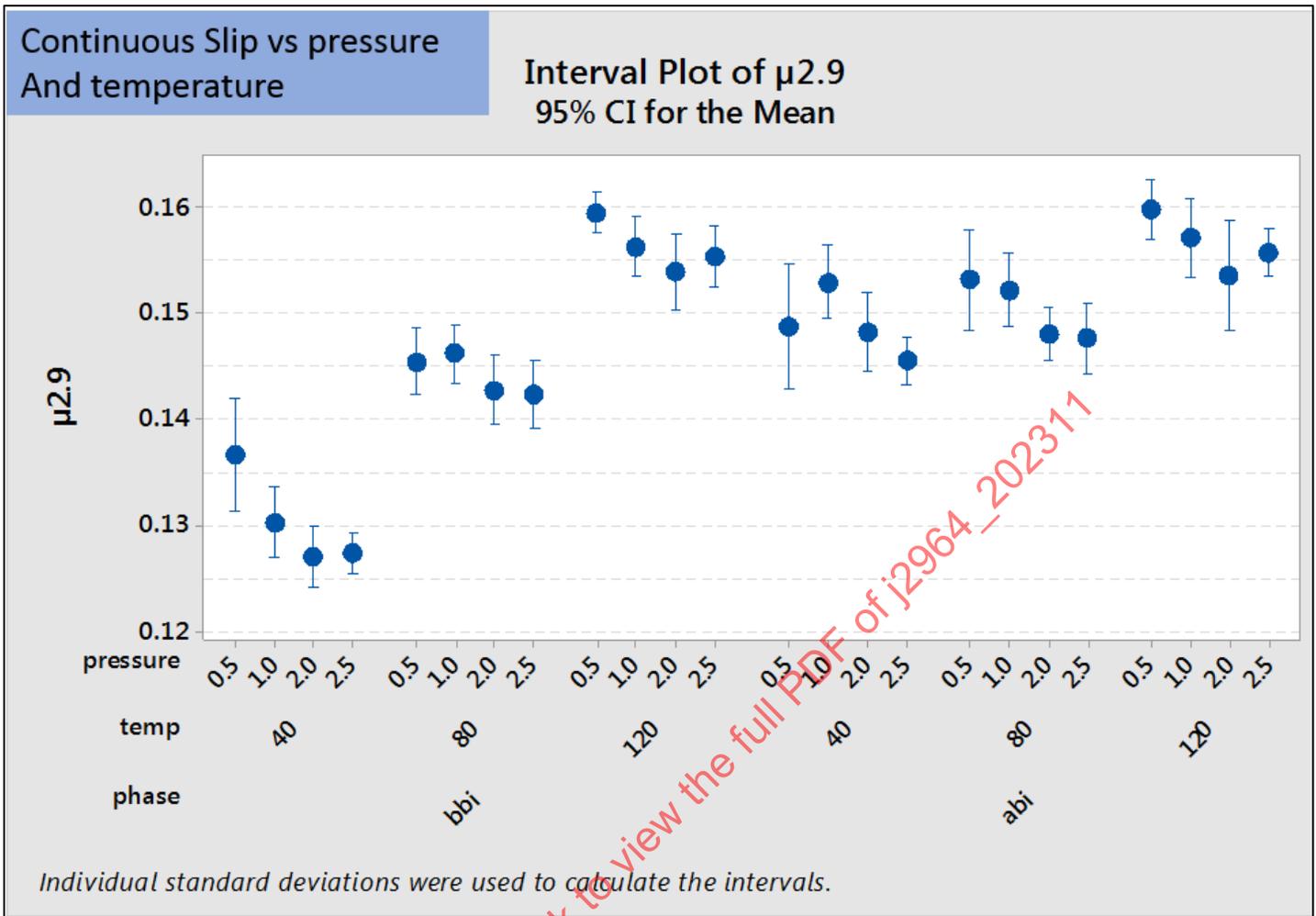


Figure C1 - Interval plot continuous slip  $\mu_{2.9}$

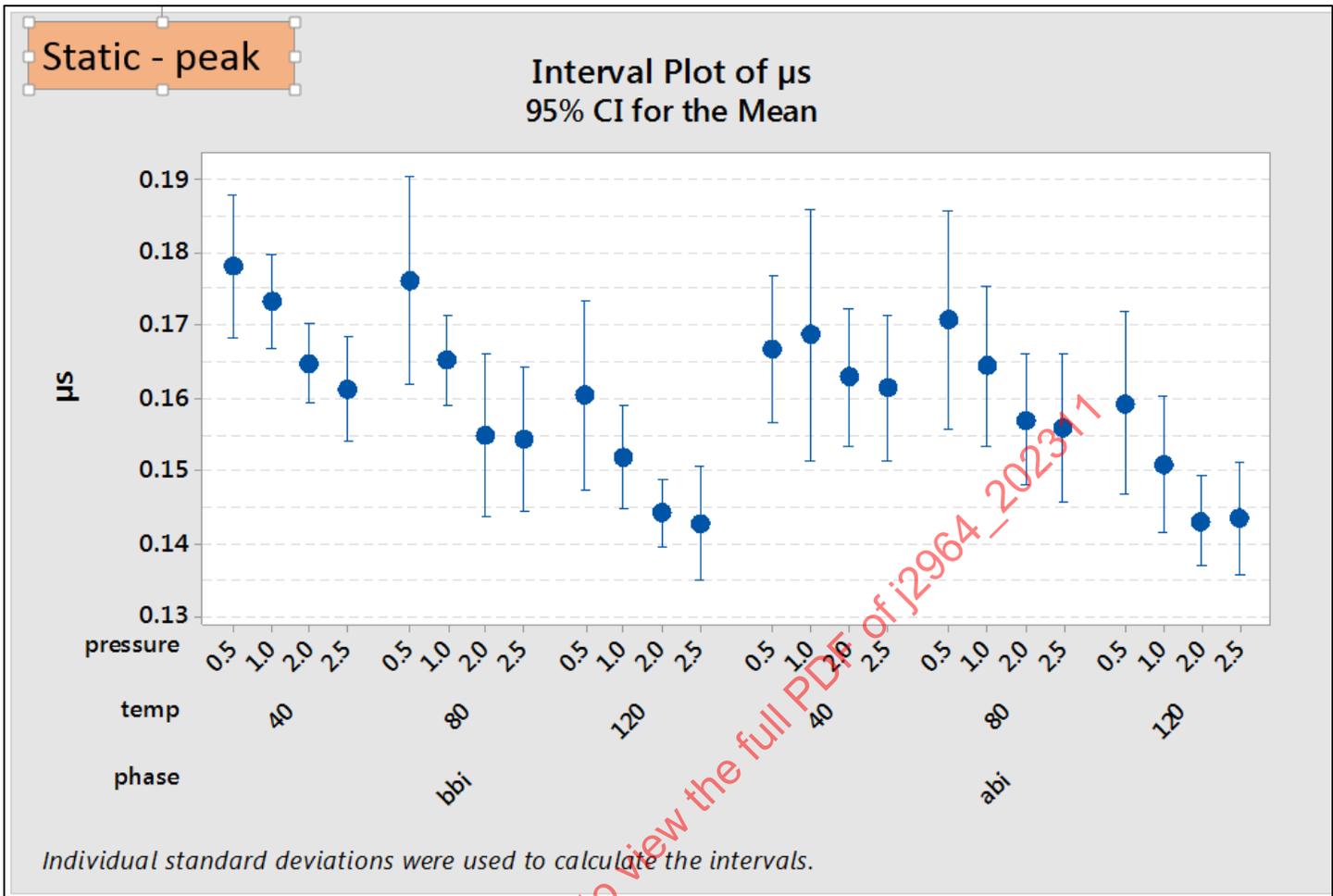


Figure C2 - Interval plot static  $\mu_s$