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SAFETY NOTICE: IMPORTANT CE SYMBOLS

The symbol  means Main Power.

The symbol  means Air Flow Control.

The symbol  means Heat.

The symbol  means Motor.

The symbol  means Speed Control.

Do not exchange or use any power cord other than what has been provided by Tannas Co. & King Refrigeration. If the power cord for the instrument needs replacement, contact Tannas Co. & King Refrigeration.

The instrument exceeds 18 Kg. If it must be lifted or carried, lift from the bottom with hands supporting both sides of the base and use safe lifting practices. Use two able bodied persons to lift if the weight exceeds the carrying capacity of a single person. When transporting the instrument use a platform cart to safely move it.

I. INTRODUCTION

A. History of TBS

The Tapered Bearing Simulator (TBS) Viscometer was developed to provide a precise measurement of the rheological properties of lubricating fluids over at least a temperature range of 100°C to 150°C, and at a conservatively estimated shear-rate range of one hundred thousand (100,000; or 1×10^5) to seven and one-half million (7,500,000; or 7.5×10^6) reciprocal seconds (sec^{-1}). Originally, the instrument was developed to determine the operating properties of engine oils in the journal bearing -- hence, the name. The first models to be made available were operated with single speed motors with upper viscosity limits of approximately 12-20 centipoise (cP). These units retained the ability to change shear rates through adjustment of the rotor and stator relationship.

An interlaboratory program, sponsored by Subcommittee D02.07 on Flow Properties of the American Society for Testing and Materials (ASTM), culminated in ASTM test method D 4683 outlining the application of the TBS specifically to automotive engine oils. The D4683 method calls for viscosity determinations in the TBS Viscometer at shear rates of $1 \times 10^6 \text{ sec}^{-1}$ and temperatures of 150°C. This ASTM program was part of a direct response to a 1977 request from the Society of Automotive Engineers (SAE) to "develop a test method that incorporates high-temperature, high-shear viscometric and the rheological characteristics, and which predicts the performance of both single and multi-grade [i.e. both Newtonian and Viscosity Index (V.I.) improved] engine oils, in engine bearings and/or ring and cylinder areas." The ASTM D4683 method should be consulted for Method Summary, Definitions of Terms, and anticipated Repeatability and Reproducibility.

In the mid-1990s, the TBS was further developed to extend the range of shear rates to meet the needs of those seriously interested in correlating engine oil viscosity with bearing oil film thickness and fuel efficiency in operating engines. The SuperShear TBS (SSTBS) utilized the same basic design of previous models except for two essential modifications: a DC multi-speed motor, and a 12-position speed selector switch (800 to 8000 RPM) on the control console box. In addition to dramatically increasing the shear rate capability and range, the new motor achieved higher torque outputs which permitted analysis of oils of more than 30 cP viscosity. These achievements were the first of their kind in HTHS measurements.

The TBS 2100E series Viscometer was formally introduced in late 1998 and effectively replaced all previous models of the TBS. While the new model incorporated the best features and benefits of previous models, it also brought with it some new technologies which served to simplify operation and maintenance procedures and allowed the unit to be constructed with a smaller footprint. The newest models of the TBS 2100E series include a fully automated, computer-controlled system which establishes operating position and injects the unknown samples. A Semi-Automation (FA-MI) package is also available.

Besides automotive engine oils, the TBS Viscometer has been used in several other applications including hydraulic fluids, automatic transmission fluids, gear oils, printing inks, water-based fluids, shock absorber fluids, and has been considered for whole blood and blood plasma applications.

B. Introduction to TBS

Through much research and development, it has been possible to establish the TBS as the world's first commercial, *absolute*, very high shear rate viscometer on which the shear rate can be measured and set while the instrument is operating. This ability is unique to the TBS.

The principle involved allowing both the measurement of -- and change in -- shear rates during operation is variable-gap geometry of an identically matched rotor and stator. For the TBS Viscometer, the degree and precision of taper is very important to the function of the instrument and is highly controlled during manufacturing. The rotor and stator are provided as specifically matched sets and are not individually interchangeable.

The rotor exhibits a reactive torque response when it encounters viscous resistance from an oil that fills the gap between the rotor and stator. This response is displayed on a torque meter built-in to the control console box and can be recorded. The clearance between the rotor and stator is established through the use of special calibration oils and a non-Newtonian reference fluid. Once a gap has been established at the desired shear rate, other oils of unknown viscosity may be examined at the specified shear rate.

Operation of a TBS Viscometer is achieved with about 3.5 milliliters (mL) of test oil, but requires at least 30 mL of samples for effective use of the '*chase-flush*' technique of flushing out the previous fluid with the introduction of the new oil for test (50 mL is recommended). Under standardized conditions, the viscosity of a fluid can be measured in approximately 5-7 minutes.

II. UNPACKING AND INSPECTION

A. TBS Shipment

All Components and Parts for the TBS Viscometer are contained in a series of boxes that, in turn, are packaged in one major container mounted on a pallet.

B. Initial Inspection

While care has been taken to minimize damage during shipment, careful visual inspection should be made of the exterior carton and of the individual packages to identify any obvious damage due to mishandling en-route. Tannas Co includes indicators on all packages which show if the container has been dropped or tipped during shipment. It is the responsibility of the buyer to resolve such damages with the carrier at the time of delivery.

C. Unpacking

1. Refer to the Packing List on each box for a detailed accounting of what items are to be expected in each container. Unpack all component parts and place them on a workbench that allows ample room for assembly.

Note: The TBS Viscometer is a delicate instrument that will require care during assembly as well as in subsequent operation. In particular, the rotor and stator for the viscometer are matched sets. They cannot be replaced singularly; if the rotor becomes damaged, the stator will also need to be replaced (and vice versa). Such replacement is essential since any damage impairs the function of the viscometer.

Note: Read all assembly and pre-operating instructions before attempting to begin assembly. Become familiar with the major component parts of the TBS Viscometer. Some items for use with the TBS are stored in an included toolbox.

2. The four-corner level-adjustment screws for the unit have been installed on the TBS chassis upside-down for shipping. Remove the plastic endcaps and locking nuts and disengage the plywood base, which may be set aside. Re-insert the four bolts into the base plate with the knurled heads now on top. Thread on the locking nuts and replace the plastic endcaps (feet) on the bottom side of the bolt (underneath the base plate). Adjust the level-adjustment screws until the TBS chassis is level.

3. The control console, with a plastic overwrap, is individually packaged in a separate box. The 'top side' of the box is identified with the label.

4. The motor is packaged in a separate container appropriately labeled.

5. Final boxes contain:

- a. Tool Box and AutoSampler (if ordered).
- b. Reference Oils which are on a separate pallet.

III. INSTRUMENTATION AND PARTS

A. Parts Description

1. Alignment Tool – This is used to align the motor shaft to the stator.
2. Elevator - The motor and the attached rotor are raised and lowered by means of the elevated motor platform. The gap between the rotor and stator is controlled by adjustment of the platform height. Vertical movement of the motor platform is achieved through use of the "height adjustment wheel" at the rear of the unit and via the computer for Full-Auto systems.
3. Elevator Motor- The motor is positioned on top of the chassis elevator. It is computer controlled for raising and lowering the motor platform and rotor.
4. Fill Tube – The inlet to the stator housing where the sample is injected.
5. Fill Tube Support – Keeps the fill tube stable.
6. Stator Housing – A Teflon support that holds and insulates the stator.
7. Housing Cover – Teflon lids to keep foreign objects out of the stator.
8. Digital Depth Gauge Indicator – Located at the front of the motor platform, the Digital Depth Gauge Indicator is used to monitor the vertical position of the motor platform and thus the relative position of the rotor within the stator.
9. Motor - The motor operates at 12 speeds from 800 to 8000 RPM. The motor is mounted on an In-line Load Cell. The force attempting to rotate the load cell is directly related to the viscous resistance being experienced by the rotor. The force is transmitted to the load cell and a resulting value is displayed on the Torque Meter on the Control Console.
10. Rotor - The Rotor is suspended from the motor by a flexible wire shaft using the patented Siamese Collet Assembly. The tapered Rotor is machined to match its accompanying Stator and has two parallel flat surfaces on the side. Any attempt to operate the TBS unit using unmatched Rotor/Stator combinations can result in less-precise data and an increased chance of damaging the viscometer.
11. Siamese Collet Assembly – A combination of two Siamese Collets coupled by a small flexible wire shaft. The collet assembly effectively connects the Rotor to the Motor.
12. Stator - The Stator has an internal taper matching its accompanying Rotor. The Stator is housed within the Stator Housing which provides thermal insulation and is electrically heated and air-cooled.

B. Electronics Description

1. Console Box – The TBS is designed to operate specifically at either 120 volts or 220 volts and with either 50 or 60 Hz cycle current. It is the responsibility of the owner to provide the proper power supply. The main controls are visible across the front panel of the Console Box. The air flow meter is mounted at the extreme left and is used to adjust the cooling air supply to the stator housing. However, experience dictates no airflow will be required to test fluid viscosities below 6 cP when operating at 150°C. The console box also contains the controls for the Elevator Motor. These are maintenance free and should only be serviced by a trained technician.

2. Temperature Controller - This controller is located next to the air flow meter on the Console Box. The temperature of the Stator, which can be displayed in degrees Celsius or degrees Fahrenheit, is measured and controlled through a single RTD sensor inserted into the Stator via a hole in the rear half of the Teflon cover. Operator control is largely limited to setting the temperature. The push buttons at the bottom of the controller provide menus and the ability to step through a full range of numbers. Instructions for re-establishing the PID settings in the event of a program deletion can be found in the appendices of the Operations Manual.

3. Torque Meter - The torque meter displays the force being applied through viscous resistance of the oil on the rotor (during viscometric analysis). Zero adjustment is achieved through the steps outlined in Section V. B. (page 11) of this manual.

4. Outputs - On the rear of the console is an output connector to permit strip-chart recording of the temperature and torque measurements. For Full-Auto systems, there is also a DAQ cable connection which allows communication with the computer to monitor and control the TBS.

5. Switch Controls - The three switches on the right side of the front panel control the Heat (on and off), Motor Power (on and off), and Main Power (on and off). There is also a Motor Speed control dial (12 speeds selections).

C. Safety

The TBS Viscometer can be operated in a safe and trouble-free manner. Nonetheless, personal injury can occur if certain safety practices are not made a part of routine operations. Particular attention should be given to the following:

1. Careful use of volatile solvents for cleaning/flushing operations – Care should be exercised to maintain vapor inhalation to a minimum, either by performing all cleaning in a vented hood or by restricting the volumes employed in a well-ventilated room. Secondly, any open flames or sources of spark ignition should be eliminated from the operations area when solvents are used.

2. Heated components when operating at high temperatures — e.g., 150°C – Certain procedures call for manipulating the Rotor within the Stator when the latter has

been heated to test temperature. Inasmuch as the use of gloves would hinder these manipulations, particular care must be observed to avoid contacting the hot surfaces.

3. Avoid any attempt to violate the integrity of the Control Console while the unit is electrically charged – There should be little reason to explore the console for maintenance without first consulting Tannas personnel or an authorized representative.

4. Maintain only moderate pressure on the Glass Syringe plunger to avoid fracturing the syringe wall – Oil injection should be restricted to a rate of no more than 2-3 mL per second.

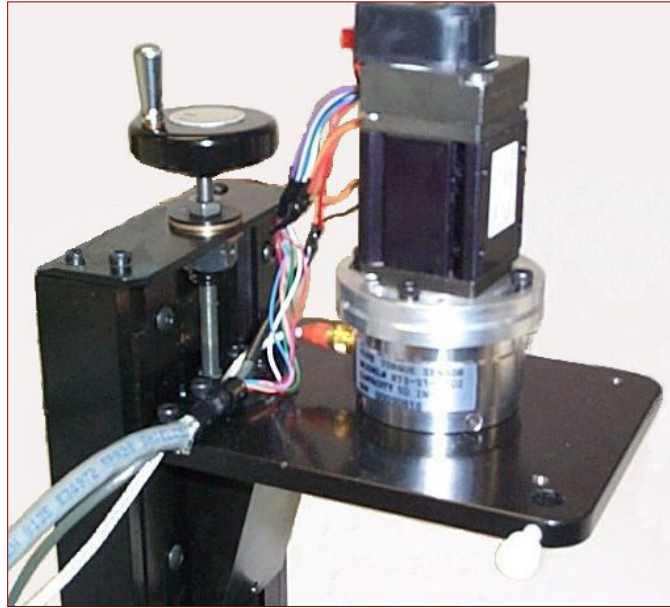
IV. SETUP

A. Initial Setup

1. Although the pre-assembled TBS chassis should remain secure during shipment, abnormal in-transit shock may loosen the motor platform or alter the freedom with which the platform may be raised and lowered. After leveling the chassis, verify that the motor platform does not exhibit any free movement by attempting to hand-move the front right edge of the platform in both up/down and back/forth orientations. If the platform is stable and no movement occurs, continue to follow subsequent directions. If some "wobble" should occur, however, contact the Tannas Technical Service department for instructions on how to stabilize the motor platform.

Additionally, manually rotate the height-adjustment wheel to both lower and raise the motor platform. This movement toward both the lower and upper travel limits -- a span of about 1 1/2 inches (38 mm) -- should be achieved with no binding. If the up-and-down movement is "smooth", proceed to subsequent directions. If, on the other hand, some binding does occur, re-alignment of the internal ball bearings in the elevator-slide assembly should be performed. Contact Tannas Technical Service for more information.

2. Motor and Transducer Assembly (*see photo below for final assembly*)
 - a. Remove the black motor cover from the motor platform by removing the two Allen screws in the front of the cover.
 - b. Mounted on the motor platform are the transducer and the bottom mounting plate with four (4) 10-32 Allen screws protruding from its top. Remove the four screws.
 - c. The motor is shipped separately from the rest of the unit to avoid damage during shipping. Remove the motor from the box. Note that the top mounting plate is attached to the motor and must remain in this condition.
 - d. Place the motor shaft through the bottom mounting plate and transducer and seat the top mounting plate into the bottom mounting plate.
 - e. Direct the motor wires to protrude toward the elevator knob. They should be secured onto the motor plate with wire clips. Be sure to leave enough slack in the wires to ensure that they don't pull on the motor or load cell.
 - f. Re-install the four 10-32 screws through the elongated slots of the top mounting plate and tighten into the threads of the bottom mounting plate.



- g. Carefully place the motor cover over the motor/transducer assembly with the slot of the cover facing the elevator knob. The motor and transducer wires should not be in contact with the motor cover.
3. Using the four base plate adjustment screws, and with the aid of the bubble level indicator, verify that the viscometer is level.
4. Place the Teflon Stator Housing on the base of the chassis, aligning the three holes in the Stator Housing with the corresponding holes in the chassis base. Locate the Heater Cable in the Tool Box. Plug the cable into the male fitting on the Stator Housing and screw it until it locks. The green ground wire should be fastened to the grounding screw on the base plate. Do not, as yet, attach the Heater Cable to the Console Box.
6. If necessary, fasten one of the two 6-foot (1.8-meter) pieces of PTFE tubing to the air inlet fixture on the Stator Housing. Subsequently, this air inlet tube will be attached to the rear of the Console Box. (The use of air is only used for 100°C operation, or at extremely high shear rates).
7. Electrical Connections: Install the Power Cord at the rear of the Console Box but do not connect to the power (outlet) source. Make the connections of the Heater Cable, Motor Cable, RTD cable, and Load Cell cable to their specific locations (so identified) on the back of the Console Box. The cables will fit only in their proper receptacles (identified by pin number) and only in one direction. Tighten locking nuts. At this time the free end of the airflow tube (attached to the Stator Housing) can be inserted into the "air outlet" fitting on the back of the Console Box.

Note: If using the Full-Automated TBS, it is required to also plug the Elevator motor cable into the console box. For both the Full and Semi-Automated systems, the DAQ cable is required to be plugged into the console box and into the computer (via the four-port USB hub). In addition, the Digital Depth Gauge Indicator will need to be plugged into the USB hub on both models. Finally, the software lock USB will need to be connected to the USB hub. Cables are generally labeled with color dots to aid in identifying their proper locations.

8. Insert the stem of the Digital Depth Gauge Indicator through the hole in the front left corner of the motor platform. Align the bottom extension of the Digital Depth Gauge Indicator so that it is flush with the bottom of the motor platform and secure the indicator in place using the white nylon screw.

B. Stator Alignment

1. Thoroughly clean the Stator (and appendages) and Stator Housing Covers using clean solvent. A stream of clean, dry air may be used to facilitate solvent evaporation after cleaning. Cleanliness of the stator (freedom from any dust/dirt particles) is essential to future viscosity measurements.

2. Locate the plastic Alignment Tool in the Tool Box. The purpose of the Alignment Tool is to assist in positioning the Stator directly below the motor shaft. Proper alignment of the Rotor and Stator is critical to the satisfactory operation of the TBS Viscometer.

Note: The alignment tool should only be used when the stator is cool. Otherwise the plastic may melt and cause potential loss of the tool and damage to the stator.

3. With the Stator clean, dry and at room temperature and motor platform to the "all the way up" position, gently place the Alignment Tool in the stator well. Note that the tool is scribed with several parallel, horizontal "depth marks." Lift the Alignment Tool part way out of the stator well and then permit the tool to "free fall" into the well. Repeat multiple times while observing the depth of penetration and listening for the 'light thud' sound indicating uniform, full penetration, into the well. Note the depth of the Alignment Tool in the stator after full penetration. Slight rotation of the alignment tool between subsequent drops into the Stator well will overcome any tendency for the tool to "hang up" in the well during this exercise.

4. With the Alignment Tool resting in the stator, slowly lower the motor platform using the height-adjustment-wheel on the elevator until the bottom of the motor shaft is just above the orifice at the top of the Alignment Tool. As the motor platform is lowered, the Digital Depth Gauge Indicator stem will contact the height adjustment post and begin to register. Lift the Alignment Tool until it slides onto the motor shaft, and permit it to free-fall into the stator well. Lift, turn, and drop several times – listening for the 'thunk' described earlier. To achieve maximum tool penetration into the stator well, it is necessary to adjust the Stator Housing in small increments to some "optimum" location below the motor shaft. Continue to lower the motor platform and make minor adjustments in the position of the stator housing until the Digital Depth Gauge Indicator registers at least half of its full travel (15 mm) and full tool penetration can still be maintained. Once this location has been determined, tighten the three Nylon screws around the base of the Stator Housing to the base plate and reconfirm that the proper alignment has not been altered via the Alignment Tool.

5. Gently attach the length of Drain Tubing (minimally 3 feet or 1 meter) to the stainless steel Oil Drain Tube on the Stator Housing. This tubing will serve to direct the overflow of test oils to an appropriate waste-oil receiver. Take care not to move the position of the stator housing.

6. Elevate the motor platform to remove the Alignment Tool; replace the Housing Covers; adjust the Fill Tube Support and tighten its two screws – being careful not to disturb the location of the Stator Housing.

7. Insert the RTD probe into the Stator through the rear stator cover opening. Before doing so, however, make sure that the RTD hole in the Stator is free of any residual solvent -- which will boil when the Stator is heated (subsequently) and may force the RTD probe from the receptacle.

Note: Ensure that the RTD probe is completely inserted into the stator. If the probe is not inserted to the bottom of the receptacle in the Stator, improper temperature measurement and control may lead to unsatisfactory results during sample testing.

V. PRELIMINARY CALIBRATION

A. Temperature Calibration

1. In anticipation of TBS Viscometer operation, re-check all electrical connections. Ensure that the Main Power switch, Heat switch, and Motor switch on the Console Box are all in the “off” position. Only then plug in the Power Cord to an appropriate power (outlet) source. To energize the Console Box, turn on the “Main” power switch, and push the black “Reset” button on the top right of the front of the console box. This will activate the temperature and torque readouts.

2. The Temperature Controller monitors the stator well temperature via the RTD cable inserted through the rear stator cover. Readout can be in either degrees Celsius (default) or degrees Fahrenheit. The setpoint temperature can be adjusted by pushing the up or down arrow keys but is not necessary at this time. If desired, a boiling point can be performed by placing the RTD into boiling distilled water and temperature compensated for atmospheric pressure. If an adjustment is necessary, see the temperature controller manual to offset the difference. This step was performed prior to shipment.

B. Torque Setting

The Torque Meter is factory set. The offset stored in the unit at Tannas is located in Torque Meter Setting Page in the Appendix of this manual. The torque display should be approximately zero (+/- 30) at this time. If not, the first step is to adjust the position of the motor and torque sensor cables on the motor platform. Slide the cables through the wire clips until the torque display is close to zero and tighten the clips to secure the wires in place. Take care to leave sufficient slack in the cables so that they are not pulling on the torque sensor or motor when they are secured to the motor platform.

Alternatively, the Torque Meter offset may be adjusted in order to set the torque display to zero. Adjust the Torque Meter offset by pressing the menu button repeatedly until the “RDG OF” (Reading Offset) is displayed. Then select the “Max.” button once. The number displayed will be the current offset. The “Min” button will change the number place you are currently on. The “Max” button will change the digit. Selecting the button once will automatically zero the meter. Selecting the button again will incrementally increase the meter reading by (1). The extreme left-hand number place will go to the negative sign after the number zero.

After making any change the “Reset” button on the Torque Meter must be selected two times to store the change.

Similar procedures are kept for making changes to any other settings. However, before making any other changes to the settings, contact a Tannas engineer for help or troubleshooting.

Note: If a zero still cannot be obtained, the four transducer screws on the underside of the motor platform can be tightened and/or loosened to help in the process. Do not loosen the transducer screws so much the screws do not hold the transducer in place or so tight they strip the screws. This final method is only to be used as a last resort.

VI. TBS OPERATION

A. New or Cleaned Rotor/Stator Setup

1. Ensure that the Motor Power switch is in the “off” position. Check the bubble level indicator and make any required adjustments. Raise the motor platform to a fully elevated position and locate (in the Tool Box) the Rotor and Siamese Collet Assembly. These may be rinsed with solvent and air-dried to remove any residual oil/dirt. With care, insert the rotor shaft completely into one end of the Siamese Collet Assembly and tighten the nuts.

Note: The two nuts on each end of the Siamese Collet Assembly tighten in opposite directions. Care should be taken not to ‘mar’ the nuts while wrenching.

Note: The rotor will fit into the opening of one of the two Siamese Collets, and the other Siamese Collet will fit the motor shaft. Take care to insert the rotor into the correct Siamese Collet.

2. Turn on the Digital Depth Gauge Indicator by pressing the “Data” button once. Press the “Set” button two times. Next, press and hold the “Set” button until “INC” appears (incremental value) above the digital numbers. Press the “Mode” button once to change the gauge from inches to mm.

3. Remove the Stator Housing Covers and RTD probe. Place a cloth or paper towel over top of the stator and connect the Siamese Collet Assembly, with attached Rotor, to the Motor Shaft using one end of the Siamese Collet. This collet end should be placed on the Motor Shaft with about 1/2 of its top nut exposed beneath the bottom retainer of the motor plate. Tighten the upper nut. Remove the cloth.

4. Begin lowering the motor platform while carefully guiding the Rotor into the stator well. It is recommended to manually rotate the rotor while lowering the motor platform by turning the upper Siamese Collet (attached to the motor shaft) clockwise between the thumb and index finger. Continue to lower the motor platform until the top of the Rotor is flush with the top surface of the Stator. A flat 6-inch scale or similar tool used as a feeling aid can be laid across the top of the Stator to assist in finding an accurate ‘flush’ position.

5. Press the “Set” button to zero the Digital Depth Gauge Indicator. This establishes the base “zero” position of the rotor depth relative to the stator. Replace the Housing Covers and re-insert the RTD through the access hole into the stator well, again ensuring that the RTD is completely inserted to the bottom of the stator well.

6. Fill a clean Glass or disposable plastic Syringe with 50 mL of the BIF-03 (Break-in Fluid) supplied with the TBS Viscometer. Attach the syringe directly to the Stator Fill Tube and slowly inject the oil using the “30-10-10” technique. First, inject 30 mL of fluid (at a rate of approximately 2-3 mL per second) and allow the temperature to begin climbing back towards 150°C. Then, inject another 10 mL and allow the temperature to once again climb back towards 150°C. Finally, inject the last 10 mL of oil. Note the excess oil will flow over the top of the stator and exit the Stator Housing via the Oil Outlet and Oil Drain Tube.

Note: Ensure no kinks in the Oil Drain Tube obstruct free flow of the oil to the waste container. Also, make certain the end of the Oil Drain Tube is not immersed in the waste

oil accumulated in the waste container. These are two common reasons that back-up may occur and prevent proper draining of the waste oil into the waste oil container.

Note: Due to the formulation of BIF-03, a filter should not be used when injecting this oil. However, for all other oils (reference oils and unknown samples), the Filter Housing (containing a 10 micron filter) should be attached to the fill tube before connecting a glass or disposable plastic syringe.

7. Adjust the setpoint temperature on the Temperature Controller to 150°C by pushing the “up” arrow until the readout shows 150. Turn the Heat switch to the “on” position. During this initial heating check, make sure that the RTD remains securely positioned in its hole in the stator.

It will require about 20-30 minutes to warm the Rotor/Stator Set from room temperature to 150°C and stabilize at this temperature.

Note: Experience has demonstrated that for testing of low-viscosity oils at 150°C at $1 \times 10^6 \text{ sec}^{-1}$, no cooling airflow is required. However, if at any time during operation the temperature readout value drifts upward above the temperature set point by more than 0.3°C and remains there, air cooling of the Stator Housing should be implemented by adjusting the airflow valve on the lower left-hand side of the Console Box. See Section VII. B. of this Operations Manual for more information.

B. Finding Initial Rubbing Contact and Break-In of Rotor/Stator Set

Rubbing Contact is the rotor depth at which the rotor will no longer freely turn in the stator. This position is important to note as an absolute maximum depth at which the instrument should operate. If the motor is turned on with the rotor at a position deeper than Rubbing Contact, there is a risk of the rotor “locking up” within the stator or causing damage to the rotor and/or stator.

Note: Finding Rubbing Contact is **not** required every day. It is only required when there has been some physical change to the instrument, for example:

- Initial instrument setup
- The collet wire was damaged, and the Siamese Collet Assembly was re-assembled with a different collet wire
- The Stator Housing was removed from the TBS chassis for cleaning
- Damage occurred to the rotor and/or stator set and they were replaced
- The instrument was disassembled, moved, and re-assembled

To find initial Rubbing Contact, perform the following steps:

1. Allow the rotor/stator set to achieve temperature equilibrium (150°C) for approximately 30 minutes. Slowly lower the motor platform by turning the wheel on top of the motor while simultaneously rotating the collet shaft (and Rotor) clockwise with the other hand.

CAUTION: HOT SURFACES - The surface of the Stator is now hot. Care should be taken when handling the collet.

Continue this operation until a slight drag is felt in the rotation of the collet. At this point, the rotor is approaching initial Rubbing Contact. Continue to lower the motor platform (while rotating the collet shaft) very slowly until the collet no longer turns. This indicates the 'rubbing contact' between the Rotor and Stator. Record the Digital Depth Gauge Indicator reading and *raise* the motor platform 0.500 millimeters. At this point, check for free rotation of the Rotor by hand.

2. Set the Motor Speed Dial to Speed Setting "6" and turn "on" the Motor. Re-check the temperature set point. After complete warm-up of about 30 minutes, cautiously *lower* the Rotor in 0.100-millimeter steps. Watch the torque value at each change and stop lowering the Rotor when the torque readout reaches 1200. Then, allow break-in for approximately one hour.

Note: Even though the Rotor/Stator Set combination provided with the TBS represents a 'matched pair' that, before shipment, had been broken-in using the same BIF-03 oil, the exercise described in the step above serves to provide user assurance that all components have been re-assembled satisfactorily.

C. Rubbing Contact for Operation

1. With the motor and temperature switches still in the "on" position, raise the platform up 0.200 mm from the initial rubbing contact position. Connect the Filter Holder (with a clean 10 micron filter paper installed) to the Inlet Tube. Fill a clean syringe with 50 mL of Idling Oil and connect it to the Filter Holder. Slowly inject the Idling Oil (using the 30-10-10 technique) to displace the BIF-03 fluid in the stator well.

2. After the instrument stabilizes at the set temperature (150°C), turn the motor "off". Slowly lower the Rotor until 'rubbing contact' is felt again. Record the position of the Digital Depth Gauge Indicator. Raise the motor platform 0.500 mm.

Note: If the TBS Software is being used, the Rubbing Contact position found in this step should be input into the software.

3. Verify that the Torque meter readout is still zero (+/- 30). If necessary, make adjustments according to the steps outlined in Section V. B. of this Operations Manual to achieve zero torque reading.

4. Check for free rotation of the rotor by hand. Turn "on" the motor switch and allow the instrument to stabilize at 150°C for one hour. If a tachometer is available, verify that the motor is operating at 3500 RPM at speed setting 6.

D. Crossover Calibration: Establishing the Operating Position

A Crossover Calibration is used to establish the operating position of the rotor within the stator that will result in a known shear rate—normally $1 \times 10^6 \text{ sec}^{-1}$. The tapered geometry of the rotor and matching stator set allow the operator to increase shear rate by lowering the rotor deeper into the stator, which decreases the gap between the rotor and stator and thus increases the shear rate (and vice versa).

To find the operating position, the torque outputs of a non-Newtonian Reference Oil (whose viscosity is affected by shear rate) and a Newtonian Reference Oil (whose viscosity

is not affected by shear rate) are recorded at different motor platform positions (rotor depths), and linear regressions are performed to create lines of best fit for the data. Since the viscosities of both oils are known to be the same at 150°C and $1 \times 10^6 \text{ sec}^{-1}$, the motor platform position where the two lines “crossover” indicates the operating position where the shear rate is $1 \times 10^6 \text{ sec}^{-1}$. This technique is also described in ASTM D4683.

Note: A Crossover Calibration is **not** required every day. It is only required when there has been some physical change to the instrument, for example:

- Initial instrument setup
- The collet wire was damaged, and the Siamese Collet Assembly was re-assembled with a different collet wire
- The Stator Housing was removed from the TBS chassis for cleaning
- Damage occurred to the rotor and/or stator set and they were replaced
- The instrument was disassembled, moved, and re-assembled

Under normal conditions, the operating position for a given rotor/stator set will remain constant. If the operating position for this instrument has already been established and none of the above conditions have occurred which would require a Crossover Calibration, go to the Viscosity Calibration portion of the Operation Manual.

To conduct a Crossover Calibration, perform the following steps:

1. A double flush of 50 mL each (using the 30-10-10 technique) of Non-Newtonian Reference Oil (NNR-03) is recommended to ensure complete displacement of the Break-in Fluid and/or Idling Oil and to prepare the unit for calibration.
2. Lower the motor platform to a depth 0.100 mm above the Rubbing Contact position. After the torque and temperature readings have stabilized, record the torque reading and the motor platform position.
3. Raise the motor platform 0.100 mm and once again record the torque value once the temperature and torque stabilize.
4. Repeat Step 3 twice more to obtain a series of four (4) torque and motor platform depth readings.
5. Linear regression analysis of the reciprocal of torque ($1/T$) readings vs. Digital Depth Gauge Indicator values should produce a Correlation Coefficient of at least 0.998 for NNR. Table 1 reflects a series of torque and motor platform depth settings in which an acceptable Correlation Coefficient is obtained.
6. If an acceptable Correlation Coefficient is not obtained, repeat Steps 1-5 above. If an unsatisfactory Correlation Coefficient occurs again, contact Tannas Technical Service or an authorized representative.

Table 1. Typical Crossover Calibration Data Using NNR-03 @ 150°C

Rubbing Contact: 13.509 mm

Platform Setting (mm)	Torque Display Reading
13.410	1178.6
13.311	885.9
13.212	732.5
13.111	627.5

Correlation: 0.9986
Intercept: 13.757 mm
Slope: -402 mm/(1/T)

7. Once an acceptable Correlation Coefficient is obtained with NNR-03, inject 50 mL of a Newtonian Reference Oil (R-400) using the 30-10-10 technique and allow temperature to stabilize at 150°C. Repeat Steps 2-4 above.

Note: The Newtonian Reference Oil (R-400) and the Non-Newtonian Reference Oil (NNR-03) should have similar viscosities at 150°C.

8. Linear regression analysis of the reciprocal of torque (1/T) readings vs. Digital Depth Gauge Indicator values should produce a Correlation Coefficient of at least 0.999 for R-400. Table 2 reflects a series of torque and motor platform depth settings in which an acceptable Correlation Coefficient is obtained.

9. If an acceptable Correlation Coefficient is not obtained, repeat Steps 7-8 above. If an unsatisfactory Correlation Coefficient occurs again, contact Tannas Technical Service or an authorized representative.

Table 2. Typical Crossover Calibration Data Using R-400 @ 150°C

Rubbing Contact: 13.509 mm

Platform Setting (mm)	Torque Display Reading
13.409	1258.0
13.312	912.1
13.211	726.2
13.112	608.0

Correlation: 0.9995
Intercept: 13.691 mm
Slope: -350 mm/(1/T)

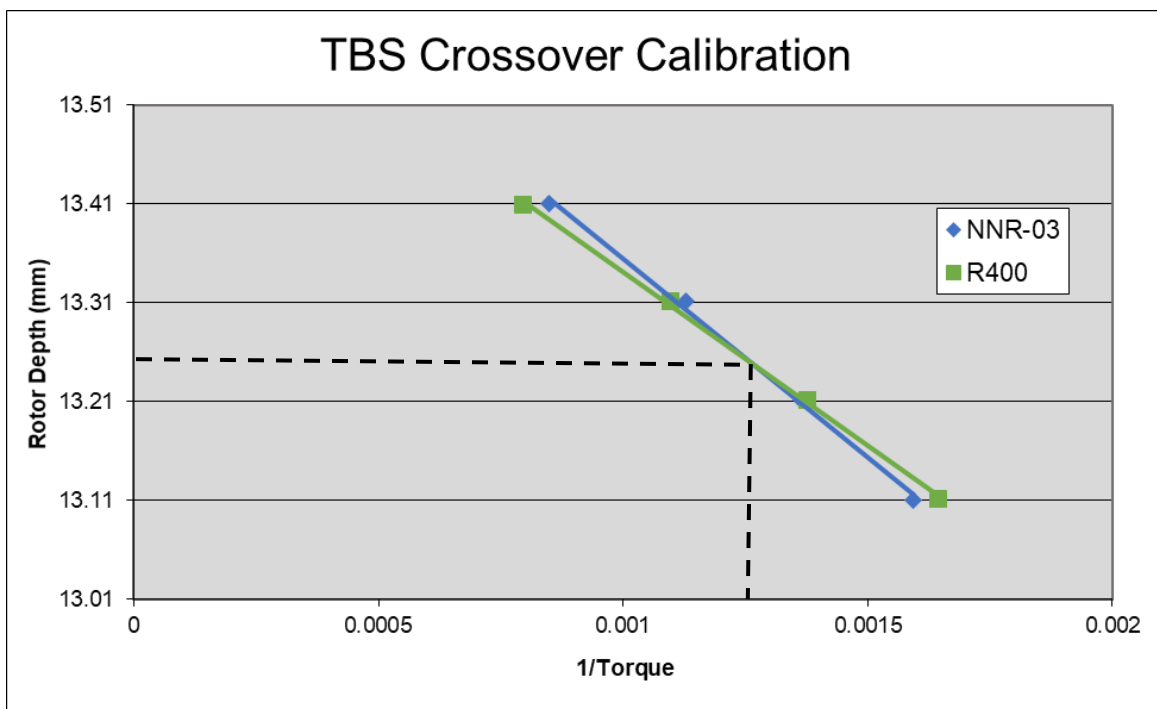
10. The (1/T) data for NNR-03 and R-400 should be equal at some motor platform depth. This may be determined by plotting the linear regression equations for both NNR-03 and R-400 and calculating this point. Table 3 and Figure 1 illustrate the typical data used to establish a crossover value—the point where R-400 and NNR-03 have equivalent viscosities at $1 \times 10^6 \text{ sec}^{-1}$ and 150°C.

Table 3. Complete Crossover Calibration Data
 Rubbing Contact: 13.509 mm

Platform Setting (mm)	NNR-03		R-400	
	Torque	1/Torque	Torque	1/Torque
13.41	1178.6	0.000848	1258.0	0.000795
13.31	885.9	0.001129	912.1	0.001096
13.21	732.5	0.001365	726.2	0.001377
13.11	627.5	0.001594	608.0	0.001645

Crossover/Operating Position: 13.245

Figure 1. TBS Crossover Calibration.



11. If no crossover occurs, the results indicate that the Rotor/Stator gap of 3.5 microns (equivalent to the shear rate of $1 \times 10^6 \text{ sec}^{-1}$ at the set speed) has not been reached. Under these circumstances, both the R-400 and NNR-03 oils will need to be re-examined

Note: After prolonged use of the TBS Viscometer, deposits accumulated on the Rotor/Stator Set may contribute to a drift in the operating position. Typically, continuous use of the unit will require a weekly Idling Oil flush. Routinely flush the viscometer with the motor “on” and at temperature.

Automated Systems with TBS Software:

If your TBS Viscometer is operated with the TBS Software, most of the steps above are carried out automatically. See the associated manuals for more information.

E. Viscosity Calibration: Torque – Viscosity Relationship at Operating Position

A Viscosity Calibration is used to establish a relationship between the torque readings from the instrument and the absolute (dynamic) viscosity of the oil being tested. A Viscosity Calibration will also verify that the Operation Position of the motor platform is correct. During a Viscosity Calibration, a series of Newtonian Reference Oils with different known viscosities are tested and a linear regression is established correlating the individual torque output readings from the instrument to the known viscosities of the Reference Oils.

Note: Up to six, but a minimum of four calibration oils are used for the Viscosity Calibration.

To conduct a Viscosity Calibration, perform the following steps:

1. With the TBS Viscometer set at 150°C, the motor in the “on” position, and the motor platform set at the Operation Position established from the Crossover Calibration, inject 50 mL of R-200 using the 30-10-10 technique. Wait for the temperature to stabilize at 150° and record the torque output.
2. Inject 50 mL of R-450 using the 30-10-10 technique. Wait for the temperature to stabilize at 150° and record the torque output.
3. Using a linear regression program, calculate a line of best fit correlating torque to viscosity using the known viscosities of R-200 and R-450 and the recorded torque outputs. This line of best fit should take the form of $\text{Viscosity} = \text{slope} * \text{Torque} + \text{Intercept}$.
4. Inject 50 mL of NNR-03 using the 30-10-10 technique. Wait for the temperature to stabilize at 150° and record the torque output.
5. Calculate the theoretical viscosity of NNR-03 using the line of best fit from Step 3 and the torque output reading from Step 4. If the calculated viscosity of NNR-03 is +/- 0.05 cP from the reference value on the bottle, continue to Step 6. If the calculated viscosity is outside that range, the Operating Position must be adjusted, and Steps 1-4 must be repeated.

Note: For every 0.05 cP that the calculated viscosity of NNR-03 is higher than the value on the bottle, move the motor platform down by 0.020 mm. For every 0.05 cP that the calculated viscosity of NNR-03 is lower than the value on the bottle, move the motor platform up by 0.020 mm.

Example: With an initial Operating Position of 13.245 mm, the calculated viscosity of NNR-03 is 3.70 cP but the value on the bottle is 3.55 cP. Since the calculated viscosity is higher by 0.15 cP, move the motor platform down by 0.060 mm to 13.305 mm.

6. Inject 50 mL of R-300 using the 30-10-10 technique. Wait for the temperature to stabilize at 150° and record the torque output.

7. Inject 50 mL of R-400 using the 30-10-10 technique. Wait for the temperature to stabilize at 150° and record the torque output.

8. Modify the linear regression found in Step 4 using all (4) data points to calculate a refined linear torque-viscosity relationship. The correlation should be at least 0.999. If an acceptable correlation is not found, Steps 1-7 must be repeated. If the correlation is

greater than 0.999, samples of unknown viscosity may be tested. Table 4 and Figure 2 illustrate the typical data used to establish a Viscosity Calibration.

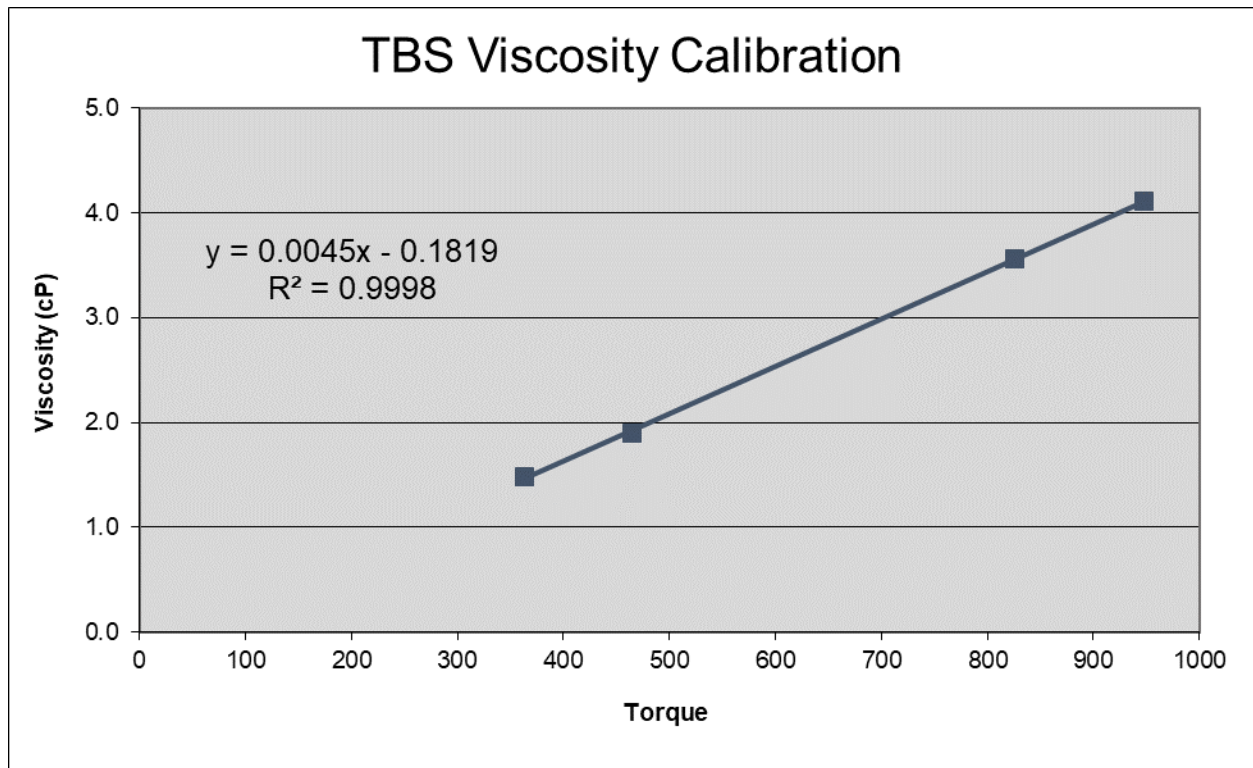
Table 4. Typical Viscosity Calibration Data

Reference Oil	Viscosity at 150°C (cP)	Torque
R-200	1.48	363.1
R-450	4.11	947.2
R-300	1.90	464.6
R-400	3.56	826.2
NNR-03	3.52	816.9

	2 Point	4 Point	
Correlation	1.0000	0.9999	0.999 minimum
Slope	0.00450	0.00453	
Intercept	-0.15	-0.18	±0.35 cP
NNR-03 Viscosity	3.53	3.52	NNR-03 value ±0.05 cP

Note: Up to six, but a minimum of four calibration oils are used for the Viscosity Calibration.

Figure 2. TBS Viscosity Calibration



Automated Systems with TBS Software:

If your TBS Viscometer is operated with the TBS Software, most of the steps above are carried out automatically. See the associated manuals for more information.

F. Sample Testing

After a Viscosity Calibration has been performed and a torque-viscosity relationship established, samples of unknown viscosity may be tested by performing the following steps:

1. Inject 50 mL of NNR-03 (using the 30-10-10 technique) and verify that the calculated viscosity (using the equation found in the Viscosity Calibration) is within +/- 0.05 cP of the value stated on the Reference Oil bottle.
2. Fill a clean Glass or disposable plastic Syringe with 50 mL of oil sample. Inject the oil using the 30-10-10 technique and allow the temperature and torque to stabilize. Record the torque output value and calculate the viscosity using the equation found in the Viscosity Calibration.

*Example: After injecting a sample of unknown viscosity, the torque reading stabilizes at 596. Using the equation found in the example Viscosity Calibration, the viscosity can be calculated as $0.0045 * 596 - 0.1819 = 2.50 \text{ cP}$*

3. NNR-03 should be periodically injected to verify the validity of the Viscosity Calibration. ASTM D4683 dictates that after every (6) samples are tested, NNR-03 should be checked. If the calculated viscosity of NNR-03 is within +/- 0.05 cP of the value on the Reference Oil bottle, sample testing can continue. If the calculated viscosity of NNR-03 is outside this range, a new Viscosity Calibration must be performed.

Automated Systems with TBS Software:

If your TBS Viscometer is operated with the TBS Software, most of the steps above are carried out automatically. See the associated manuals for more information.

G. Day-to-Day Operation

Under normal operating conditions, the Operating Position (platform height) should remain constant so long as testing is maintained at 150°C. Please see separate instructions for operating at other temperatures.

It is recommended to leave the instrument in continuous (overnight) operation after injecting Idling Oil to improve operational efficiencies and reduce the time to begin running test samples from day-to-day. For operating in Continuous Operation Mode, please see Section 1 below.

Occasionally, overnight operation is impractical. However, experience indicates that most often the Operating Position will remain constant even if the TBS Viscometer is shut down. For Non-Continuous Operations (i.e., Shutdown), refer to Section 2 below.

1. Continuous Operation Mode:

When the TBS is not scheduled to analyze samples for a period of time exceeding 20-30 minutes, prepare the unit to “idle.” Keep the unit at 150°C, the motor in the “on” position, and the platform at the established Operating Position. Inject 50 mL of Idling Oil using the 30-10-10 technique after the last sample has been analyzed.

Note: It is not recommended to operate the TBS longer than 20-30 minutes with any fluid other than Idling Oil or BIF.

a. Same day analyses

If the next set of sample analyses occur on the same day as the established Viscosity Calibration was performed, another Viscosity Calibration does **not** need to be performed before continuing with sample testing.

When ready to operate the TBS again to analyze more samples, ensure that the motor platform is at the established Operation Position, the temperature is stabilized at 150°C, and the motor is in the “on” position. Then proceed with sample testing as outlined in Section VI. F. of this Operations Manual.

b. Multi-day Analyses

When the TBS Viscometer has been in continuous operation overnight with Idling Oil, it is recommended to perform a Viscosity Calibration on the day samples will be tested. As noted above, Rubbing Contact and Cross Over Calibrations are not required unless otherwise needed.

2. Non-Continuous Operation Mode

- a. To completely shut down the TBS unit, inject Idling Oil and turn “off” the heat and motor. Then, turn “off” the Main Power switch.

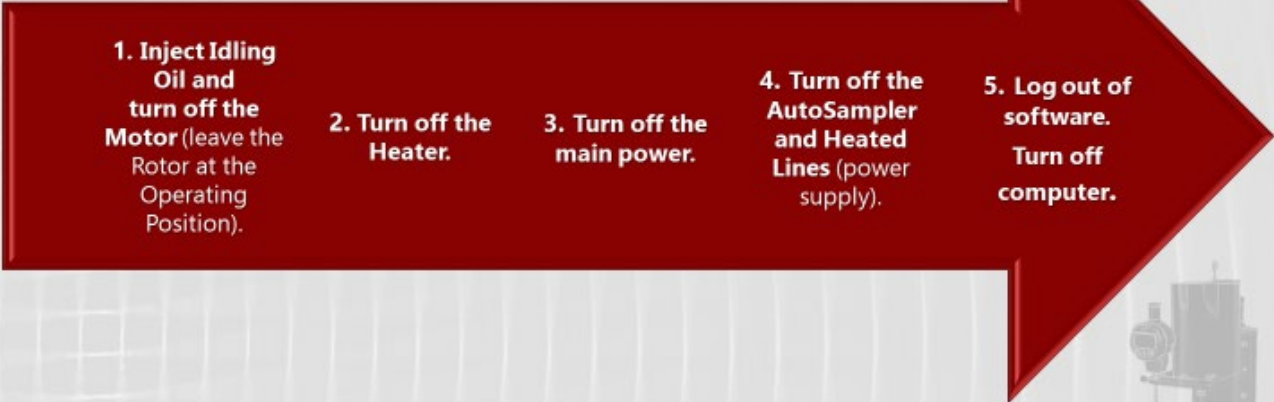
Note: A complete shutdown is not recommended when operating at very high shear rates (above $3 \times 10^6 \text{ sec}^{-1}$) because of the possible lock-up that may occur from the expansion and contraction of the Rotor/Stator Set. If a shutdown is needed, it is recommended to lower the shear rate to at or below $1 \times 10^6 \text{ sec}^{-1}$. Contact Tannas for further instructions.

- b. To restart the TBS after a cold shutdown, make sure the Motor and Heat switches are in the “off” position and the motor platform is at the established Operating Position. Turn on the Main Power switch, press the “Reset” button, and turn the Heat switch to the “on” position. Allow the temperature to stabilize at 150°C for approximately 15 minutes. Inject 50 mL of Idling Oil (using the 30-10-10 technique), and once again allow the temperature to stabilize at 150°C. Before turning “on” the Motor, rotate the Rotor within the Stator by hand to ensure there is no binding. If the Rotor rotates freely by hand, turn “on” the Motor and allow the TBS unit to reach temperature equilibrium at 150°C (approximately 1 hour).


- c. Once the temperature has stabilized, perform a Viscosity Calibration to establish the proper correlation between torque and viscosity. After a successful Viscosity Calibration, proceed with testing samples.

Instrument Shutdown

If it is necessary to shut down the unit, perform the following:

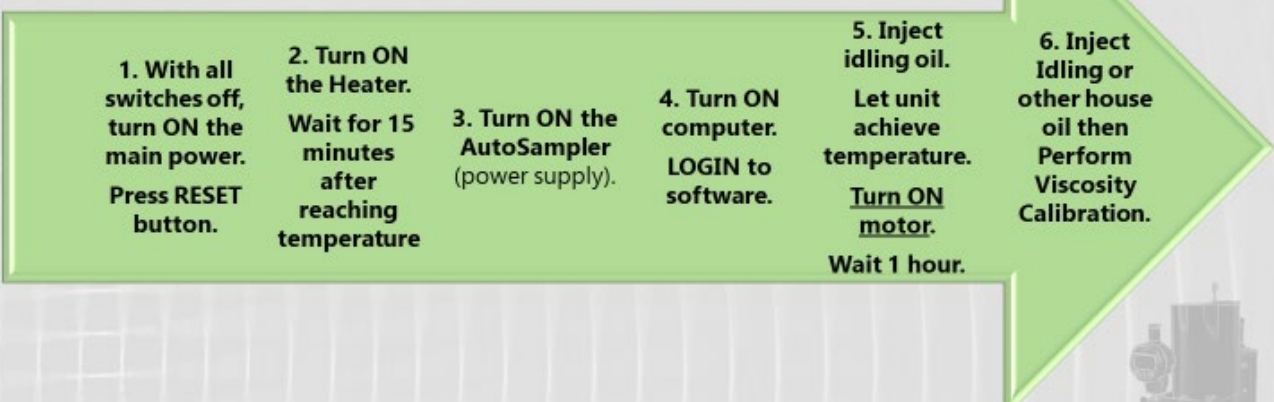


- 1. Inject Idling Oil and turn off the Motor** (leave the Rotor at the Operating Position).
- 2. Turn off the Heater.**
- 3. Turn off the main power.**
- 4. Turn off the AutoSampler and Heated Lines** (power supply).
- 5. Log out of software. Turn off computer.**




Instrument Start-up

To re-start the system after shutting down:



- 1. With all switches off, turn ON the main power. Press RESET button.**
- 2. Turn ON the Heater. Wait for 15 minutes after reaching temperature**
- 3. Turn ON the AutoSampler** (power supply).
- 4. Turn ON computer. LOGIN to software.**
- 5. Inject idling oil. Let unit achieve temperature. Turn ON motor. Wait 1 hour.**
- 6. Inject Idling or other house oil then Perform Viscosity Calibration.**



Automated Systems with TBS Software:

If your TBS Viscometer is operated with the TBS Software, many of the steps above are carried out automatically. See the associated manuals for more information.

H. Operation at 100° and 80° Temperatures

The TBS Viscometer can be operated at temperatures other than 150°C with several operational modifications. For operation at 100°C, use ASTM D6616 for more specific information. Note that these guidelines apply for operation at a shear rate of $1 \times 10^6 \text{ sec}^{-1}$.

Operating Notes:

1. Operating the TBS at 100°C or 80°C is the same as 150°C with the following changes:
 - a. The Reference Oils used to perform the Crossover Calibration at 100°C are NNR-10 and R-2400, as they are formulated to have the same viscosity at 100°C. The Reference Oils used to perform the Crossover Calibration at 80°C are NNR-80 and R-300, as they have the same viscosity at 80°C. Tolerances for the NNR are +/- 0.1 cP from the value listed on the bottle.
 - b. The Reference Oils used to perform the Viscosity Calibration for 100°C are R-2200, R-2300, R-2350 and R-2400. The Reference Oils used to perform the Viscosity Calibration for 80°C are R-100, R-200, R-300, and R-350.

Note: If the TBS Software is used, the viscosities of the Reference Oils should be updated for the specific test temperature. For example, R-200 has a viscosity of ~1.6 cP at 150°C but a viscosity of 3.5 cP at 100°C.
 - c. Adjust the air flow or use a chiller bath to account for viscous heating.
 - d. Make sure the temperature calibration offsets are set. Each temperature **MUST** have a calibration performed as each may have a different offset.

Setup:

1. Verify the accuracy of the temperature at 100°C (or 80°C) using a certified thermometer. (Be sure to turn “off” the heater during this time).
2. With the motor turned “off” and the rotor set at the operating position for 150°C, adjust the set temperature on the Temperature Controller to 100°C (or 80°C). Push the “up/down” arrow until the read out shows 100 (or 80). During this initial heating check, make sure that the RTD remains securely positioned in its hole in the stator.
3. Inject 50 mL of Idling Oil (using the 30-10-10 technique) into the stator, turn “on” the motor, and set the air flow to at least 100 mL/min. Setting this too high or too low may result in temperature instability. If using a chiller bath, turn it on at a temperature setting of approximately 80°C.

Note: It will require about 60 minutes for the Rotor/Stator Set to heat from room temperature and stabilize at 100°C.

4. Find Rubbing Contact and set the motor platform to 0.150 mm above that point.
5. Using the specified Reference Oils for the desired temperature, perform a Crossover Calibration and Viscosity Calibration.

Note: If the unit is running for more than 2 hours with Idling Oil, one extra flush of another oil (typically NNR) will be necessary before performing any calibrations or sample runs.

6. Run samples.

1. Operating at temperatures other than 150°C, 100°C, and 80°C

It is possible to run the TBS Viscometer at temperatures other than 150°C, 100°C, and 80°C. The following steps describe how to correctly determine the Operating Position.

1. Perform a Crossover Calibration and Viscosity Calibration at 150°C or a temperature nearest to the new temperature desired, using the Reference Oils specified at that temperature. Record the information.

2. Raise the motor platform by 0.200 mm and change the temperature to the new desired temperature.

3. Inject 50 mL of Idling Oil and let the temperature stabilize for one (1) hour. During this hour it is best to maximize the cooling (air or chiller) as necessary. Typically, temperatures below 100° require this additional cooling.

4. Inject R-400 and allow the unit to stabilize at the new desired temperature. Find Rubbing Contact and *raise* the motor platform by 0.150 mm. Inject Idling Oil, turn “on” the Motor and let it warm up for 10 minutes.

5. Inject R-400 and record the torque outputs and motor platform positions at a minimum of four motor platform positions. Each point will be 0.100 mm above the previous point, as done in the Crossover Calibration (Section D above). Perform a linear regression of these four points.

6. Operating position analysis:

Equation:

New operating position = R-400 intercept @ new temperature – (R-400 intercept @ 150°C – operating position @ 150°C)

The R-400 intercepts are determined from the linear regression at each temperature. The result of the above equation will be the operating position for the new temperature.

7. Perform the Viscosity Calibration at the new temperature and new operating position, without injecting NNR-03 after injecting the lowest viscosity and highest viscosity Reference Oils (NNR-03 is not valid at temperatures other than 150°C because of its non-

Newtonian characteristics). If the correlation of the Viscosity Calibration is >0.998, Sample Analysis can be performed.

Note: It is recommended to use NNR-03 or NNR-10 as a quality check for drift. If the measured value of the NNR changes by ± 0.1 cP over time (depending on the temperature), a new Viscosity Calibration should be performed.

J. Operation at Other Shear Rates

The TBS 2100E series Viscometers can be operated at a wide range of shear rates using two different methods. There is the “gap setting” method where the gap between the Rotor and Stator is varied to change the shear rate. They are directly proportional since the Rotor and Stator tapers are linear.

Another way to change the shear rate is called the “speed setting” method. Since shear rate and speed are directly proportional, changing the rotational speed of the rotor will change the shear rate. The speed range for the TBS 2100E series Viscometers is 800 to 8000 RPM.

It is possible to also combine the two methods to achieve either very high or very low shear rates.

1. Gap Setting Method – (shear rates from 200,000 cP to 2,500,000 cP at 3500 RPM)
 - a. Once a Crossover Calibration has been achieved at $1 \times 10^6 \text{ sec}^{-1}$ at the desired temperature, a calculation can be applied to determine the new operating position for the new shear rate. The equation is as follows:

Equation:

$$\text{New Operating Position} = (\text{R-400 Intercept}) - [(\text{R-400 Intercept} - \text{Operating Position}) * (1 \times 10^6 \text{ sec}^{-1} / \text{new shear rate})]$$

See Table 5 for an example.

TABLE 5. Gap Setting Method (By Motor Platform Positioning) for Specific Shear Rates

Shear Rate (Sec ⁻¹)	@3600 rpm		@3000 rpm	
	Platform Position (mm)	Gap (microns)	Platform Position (mm)	Gap (microns)
1,500,000	10.177	2.33	10.235	1.94
1,000,000	10.003	3.50	10.090	2.92
750,000	9.829	4.67	9.945	3.89
500,000	9.480	7.00	9.654	5.83
250,000	8.434	14.00	8.783	11.67

- b. Set the new operating position and wait a minimum of 30 minutes for temperature stabilization. If the shear rate is high and requires cooling air, then the air must be introduced one (1) full hour prior to the establishment of the gap at $1 \times 10^6 \text{ sec}^{-1}$.

2. Speed Setting Method

a. Choose the desired shear rate(s), then perform a Crossover Calibration at $1 \times 10^6 \text{ sec}^{-1}$ with a speed setting that will allow for the desired shear rate at another speed (i.e., calibrate $1 \times 10^6 \text{ sec}^{-1}$ at 4000 RPM then turn the speed to 8000 RPM to achieve $2 \times 10^6 \text{ sec}^{-1}$).

The Viscosity Calibration (four oil calibration) can be applied at the speed of the desired shear rate.

b. If a shear rate range is desired, place one Newtonian Reference Oil that is close to the viscosities of the oils to be analyzed and record the torque at each speed. Perform a linear regression using speed as the (x-axis) and torque as the (y-axis). Then apply the following equation when testing the samples.

$$\text{Equation: } V = ((T - b) / S) * K$$

Where V is the unknown viscosity, T is the sample torque at the individual speed, b is the intercept of the regression, S is the chosen speed and K is the viscosity of the calibration oil (which is divided by the slope of the regression).

If the shear rate is high and requires the input of air, then the air must be introduced one (1) full hour prior to the establishment of the gap at $1 \times 10^6 \text{ sec}^{-1}$. See Table 6 for an example.

Table 6. Speed Setting Method for Range of Shear Rates

RPM	Shear Rate, sec^{-1}		
800	50000	533300	1000000
1500	93750	1000000	1875000
2000	125000	1333000	2500000
2500	156300	1667000	3125000
3000	187500	2000000	3750000
3500	218750	2333000	4375000
4000	250000	2667000	5000000
4500	281300	3000000	5625000
5000	312500	3330000	6250000
6000	375000	4000000	7500000
7000	437500	4670000	8750000
8000	500000	5330000	10000000

Automated Systems with TBS Software:

It is possible to perform the above operations with both the Semi and Full-Automated TBS 2100E Viscometers. However, these functions will have to be performed manually (i.e. they are not automated in any way). If the operator needs to change the speed between temperatures, it is often handy to have a second reference oil rack on hand. These can be ordered from Tannas Co.

VII. MAINTENANCE/TROUBLESHOOTING GUIDE

A. Stator Support O-Ring Replacement

If oil is leaking from the bottom of the Stator Housing, it may be necessary to replace the Stator Support O-Rings. Because the Stator Support O-Ring is exposed to the elevated temperatures found in the Stator Housing, elastomer deterioration can be expected with time.

To facilitate replacement of the Stator Housing O-rings, the heater/stator assembly must be removed from the housing. Carefully remove the Thin-Film Heater from around the Stator as it will need to be replaced with new tape stripes later.

Note: It is recommended to call a Tannas Technical Representative for specific instructions on this procedure, or to return the entire housing assembly to Tannas for repair.

Note: When the stator housing is re-positioned, the alignment process (Section IV, B) will need to be repeated.

Replacement of the Stator Support O-ring requires the removal of the Stator Housing Assembly from the chassis base plate and is performed through the following steps:

1. Unscrew and remove the Fill Tube from the Stator Housing.

Note: It is IMPORTANT to remove the Fill Tube from the Stator Housing prior to loosening the Stator Support retaining screws.

2. On the underside of the Stator Housing are 3 machined screws. These anchor the Stator to the Stator Support, which in turn secures the Stator into the Stator Housing. Remove the three screws and the Stator Support.
3. Carefully remove the used O-ring, which may be stuck to the bottom of the Stator. In this case, a pick can be used to aid in the removal of the O-ring.
4. Clean the O-ring groove on the Stator Support with a paper towel or soft cloth dipped in Hexane or other appropriate solvent.

Note: IMPORTANT! Be sure all of the old Teflon tape is removed from the threaded hole on the Stator Support. Failure to properly clean this opening may allow Teflon particles to flow into the Rotor/Stator gap during an injection of oil causing bad data and possibly catastrophic failure of the Rotor/Stator Set.

5. Place a new O-ring in the Stator Support groove. Hold the Stator Housing with the bottom side down and carefully fit the Stator Support up into the opening on the bottom of the housing. Hold pressure between the two parts to capture the O-ring in place and flip the Stator Housing Assembly bottom side up on the bench top.
6. Look into the Fill Tube hole on the housing and rotate the Stator Support until the threaded hole for the Fill Tube can be seen. Install the 3 screws until they just begin putting pressure on the Stator Support. Wrap the Fill Tube threads with 2 or 3 turns of Teflon tape. Thread the tube a few turns into the housing and Stator Support. Now finish tightening the 3 Stator Support screws and the Fill Tube. Conduct a leak test as described in Section VII, D of this manual.

B. Cooling-Air Adjustment

1. Air-cooling of the Stator Housing generally is required only when higher viscosity oils are being tested or when testing at temperatures below 150°C is pursued. The air-flow tube affixed to the Stator Housing is also inserted into the 'air outlet' fitting on the back of the Console Box. The 'air-inlet' position on the console is designed to accept a supply (60 psi maximum) of dry, filtered air.

2. Turn on the regulated (60 psi maximum) air supply. Locate the black air-control knob of the regulator on the rear of the Console Box and pull out to open. With the valve open, air is admitted to the air flow control knob on the front side of the Control Console. Turn the black control knob, located on the left-hand side of the Control Console, to open fully. Maximum airflow is now directed to the Stator Housing. Adjust the black air-control knob on the back -side of the Console Box until the flow-indicator ball in the flowmeter floats just at the top of the meter scale. Then "lock" the black air-control knob by pushing it in. Air flow to the Stator Housing now can be controlled within the range of the flowmeter scale -- measured in standard cubic feet (SCF) per hour -- using the knob on the flowmeter. Allow it to stabilize for one hour after changing the air-flow.

Note: Any time the air-flow rate is changed, the calibration must be repeated because of expansion and contraction characteristics. We recommend if air is required to set it at the maximum setting.

C. Rotor-Stator Lockup

1. Finding the Rubbing Contact must be done carefully. This is a skill that takes patience to learn. Occasionally operators have found they have seized a rotor inside a stator. To minimize this occurrence, it is advisable when finding Rubbing Contact to use an oil similar in viscosity to R-450. However, BIF-03 is the primary option that should be used when close Rotor/Stator contact is expected.

2. Surface interference between the Rotor and Stator may be intermittent or it may result in complete immobility. Intermittent contact with the Stator by the Rotor may be the result of a misaligned Stator, or a Rotor that has picked up brass from the Stator. If true lockup should occur while running, the Motor should be turned "off" immediately. Occasionally, the Rotor can be removed by injecting Idling Oil and increasing the set point temperature by 20-40°C (the setpoint temperature should not exceed 190°C). This may cause the Stator to expand enough to allow the Rotor to release when raising the motor platform.

Note: Prying up on the Siamese Collet with a screwdriver will often damage the Stator Housing, Stator and/or collet. Returning the complete Stator Housing assembly (with Rotor detached from collet) to Tannas is the safest way for a locked-up Rotor/Stator Set to be evaluated for possible salvage (repair).

3. If successful in extracting the Rotor, evidence of beryllium-copper metal on the Rotor surface can be detected with the aid of a low-power magnifying glass, preferably with supplemental lighting. If small specs of dark material can be seen, it should be sent to Tannas for repair.

4. Examine the Stator walls for "grooving" both visually and with the fingernail of the small finger (once the stator has cooled to room temperature). Extensive surface roughness must be removed with a precision lapping tool and for this purpose the Rotor and Stator should be returned to Tannas for the lapping (repair) operation. If evidence of extensive grooving is not apparent, follow the cleaning procedures mentioned below:

- a) Remove the Stator from the Stator Housing following the procedures outlined in Section VII. A of this manual.
- b) Place the Rotor and Stator in a heated sonic cleaning bath filled with either glass cleaner or water diluted VarClean.
- c) Make sure the Rotor and Stator are separated by at least two inches when placed in the sonic bath.
- d) Run the sonic cleaner overnight for a thorough cleaning.
- e) Rinse both items with water and dry once completed.

5. Re-assemble the Stator in its housing and leak check when re-positioned; re-alignment of the Stator Housing is required.

D. Cleaning a TBS Rotor/Stator Set

Visual Inspection of the Rotor/Stator Set for Varnish – It is always good practice to inspect the rotor periodically especially when using the TBS on oils with a tendency to form varnish.

- Varnish on the Rotor and Stator walls can cause poor results during calibration runs as well as excessive viscosity calibrations.
- Also, when the Crossover calibration results start to slowly drop in correlation (value of R2 becomes less than 0.999) this is usually a first indication that the Rotor and Stator are starting to varnish.
- A good practice to prevent this condition from occurring is to periodically clean the Rotor/Stator with Tannas Varclean varnish remover.

Procedure –

1. Turn off the motor and the heat.
2. Remove the RTD, two Teflon Lid halves, and raise the Rotor completely out of the Stator and rotate with fingers to see if it is discolored.
3. If the Rotor is discolored, lower the Rotor carefully back into the Stator to a position close to 1 mm above its previous operating position.
4. Re-insert the RTD only (not the lids). When the Stator temperature becomes less than 100°C, inject Varclean until it reaches the top of the Stator.
5. Allow the Rotor and Stator to soak until the next day (a period of 12 to 24 hours).
6. The next day at ambient temperature, flush the Stator with 200 ml of distilled hot water while slowly turning the Rotor in the Stator by hand during this injection.
7. Then inject 200 ml of any oil while again slowly turning the Rotor by hand.

8. Replace the Teflon lids and the RTD.
9. Inject 25 mL of Idling Oil into the Rotor/Stator while slowly turning the Rotor by hand.
10. After injection of Idling Oil, heat the Rotor/Stator set back to 150°C.
11. Find rubbing contact, raise the Rotor by 0.5 mm and turn on the motor.
12. After one hour of operation, turn off the motor, recheck rubbing contact, raise the Rotor by 0.1 mm (check to make sure the Rotor turns freely), restart the motor and start the Crossover calibration.

E. Checking for Leakage

1. Before affixing the Stator Housing to the base plate, it is recommended to conduct a "leak test" of the housing. The machined beryllium copper Stator has been mounted in the Stator Housing using an elastomeric O-ring. To leak-check the Stator within the Stator Housing, apply a slight vacuum on the Stator well. First, seal the Stator well opening (top) with a smooth, clean rubber stopper. Then, load a minimal quantity (about 5 mL) of any clean flushing oil into the Glass Syringe (preferably a non-additive neutral petroleum stock with a viscosity in the range of 12-15 cSt at 40°C). Use this oil to thoroughly wet and lubricate the plunger/barrel interface of the syringe.

With the Stator Housing conveniently placed on the laboratory bench, attach the syringe to the Fill Tube and pull up and hold the syringe plunger. After an initial influx, the absence of any air bubbles leaking into the syringe is indicative of a tight O-ring seal. If continuing air leakage is evident, seal adjustment (or replacement) can be completed following the directions given in Section VII. A. of this Maintenance/Troubleshooting Guide.

At this point, to avoid introduction of any oil into the Stator housing, break the partial vacuum by removing the rubber stopper from the Stator before releasing the syringe plunger and removing the syringe altogether. Any traces of oil in the Fill Tube can be removed by solvent flushing followed by air-drying.

2. Position the Stator Housing with the Fill Tube facing the front of the viscometer unit. Loosen the two Nylon screws holding the Fill Tube support bracket; do not re-tighten until alignment is complete. Insert the three Nylon screws previously set aside and loosely attach the Stator Housing to the base plate.

F. Installing the Siamese Collet Assembly

The Rotor is driven by the Motor via the Siamese Collet Assembly. The Rotor is fastened on one end and the motor driveshaft on the other. **Both ends are the same size.**

The Siamese Collet Assembly consists of two double-faced or "Siamese" collets on both ends of a flexible collet wire shaft. This invention provides a coaxial wire flexi-shaft with ease of replacing the wire shaft at any time and serves to prevent damage to the motor in the event that a Rotor/Stator lockup occurs.

The Siamese Collet Assembly is shipped from Tannas fully assembled with the wire shaft in place. However, occasionally the need will arise to replace the wire shaft, which may be performed using the following steps:

1. Raise the TBS motor platform until the Rotor is completely free from the Stator well. Place a paper towel over the Stator well opening to prevent the Rotor from falling once the Siamese Collet Assembly is removed from the motor shaft. Lower the motor platform until the rotor is resting gently on the paper towel.
2. Loosen the nut connecting the upper Siamese Collet to the motor shaft. When either loosening or tightening any nut on either of the Siamese Collet sets, it is necessary to use two wrenches (provided in the TBS Tool Box kit).
3. Raise the motor platform until the Siamese Collet Assembly can be removed from the motor shaft.
4. Loosen the two wire nuts—one on either side of the Siamese Collet Assembly—and remove the wire shaft. Insert a new 55-mm (2-3/16") wire shaft completely into the Rotor collet until it contacts the end of the rotor shaft. Tighten the rotor nut.
5. Insert the other end of the wire shaft into the upper collet set. Position the upper collet such that there is approximately 25 mm (1") of exposed wire shaft between the two collet sets. Tighten the upper collet nut.

Note: Tannas produces a Collet Assembly Tool which holds the two Siamese Collets exactly one inch apart from one another and aides in the installation of the collet wire between the two collets. Contact Tannas or your local representative for more information.

6. Install the completed Siamese Collet Assembly on the motor driveshaft by sliding the motor driveshaft into the upper collet. Lower the motor platform until the Rotor is again supported by the paper towel covering the Stator well. Tighten the upper collet nut securing the Siamese Collet Assembly to the motor driveshaft.

If the collet wire shaft is broken, usually the Rotor will need to be removed from the Stator by first removing the upper portion of the Siamese Collet set from the motor shaft. Getting the Rotor and lower portion of the Siamese Collet set out of the Stator can sometimes require expert Tannas assistance, as described earlier.

To remove the upper section of the Siamese Collet set from the motor shaft, raise the motor platform to provide good access to the motor nut. Loosen this nut until the upper Siamese Collet set can be removed. Loosen the wire nut on this collet set until the wire shaft is free. If the wire shaft can be removed, do so. If not, (in the case when the wire shaft is broken at the collet face), use another wire shaft to push out the piece of the broken wire from the other side of the Siamese Collet.

Removing the Rotor from the Stator can be simply a matter of pulling it out by the remaining wire shaft still connected to the lower Siamese Collet set. In the case of a very difficult Rotor/Stator lockup, contact Tannas Technical Service to aid in removal of the Rotor. It may be necessary to repair the set.

Whatever the status of the Rotor and Stator, once the Rotor is removed and a new or repaired Rotor/Stator set is readied for further viscometric work, the reassembly of the Siamese Collet Assembly proceeds as in the previous section.

G. TBS Troubleshooting Guide

Symptom	Problem	Solution
No Power	<ol style="list-style-type: none"> 1. Blown Fuse 2. Heater not connected 3. Blown overtemp. fuse 	<ol style="list-style-type: none"> 1. Replace main fuse 2. Connect heater cable and press the reset button. 3. Replace overtemp. fuse & press the reset button.
Temperature Controller flashes bad input	<ol style="list-style-type: none"> 1. Bad or missing RTD 2. Bad Temperature Controller 	<ol style="list-style-type: none"> 1. Replace or install RTD 2. Call Tannas Co.
Poor correlation on Crossover Calibration	<ol style="list-style-type: none"> 1. Temperature not stable at each position before reading. 2. Rotor/stator set dirty 3. Damaged Load-cell 4. Rotor/stator set damaged 	<ol style="list-style-type: none"> 1. Re-do crossover or check PID setting. 2. Clean according to manual 3. Call Tannas Co. 4. Call Tannas Co.
Poor correlation on Viscosity Calibration	<ol style="list-style-type: none"> 1. Wrong oils and/or wrong viscosities used. 2. Rotor/Stator set dirty 3. Damaged Load-cell 	<ol style="list-style-type: none"> 1. Re-do calibration 2. Clean according to manual 3. Call Tannas Co.
High intercept value on Viscosity Calibration	<ol style="list-style-type: none"> 1. Unit is not zeroed properly. 2. Motor wires pushing or pulling on motor. 3. Rotor/Stator set dirty 4. Bent shaft on collet 5. Misalignment of housing 	<ol style="list-style-type: none"> 1. Adjust zero on Torque Meter 2. Turn off motor, raise platform and adjust wires. 3. Clean according to manual 4. Replace collet shaft 5. Cool and re-align housing
Torque Meter will not zero	<ol style="list-style-type: none"> 1. Torque sensor mounting is improperly set. 2. Torque Meter needs adjustment. 	<ol style="list-style-type: none"> 1. Tighten and/or loosen Load-cell mounting screws. 2. Adjust the offset setting in the Torque Meter.
Fluctuating torque on meter is greater than ± 5 .	<ol style="list-style-type: none"> 1. Stator temperature and/or room temperature not stable. 2. Bent shaft on collet 3. Rotor/Stator set dirty 	<ol style="list-style-type: none"> 1. Check for room drafts and adjust PID. 2. Replace shaft 3. Clean according to manual
Torque drops on some oils but not others	<ol style="list-style-type: none"> 1. Leaving non-Newtonian oil in too long before testing. 	<ol style="list-style-type: none"> 1. Re-run sample
Indicator drifts (vibrates) more than 0.01 mm.	<ol style="list-style-type: none"> 1. Bent shaft on collet 2. Misalignment of housing 3. Vibration from facility 	<ol style="list-style-type: none"> 1. Replace shaft 2. Cool and re-align housing 3. Eliminate bench vibration
Computer readout of Micrometer reading zero (<i>Full-Auto only</i>)	<ol style="list-style-type: none"> 1. Bad battery in Micrometer 2. Loose cable connection 3. Vibration from facility 	<ol style="list-style-type: none"> 1. Replace Micrometer battery 2. Check Micrometer cable 3. Eliminate bench vibration

VIII. WARRANTY & LIABILITY

TAPERED BEARING SIMULATOR (TBS) VISCOMETER Limited One (1) Year Warranty

Tannas Company warrants for one year from date of commissioning any TBS Viscometer unit according to the following terms:

Any part of the unit manufactured or supplied by Tannas and found in the reasonable judgment of Tannas to be defective in material or workmanship will be repaired or replaced by Tannas without charge for parts and labor.

That portion of the TBS Viscometer including any defective part must be returned to Tannas Company within the warranty period. The expense of returning the unit to Tannas Company for warranty service will be paid for by the buyer. Tannas' responsibility in respect to warranty claims is limited to making the required repairs or replacements, and no claim of breach of warranty shall be cause for cancellation or rescission of the contract of sale of any unit.

This warranty does not cover any TBS Viscometer unit that has been subject to misuse, neglect, negligence, or accident. The warranty does not apply to any damage to the unit that is the result of improper installation or maintenance, or to any unit that has been operated or maintained in any way contrary to the operating or maintenance instructions as specified in the TBS Viscometer Operations Manual. The warranty does not cover any unit that has been altered or modified so as to change its intended use. This includes any software modifications or additions to the Tannas supplied computer.

In addition, the warranty does not extend to repairs made necessary by the use of parts, accessories, or fluids that are either incompatible with the unit or adversely affect its operation, performance, or durability.

Tannas reserves the right to change or improve the design of TBS Viscometer units without assuming any obligation to modify any unit previously manufactured.

THE FOREGOING EXPRESS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED INCLUDING WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

TANNAS' OBLIGATION UNDER THIS WARRANTY IS STRICTLY AND EXCLUSIVELY LIMITED TO THE REPAIR OR REPLACEMENT OF DEFECTIVE PARTS, AND TANNAS DOES NOT ASSUME OR AUTHORIZE ANYONE TO ASSUME FOR THEM ANY OTHER OBLIGATION.

TANNAS ASSUMES NO RESPONSIBILITY FOR INCIDENTAL, CONSEQUENTIAL OR OTHER DAMAGES INCLUDING, BUT NOT LIMITED TO, LOSS OR DAMAGE TO PROPERTY, LOSS OF REVENUE, LOSS OF USE OF THE UNIT, LOSS OF TIME, OR INCONVENIENCE.

IX. SPARE PARTS/REPLACEMENT ITEMS

The following tabulation lists specific part numbers to aid in ordering replacement items. Although some spare parts are provided in the Tool Box, one should consider also stocking some key items in order to reduce down time. Those most likely to need early replacement are reference oils, syringes, filter-holders, filter papers, and fuses. We also recommend stocking an 'extra' Rotor/Stator Set and Stator Housing Assembly.

<u>ITEM DESCRIPTION</u>	<u>PART NUMBER</u>	
	<u>Pint</u> (0.47 liter)	<u>Half Gallon</u> (1.89 liter)
<u>High Temperature, Newtonian Reference Oils</u>		
R-100	020100	040100
R-200 / R-2200	020200	040200
R-300 / R-2300	020300	040300
R-350 / R-2350	020350	040350
R-400	020400	040400
R-450 / R-2450	020450	040450
R-500	020500	040500
R-600	020600	040600
R-2400	020240	040240
<u>High Temperature, High Shear, Non-Newtonian Reference Oils</u>		
NNR-03	020024	040024
NNR-10	020025	040025
NNR-80	020026	040026
<u>TBS Specialty Oils</u>		
BIF-03	010001 (1/4 pint only)	
Idling Oil	020010	040010
<u>TBS Spares and Consumables</u>		
Rotor/Stator Set – Calibrated	300252	
Stator Housing Assembly-2100E (w/Lids)	300288	
TBS Stator Housing Lids	300477	
O-Rings (Viton)		
Stator Support (5-pack)	300520	
Stator Housing (5-pack)	300512	
Glass Syringe (50cc)	300569	
Disposable Syringe (50cc) (20-pack)	300513	
Filter Holder	300547	
Filter Paper – nominal 10 micron (50/pk)	300548	
TBS 2100E series Siamese™ Collet Assembly	300315	
Thin-Film Heater	300541	

<u>ITEM DESCRIPTION</u>	<u>PART NUMBER</u>
PI Film Tape	950905
Alignment Tool – TBS 2100E	300493
RTD Assembly (Temperature Sensor)	300263
Thermal Cut-off Fuse Assembly	300274

X. REPAIRS

Experience dictates that the malfunction most frequently encountered with a TBS is a lockup of the Rotor/Stator Set. Extensive surface damage to either the rotor or stator will require that the pair be returned to Tannas for evaluation and possible repair.

On occasion, it is possible that one or more other major components of the TBS will need to be returned also. In every case, contact a Tannas representative for shipping advice. Wherever possible, shipment should be made in the original shipping container, using Motor Freight or United Parcel Service, to:

**TANNAS COMPANY
4800 James Savage Rd.
Midland, MI 48642
USA
ATTN: TBS Manager**

Insurance to cover loss in transit is advisable.