HR and DHR SERIES
DISCOVERY HYBRID RHEOMETER

Getting Started Guide
for Discovery Series Hybrid Rheometers
HR 10/20/30 and DHR 1/2/3

Revision H   Issued May 2022

Notice

The material contained in this manual, and in the help for the software used to support this instrument, is believed adequate for the intended use of the instrument. If the instrument or procedures are used for purposes other than those specified herein, confirmation of their suitability must be obtained from TA Instruments. Otherwise, TA Instruments does not guarantee any results and assumes no obligation or liability. TA Instruments also reserves the right to revise this document and to make changes without notice.

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Introduction

Important: TA Instruments Manual Supplement

Please click the TA Manual Supplement link to access the following important information supplemental to this Getting Started Guide:

- TA Instruments Trademarks
- TA Instruments Patents
- Other Trademarks
- TA Instruments End-User License Agreement
- TA Instruments Offices

Notes, Cautions, and Warnings

This manual uses NOTES, CAUTIONS, and WARNINGS to emphasize important and critical instructions.

NOTE: A NOTE highlights important information about equipment or procedures.

CAUTION: A CAUTION emphasizes a procedure that may damage equipment or cause loss of data if not followed correctly.

MISE EN GARDE: UNE MISE EN GARDE met l'accent sur une procédure susceptible d'endommager l'équipement ou de causer la perte des données si elle n'est pas correctement suivie.

A WARNING indicates a procedure that may be hazardous to the operator or to the environment if not followed correctly.

Un AVERTISSEMENT indique une procédure qui peut être dangereuse pour l'opérateur ou l'environnement si elle n'est pas correctement suivie.

Regulatory Compliance

Safety Standards

For Canada

CAN/CSA-C22.2 No. 61010-1 Safety requirements for electrical equipment for measurement, control, and laboratory use, Part 1: General Requirements.

CAN/CSA-C22.2 No. 61010-2-010 Particular requirements for laboratory equipment for the heating of materials.

For European Economic Area

(In accordance with Council Directive 2006/95/EC of 12 December 2006 on the harmonization of the laws of Member States relating to electrical equipment designed for use within certain voltage limits.)

EN 61010-1:2010 (3rd Edition) Safety requirements for electrical equipment for measurement, control, and laboratory use, Part 1: General Requirements + Amendments.

EN 61010-2-010:2003 Particular requirements for laboratory equipment for the heating of materials + Amendments.

For United States

UL61010-1:2012 Electrical Equipment for Laboratory Use; Part 1: General Requirements.

UL61010A-2-010:2015 Particular requirements for laboratory equipment for the heating of materials + Amendments.

Electromagnetic Compatibility Standards

For Australia and New Zealand

AS/NZS CISPR11:2004 Limits and methods of measurement of electronic disturbance characteristics of industrial, scientific and medical (ISM) radio frequency equipment.

For Canada

ICES-001 Issue 4 June 2006 Interference-Causing Equipment Standard: Industrial, Scientific, and Medical Radio Frequency Generators.

For the European Economic Area

(In accordance with Council Directive 2004/108/EC of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility.)

EN61326-1:2012 Electrical equipment for measurement, control, and laboratory use-EMC requirements-Part 1: General Requirements. Emissions: Meets Class A requirements per CISPR 11. Immunity: Per Table 1 - Basic immunity test requirements.

For the United States

CFR Title 47 Telecommunication Chapter I Federal Communications Commission, Part 15 Radio frequency devices (FCC regulation pertaining to radio frequency emissions).

Supplier's Declaration of Conformity

47 CFR § 2.1077 Compliance Information

Unique Identifier:

HR 30 Discovery Hybrid Rheometer: **534003.901**

HR 20 Discovery Hybrid Rheometer: **534002.901**

HR 10 Discovery Hybrid Rheometer: **534001.901**

HR 3 Discovery Hybrid Rheometer: **533003.901**

HR 2 Discovery Hybrid Rheometer: **533002.901**

HR 1 Discovery Hybrid Rheometer: **533001.901**

Responsible Party:

TA Instruments
159 Lukens Drive
New Castle, DE 19720
302-427-4000
www.tainstruments.com

FCC Compliance Statement:

This device complies with Part 15 of the FCC rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Safety

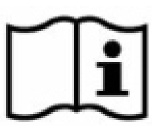
Do not attempt to service this instrument, as it contains no user-serviceable components.

Required Equipment

While operating this instrument, you must wear eye protection that either meets or exceeds ANSI Z87.1 standards. Additionally, wear protective clothing that has been approved for protection against the materials under test and the test temperatures.

Instrument Symbols

The following label is displayed on the instrument for your protection:

Symbol	Explanation
	This symbol indicates that you should read this Getting Started Guide for important safety information. This guide contains important warnings and cautions related to the installation, operation, and safety of the instrument. Ce symbole indique que vous devez lire entièrement ce guide de démarrage. Ce guide contient d'importants avertissements et mises en garde relatifs à l'installation, à l'utilisation et à la sécurité de l'instrument.
	This symbol indicates that a hot surface may be present. Take care not to touch this area or allow any material that may melt or burn to come in contact with this hot surface. Ce symbole indique la présence possible d'une surface chaude. Prenez soin de ne pas toucher cette zone ou de laisser un matériau susceptible de fondre ou de brûler entrer en contact avec cette surface chaude.
	This symbol indicates that you are advised to consult this manual for instructions. Ce symbole indique que nous vous recommandons de consulter ce manuel pour les instructions.

Please heed the warning labels and take the necessary precautions when dealing with these areas. This *Getting Started Guide* contains cautions and warnings that must be followed for your own safety.

Warnings

WARNING: No user serviceable parts are contained in the rheometer. Maintenance and repair must be performed by TA Instruments or other qualified service personnel only.

AVERTISSEMENT: Le rhéomètre ne contient aucune pièce réparable par l'utilisateur. La maintenance et la réparation doivent être effectuées uniquement par TA Instruments ou tout autre personnel d'entretien qualifié.

WARNING: Always unplug the instrument before performing any maintenance.

AVERTISSEMENT: Débranchez toujours l'instrument avant de procéder à la maintenance.

WARNING: It is recommended that this instrument be serviced by trained and skilled TA Instruments personnel at least once a year.

AVERTISSEMENT: Il est recommandé que l'entretien de cet instrument soit assuré par le personnel formé et qualifié de TA Instruments au moins une fois par an.

WARNING: This equipment must not be mounted on a flammable surface if low flashpoint material is being analyzed.

AVERTISSEMENT: Cet équipement ne doit pas être monté sur une surface inflammable si un matériau à point d'éclair bas est en cours d'analyse.

WARNING: An extraction system may be required if the heating of materials could lead to liberation of hazardous gasses.

AVERTISSEMENT: Un système d'extraction peut être requis si le chauffage des matériaux risque d'entraîner la libération de gaz dangereux.

WARNING: Take adequate precautions prior to heating of materials if it can lead to explosion, implosion or the release of toxic or flammable gasses.

AVERTISSEMENT: Prenez des mesures de précaution adéquates avant de chauffer des matériaux, si cela peut entraîner l'explosion, l'implosion ou le dégagement de gaz toxiques ou inflammables.

Electrical Safety

Always unplug the instrument before performing any maintenance.

Supply voltage: 110 to 230 VAC

Fuse type: 2 x T15A H250 V

Mains frequency: 50 to 60 Hz

Power: 1.4 kW

DANGER: Because of the high voltages in this instrument, maintenance and repair of internal parts must be performed by TA Instruments or other qualified service personnel only.

DANGER: À cause de la présence de tensions élevées dans cet instrument, la maintenance et la réparation des pièces internes doivent être effectuées uniquement par TA Instruments ou tout autre personnel d'entretien qualifié.

WARNING: This instrument must be connected to an earthed (grounded) power supply. If this instrument is used with an extension lead, the earth (ground) continuity must be maintained.

AVERTISSEMENT: Cet instrument doit être connecté à une alimentation électrique mise à la terre. Si cet instrument est utilisé avec un fil de rallonge, la continuité de la mise à la terre doit être maintenue.

WARNING: During the installation or reinstallation of the instrument, ensure that the external connecting cables are placed separate from the mains power cables. Also, ensure that the external connecting cables and the mains power cables are placed away from any hot external parts of the instrument. Note: Ensure that the mains power cable is selected such that it is suitable for the instrument that is being installed or reinstalled, paying particular attention to the current rating of both the cable and the instrument.

AVERTISSEMENT: Pendant l'installation ou la réinstallation de l'instrument, assurez-vous que les câbles de raccordement externes sont placés séparément des câbles du secteur électrique. Assurez-vous également que les câbles de raccordement externes et les câbles du secteur électrique sont placés à distance des pièces externes chaudes de l'instrument. Remarque: assurez-vous de sélectionner un câble du secteur électrique qui soit approprié à l'instrument installé ou réinstallé, en prêtant une attention particulière au courant nominal du câble et de l'instrument.

Chemical Safety

- Do not use hydrogen or any other explosive gas.
- Use of chlorine gas will damage the instrument.
- If you are using samples that may emit harmful gases, vent the gases by placing the instrument near an exhaust.
- Instrument may be installed in a glovebox enclosure.

Table of Contents

Chapter 1:

About the Discovery Series Rheometers

Overview

This chapter reviews the history of rheology, and traces the development of combined motor and transducer (CMT) rheometers. The models in the Discovery Series are introduced, and brief descriptions of their main components and accessories are given. Please read this chapter carefully to familiarize yourself with the terminology used throughout this manual.

A Brief History of Rheology and the Development of CMT Rheometers

In 1929, Professor Eugene Bingham, a physical chemist working at Lafayette College in Pennsylvania, decided that the study of the deformation and flow of matter was important enough to merit its own title. On the advice of a Professor of Classics, he coined the term “rheology”, from the Greek rew (rheo) meaning flow. But the discipline of rheology is much older than the word. The first formal scientific description of a rheological phenomenon appeared in Isaac Newton's Principia Mathematica, published in 1687, where he suggested that “the resistance which arises from the lack of slipperiness of the parts of [a] liquid, other things being equal, is proportional to the velocity with which the parts of the liquid are separated from one another.” Today we would say that the shear stress is proportional to the shear rate, and we would call the constant of proportionality the viscosity of the liquid. As we now know, Newton's postulate applies only to a limited class of low molecular weight liquids, over finite ranges of shear rate or stress. Rheology is usually more concerned with materials whose behavior is non-Newtonian, in that their viscosity is a function of shear rate or stress. Such materials include polymers, paints, inks, creams, gels, shampoos, drilling fluids, adhesives, and many foodstuffs.

It seems that Newton conducted no experimental work on the viscosity of liquids, and it was not until the middle of the nineteenth century that work in that area was led by Poiseuille. The operating principle of most of the early viscometers, including Poiseuille's, was that the fluid was driven by pressure or gravity through a capillary or other constriction, and the rate of flow measured. Devices of this design are still in use today, but, although they may have the advantage of simplicity of construction and operation, they have the drawback that the sample can only be subjected to a finite strain.

However, a great step forward was made in the 1880's when the rotational viscometer was introduced by Couette and others. In this type of device, the sample is situated either in the annular gap between two concentric cylinders, as in Couette's original design, or in the gap between two concentric, horizontally mounted, parallel platens. One of the cylinders or platens (the stator) is fixed, the other (the rotor) is rotated, and provided that the rotation can be permanently maintained, there is no limit to the strain that the sample can be subjected to. In Couette's design, the outer cylinder was fixed, the inner was driven by a weight connected to it through a series of pulleys. The angular velocity of the rotating cylinder was calculated from the time taken for the weight to fall. This design is interesting for two reasons, one being that it was the stress that was controlled (through the weight) rather than the strain or strain rate, the other being that actuator and detector were mounted on the same axis. It happens that the first of these gave rise to the term used to describe the successors to this type of viscometer: “controlled stress”. They might alternatively have been described by the second as “combined motor and transducer” (CMT). This term is now preferred, since modern rheometers can operate in both controlled stress and controlled rate modes.

It was many years before an electrically driven version of Couette's CMT apparatus was developed. The next major advance in rheological instrumentation was introduced by Weissenberg in the 1940's. Weissenberg's intention was to investigate the viscoelasticity of polymer melts and solutions, but the viscometers that existed at the time were not suitable for this study. This led to the next advance in instrumentation.

The study of elasticity parallels closely the study of viscosity. The first scientific reference to elasticity was made by Robert Hooke, a correspondent and rival of Newton's, who published his famous anagram "CEIINOSSITTUU" in 1676, revealed as "ut tensio sic uis" (as the extension, so the force) in 1679. Hooke's Law, as it came to be called, was supported by experimental observation, but it was not until the work of Young in the early nineteenth century that it was realized that the law could be applied to material properties, rather than simply to extensive sample properties. In modern terminology, we would summarize Young's findings by saying that the strain is proportional to the stress, and we would refer to the "constant of proportionality" as the "modulus of the material." Later in the nineteenth century, the work of Maxwell, Voigt, Kelvin, Boltzmann and others showed that the distinction between viscous liquids and elastic solids was not as clear as had previously been thought. Most of the materials listed above as non-Newtonian, are also viscoelastic, in that they exhibit aspects of both types of behavior. (The names of the scientists who contributed to the development of rheology reveal its importance: Einstein was also involved, and rheologists like to say that in their discipline Newton, Maxwell and Einstein did the easy bits.)

To conduct his investigation into polymer viscoelasticity, Weissenberg developed the first modern, electrically driven, rheometer during the early 1940s, the basis of which was a lathe turned on its end. As such it differed in two very significant ways from the Couette viscometers, firstly in that it was what later became called a controlled rate rheometer, and secondly in that the actuator and detector were mounted on separate axes. To adopt the principle of naming used above, this can be called the "separate motor and transducer" (SMT) design. The principle of operation was that one of the platens of the measuring system was rotated at a set angular speed, the torque transmitted by the sample being measured at the other platen. Weissenberg called his instrument a "Rheogoniometer," since both the torque and the axial force could be measured, the latter being used to calculate the normal stress which results from the elasticity of the sample. In the late 1940s the rheogoniometer was commercialized, but its price was beyond the range of most materials testing laboratories. In 1970, Chris Macosko and Joe Starita formed the Rheometrics company (later renamed Rheometric Scientific) to produce a lower cost alternative, and launched the first of a long line of high quality SMT rheometers that led eventually to the modern ARES. Rheometric Scientific was acquired by TA Instruments in January 2003, and its products continue to be manufactured and developed.

In the meantime, interest revived in CMT instruments, partly because of a desire to perform creep tests, and partly because of the need to investigate the phenomenon of the yield stress in more detail, for which the available SMT rheometers lacked the sensitivity. To these ends, Jack Deer, who was employed as a technician at the London School of Pharmacy, designed a rotational rheometer based on the Couette viscometer, but with the weight replaced, originally by an air-turbine drive, and later by a drag cup motor (both shown in Figure 1). To reduce the friction in the instrument, an air bearing was introduced. Deer's first published description of the instrument appeared in 1968 [Davis, Deer and Warburton, J. Sci. Instr. 2, 933-936, 1968]. He began to commercialize it shortly afterwards. In the early 1980's the design was taken up by the Carri-Med company, at Deer's instigation, and that company launched its first rheometer, the CSR, in 1984 (shown in Figure 2).

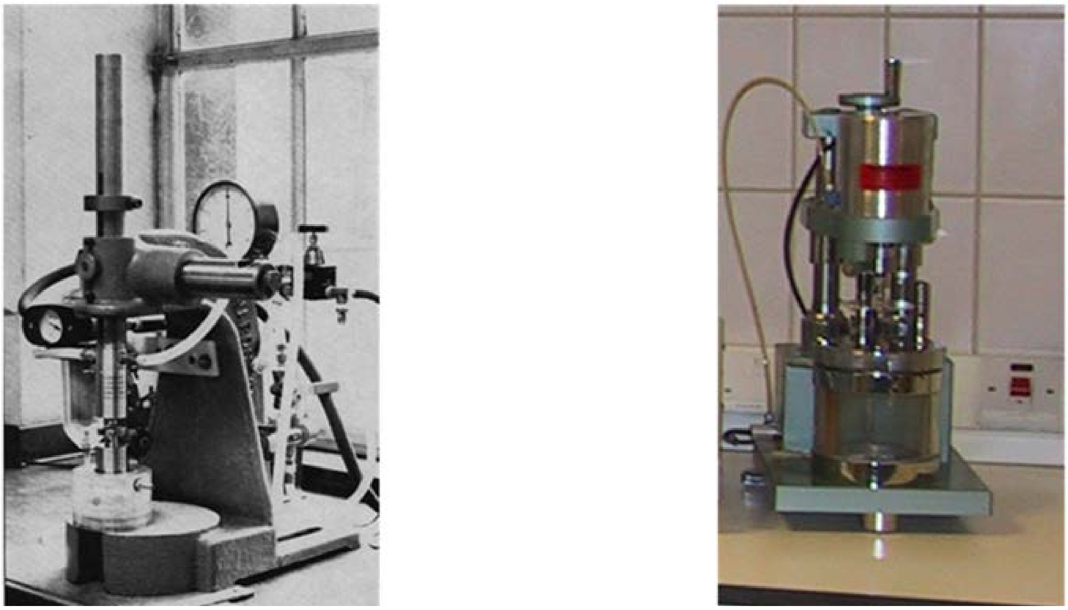


Figure 1 Jack Deer's Air Turbine Rheometer (left); Deer Rheometer (right).

Figure 2 CSR.

Carri-Med acquired the rights to the Weissenberg rheogoniometer in 1990, but the mainstay of its business remained the CMT successors to the Deer, which included the CSL and CSL2 (shown in Figure 3), until the company was purchased by TA Instruments in 1993. From that time on, progress in CMT technology has been remarkable, with the AR 1000 launched in 1996 and the AR 2000 in the year 2000 by TA Instruments. Both these instruments used air bearings, but the limits of that technology appear to have been reached, and for the AR-G2 (Figure 4), launched in 2005, a magnetically levitated bearing was used. This and other developments by TA Instruments have advanced the instrumentation further. Developments, for example, in the drag cup motor and the electronics, have led to substantial improvements in the low torque, controlled rate, and transient performances of the instrument.

Figure 3 CSL^2.

Figure 4 AR-G2.

The Discovery Hybrid Rheometer Series (HR 1, HR 2, and HR 3) expanded on the AR-G2 advancements by incorporating the Force Rebalance Transducer (FRT) technology for axial force measurements.

Figure 5 DHR and electronics box.

The Discovery HR X0 Series (HR 10, HR 20, and HR 30) is the latest CMT rheometer from TA Instruments, featuring the third generation of magnetic bearing technology for the most accurate torque measurements, a large easy to use touch screen, and improved Smart Swap™ technology, sample lighting, and improvements in the speed and range of the head travel.

Figure 6 HR X0 Series.

The Discovery Hybrid Rheometer (DHR)

The Discovery Series rheometers (HR 10, HR 20, HR 30) are the world's most advanced combined motor and transducer (CMT) rheometers. The systems consist of a main instrument and a separate electronics box. The interplay between the rheometer main unit and the electronics is described in "Key Rheometer Components" on page 17.

A schematic of the DHR is given in the figure below.

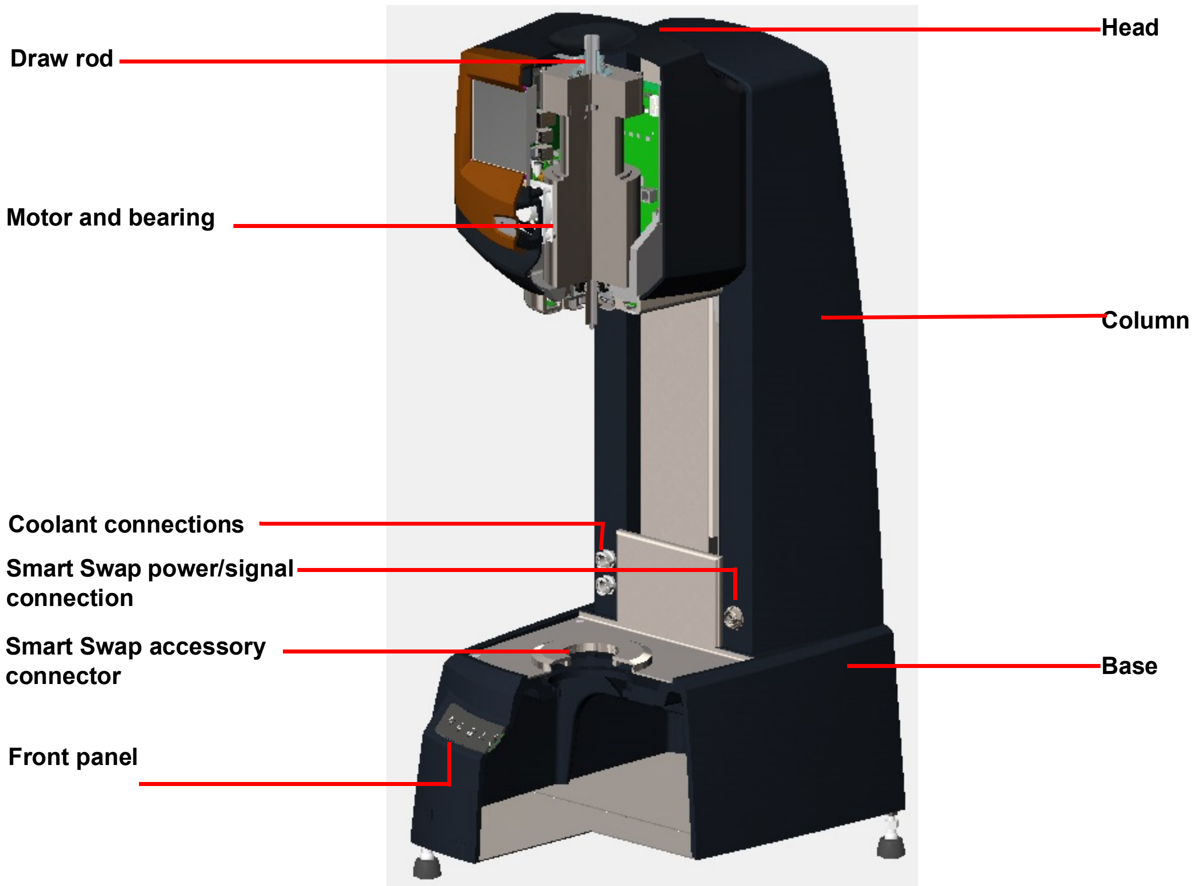


Figure 7 The DHR (HR 10/20/30 shown).

Description

The body of the rheometer is a rigid, metal casting comprising a base and column.

The instrument head is attached to a ball-slide, which is mounted within the column. The vertical position of the head is controlled by driving the screw of the ball-slide. The head contains the following:

- The drag cup motor, with an armature that forms the rotating spindle of the rheometer.
- A magnetic thrust bearing that supports the drive shaft and two radial air bearings that align it.
- An optical encoder that determines its angular position.

Each of these components is described in more detail in "Key Rheometer Components" on page 17.

Key Rheometer Components

The main components of the rheometer are described below. If you have a good understanding of the design and function of each component, it will make efficient use of the rheometer easier. This section describes, in detail, the design and functions of the:

- Casting
- Ball slide
- Magnetically levitated thrust bearing
- Radial air bearings
- Motor
- Encoder
- Axial force transducer
- Electronics
- Front panel
- Smart swap
- Auto GapSet Mechanism
- Display

Casting

The body of the rheometer is an aluminum casting, consisting of a base and column. The casting is an important component of the rheometer, as it needs to be rigid to axial and torsional stresses, robust, and capable of being machined to high precision and accuracy to ensure correct alignment of the other components of the instrument. Computer Numerical Control (CNC) machining is used to ensure concentricity, flatness and parallelism in the measuring system when attached.

Ball Slide

The instrument head assembly containing the motor, bearing, and optical encoder is mounted on a stiff, linear motion, precision ball slide guide. The ball slide is mounted within the instrument column. A motor located in the base of the casting drives the ball slide screw, moving the instrument head vertically. Its position is measured by a linear encoder mounted on the ball slide.

WARNING: Pinch points are present at the top and bottom of instrument head travel. Keep hands away from top and bottom of the instrument when it is in motion.

AVERTISSEMENT: Des points de pincement sont présents en haut et en bas de la course de la tête de l'instrument. Éloignez vos mains du haut et du bas de l'instrument lorsqu'il est en mouvement.

Magnetically-Levitated Bearing

All CMT rheometers contain a bearing, and it is this component that largely controls the quality of data that can be obtained on the instrument. The design of a bearing is a compromise involving several properties such as friction, stiffness, air consumption and tolerance to contamination and misuse. To keep the friction low, non-contact bearings have always been used in the better quality rheometers. A thrust disc is mounted horizontally on the rotating spindle of the rheometer and, on traditional instruments, this disc is supported within a chamber by air introduced from below at high pressure. To prevent the spindle moving upwards, air is also introduced into the chamber from above, and to prevent it moving laterally, radial air-bearings are used.

In the Discovery Series rheometers, the thrust disc is retained, but it is levitated magnetically. The thrust disc is constructed from a magnetically susceptible material. Electromagnetic actuators are positioned above and below the disc, the strength of the magnetic field generated by each actuator is controlled through the current supplied to its coils. The stronger the field, the greater the attraction between the actuator and the thrust disc. The axial position and motion of the spindle are detected by sensors mounted above the upper actuator, and can be closely controlled by varying the supplied current to each actuator coil.

This arrangement has advantages over the traditional air-bearing in many respects. The gap between the thrust disc and the stationary components of the instrument can be much wider, of the order of millimeters rather than micrometers. This results in both the friction of the bearing being substantially lower, and increases the smoothness of rotation. The latter is particularly important, since it means that the variation in the bearing characteristics with angular position, that are inevitable for any real bearing, can be more easily allowed for by calibration ("mapping"). The axial stiffness of the bearing is increased, because of the tightness of the control loop governing the axial position (to prevent lateral movement of the shaft, radial air-bearings are used). The air consumption is reduced, and the wider gap and more durable materials used make the bearing more robust and less susceptible to contamination.

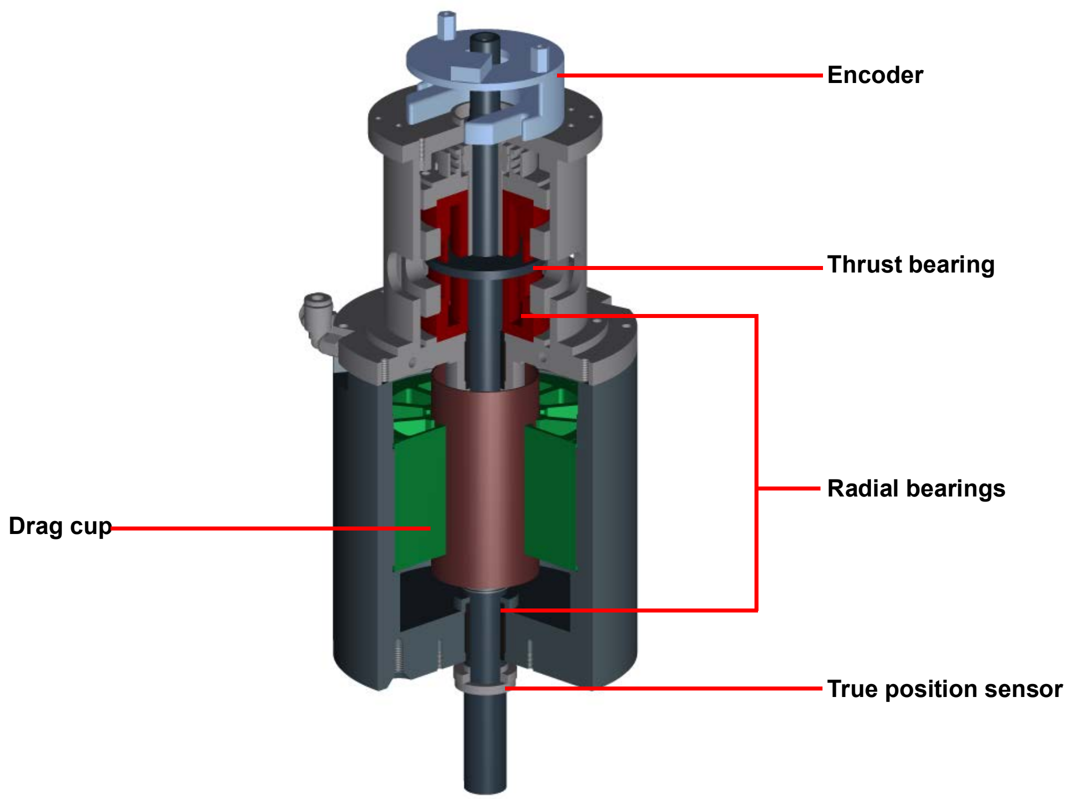


Figure 8 DHR motor bearing.

Radial Air Bearings

Radial bearings provide stiffness and support in the radial direction. The Discovery Series rheometers are designed with two porous carbon radial bearings, located above and below the motor.

Motor

The requirement that the bearing used on the rheometer should be low in friction applies equally to the motor. The Discovery Series rheometers use a non-contact “drag cup” motor. A thin-walled metal cup is mounted on the rotating spindle of the rheometer. A magnetic field rotating at thousands of revolutions per minute is generated by continuously varying the current supplied to stationary pole pieces surrounding the cup. This produces an eddy current in the cup, which generates a second magnetic field. The two fields oppose each other, in accordance with Lenz's law, and the cup field is forced to follow the rotating field. Hence, the cup is “dragged” round by the rotating field, and a torque is generated whether the cup moves or not.

Drag cup motors have many desirable characteristics besides their low friction. Since they have no fixed magnets, the torque produced is independent of the angular position. Futhermore, the torque is approximately proportional to the square of the current, which means that a wide torque range is produced by a relatively narrow current range. The rotating components of the motor have a very low moment of inertia—the limit is the thinness to which the cup walls can be machined. Low inertia is important whenever the angular velocity of the moving parts is changed, for example, during transient or dynamic experiments, or steady changes in torque.

Drag cup motors can get hot during use, and the torque output will vary with temperature. The motor incorporates a patented drag cup temperature sensor. The temperature of the drag cup is measured, and the input to the motor corrected, ensuring the most accurate possible torque output.

The low friction and inertia of the motor–together with sophisticated modern electronics–allow close control of the motor, controlled torque, and controlled displacement or angular velocity modes without requiring any input from the user. Although designed according to the principles of traditional controlled-stress rheometers, the Discovery Series rheometers are capable of delivering excellent performance in both controlled-stress and controlled-strain tests.

Optical Encoder

The transducer used to determine the angular position of the rotating spindle should have high resolution, low friction (*i.e.*, non-contact), low moment of inertia, and a rapid linear response. These criteria are met by an optical encoder. This consists of a non-contacting light source and photocell, arranged on either side of a transparent disc mounted on the rheometer spindle. At the edge of this disc are extremely fine, photographically etched radial lines, which form a diffraction grating. A stationary segment of a similar disc is also mounted between the light source and the photocell, and the diffraction pattern formed by the light transmitted through the gratings is detected by the photocell. As the spindle rotates, the diffraction pattern changes. The associated electronic circuitry interpolates and digitizes the resulting signal, to produce digital high resolution, angular position data.

The angular velocity of the rotating spindle is calculated from successive readings of the angular position, and since this is done at electronic processor speed, the encoder effectively has two outputs, the angular position and the angular velocity.

In the HR 20 and HR 30, the performance of the encoder is enhanced by using a dual reader configuration. This patent-pending design improves the basic resolution and noise level of the displacement signal as well as removing drift and improving phase resolution.

Axial Force Transducer

When a viscoelastic liquid is sheared, a force can be generated along the axis of rotation of a cone or parallel plate geometry. For this to happen, the structure responsible for the elasticity must not be completely disrupted by steady shear.

For this reason, colloids, suspensions, etc., although elastic at rest, become effectively inelastic under steady shear and can show negative normal forces due to inertial effects. However, polymer solutions and melts, and products incorporating them, are typically elastic under shear because of the long lifetime of the molecular entanglements.

Normal force measurements are made with cone and plate or parallel plate geometries; therefore, it is important to use a method to detect the force that does not allow significant changes in the gap. This would result in the actual shear rate varying with normal force, due to deflections of the force-detecting component.

Axial force control is also important for making measurements under tension or compression, and for loading delicate samples where it is important to retain their structure.

The DHR uses a Force Rebalance Transducer (FRT) to measure axial force. It provides the most accurate normal force measurements because the drive shaft is maintained in its vertical null position; it does not require a physical movement like capacitive sensors or strain gauges. The FRT technology also enables the ability to perform Dynamic Mechanical Analysis (DMA) measurements on solids sample through bending, tensile, or compressive deformation modes. This feature is available as a standard feature on the HR 30 and is optional on the HR 20 and HR 1/2/3 rheometers.

Front Panel

Some of the operation of the rheometers can be controlled through buttons on the front panel (shown in the figure below), as well as through the instrument control software (TRIOS software).

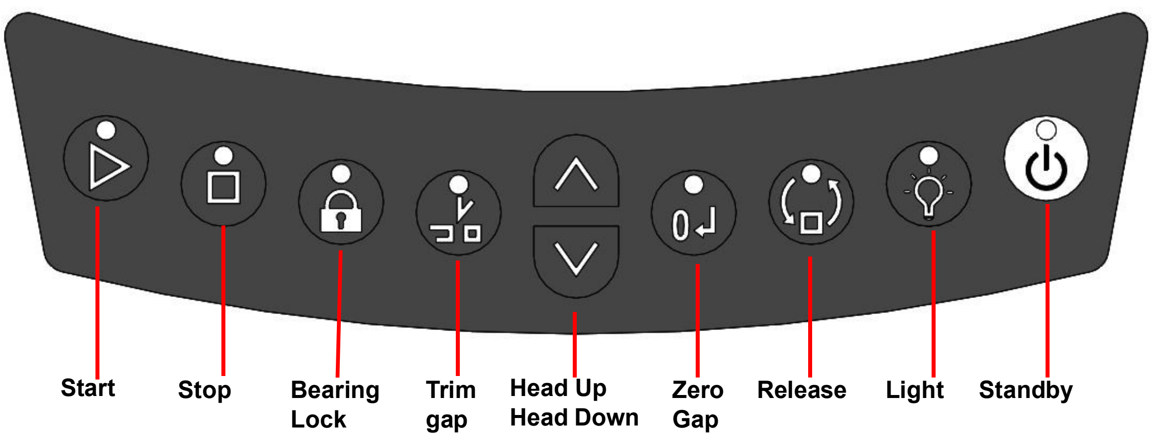


Figure 9 HR 30/20/10 Series Front panel.

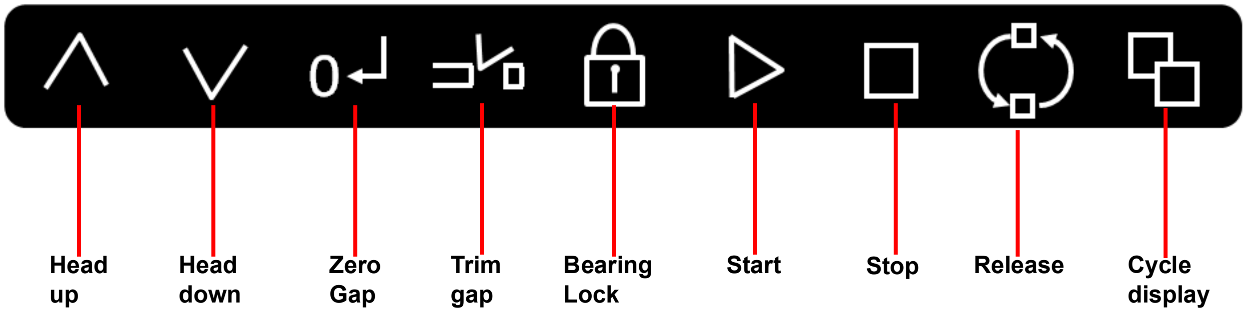


Figure 10 HR 1/2/3 Series Front panel.

Explanation of the front panel from left to right:

- **Start**: Used to start an experimental procedure. When the button illuminates green, pressing it starts the current active experiment in TRIOS. If the geometry is not at the measurement gap, the gap automatically closes before starting the experiment.
- **Stop**: Terminates whatever operation the instrument is performing, for example finding the gap zero, mapping the bearing or running an experimental procedure. A flashing red light indicates that a measurement is in progress.
- **Bearing lock**: Applies a software lock to the bearing to prevent the instrument's shaft from rotating. This lock is over-ridden when the experimental procedure starts. A continuous red light indicates the bearing is locked. Pressing the button when the bearing is locked releases it. If the button is pressed for 3 seconds, the bearing rotates to its "home" position and then locks. This is indicated by a flashing red light. The "home" position is used when fitting a geometry.
- **Trim gap**: Used to lower the instrument head to the trim gap and set the final gap. The first time the button is pressed the light flashes red until the trim gap is reached, at which point it changes to a flashing green. The green light on the Start button is also illuminated. If the Start button is pressed, the gap closes to the geometry gap and the currently active experiment in TRIOS software starts. If Trim gap is pressed again, then the gap closes to the geometry gap. During the closure, the light is a continuous red, changing to a continuous green when the geometry gap has been reached. The start button also illuminates green.
- **Head up**: Used to raise the instrument head.
- **Head down**: Used to lower the instrument head.
- **Zero gap**: Starts the automatic gap zero position routine. A flashing red light on the button indicates that the routine is active.
- **Release**: Used as the Smart Swap release button.
- **Light**: Used to turn on and off the sample lighting (HR 10/20/30 only).
- **Standby**: Used to cycle the instrument test station power from standby to on (HR 10/20/30 only).
- **Cycle display**: Used to display alternative screens on the instrument's user interface (HR 1/2/3 only).

Adjusting Brightness of the LCD Display - HR 1/2/3 Only

The display brightness can be adjusted from the HR 1/2/3 front panel.

1 Press the cycle display button until the network settings are displayed.

Figure 11 DHR front panel.

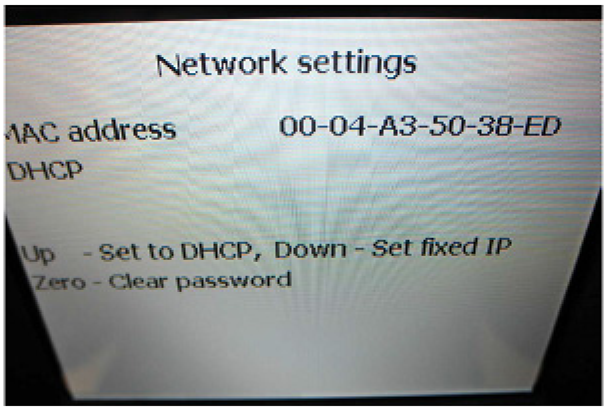


Figure 12 Network settings screen.

2 Press and hold down the cycle display button (do not lift your finger off the button). The display will cycle to the TA Logo view, and gradually the display will brighten. Release the button when the display brightness is sufficient.

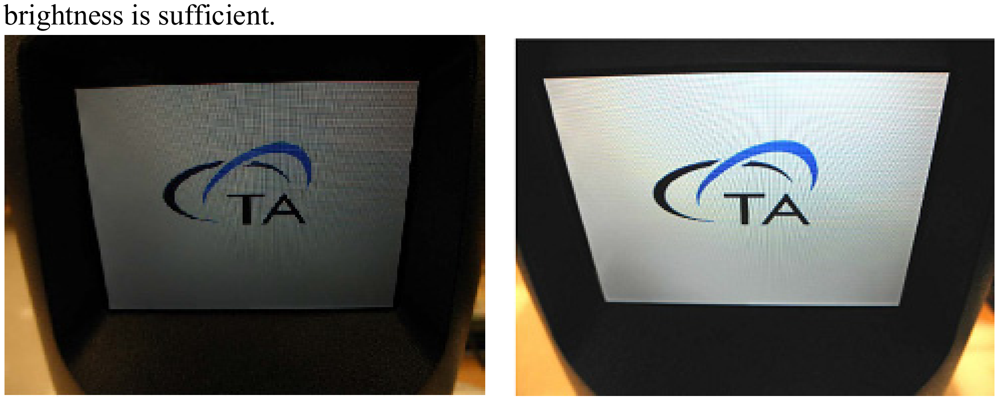


Figure 13 Dim display (left); Brightness adjusted (right).

Touch Screen (HR 10/20/30 only)

Some of the operation of the HR 10/20/30 rheometers can be controlled through the touch screen (shown in the figure below), as well as through the instrument control software (TRIOS software). See TRIOS Help for more information on the touch screen operation.

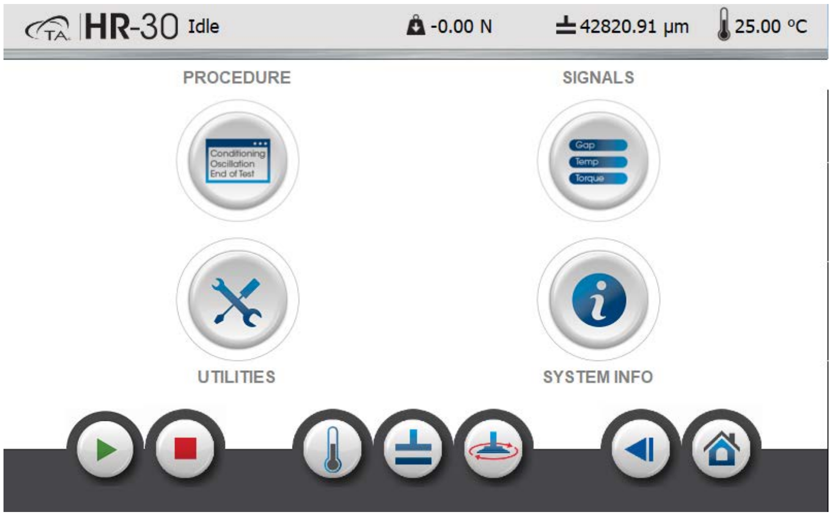


Figure 14 Touch screen.

Smart Swap™

The Discovery Series rheometers feature Smart Swap technology that automatically senses the temperature control system present and configures the rheometer operating software accordingly, loading all relevant calibration data. The use of this feature is covered in this manual.

SmartSwap™ geometries are also standard across the entire range of the Discovery Series rheometers. These geometries can be automatically identified when installed on the rheometer. Smart Swap geometries for the HR 1/2/3 employ a magnetic coating on the head of each geometry provides the read/write technology that will uniquely identify it to the instrument. Smart Swap 2 geometries for the HR 10/20/30 encode the geometry's information through a bar code that is read by the instrument—when installed, the instrument will correctly identify and automatically fill information about the geometry such as plate or diameter, cone angle, cone truncation gap, etc.

Auto GapSet Mechanism

The auto GapSet facility has four major functions, as follows:

- Automatic setting of gaps via software
- Programmed gap closure
- Thermal gap compensation
- Axial force control (in conjunction with the axial force transducer)

These features of the GapSet mechanism are described in detail in the TRIOS software Help.

True Position Sensor

No motor is 100% efficient, so there is always heat generated as a by-product of torque development. This can result in thermal expansion of components within the motor/bearing. An inductive linear position sensor located at the point the drive shaft exits the motor housing measures movement due to thermal expansion and makes a real-time adjustment to the geometry gap. The True Position Sensor is standard on all DHRs and is always active. It works with all geometries and environmental systems.

The performance of the True Position Sensor is enhanced by using the motor water cooling option. The water flows though a channel in the motor carriage casting before routing through the motor core. This provides a thermal break and is particularly effective when using environmental systems such as EHP and ETC.

NOTE: The water cooling is optional, but recommended during high-torque, long-lasting test procedures.

Discovery Series Rheometer Geometries

Standard geometries for the rheometers are constructed from stainless steel, hard anodized aluminum, or titanium.

NOTE: This applies only to the face of the geometry in direct contact with the sample, the shaft may be constructed from other materials.

Other materials may be available on request, at additional charge. The geometry should be as low in density possible, to minimize its moment of inertia, it should be chemically resistant to the sample, and it should have a surface texture that provides adhesion to the sample, to eliminate slippage.

The available geometries are listed below. Refer to TRIOS Help for additional details.

- Cone and plate
- Parallel plate
- Concentric cylinders
- Double gap concentric cylinders
- Solid sample (rectangular)
- SER2 Universal Testing Platform
- Interfacial
- Starch

Smart Swap™ Geometries

Each geometry has a bar code for identification purposes. When a Smart Swap Geometry is attached to the rheometer, a sensor registers the attachment and slowly spins the shaft to read the bar code. The geometry file associated with this bar code is then loaded by the software.

Figure 15 Smart Swap geometry.

Instrument Specifications

The tables below contains the technical specifications for each of the tiers of Discovery Hybrid Rheometers.

Table 1: HR 30 Technical Specifications

Item/Area	**Specifications**
Main Instrument Width Height Depth Weight	 34 cm (13.4 in) 91 cm (35.8 in) 48 cm (18.5 in) 42.4 kg (93.5 lbs)
Electronics Box Width Height Depth Weight	 23 cm (9 in) 36 cm (14.2 in) 40 cm (15.7 in) 10.7 kg (23.6 lbs)
Minimum torque oscillation Minimum torque steady shear Maximum torque Torque resolution Minimum frequency Maximum frequency Minimum angular velocity[1] Maximum angular velocity Displacement resolution Step time, strain[2] Step time, rate[2] Maximum normal force Normal force sensitivity Normal force resolution (mN)	0.3 nN.m 1 nN.m 200 mN.m 0.05 nN.m 1.0E-07 Hz 100 Hz 0 rad/s 300 rad/s 2 nrad 15 ms 5 ms 50 N 0.005 N 0.5 mN
Operating environment conditions	Temperature: 5 to 40°C Relative humidity: 80% (non-condensing) up to 31°C, decreasing linearly to 50% at 40°C. Installation category II Pollution Degree 2 Maximum altitude: 5000 m The degree of protection for this instrument according to EN 60529 is IP20.

1. Zero in controlled stress mode. Controlled rate mode depends on duration of point being measured and sampling time.
2. Results at 99% of commanded value.

Table 2: HR 20 Technical Specifications

Item/Area	Specifications
Main Instrument Width Height Depth Weight	 34 cm (13.4 in) 91 cm (35.8 in) 48 cm (18.5 in) 42.4 kg (93.5 lbs)
Electronics Box Width Height Depth Weight	 23 cm (9 in) 36 cm (14.2 in) 40 cm (15.7 in) 10.7 kg (23.6 lbs)
Minimum torque oscillation Minimum torque steady shear Maximum torque Torque resolution Minimum frequency Maximum frequency Minimum angular velocity[1] Maximum angular velocity Displacement resolution Step time, strain[2] Step time, rate[2] Maximum normal force Normal force sensitivity Normal force resolution (mN)	1 nN.m 3 nN.m 200 mN.m 0.05 nN.m 1.0E-07 Hz 100 Hz 0 rad/s 300 rad/s 2 nrad 15 ms 5 ms 50 N 0.005 N 0.5 mN
Operating environment conditions	Temperature: 5 to 40°C Relative humidity: 80% (non-condensing) up to 31°C, decreasing linearly to 50% at 40°C. Installation category II Pollution Degree 2 Maximum altitude: 5000 m The degree of protection for this instrument according to EN 60529 is IP20.

1. Zero in controlled stress mode. Controlled rate mode depends on duration of point being measured and sampling time.
2. Results at 99% of commanded value.

Table 3: HR 10 Technical Specifications

Item/Area	Specifications
Main Instrument Width Height Depth Weight	 34 cm (13.4 in) 91 cm (35.8 in) 48 cm (18.5 in) 42.4 kg (93.5 lbs)
Electronics Box Width Height Depth Weight	 23 cm (9 in) 36 cm (14.2 in) 40 cm (15.7 in) 10.7 kg (23.6 lbs)
Minimum torque oscillation Minimum torque steady shear Maximum torque Torque resolution Minimum frequency Maximum frequency Minimum angular velocity[1] Maximum angular velocity Displacement resolution Step time, strain[2] Step time, rate[2] Maximum normal force Normal force sensitivity Normal force resolution (mN)	5 nN.m 5 nN.m 200 mN.m 0.1 nN.m 1.0E-07 Hz 100 Hz 0 rad/s 300 rad/s 10 nrad 15 ms 5 ms 50 N 0.01 N 1 mN
Operating environment conditions	Temperature: 5 to 40°C Relative humidity: 80% (non-condensing) up to 31°C, decreasing linearly to 50% at 40°C. Installation category II Pollution Degree 2 Maximum altitude: 5000 m The degree of protection for this instrument according to EN 60529 is IP20.

1. Zero in controlled stress mode. Controlled rate mode depends on duration of point being measured and sampling time.
2. Results at 99% of commanded value.

Table 4: HR 3 Technical Specifications

Item/Area	Specifications
Main Instrument Width Height Depth Weight	 32 cm (12.5 in) 76 cm (30 in) 42 cm (16.5 in) 32 kg (70.5 lbs)
Electronics Box Width Height Depth Weight	 26 cm (10 in) 48 cm (19 in) 44 cm (17 in) 14 kg (31 lbs)
Minimum torque oscillation Minimum torque steady shear Maximum torque Torque resolution Minimum frequency Maximum frequency Minimum angular velocity[1] Maximum angular velocity Displacement resolution Step time, strain[2] Step time, rate[2] Maximum normal force Normal force sensitivity Normal force resolution (mN)	0.5 nN.m 5 nN.m 200 mN.m 0.05 nN.m 1.0E-07 Hz 100 Hz 0 rad/s 300 rad/s 2 nrad 15 ms 5 ms 50 N 0.005 N 0.5 mN
Operating environment conditions	Temperature: 5 to 40°C Relative humidity: 80% (non-condensing) up to 31°C, decreasing linearly to 50% at 40°C. Installation category II Pollution Degree 2 Maximum altitude: 5000 m The degree of protection for this instrument according to EN 60529 is IP20.

1. Zero in controlled stress mode. Controlled rate mode depends on duration of point being measured and sampling time.
2. Results at 99% of commanded value.

Table 5: HR 2 Technical Specifications

Item/Area	Specifications
Main Instrument	
Width	32 cm (12.5 in)
Height	76 cm (30 in)
Depth	42 cm (16.5 in)
Weight	32 kg (70.5 lbs)
Electronics Box	
Width	26 cm (10 in)
Height	48 cm (19 in)
Depth	44 cm (17 in)
Weight	14 kg (31 lbs)
Minimum torque oscillation	2 nN.m
Minimum torque steady shear	10 nN.m
Maximum torque	200 mN.m
Torque resolution	0.1 nN.m
Minimum frequency	1.0E-07 Hz
Maximum frequency	100 Hz
Minimum angular velocity[1]	0 rad/s
Maximum angular velocity	300 rad/s
Displacement resolution	10 nrad
Step time, strain[2]	15 ms
Step time, rate[2]	5 ms
Maximum normal force	50 N
Normal force sensitivity	0.005 N
Normal force resolution (mN)	0.5 mN
Operating environment conditions	Temperature: 5 to 40°C Relative humidity: 80% (non-condensing) up to 31°C, decreasing linearly to 50% at 40°C. Installation category II Pollution Degree 2 Maximum altitude: 5000 m The degree of protection for this instrument according to EN 60529 is IP20.

1. Zero in controlled stress mode. Controlled rate mode depends on duration of point being measured and sampling time.
2. Results at 99% of commanded value.

Table 6: HR 1 Technical Specifications

Item/Area	Specifications
Main Instrument	
Width	32 cm (12.5 in)
Height	76 cm (30 in)
Depth	42 cm (16.5 in)
Weight	32 kg (70.5 lbs)
Electronics Box	
Width	26 cm (10 in)
Height	48 cm (19 in)
Depth	44 cm (17 in)
Weight	14 kg (31 lbs)
Minimum torque oscillation	10 nN.m
Minimum torque steady shear	20 nN.m
Maximum torque	150 mN.m
Torque resolution	0.1 nN.m
Minimum frequency	1.0E-07 Hz
Maximum frequency	100 Hz
Minimum angular velocity[1]	0 rad/s
Maximum angular velocity	300 rad/s
Displacement resolution	10 nrad
Step time, strain[2]	15 ms
Step time, rate[2]	5 ms
Maximum normal force	50 N
Normal force sensitivity	0.01 N
Normal force resolution (mN)	1 mN
Operating environment conditions	Temperature: 5 to 40°C Relative humidity: 80% (non-condensing) up to 31°C, decreasing linearly to 50% at 40°C. Installation category II Pollution Degree 2 Maximum altitude: 5000 m The degree of protection for this instrument according to EN 60529 is IP20.

1. Zero in controlled stress mode. Controlled rate mode depends on duration of point being measured and sampling time.
2. Results at 99% of commanded value.

Chapter 2:

Installing the Instrument

Overview

Normally the installation of your new system will be carried out by a member of the TA Instruments sales or service staff, or their appointed agents, and it will be ready for you to use. However, should you need to install or relocate the instrument, this chapter provides the necessary instructions.

Removing the Packaging and Preparing for Installation

If needed, the first step is to carefully remove all items from any and all packaging. We recommend that you retain all packaging materials in case the instrument has to be shipped back to TA Instruments at some point in the future (for example, in the case of some upgrades).

Installation Requirements

It is important to select a location for the instrument using the following guidelines. For detailed installation specifications, refer to the Site Preparation Guide located in TRIOS Help.

Choose a location that is...

In

- An indoor area only (A clean environment).
- Altitude up to 5000 m.
- A temperature-controlled area (5°C to 40°C).
- An area where the maximum relative humidity is 80% for temperatures up to 31°C, decreasing linearly to 50% relative humidity at 40°C.
- An area with ample working and ventilation space around the instrument, approximately 2 meters in length, with sufficient depth for a computer and its keyboard.

On

- A stable, vibration-free work surface.

Near

- A power outlet. (Mains supply voltage fluctuations not to exceed ±10% of the nominal voltage, installation category II.)
- Your computer for direct connection of a serial or network port.
- Air Bearing Gas Pressure (air or nitrogen) must be clean, dry, oil-free compressed gas at 345–1034 kPa gauge (50–150 psig). The dew point should be –20°C or better. Flow rate should be 2.5 L/min. A 1/4 NPT female connection must be provided for the rheometer main gas supply.

Away from

- Dusty environment (pollution degree 2).
- Exposure to direct sunlight.
- Poorly ventilated areas.

After you have decided on the location for your instrument, refer to the following sections to unpack and install your Discovery Series rheometer.

Connecting the System

Connecting the system together should present no problems, as long as you use instructions found in the following sections.

Connecting the Rheometer to the Electronics Box

The electronics box forms the link between the rheometer and the computer. All the required processing is done within the electronics box. The following steps should be followed to connect the two units together (refer to Figure 16 and Figure 17 below).

1 Push the female end of the power cable into the **Power** port on the back of the rheometer and the other end in the **Power** port on the back of the electronics box.

2 Push the D-type cable into the **Signal** port on the back of the rheometer and connect the other end to the **Signal** port on the back of the control box.

NOTE: Discovery rheometers communicate with the control computer via an Ethernet link, as described in the next section.

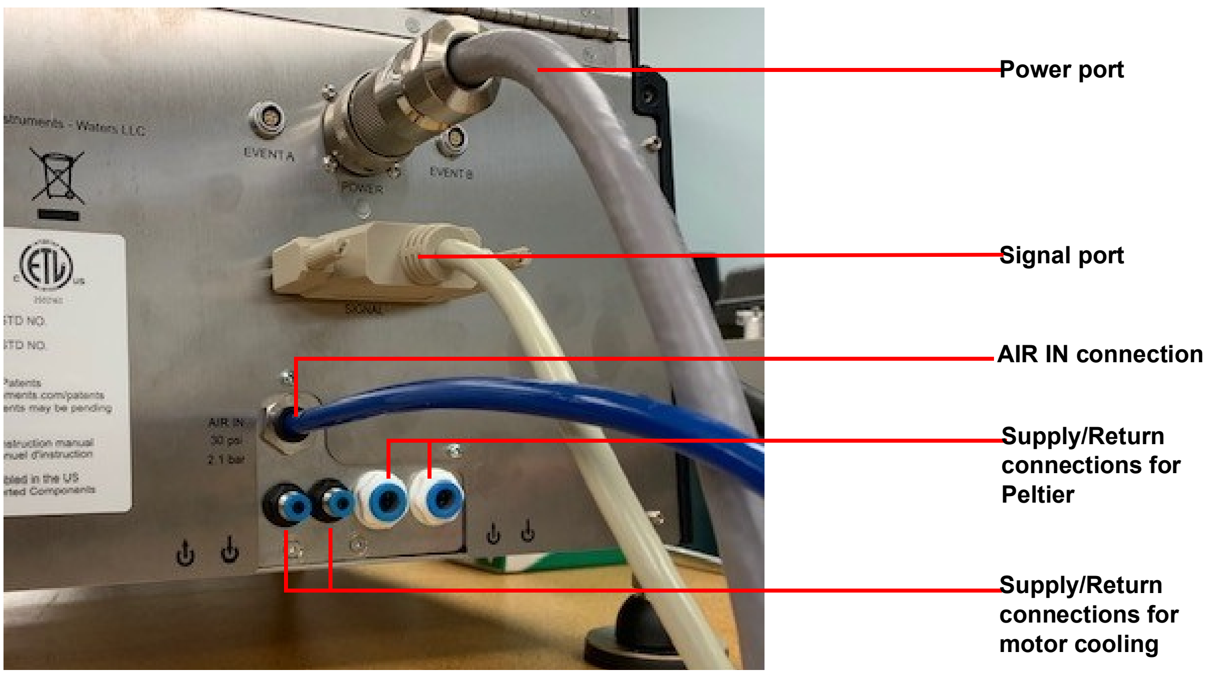


Figure 16 Cable connections to make on rheometer back panel.

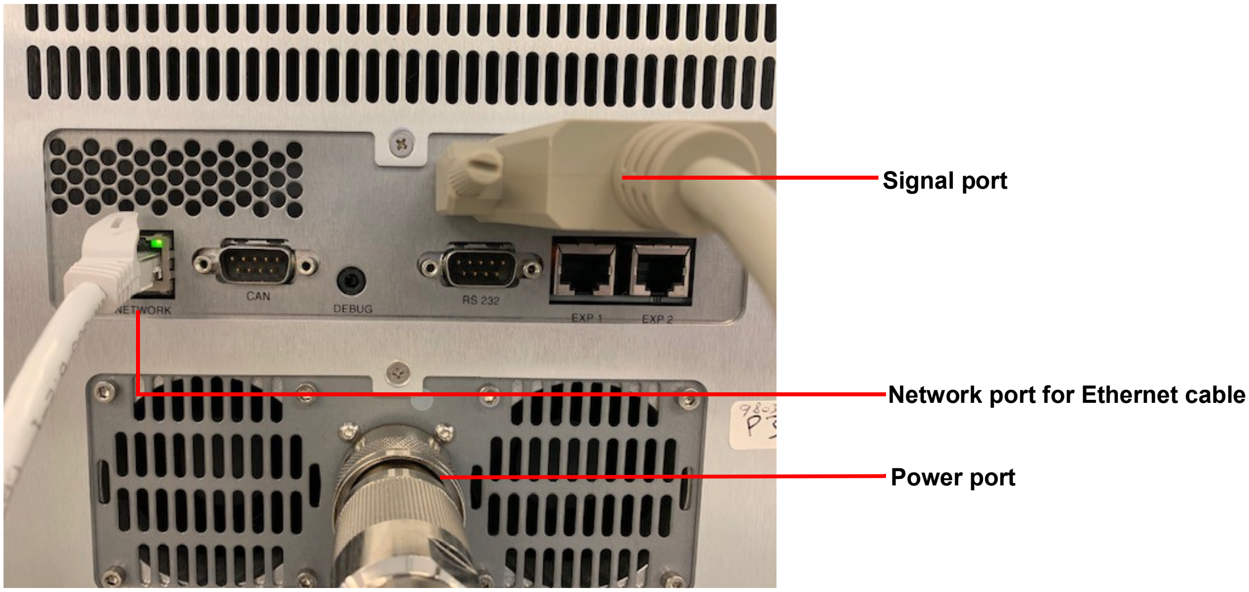


Figure 17 Cable connections to make on electronics box back panel.

Connecting the Computer to the Electronics Box Using Ethernet Communications

Ethernet communications can be setup in two ways. The electronics box and computer can be connected directly via a single Ethernet cable, or both can be connected using separate cables to a Local Area Network [LAN] or router. Full details are provided in the software installation instructions.

Connecting Air and Water to the Rheometer

Refer to Figure 16 on the previous page for the locations of the relevant connections in the instructions below.

1 For Peltier-based temperature control options, connect a supply of water to the supply and return connections at the rear of the rheometer.

2 Connect the air supply (from the air regulator assembly) to the **AIR IN** connection. Set the regulator to 2 bar (30 psi).

Connecting the TA Air-Cooled Peltier Circulator or TCube Edge Circulator

Peltier-based environmental control systems such as the Peltier Plate or the Peltier Concentric Cylinder Jacket require continuous counter-cooling. Refer to Figure 16 and Figure 17 for the locations of the relevant connections in the instructions below.

To connect the Peltier Circulator or TCube Edge Circulator, connect the supply and return hoses to the flow supply and return connections on the rear of the rheometer.

NOTE: After the system has been started, recheck the level of water in the reservoir and refill to the inner rim, if necessary.

CAUTION: Do not put any liquid other than Koolance (P/N 203854.901) in the circulator reservoir.

MISE EN GARDE: Ne mettez aucun liquide autre que Koolance (P/N 203854.901) dans le réservoir du circulateur.

Connecting Motor Cooling

The Discovery Series rheometer will operate without motor cooling, but may shut down if operated at maximum torque for prolonged periods. Providing a source of cooling allows the rheometer to operate at maximum torque indefinitely. It also improves the performance of the True Position Sensor.

To avoid condensation within the instrument, use water close to ambient temperature. For best performance, allow time for the instrument to thermally stabilize before taking measurements.

Establishing Power to the System

To establish power to the electronics box and DHR, follow the instructions below.

1 Plug the AC power cord into the AC power socket on the lower back panel of the electronics box. Refer to Figure 18.

2 To power on the ECU, press the power switch on the electronics box to the On (**I**) position.

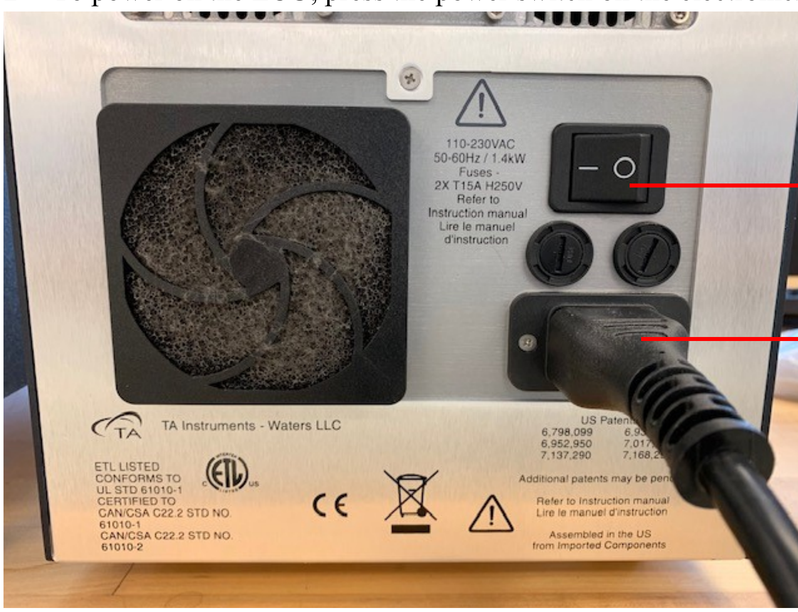


Figure 18 Lower back panel of electronics box.

3 To power on the Test Station, press the **Standby** button on the instrument keypad.

Leveling the Rheometer

Optimum performance depends upon the instrument being level and in a sturdy position to avoid the possibility of rocking. To check and see whether your instrument is level, simply place a bubble spirit level on the Smart Swap base, or installed temperature system (for example, Peltier Plate). If the instrument is not leveled, screw the adjustable feet (located at each corner of the instrument) either in or out, as necessary. Check the spirit level after each adjustment.

Once you have the instrument leveled correctly, press each corner of the instrument to check that all four feet are in contact with the laboratory bench. Any movement caused by pressing should be rectified by adjusting the feet, and then rechecking the level. An 'L'- shaped level with a bubble in each arm is the most convenient type to use for this process.

Installing a Geometry

1 Turn on the compressed air supply to the instrument and remove the bearing clamp by turning the draw rod counterclockwise (anti-clockwise). Refer to Figure 7 for draw rod location, if necessary.

2 Power on the instrument and allow it to initialize (about 30 seconds to 1 minute).

3 Push the geometry up the spindle and hold it while locating the draw rod in the screw thread of the geometry.

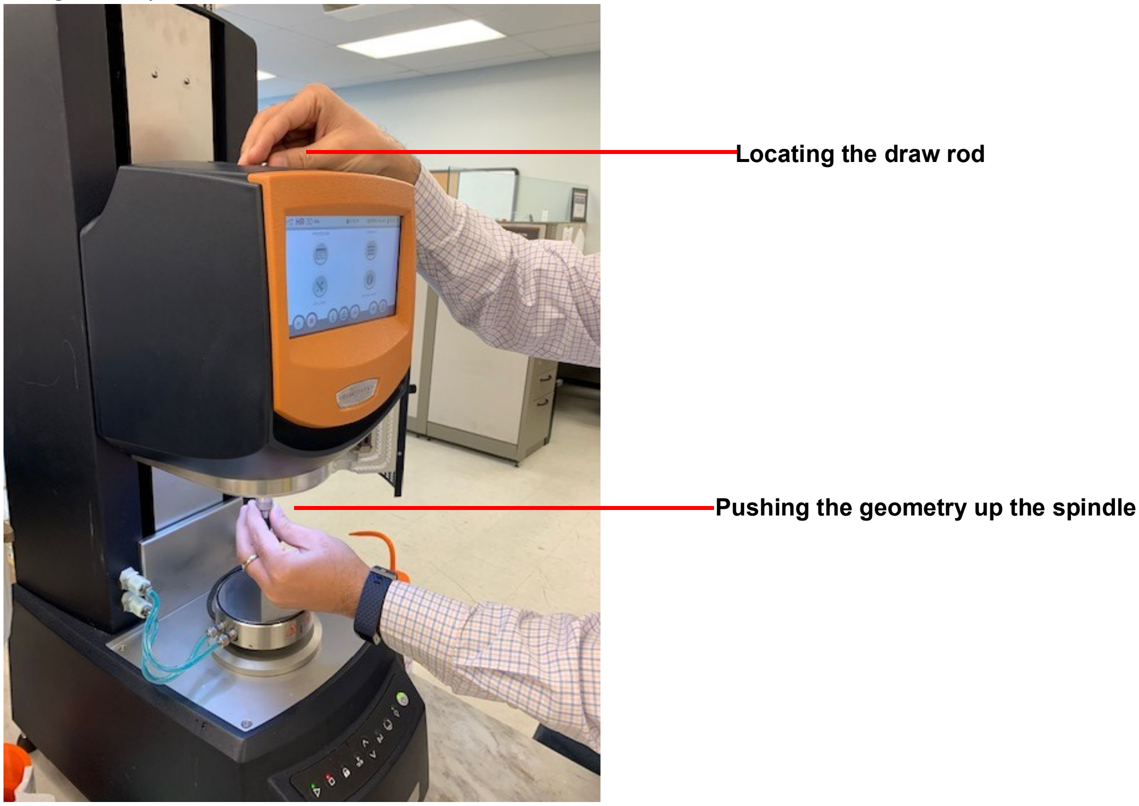


Figure 19 Installing the geometry.

4 Rotate the draw rod clockwise. The draw rod screw thread will pull the geometry upwards into position on the spindle. It should be screwed finger tight, but not forced.

NOTE: If Smart Swap is turned on, the geometry rotates a few seconds after it is fitted to enable identification.

NOTE: To remove the geometry, perform this operation in reverse.

To install the geometry so that it is in the same position each time:

1 Move the motor shaft to the home position by holding the Lock button for 3 seconds until you hear a short beep. Alternatively, click the **Go to Home Position** in TRIOS software.

2 Align the notch on the Smart Swap geometry with the notch on the Smart Swap cover and screw in the draw rod.

NOTE: If Smart Swap is turned on, the geometry rotates a few seconds after it is fitted to enable identification.

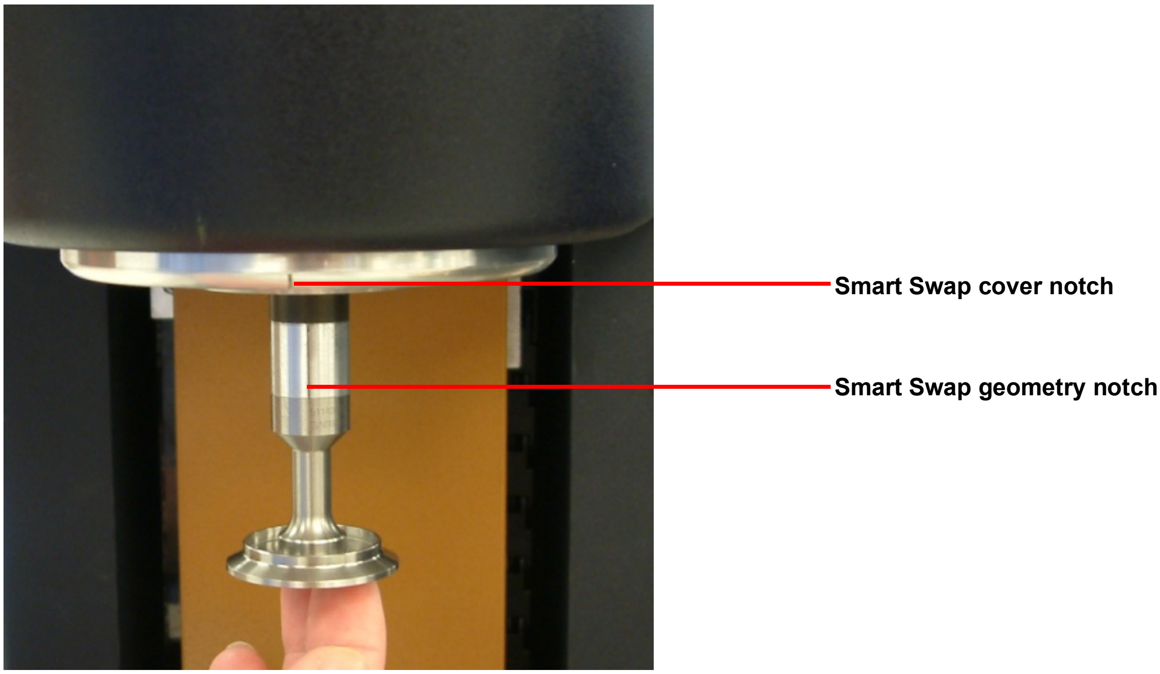


Figure 20 Aligning the Smart Swap geometry notch and Smart Swap cover notch.

Chapter 3:

Environmental Systems and Accessories

Environmental System Options

For a full list of DHR Environmental Control Units, see the TA Instruments website.

- **Peltier Plate Accessories**: Peltier systems offer a wide temperature range of –45°C to 200°C and are used with plates and cones up to 60 mm in diameter. Models include the Standard, Stepped and Stepped Disposable, and Dual Stage Peltier Plates. Refer to the Peltier Plate Getting Started Guide for additional information.

Figure 21 Peltier Plate on HR 10/20/30

- **Upper Heated Plate for Peltier Plate**: The Upper Heated Plate (UHP) is compatible with all Peltier Plate models and provides upper plate temperature control. The UHP features 8, 25, and 40 mm diameter cones and plates and a maximum temperature of 150°C. To extend the upper heater temperature range to 150°C or above, use the Electrically Heated Plates option. Refer to the Upper Heated Plate Getting Started Guide for additional information.
- **Peltier Concentric Cylinder**: The Peltier Concentric Cylinder offers a temperature range of –20°C to 150°C, and combines the convenience of Smart Swap™ and Peltier heating technology with a wide variety of cup and rotor geometries. Refer to the Peltier Concentric Cylinder Getting Started Guide for additional information.
- **Electrically Heated Cylinder**: The Electrically Heated Cylinder is used for concentric cylinder rheological measurements over a broad temperature range (ambient to 300°C). Refer to the Electrically Heated Cylinder Getting Started Guide for additional information.
- **Electrically Heated Plate (EHP)**: The EHP provides active heating and cooling of parallel plate and cone and plate geometries, with a maximum temperature of 400°C. The optional Gas Cooling Accessory extends the minimum temperature to –70°C. The Upper EHP can be used with lower Peltier Plates for temperature control to 200°C and as temperature control to 150°C for UV curing options. Refer to the Electrically Heated Plate Getting Started Guide for additional information.
- **Environmental Test Chamber (ETC)**: The ETC is a high temperature Smart Swap™ option that uses a controlled convection / radiant-heating concept and has a temperature range of 50 to 600°C with heating rates up to 60°C/min. The minimum temperature can be extended to -160°C using liquid nitrogen, or to -85°C using the ACS-3 air chiller. Refer to the ETC Getting Started Guide and ACS Getting Started Guide for additional information.
- **Relative Humidity (RH) Accessory**: The DHR-RH Accessory enables accurate control of sample temperature and relative humidity over a wide range of operating conditions while preventing condensation. It offers a temperature range of 5°C to 120°C with a humidity range of 5% to 95%. Refer to the Relative Humidity Accessory Getting Started Guide for additional information.

Accessories

For a full list of accessories, see the TA instruments website.

- **ACS Chiller System**: The ACS Chiller System is used for sub-ambient temperature control and general cooling of the DHR with Environmental Testing Chamber accessory. The ACS-2 cools to –50°C and the ACS-3 cools to –85°C. Refer to the Air Chiller System for the DHR Rheometer Getting Started Guide for additional information.
- **Asphalt Submersion Cell**: Used to measure asphalt binders immersed in a water bath. Refer to the Asphalt Submersion Cell Getting Started Guide for additional information.
- **Dielectric Accessory**: Used to simultaneously collect rheological and dielectric information, or to collect dielectric information independently. A wide range of frequencies is available (20 Hz to 1 MHz and higher if using the LCR Meter). Refer to the Dielectric Accessory Accessory Getting Started Guide for additional information.

Figure 22 Dielectric Accessory on HR 1/2/3.

- **Dynamic Mechanical Analyzers**: Used to study the dynamic mechanical analysis in tension, compression, and bending of solid samples; when used, rotary motion is locked and only an oscillating linear motion is applied to the sample.
- **Electrorheology (ER) Accessory**: Used to characterize ER fluids up to 4,000 volts using either parallel plate or concentric cylinder geometries. Refer to the Electrorheology Accessory Getting Started Guide for additional information.
- **Environmental Testing Chamber (ETC) Viewer**: Used to view the edge of plates and cones and the torsion sample, capture images with data point (not fast sampling), and view point image in TRIOS results files. Refer to the Environmental Test Chamber Getting Started Guide for additional information.

Figure 23 High Sensitivity Pressure Cell on HR 1/2/3.

- **Gas Cooling Accessory**: The Gas Cooling Accessory is used with Electrically Heated Plates, and is designed for automatic refilling from a low pressure (170 kPa gauge [25 psig] maximum) bulk storage tank located within 1.8 meters (6 feet) of the GCA. Refer to the Gas Cooling Accessory Getting Started Guide for additional information.
- **High Sensitivity Pressure Cell**: Used for rheological evaluation of sensitive samples using dynamic oscillatory and flow testing while varying temperature, pressure, and rheological test parameters. Requires TRIOS software version 5.0 or higher and the Peltier Concentric Cylinder with heating/cooling circulator. Refer to the High Sensitivity Pressure Cell Getting Started Guide for additional information.
- **Immobilization Cell**: A Smart Swap™ accessory used to investigate the immobilization kinetics if a coating mate-

rial as its liquid component is drawn into a substrate by a vacuum. Temperature range, which is dependent on circulator and fluid, is from –10°C to 150°C. Refer to the Immobilization Cell Getting Started Guide for additional information.

- **Interfacial Accessories**
  - **Bicone Interfacial Accessory**: Used to determine the viscosity of the interface between two liquid phases.
  - **Du Noüy Ring**: Used to determine the linear viscoelastic properties of the interface between liquid and air. Refer to the Du Nouy Ring Supplement for additional information.
  - **Interfacial Double Wall Ring (DWR)**: Measures the viscous and linear viscoelastic properties of the interface between liquid-liquid and liquid-air.
  - **Interfacial Exchange Cell**: Used to study interfacial properties of a system while varying the properties of the subphase component. Used in conjunction with the Interfacial Double Wall Ring. Refer to the Interfacial Exchange Cell Getting Started Guide for additional information.

Figure 24 Interfacial Subphase Exchange Cell on HR 1/2/3

- **MagnetoRheology Accessory**: Used to control magnetic flux density with a range of 0 to 1 Tesla while a steady, transient, or oscillatory rheological experiment in parallel plate or cone and plate geometry is performed. Temperature range is dependent on circulator and circulator fluid. Refer to the SALS Accessory Getting Started Guide for additional information.

Figure 25 Modular Microscope Accessory on HR 1/2/3

- **Modular Microscope Accessory (MMA)**: Enables complete flow visualization (including counter-rotation) with simultaneous rheological measurements. The high-resolution camera collects images up to 90 fps and magnification up to 100x. Refer to the Modular Microscope Accessory Getting Started Guide for additional information.
- **Optics Plate Accessory (OPA)**: An open optical system that permits basic visualization of sample structure during rheological experiments. Temperature range from –20°C to 100°C with plate and cone geometries up to 60 mm diameter. Refer to the Optics Plate Accessory Getting Started Guide for additional information.
- **Pressure Cell**: A sealed vessel that can be pressurized up to 138 bar (2000 psi) over a temperature range of –10 to 150°C. Refer to the Pressure Cell Getting Started Guide for additional information.
- **Rheo-Raman Accessory**: Used for simultaneous collection of Raman spectroscopy data during rheology experiments. Temperature control up to 100°C using Upper Heated Plate and integrates with Thermo Fisher™ iXR Raman spectrometer. Refer to the Rheo-Raman Accessory Getting Started Guide for additional information.
- **Small Angle Light-Scattering (SALS) Accessory**: An option for simultaneously obtaining rheological and structural information, such as particle size, shape, orientation and spatial distribution. The

SALS is available for the HR 20/30 and HR 2/3 rheometers. It features patented Peltier Plate temperature control and the scattering angle (θ) range over which measurements can be made is ~ 6°C to 26.8°C. Refer to the SALS Accessory Getting Started Guide for additional information.

- **Starch Pasting Cell**: A Smart Swap™ accessory used to characterize the gelatinization of raw and modified starch products and the properties of starch gels. Sample temperature is measured and controlled in a temperature chamber with heating/cooling rates up to 30°C/min. Refer to the Starch Pasting Cell Getting Started Guide for additional information.
- **Tribo-Rheometry**: Used to make coefficient of friction measurements between two solid surfaces under dry or lubricated conditions. Compatible with Advanced Peltier Plate, Stepped Disposable Peltier Plate, and ETC. Four standard geometries are available – Ring on Plate, Ball on Three Plates, Three Balls on Plate, and Ball on Three Balls. Refer to TRIOS Help for additional information.
- **UV Curing Accessory**: Smart Swap™ accessory for rheological characterization of UV-curable materials for the HR 10/20/30 and HR 2/3 rheometers. Refer to the UV Curing Accessories Getting Started Guide for additional information.

Figure 26 Starch Pasting Cell on HR 1/2/3.

Chapter 4:

Use, Maintenance, and Diagnostics

Startup and Shutdown Procedures

Starting Up the Rheometer

Follow the steps below to start the rheometer:

NOTE: This assumes that the rheometer has already been correctly installed.

1 Check that the air supply is turned on.

2 Remove bearing clamp if fitted.

3 Turn on fluid circulation, if required for correct operation of the installed temperature system.

4 Power on the system by pressing the power switch on the electronics box to the On (**I**) position. Refer to Figure 18 for power switch location.

5 Connect to rheometer via the software.

Shutting Down the Rheometer

Follow the steps below to shut down the rheometer:

1 Turn off the power to the system by pressing the Standby button on the Test Station and then pressing the power switch on the electronics box to the Off (**0**) position. Refer to Figure 18 for power switch location.

2 Turn off any fluid circulation.

3 Fit the air bearing clamp if it is likely that the bearing will be disturbed while the air is off. In the case of the EHP, UHP, and ETC (doors closed), simply removing the draw rod should be sufficient to protect the bearing unless the instrument is going to be moved.

NOTE: It is recommended that the air be left on and that the bearing remain unclamped.

4 Turn off the air supply.

Maintenance and Repair

CAUTION: Adjustment, replacement of parts, maintenance and repair should be carried out by trained and skilled TA personnel only. The instrument should be disconnected from the mains before removal of the cover.

WARNING: The cover should only be removed by authorized personnel. Once the cover has been removed, live parts are accessible. Both live and neutral supplies are fused and therefore a failure of a single fuse could still leave some parts live. The instrument contains capacitors that may remain charged even after being disconnected from the supply.

AVERTISSEMENT: Seul le personnel autorisé doit retirer le couvercle. Une fois le couvercle déposé, les pièces sous tension sont accessibles. Les alimentations sous tension et neutres comportent des fusibles et par conséquent la défaillance d'un seul fusible n'empêche pas d'autres pièces d'être encore sous tension. L'instrument contient des condensateurs qui peuvent rester chargés même après leur déconnexion de l'alimentation.

WARNING: Use two people to lift and/or carry the instrument. The instrument is too heavy for one person to handle safely.

AVERTISSEMENT: Demandez à deux personnes de soulever et/ou de porter l'instrument. L'instrument est trop lourd pour qu'une seule personne le manipule en toute sécurité.

Moving the Instrument

Please follow these recommendations when you move or lift the instrument and its accessories:

- Always remove the temperature control module from the rheometer before attempting to move it. Details on how to do this can be found in TRIOS Help.
- When moving the rheometer, the bearing clamp should always be in place, ensuring that the bearing cannot be moved.

1 Ensure that the draw rod is installed.

2 Push the bearing clamp up onto the draw rod. Hold it in place and turn the knob at the top of the draw rod in a clockwise direction to engage the bearing clamp. Continue to turn the draw rod until it is finger tight.

CAUTION: Always hold the clamp and turn the knob, never the other way round.

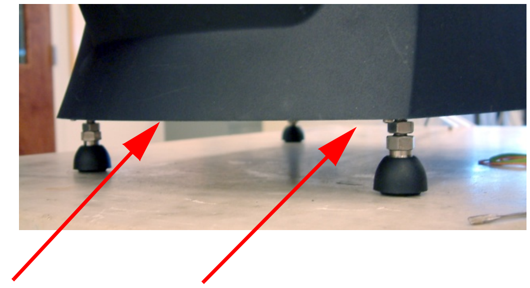
MISE EN GARDE: Tenez toujours la bride de serrage et tournez le bouton, jamais dans l'autre sens.

3 Lifting the instrument should always be done with two people. With each person standing on either side of the instrument, place hands in the locations shown below and lift upwards, keeping the instrument in an upright position. See the figure on the next page.

Rear of instrument

Each person grasps the rheometer rear cover with one hand in the locations shown above.

Front of instrument



Each person places one hand underneath the front cover of the rheometer and grasps the front foot.

Figure 27 DHR lift handle locations.

4 Treat the rheometer with the same degree of care you would take with any scientific laboratory instrument.

Startup Errors

The instrument has some power on self test (POST) routines.

If the electronics box issues groups of beep codes while flashing the TA logo in time with the sounder, then there is either a serious error which prevents the system from proceeding further, or there is a less serious error but no display is available to notify the user. Please see "System POST Error Codes" on page 48.

If it is a less serious error with no display available, the system should continue after 60 seconds but may not work correctly depending on the nature of the error.

If the electronics box issues a repeated sequence of three tones, then there is an error which should be listed on the display but there is no keypad available for the user to acknowledge the error. In this case the system should continue after a short period but may not work correctly depending on the nature of the error.

There are 3 error screens that may be displayed:

System Issues

Module name   Firmware status   Module status   Module POST

Firmware status can be: Not found, Unknown, Outdated, Current, Newer, Experimental

FPGA Version Issues

Module name   FPGA status   FPGA version

FPGA status can be: Not found, Unknown, Outdated

Power Drive Issues

Motor drive   Control mode   FPGA status

and/or

Gap set drive   Control mode

The display and keypad modules are marked as optional for the self test and so their absence should not in itself cause any errors.

If the display is blank (white) but cycles between bright and dim every 1 second, then there is a problem with the display graphics file data.

System POST Error Codes

Table 7: DHR Series POST Error Codes

Number of Beeps	Code (hex)	Description
1	1	Signal cable not fitted
2	2	Power cable not fitted
3	4	Instrument ±48V supply not activated
4	8	System controller communications failure
5	10	Heater drive communications failure
6	20	Display not present
7	40	Keypad not present
8	80	Sensor board magnetic bearing data communications failure
9	100	Sensor board encoder data communications failure
10	200	Magnetic bearing actuator fault
11	400	Motor drive activation failed
12	800	Gap set drive activation failed
13	1000	Module firmware version error
14	2000	Module status/POST error
15	4000	FPGA version error

Module Status Codes

Table 8: DHR Series Module Status Codes

Code (hex)	Description
1	Unexpected processor reset
2	Supply rail out of range
4	Temperature out of range
8	Sensor fault
10	Output fault
20	Power fail indicated
40	System heartbeat timeout
80	CAN rx overflow
100	CAN tx timeout
200	Module startup
400	CAN rx overrun