MiTi Developments

Mohawk Innovative Technology, Inc.®

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High Speed, High Temperature Tribometers, HTP Series

This unique series of high temperature, friction, and wear tribometers can also be used as a pin-on-disc tribometer. It can measure the tribological properties of high temperature metallic alloys from room temperature to 900ºC. The test atmosphere is established by a controlled flow rate of a purge gas. All components within the test chamber are compatible with oxidizing, inert or reducing gases.

INTRODUCTION

Conventional tribometers have been proven to suffer from shortcomings in accurately simulating operating conditions of advanced systems, which adversely impacts the validity of results and the conclusions that are drawn from them. Generally, tribometers are not designed to simulate the high speeds and high temperatures in the range these tribometers have been specifically built for. The design especially differs from conventional tribometers in that dynamic factors have been carefully taken into account.

The motivation for the design and fabrication of this series was to achieve the capability to determine the friction and wear of high temperature materials in an atmosphere and under sliding conditions relevant to high temperature aerospace and terrestrial applications. Considerable commercial benefit can be derived from reliable correlative testing, specifically in reducing development time for products and in minimizing the cost of testing. This is a proven, advanced, high speed (10,000rpm), high temperature (900ºC) friction and wear test system (pin-on-disk type tribometer) with durable, least complex and yet elegant features, delivering superb performance. It is also available in a 40,000rpm model.

This test facility has extremely high accuracy, permits the use of various sized specimens, and incorporates a purge chamber. Achievement of extremely low run-out is addressed, as well as reduction of dynamic, system-induced error in conducting tribological tests. Specifically, variation in friction and wear measurements is often attributed to stick-slip phenomena. However, some of this may be attributed to variation in the actual applied load due to dynamic error. Once this error has been removed from the data, the true tribological phenomena may be elucidated and interpreted for better development of tribocomponents.

MiTi® has designed and fabricated other high performance tribometers. Described briefly below are one manufactured for the U.S. Air Force Research Laboratory of the Wright Patterson Base and another for the University of Florida.

DESIGN SPECIFICATIONS

Pin-on-disk type tribotesters are normally used for initial candidate screening. Conventional tribotesters have been proven to suffer from shortcomings in accurately simulating operating conditions of advanced systems, which adversely impacts the validity of results and conclusions drawn from them. Proper design techniques result in a tribometer that is genuinely capable of simulating expected material and lubricant operating conditions, thereby enabling accurate predictions of the friction and wear behavior of advanced materials and coatings under conditions relevant to high temperature aerospace and terrestrial applications. To meet these development needs, this test facility has been developed to be: 1) highly accurate; 2) less sensitive to dynamically-induced error; 3) accommodating to the use of various sized specimens; and 4) highly accurate when simulating operating conditions.
The design specifications for this tribometer include the following capabilities:

1. Continuous unidirectional rotation over a large range of sliding velocities to simulate shaft bearing and seal sliding motion.
2. High temperature capability
3. Atmosphere control: controlled humidity, air, inert gases and hydrogen
4. Specimen geometry: provisions for various contact configurations
5. Sliding velocity
6. Specimen temperature: ambient to 900ºC
7. Atmosphere: Purge gas of air or inert gas

DESCRIPTION OF TRIBOMETER

A schematic of the side view and top view of the tribometer are shown in Figs.1 and 2.

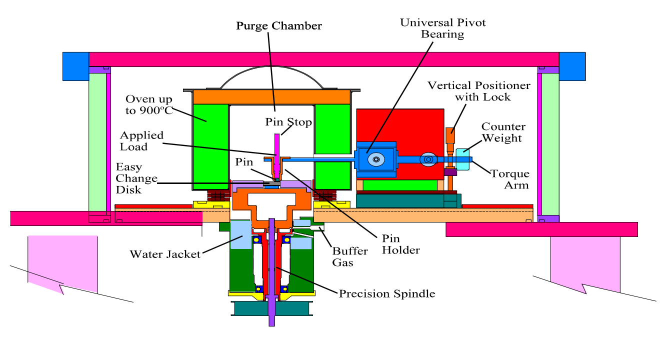

Figure 1 Side View of Tribometer

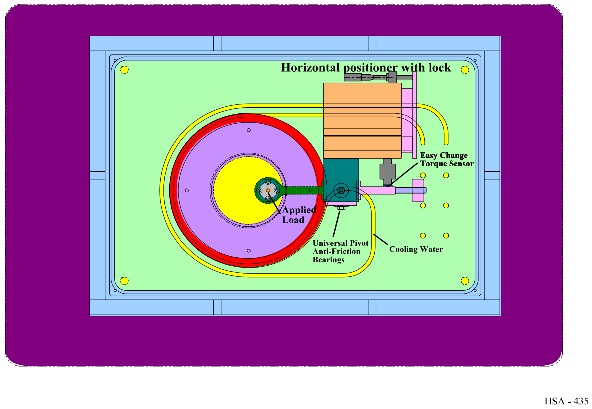

Figure 2 Top View of Tribometer

In this design the disk holder is supported by a precision spindle driven by a variable speed motor, up to 10, 000rpm, whereas other tribometers commonly operate at speeds well below 3600rpm. The MiTi® tribometer facilitates a more realistic simulation of the hostile environments that new materials and lubricants will be required to withstand; and it is capable of temperatures up to 900ºC. The spindle is supported on grease-packed ball bearings. To protect the bearings from the high temperatures they are located at a distance from the hot test zone, and temperatures of the spindle and spindle components are kept to a minimum via a water cooling jacket and cooling buffer gas.

Additional capabilities of the tribometer include normal loading from 100 to 500 grams (0.22 to 1.1lb), multi-track testing on the same disk specimens ranging from 3.18 to 79.4mm (0.125 to 3.125inches) in diameter with thickness ranging up to 6.35mm (0.25inch) thick, and the ability to accept pin specimens of 1.59 to 6.35mm (0.0625 and 0.25inch) diameter. To permit multiple tracks per test disk, a horizontal micropositioner is utilized to move the entire torque arm assembly toward and away from the center of test disk rotation. It incorporates a lock to secure the slide and eliminate vibrations/structural noise from affecting the data, and provides a means to change the diameter of the wear tracks. A vertical micropositioner positions the load arm.

Besides the specimen installation and alignment approach, particular attention has been paid to the design of the pin/torque arm. A pin holder cup approach was selected, since pin specimens are likely to be less expensive and may be used for multiple tests without refinishing. The pin is held within an assembly which allows the pin to be locked in place so that it does not rotate inside the holder, as shown in Fig. 3. The assembly can be easily removed from the torque arm in order to examine the worn pin surface at test intervals and then returned to the same position for continued testing. The torque arm is supported by a low friction universal pivot bearing and balanced via a counterweight and precision level.

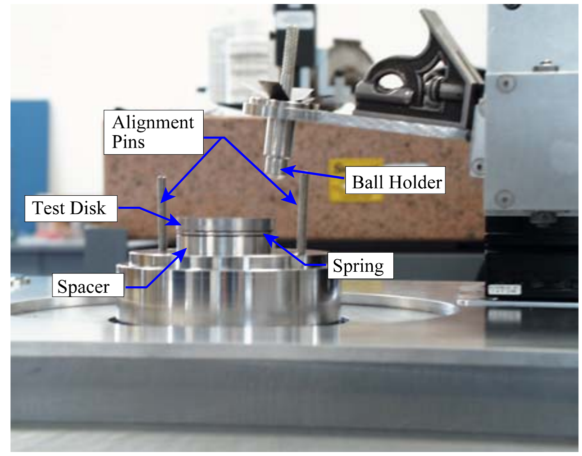

Figure 3 Critical Elements of the Tribometer

A light weight torque arm with integral level indicator minimizes dynamic load fluctuations. Applying the load directly over the pin minimizes dynamic load fluctuations and eliminates the calibration step.

Figure 4 shows the set-up of the High Temperature Tribometer. Antifriction universal bearings are used in the torque axis to minimize the parasitic friction and drag that would otherwise influence the test measurements. Finally, a non-contacting, eddy current displacement sensor is used to measure wear rate, to provide a measure of initial alignment, and to measure system health via detection of any fluctuations in the torque arm's vertical position.

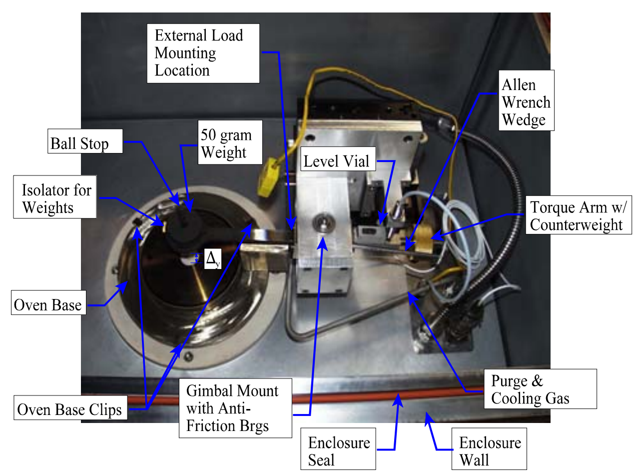

Figure 4 High Temperature Tribometer Set-up

The relationship of the pin, disk in terms of friction, wear and tribological phenomena are influenced by system geometry and dynamic factors, which are generally not taken into account. For example, in many pin-on-disk tribotesters, the disk is placed on a flat surface, which forces the bottom surface of the disk to be the reference surface. Since even the highest achievable tolerances of flatness and parallelism still do not provide truly perfect geometry, a high degree of dynamic error is introduced. In the present tribotester, such dynamic error is eliminated or reduced by many techniques, including the disk holder cap.

The cap allows easy change out of test specimens, but more importantly there is a spring with optimized stiffness beneath the disk. This presses the top surface of the disk up against the precision knife edge within the cap, thereby causing the upper surface of the disk to be held highly perpendicular to the axis of rotation. The upper surface of the disk is the desired test reference surface. However, in conventional tribotesters, the disc is generally placed on a plate, causing the true reference surface to be the disk's lower surface and introducing the requirement that both upper and lower surfaces be held to tight tolerances of flatness, parallelism, and surface finish. MiTi®'s approach (spring beneath disk and cap with knife edge) relaxes the tight tolerance requirements, thereby greatly reducing specimen complexity and manufacturing cost, while simultaneously greatly improving accuracy. The force of the spring also prevents the disk from rotating within the holder.

A purge chamber and a double labyrinth seal arrangement is included in the facility to minimize the volume of gas required during testing. The oven chamber is purged with gases such as argon or nitrogen. Insulation surrounds the oven chamber as well as the bottom of the static platform to protect the drive system from the high temperatures, in addition to minimizing structural distortion that may affect alignment during testing. Heating elements are completely

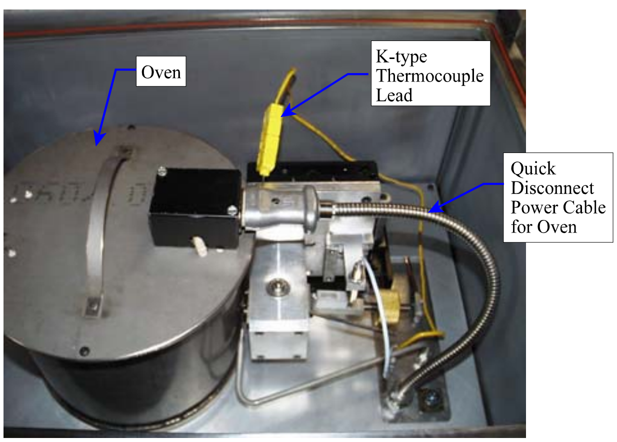

Figure 5 High Temperature Oven Enclosure

enclosed in the oven shell to prevent sample contamination, as shown in Fig. 5.

Thermocouples are used to monitor chamber, inlet purge gas, table, bearing and other temperatures for test data, control and operation safety purposes.

COMPUTER DATA ACQUISITION SYSTEM

The tribological data from the tribometer is monitored, manipulated and stored by a computerized data acquisition system. The system is based upon a personal computer interfaced to the rig instrumentation by an analog to digital converter. Dedicated software, displays, manipulates and stores the data in a meaningful format. The data can be transferred to spreadsheet format programs for further manipulation and graphing.

TECHNICAL APPROACH

The most critical first step in tribological simulator testing under extreme conditions is to design a reliable tester. This requires careful integration of materials selection, thermal analysis, and system dynamic analysis. Among the key issues that must be addressed during the design of the high temperature tribometer to assure accurate and reliable friction and wear data, are: 1) rotating specimen and holder installation and alignment with the spin axis, 2) pin/torque arm dynamics and weight and 3) the measurement system (normal load, torque/friction, and wear rate, etc.).

The disk holder permits easy change outs of specimens and, most importantly, precisely aligns the specimen test face perpendicular to the spin axis. Fixturing that accurately aligns the specimen (test face flat and perpendicular to the spin axis) is necessary to minimize the dynamic normal load fluctuations during testing. Similarly, the pin and pin holder assembly weight must be minimized.

The design approach establishes a common base for the drive system, including the rotating specimen table and the pin/pin holder/torque arm, with precisely located and positioned mounting points. By insulating the mounting points from the oven test chamber, thermally induced misalignment distortions are avoided. The upper surface of the specimen is ground flat and parallel to the drive system axis, which relaxes the strict tolerance requirement that the back face of the specimen is machined parallel to the front test face, as would be required if the specimen mounting table was used as the reference surface. The latter approach requires precision machining of both test disk faces to assure parallelism.

Besides the specimen installation and alignment approach, particular attention was paid to the system dynamics/dynamic contact issues. Conventional tribometers run at slower speeds, however, the influence of dynamic factors cannot be ignored. Furthermore, advanced systems will operate at much higher speeds and must be adequately simulated for accurate prediction of material behavior. It was also analytically determined that the expected thermal mismatch between the pin stop and variety of pin materials would allow the pin to rotate in the pin holder. An iterative approach was utilized with finite element modeling and experimental testing to develop pin stops to provide a proper mounting for the pin and yet prevent pre-damaging of the pin.

Because proper attention was paid to system alignment and dynamics, the HTP 10 Tribometer had measured maximum run out at 10,000rpm of less than 2.54µm (0.0001 inch).This achievement, combined with the calculated method of eliminating dynamic error, assures the most reliable and accurate prediction of data.

QUALITY- ASSURANCE PROCEDURES

As part of the check-out procedure for the rig, some typical material screening samples were prepared:440C vs 440C, WS_2

vs 440C, and $CaSO_4$ vs Sapphire. These samples were meant to verify the accuracy of the measurements and to establish self consistency. Samples were generally parallel to within 0.0001 inch and had a 1 micron surface finish. Waviness of the samples was not measured. WS_2 coated 440C samples were selected with reference to the prevalent use of WS_2 as a low temperature component in space and dry lubricants. WS_2 is often combined with Tungsten Carbide and diamond-like Carbon, which is incorporated to accommodate wet conditions. Calcium silicate was applied on top of a Titanium Nitride coating, which provided a hard base and prevented diffusion of the underlying substrate metal.

CUSTOM TRIBOMETERS

MiTi® designs unique friction, wear and lubricant test machines, such as these two, for the evaluation of advanced bearing materials and lubricants under controlled conditions.

Figure 6 shows the HTB-70, a unique 70,000rpm tribometer designed to assess high temperature, solid film lubricants under high sliding velocities and to evaluate the load capacities of compliant foil bearings.

Figure 7 shows the HTP-5 tribometer, 1500ºF pin-on-disk tester designed to provide precision specimen alignment for high quality friction and wear data under static loadings up to 500 grams.

About MiTi®

Mohawk Innovative Technology, Inc., (MiTi®) is one of the world's leading developers and suppliers of high efficiency, oil-free compliant foil, magnetic, hybrid and auxiliary bearings for high-temperature, high speed and load applications. MiTi® is committed to providing innovative, cost-effective and timely rotor bearing system solutions for challenges in high-speed rotating machinery.

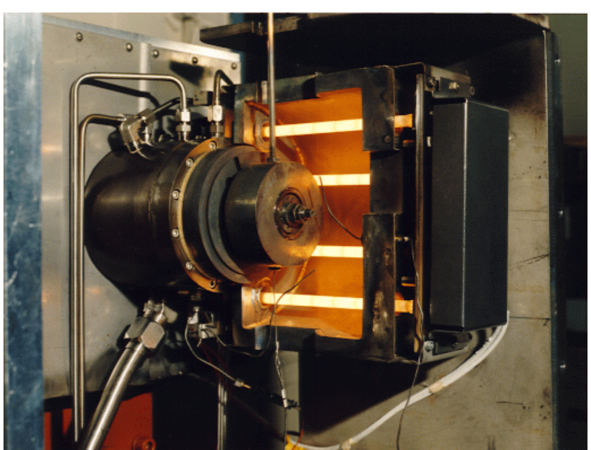

Figure 6 HTB-70 Tribometer

MiTi® occupies a 13,000 square foot stand-alone facility that includes engineering design offices, manufacturing, testing and quality control facilities, a well-equipped precision machine shop, and laboratory space for research and development. Forming, welding, material heat treating, and

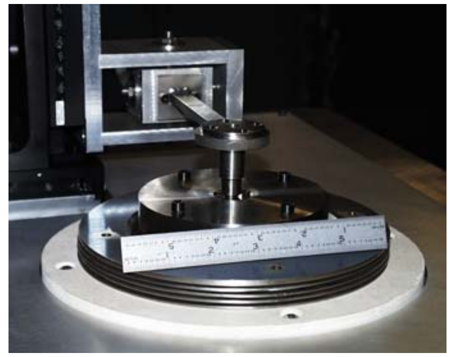

Figure 7 HTP-5 Tribometer

lubricant coating facilities accommodate the manufacture of compliant foil gas bearings and seals, magnetic bearings, and auxiliary bearings. For high-speed machinery development, MiTi® has both component dynamic balancing machines and portable balancing machines for in-place balancing of high speed rotors.

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