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# DEVELOPMENT OF A MULTIFUNCTIONAL TRIBOMETER: DESIGN CONCEPT

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***Abstract:*** *Tribometer is a testing device which is used to measure tribological properties of materials or systems like friction force, wear rate and related phenomenon developed between surfaces in a relative motion. Until it was first invented by Leonardo da Vinci – the first tribologist, many types of tribometers have been developed. Since tribological problems are present in almost any field of engineering, various tribometers are in use to simulate all kinds of situations encountered in the real applications. In recent years, modular or multi-functional tribometers have been developed and transferred to the tests applications. In this study, a new tribological test platform is presented concerning its design, modular concept, operative system and loading options. This multi-functional tribometer was designed to conduct various tribological tests in the same test platform by chancing the modules. Developed tribometer can work together with the modules of "pin-on-disc", "linear reciprocating", "block-on-ring", "high temperature", "tribo-corrosion", "lubrication" and "piston ring on cylinder liner". The test platform was also designed to be flexible, and new simulators or modules can be adapted added if they are needed. On the other hand, the system has four main motion types of rotary, reciprocating, block on ring and angular rotary. The innovative design aspects are suitable to allow for a variety of probes, sample surfaces, and testing conditions. A user friendly software was also developed to evaluate, control and digitalize the data coming from the sensors and other electronic parts during testing.*

***Keywords:*** *Tribometer, tribotester, multi-functional tribometer, modular tribometer, tribology, friction, wear, lubrication.*

## 1. INTRODUCTION

Tribology is the science and technology that investigates the interaction of surfaces in relative motion in the form of friction, wear, lubrication and other design aspects of materials science. These concepts of tribology have several practical implications in our everyday lives. For example, the friction between our feet and the ground allows us to walk and drive each day. Tribology, on the other hand, is an experiment-oriented branch of a complex, interdisciplinary science, in which testing plays a major role in the solution and/or understanding of technical problems [1]. Tribological problems are often complex, and their understanding and solution rely on experimental data obtained from laboratory tests. Various standard or non-standart test methods have been developed and used for this purpose. The results obtained from these tests are sensitive to the choice of test method and test conditions.

A tribometer (or tribotester) is a generic name given to a machine or device used to perform tests and simulations of wear, friction and lubrication [2]. In this regard, the first tribometer was invented by Leonrado da Vinci

– the first tribologist [3,4]. His first concepts are shown in Fig. 1.

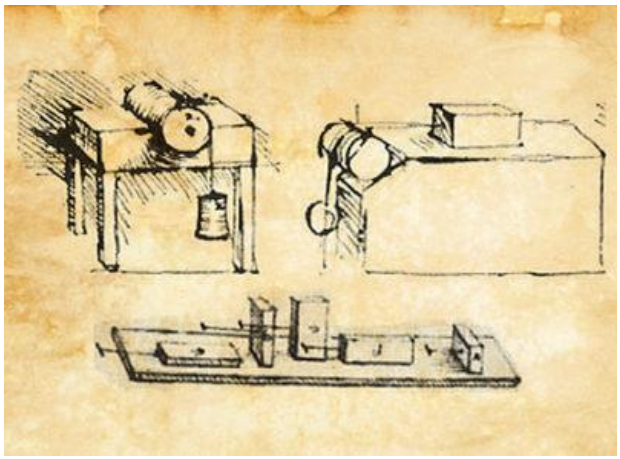


**Figure 1.** First tribometer concepts invented by Leonrado da Vinci who is known as the first tribologist.

In the tribometers, for generating the displacement, two basic movements are used: an oscillating linear (or reciprocating) movement (e.g., in the sledge configuration) or a rotating movement (e.g., in the pin-on-disk configuration). The advantage of the linear movement is to have the same relative displacement for each point of the contact area. The disadvantage is the restricted velocity which can be achieved. A rotating movement allows much higher relative velocities and is mostly used if a constant velocity is desired [5,6], On the other hand, new movements have been applied to the tribometers like angular reciprocating by using new driving system like servo- or stepper-motors. By using such motions types, more simulations become possible in tribological applications.

There are various tribological testing instruments in the market. Most of them have single or limited functional test capability. But in recent years, modular or multifunctional tribometers have been developed and transferred to the market. As looking at the tribometers developed so far, each has its original concept design regarding the application areas. Some of them have been developed devoid of multi-functionality, although some have limited multi-functionality. So it seems to be very beneficial to develop tribological test platform where more modules can work separately on that platform. Also, new driving and loading systems are required to adapt to such new multi-functional tribometers. Recently, some tribology-oriented companies have focussed on this issue and developed such tribometers. But each tribometer has its secret design concept and/or patent productions.

Therefore, this work presents the design, development and production of a new flexible tribological test platform (multi-functional tribometer) by which various modules can be worked. For this purpose, a special software was also developed to handle and process large amounts of high throughput tribological data.

## 2. MULTIFUNCTIONAL TRIBOMETER

### 2.1. Design concept and system overview

Before designing a new apparatus, one must identify its particular purposes. This determines the functional requirements of the apparatus, and it will differ for each machine part, type of machinery, and system. For the multifunctional tribometer developed, the following main features or parameters were selected initially:

- ✓ Standard loads up to 100 N. But it can be upgraded or low-graded by selecting high- or low-capacity load-cells.
- ✓ Speed control of the rotating disk
- ✓ Disc rotational speeds up to 3000 rpm
- ✓ A new user friendly software to set up experiments, handle, store and analyse the data with real time display of measurement data
- ✓ Continuous wear depth measurement option between
- ✓ Variable test path radius
- ✓ Variable stroke and frequency in reciprocating module
- ✓ Automatic stop when the coefficient of friction reaches a threshold value or when a specified number of turns is reached
- ✓ Measuring the test temperature continuously near or inside the abrading samples
- ✓ Measuring the environment temperature and relative humidity continuously

- ✓ Capturing the coefficient of friction between the sliding parts or samples.
- ✓ Test temperature options from room temperature up to 1000 °C with a sophisticated high temperature module.
- ✓ Tribo-corrosion tests option in variety of corrosive liquid with well-designed trbo-corrosion module.
- ✓ Test option for conforming surfaces with a specifically designed block-on-ring module.
- ✓ A specified test option for piston-ring configurations with piston ring and cylinder liner test module.
- ✓ A test option for lubricated system with lubrication or liquid module.
- ✓ Test options with dead weights or spring-assisted mechanically loading
- ✓ Measuring the applied normal loads by a sensor.

Figure 2 shows a general 3-D view of the developed tribometer platform with the main modules, which is constructed based on the design rules described above. The instrument can be roughly divided into three sections: An upper loading and measuring section, a middle test platform section and a lower controlling and driving section. The upper loading and measuring section has the critical parts of the tribometer. Because the loading is required to change the loading force which influences the friction force. This part has two important components: First one is the arm having a load-cell for measuring the friction force and a sensitive distance sensor for measuring the wear depth consciously during the tests. The second one is preferable loading system which can be operated with dead weights and also spring-assisted weights. This may give the users to choose one of them according to their budget and system requirements. Furthermore, this system was especially designed to be able to adapt a closed-loop loading control with servo-driving system. The middle section provides a platform for modular exchange where all developed modules can easily be fixed and changed. This section includes driving shaft, a sled system on which the upper portion was built. Also the mechanical loading system was also fixed on this section. The lower section has the control and driving components as well as sensor's amplifiers.

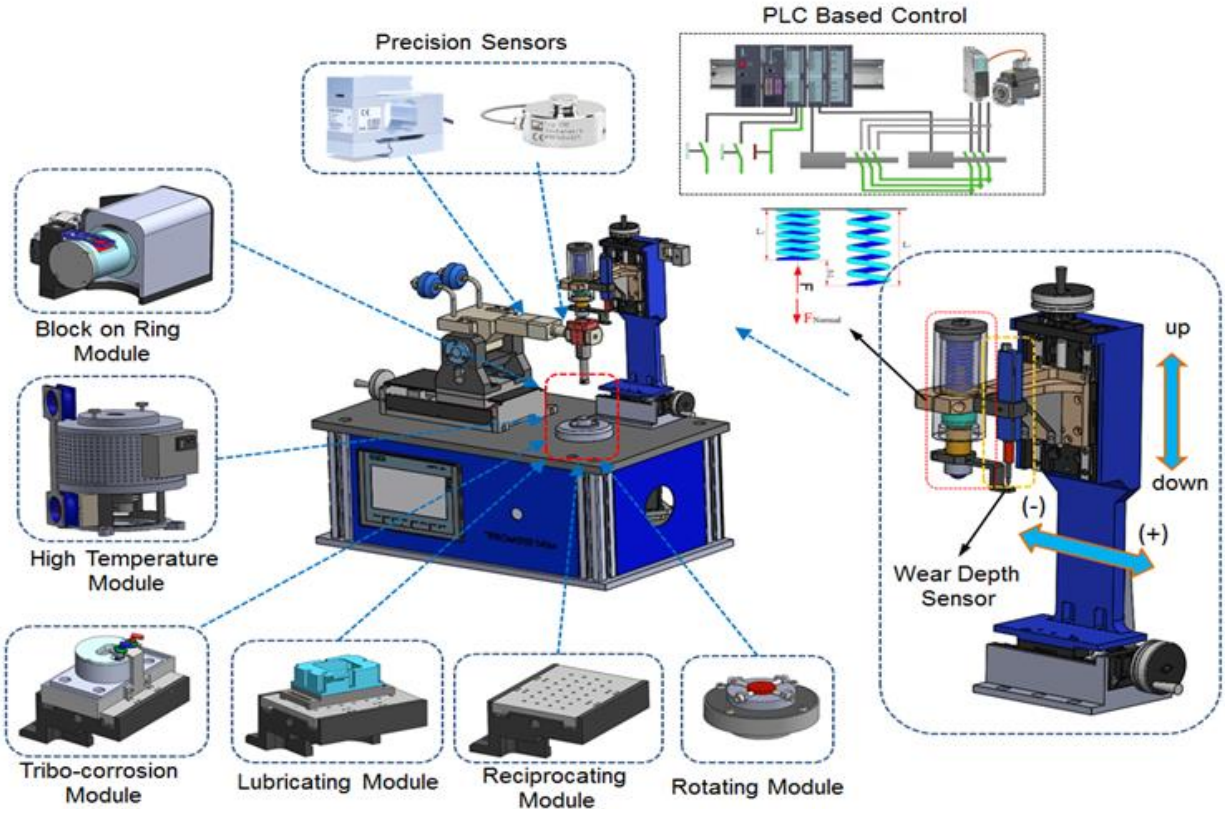



**Figure 2.** A general 3-D views of multifunctional tribometer with the main moudules.

## 2.2. Modules developed for Multi-Functional Tribometer

There are three main motion mode in developed tribometer: rotary, reciprocating and angular rotary. All functional modules were developed to be able to work with these motions modes. The main modules developed are summarized below:

**Pin-on-disc module (Rotary Module)**

This module was designed to be able to conduct the rotary tests according to ASTM G-99. A general 3D view of that module is shown in Fig. 4. In this module, various specimen holders were designed to be able to fixed the specimens from simple to the complex shapes. A rod connected to the loading arm was especially designed on which pin and ball type of samples can easily be fixed. The normal load is applied via this rod.

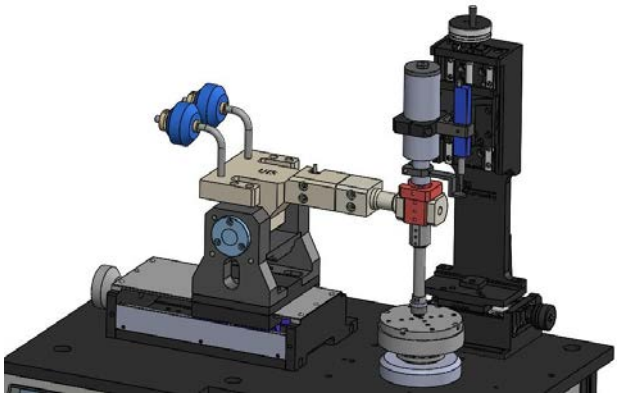


**Figure 4.** A general 3D view of the pin-on-disc (rotary) module.

**Linear reciprocating module**

This module was designed to be able to conduct the reciprocating tests according to ASTM G-133 [7]. A general 3D view of this module is shown in Fig. 5. In this module, a special disk and plate holder are used. Plate holder is mounted on guide pillars trough guide bushes with ball-bearing, which assure precise movement. In this system, the rotational motion is changed to a linear forward and backward motion (reciprocating) by a special mechanism. Thus, there is no need to use one more driving system and only one driving unit is used for both rotary and reciprocating motion modes. The stroke of the test can easily be fixed by a screw, and frequency is fixed by adjusting speed of the driving unit. The length of reciprocating moving depends on diameter of the disk. A special sample holders were placed onto the upper plate by which it is possible to fix the test samples by various shapes.

**High Temperature module**

High temperature test module was developed to analyse of friction and wear properties of the materials. especially for the development and quality control of some systems/tools like cutting tools, combustion engines and steam turbines, jet engines and power plants.

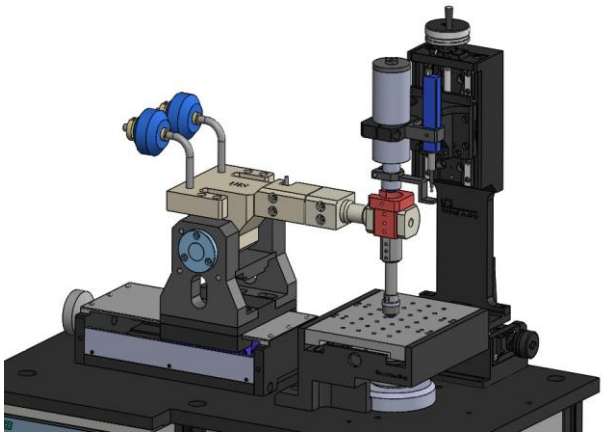


**Figure 5.** A general 3D view of linear reciprocating module.

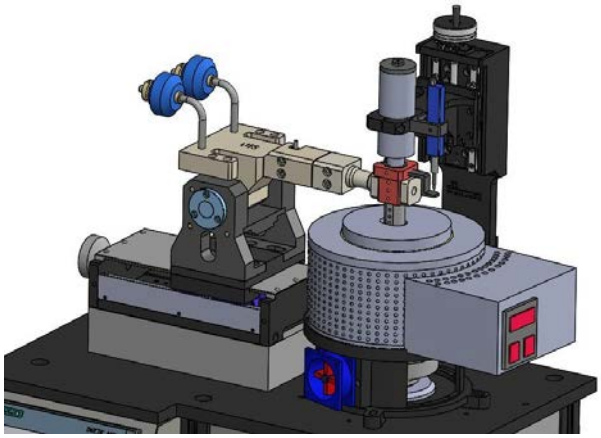


**Figure 6.** A general 3D view of high temperature module developed for the multi-functional tribometer.

This module warms up the sample homogeneously with a well-designed furnace/oven, and it accurately controls the sample temperature up to 1000 °C to simulate materials' in-service condition. The rotating

parts inside the oven was manufactured by super alloys or high temperature stainless steels to be able to guarantee the minimum distortion during testing. Temperature set-point, set as a gradual increase or decrease in temperature, or even cycled through a series of steps can be programmed and controlled by PID controller. The oven of this system ensures that both disc and counter specimens are at the same temperature. The oven is fixed on a lover platform which includes cooling fans and design-assisted cooling parts. The model was designed concerning the minimum heat spreading out of the oven. A general 3D view of this module is shown in Fig. 6.

**Block-on-ring module**

The block-on-ring module is typically used to evaluate friction and wear of materials and lubricants where a ring/bearing/shaft is rotated under axial load according mainly to the ASTM G77 [8]. This allows to test the bearings, rings, shafts, seals, lubricant, grease etc. Thus this setup is a highly used one in the oil industry. The system has its own measuring and driving units except for normal loading. The loading is applied by main tribometer. The system allows both dry and lubricated tests. A special lubrication cap was designed to be able to evaluate the effect of lubrication in-between tribological systems.

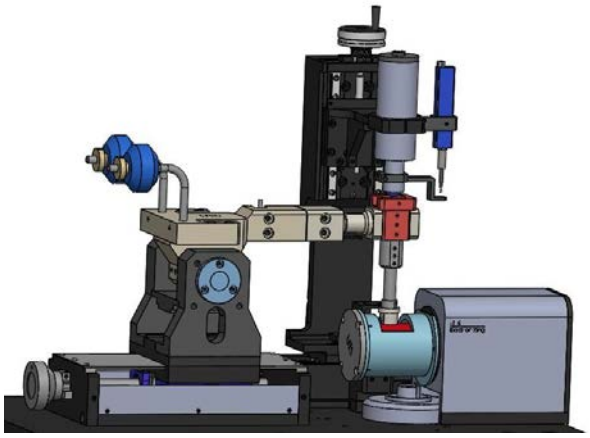


**Figure 7.** A general 3D view of block-on-ring module developed for the multi-functional tribometer.

The tests can be easily configured by defining the temperature (up to 200 °C), test load (up to 100 N) and rotation speed (up to 3000 rpm). The rotating shaft is supported from both ends to prevent bending under high loads. With this developed module, several customized tests can also be performed including testing real components. A general 3D view of this module is shown in Fig. 7.

**Tribocorrosion module**

Tribo-corrosion module is characterized the materials/systems working under the combined effects of mechanical wear and corrosion. It is indispensable for evaluation of systems like pipes, pumps, fuel cells, batteries, biomedical and marine products and any material exposed to wear in a corrosive environment.

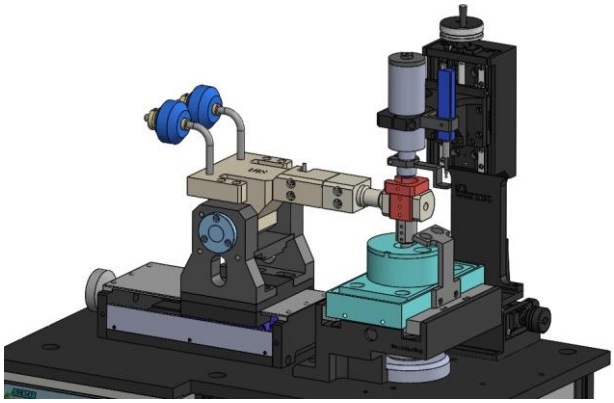


**Figure 8.** A general 3D view of tribocorrosion module developed for for the multi-functional tribometer.

This module was designed to be able to conduct the friction and wear tests into various corrosive environments (such as salt water, body fluid, acidic solutions, etc) on both rotative and reciprocating modules. The module designed for reciprocating motion mode can make the electro-tribocorrosion tests by the addition of potansiyostat. The module is made of corrosion-resistant material. For the removal of the heat generated during tribo-corrosion tests, a constant temperature bath with a water circulation system can be adapted. A general 3D view of this module is shown in Fig. 8.

**Lubrication module**

It is well known that for many industrial applications, friction and wear behavior of materials or systems working in liquid or oily

environments and their characterization are extremely important. This module can work with both rotary and reciprocating main motion modes. This can also be used for different liquid environments with special corrosion cell design. An optional oil/liquid heating system is also developed.

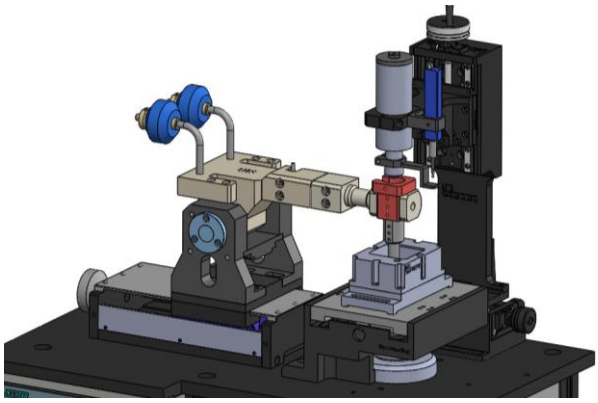


**Figure 9.** A general view of lubrication module and/or liquid container developed for the multi-functional tribometer.

This module was developed for two different options. In the first option, a cell was developed by wich test samples are immersed into the liquid or oil bath. In the other option, a drop-in lubrication was simulated . With this option, a flow rate regulated oil can be sent to the sample container as dropping after fixing by a sensetive valf. A genral 3D view of lubrication module is shown in Fig. 9.

**Piston Ring and Cylinder Liner Test module**

A significant portion of the friction loss in the power cylinder system stems from the contact between the piston skirt and the cylinder liner. The interaction between the piston skirt, lubricant, and cylinder interfaces is quite complex due to the constant changes in force, temperature, and speed in a real life engine. Optimizing each factor is key to obtaining optimal engine performance. The friction coefficient and wear rate will be observed to better understand how the interfaces behave in real-life applications. For evaluate the friction-lubrication and wear of such system, a special module was developed. This module works mainly with the reciprocating motion mode both in oily and oil-free environments. The module can make tests in different frequency and strokes. In addition, the module was designed to be heated in both dry and oily environments up to 200 °C with a precision heating system. A design has been made with the cylinder on the table and the segment on the upper arm.

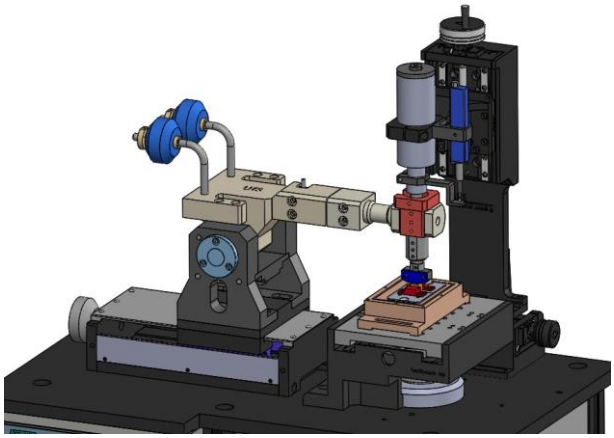


**Figure 10.** A general view of piston ring and cylinder liner test module.

A special ring catch is attached to the upper arm to be able to simulate the actual conditions. It is also possible to perform tribological characterization of the lubricants used with this module. A general 3D view of this module is shown in Fig. 10.

**Environment chamber option**

A chamber was also designed to create a gaseous environment in the test area in which non-corrosive gases like Argon, Nitrogen or controlled humidity air can be created.

## 2.3. Software and control of the tribometer

A special software was developed for this multifunctional tribometer. The control and software diagram is shown in Fig. 11. This software has four parts: Machine control, data acquisition, analysis and display. Test plan and sample related information is entered in the machine control module before starting of a test. Software controls the test parameters like speed, cycle, test duration, sling distance. Various outputs like friction force, coefficient of friction, wear depth and temperature are acquired. Acquired data can be presented in several ways. Graphs of individual test can be printed.

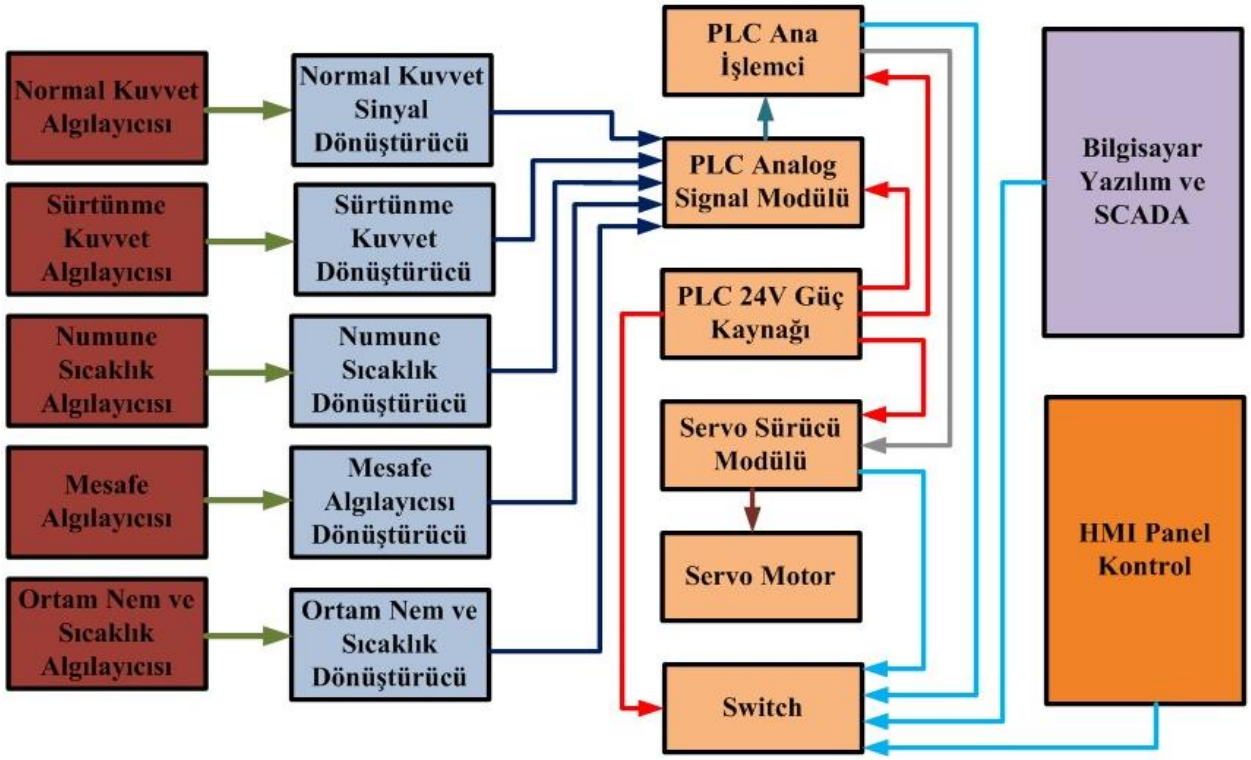
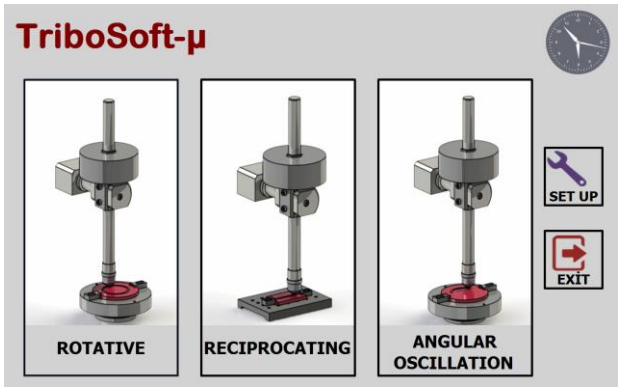
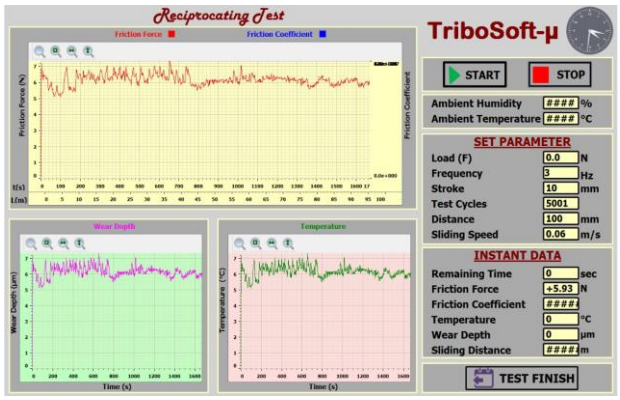



**Figure 11.** Software and control diagram of developed tribometer.




(a)




(b)

**Fig. 12.** A general view of the test screen of the software: (a) Initial screen where the proper drive mode is chosen and (b) main test screen where all set and measuring parameters can be screened as both numerical and graphical.

The system calculates the coefficient of friction values based on the measured values of the normal and frictional forces and displays them on a graph in real time. Acquired data can be exported to other software in Excel format. Some representative views of interfaces are shown in Fig. 12.

## 3. CONCLUSIONS

In this study, a new multifunctional tribological test platform was designed and built. Developed tribometer can work together with the modules of “pin-on-disc”, “linear reciprocating”, “block-on-ring”, “high temperature”, “tribo-corrosion”, “lubrication” and “piston ring on cylinder liner”. On the other hand, the system has four main motion types of rotary, reciprocating, block on ring and angular rotary. The innovative design aspects are suitable to allow for a variety of probes, sample surfaces, and testing conditions. A user friendly software was also developed to evaluate, control and digitalize the data coming from the sensors and other electronic parts during testing.

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