Design of Pin on disk tribometer under international standards

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Abstract. The document exposes a machine built for testing the friction, lubrication and spoilage. Its test conditions have a large filed of options to execute tribology tests checking the working conditions, like movement way (reciprocating or linear), parts in contact, movement speed, self-lubrication, part geometry, temperature range, humidity, materials. To perform this test, the tribometer use the principle of the disc revolution, the load is applied directly over the arm and do the measure according to the standard obtaining the results with accuracy. The use load cell to measure the force created during the test and at the same time get the distance of the wear track in real time.
As a result, it can be calculated by software the coefficient of friction using the data got completing the purpose of the tribotester machine.

Keywords: Friction · Tribometer · Wear· Lubrication.

1 Introduction

The use and basic aspects of tribology are old. The term comes from "tribos" that in Greek means "rubbing", of course, some significant tribological observations were proposed by scientists and engineers from Greek. During 400 B.C., Aristotle proposed that the friction is very low for circular objects and it is easy identifying in other geometries objects [4].Nowadays, all enterprise is trying to save money through the study of the wear and friction field to increase the lifetime in machine parts lowering the maintenance cost[2]. To determine friction coefficients everybody think that is so simply like the normal force and the opposition produced between the object and a surface during a relative tangential motion, but is necessary to remember the tribology is an entire science and its main proposal is to easy this measurement and standardize it. Since begin of the history of the science researcher have measured frictional quantities with help of different devices like pulleys, spring scales or ramps [5].

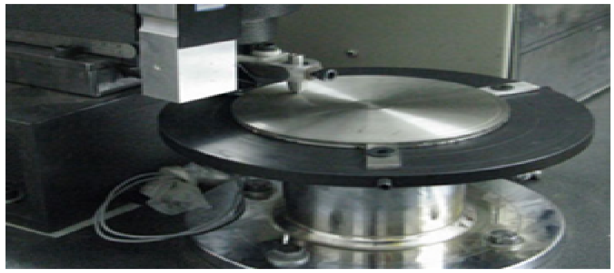

Fig. 1. Pin on Disk Tribometer [9]

The opposition to the movement between contact surfaces is known as friction, it produces surface heat and wear of the material. Inside of an engine, it reduces the power unit. The friction depends on some characteristics of the material like surface finishing, part material, the pressure between objects and the speed movement between objects in contact. [6].Inside of machine the friction between parts can be not optimal measured and it could be expensive; thus, currently we can get this friction data in the laboratories that obtain previously from instruments called tribometers. One simple definition for a tribometer will be a way to evaluate the fiction force. Figure 1 shows the work way of the tribometer pin on disk

Table 1. Standarized Methods[3]

ASTM Standard	Title	Parameters Measured
G99 – 05	Wear test with a tribotester	Losses in the geometric volume
D 2981 – 94	Solid Film Lubricants in Oscillation Motion	The coefficient in case of failure by friction or wear
D913 – 03e1	Resistance to Wear of Traffic Paint	Degree of substrate in hedge distinctive zone of wear
B611 – 85	Cemented Carbide wear resistance and abrasion	Wear number and abrasion toughness
D3702 – 94	Self Lubricating Materials, wear rate and friction coefficient	Coefficient of friction and wear

Currently,there are several techniques working since occupying petty prototypes or occupy the correspondent part. Since to tribology was born several test friction standards were set forth; nevertheless,In the actuality, some world organizations that voluntary and government-sponsored have suggested practices guidelines (standards) to lead engineers to structure the data of measured friction. Nonstandard methods are useful as well to make the process. In the present work we focus on the existing standards developed for the tribology study which are described by ASTM Standards in the table 1 show bellow.

The standards identify the variables to be controlled and which of these variables will be allowed, the way to get the data, and the way to be presented the results. But, is important to know that if some parameter is not mentioned on a standard it does not mean that the affection of it could not be significant under another set of circumstances [7].

In the previous studies a mathematical semi-physical phenomenological base model of sliding pairs is developed in order to predict the wear rate [14] and a model focused in the control design respect to the moving parts in the tribometer machine [10]. So the mechanical parametric desing is a main part in the machine develop in order to reduce a optimaizing the economical factor. Friction measuring laboratory techniques had been used and developed for a variety of purposes in the table 2 the purposes shall be describe.

Table 2. Tribometer Classification [7]

Number	**Tribometer Classification by purpose of development**
I.	For particular machine tribocontact situationsimulation.
II.	Evaluation of candidate-bearing materials.
III.	Evaluation of lubricants .
IV.	To qualify lubricants for use on the basis of established criteria.
V.	To monitor part surface.
VI.	To acquire nontribosystem-specific friction data as a means to compare and develop new materials
VII	To investigate the fundamental nature of friction

Several variables can affect friction. Some of the most important of these variables are listed like: (a) Velocity, normal force and acceleration characteristics, (b) System stiffness, (c) Motion direction related to the surface configuration, (d) Surface finishing and cleanliness, (e) frictional heating, (f) Relative humidity, (g) Lubricant characteristics, (h) impurity presence.

Standard ASTM G99 explain the test guidelines to calculate the material wear while the contact parts movement using a pin-on-disk tester. The process shall be made in pairs and nominally located in non-abrasive conditions. These experimental guidelines show the correct steps for the principal areas attention in using this type of apparatus to measure wear. One of the main purposes using this apparatus is determine the coefficient of friction of the materials, During pin-on-disk method is necessary to have a pair of samples. The first will a pin with a round end which is perpendicularly located respect to the other sample material. The pin specimen commonly is a ball rigidly held. The test machine causes either the pin sample or the disk revolving about the center. Therefore, the sliding path (in either case) is a track whit a circular shape on the disk surface as shown in the figure 2 in blue colour. This kind of test may develop putting the plane of the disk oriented either horizontally or vertically. And something important to remark, at time to design the tribometer is that the wear results can be different using different orientations of the apparatus [8].

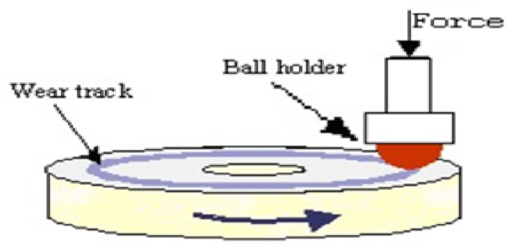

Fig. 2. Pin on Disk function sketch [11]

The next part of this report is configured with the following sections: II materials and methods. III results . Finally, IV conclusions and future work.

2 Materials and Methods

The given data parameters in international standards shall be considered for the design, to enhance the main machine parameters to assure a good friction test, getting optimal material junction grade in the different machine mechanisms, consequently, this work is developed in two phases a) Conceptual design, b) Analytical Design [2].

2.1 Conceptual design

For develop the conceptual design is necessary start with a part selection and then present the different concepts to study to choose the best one.When the international standards were studied the different requirements are selected and shown in Table 3 according to the importance of each one of these.

Table 3. List of requirements for Pin on Disk construction

No.	Description	Classificat ion	Num. value	Impor tance	No.	Description	Classifica tion	Num. value	Impor tance
1	Stability	Structural		B	10	Operating load of specimens	Specific by norm	0,1 m/s (60 rpm with disk diameter of 32mm.)	S4
2	Minimization of action space	Structural		B	11	Operating speed rotation of the disk	Specific by norm	0,1 m/s (60 rpm with disk diameter of 32mm.)	S3
3	Comfort ability for users	Ergonomic		B	12	Operating temperature	Specific by norm	23C	S7
4	Does fit fire safety regulations	Safety		B	13	Operating atmosphere: humidity	Specific by norm	Relative humidity range 12 to 78%	S8
5	Must avoid cause accident by detachment of parts	Safety		S10	14	Less vibration as possible of the machine to make sure high accuracy in the results	Structural		W5
6	Must provide power protection in case of power shortage	Safety		B	15	Less noisy as possible to avoid interfere the tested results	Structural		W5
7	Alert in case of malfunction (light, sound)	Economic		S3	16	Wear Measuring Systems	Specific by norm	Linear instrument: senility 2.5 m or better. Balance to measure the mass loss: sensitivity of 0.1 mg or better	B
8	Long service lifetime	Economic		S6	17	Surface Finish	Specific by norm	Surface roughness of 0.8 m (32 in.)	B
9	Emergency stop possibility	Safety		S2	18	Dimensions of the specimens	Specific by norm	Pin: Diameter of 2 to 10 mm. Length is not specified by the norm.	B

Shall be used a popular system of notations B, S, W to classify the importance of the requirements, meaning Basic, Standard and Wished requirements, respectively – they order lowering degree of importance. The numbers preceding the letters mean a scale of importance from uttermost as 1 to least important as 10, to provide further classification. This optional extra scaling was not applied to Basic requirements since they were considered equally important, a complete Must.

2.2 Parts Selection

The existing tribometer tester in being on market was investigated identifying repetitive parts of the machine to choose the best characteristics set to use in conceptual design and then check with the necessary requirements in the different standards with which our device is designed. Table 4 shows the repetitive parts.

After had analyse the Matrix of concepts-functions of existent tribometers in the previous table4 where were examined the more repeated solutions concepts for each part of the tribometers existent in the market, now is possible develop our own designs of tribometer. The conceptions were first designed and after,

Table 4. Matrix of concepts-functions of existent tribometers

Functions / features	Sub functions	Concepts	1 Ducom Pin on Disk	2 Disc tribometer horizontal loading	3 MCR Tribology Cell T-PID/44	# of machines using the concept	Concept more repeated
Geometry	-	Horizontal	x		x	2	E
		Vertical		x		1	
Rotation	-	Pin Rotation			x	1	
		Disk Rotation	x	x		2	E
Pin specimen holder and lever arm	Pin holder	Chuck pin holder		x	x	2	E
		Press pin holder	x			1	
	Disk holder	Disk holder external fit	x	x	x	3	E
		Centre holder external fit	x	x	x	3	E
Motor Drive	-	Direct to the shaft				0	
		Belts	x	x		2	E
		Gears			x	1	
Wear Measuring Systems	-	Load cell	x	x	x	2	E
		Torque sensor				0	
		Piezoelectric sensor				0	

its 3D models were developed using a CAD system. According to this, the three different designs are presented with its simulation results below.

2.3 Catalog Parts Selection

The main parts of the machine are selected from catalogs and web pages of the companies that are dedicated to the design and sale of the motor, motor drive and the chuck[2] to verify the correct operation of the mechanisms..

Disk Rotation The disc revolution to realize the test for use of the load applied directly over the arm and do the measure according to the standard obtaining the results with accuracy. To drive the disk of the revolution of the machine, transmit the torque of the test and the control of speed is used different ways to transmit the torque to the shaft to move the disk. When one machine need torque middle or low, is necessary use belts to transmit the required force and to reduce the vibrations produced by the friction during the test. Is important reduce these vibrations because can affect directly to the engine producing failure if the needed torque is high, is used gears to transmit the necessary force, but the vibrations could affect.

Figure 3 motor drive system is shown, in relation with the international standards the machine will work under middle to low torque in that way a belt drive system is chosen.

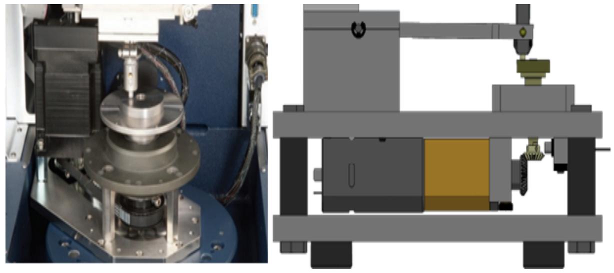

Fig. 3. Motor drive system

Disk holder for fit the sample disc is possible use the bolts to make sure the disk will be in the correct position. For fit it is possible use one bolt in the middle of the disk to fix the sample with the disk of the revolution of the machine. Other option for fitting the disk can be use some bolts in the perimeter of the disk to fix the sample with the revolution disk of the machine as is visible on Figure 4

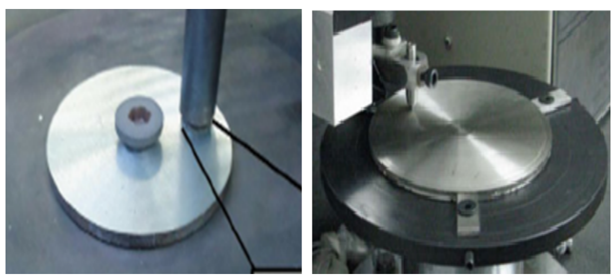

Fig. 4. Disk holder [9]

Pin holder The process of adjusting the sample in the arm will be done by different techniques depending on the material to be used. The chuck fit the specimen of the test to the arm and allows using different size of the pin of the materials. The other way to fit the pin is through or two metallic pieces fixed by bolts to the arm and between of that pieces is located the sample of material as is visible on Figure 5

Wear Measuring Systems The figure 6 shows the used system in most of the existent tester in the market use load cell to measure the force created during the test and at the same time get the distance of the wear track in real time. It can be calculated by software the coefficient of friction using the data got completing the purpose of the tribotester machine.Some different algorithms are necessary to

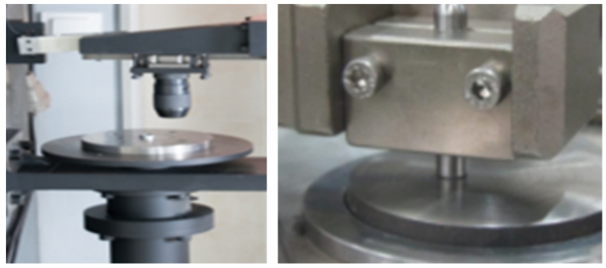

Fig. 5. Pin holder [1]

determine the appropriate one that can be presented to the previously acquired data set. The main task is the identification of a wear track [13, 15, 12].

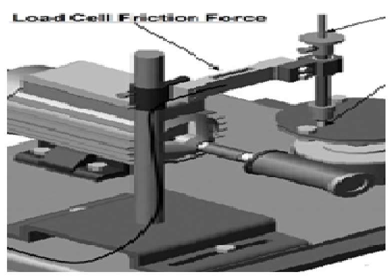

Fig. 6. Pin holder [1]

2.4 Machine Concepts Designs

After had analyzed the matrix of concepts-functions of existent tribometers in table 4 and after the selection of components, the geometry proposal of three different models will be carried out to find the device that allows the greatest precision and repetition in the results during the process [2].

Tribometer with the load over the measurement arm The most important characteristic in the measurement machine is the way to apply the load; in this case, the load is located directly over the measurement arm and in the load space, and so reducing the machine size as are shown in the figure 7.

Tribometer with the load in one side the measurement arm In the design number 2 the load is located in one side of the machine with an extension the measurement arm and in the load space as is showed in the figure8 below.

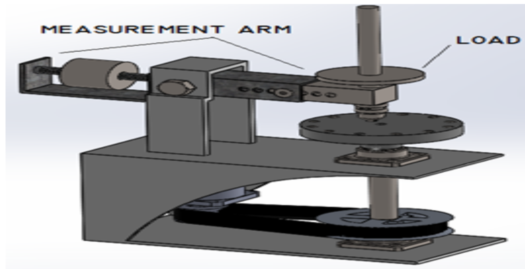

Fig. 7. Tribometer with the load over the measurement arm [7]

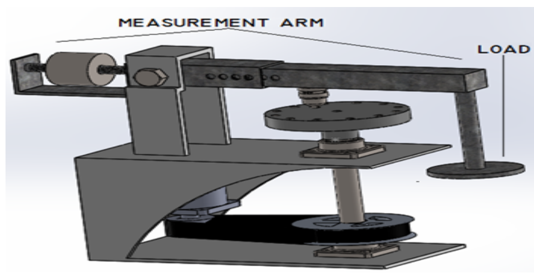

Fig. 8. Tribometer with the load in one side the measurement arm [7]

Tribometer with the horizontal load in the end the measurement arm For this design the load is positioned in one side of the machine with an extension the measurement arm. But in the design 3 now the load space is located in horizontal position. The model of the design 3 can be appreciated in the figure 9.

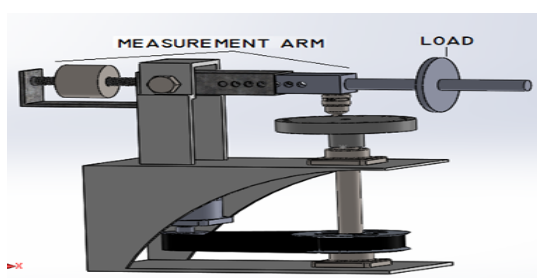

Fig. 9. Tribometer with the horizontal load in the end the measurement armr [7]

3 Results

In order to obtain a machine that works correctly, tension and stress studies should be sought for the analysis of results.

3.1 Stress Analysis The stress analysis shows the behavior of the machine under the work forces, ensuring the minimum deformation with respect to the applied forces. The behavior of the structure of each design with respect to the working forces is shown in 10,getting as a result extremely low deformations, allowing to verify that the designed structure is adequate for this function [2].

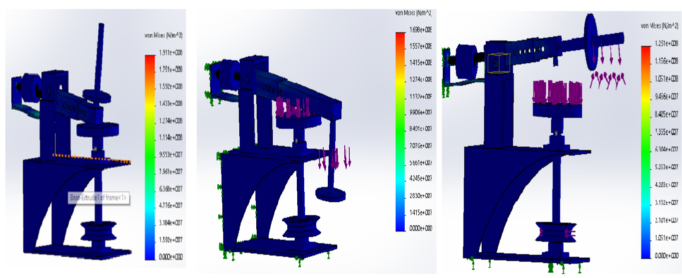

Fig. 10. Tribometer Stress Data Analysis Result [7]

3.2 Strain Analysis As shown in11 the analysis of deformation data in the structure allows detecting changes in the shape or size of a body due to the applied forces. It can also be seen that the designed machine is working in a safe area within the elastic zone of the behavior of the materials [2].

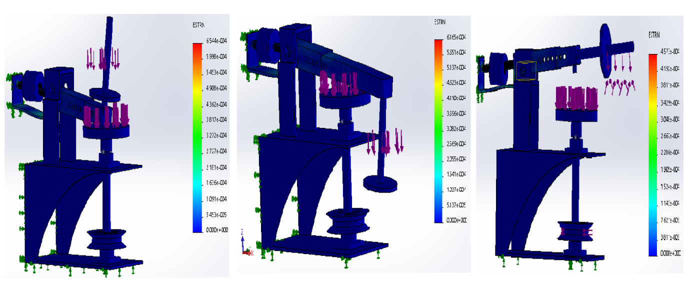

Fig. 11. Tribometer Strain Data Analysis Result [7]

3.3 Displacement Analysis After the comparison of each concept model respect to stress and deformation aspects, the obtained behavior is very similar between it, getting a good functioning in all cases, this is the reason because to select the most optimal model to make this work he most important aspects is the displacement analysis mainly in the work area that is in contact with the analysis samples and the all their components. The displacement analysis shows that the maximum displacement in the tester is low and no one displacement in the design overcomes the critical limits of functioning as is possible see in the figure12 [2].

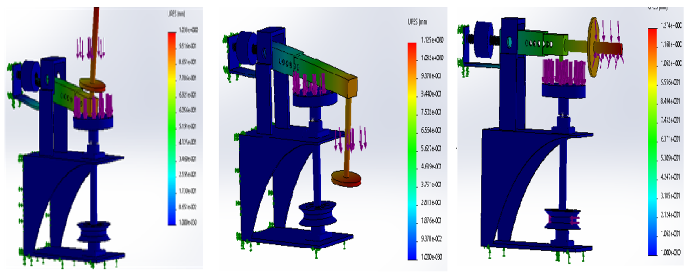

Fig. 12. Tribometer Displacement Data Analysis Result [7]

3.4 Model Comparation After the result analysis is necessary to determine the stiffness of the models to select the best one, in that context the displacement and deformation are analyzed.

Stiffness Ratio: Is the ability of a structural element to withstand efforts without acquiring large deformations. and it is defined by the equation [2]:

$$K_i = \frac{F_o}{\sigma_i} \quad (1)$$

Where:
K_i = Stiffness modul.
F_o = Aplied Force.
σ_i= Displacement.

Mass to Stiffness Ratio: Consists of the elastic module per unit of mass that allows us to identify the most optimal design of our models thus selecting the model with the highest index between stiffnes and mass [2].

Analysing the matrix showed in Table 5 is possible to see that the value of Mass to stiffness ratio is biggest in the design #2. Therefore we select the second one concept like the best design.

Table 5. Tribometer Mechanical Data Analysis Result [7]

Parámetro	Concept 1	Concept 2	Concept 3
Mass [Kg]	31.33	32.726	30.387
Maximun Desplazamiento $[mm]$	8.749 10$\hat{3}$	4.708 10$\hat{3}$	7.557 10$\hat{3}$
Stiffness	45719.51	84961.76	52931.057
Mass to Stiffness Ratio	1459.288	2596.154	1741.89

4 Conclusions and Future Works

The adaptive method type H is applied to obtain the study of convergence of results shown in the Figure13, the selection criterion used to define the optimal model guarantees the functioning of the concept and the correct parts selected.

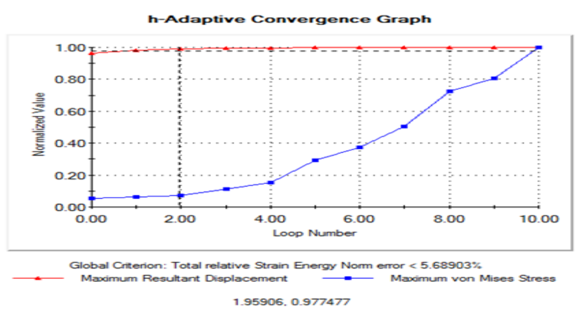

Fig. 13. Tribometer Displacement Data Analysis Result [7]

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