Reciprocating sliding motion tribometer design

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Abstract

This work shows the design process for the construction of a reciprocating sliding tribometer used for the tribological study of materials, coatings and lubricants. In the development of the final design, a methodology is shown that includes an analysis of the client's needs, a state of the art of the already existing tribometers, a stage of conceptual designs, evaluation of the conceptual designs and then to arrive at a detailed engineering and manufacturing that resulted in the design of a functional tribometer and up to 14 times cheaper than those that exist in the market. This tribometer has commercial parts, some from custom design and is manufactured with conventional manufacturing processes. The design methodology used allows optimizing resources and maximizing results, all of the above in just 16 weeks.

Keywords
Tribology, friction, reciprocating tribometer and CAD.

1. Introduction
Tribology is the study of lubrication, friction, and wear between surfaces in relative motion (Shewan et al. 2020). It is an interdisciplinary area, as it is linked with materials, chemistry, physics and biology (Yan 2010). Since the beginning of the twentieth century, knowledge in all areas of tribology has expanded tremendously, due to enormous industrial growth, which led to the demand for an improved understanding of tribology (Affatato and Grillini 2013).

Wear is a measure of progressive material loss as a result of relative motion between the operating surfaces in contact. In the industrial sector, wear is a massive problem and its direct cost is estimated to vary between 1 and 4% of the net gross national product (Mahadikar et al. 2020).

In the modern era, research has been done with the purpose of developing techniques for wear reduction of tools and to increase its lifetime. Currently, the devices used to study the tribological properties of materials are the tribometers. However, the design and the selection of this machine is crucial.

A carefully selected tribometer can simulate all the critical characteristics of a wear or friction problem without the difficulties associated with the experimentation on actual equipment. Conversely, a poorly designed or selected tribometer can provide entirely false results (Stachowiak et al. 2004).

There are several common bench tests existing for friction and wear measurements, that are pin-on-disc, block-on-ring, linear reciprocating, and four balls which are classified based on test geometry, type of contact, contact geometry, and relative motion (Tiruvenkadam et al. 2013).

In this paper, the design of a linear reciprocating tribometer is developed. Reciprocating motion is found in a wide range of mechanisms, including reciprocating engines and pumps (Mccarthy 2018). The principle of operation of a linear reciprocating tribometer consists of sliding test samples against a stationary counter surface under load and recording the parameters of interest (Mohan et al. 2009). With this tribometer, it will be possible to measure friction and wear between two materials, and determine the performance of different lubricants.

Objectives

General objective
Design a sliding reciprocating motion tribometer to enhance the capabilities of the Tribology laboratory.

Specific objectives
- Accomplish the standard ASTM F732
- Conventional manufacturing processes
- Minimize the number of parts and adjustments
- Manufacturing cost less than 500 USD
- 100% mechanical design

Scopes
- Detailed design of the tribometer
- Manufacturing drawings
- List and costs of materials
- Manufacturing costs
- Kinematics of motion (simulation)

2. Literature Review

A search for already existing reciprocating machines was performed, 9 tribometers were investigated: T-17, TE-67 , T-50, TE-37, TRB3, MFT-5000, T30M-HT, DDS, and TE 77.

From each machine investigated, the input parameters were obtained. Among them are, the load, the linear velocity, angular velocity, the test duration, the amplitude, and the temperature. The output parameters were also acquired, including the coefficient of friction, the friction force, the wear, and number of cycles.

Moreover, the technical specifications were investigated for each one of the machines, among which are the amplitude, the frequency, the pin diameter, the steel pellet diameter, the tribometer dimensions and weight.

Additionally, an investigation of reciprocating linear motion mechanisms was done. Between the mechanisms are the slider-crank mechanism, a variant of it, the scotch yoke, a mechanism that uses a cam, the rack and pinion, some mechanisms that perform this movement due to the design of its components, and others that use a gear system.

3. Methods

The following methodology was carried out:
1. State of the art research: Through searching for similar machines that already exist.
2. Definition of variables: By means of commercial values and the standard.
3. Design options: Each team member came up with a different design.
4. Morphological matrix: Each design was evaluated and a winner was selected.
5. Winning Design: The winning concept was worked on.

Later, detailed engineering was carried out

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1. Initial CAD
2. Manufacturing drawings
3. Parts purchased with costs

4. Data Collection

Variables

In order to decide the values of the variables of the tribotester to be designed, the values of these variables obtained from the investigation of the tribometers already existing were taken into account. The values of the ASTM F732 standard and of the T-17 tribometer were also considered in Table 1.

Table 1. Tribometers variables ranges

Variables	Ranges	TLR
Load	225 - 5000 N	350 N
Frequency	0.5 - 80 Hz	2.92 Hz
Amplitude	0.5 - 60 mm	40 mm
Angular velocity	máx. 5000 RPM	máx. 1050 RPM
Linear velocity	75-8000 mm/s	2200 mm/s
Pin diameter	9 - 25 mm	9 - 25 mm
Pellets diameter	¼" - ½"	¼" - ½"
Plate dimensions	36 - 76 x 17 - 62 mm	62 x 47 mm
Tribometer dimensions	smaller than a desk	40 x 40 cm
Tribometer weight	lowest possible	22 kg
Power	--	¼ HP

Design options

Based on investigation, each member of the team selected a conceptual design taking in consideration the lock up of the pin or ball , how to hold the work plate, load application, the transformation of rotational to linear reciprocating movement and the device for sensing friction. The parts of each conceptual design are described below in table 2.

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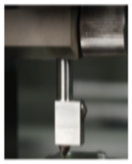
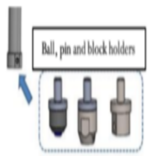
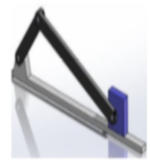
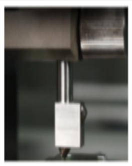
Table 2. Conceptual designs

Conceptual design	Pin/ball holder	Plate holder	Load application	Motion	Friction sensor
1					
2					
3					

➔ Conceptual design 1

In this design the pin is locked in place from the pressure generated by a perpendicular screw; to hold the plate, a table with holes is used, which allows to put different sizes plates and in different positions. The load application is through disc shape weights, placed on a weight stem, and the rotational motion of the motor is transformed to linear reciprocating by a mechanism with a worm and half gears.

➔ Conceptual design 2

In the second design, to hold the pin in place, a router collet chuck is used. To put the plate in position, as well as the first design, a holed table is used, and the load application, likewise, is through disc shaped weights. The reciprocating motion is via a gear crank mechanism.

➔ Conceptual design 3

Lastly, the third design sets the pin in place with a perpendicular screw, like the first design. To hold the plate, the work table has a space where the plate fits perfectly, and it can also house lubricant. The load application is through weights and the movement becomes from rotational to linear reciprocating by a scotch yoke mechanism.

All three designs have the same load sensor since it was decided to apply the same as the ones used in the tribotesters installed in the university.

<u>Morphological matrix</u>

Next, to analyze the pros and cons of each design, and to select the winning design, a morphological matrix was used. The categories to grade were divided into the following:

- Machinability
- Amount of parts
- Assembly / adjustment
- Parts availability
- Number of possible failing parts
- Amount of different parts
- Variable adjustment
- Friction sensing
- Tribotester volume

After the definition of the categories, to define the relative importance of each one, a score of 5 to 10 was assigned, with 5 being the least important and 10 the most important. Then, 3 values were used to grade each category of the three conceptual designs, 1 for deficient, 3 for regular and 9 for good. In the end, to obtain the final score of each design, the relative importance of each category was multiplied by its corresponding grade.

Winning design

The table with the graded categories of each design and its final score is shown next table 3

Table 3. Morphological matrix

Relative importance	10	8	9	7	8
CD	Machinability	Amount of parts	Assembly / adjustment	Availability	# of possible failing parts
1	1	3	9	1	1
2	3	9	3	3	9
3	9	3	1	3	3

Relative importance	8	7	5	6	
DC	Amount of different parts	Variable adjustment	Friction sensing	Volume	**Final score**
1	9	1	9	9	308
2	1	9	9	3	**356**
3	3	9	9	3	300

The winning conceptual design was the second one. Based on this design, the development of the tribometer was started.

5. Results and Discussion

Detailed engineering

CAD

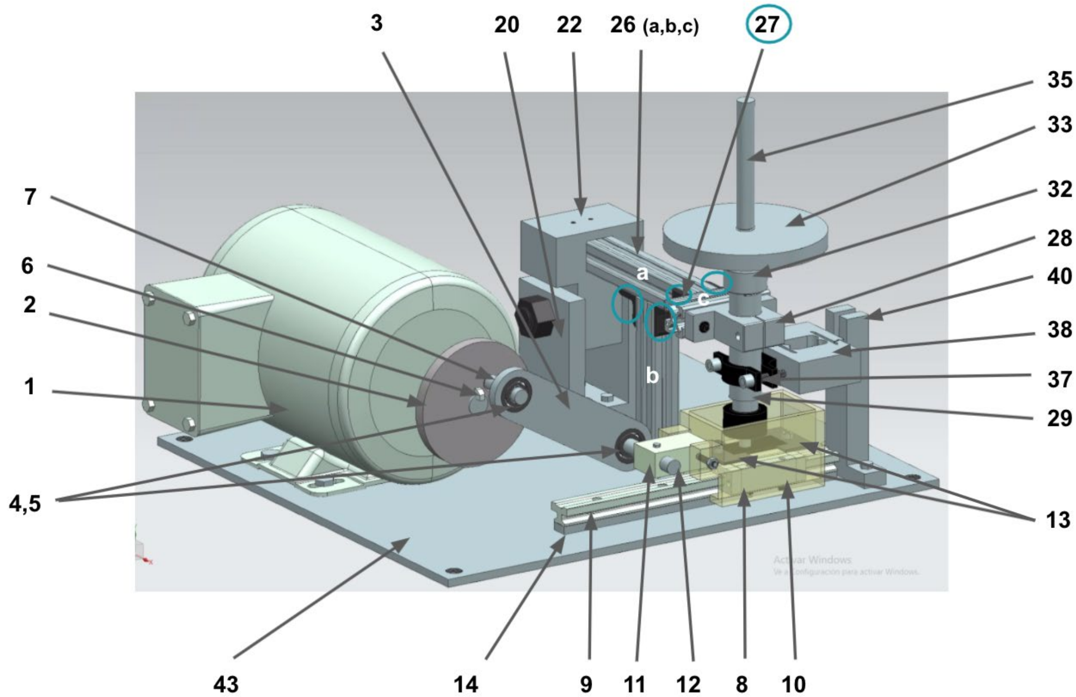


Figure 1. TLR CAD

1. Motor ¼ HP	10. Oil box	28. 1" pipe clamp
2. Crank	11. Connection crank - oil box	29. Clamping nozzle extension
3. Connecting rod	12. Connection pin	32. Reducer coupling
4. Bearings	13. Plate holder	33. Weight holder disc
5. Locks	14. Rail base	35. ½" weight holder tube
6. Wedge	20. U part	37. Clamp-sensor
7. Crank pin	22. T part	38. Sensor
8. Carriage	26. Aluminum profile	40. Sensor support
9. Rail	27. L brackets	43. Base-plate

Machine description

The tribotester has 3 main parts, the engine with the gear crank mechanism, the carriage with the rail and the arm.

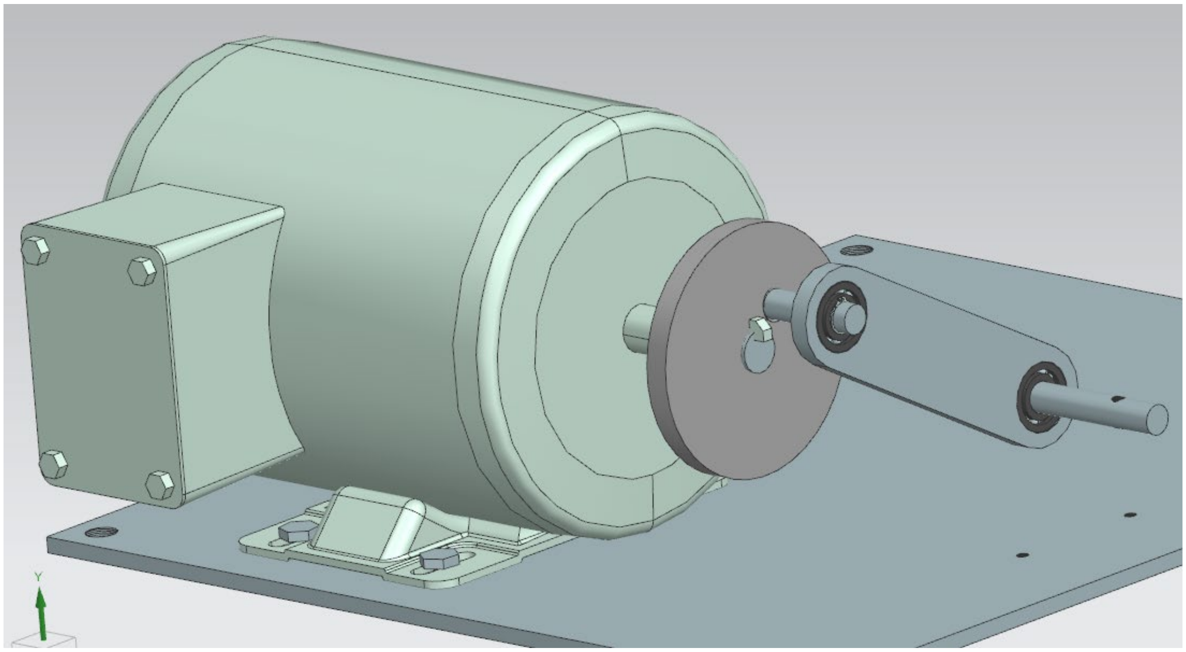


Figure 2. Engine with the gear crank mechanism

The first part of the engine and its transmission of movement. It has a power of ¼ hp, and a variable speed drive will be connected to regulate the rotation of the output shaft. The output shaft is connected to the circular part that will act as a connecting rod thanks to a key with a step.

In addition, to ensure the subjection of the pin, a nut was added on the back and a padlock for the shaft and the ball bearing on the front.

The radius is 20 mm, from the center of the shaft to the center of the pin, to obtain the amplitude of 40 mm.

Two bearings were added on the crank to make movement possible, the last pin being the one that will communicate with the box.

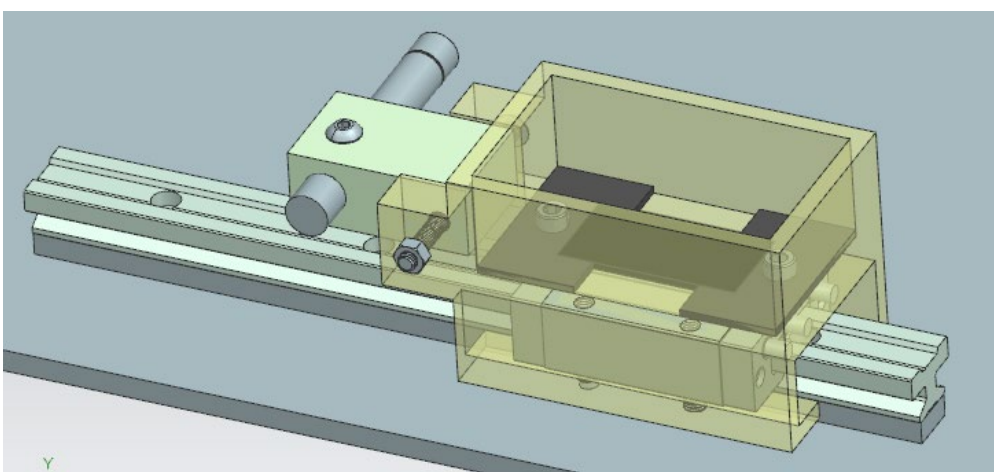


Figure 3. Carriage, oil box and guide rail

The second part of the tribometer consists of a carriage and a guide rail. The oil box will be on top of the carriage, fixed with screws to the bottom of the carriage, so it can move with it.
Inside the lubricant box it can be found the work piece, which is held by two u-shaped parts and two screws. Next, the crank-oil box connection will be fixed with screws, on one side to the connection pin and on the other side to the oil box.

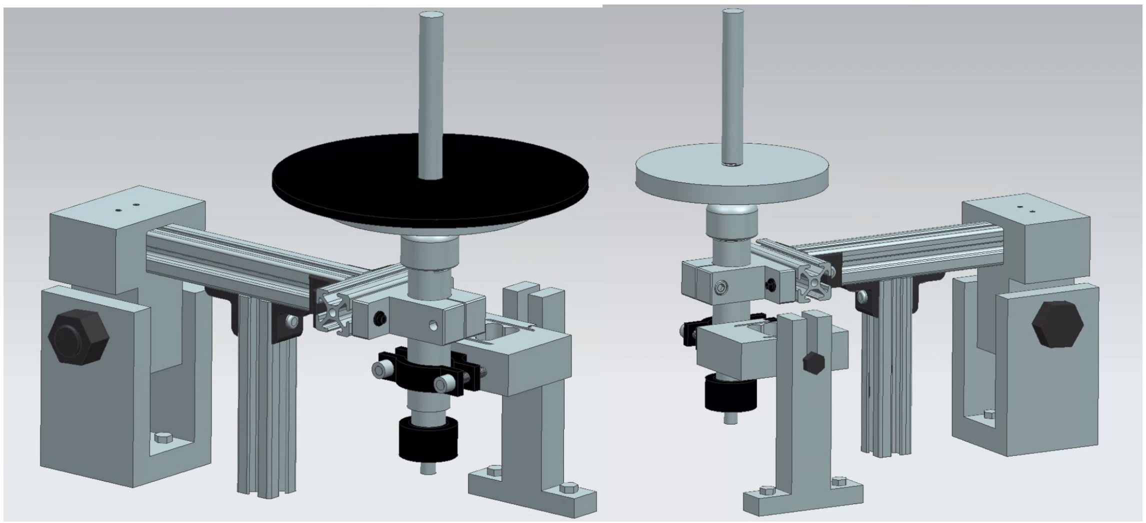


Figure 4. Tribometer arm

The "arm" part is made of an extension of a router collet chuck in which the pin is placed, this piece has a thread at the top so that a threaded reducer coupling can be fitted. Above the coupling, a weight holder tube fits , which has a screwed disc where the weights rest.

This whole set of parts is put into position with a clamp, and to connect this clamp to the main aluminum profile of the arm, a smaller profile and two L-shaped brackets are used. Two machined pieces, T and U shaped, hold the complete arm, and by means of a screw, inclination in the arm is allowed. This to facilitate the assembly and disassembly of the pin. Under the main aluminum profile, connected by two other L-shaped brackets, another aluminum profile is placed, which serves as a rest for the arm when there is no working pin.

One end of the load sensor is placed in position by a clamp that connects with the router collet chuck extension; and at the other end, through a screw that tightens into the sensor support on the right.

5.1 Numerical Results

<u>Costs</u>

<u>Purchased parts</u>

Most of the parts used on the TLR design are from McMaster, some are from other sites. Down below it is shown a tables 4,5 and 6 with the part number of every piece and their cost in dollars:

Table 4. Costs of purchased parts

Part	Part number	Cost (dlls)
Motor ¼ hp	RMW1-4	$70

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Varidrive	--	$54
[2] Bearings	5972K95	$21.26
[2] Locks	97633A195	$6.08
Wedge	98471A117	$7
Carriage	9867K2	$51.11
Rail	9867K12	$17.50
[2 ft] Aluminum profile	47065T209	$7.79
[4] L brackets for the rail	47065T236	$20.84
1” pipe clamp	47065T205	$34.10
Clamping nozzle extension	C25 ER20A	$26.00
Collet	ER20	$9.00
Weight holder disc	1610T48	$12.60
½” weight holder tube	9056K92	$4.54
Clamp-sensor	--	$1.50
[4] M4 20 mm screw	91290A168	$0.46
[2] M5 5 mm screw	92290A277	$2.32
[5] M5 25mm screw	92290A252	$0.93
M5 65 mm screw	94500A299	$1.00
[2] M5 nut	90592A095	$0.04
[4] M8x1.25 mm screw, 20 mm length	91310A533	$0.88
[2] 5-40 Set screw, 1/4" length	92311A124	$0.12
3/4"-16 screw, 3 1/2" length	91286A512	$5.86
3/4"-16 nut	95505A618	$0.52
M8x1.25mm Set screw, 18 mm length	91390A613	$0.48
M8x1.25 mm screw, 30 mm length	91310A536	$0.28
[2] M8x1.25 mm screw,16 mm length	91310A530	$0.20

Manufactured parts

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Table 5. Costs of manufactured parts

Part	Material	Cost (dlls)
Crank	Steel	$5
Connecting rod	Steel	$5
Crank pin	Steel	$5
Oil box	Nylamid	$88
Connection crank - oil box	Aluminum	$12.5
Connection pin	Steel	$5
Plate holder	Aluminum	$7.5
Rail base	Steel	$7.5
U part	Aluminum	$12.5
Tpart	Aluminum	$12.5
Reducer coupling	Aluminum	$7.5
Sensor support	Aluminum	$12.5
Base-plate	Steel	$25

Table 6. Total cost of par

	Cost
Purchased parts	$356.5
Machined parts	$205.5
Total	$562

5.3 Proposed Improvements

As shown in table 6, the target price was raised by 12%, due to the elevated prices of some parts at McMaster in comparison to local suppliers, thus, in order to reduce the cost, it would be convenient to look in these businesses.

6. Conclusion

In this project, a tribotester was designed, in order to replicate the reciprocating movement of different industry applications, as well as, predict the materials performance in constant friction situations. In addition, due to the design

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of this tribometer, it will be possible to test different lubricants, and, through wear analysis, the most optimal lubricant will be selected for the application.

On the other hand, one of the challenges presented during the development of this project was the remote design of the tribotester, because a good communication between the team members and a good work distribution was necessary. Moreover, another challenge presented was the necessity of doing multiple changes in the design of the tribometer in accordance with the evolution of the project.

Furthermore, the opportunity to develop different knowledge areas of the Mechanical Engineering program was given, the main area was mechanical design, where the NX Software was used, for the CAD, drawings and motion simulation. Also, the manufacturing processes and the material selection were approached. Additionally, on the administrative side, the most adequate parts were searched and a cost analysis was carried out.

Finally, during the development of the project, we realized that a crucial part was the weekly control of activities, since it allowed us to distribute the workload. In addition, we were able to observe the evolution of the project week by week. Unfortunately, due to the pandemic, we lost the opportunity to build the machine. So, the next possible step is to build the tribometer and start doing experiments.

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Biographies

Demófilo Maldonado Cortés is a Mechanical Engineer from UDEM (1992) , Master of Science in Mechanical Engineering from ITESM (1996), PhD in Tribology at the Krakow Polytechnic in Poland (2010), author of a book on tribology, scientific articles and international conferences, industrial and scientific experience for more than 30 years. He is currently a professor in the Department of Mechanical and Electronic Engineering at UDEM

Lizbeth Pérez Alvizo is a mechanical engineer student at Universidad de Monterrey. She was born in Morelos, Coahuila in 1999, but since 2014, she has studied in Monterrey, Nuevo León. All her life, she has been interested and involved in mechanical issues due to her fathers job as a water driller, main reason she is studying engineering. Along with her studies, she used to be part of the representative soccer team of the university from 2017 to summer of 2021. She is currently in her last semester and for her thesis she is working on a project related to improving the lifetime of milling tool inserts with laser surface texturing. In addition, she is working as an intern at FRISA as a process engineer in the forging department.

Yadira Lissete Rangel Acosta is a mechanical engineering student at the University of Monterrey, she will graduate in December 2021, for her thesis she is working with this same team on a project that consists of laser texturing tool inserts with the aim of reducing the process energy. She was born in 1998 in Monterrey, N.L., Mexico. She graduated high school at Prepa UDEM USP, Mexico, and received honorable mention. For her university social service, she volunteered at the Centro Ocupacional Logros, an institution for autistic people in Monterrey. At the beginning of the year 2021, she participated in the online intermediate German course with the Duale Hochschule Baden-Württemberg. She currently works as the supplier quality intern and helps in the incoming inspection department at Johnson Controls, N.L., Mexico.

Jesús Ricardo Puente Martínez is currently a mechanical engineer student at University of Monterrey. Born in 1998 in Monterrey, Nuevo León, Mexico. Since the beginning of his studies, his major areas of interest have been Mechanical Design, Materials Engineering and Manufacturing Processes. Having worked in this project was a very satisfying experience for him and to have the opportunity to learn more about these areas from his professors. As a titulation project he is collaborating with the same team, and now they're working on laser surface texturing for tool inserts in milling processes. Also he is working as an intern at FRISA as a production planner engineer for the open die division.

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