DESIGN AND DEVELOPMENT OF A TRIBOMETER FOR DENTAL APPLICATIONS

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Abstract

This work deals with the design and development of an experimental apparatus that allows the tribological characterization of the dental mastication human activity, namely in what concerns the friction and wear phenomena. For this purpose, an actuation system that reproduces, in a realistic manner, the mastication movements of sliding and impact among the jawbones was designed. This paper analyses and discusses the most significant design phases, including selection and prototype implementation of the necessary sensors and actuators. The overall instrumentation and control system architecture will also be presented.

Keywords: Biomechanics; Mechanical Design; Tribology; Dental Tests.

Resumo

Neste trabalho é apresentado o projecto e desenvolvimento de um equipamento laboratorial que permita caracterizar o processo de mastigação dentária em termos tribológicos, nomeadamente no que diz respeito aos fenómenos de atrito e desgaste. Para este propósito foi concebido e projectado um sistema de actuação que reproduza, de modo fiel, os movimentos de mastigação, quer de deslizamento e de impacto entre as maxilas. Neste artigo são analisadas e discutidas as principais fases referidas do projecto, incluindo a selecção e a implementação física do protótipo, de todos os sensores e actuadores necessários. A arquitectura do sistema de instrumentação e controlo é ainda apresentada.

Palavras-chave: Biomecânica; Projecto mecânico; Tribologia; Testes dentários.

1. Introduction

It is well known that the masticatory performance is associated with the quantitative movement parameters of duration (rhythm), velocity and displacement of the mandible and the bite force, in relation to the chewing cycle [11]. During the mastication, the basic movement of the mandible is more than a rhythmic movement upward and down. The cycle includes a frontal and posterior movement, a rotation in the horizontal plan and a lateral deviation of the mandible. The standard movement of an adult's mandible during the mastication presents a descend appearance in the frontal plan, with a medium opening and a lateral closing, as shown in Figure 1a). This action is called of Bennett movement. The maximum extension of the lateral and vertical movements in the normal mastication is about of half of the maximum vertical and lateral movements. The frontal-posterior movement of the mandible is shown in the Figure 1b), while the pattern of the movement of the mandible observed in the superior view is represented in the Figure 1c) [9].

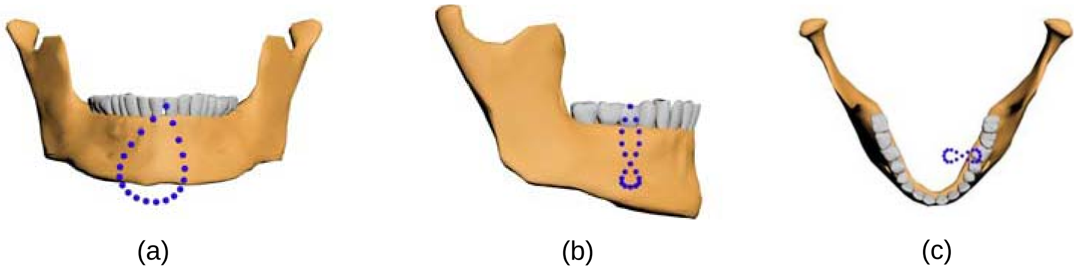


Figure 1. Standard curve of the mandible movement based on: (a) Bennet movement (1989); and (b) and (c) in the studies performed by Gibbs and Lundeen (1982) {Adapted from [6]}.

Trajectories of reference points, such as the incisor, working condyle and/or balancing condyle in the frontal, sagittal and/or horizontal planes have been used for analysis of masticatory performance [11, 10, 14]. Improvement of such performance is related to the reduced duration or an increased rhythm of the chewing cycle and, finally, an increased mandibular velocity [11].

In order to analytically characterise masticatory efficiency, it is necessary to continuously measure all the mastication of sequence phases. These measurements may include the following parameters frequency, length of chewing, tracking of jaw movement, force distribution, application of compression and shear forces.

Furthermore, the force applied to a single tooth is also different to the total force between all the contacting teeth during chewing. On foods such as biscuits, carrots and cooked meats, the applied force ranges between 70 and 150 N on a single tooth, while forces on all the contacting teeth can vary from 190 to 260 N. This value is much smaller than the maximum bite force that can be applied to the molars which measures 500-700 N [1, 3, 15].

The teeth wear can occur due to the phenomenon of abrasion caused by the mastication where contact among the dental surfaces exists. In order to find solutions, this type of wear needs several studies in the field of material testing. There are also other types of wear, such as, those caused by the use of abrasive substances for the teeth cleaning and due to the teeth tighten, that is the disturbance in that the human stays with the surface of the teeth leaned, as if it was to crunch into unceasingly some thing, nevertheless, without having any objects in the mouth, as it is illustrated in Figure 2.

Figure 2. Typical wear types in teeth {Adapted from [8]}.

Over the last few years, several chewing simulation devices have been developed for different purposes [2, 4, 5, 12, 13]. One of them was used for testing dental materials [2], in which two servo-hydraulic actuators are combined to produce the force movement cycle of human mastication. The application limitations of this device are the price of the technology involved, the purchase availability and the operation range.

The motivation for this project comes from the necessity of the tribology research group of the Department of Mechanical Engineering in doing the tribological characterization (wear and friction) of the chewing operation. For that, due to the mentioned limitations and drawbacks of the available devices, an equipment, named tribometer, has been developed for testing dental materials.

With the purpose to achieve of the project goals, in first place, it was obtained the design specifications, based on the opinion of the futures users. Then, it was carried out a detailed study of the tribometers state of the art. Afterwards, it was performed the conceptual design, being determined the operation parameters, as well as, the input and output variables of the system. In this phase of the project, a sketch of the equipment was realized with the definition of the main components and their interconnections. Finally, the design and selection of the system's components was performed accordingly.

This paper is organized as follows: Section 2 provides a brief overview of the thematic literature related to tribometers state of the art. Then, in section 3 presents the dental tribometer conceptual design. Section 4 discusses the detail design, independently for the superior and inferior actuations systems of the dental tribometer and finally, in section 5 deals with the main conclusions reached and some future work perspectives are outlined.

2. Tribometers state of the art

It is well known that the tribometers are equipments that simulate situations of contact and relative movement among pieces. In the market, there is only a very few tribometers that can used to several tests types, such as friction, resistance temperature test, pin on plate and pin on disk, as Figures 3, 4 and 5 show.

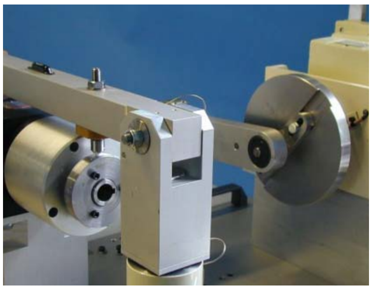


Figure 3. Tribometer "pin on ring".

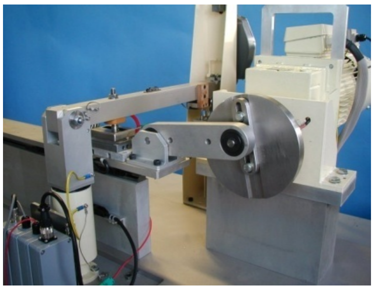


Figure 4. Tribometer "pin on disk".

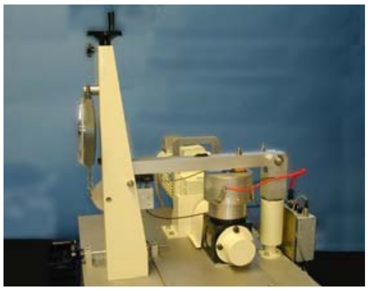


Figure 5. Tribometer "pin on plate".

To sum up, in the human mastication simulation field, the tribometers more frequently used are the "pin on plate" and "pin on disk".

3. Conceptual design

The bibliographical research allowed to conclude that the mastication movements can be decomposed in two basic phases, the impact movement (i.e., opening and closing of the mandible) and the sliding movement of the teeth. As combination of these movements, it is obtained the U cycle. Thus, it is intended in the present work that the experimental apparatus be able to execute these three movements, the impact movement, the sliding movement and the movement composed by these two, the cycle in U, and also an additional movement to adjust the sample position is demanded.

Conjugating this information with the initially defined design specifications, they are obtained the input and outputs design variables for the system developed. The input variables considered here can be listed as follows, the applied normal force in the sample, the force application law (force versus time), the linear velocity and displacement of the inferior movement. On the other hand, the tangential force, the real displacement in the inferior movement and the wear sample piece were considered as output variables. Moreover, with knowledge of the values of the normal force and the tangential force it is obtained the friction coefficient, which will be an indirect output variable, as it is schematically demonstrated in the sketch of Figure 6.

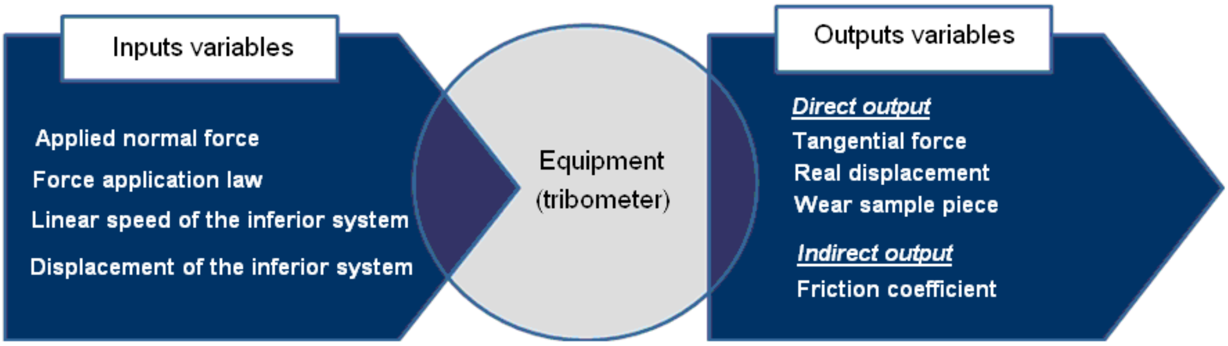


Figure 6. System input and output variables.

Subsequent to the definition of the equipment input and output variables and its movements type, it was performed an analysis of the main components to be incorporated. For the purpose of the mastication movements of simulation it is necessary to control two independent motion systems, one in the superior part of the equipment, which will be responsible for the simulation of the opening and closing of the maxillaries (that is, tribometer pin impact) and other in the inferior part of the equipment that will be responsible for the sample sliding movement.

The main objective of this equipment here presented is to test the wear among a tribological pair composed by a pin and a sample. For that it is necessary design an attachment system for the sample and pin. In addition, it is necessary to acquire data on the forces (axial and normal), temperature, displacement of the inferior movement system and position of the superior movement system, thus sensors to allow measure these parameters were incorporated. Finally, in order to be possible the treatment of the signals, corresponding to each one of the parameters, it is necessary to develop an acquisition system with data treatment. The Figure 7 presents a diagram block with the main parts of the developed equipment.

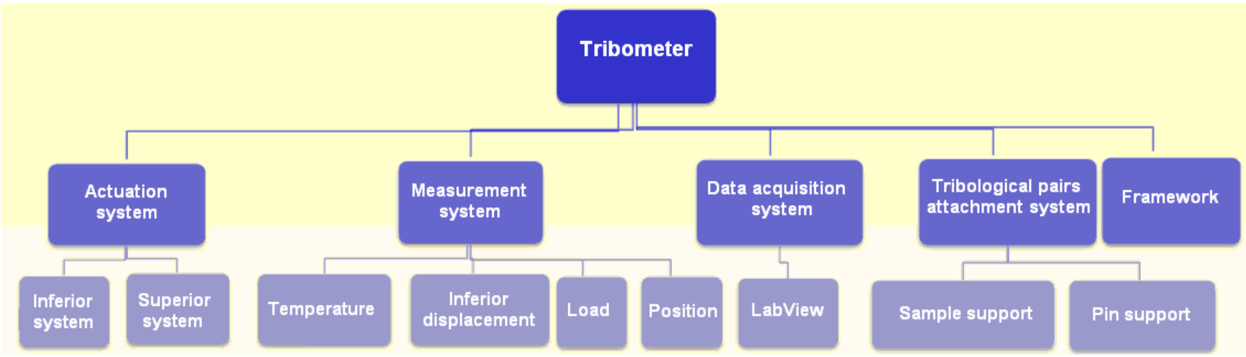


Figure 7. Main equipment parts.

4. Detail design

In first place, it was necessary to obtain a complete list of the design specifications, in order to avoid omissions that can implicate in the future major alterations. This procedure was done taken into account the main equipment specifications as follows:

- Good repeatability and precision in the forces application;

- Possibility of pin impact and sample sliding movements;

- For the sample sliding movement (horizontal), a maximum displacement of 10 mm with a measurement error of 1μm;

- Possibility of execution of electrochemical tests;

- The force magnitude in the pin impact movement between 3 N and 10 N (typical test). However, an enlarged force range it was considered (0.005 N to 200 N) in order to increase the application range of the equipment;

- Variable frequency of the movements, with the average value of 1Hz;

Based on above listed design specifications, it was selected the technology most appropriate for the actuation/movement systems. The options analyzed included electrical, hydraulic and pneumatic systems, and the choice, due to financial and technical factors (precision, force range, simplicity and maintenance) it relapsed on the electrical systems.

Then, the next step consisted of define the type technology used. Thus, several alternatives for each actuation/movement systems were analyzed and compared. The superior movement system is more complex than the inferior system, because it should be guarantee normal load application during the movement. On the other hand, the inferior movement system, which corresponds to the horizontal sliding movement, is subjected to a vertical force loaded by the superior system.

In a general way the developed equipment can be divided in four main parts (Figure 8):

- "Superior actuation system" - responsible for the pin impact movement;

- "Inferior actuation system" - responsible for the sample sliding movement;

- "Controller"- responsible for the sensors data acquisition, treatment and actuators control;

- "Machine framework" – responsible for the accommodation of all machine parts.

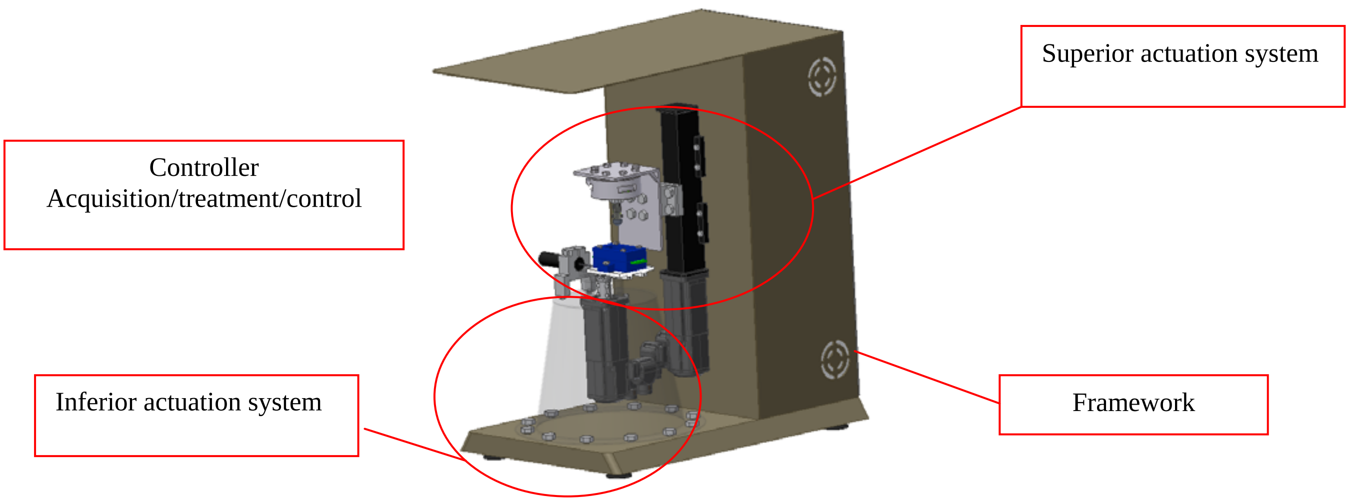


Figure 8. Main equipment parts.

4.1. Superior actuation system

According to a market systems evaluation were considered four alternatives solutions for the superior actuation system (pin impact), the separate purchase of components, the module PSK60, the servo screw CMS50S, the module Star with spindle and the module Star with belt [7]. Table 1 shows the solution selection procedure based on five main specifications.

	Precision	Force range	Reliability	Maintenance	Cost	Total
Specification weight	0,3	0,3	0,2	0,1	0,1	1
Separate purchase of components	3	3	3	3	5	3.2
Module PSK60	5	5	5	4	2	4.6
Servo screw CMS50S	4	5	5	4	3	4.4
Module Star (Spindle)	5	4	3	4	5	4.2
Module Star (Belt)	5	1	3	5	5	3.4

Table 1. Value specifications analysis for the superior actuation system.

By analysing the data reported in Table 1, it can be concluded that the module PSK60 (Figure 9) it is the best solution for the superior actuation system.

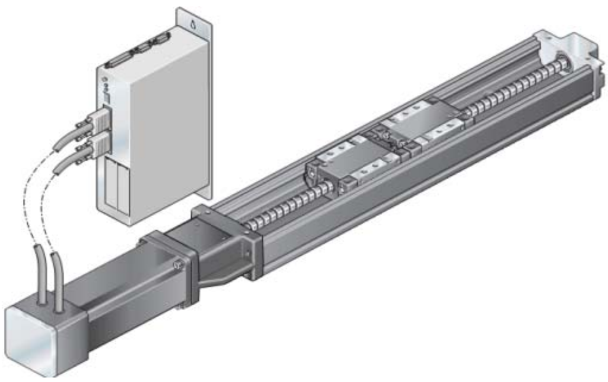


Figure 9. Precision module PSK60 (Rexroth).

Figure 10. Assembly of the wear pin sphere and load cell.

Figure 11. Wear pin sphere cylindrical support.

Figure 12. Load cell support plate.

On the other hand, the wear pin sphere surface, illustrated in Figure 10, performed by the superior actuation impact system will be in Teflon due to be an inert substance that doesn't react with other chemical substances, except in very special situations. Another good quality is its impermeability, which allows their application in humid environments.

The wear of the sphere can be fixed to a cylindrical support (shown Figure 11) through two screws, as Figure 10 shows. Thus, it was chosen this no permanent fixation type to allow changing the sphere among tests in an easy and rapid manner.

This cylindrical support (Figures 11) has a hole that allows the attachment of the wear tip (wear sphere) and a screw part in the back to link to the load cell through a support plate (Figure 12). This would be the easiest and reliable form of doing the connection, once time some systems of fixing type "clik" acquire gaps along the service life.

Figure 13 shows the assembly of the whole of the superior actuation system, which includes: module PSK60, pin support, pin, L support and load cell.

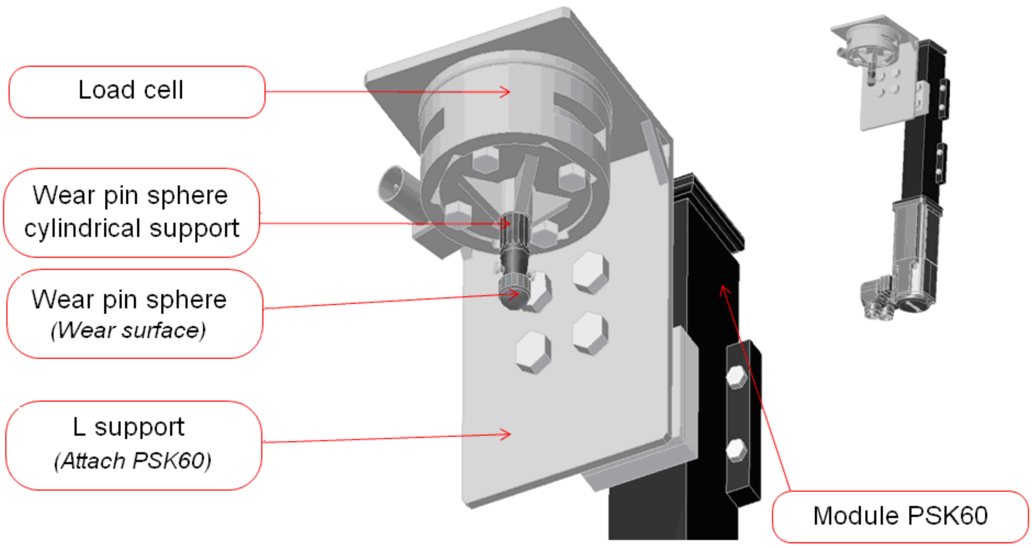


Figure 13. Overall view of the tribometer superior actuation system.

4.2. Inferior actuation system

In order to ensure the sample sliding movement, performed by the inferior actuation system, two alternative solutions were considered, the rod-crank and spindle mechanisms. Table 2 shows the solution selection procedure based on five main specifications.

	Course regulation	Velocity range	Reliability	Execution easiness of sliding tests	Execution easiness of the cycle in U	Total
Specification weight	0.15	0.15	0.25	0.25	0.20	1
Rod-crank	4	5	5	5	2	4.25
Spindle	5	3	3	3	5	3.7

Table 2. Value specifications analysis for the inferior actuation system.

In agreement with the specifications optimization process, the rod-crank mechanism was selected for the inferior actuation system. In fact, this mechanism is the most appropriate for the execution of reciprocates sliding tests, due to its easiness to undertake the motion direction inversion. Figures 14 and 15 show, in detail, the rod-crank mechanism developed.

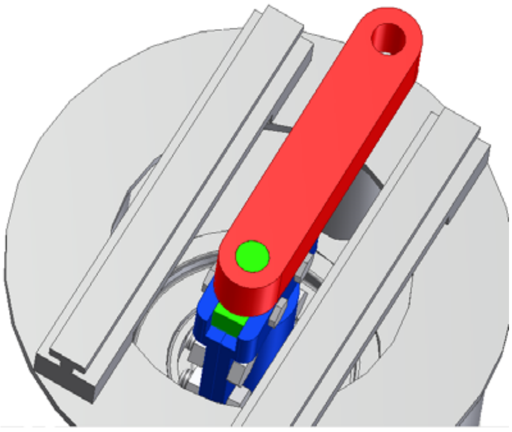


Figure 14. Top view of rod-crank mechanism.

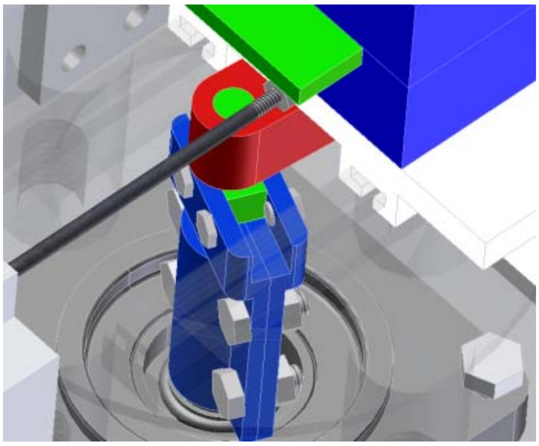


Figure 15. Lateral view of the rod-crank mechanism.

To perform impact and sliding cycles (that is, the cycle in U) it is necessary stop, with precision, the inferior actuation system, what cannot be guaranteed by the rod-crank mechanism actuated by a servomotor. The study of this situation is quite complex and it is not possible to simulate accurately with the available software's. Thus, it is mandatory to execute experimental tests later. The rod-crank mechanism was selected, given the described advantages and due to the reason of not increasing the equipment cost significantly.

Figure 16 shows the assembly of the whole inferior actuation system, which includes: rod-crank mechanism, wear sample fixation support, linear guides, LVDT displacement sensor and corresponding LVDT support.

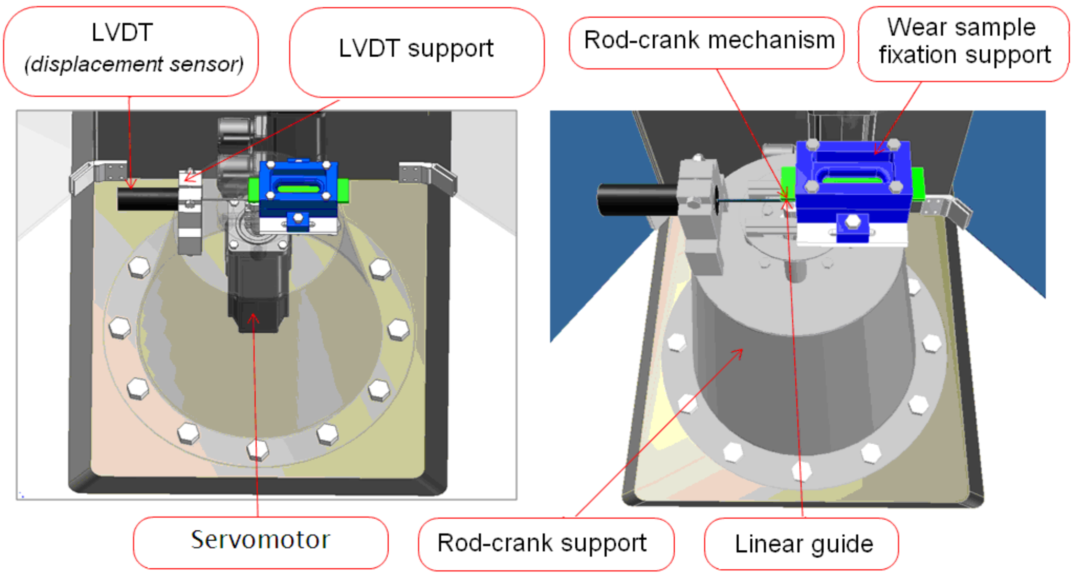
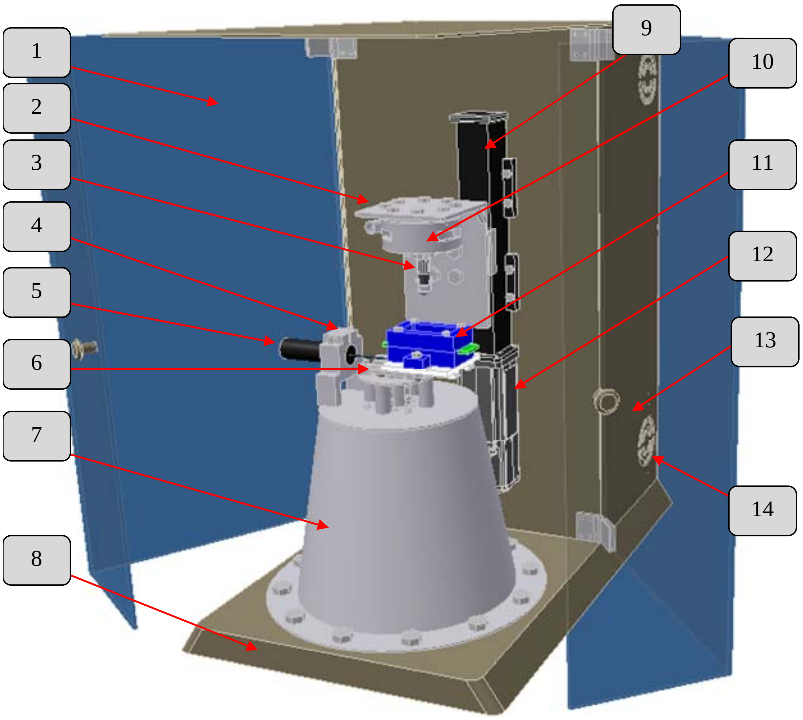


Figure 16. Overall view of the tribometer inferior actuation system.

4.3. Developed dental tribometer

In this section, a general view of the dental tribometer that was developed in this study is illustrated, in which its main components are illustrated, as it can be observed in Figure 17.



1 – Security doors
2 – Support in L
3 – Wear pin support
4 – LVDT support
5 – LVDT
6 – Inferior actuation system - rod-crank
7 – Rod-crank system support
8 – Base
9 – Module PSK60
10 – Load cell
11 – Wear sample support
12 – Servomotor of the inferior actuation system
13 – Rear box – controller installation
14 – Ventilation

Figure 17. Assembly of the dental tribometer.

5. Conclusions

An actuation system that reproduces in a realistic manner the mastication movements of sliding and impact among the jawbones has been presented and discussed throughout this work.

The development of this device intends to uniform the test method of dental materials, in order to obtain the more quantitative output results with larger reliability, independent of operator/personal interpretations, controlling in an automatic way the parameters involved in the mastication operation, namely in what refers to the displacement, velocity, acceleration and forces.

The main merit of this project is its innovative equipment concept, when compared to those available in the market with special interest for the dental prostheses industry, and constitute a fundamental and important contribution for the research and development of this type of medical devices.

The future work, some talks can be identifies, namely in what concerns the kinematics study of the cycle in U and to the controller's programming. On the other hand, the development of new modules can be done, such as the one that allows to perform fretting fatigue tests.

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