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SIMULATOR FOR TESTING THE FRICTION TORQUE OF THE FEMORAL HEAD OF A HIP PROSTHESIS

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Abstract: *A hip joint simulator has an important role in the preclinical validation of implants, in improving their quality and acquiring additional knowledge on tribological processes involving joint prostheses. Hip simulators should be able to provide testing conditions very close to the physiological, kinematics and anatomical conditions of human joints. In actual fact, no simulator meets exactly such quality conditions. In order to perform hip implant tests recreating as closely as possible the actual conditions of joints, we have designed a laboratory simulator for testing the friction coupling of the femoral head of a hip prosthesis.*

Key words: *simulator, implants, wear.*

1. Introduction

A wear testing machine, which is able to test actual prostheses, is called a hip simulator. Over the years various researches on various types of simulators and implants have been performed.

In terms of kinematics, there are three different categories of hip simulators: with independent movements on each of the three axes, with biaxial oscillating motion, and with oscillating motion on one axis.

The purpose of this paper is to design a simulator of the type mentioned in the first category, therefore a simulator which performs three movements: flexion-extension, internal rotation - external rotation and micro separation movements.

The flexion-extension movement. Flexion is the motion consisting in the anterior part of the thigh's moving towards the anterior part of the abdomen, while extension is the opposite of flexion, i.e. consists in the posterior part of the thigh's moving towards the buttock.

The internal rotation - external rotation movement. Rotational movements take place around a vertical axis, passing through the center of the femoral head [2].

The micro separation (pushing) movement occurs during the swinging phase of the walking cycle (flexion-extension) and has an allowance under 500 μm [3]. During walking there occurs a displacement of the femoral head (called lateralization), since the femoral head cannot remain centered in the acetabular cup.

The word "micro separation" is not technically correct, as the head remains in contact with the cup edge. A more appropriate term would be "head micro lateralization" [1], [4]. Since the literature uses the term of "micro separation", we chose to use the same term.

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2. The Components of the Designed Simulator for Testing the Friction Torque of the Femoral Head of a Hip Prosthesis

The simulator we have designed for testing the friction torque occurring in the femoral head of a hip prosthesis is shown in Figure 1.

The overall dimensions of the experimental stand are: 1498 mm x 981 mm x 652 mm.

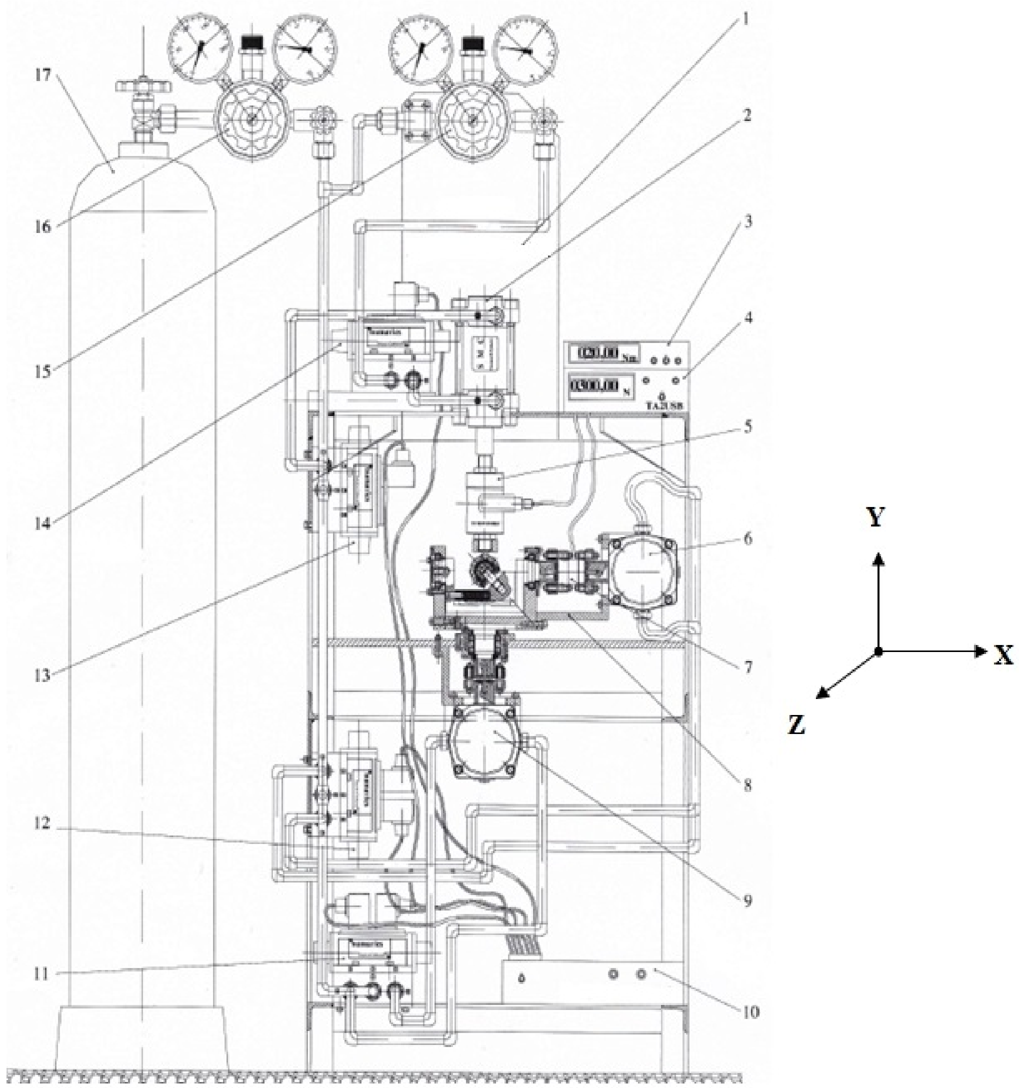

Fig. 1. *Simulator for testing the friction torque occurring in the femoral head of a hip prosthesis:*
1 - *Bed;* 2 - *Linear pneumatic motor;* 3 - *Momentum display;* 4 - *Force display;* 5 - *Force sensor;* 6 - *Rotary pneumatic motor 1;* 7 - *Momentum sensor;* 8 - *Oscillating plate;* 9 - *Rotary pneumatic motor 2;* 10 - *Command module;* 11 - *Distributor 1;* 12 - *Distributor 2;* 13 - *Distributor 3;* 14 - *Distributor 4;* 15 - *Regulator class II;* 16 - *Regulator class V;* 17 - *Nitrogen container*

2.1. Stains

During the flexion-extension, internal rotation - external rotation and micro separation movements, the joint is subjected to the action of certain forces that will be reproduced using a SMC-type linear pneumatic motor, actuated by two pneumatic distributors supplied by two after-valve pressure regulators fitted on a nitrogen container under a pressure of 200 atmosphere.

Thus, for the flexion - extension movement, the distributor (Figure 1, item 13) supplies the pneumatic motor with the pressure needed to exert a force of 300 daN on the joint, in the direction of the negative Y-axis. The value of this force can be changed by varying the amount of pressure provided by the pressure regulator.

For the internal rotation - external rotation movement, the distributor shown in Figure 1, item 14, supplied by the pressure reducing valve shown in Figure 1, item 15, provides under-pressure fluid to the linear pneumatic motor shown in Figure 1, item 2, which will act on the implant with a force of 50 daN in the positive direction of the Y-axis. At the same time, the distributor shown in Figure 1, item 11 will actuate the pneumatic rotary engine shown in Figure 1, item 9, which will simulate the internal rotation - external rotation movement.

3. The Oscillating Plate Component

The oscillating plate (Figure 2) is designed to simulate real flexion-extension, internal rotation - external rotation, and micro separation movements.

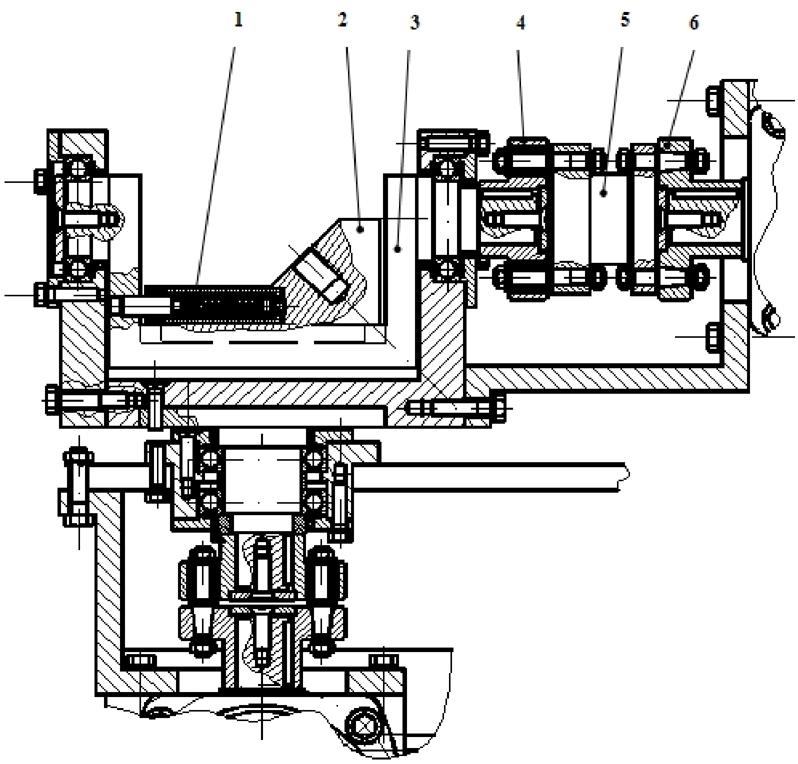

Fig. 2. *Oscillating plate:*
1 - *Micro separation device;* 2 - *Holder 1;* 3 - *Rocking holder 1;*
4 - *Semi coupling 1;* 5 - *Momentum transducer;* 6 - *Semi coupling*

In addition to simulating the above-mentioned movements, due to the momentum transducer shown in Figure 2, item 5, the oscillating plate allows determining the values of the frictional moments and therefore the values of the frictional forces that occur during the flexion-extension movement, which is the basic movement involved in walking.

As can be seen in Figure 2, the oscillating plate assembly can rotate the rocking holder 1 shown in Figure 2, item 3, around a horizontal axis, in order to simulate the flexion-extension movement.

At the same time with the mounted parts' rotation around the horizontal axis, automatically there occurs the micro separation movement by sliding the holder 1 shown in Figure 2, item 2, on the rocking holder 1 shown in Figure 2, item 3; this movement is enabled by guides 1 and 2.

The microseparation movement occurs when the force acting on the Y-axis of the implant changes its direction and amplitude.

The microseparation movement is driven by a well-defined force whose value must remain absolutely constant during the movement of the holder 1 shown in Figure 2, item 2, on the X-axis.

To achieve this movement, a special device (presented in detail in Figure 3), called ”micro separation movement device”, as shown in Figure 2, item 1, is mounted between the holder 1, shown in Figure 2, item 2, and the rocking holder 1 shown in Figure 2, item 3.

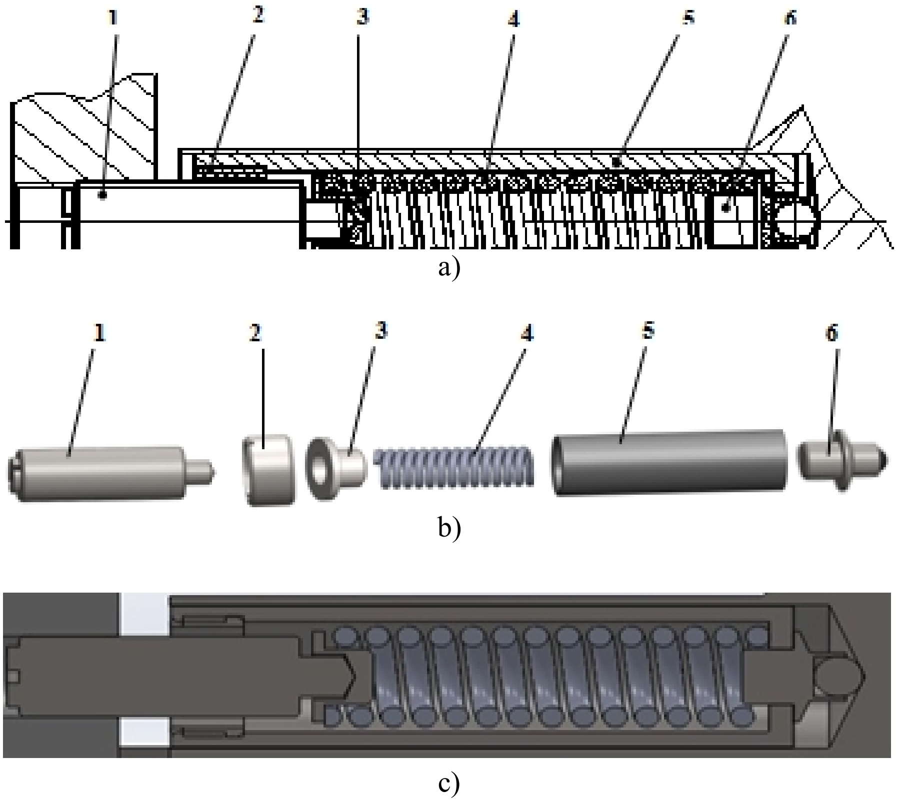

Fig. 3. *Micro separation movement device:*
a) *2D design of the assembly; b*) *3D model of the parts; c*) *3D model of the assembly;*
1 - *Push screw;* 2 - *M12 Nut;* 3 - *Spring holder 1;* 4 - *Spring;*
5 - *Spring guide;* 6 - *Spring holder2*

This is possible by compressing springs much longer than necessary but with low rigidity and fitting them inside finite length tubes. This system allows adjusting the amount of force required by micro separation and prevents its variation during the micro separation movement. The device performs a controlled medial-lateral movement representing the allowance of 500 μm. During the two movements there can be extracted the data regarding the value of the friction torque occurring in the implant; these values are shown on the display connected to the torque transducer. The second movement mentioned above, namely the internal rotation - external rotation movement, is simulated using the second rotary pneumatic motor which, by means of a coupling identical to the one used for the flexion-extension movement, transmits the movement on the Y-axis.

During this movement's transmission, the implant is in the micro separation position since the force applied on the Y-axis is exerted from the bottom to the top. The friction torque affecting the implant can be measured for this movement as well, provided that a momentum transducer is inserted between the two semi couplings.

4. Modeling the Oscillating Plate's Components with SolidWorks

In order to simulate the movement of the oscillating plate, we performed the three-dimensional modeling of its components, presented in Figure 4.

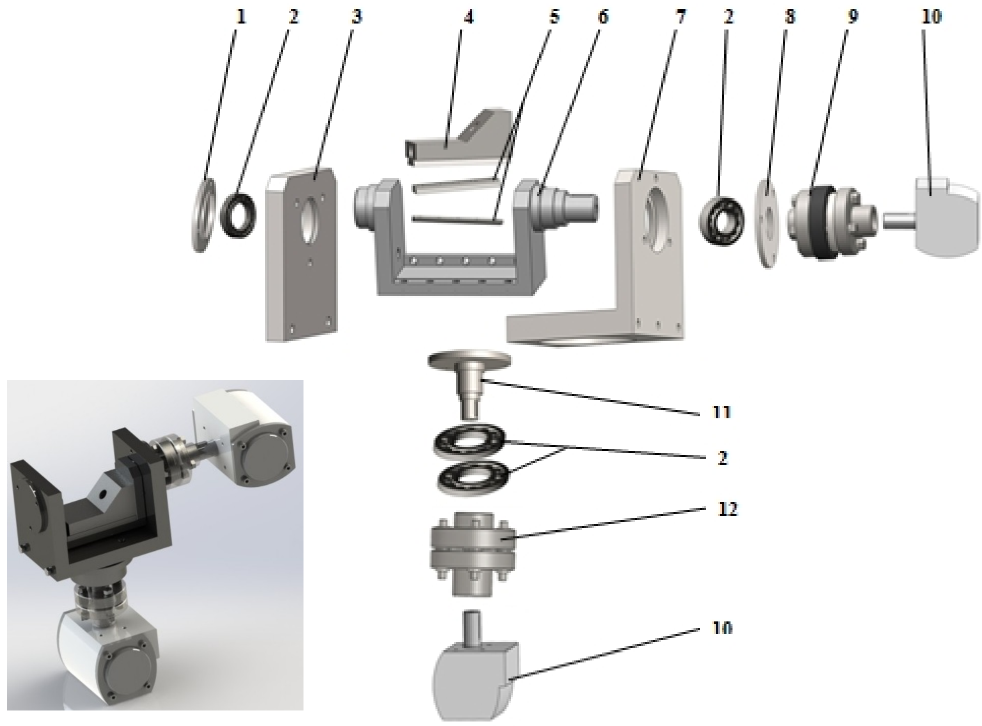

Fig. 4. *Micro main components of the oscillating plate, designed in SolidWorks:*
1 - *Flange 1;* 2 – *Bearings;* 3 - *Rocking holder 2 (left bearing plate);* 4 - *Holder 1;*
5 – *Guides;* 6 - *Rocking holder 1;* 7 - *Rocking holder 2 (right bearing plate);*
8 - *Flange 2;* 9 - *Semi coupling 1 (with momentum transducer);*
10 - *Rotary motors;* 11 - *Holder 2;* 12 - *Semi coupling 2*

5. Conclusion

In the case of the flexion-extension movement, the force applied on the implant has two different values and acts on different directions on the Y-axis; simultaneously, the micro separation process takes place on the positive and implicitly the negative X-axis direction, due to the action of the force created by the spring-based system.

For the second type of movement (internal rotation - external rotation movement), which takes place completely separately (due to manner of actuation designed for the simulator's execution components), the F force exerted on the Y-axis acts only on the negative direction, at its lowest value, while the implant is situated in the micro separation position.

The two movements (both on the X-axis and the Y-axis) are enabled by the two roller bearing assemblies that eliminate the possibility of confronting high friction forces during the rotation movements, which does not affect the values of the frictional moments occurring in the implant's coupling.

During the first type of movement (the flexion-extension movement), friction will occur vertically, both on the lower and the upper part of the implant (depending on how the force acts). In the second movement's case, friction will occur on the same vertical direction, but will affect only the lower part of the implant.

The simulator for testing the friction torque occurring in the femoral head of a hip prosthesis was devised to enable obtaining the two movements through a rigorous design which allows both observing the limits of the movements on the two directions and, most of all, eliminating the friction between the two pairs of bearings.

Consequently, we opted for a bearing assembly that eliminates completely the possibility of blocking by tightening the parts used to obtain the oscillating plate assembly.

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