Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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DAAAM Symposium

AN IMPROVEMENT OF DESIGN OF THE HIP JOINT WEAR SIMULATOR

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Abstract: *Researches on development of an advanced design of the hip joint wear simulator, which meets demands of standard ISO/DIS 14242 on angular movement waveforms and waveform of the loading cycle possessing the minimum complexity, sufficient reliability, "cleanliness" of test environment and flexibility in readjustment depending on requirements on trials has been executed.*
Key words: *hip prosthesis, wear, simulator testing*

1. INTRODUCTION

The simulator design is developed for the interdepartmental laboratory of biomechanics created at the Sevastopol National Technical University in Sevastopol (Ukraine) and now the manufacture of the simulator for trial of hip joint prostheses on wear is begun.

At designing of a simulator were guided *by the following purpose*. The hip joint wear simulator would meet requirements ISO 14242 on angular movement profiles and loading cycle waveform, would possess minimum complexity, sufficient reliability, the "clean" testing environment and could be flexible in readjustment depending on test requirements. Also units of the developed simulator should satisfy to necessary performances of their durability and rigidity for maintenance of requirements of the specified standard at realization of constructive decisions with minimum expenses at cost.

2. RELATED WORK

The given study is continuation of the researches executed in a work (Pakhaliuk et al., 2009) where hip simulators' mechanical structures of all previous known simulators have been analyzed; ten contemporary hip simulator designs on motion profiles (Saikko & Calonius, 2002) have been studied and compared; the base design-prototype (HUT-4) (Saikko, 2005) is determined, wherein the kinematics configuration and mechanical units are applied in simulators of some corporations (EndoLab), developed to meet the requirements of standard ISO 14242 according to which the angular motion profiles differs from the sine wave form, phases of angular displacements FE and IOR differ on π, but FE and AA – about on $\pi/2$. Frequency of a cycle makes 1Hz± 0.1Hz.

Shortcomings of the existing simulators consist in the following. The anatomic Euler sequence set of rotations FE→AA→IOR for simplification of a design of devices where rotation IOR is carried out due to rotation of a cup, instead of a femoral head (***, 2009) is not provided. The existing pneumatic drives technically not able to reproduce the loading cycle waveform presented in ISO 14242 (very sharp peaks), at necessary frequency 1Hz as the proportional valve of pressure at the specified frequency can iterate only seven points, and presence not less than twenty ones is necessary.

Hydraulic drives can lead to "pollution" of the environment of test that is inadmissible at holding trials such objects of biomedicine as implants. In the further for meeting to requirements of standard the base design-prototype has been in appropriate way advanced to the base advanced simulator and then to its more universal modifications with application of pneumatic or electromechanical axes (Pakhaliuk et al., 2009).

3. RESEACH WORK

Given the specified shortcomings of pneumatic and hydraulic drives, the design of the advanced base simulator can be modified to a construction using operated electromechanical axes (by FESTO corporation), both for creation of loading, and for providing of angular movements with the purpose of unification of type of a drive and increase of its durability.

Modification consists that for providing of angular displacements FE, AA and IOR, three independent electromechanical axes 1 consisting of the step-by-step motor with a reducer and a drive with a toothed belt are used. The simulator contains two blocks including four test stations everyone, wherein three stations 2 are moving, and other one is stationary for trial on soak 3 (Fig.1). All moving stations of the device are rigidly linked among themselves and realize identical oscillations from the specified drives which are easily installed and removed, doing a construction flexible in readjustment. For depreciation of the device (up to 25 % on each block) its modification when IOR-movement is applied due to rotation of a spherical femoral head 1 around of a moving vertical axis by means of the rotary lever 3 can be used. It is placed parallel to the longitudinal FE-axis and has a sliding contact throughout the test with motionless guide 2, put on the simulator frame foundation (Fig.2).

Having executed evaluations of kinematics of the device in Mathlab (The MathWorks, Inc) at linear interpolation of profiles FE and AA or cubic splines, it has appeared, that its modification gives very high accuracy of duplicating of the mentioned IOR-movement profile both according to standard ISO 14242, and for walking gait of the person (Johnston & Smidt, 1969). It, thereby, ensures an opportunity of lowering of amount of drives at set where are operated two other movements FE and AA, what displays the analysis of IOR movement profile in fig. 3 and even such rather complex one as in fig. 4.

This fact specifies that in hip joint there is an obvious coordination and correlation between angular movements concerning axes of rotation FE, AA and IOR and the certain constructive regularity on exact reproduction of one of angular movement (IOR) by means of a rotary lever at the condition that two other movements (FE and AA) is determined.

Exactitude of reproduction of angular movement waveforms is influenced a ratio of sizes of the lever R/L and the location of motionless guide 2 in a cross-section direction concerning the vertical plane which is passing through longitudinal FE-axis.

In case of need, the operated electromechanical axis instead of a rotary lever can be easily installed. Vertical loading on an acetabula component (cup) with the maximal value of 3kN on each test station is created on all stations of each block through two-arm lever mechanism with the certain reduction ratio by the electromechanical axis including a servomotor with a reducer and a drive with a toothed belt.

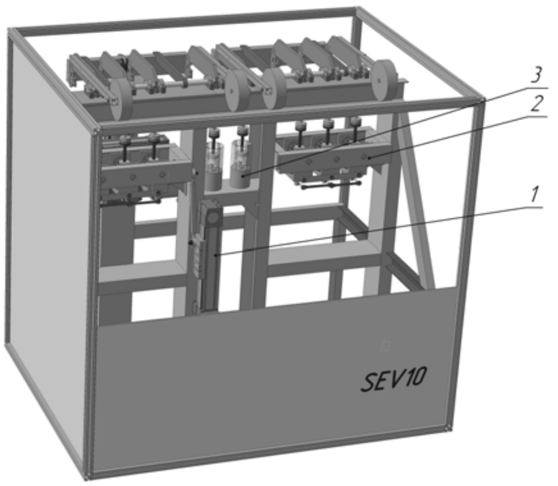

Fig. 1.General view of the simulator advanced

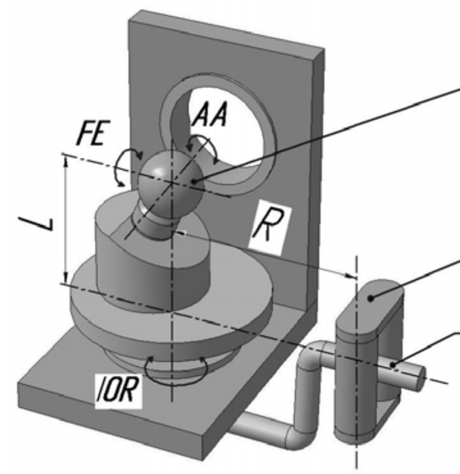

Fig. 2. Design scheme of the rotary lever with guide

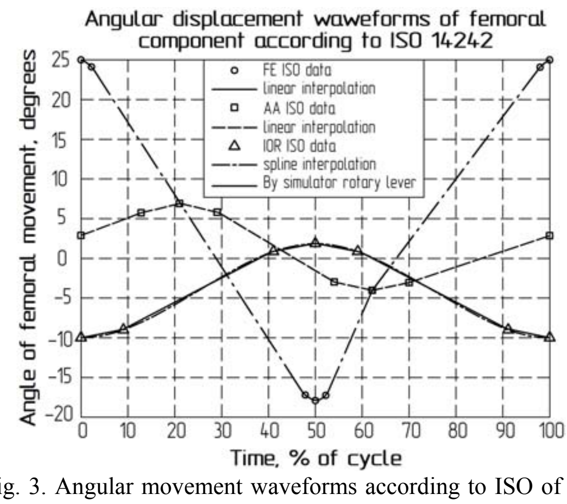

Fig. 3. Angular movement waveforms according to ISO of the simulator advanced (dotted and dash-dotted lines) and with rotary lever (continuous line)

Given the admissible errors of realization of magnitude of loading and angular movements specified in standard ISO 14242 (±90N), 3D models of various modifications of the common design of a frame of the device, a moving frame, a unit of a U-shaped bow, and the lever loading mechanism are developed. And then numerical calculations on durability and rigidity for defined allowable magnitude of a total deformation of mentioned units in ANSYS Workbench (ANSYS, Inc.) are executed.

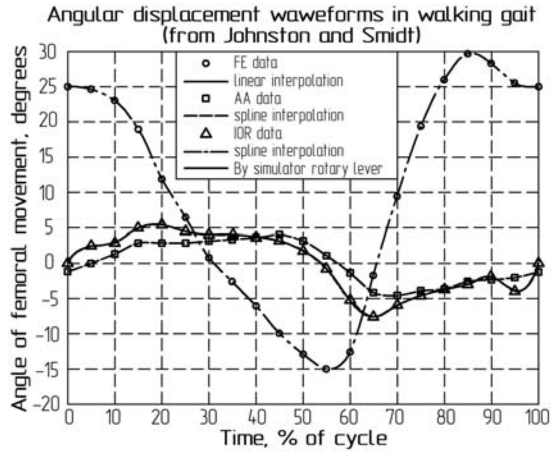

Fig. 4. Angular movement waveforms in walking gait of the simulator advanced (dotted and dash-dotted lines) and with rotary lever (continuous line)

The analysis of results has allowed selecting the most rational designs of examined units, taking into consideration as well the factor of cost. In view of complexity of a simulator design, implementation of any analytical evaluations would create serious mathematical difficulties, significant time expenses, and thus would not guarantee reliability of results and would be all the same approximate.

4. CONCLUSION

Modification of the advanced base simulator is executed. For the first time electromechanical axes which can reliably provide recurrence of the loading cycle profile, presented in ISO 14242, at frequency 1Hz are applied to creation of loading in a simulator, that technically not able to execute the existing pneumatic drives. The developed design of a simulator allows: to test friction pairs according to the requirement of the Customer under any test protocol; to execute perfection and development of new methods of processing of perspective materials of hip prosthesis friction pairs; to pass further to prediction of a resource of hip prosthesis friction pair on the basis of perfection of mathematical simulation methods of wear process. *In future* the experience of designing and manufacturing of the specified simulator will allow developing novel designs of simulators needed for trial of spine, artificial limbs of various extremities, artificial joints and implants.

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