Application of CAD Software for Developing new Radiography Positioner System

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Abstract — **In this paper the application of SolidWorks as a Computer Aided Design (CAD) software for developing modern mechatronical medical devices and robots, on an example of a new Radiography Positioner System is presented. SolidWorks can be used for virtual designing and modelling three-dimensional models, while the SolidWorks Motion Simulation module, as an integral part of the SolidWorks software, is very useful for analysis of kinematics and dynamics of moving assemblies and parts. The application of a CAD software is very important for sizing actuators, determining boundary conditions for stress analyses, analyzing the impact of dynamic imbalance, defining the path of individual points and parts in the developing process of the new Radiography Positioner System, because CAD has become nowadays an especially important technology within the scope of computer-aided technologies, with benefits such as lower product development costs and a greatly shortened design cycle.**

Key words - CAD; Mechatronical medical devices; Robotics; Radiography positioner system; Virtual modeling

I. INTRODUCTION

Nowadays, modern mechatronical devices in medicine occupy an important place because the concept of mechatronics, especially robotics is extensively applied to medical devices for surgery, diagnostics and rehabilitation. It is therefore necessary to involve a contemporary approach of computer aided design of modern mechatronical medical devices and medical robots [1-10]. It is based on developing virtual prototypes and using simulation at different levels of the design process in order to test the functioning of developing devices in real conditions, components stressing and the ability of carrying loads, collision of parts during the movement, sizing of actuators and the final optimization of component parts. This approach affects the acceleration of the design process, timely problem solving, developing of more creative and reliable products, reducing of the cost of the real prototype, potential subsequent prototype modifications, the production process and overall costs and time required to create a new product and to place it on the market. For that purpose, a variety of software packages that integrate in the latest versions functionalities from different designing areas have been used.

The application of CAD technologies in developing medical robots, design of the mechanical structure of a medical robot an integrated approach to modelling of structural, kinematic and dynamic aspects simultaneously is very rare. At the same time, it lacks a generalized approach for the conceptual solving and for the structural synthesis of mechanisms of medical robots. This has highlighted the need to present a unified approach for modelling moving mechanical assemblies based on the theory of Multi Body Systems – MBS [11-15]. For the structural synthesis based on the theory of systems with more bodies, the mechanical part of a system is defined as a set of bodies joined by joints that allow them to move rectilinear or rotary, depending on degrees of freedom that are limited or remained free. One of the main advantages of this type of designing is the ability to perform virtual measurements at any point or field for any parameter (position, velocity, acceleration, force, torque, and so on). These are not always possible in real, physical models due to lack of sufficient space for transducers mounting, or the lack of appropriate measuring equipment. Also, this approach helps to make quick decisions regarding any changes in the structure of the system without any additional costs or subsequent tests. During simulations of virtual prototypes the final prediction of the dynamic behaviour of the final product can be achieved much earlier than with traditional design approaches, which can result in more efficient and economical design solutions. This contemporary approach to the analysis of virtual prototypes of mechanical assemblies with moving brings several significant advantages: reducing development time and costs of a new product by reducing the number of developing steps during the design process, reducing the number of expensive physical prototypes and tests on them, as well as improving quality and efficiency of fully improved products. Significant experiences related to the importance of using virtual prototypes in the design phase of products, as well as increasing usage of methods related to the analysis of MBS were subjects of many published papers [16-18].

Modern medicine requires robots that can achieve high precision positioning of instruments that perform interventions. For this purpose it is necessary to ensure accurate placement of the systems that are used to determine the spatial relationship of instruments and patients. Radiography Positioner System as a part of the advanced mechatronical medical device, serve as a positioner of the unit for getting 3D images of the patient's spinal vertebrae during surgery without the knife – percutaneous vertebroplasty. System was developed using the software SolidWorks and its functional units, the basic CAD module for virtual design and modelling of three-dimensional models, as well as the module SolidWorks Motion Simulation for solving the most important engineering problems in the analysis of kinematics and dynamics of moving assemblies, i.e. mechanisms, sizing actuators, determining boundary conditions for stress analysis, determination of the dynamic imbalance impact, analyzing of load transfers in bearings and defining the path of individual points [19].

II. Computer Aided Design Process of a New Radiography Positioner System

In order to perform analysis and simulation of mechanical operations of motorized assemblies, as well as determining factors such as power consumption and collisions between moving parts, the modern software packages are used to help in determining whether an assembly is suitable to withstand the design loads, some parts will be broken under certain circumstances, and what will be in the case of the failure with the final safety of the device. For these types of simulations and analyses the SolidWorks Motion Simulation module is used, which is, as a functional unit, located within the SolidWorks software platform. Within this module the motion can be analyzed as a motion with constant moving, constant speed or constant acceleration. In such way, moving, speed or acceleration of the individual members of the model are developed as a simultaneous function of time. Furthermore, reaction forces/torques can be defined by this module in each joint, and also it can help in dimensioning of springs and shock absorbers that are necessary for the proper mechanisms functioning. In order to determine the necessary forces which are able to overcome the movement resistance the real parameters of the geometry and masses of parts, as well as the friction in the contacts are taken into account. Finally, the SolidWorks Motion Simulation is used for actuators dimensioning that are needed to drive moving parts of mechanisms of complex moving assemblies.

The mechanical part of the developed new Radiography Positioner System (Fig. 1) consists of two parts, an immobile part - the frame (1) and a moving part - the C-arm assembly composed of several sub-assemblies (2), (3) and (4). The C-arm assembly has 3 degrees of freedom: z translation, φ_1 and φ_2 rotations. The sub-assembly (2) can move linear up and down (the stroke ±150 mm). The rotation φ_2 of ±30° is realized by the sub-assembly (3). The sub-assembly (4), C-arc, with the radiation source (5) and the x-ray receiver (6) can rotate by angle φ_1 for ±15° around vertical plane, and ±15° around horizontal plane. The linear motion of the sub-assembly (2) is realized by one linear actuator (7). As a driving element for the rotation φ_2 of the C-arm sub-assembly (3) an AC servo motor was used (8).

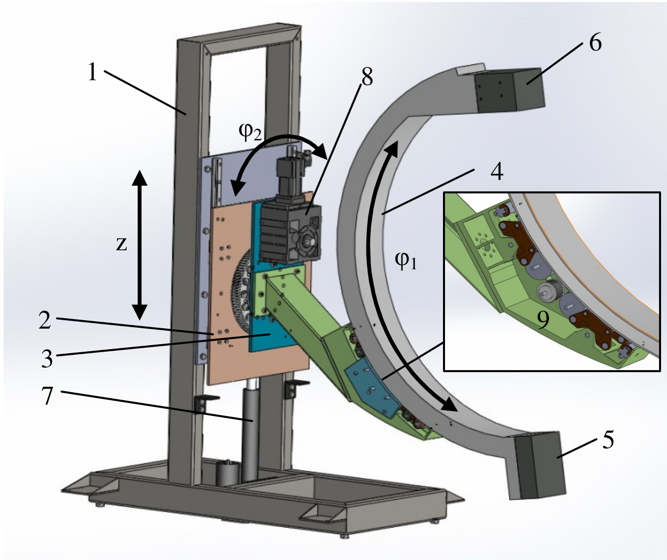
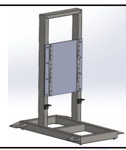
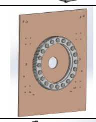
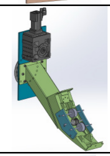


Figure 1. The new Radiography Positioner System

The rotation φ_1 of the sub-assembly (4) is realized by a timing belt pulley (9) which should be driven by a motor. Masses of the sub-assemblies used for the virtual prototype are given in Table 1.

Table 1. Masses of the sub-assemblies

Sub-assembly number	**Sub-assembly**	**Mass [kg]**
(1)		73.44
(2)		26
(3)		56.1
(4)		69.3

First, the linear up and down motion of the C-arm assembly (Fig. 2) along the guides was done in order to determine the force required to overcome movement resistance forces. The construction of the C-arm assembly is attached to a support plate to which one pair of linear guides is attached and fixed to a frame.

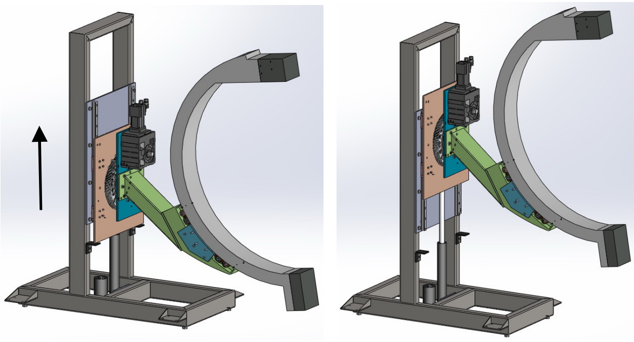


Figure 2. The analysis of the C-arm assembly linear motion

This allow linear up and down motion of the C-arm assembly. The force of the linear drive directed in the direction of the linear guide, for the diagram of velocity shown in Fig. 3, obtained by analyzing the movement of the C-arm assembly is shown by the diagram in Fig. 4. The movement of the C-arm assembly structure is limited by the length of the linear guide to 300 mm.

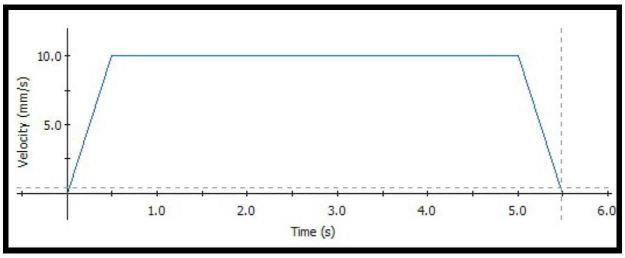


Figure 3. The velocity diagram of the linear actuator for the C-arm assembly linear motion

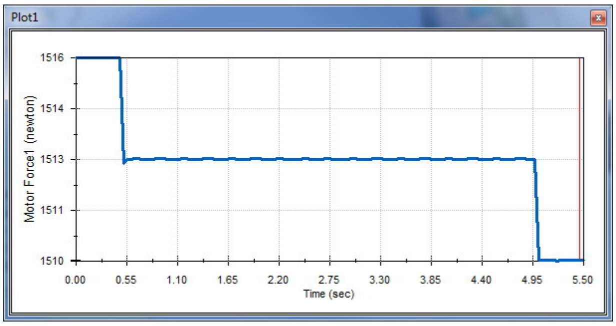


Figure 4. The force diagram of the linear actutor for the C-arm assembly linear motion

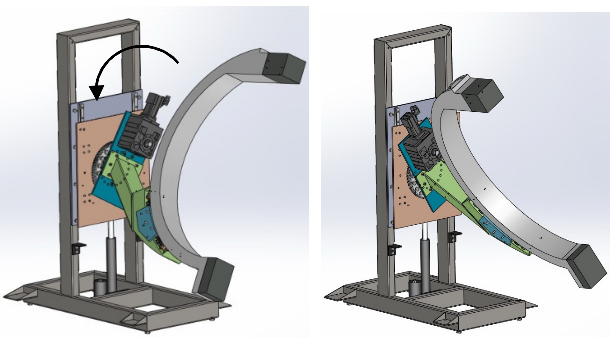


Figure 5. The analysis of the C-arm assembly rotation around the support plate

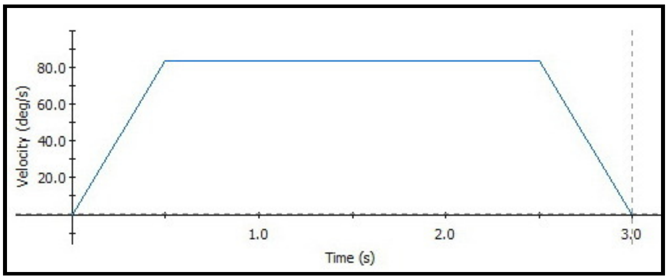


Figure 6. The velocity diagram of the AC servo motor for the C-arm rotation around the support plate

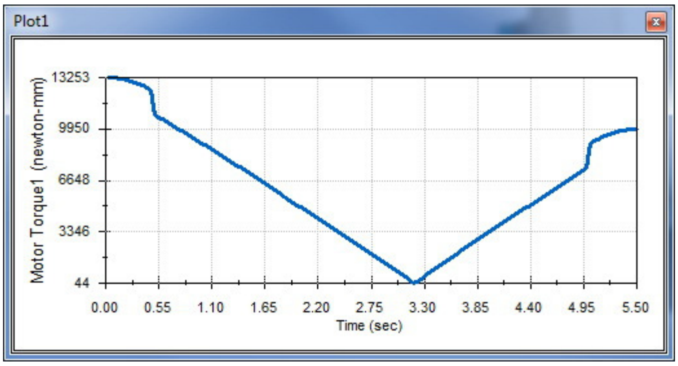


Figure 7. The torque diagram of the AC servo motor for the C-arm rotation around the support plate

During the analysis of the C-arm assembly rotation around the support plate (Fig. 5) the torque needed to rotate the C-arm from one (-30°) to the other end position (+30°) was determined. For the analyze the C-arm assembly was rotated for 60° in the positive mathematical direction with the angular velocity of the AC servo motor according to the diagram shown in Fig. 6. The measured torque of the AC servo motor is shown by the diagram in Fig. 7.

The analysis of the torque required to rotate the C-arc with the radiation source and the x-ray receiver, was done for the following three cases: the rotation around the vertical plane for 30° (from -15° to +15°), as shown on Fig. 8; the rotation around the horizontal plane for 30° (from -15° to +15°), as shown on Fig. 11; and for the rotation from the vertical to the horizontal position (the total angle of 120°), as shown on Fig. 13.

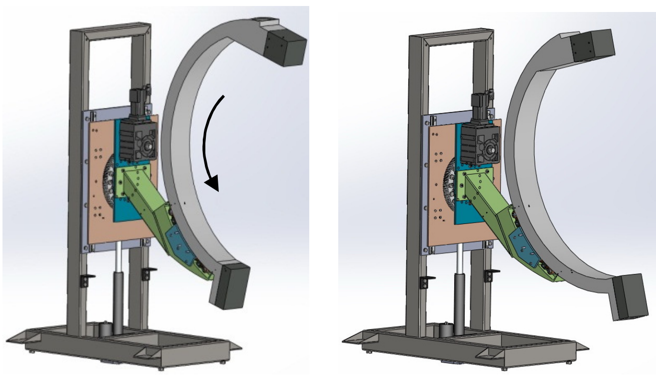


Figure 8. The analysis of the C-arc rotation around the vertical plane for 30°

The measured torque of the drive for the first case, the rotation around the vertical plane for 30°, for the required angular velocity according to the diagram on Fig. 9, is shown on Fig. 10.

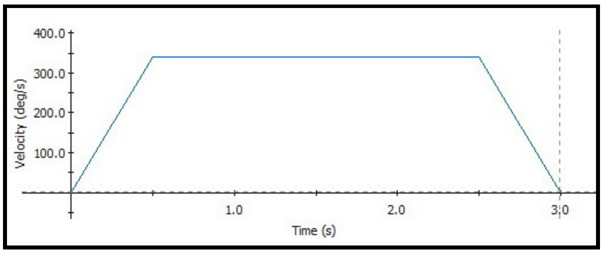


Figure 9. The velocity diagram of the drive for the C-arc rotation around the vertical plane for 30°

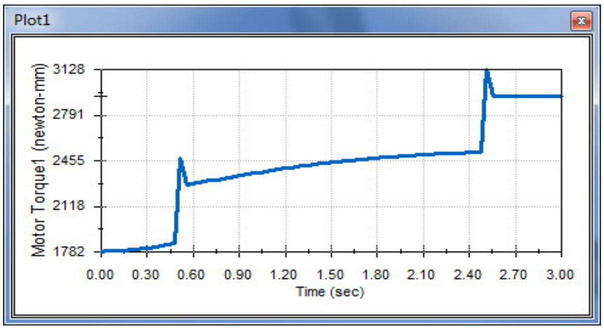


Figure 10. The torque diagram of the drive for the C-arc rotation around the vertical plane for 30°

For the second case, the measured torque of the drive for the C-arc rotation around the horizontal plane for 30°, for the same required angular velocity as in the first case, is shown on Fig. 12.

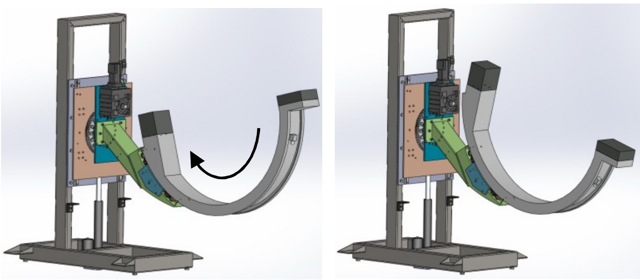


Figure 11. The analysis of the C-arc rotation around the horizontal plane for 30°

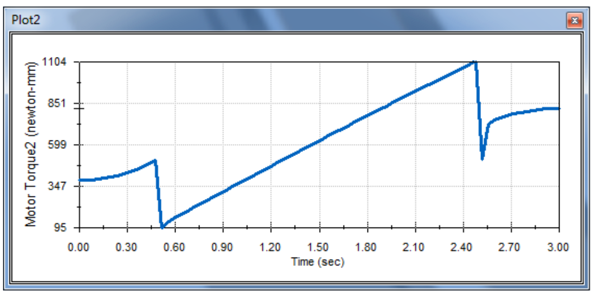


Figure 12. The torque diagram of the drive for the C-arc rotation around the horizontal plane for 30°

Finally, the analysis was done for the third case, for the C-arc rotation from the vertical to the horizontal position, for the required angular velocity according to the diagram on Fig. 14.

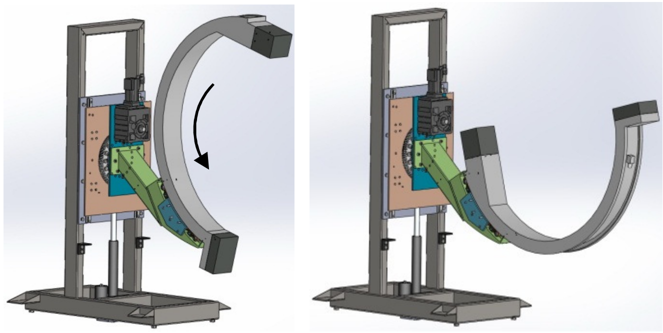


Figure 13. The analysis of the C-arc rotation from the vertical to horizontal position

The diagram in Fig. 15 shows the measured torque of the drive for the C-arc rotation from the vertical to the horizontal position.

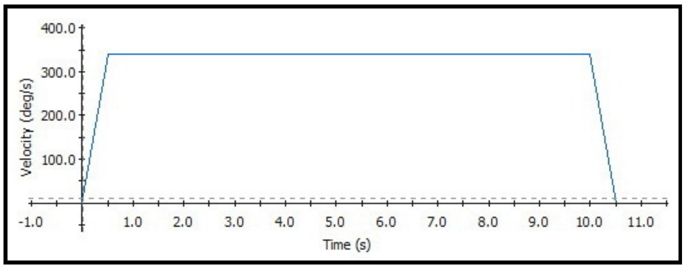


Figure 14. The velocity diagram of the drive for the C-arc rotation from the vertical to the horizontal position

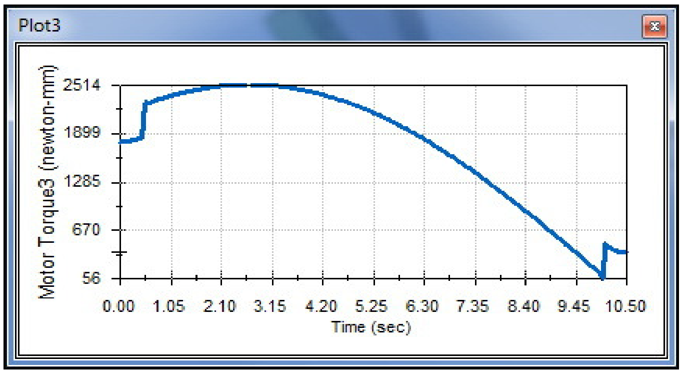


Figure 15. The torque diagram of the drive for the C-arc rotation from the vertical to the horizontal position

A prototype of the complex assembly of the new Radiography Positioner System, shown in Fig. 16, has made after the successful application of SolidWorks as a computer aided design software for developing modern mechatronical medical devices and robots. This prototype will be further used to check the results of the maximal forces and torques for driving moving parts of the Radiography Positioner System assembly obtained by analysis and simulation of the three-dimensional model in the SolidWorks Motion Simulation module, that were used for sizing the drivers of the prototype.

Figure 16. The prototype of the developed Radiography Positioner System

III. CONCLUSIONS

Modeling and analysis of complex mechanical assemblies with moving parts by using MBS method involve the following steps: defining a multi-body system; determination of coordinate systems of used bodies, defining a geometric model of the whole system, setting up a system of equations describing geometrical and kinematic constraints, formulation of differential equations of motion, assigning material characteristics of the bodies (masses and moments of inertia); determining reaction forces and moments, calculation of algebraic and differential systems of equations describing the dynamic behavior and so on.

In recent years, with the development of powerful computer hardware solutions, a new approach to the analysis of virtual prototypes of mechanical assemblies of moving parts is significantly developed by the application of the model of MBS. This approach is reflected in forming of the detailed model and its usage in virtual experiments, in a similar way as it would be in the case in the reality with the physical prototype. However, in this case it is no longer necessary to wait for months to create a physical prototype that would be subjected to tests and later processing and expensive repairs with the final aim of achieving the desired characteristics.

In this paper a successful application of the computer aided design software is presented for developing a new Radiography Positioner System. This positioning system represents a technical innovation in comparison to existing modern solutions because it is a part of an overall system of the intelligent mechatronic medical robot interface. The software platform SolidWorks and its functional module SolidWorks Motion Simulation are very useful for designing and analyzing virtual prototypes. One of the main advantages of this approach in developing new products is the ability to perform virtual measurements at any point and for any parameter (position, velocity, acceleration, force, torque, and so on). These are not always possible in real, physical models due to lack of sufficient space for transducers mounting, or the lack of appropriate measuring equipment. Moreover, the application of CAD software is very important for sizing actuators, determining boundary conditions for stress analyses, analyzing the impact of dynamic imbalance, defining the path of individual points and parts and so on. Also, this approach helps to make quick decisions regarding any changes in the structure of the system without any additional costs or subsequent tests. During simulations of virtual prototypes the final prediction of the dynamic behaviour of the final product can be achieved much earlier than with traditional design approaches, which can result in more efficient and economical design solutions. This contemporary approach to the analysis of virtual prototypes of mechanical assemblies with moving parts brings several significant advantages: reducing development time and costs of a new product by reducing the number of developing steps during the design process, reducing the number of expensive physical prototypes and tests on them, as well as improving quality and efficiency of fully improved products.

ACKNOWLEDGEMENTS

This research has been supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Project HUMANISM, code III44004 – Intelligent Human-Machine Mechatronic System for Medical Applications).

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