SYNTHESIS OF A HOSPITAL BED LIFTING AND TILTING MECHANISM USING ADVANCED SIMULATION TECHNIQUES

Doru-Ioan BOBLEA, Mariana TROFIMESCU, Paun ANTONESCU

ABSTRACT: The hospital beds have been around in different forms and shapes since the beginning of the medicine. However, the hospital beds with multiple features appeared around the beginning of the 19th century. Beds with adjustable side rails first appeared in England some time between 1815 and 1825 [1]. The modern 3-segment adjustable hospital bed was invented by Willis Dew Gatch, chair of the Department of Surgery at the Indiana University School of Medicine, in the early 20th century. This type of bed is sometimes referred to as the Gatch Bed [1]. Further to this, different structures / shapes of hospital beds have been developed based on different medical applications. The complex mechanical structures used in the last years created difficulties in the structural analysis of the mechanisms used.

1. Introduction

This paper presents the patient support lifting and tilting mechanism used in a hospital bed. This mechanism has been patented by one of the biggest world hospital beds producer - *Hill-Rom*, an American company [2]. This invention relates generally to hospital beds, and more particularly to hospital beds which convert from a bed configuration to a chair configuration and which, in doing so, provide for patient egress from the foot end of the bed and access to an onboard patient care module [2] (fig, 1).

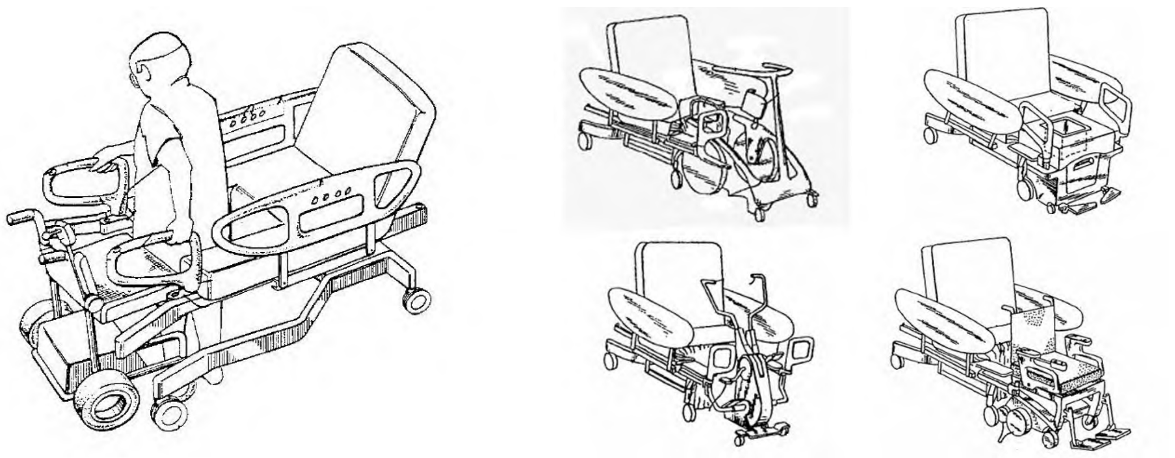


Fig. 1. Hospital bed [2]

During a patient's stay in a hospital, the patient is normally confined to his or her hospital bed for some period of time, at least initially. During this portion of the patient's hospital stay, all of the care functions provided by attending physicians, nurses and the like are provided to the patient as he or she resides on the hospital bed. Since the patient is not ambulatory during this period of his or her stay, the patient is unable to leave the hospital bed and travel to, for example, the bathroom.

Thus, attending personnel must provide the patient with a bedpan for use on the bed. As is appreciated, use of a bedpan on a hospital bed by a patient who is in generally supine position is difficult and cumbersome, at best. It has therefore been the objective of the present invention to provide a hospital bed which includes an on-board toilet module which permits use by a patient in a conventional manner. Another advantage of the present invention is that the hospital bed converts to a chair [2].

2. Brief description of the hospital bed

Hospital beds which convert to a chair configuration have been known for some time. The present bed can be converted into different configurations. Different sequence side elevation views are presented in figure 2.

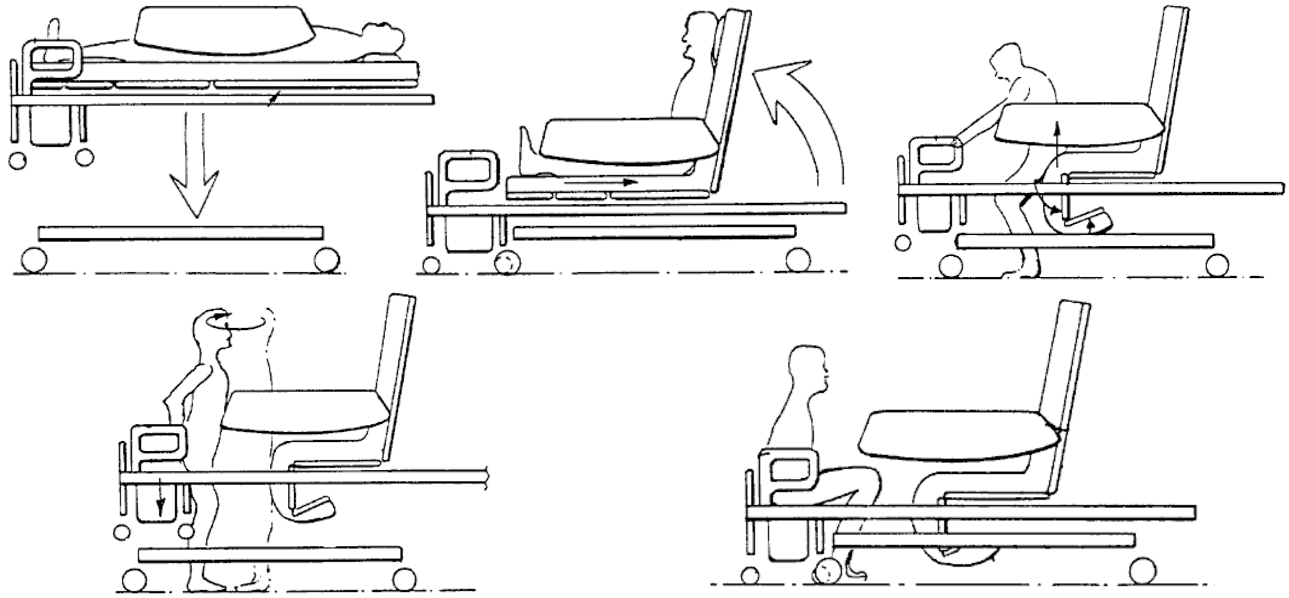


Fig. 2. Sequence side elevation views of the bed [2]

3. Synthesis of the patient support lifting and tilting mechanism

The hospital bed comprises of a base with casters, a main frame mounted above the base, a patient support platform mounted on the main frame and including a leg panel. The patient support platform can be lifted / lowered or tilted at different angles by means of the lifting frame (4). For a better understanding of the mechanism, a 3D model has been produced using parametrical design software (fig. 3). The model approximates the original dimensions / scale of the patented mechanism.

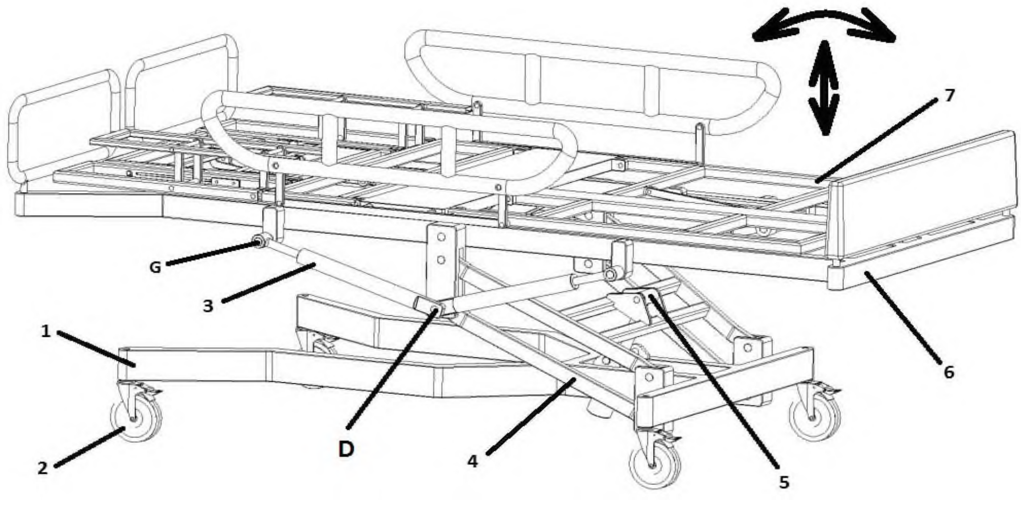


Fig. 3. Lifting and tilting patient support platform mechanism – 3D model

The following components can be identified in the above figure: 1 – base, 2 – casters, 3 – tilting cylinders, 4- lifting frame, 5 – lifting cylinder, 6 – main frame, 7 – patient support platform.

The patient support platform has two adjustments: a height adjustment and a tilting adjustment. The height can be adjusted using the lifting cylinder (5) and the parallelogram mechanism (4). The advantage of having a parallelogram mechanism is that the patient support platform lifts parallel with the ground. The tilting feature of the patient support can be achieved by means of the two cylinders (3).

It can be noticed the fact that in point *D* (fig. 3) is a multiple joint which allows the lifting / lowering of the patient support platform on one side and the tilting of the platform on the other side.

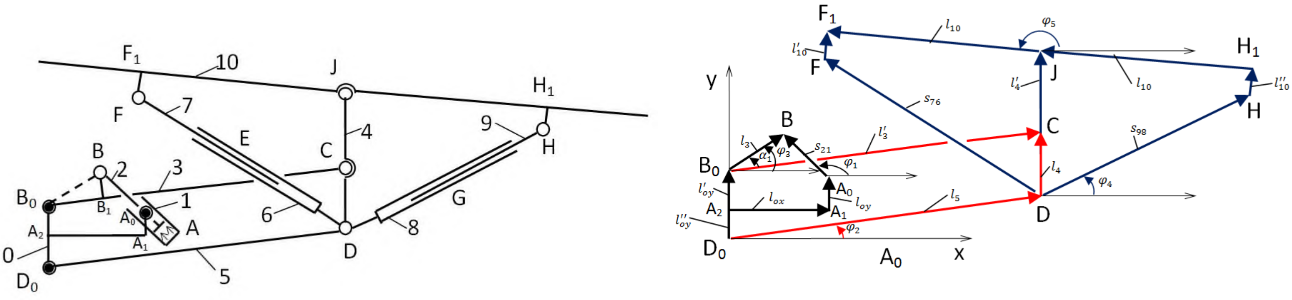


Figure 4. Structural / Vectorial schematic of the lifting / tilting mechanism

Based on the structural and vectorial schematics shown in figure 4, we can calculate the "mobility of the mechanism". The mobility of the mechanism is expressed through a integer positive number called *degree of mobility* (*freedom*) which represents the number of geometrical-kinematic parameters necessary for the univocal determination of the displacements (including the determination of positions), velocities and accelerations of all kinematic elements of the machine [3].

Based on figure 4, we can determine a number of four closed contours: $A_0ABB_0A_0$, $B_0CDD_0B_0$, $DEFJD$ and $DGHJD$. The easiest way of calculating the mobility is by using [3] the following formula:

$$M_b = \sum_{m=1}^{5}(m \cdot C_m) - \sum_{r=2}^{6}(r \cdot N_r) \qquad (1)$$

where: $m =$ freedom degree, $C_m =$ kinematic joints, $r =$ rank of the associate space and $N_r =$ number of closed contours. Based on the above information, the mobility of the mechanism is:

$$Mb = (6-5)14 - (6-3)4 = 2 \qquad (2)$$

The result is considered valid as the mechanism can perform two independent movements. Even though we have three cylinders, two of them (6,7 and 8,9) cannot work at the same time – when one is active, the other one is passive or in another words one cylinder drives the other one.

Apart of the standard methods of calculating the displacements, velocities and accelerations (finding the displacement equations, doing the first and second derivative to find velocities and accelerations and then using specialized mathematical software to determine the plots) this paper presents a simulation method of calculating all these parameters in a quicker and safer way in terms of miscalculation.

To do this, the mechanism has been analyzed using *SolidWorks Motion*, a feature of the *Solid Works 3D* design package. Few of the advantages using the latest simulation techniques would be:

- increased efficiency of the design process, having the possibility to simulate mechanical systems [4]
- moving parameter settings of a mechanism, motion simulation and result improvement using design iterations [4]

- motion simulation of the mechanism to determine collisions between components prior to the manufacturing process [4]

The first step in developing the motion analysis of a mechanism is to generate a 3D model of the analyzed mechanism using 1:1 scale.

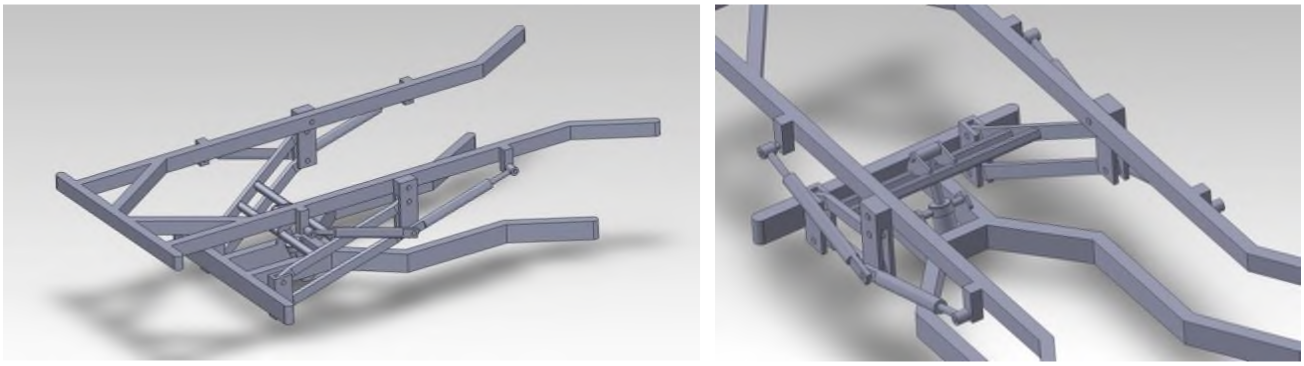


Fig. 5. Simplified 3D model of the bed

In order to reduce the simulation time, a simplified 3D model of the bed has been produced (figure 5). This model reflects the lifting and tilting mechanism which is about to be analyzed.

Once the model completed and all the materials defined, the next step is to run the *Motion Analysis* feature within *SolidWorks* (fig. 6).

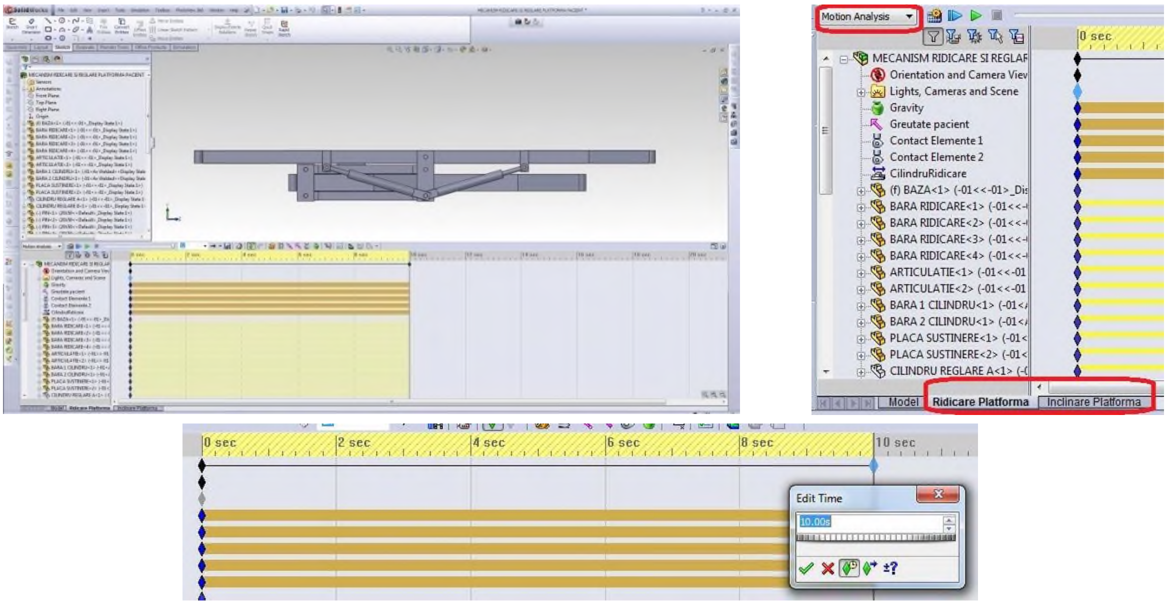


Fig. 6. Motion Analysis

Using the above controls, the operating time has been set to 10 seconds for a complete movement of both lifting and tilting of the patient support platform, in two different analyses. Once the operating time set, the next step is to define the working parameters of each cylinder. For the lifting cylinder, a stroke of *100mm* has been set at a constant speed (fig. 7) and for the tilting cylinder stoke was set to *95mm* (fig. 8). In both situations, the acceleration and jerk are considered zero.

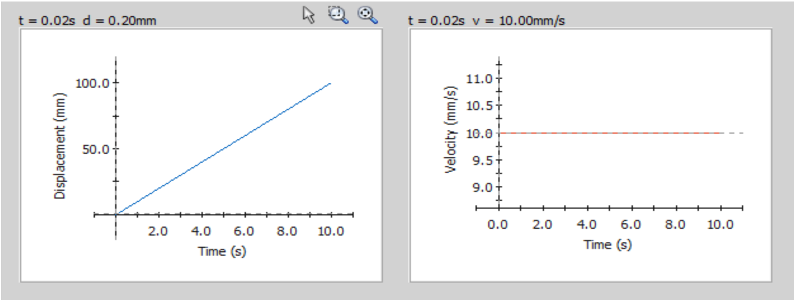


Fig. 6. Lifting cylinder parameters

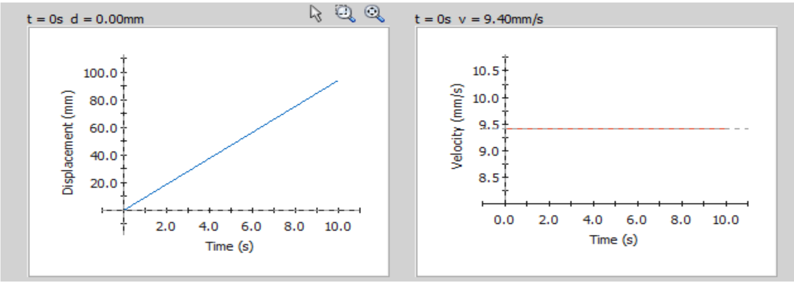


Fig. 7. Tilting cylinder parameters

The software gives the possibility of setting a various range of parameters (ie solver type, iterations, accuracy etc) but for the present analysis the default settings have been used.

Further to the analysis all the displacements, velocities and accelerations of the kinematic elements have been calculated. The result plots are presented in the subsequent figures.

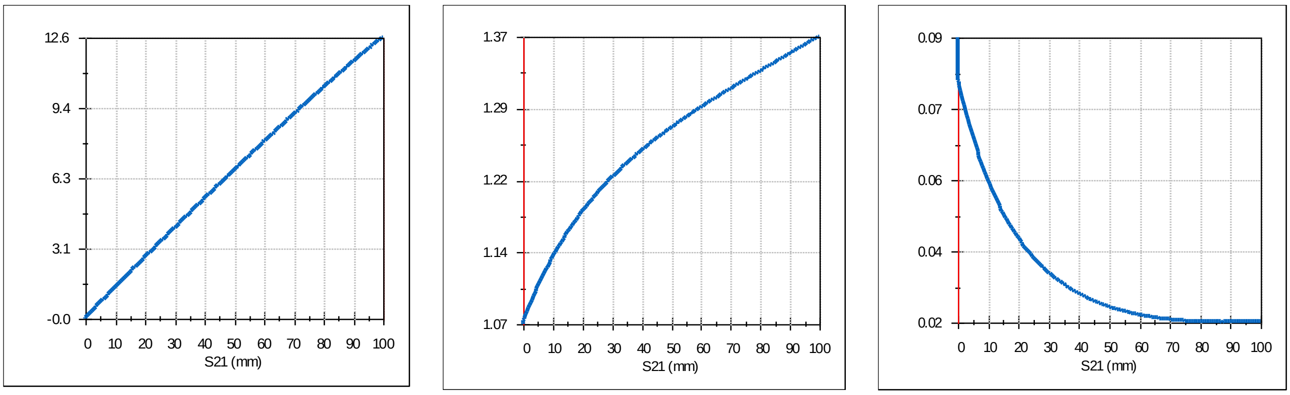


Fig. 8. Displacement, velocity and acceleration - φ_1

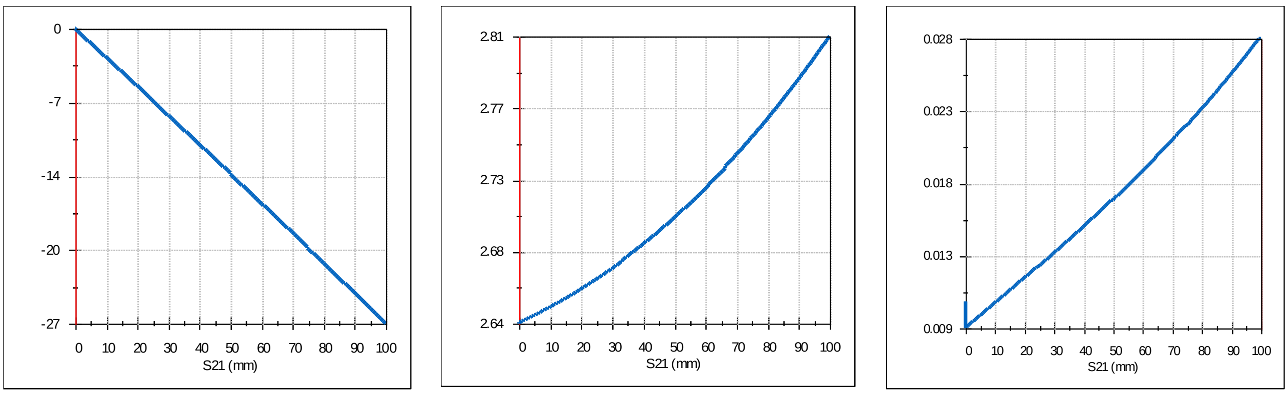


Fig. 9. Displacement, velocity and acceleration - $\varphi_2 = \varphi_3$

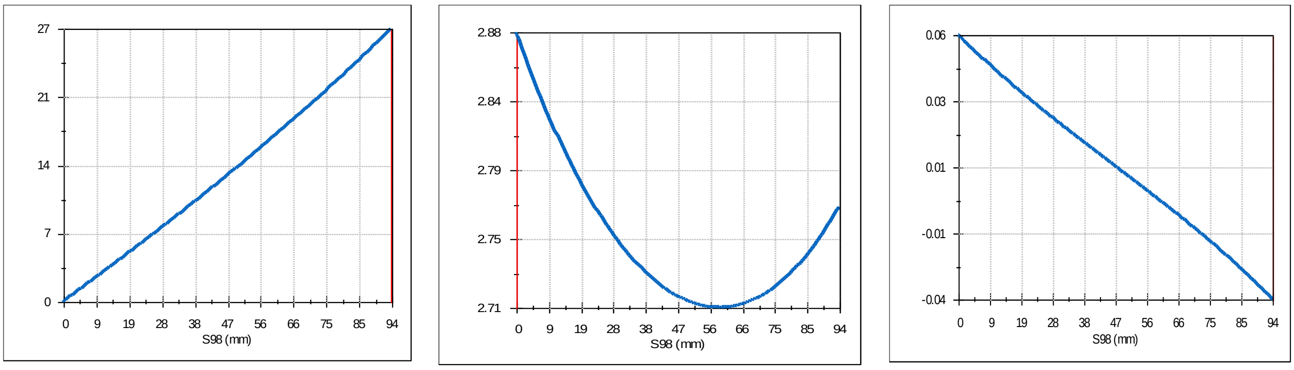


Fig. 10. Displacement, velocity and acceleration - φ_4

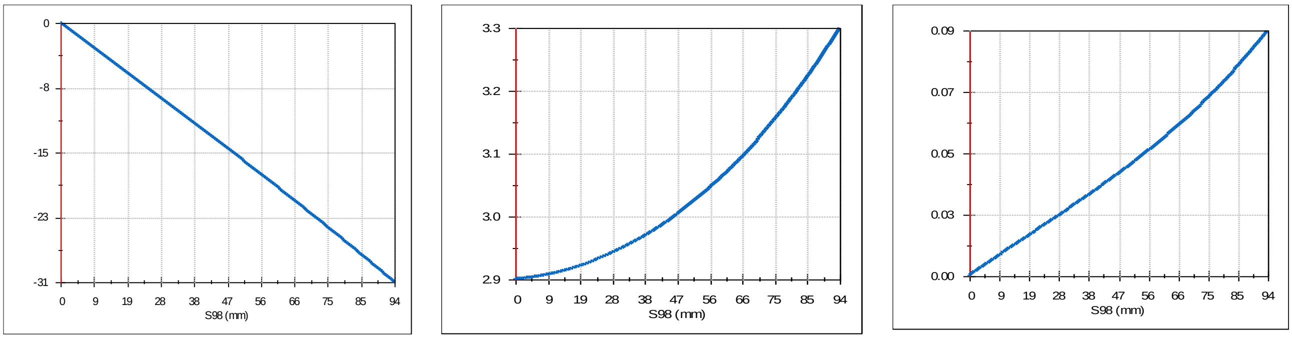


Fig. 11. Displacement, velocity and acceleration - φ_5

Also, the software can perform a kinetostatic analysis, calculating the reaction forces within the mechanism as well as the force required for the actuator to lift the mechanism (motor force). In order to simulate real conditions, gravity can be applied for the entire system as well as friction coefficients within the joints.

For demonstration purposes, a force of *2,000N* has been applied evenly onto the patient support platform simulating the weight of the patient (fig. 12), gravity has been applied as well and the friction coefficients have been ignored.

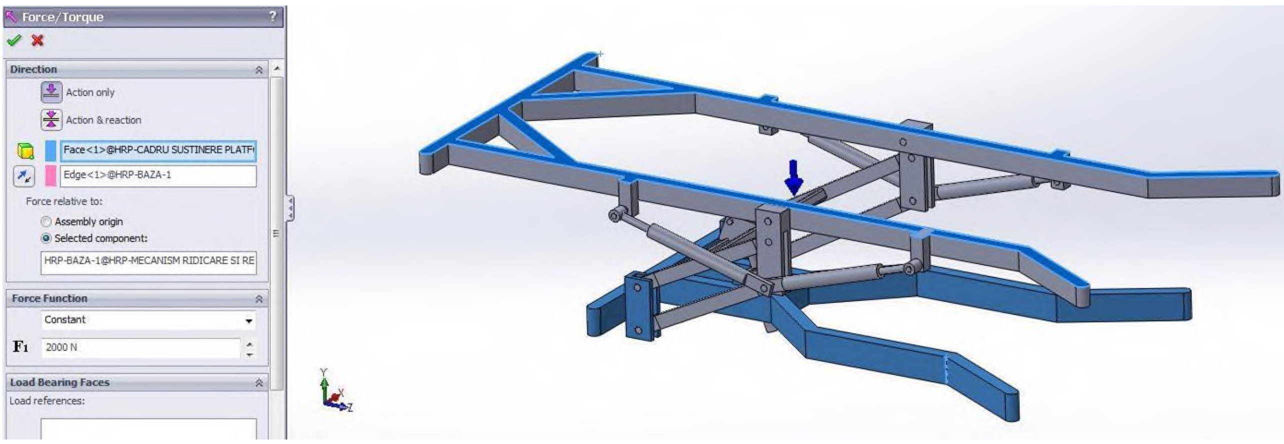
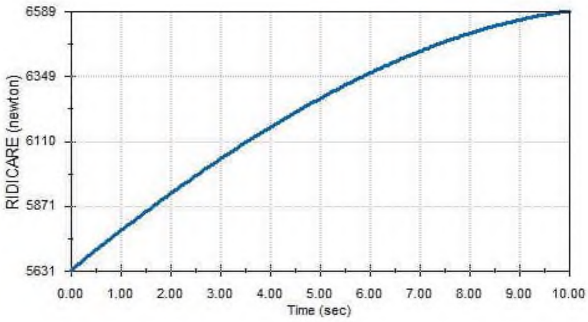


Fig. 12. Load

Further to the analysis, the forces required for the actuators to lift and tilt the patient support platform are shown in figure 13.



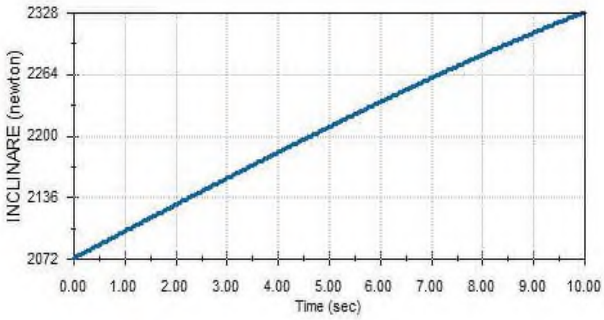


Fig. 13. Lifting cylinder / tilting cylinder

4. Conclusions

This paper presented briefly the capabilities of latest generation parametrical design and simulation software. First of all, the 3D design capability of the software gives the possibility of designing the mechanism at a 1 to 1 scale, up to the last detail.

At this stage, the designer can already predict interferences and collisions of components. Once the design completed, different materials can be applied for individual components. From this point further, the motion analysis modules embedded in the software can perform a complete kinematic and kinetostatic analysis of the entire model, calculating different parameters due to material condition, coefficients of friction, external loads, joint type, gravity etc.

5. References

1. **www.askdeb.com/health/bed/** , "*Who invented the hospital bed*?"
2. **Patent no. US 6,374, 436 B1** from 23rd of April 2002, *Hospital Bed*
3. **Antonescu, P.**, "*Mechanisms and machine science"*, Printech, Bucharest 2005
4. **Filip, V.**, "*Mecanisme"*, - Bibliotheca, 2005