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DYNAMIC ANALYSIS OF AN EXOSKELETON ROBOT CONSIDERING FRICTION IN JOINTS

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Abstract: *In this paper, we analyze the dynamics of a multibody mechanism in the structure of an exoskeleton robot intended to assist the motion of people with locomotor disabilities. The mechanism implemented as a leg of an exoskeleton has in its structure 9 kinematic elements and 14 rotational kinematic torques. We will analyze the dynamic behavior of the exoskeleton in two situations, namely: without friction consideration and with friction consideration. Also, in the last part of the paper we will present aspects of manufacturing by 3D printing technology. We will detail aspects on the use of the CURA Ultimaker software to obtain the G-code for the 3D printer.*

Key words: *robot exoskeleton, multibody dynamics, joint friction.*

1. INTRODUCTION

Lately, research in rehabilitation robotics has made significant progress, supported by the well-known research in computer science and computing. The first prototypes of exoskeleton systems were developed in the 7th decade of the 20th century, first for military applications and then for the rehabilitation of people with locomotor disabilities. An exoskeleton is defined as a robotic system that imparts additional force to the lower limbs of a human subject. Most achievements in this field of rehabilitation exoskeletons are those with motors in couplers. Another category of exoskeletons developed, are those that use a closed kinematic chain as the construction solution of the leg. For this purpose, constructive solutions based on kinematic chains of the articulated quadrilateral or pantograph mechanism type are developed. In this paper we present an original exoskeleton solution based on a kinematic chain with 9 kinematic elements and 14 kinematic rotational torques. The robotic system is simulated with ADAMS software in two scenarios: without and with friction in the kinematic torques. Obviously the second simulation hypothesis is the closest to the real operation of the robotic system. Modeling of mobile mechanical systems with consideration of friction in kinematic couplings is presented in many papers, with applications to cable driven upper limb exoskeleton [1], spherical upper limb rehabilitation robot [2, 3]. In previous papers we presented different types of exoskeleton systems for upper limb assist [2-7], or for lower limb assist even used for stair climbing assist [8-10]. A high-performance exoskeleton solution with quadrilateral kinematic chains is presented in [10]. A patent for an exoskeleton solution has been obtained [11]. The study of the friction in the bearings is detailed in [12]. Kinematic and dynamic analyses of the stability of normal and pathological human gait and of lower limb joints are detailed in [13-16]. Aspects of detailing 3D printing aspects are shown in [17-20]. Studies are also carried out presenting research on numerical simulations and experimental evaluation of human and humanoid gait, based on virtual mannequin and on wearable sensors [21-22].

The paper is structured as follows. After the introduction, aspects of the structure and dynamics in ADAMS of the exoskeleton system without and with friction in torques are presented. In the last part the 3D printing of the exoskeleton is presented.

2. DESIGN AND SIMULATION OF EXOSKELETON ROBOT

The kinematic scheme of the leg mechanism is shown in Fig. 1.

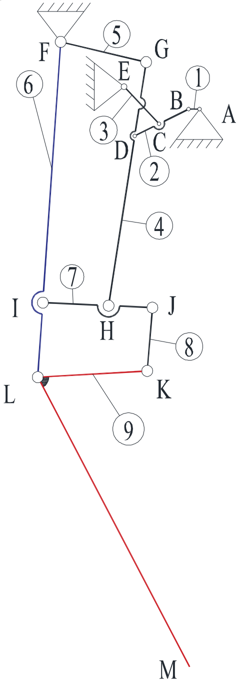


Fig. 1. Kinematic scheme of the exoskeleton leg.

According to the kinematic scheme it can be seen that element 6 structurally represents the femur of the human foot. Element 9, specifically the LM portion, structurally represents the tibia. The F joint structurally represents the hip joint, and the L joint structurally models the knee joint. Point M represents the ankle joint, which is not motor.

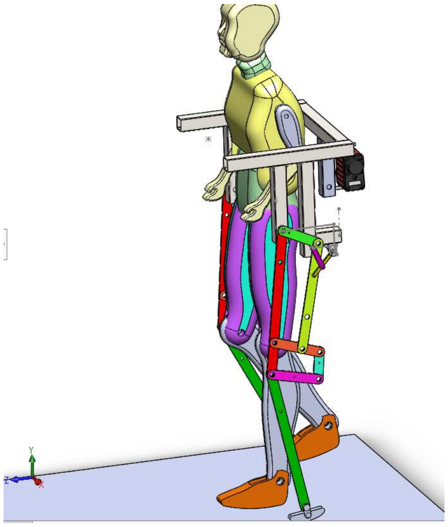


Fig. 2. Exoskeleton design in Solid Works.

Based on this kinematic scheme, we developed a virtual model of the exoskeleton robot, which is shown in Fig. 2. This virtual prototype is designed with the Solid Works software.

2.1 Exoskeleton simulation in ADAMS, without joint friction

We simulated the exoskeleton robot in ADAMS without considering the friction in the kinematic couplings. As motion law we defined an angular velocity of 4 rad/s in coupling A.

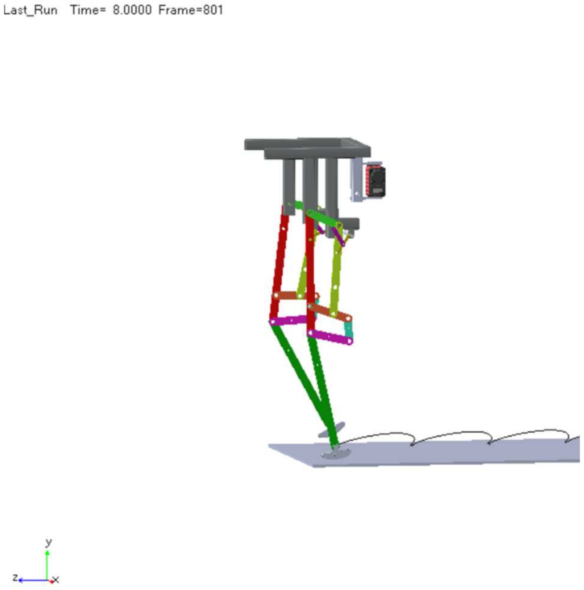
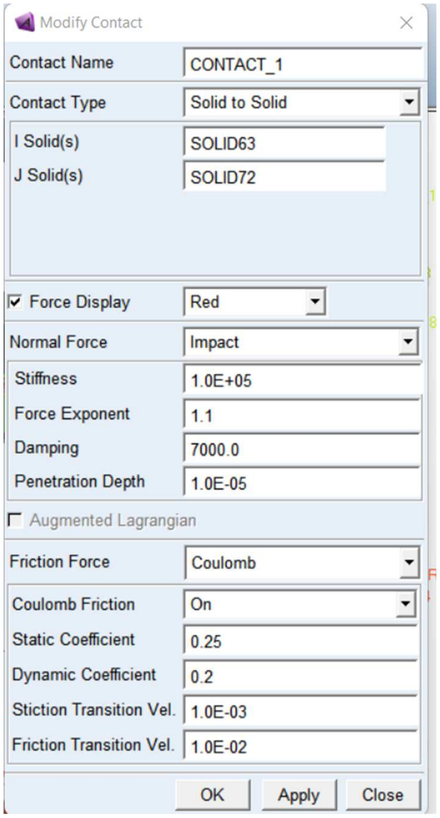


Fig. 3. Exoskeleton computed trajectory in ADAMS.

In fig. 3. we have shown an aspect from the simulation, in which we have followed the visualization of the trajectory performed by the ankle joint.

The contact parameters between the exoskeleton foot and the ground were defined as shown in Fig. 4. This is very important because the proper definition of the contact substantially influences the results obtained for the dynamic parameters. These parameters are: contact stiffness, contact damping, penetration depth and contact force exponent.

Also, for the contact between the foot and the ground, the friction between the sole and the ground must be taken into account. As can be seen in Fig. 4 we have specified the coefficient of friction with a value of 0.2 in dynamic mode.



Contact Name: CONTACT_1
Contact Type: Solid to Solid
I Solid(s): SOLID63
J Solid(s): SOLID72
☑ Force Display: Red
Normal Force: Impact
Stiffness: 1.0E+05
Force Exponent: 1.1
Damping: 7000.0
Penetration Depth: 1.0E-05
☐ Augmented Lagrangian
Friction Force: Coulomb
Coulomb Friction: On
Static Coefficient: 0.25
Dynamic Coefficient: 0.2
Stiction Transition Vel.: 1.0E-03
Friction Transition Vel.: 1.0E-02

Fig. 4. Contact parameters defined in ADAMS.

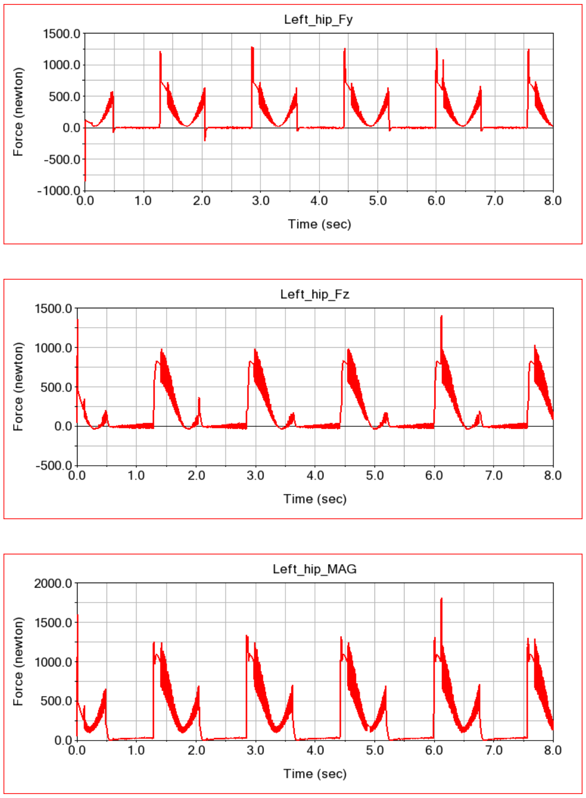


Fig. 5. Left hip joint connecting force components and magnitude, computed in ADAMS.

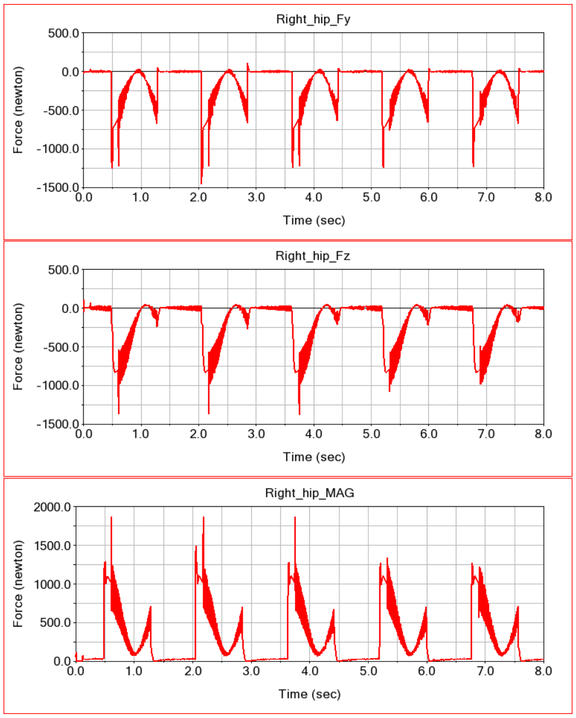


Fig. 6. Right hip joint connecting force components and magnitude, computed in ADAMS.

Figures 5 and 6 show the components of the connecting forces in the hip joint kinematic coupling for the right and left leg and the resultant forces.

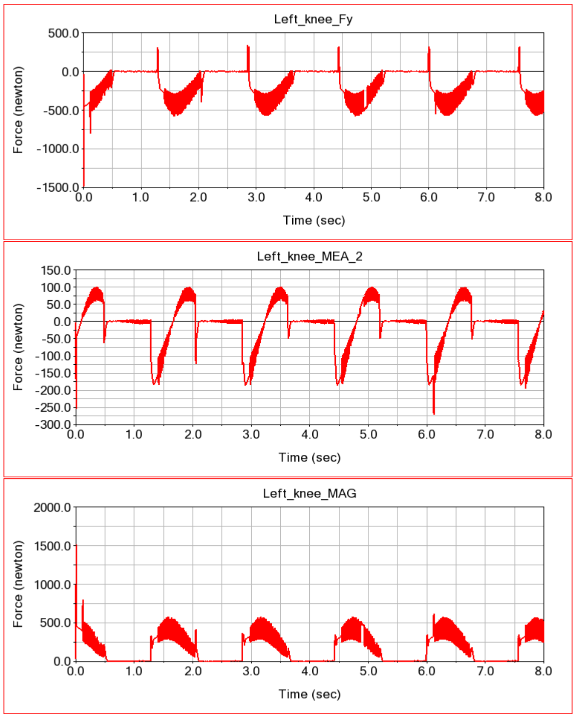


Fig. 7. Left knee joint connecting force components and magnitude, computed in ADAMS.

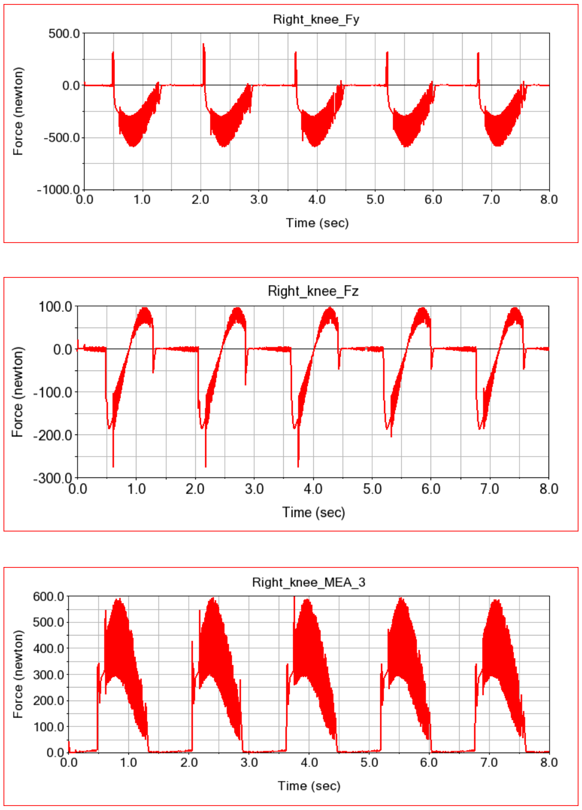


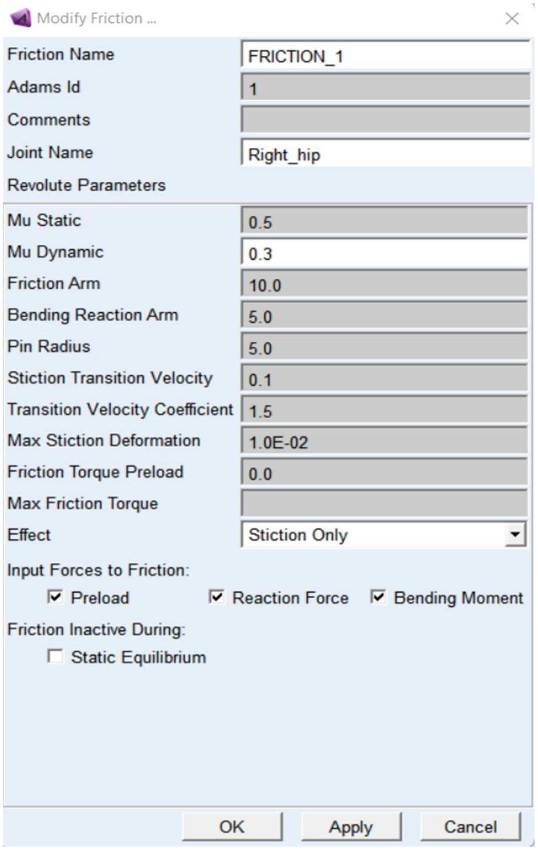
Fig. 8. Right knee joint connecting force components and magnitude, computed in ADAMS.

It can be seen that without the definition of friction in the kinematic coupling's vibrations occur due to the contact between the sole and the ground. In the next phase we will consider friction in kinematic couplings as presented below.

2.2 Exoskeleton simulation in ADAMS, with joint friction

The parameters defined for the friction-aware simulation of kinematic couplings are shown in Fig. 9. Taking friction into account leads to results closer to reality for the dynamic parameters of the mechanism. Figures 10 and 11 show the variation of the components of the connecting forces in the hip and knee joints along the vertical and horizontal axis of the reference system and their resultant values.

It can be seen that they show more linear variations when considering the friction in the mechanical couplings.



Friction Name	FRICTION_1
Adams Id	1
Comments	
Joint Name	Right_hip
Revolute Parameters	
Mu Static	0.5
Mu Dynamic	0.3
Friction Arm	10.0
Bending Reaction Arm	5.0
Pin Radius	5.0
Stiction Transition Velocity	0.1
Transition Velocity Coefficient	1.5
Max Stiction Deformation	1.0E-02
Friction Torque Preload	0.0
Max Friction Torque	
Effect	Stiction Only

Input Forces to Friction:

☑ Preload ☑ Reaction Force ☑ Bending Moment

Friction Inactive During:

☐ Static Equilibrium

Fig. 9. Definition of joint friction parameters, in ADAMS.

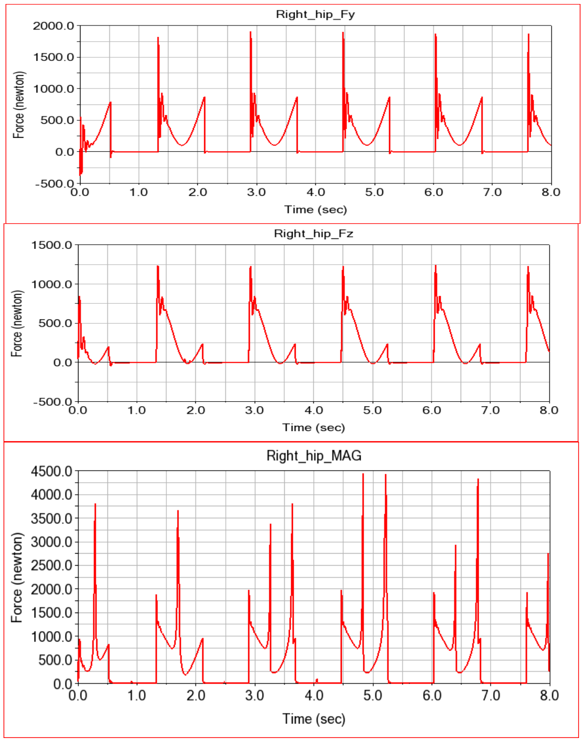


Fig. 10. Right hip joint connecting force components and magnitude, computed in ADAMS, considering joint friction.

It is observed that the presence of friction in the kinematic couplings of the mechanism reduces the vibrational effects that are transmitted in the variation of the connecting forces. Shocks are also produced at the contact between the sole and the ground due to the impact between the sole and the ground.

As numerical values, the connecting forces have a maximum value of 200 N. These results will be useful for sizing the exoskeleton elements. Rapid Prototyping, a modern technology, often used for medical applications in many other papers [ ], using a 3D printer, will then physically realize these elements.

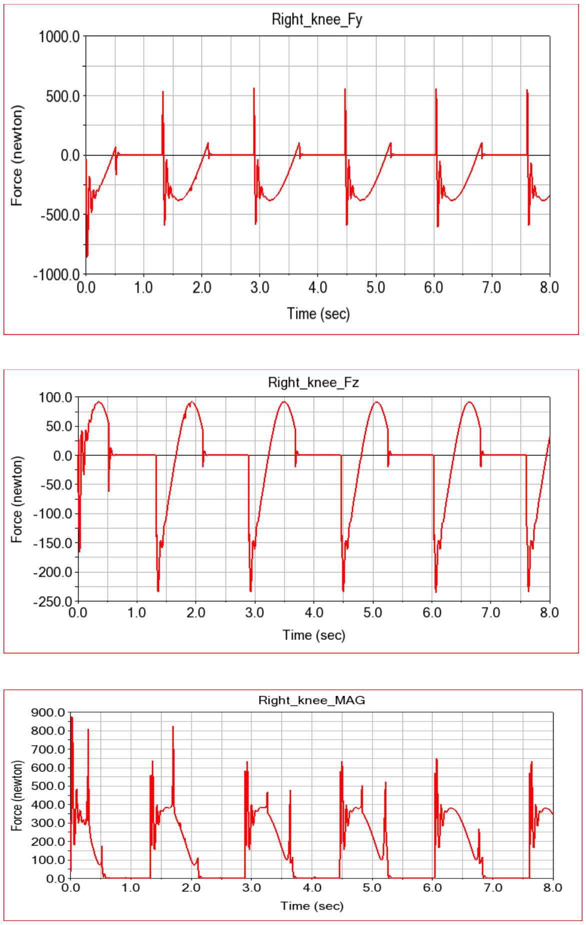


Fig. 11. Right knee joint connecting force components and magnitude, computed in ADAMS, considering joint friction.

3. ADDITIVE MANUFACTURING OF EXOSKELEON PARTS

We used a Tronxy X5SA Pro 3D printer to make the physical model of the exoskeleton.

- ✓ A brief description of this printer is given below. the key features are:
- ✓ 3.5 inch touch screen
- ✓ The screen offers an easy and intuitive user experience.
- ✓ USB and SD card connection
- ✓ These connections make the printer suitable for both online and offline printing.
- ✓ Secure 24V power supply
- ✓ This ensures faster warm-up, more stable temperatures and safer use.
- ✓ Removable printing platform
- ✓ This makes removal of the printed template very easy and convenient.

TECHNICAL SPECIFICATIONS:

Construction volume 330 x 330 x 400 mm
Maximum layer height 0.4 mm
Minimum layer height 0.1 mm
Maximum temperature 3.5 C
Maximum printing speed (mm^3/s) 150
Supply voltage 110 V-220 V
USB connectivity SD card reader
Display size 3.5 inch
Mac OS X compatible operating system, Linux
Microsoft Windows 10
STL file format
OBJ
G-code
AMF
DAE
Software included Cura
Repetier-Host

DIMENSIONS
Nozzle diameter 0.4 mm
Length 580 mm
Width 645 mm
Height 660 mm
Weight 14.5 Kg

To create the printing code, we used CURA Ultimaker software. An aspect of the analysed part to be printed is shown in Fig. 13.

For printing the part, we specified the infill degree of the part, 50%.

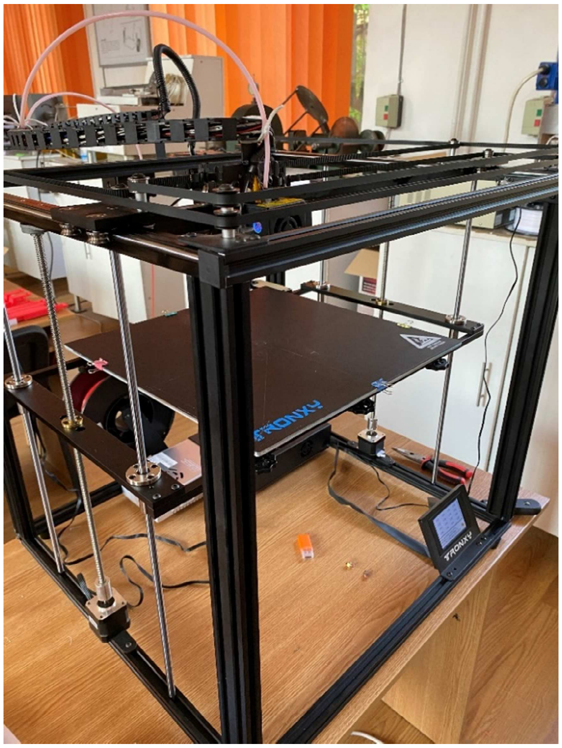


Fig. 12. Tronxy X5SA Pro 3D printer.

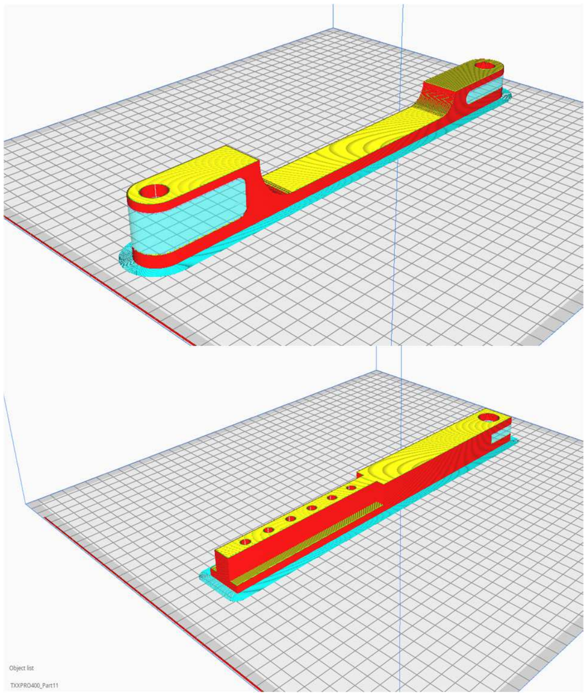


Fig. 13. Aspect of part machine code generation, for 3D printing.

The 3D printed parts are shown in Fig. 14. They will be used to assemble the physical model of the exoskeleton.

Fig. 14. Aspect of obtained parts with the 3D printer.

4. CONCLUSION

In this paper, we presented the dynamic analysis of an exoskeleton system. This analysis has been carried out using the ADAMS program, under two simulation assumptions, namely without friction in the couplings and with the consideration of friction in the couplings. The results obtained in the second simulation hypothesis are better, because there are no more vibrations in the operation of the system, considering the friction in the couplings. Next, since the virtual simulation allowed us to validate the exoskeleton model, we presented the aspect of obtaining the components using a 3D printer. These elements, obtained by 3D printing, will then be assembled to study the dynamics of the exoskeleton in the real working case.

5. ACKNOWLEDGMENT

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Analiza dinamică a unui robot exoschelet considerând frecarea din cuplele cinematice

În această lucrare, analizăm dinamica unui mecanism multicorp în structura unui robot exoschelet destinat să asiste mișcarea persoanelor cu dizabilități locomotorii. Mecanismul implementat ca un picior al unui exoschelet are în structura sa 9 elemente cinematice și 14 cuple cinematice de rotație. Vom analiza comportamentul dinamic al exoscheletului în două situații, și anume: fără considerarea frecării și cu considerarea frecării. De asemenea, în ultima parte a lucrării vom prezenta aspecte legate de fabricarea prin tehnologia de imprimare 3D. Vom detalia aspecte privind utilizarea software-ului CURA Ultimaker pentru obținerea codului G-code pentru imprimanta 3D.

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