Modeling and Kinematics Simulation Analysis of Industrial Robot Based on VisualNastran

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Abstract

In this paper, we establish virtual physical model of PUMA560 industrial robot according to kinematic model and configuration parameter of PUMA560 industrial robot under VisualNastran condition. Simulating the moving track and position from one point to another along curves and straight line when the robot clamps are attached to the load of m and simulating the changing curves of force and moment of each joint when adding dynamic load under VisualNastran condition.

Keywords: industrial robot; VisualNastran; modeling; simulation analysis

1. Introduction

The robot is an important part of the industry, they can accurately perform a variety of tasks and operations, and they don't need the safety measures and comfortable working conditions when people working. For the development and design of the robot, engineering designers can build virtual prototype model on the PC, analyzing a variety of performances of virtual prototype model, improving the design continuously according to the requirement of the task, we use the virtual prototype model to test, instead of using the traditional physical prototype [1-2]. We could reduce the design process and the development process of mechanical products through the application of virtual prototype technology, reducing the product development time, reducing development costs, improving the quality of products greatly, to get the innovative and optimized product design[3].

VisualNastran software is a tool for the development of virtual prototyping of machinery products. VisualNastran provides large modeling and simulation environment for users, designers can take modeling and kinematics or dynamics simulation analysis to many kinds of mechanical systems [4-5]. There are many advantages to this software, such as vivid and intuitive modeling, good animation effect, fast response, simple interface operation, its simulation results are consistent with the results of actual physical models[6]. We take PUMA560 robot as research object, analyzing kinematics or dynamics of mechanical system within VisualNastran to optimize the whole system.

2. PUMA560 Robot Modeling

The modeling includes establishing the geometric model, adding the constraint mechanism and establishing the driving function. We need to simplify and analyze according to the actual model size when using VisualNastran.

Establishing three-dimensional model of PUMA560 robot using geometric modeling tool under VisualNastran condition, to establish base, connecting rod 4, connecting rod 6 as cube, to establish connecting rod 1, 2, 3 and 5 as cylinder, the load ia established as sphere and named as Gruz. Importing corresponding dimension value to established geometric model according to the appearance parameter of PUMA560 robot.

We could eatablish joint to connect each connecting rod as an industrial robot after establishing geometric model. VisualNastran provides different hinge type, according to the needs of PUMA560 robot,choosing the adjacent two connecting rods from connecting rod 1 to connecting rod 6 to establis revolute joint, choosing the load and connecting rod 6 to establis rigid joint, it is fixed between the base and the earth.

According to the quality of raw data and inertial mass information of PUMA560 robot, setting quality information under "*Central inertia*" in "*Property of boby*" to each connecting rod(Figure 1), we only need to set quality to load, and we don't need to set inertia mass. We set quality information under "*CM*" in "*Property of boby*" to connecting rod 2 and connecting rod 3 when the centre-of-gravity position shifts(figure 2), connecting rod 2 shifts 0.25m and connecting rod 3 shifts 0.2m.
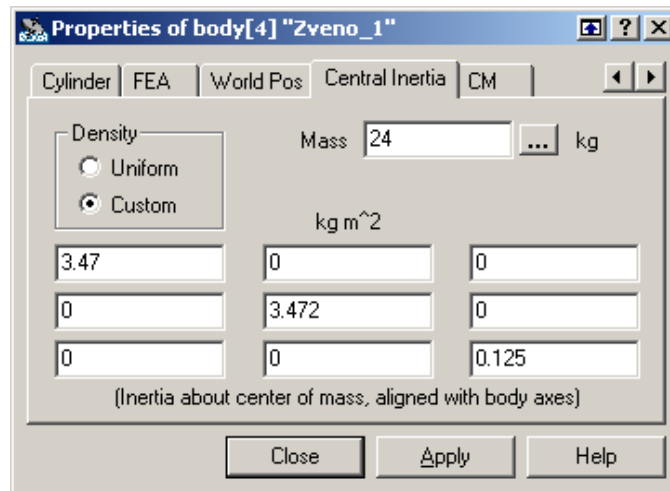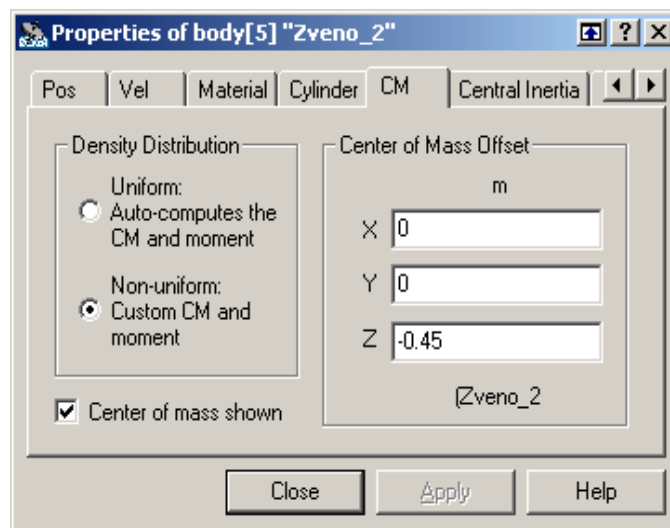
Figure 1. Tab Central Inertia

Figure 2. Tab CM

3. Kinematic Simulation of PUMA560 Robot

3.1. Curve Trajectory Analysis

Establishing the initial position of industrial robot before motion simulation. Filling in the initial angle for each joint in "*Property of Configuration*" according to table 1. We could obtain the initial state of the industrial robot(figure 3).

Table 1. Joint Initial State and Terminational State Angles

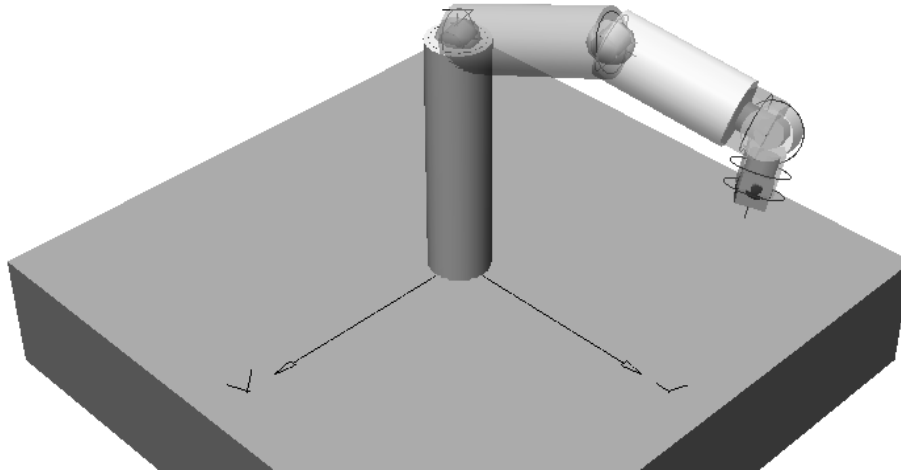| JointI		JointII		JointIII	
Initial	Terminational	Initial	Terminational	Initial	Terminational
-15	80	75	10	30	160
JointIV		JointV		JointVI	
Initial	Terminational	Initial	Terminational	Initial	Terminational
25	-90	-80	15	15	-60

Figure 3. Initial State of Simulation of Industrial Robot

In order to determine the terminational state of industrial robot, we need to calculate the speed of each joint within t of industrial robot from initial state to terminational state, the calculation formula is shown as follows:

$$\omega_i = \frac{\varphi_{\kappa i} - \varphi_{\text{н}i}}{t} \tag{1}$$

Among this formula, i: serial number(1,2...6), ω_i: speed of joint i, $\varphi_{\kappa i}, \varphi_{\text{н}i}$: initial state and terminational state angle of joint i.

Setting $t = 2$ when simulating, and bringing initial state and terminational state angle of each joint according to table 1, we could obtain the speed of each joint. In order to complete the above calculation in VisualNastran, we need to change the type from Revolute joint to Revolute motor in "*Properties of Constraint*", and choose "*Angular velocity*" in "*Properties of Motor*", and press the right button in the text box, open Edit formula, import the time and speed in "*Edit table*"(figure 4).

Choosing "*Piecewise constant*" in "*Interpolation*", and filling in the starting and ending time in "*Time*", filling in the speed of each joint in "*Value*" according to formula (1).
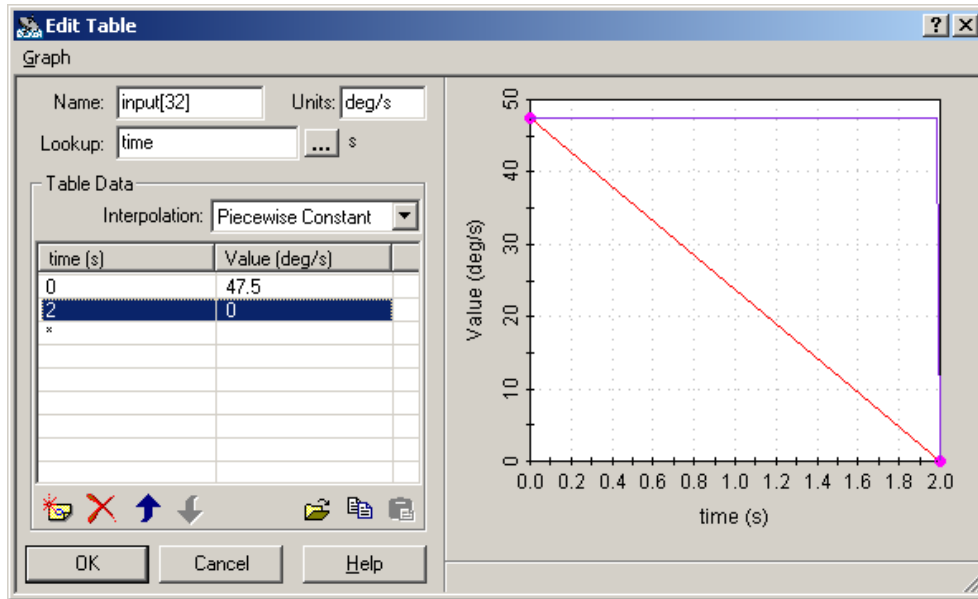

Figure 4. Edit Table Window

It will show the speed changing curve of each joint on the right side of the Edit formula(figure 5).
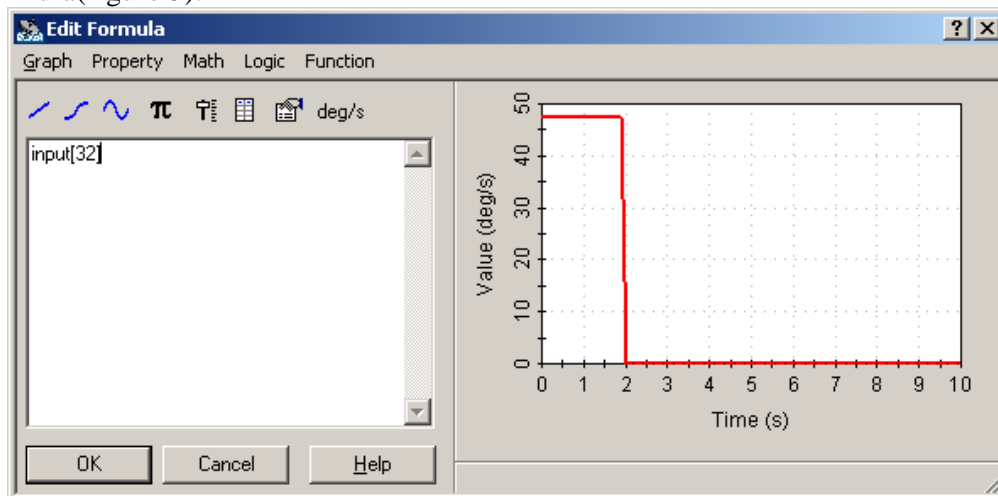

Figure 5. Edit Formula Window

We will begin to simulate the moving track of the load after editing all joints. Industrial robots will stop at the specified position if the simulation is correct, it is shown in figure 6, checking the terminational state angles of all joints if there is something wrong.
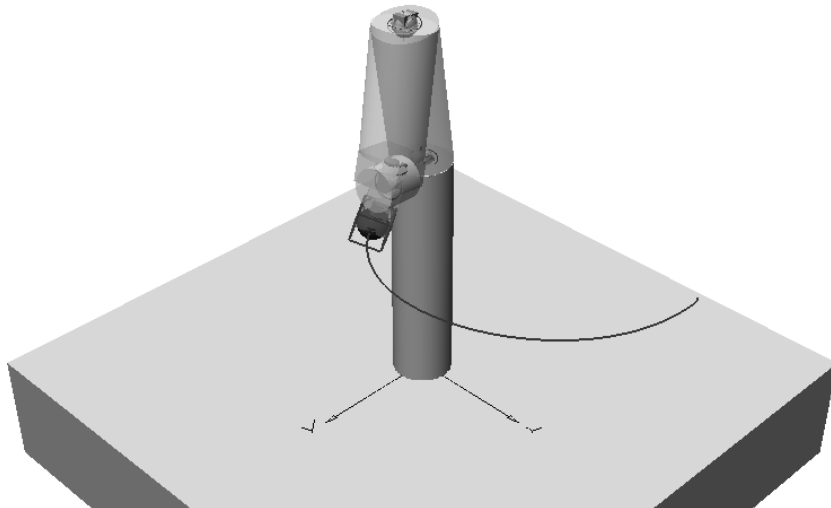
Figure. 6 Terminational State of Industrial Robot

We choose Gruz to execute the order *Меню—Insert—Meter—Position*, then choose Gruz again to execute the order *Меню—Insert—Meter—Orientation* in order to draw orientation and location changing curve of the load. It is shown in figure 7. Angle range is -200°-200°of obtained orientation curve, the program automatically add 360° to the number of actual angle values if it is less than -180°, on the contrary, the program will subtract 360°if it is more than 180°. You could click the curve and choose shortcut menu Digital if you need the exact values of coordinate and orientation of the load(figure 8).
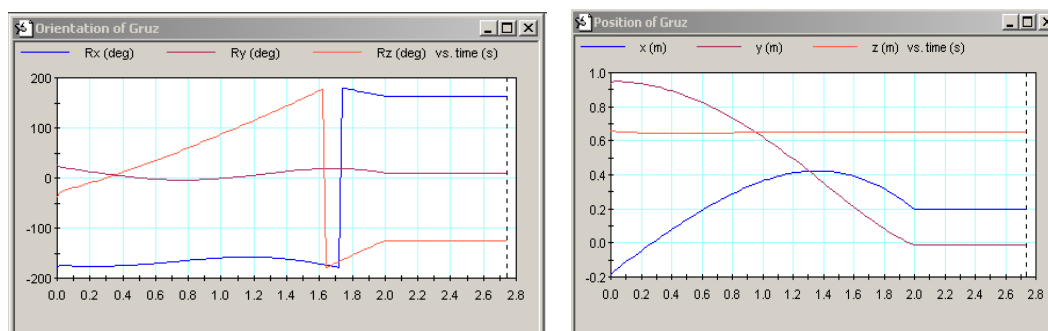

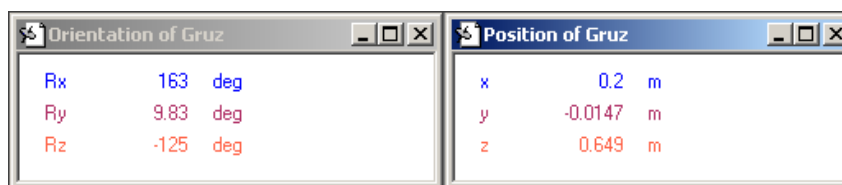**Figure 7. Orientation and Location Changing Curves**

Figure 8. Angle and Coordinate Values of Terminational State of the Load

In order to draw the torque curve of each joint, each joint chooses the menu item *Меню—Insert—Meter—Constraint torque*, then starting the simulation. Since we only care about joint torque, so we need to choose *Hide 'Tx'*, *Hide 'Ty'* and *Hide '/T/'* to each figure. Time axis range is set as 0.1s-1.9s. To eliminate the curve jumping generated by dynamic load in the process of acceleration and braking when

simulating, we need to change ratio to make the torque values visible only within a period of time. We could obtain the torque curve in figure 9.
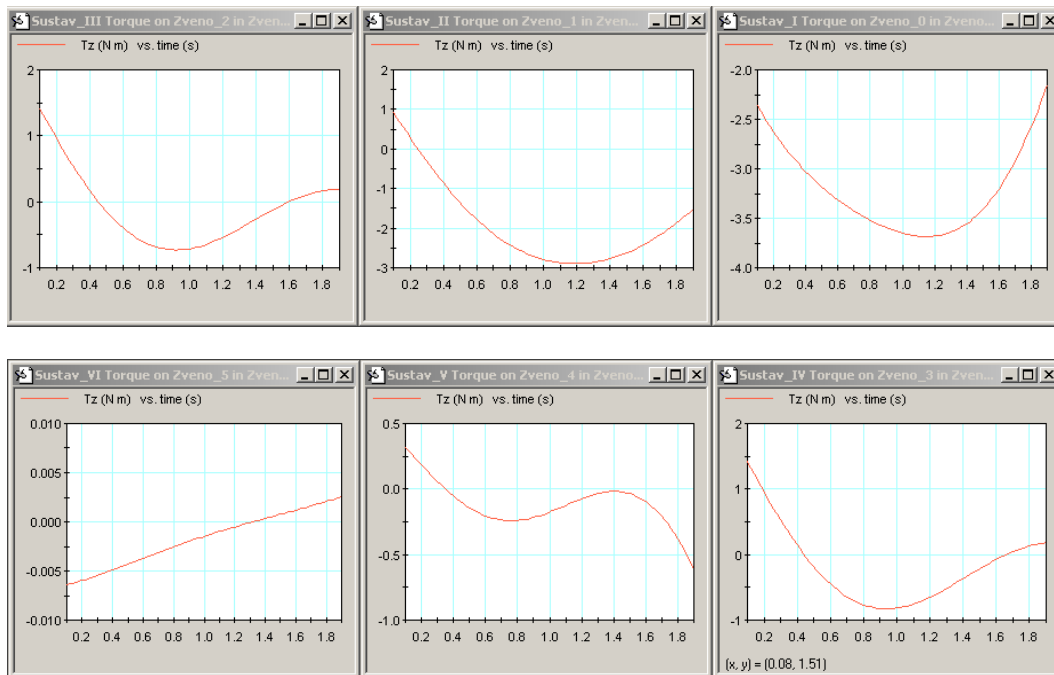

Figure 9. Torque Curves of Joint 1-6

3.2. Linear Motion Trajectory Analysis

In order to obtain the linear motion track, we need to return to the initial state of the simulation and close all graphics. Click Gruz, and read current coordinate and orientation value from *Pos* in *Properties* window(figure 10). We could calculate the speed within 2s of the load and know how the load move and rotate along each axis from initial state to terminational state according to figure 9 and figure 10.
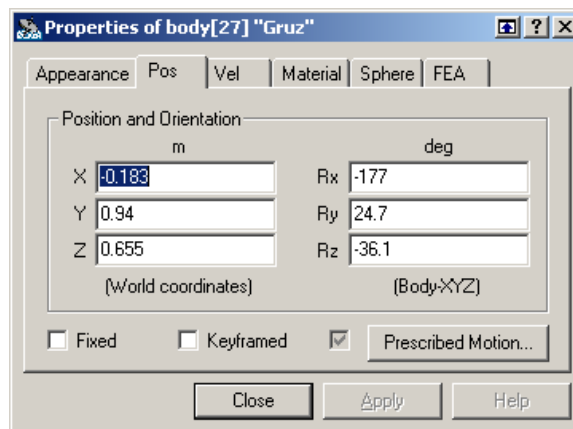

Figure 10. Coordinate and Angle Value of Load Initial State

Taking the calculated results to fill the corresponding position of *Prescribed motion* window. We could obtain the moving track from the beginning to the end of the load(figure 11).
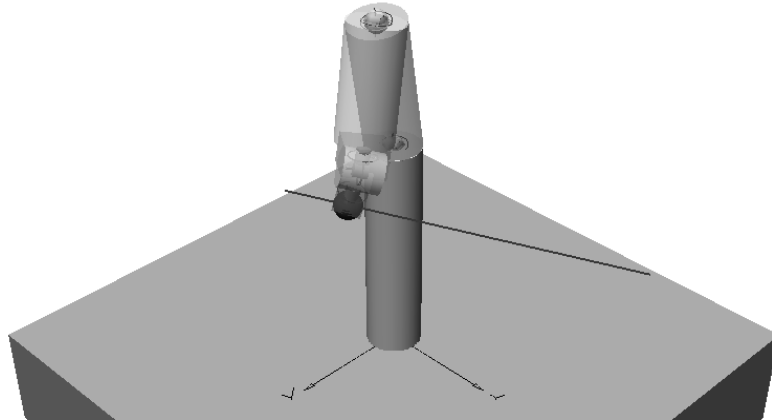
Figure 11. Linear Motion Track of the Load

Executing the order *Меню—Insert—Meter—Orientation* in order to draw angle curve of each joint, we could establish the angle curves in figure 12. Robot load couldn't have linear motion mode from the beginning to the end according to the angle curves of each joint.
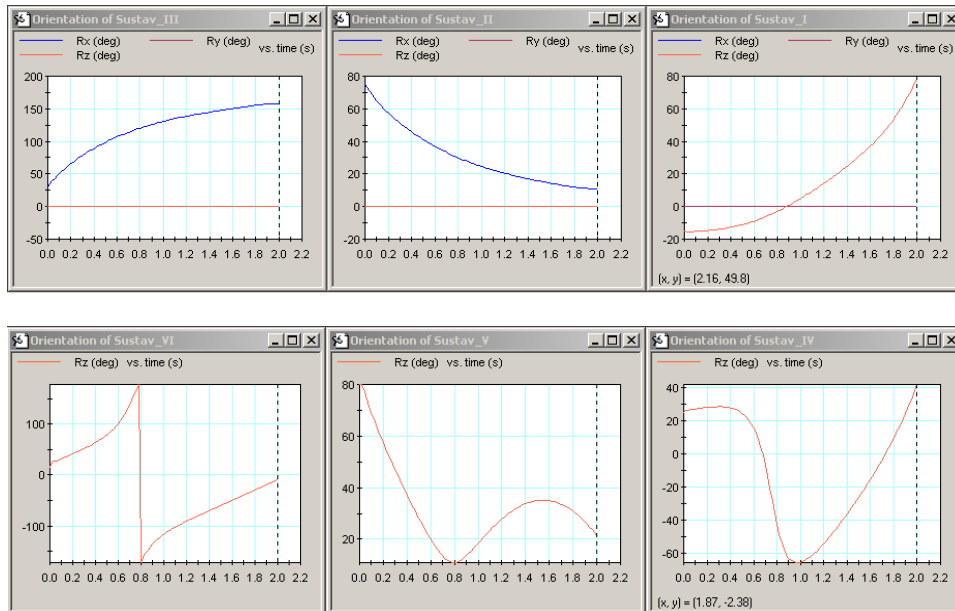

Figure 12. Angle Curves of Joint 1-6

3.3. Kinetic Analysis

In order to determine the joint dynamic load, we need to load the saved file that from the initial state to the end state of the industrial robot moving along a curved path. We need to choose the corresponding joint and execute the orders: *Insert—Meter—Constraint torque* and *Insert—Meter—Constraint force* in order to establishing the force and torque changing curves of the second and third joints. We can obtain the force and torque changing curves of any joint using the same method, and we could get the following curves in figure 13.
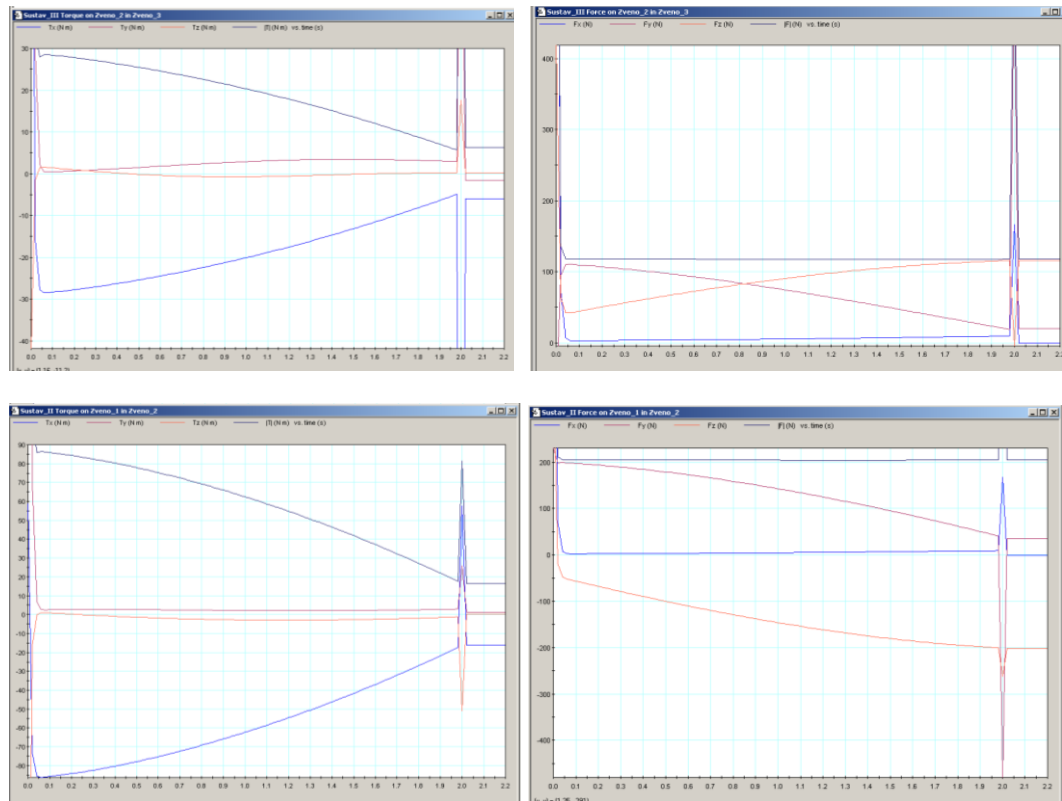
Figure 13. Force and Torque Changing Curves of the Second and Third Joint

From the figure, we could obtain that the jump point of load appears at initial time $t=0$ and terminational time $t=2$. This situation is caused by the joint changed quickly from zero to predetermined speed at the initial moment or from predetermined speed to zero at $t=2$.

4. Conclusion

According to the structure parameters of PUMA560 robot, such as length, quality and inertia mass of joint arm, we established the model of PUMA560 robot under VisualNastran situation. Using VisualNastran dynamic analysis software to simulate the motion of manipulator, and obtained the force and torque changing curves within different motion process, and analied the simulation results. So the robot modeling and simulation method that combining with VisualNastran technology has characteristics of good real-time and visibility, it applies to do kinematic and dynamic simulation analysis of complex mechanical system, and it contributes to the system optimization design.

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