



Design and (Dynamic, Stress) Analysis of a Walking Robot Leg Mechanism at High Speeds

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Abstract: Mobile robots are increasingly being used in difficult situations, such as the inspection of the inner layer of atomic power stations, environment inspections, home servicing, forestry and agriculture, planetary explorations and the exploration of non-accessible terrain like volcano craters. Either walking or wheeled mobile robots can be used to perform the above-mentioned applications. Compared to wheeled vehicles walking machines show the advantage that they can act in highly unstructured terrain without having prepared this terrain in advance by streets or rails. Legged robots cross obstacles more easily; depend less on the surface conditions and quality and, in general, exhibit better adaptability. A number of different mechanism structures of legs have been used for the walking. The most used mechanism shows the pantograph architectures as main Kinematics chain for a leg. In this project work study of feasibility for a fully rotating actuation of the pantograph- leg has been carried out. In particular, a suitable model of the leg kinematics analysis and design are presented pantograph-leg for walking machines. A parametric study has been also carried out in order to investigate the influence of some basic design parameters on its motion capabilities Simulation with Matlab software have been carried out to verify the operation of the leg. The modeling also has been carried out by Pro/ENGINEERING. Structural analysis and FEM with ADAMS software also have been carried out to check the induced stresses during the operation of the mechanism.

Keywords: Robots, Design, Dynamic & Stress Analysis, Walking Robot Leg, Pantograph And Chebyshev Mechanism, Four Bar Mechanism.

I. INTRODUCTION

Traditionally, most mobile robots have been equipped with wheels. The wheel is easy to control and direct. It provides a stable base on which a robot can maneuver and is easy to build. One of the major drawbacks of the wheel, however, is the limitation it imposes on the terrain that can be successfully navigated. A wheel requires a relatively flat surface on which to operate. Rocky or hilly terrain, which might be found in many applications as forestry, waste clean-up and planetary exploration imposes high, demands on a robot and precludes the use of wheels. A second approach to this problem would be to use tracked wheel robots. For many applications this is acceptable, especially in very controlled environments. However, in other instances the environment cannot be controlled or predicted and a robot must be able to adapt to its surroundings. Such a surrounding can be places where robots would have to step over the obstacles such as a surface where pipes are running and where they have to move on discontinuous terrain like steps. Research into legged robotics promises to overcome these difficulties. The complexity of control required for a legged robot to navigate autonomously overrun familiar terrain has made them difficult to build. Recent developments in embedded controller technology have yielded very sophisticated computing devices in relatively

small, easily programmed modules. With these advanced components, it is now possible to control relatively complex and sophisticated devices. The walking in nature is a very flexible and complex task. For example, in generating a trajectory several parts/systems are involved: muscle as actuators, bones as linkages, nerves as sensors and brain as a complex control system.

The most common walking machines are wheeled and tracked systems, but large interest can be also focused on legged machines. In fact, existing mobile robots need regular terrain to move over; while legs are more flexible and could be used even in unknown environments. The complexity of legged machines increases as number of degrees of freedom increases in the mechanism of legs. Mobile robots are increasingly being used in difficult situations, such as the inspection of the inner layer of atomic power stations, environment inspections, home servicing, forestry and agriculture, planetary explorations and the exploration of non-accessible terrain like volcano craters. Either walking or wheeled mobile robots can be used to perform the above-mentioned applications. Several walking machines and robots have been conceived, designed and built in the last twenty years to open new fields of application. Compared to wheeled vehicles walking machines show the advantage that

they can act in highly unstructured terrain without having prepared this terrain in advance by streets or rails. Legged robots cross obstacles more easily; depend less on the surface conditions and quality and, in general, exhibit better adaptability. A number of different mechanism structures of legs have been used for the walking. The most used mechanism shows the pantograph architectures as main Kinematics chain for a leg. At LARM, the Laboratory of Robotics and Mechatronics in Cassino biped walking robots EP-WaR and EP-WaR II have been designed and built with a suitable pantograph mechanism for the legs. Available prototypes of the above mentioned biped walking robots with pneumatic actuation have been used for experimental tests and to show the soundness and practical feasibility of the mechanical design as shown in Fig.1. Furthermore, exploring other types of actuation can be of interest.

In this project a study of feasibility for a fully rotating actuation of the pantograph- leg has been carried out. In particular, in this project the numerical analysis of a leg mechanism for walking machines will be presented. A suitable model of the leg has been analyzed and a simulation of Kinematics and Dynamics has been carried out. In particular, the motion capability of the leg has been studied, together with theoretical acceleration, velocity and forces. A parametric study has been also carried out in order to investigate the influence of some basic design parameters on motion capabilities of the leg.

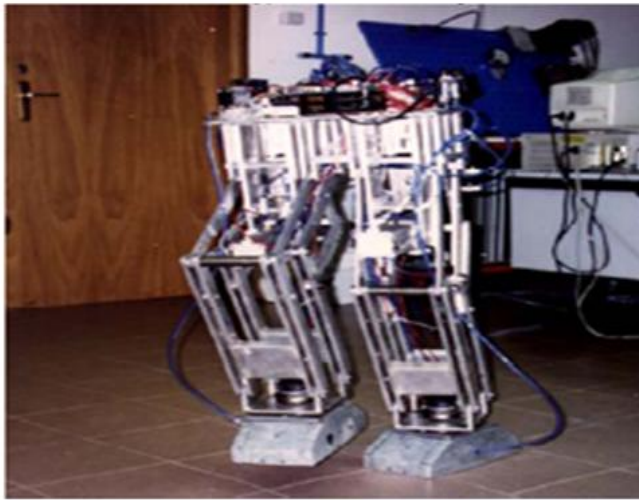


Fig.1. Prototype of EpWAR II at laboratory of robotics of Mechatronic in casino.

II. HUMAN WALK

Human walk is the most efficient bipedal walk known. It uses a dynamic walking gait. At any given condition, i.e. at any walking speed and step rate, a human chooses the most energy efficient gait for locomotion. In steady state, walking is symmetric and periodic. The physical structure of a human body consists of the musculo-skeletal system for the physical realization of the walking gait and the central nervous system for the optimization and control of the gait. The skeletal system consists of the bones which are actuated by the muscles on the skeletal system.

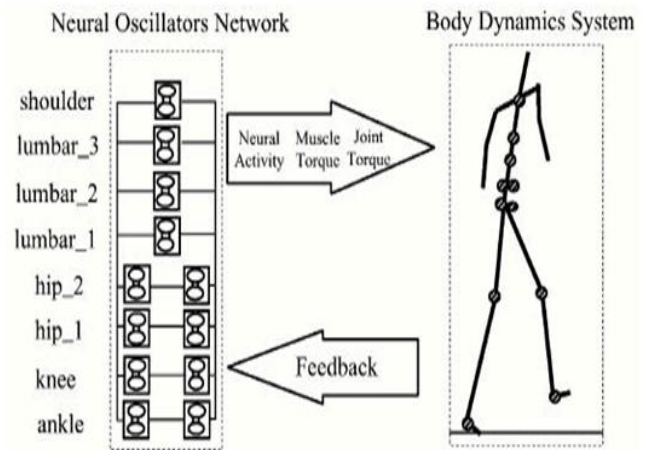


Fig.2. Body Dynamic System and Neural Oscillators Network.

The sole and knees are designed to minimize the ground impact forces by use of soft tissue at the sole and also by bending of the knees. The neuronal system autonomously produces rhythmic patterns of neural stimuli and the system of body dynamics generates movements according to the rhythm pattern as shown in Fig.2. Information concerning somatic senses, such as information about foot-ground contacts and segment angles, is fed back to the neuronal system, and the rhythm pattern of neural stimuli is regenerated based on this information. This theory holds that this interaction between the neuronal system and the system of body dynamics produces movement. The theory holds that the rhythmic pattern is generated by a network of interneuron in the spinal cord called the Central Pattern Generators (CPGs). These consist of pair of neurons called the neural oscillators. A neural oscillator consists of a pair of flexor and extensor neurons and each neuron produces a signal for either flexion or extension motion of a joint. A neural oscillator exists for each degree of freedom of the joint. The neural oscillators are able to generate the basic rhythm of joint movements in walking due to their mutual inhibition. Human locomotion is thought to use a number of principles which simplify control. The sensory feedback to the central nervous system is given by sensory receptors of joint angles and angular velocities. The somatic sensors give pressure distribution on the sole and the inclination angle and its orientation information. The eyes also help in the coordination movement and in the identification of obstacles.

A. Mechanism of Walking

For human normal walking, the motion of a leg can be divided into two phases: a propelling phase and non-propelling phase. In Fig.3, the dashed line represents the supporting leg in propelling phase and the solid line represents the swing leg in non-propelling phase. The motion trajectory of the ankle is depicted with dashed line and it is a symmetric curve. The hip trajectory is also a curve. Therefore, in order to design a leg mechanism with back-forth and up-down motion capability, the foot point of a reduced DOF leg mechanism should also be able to generate

Design and (Dynamic, Stress) Analysis of a Walking Robot Leg Mechanism at High Speeds

an ovoid curve, which is composed of a straight-line segment and a curved segment. The straight-line segment is related to the propelling phase when the corresponding leg touches the ground and the curved segment is related to the non-propelling phase, which is produced by leg when it swings from back to forth.

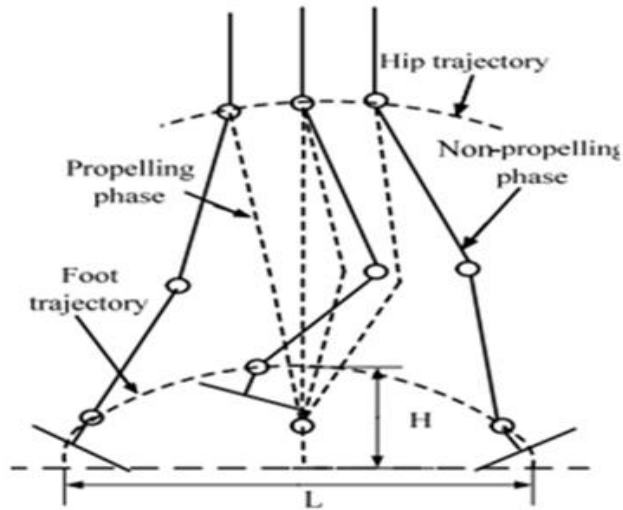


Fig.3. A Scheme For A Walking Gait.

B. Study of Robot Leg Mechanism

In comparison with the industrial manipulators, the task of building an adaptable, autonomous walking machine is more difficult. Walking machines have more active degrees of freedom (DOF) than industrial robots. To enlarge the work-space of the leg, and thus enhance the machine's ability to adapt to the terrain, each leg should have at least 3 DOF, which results in a total of 12 DOF for a quadruped or 18 DOF for a hexapod. All those joints must be controlled adequately in real time. This also means that the hardware and software systems must meet more critical requirements than those formulated for industrial robot controllers. Moreover, fully autonomous vehicles use only on-board controllers and so those controllers have to be miniaturized to an utmost extent. Mechanical structure of a walking machine should not only imitate the leg structure of living creatures (e.g., insects, spiders), but should also take into account the actuating systems properties (e.g., size, weight and power of the motors) and constraints (e.g., size of the body and the leg work-space). The need for a general solution to the problem of robot legs design that can be used either by two-, four- or six-legged vehicles, is clear. However the ability to meet this need has been hampered by the lack of adequate joint mechanisms and controls.

Joint technology is a key problem in the development of such vehicles, because hip and ankle joints require, at a minimum, pitch and yaw motion about a common center with remote location of actuation sources analogous to our muscles and joints. The lack of simple, compact, cost-effective and reliable actuator packages has also been a major stumbling block in current designs. Ineffective joint design leads to unwieldy vehicles that compensate for the instability of their simple joints by means of additional legs.

III. MODELING BY USING PRO/E

A. Introduction to Pro/ENGINEER Wildfire 5.0

Pro/ENGINEER, developed by Parametric Technology Corporation (PTC), is one of the world's fastest growing solid modeling software. Being a parametric feature-based solid modeling tool, it not only unites the 3D parametric features with 2D tools, but also addresses every design-thought-manufacturing process. Based mainly on the feedback of the users of solid modeling, this tool remarkably user-friendly and it allows you to be protective from day one. Pro/Engineering wildfire 5.0 is powerful software used to create complex designs with great precision. The design intent of any three-dimensional (3D) modeling or an assembly is defined by its specification and its use. You can use the powerful tools of Pro/ENGINEER Wildfire 5.0 to capture the design intent of any complex model by incorporating intelligence into the design. To make the designing process simple and quick, this software package has divided the steps of designing into different modules. This means each step of the designing is completed in a different module. For example, generally a design process consists of the following steps:

- Sketching using the basic sketch entities.
- Converting the sketch into features and parts.
- Assembling different parts and analyzing them.
- Documenting parts and the assembly in terms of drawing views.
- Manufacturing the final part and assembly.

All these steps are divided into different modes of Pro/ENGINEER Wildfire 5.0; namely, the Sketch mode, Part mode, Assembly mode, Drawing mode, and Manufacturing mode.

B. Features of Pro/ENGINEER

Pro/ENGINEER Wildfire 5.0 is the latest release of the industry leading, integrated 3-D CAD/CAM/CAE software. With more than 350 new capabilities and enhancements, this release helps engineers overcome key barriers to product design. Pro/ENGINEER Wildfire 5.0 provides real-time dynamic editing, enables disruption-free design and improves the user experience with easy-to-use yet powerful, highly automated commands. In addition, this release sets the standard for CAD interoperability, offers seamlessly integrated applications across disciplines such as electromechanical design, and introduces breakthrough social product development capabilities. The new capabilities in Pro/ENGINEER Wildfire 5.0 dramatically improve the engineer's efficiency and productivity throughout the design process, from concept to manufacturing.

The integration of disparate applications such as the Pro/ENGINEER Spark Analysis Extension enables users to leverage multi-disciplinary design tools, which saves time and reduces errors from data translation. New social product capabilities, which are accessed directly from the Pro/ENGINEER user interface, improve collaboration

efficiency. According to PTC, the new Pro/ENGINEER Spark Analysis Extension is the only product that performs electrical clearance and creepage analysis directly on the CAD model geometry. Engineers can improve the speed and accuracy of their analysis, ensure product safety and ultimately reduce prototype and production rework time and costs. PTC says Pro/ENGINEER is also the only CAD system enabled for social product development. Enabled by Wind chill Product Point, the new capabilities in Pro/ENGINEER improve collective knowledge sharing, design collaboration and decision making.

C. The modeling steps by using Pro/ENGINEERING

Step 1: Select File->New. When the New window is correct, click OK. This will bring up the New File Options window. Select inlbs_part_solid. Pro/Engineer lets you work in either the metric or imperial system. Also you can make sheet metal or solid parts. We will be making a solid part in the imperial system, as shown in the fig.4.

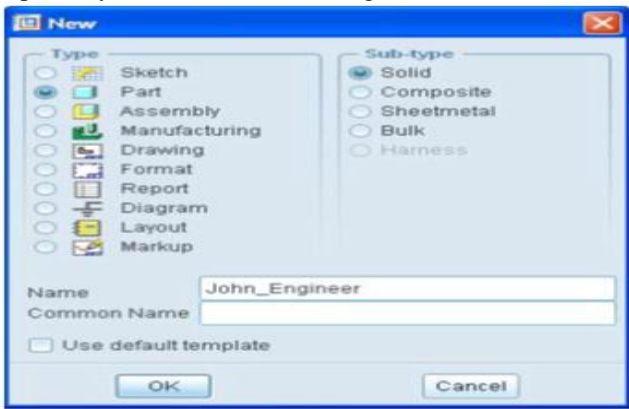


Fig.4. New File.

Step 2: When your window matches the window above the screen will change to the modeling view, which looks like this. The modeling view is used to view and edit three dimensional parts. Later we will see the Sketcher view, which lets us create two-dimensional sketches which we will then turn into solid parts, as shown in the fig.5.

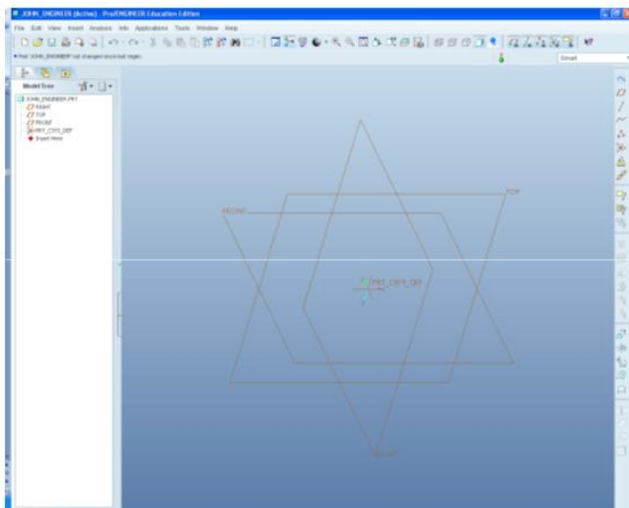


Fig.5.

Step 3: To create a body, we must sketch the outline in the two-dimensional sketcher view and then give it a thickness to extrude it into three dimensions. Click the Extrude Tool icon, which is in the toolbar on the right side of the screen.

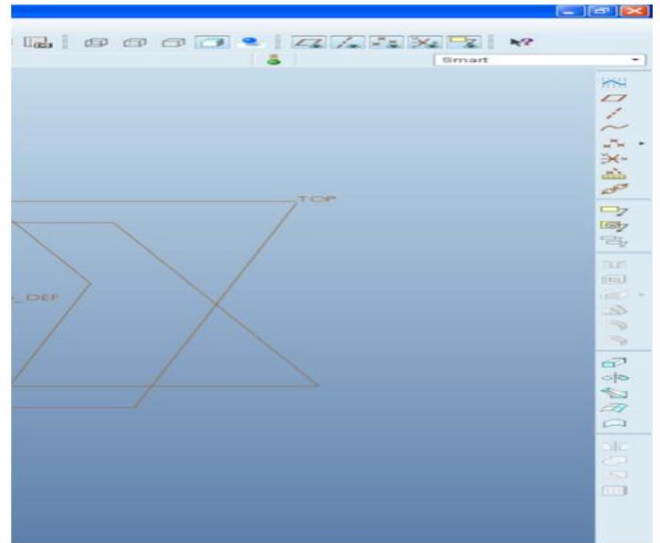


Fig.6.

The top of the screen will change to the following

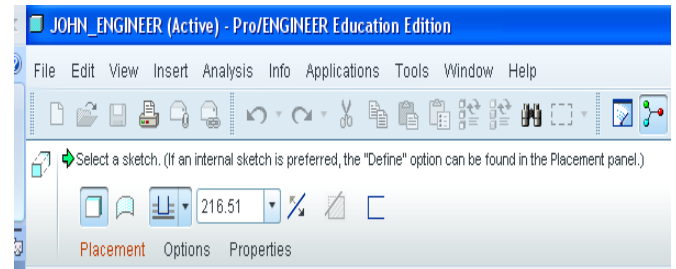


Fig.7.

Step 4: Press the Placement button (in Red). A tab will pop up as shown:

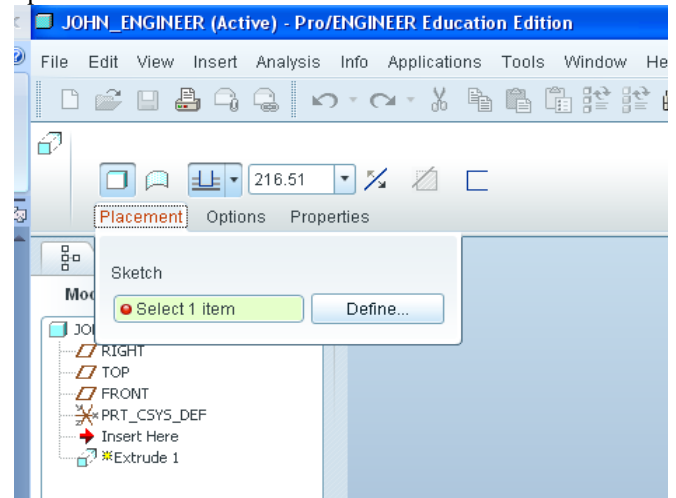


Fig.8.

Click the Define... button, a Sketch window will appear and the prompt at the top of the main screen will ask you to select a plane or surface to define sketch plane. We will be

Design and (Dynamic, Stress) Analysis of a Walking Robot Leg Mechanism at High Speeds

sketching on the plane labeled TOP. Mouse over the label of the TOP plane and it will highlight, as in the picture below.

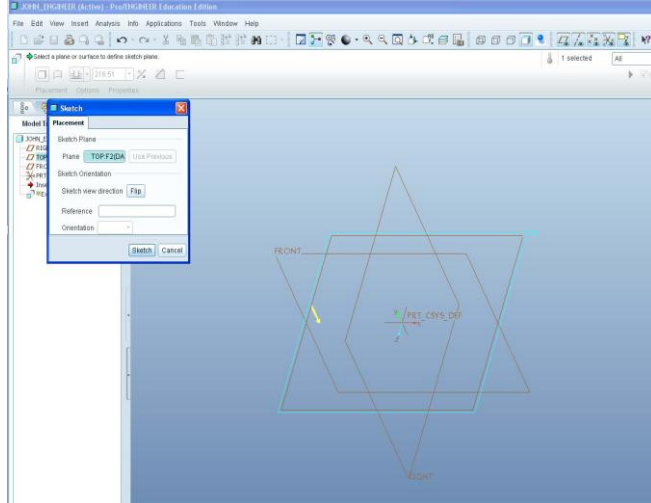


Fig.9.

The window should like this after clicking

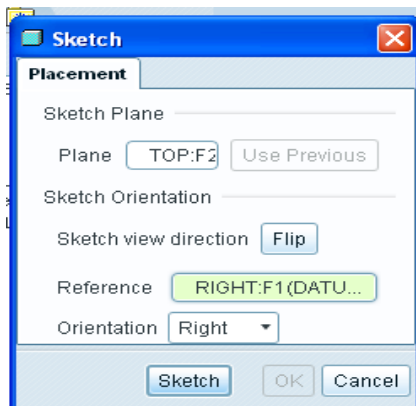


Fig.10.

Click on the TOP datum plane and click Sketch in the section window. This will bring up the References window. Click Close. The screen is now the Sketcher view. Sketcher is used to create or modify two dimensional geometry

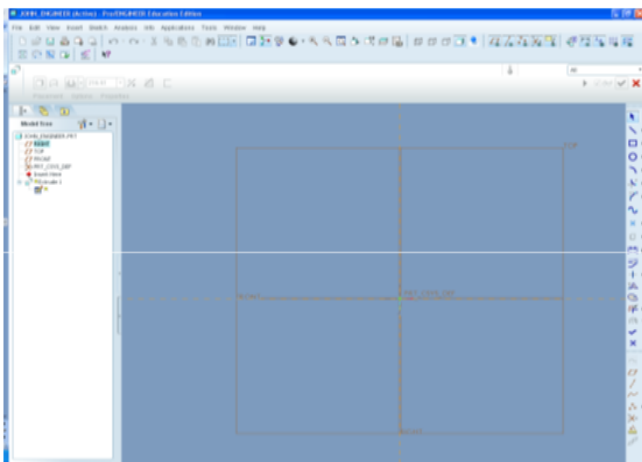


Fig.11.

A quick explanation of the sketcher toolbar is in order next. Not all the tools are used in this modeling.

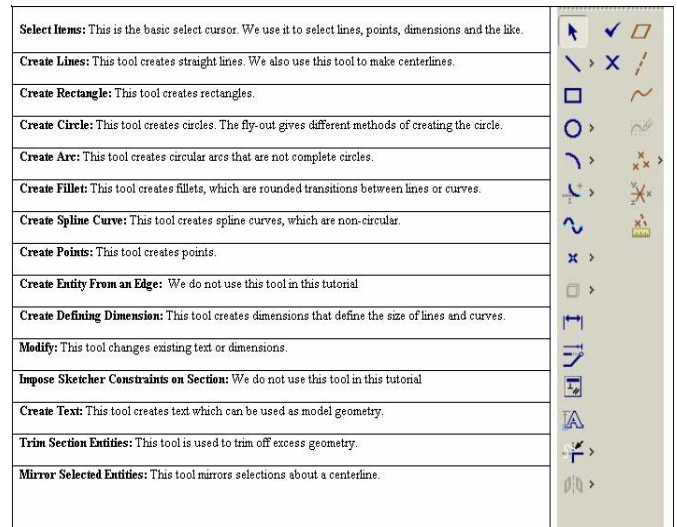


Fig.12.

IV. ANALYSIS AND MODELING BY USING ADAMS SOFTWARE

ADAMS stands for Automatic Dynamic Analysis of Mechanical Systems and was originally developed by Mechanical Dynamics Inc. (MDI). MDI was formed by researchers/developers of the original ADAMS code at University of Michigan, Ann Arbor, MI, USA. Later on, it was absorbed into McNeil Schindler Corp (MSC) in 2002. At the core of ADAMS is a large displacement code called ADAMS/Solver that solves nonlinear numerical equations. Models are built in text format and then submitted into ADAMS/Solver. In the early 90's, ADAMS/View was released which allowed users to build, simulate and examine results in a single Graphical User Environment (GUI). Today, MSC produces many general engineering analysis packages like MSC.NASTRAN, MSC.PATRAN, MSC.DYTRAN etc. and also packages which cater to industry specific users like MSC.ADAMS/Car, MSC.ADAMS/Rail, MSC. ADAMS /Engine etc. In this tutorial however, we'll be dealing with MSC.ADAMS alone. MSC.ADAMSTM Simulation Package is a powerful modeling and simulating environment that lets one build, simulate, refine, and ultimately optimize any mechanical system, from automobiles and trains to VCRs and backhoes. This tutorial is 1 intended as an introduction to using MSC.DAMS, specifically in the context of robotics, although its applications are much wider.

A. MSC.ADAMS

At the time of writing this tutorial, the running version was ADAMS 2010. The company offers subsidized versions of the software to students for academic/non-commercial usage. Please check the official site for pricing and other details. Once a copy is obtained, install the software following the instructions in their installation guide.

B. Starting a New Modeling Session:

When Adams/View is started, Adams/View displays a Welcome dialog box that lets one create a new modeling database or use an existing one. The Welcome dialog boxes also let one import modeling data and specify the working directory. Adams/View also displays the Welcome dialog box when one uses the New Database command to create a new modeling database in which to store your models. The GUI screen with Welcome dialog box is shown below.

Initial Adams/View Window

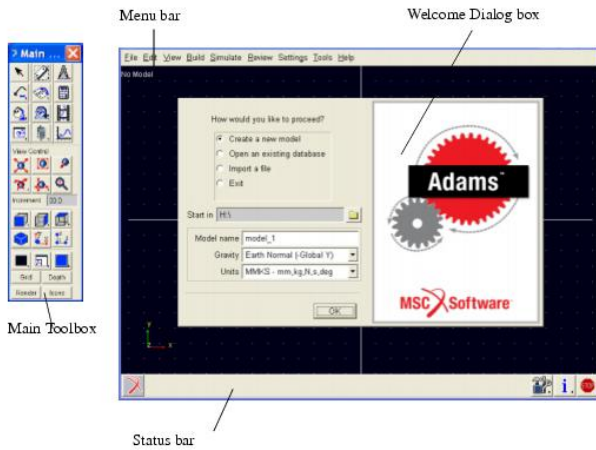


Fig.13. ADAMS GUI with Welcome Dialog Box.

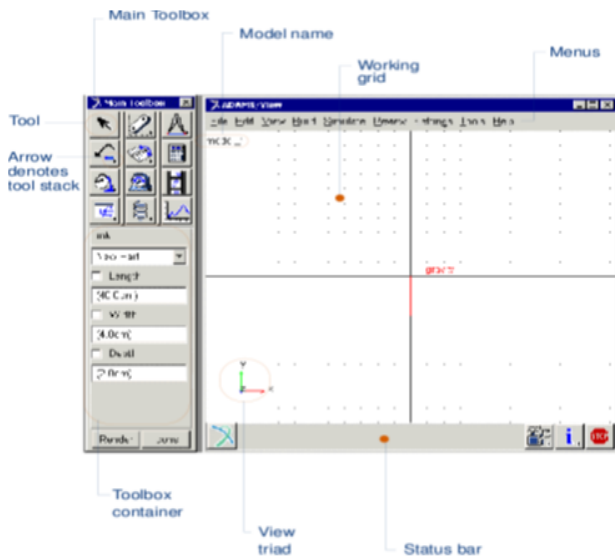


Fig.14. ADAMS View Interface.

C. Creating a Modeling Database:

When one first starts working with Adams/View, it provides options for creating a new modeling database. One can also create a new modeling database anytime during the Adams/View session. Only one modeling database can be open at a time, but it can contain multiple models. Do one of the following to create a new modeling database:

- On the File menu, select New Database.
- On the Standard toolbar, select the New Database tool.

D. Saving a Modeling Database:

The user can use the Save Database command to save the current modeling database as an Adams/View binary file. Saving the modeling database as a binary file saves all modeling information, including any customization changes made by the user. To save an existing modeling database:

a) Select one of the following:

- On the File menu, select Save Database.
- On the Standard toolbar, select the Save Database tool.

Before saving the file, Adams/View displays a message asking the user if it wants to create a backup file of the current database file.

b) Select one of the following:

- Yes - Creates a backup file of the existing database file and saves the database. When Adams/View creates a backup file, it adds a % to the end of the file extension (for example, model.bin %).
- No - Saves the database without making a backup copy of the existing database file.
- Cancel - Exit the command without saving the database.

One can save the current modeling database to a binary file with a new name. This lets one keep several versions of the database under different names and reduces the risk of losing the work if one inadvertently change or delete the model.

B. Insert the Modeling to ADAMS

After modeling by using Pro/ENGINEERING what we have discussed in previous chapter, now will insert the assemble modeling in ADAMS to get analysis. As shown in figure below.



Fig.15. Full Assemble Modeling in ADAMS.

C. Analysis of Robot Leg Mechanism

Real Constants :

- Links dimensions
- Width =2.0 cm.
- Depth =2.0cm.

Design and (Dynamic, Stress) Analysis of a Walking Robot Leg Mechanism at High Speeds

Material properties :

Material Type	MODEL_7_aluminum
Density	2.74E-06 kg/mm ³
Young's Modulus	7.1705E+04 newton/mm ²
Poisson's Ratio	0.33

Fig.16.

D. Dynamic Analysis of Links and Motion in This Robot Leg Mechanism, at N=22 rpm: In case four bar mechanisms, is an important to get analysis at A, B points, however, here will analysis by using ADAMS to get all information what are required in robot leg mechanism case. Here, will use various values of speed motion and analysis them to get velocity, displacement and acceleration plots, as shown down.

(a) Analysis part (link) number 5, at point B (marker 52), in N=22 rpm case.

Here, at point B will see the Motion and Translational for displacement, velocity, and acceleration plots in X, Y and Mag (Magnitude) components, as follow.

1. Translational Displacements:

Translational Displacement in Mag Component.

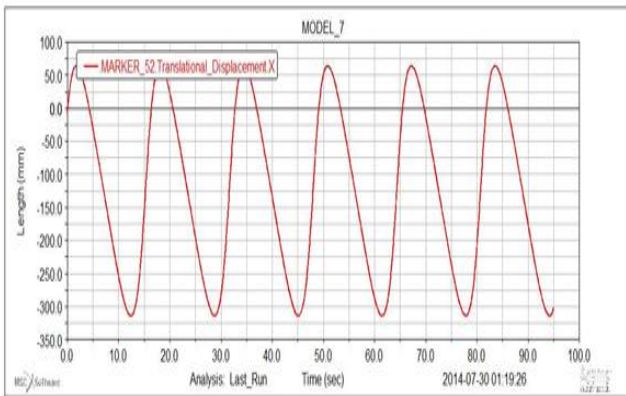


Fig.17. Translational Displacement in X Component.

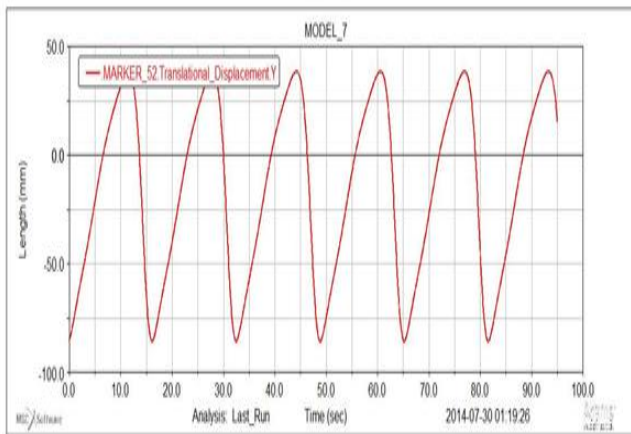


Fig.18. Translational Displacement in Y Component.

2. Translational Velocities:

Translational Velocity in Mag Component.

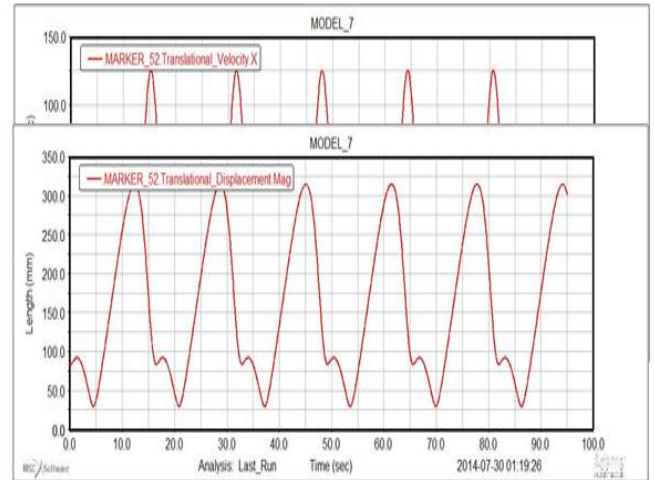


Fig.19. Translational Velocity in X Component.

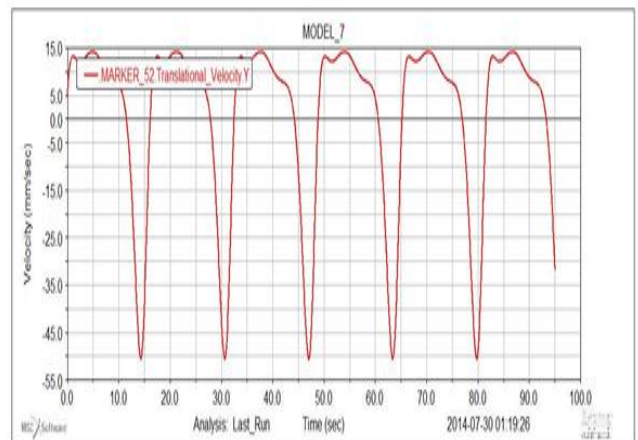


Fig.20. Translational Velocity in Y Component.

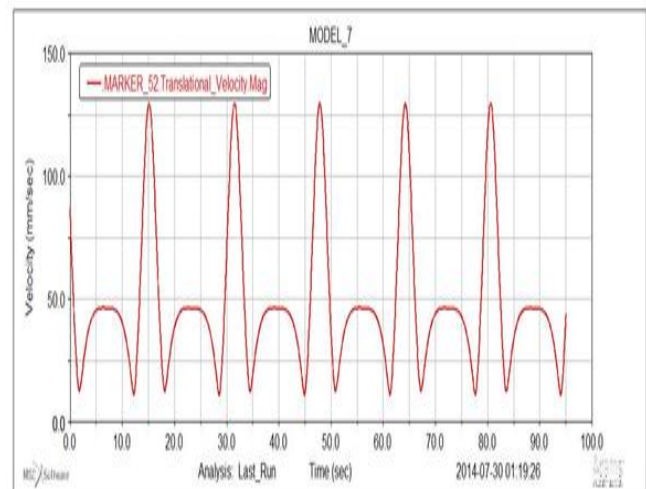


Fig.21.

3. Translational Accelerations:

Translational Acceleration in Mag Component.

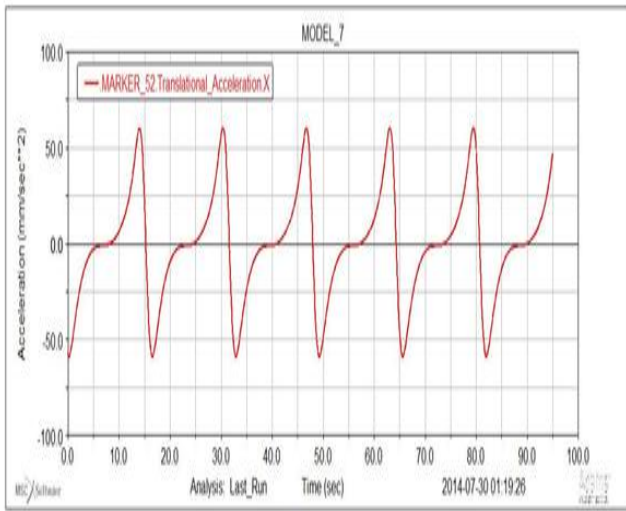


Fig.22. Translational Acceleration in X Component.

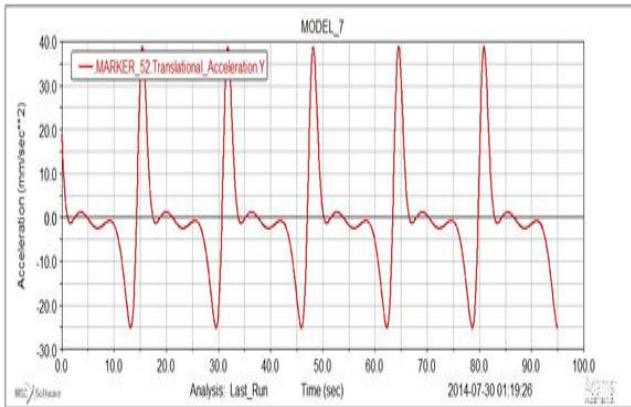
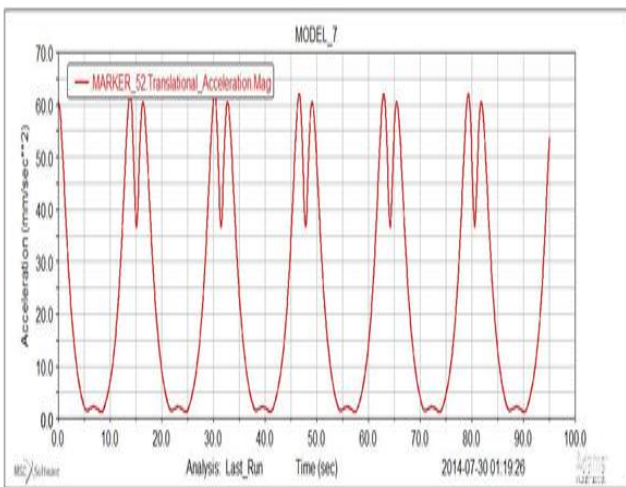


Fig.23. Translational Acceleration in Y Component.



V. RECOMMENDATIONS AND CONCLUSIONS

In this thesis, it is easy to see from analysis it had carried out, the deformation during rotate the robot leg by examine the plots; the robot leg mechanism had failed when the speeds of velocity it had increased to various values. In this project had been discussed how to get the highest speed value to keep the leg without fail and can the robot leg

mechanism operated with. The numerical analysis has been simulated by using MATLAB as well with ADAMS software. The modeling by using Pro/ENGINEERING, the modeling was by model part after part and then assembled together to get a fully model to test it in ADAMS. The dynamic analysis references points A, B of the mechanism displacements, velocities, and accelerations have been found considering the links are elastic members with the help of ADAMS.

The speed of crank is increased in steps of two times, three times, four times and five times. Finally it had been observed that for the crank speed at five times i.e., at N=110 rpm the displacements, velocities and accelerations are found by using ADAMS are comparable with rigid body magnitude components found by ADAMS after transformation to the flexible body by FEM. The dynamic analysis plots found by ADAMS for the B, A points(part5, and part9). The increasing in gradually in velocity showed the limited of speed value. If the mechanism is allowed to operate beyond this speed (N= 110 rpm) the required path trajectory will not be followed accurately and also jerks might be occurred in the mechanism. The stresses and deformation develop are high and members may be fail on this speed, and that what really happened in N =110 rpm. And this chapter focuses on the dynamic deformation during increase the velocity value by examine the change in the plots.

In deed the results showed the maximum velocity value make the robot leg mechanism fail. Areas of further research and improvement would be; A physical model of Robot Leg Mechanism can be prepared and inspected experimentally to check its performance by increasing the crank input speed. Feedback control system can be incorporated to make sure the required trajectory of the mechanism at higher speed remains unaffected. Traction force due to contact between foot and ground and friction at joints can also be incorporated in the analysis. Increase the actuators number and choose a physical model of robot leg mechanism with increasing in velocity values. Different across section of members can be test.

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Design and (Dynamic, Stress) Analysis of a Walking Robot Leg Mechanism at High Speeds

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