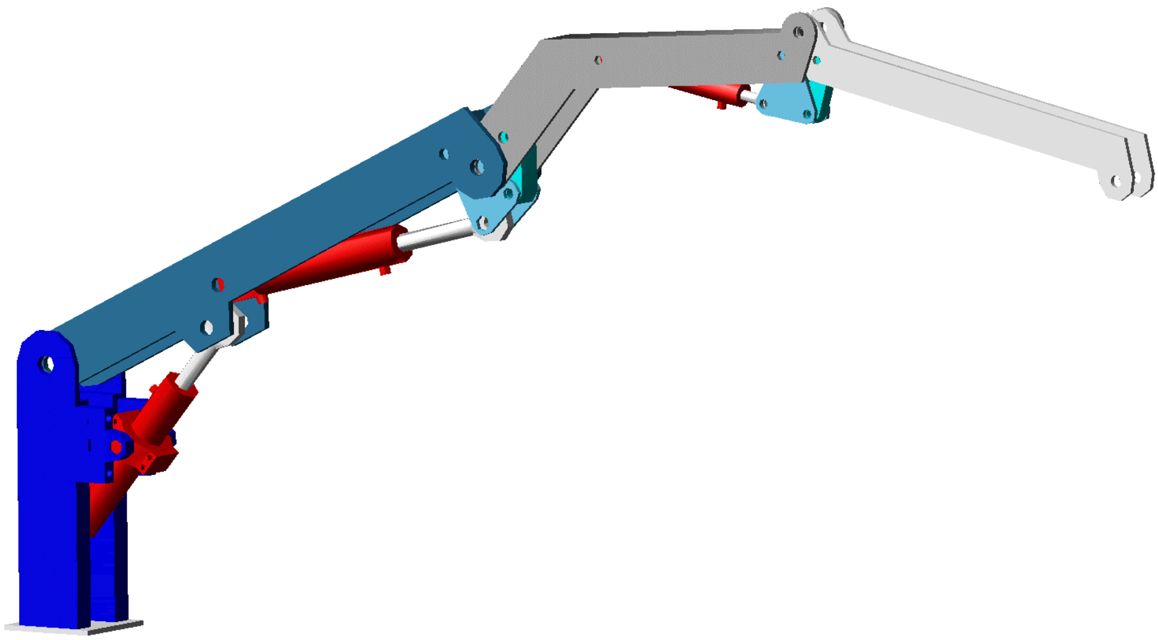
Design and development of a hydraulic Manipulator with Mechanism/Pro



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Abstract

Highly flexible handling devices which carry loads or generate great forces, demand the use of hydraulic driven manipulators. Of crucial importance here are type and quality of the mechanism conveying motion between the jibs. This paper will introduce designs of mechanism which can be applied to swing the arms of the manipulator. The development aims at computer aided design, serves to automate the process of construction, and to simulate the three-dimensional drive of mechanisms. In this process, both CAD-Software Pro/Engineer and Mechanism/Pro, the integrated multi-body system analysis module, will be applied.
The CAD system Pro/Engineer creates a consistent database which serves as basis for a highly automated design of such mechanisms. The fully parametric structure permits the change of kinematic variables at any time in order to study effects on system behaviour. The integration of the kinematic developmental environment into the CAD system significantly increases the efficiency of the whole developmental process, as the mechanism hardly ever mirrors the complete product, but usually only a small part of the whole system. Designing the structure with Pro/Engineer and Mechanism/Pro makes it possible to transfer the complete construction directly into ADAMS without the manual use of interfaces and in accordance with virtual product development.

Introduction

Highly flexible handling devices are used wherever great power dependent on place and/or time is needed. Especially the mobile use of hydraulic drives is quite common. Mainly in the building and constructing industry, a wide spectrum of possible applications opens up. Examples are construction robots, as well as assembly, mounting, cleaning, inspection, redevelopment and demolition systems for large buildings. Apart from the building industry, cleaning systems for aeroplanes and ships, rescue systems in case of disaster and loading systems for goods traffic are common and highly useful.
Important signifying quantities such as range, registration and repeating accuracy, as well as degrees of freedom in space orientation demand mulitlink robot and manipulation systems which have to be collapsible, small and mobile in order to transport them and use them in restricted spaces. Figure 1 shows the framework of a multilink manipulator. Complex mechanisms demand the use of computer-assisted calculation and design procedures so that different construction variations can be studied efficiently and in short periods of time. CAD-Software and its integrated modules for mechanical system simulation such as Mechanism/Pro are ideally suited for this.

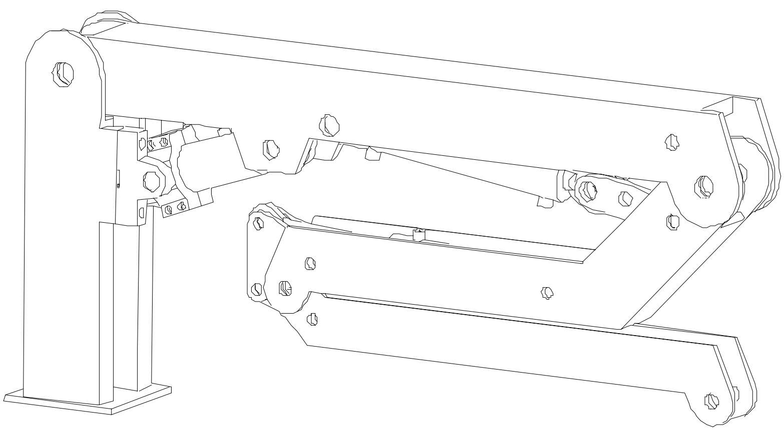

Figure 1: Multilink manipulator

Mechanisms for motion transfer between brackets

The framework of the manipulator shown in figure 1 consists of three moveable arms which are moved by three hydraulic cylinders. The moveable arms are driven via a mechanism which ensures a defined relational swinging movement of the arms in relation to each other and converts the transitional drive into a rotating drive.

Deflecting mechanisms

From the mechanism system of n-part kinematic chains, forms, which are suitable for power transmission between brackets, can be deduced. Possible constructions are based on four- to six-part kinematic chains. Table 1 shows a systematic overview over suitable forms of mechanisms. Based on the approach in rows 2, 3 first models were developed, analysed and compared to each other. Figures 2 and 3 show the respective constructive solutions.

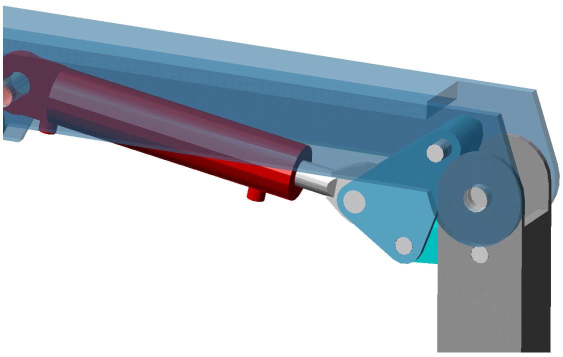

Figure 2: four-joint mechanism, Watt

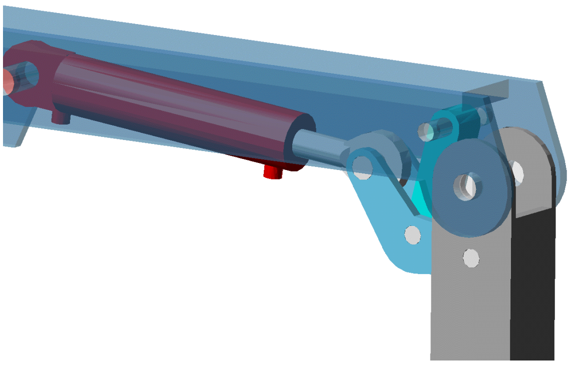

Figure 3: four-joint mechanism, Stephenson

Based on the constructional solutions shown in figures 2 and 3, the maximum slewing angle was deduced, dependent on the cylindrical lift. Figures 4 and 5 show

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the resulting diagrams. With Watt's mechanism system, a larger slewing angle can be achieved in the realised construction.

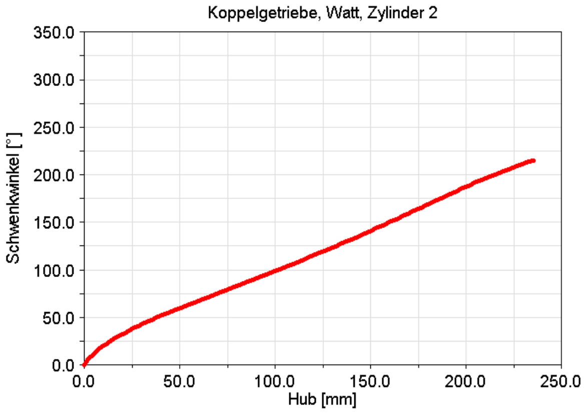


Figure 4: Force hydraulic cylinder, Watt

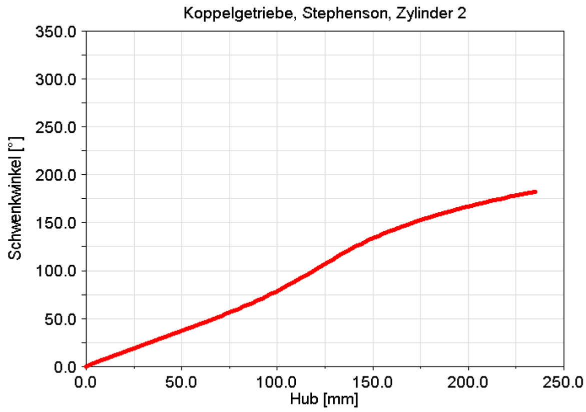
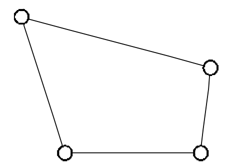
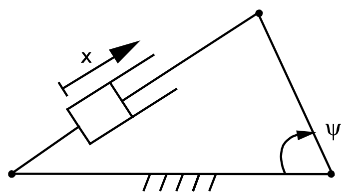
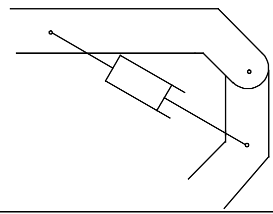
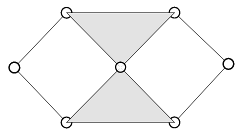
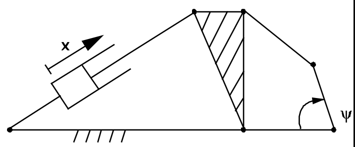
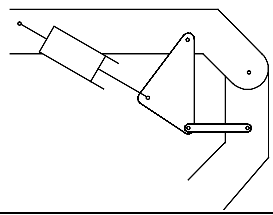
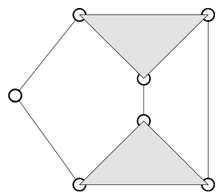
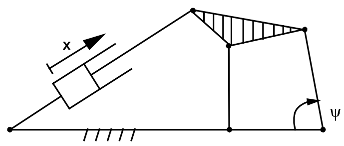
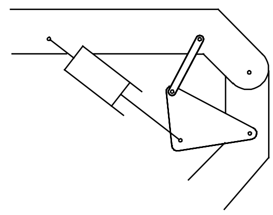
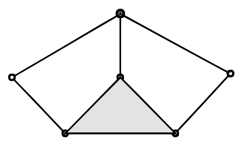
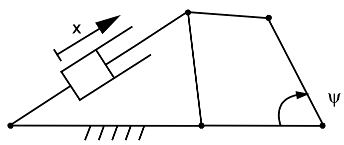
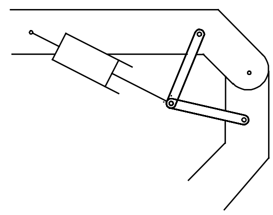


Figure 5: Force hydraulic cylinder, Stephenson

	Mechanism	links	principle	design	construction
1	4-joint mechanism	4			
2	6-joint mechanism Watt	6			
3	6-joint mechanism Stephenson	6			
4	6-joint mechanism with double joint	6			

The force needed to extend the cylinder was another test criterion. For this, a two-bracket manipulator was designed and a weight of 1,500 N fixed to its end. Figure 6

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shows the manipulator with a partly extended end-bracket. The necessary cylinder force was measured under the following premises: in one second, the end bracket is driven from 0 to a lift velocity of 50 mm/s with a STEP5 function. This speed is then kept constant to the end stop. The cylinder force needed for this was measured with both mechanisms. Figures 7 and 8 show the results.

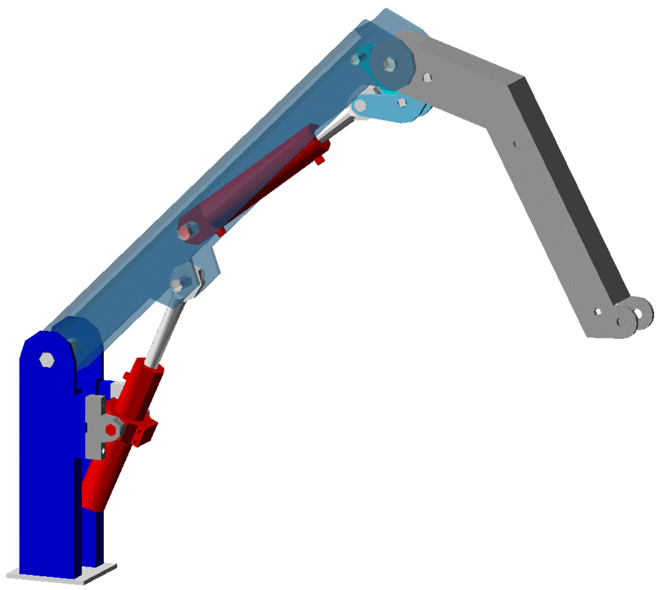

Figure 6: Manipulator to measure cylinder force

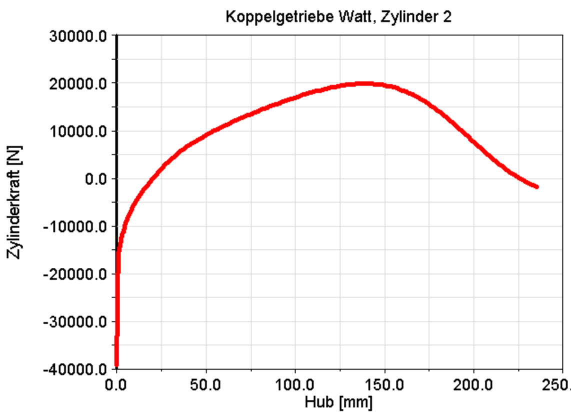

Figure 7: Cylinder force, Watt

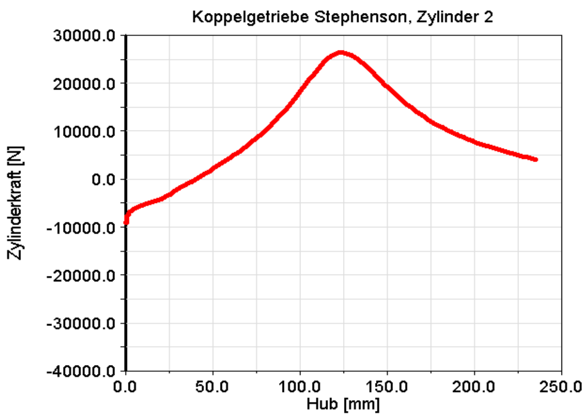

Figure 8: Cylinder force, Stephenson

Based on the mentioned results, a first virtual prototype was designed. Figure 9 shows the manipulator in working position. The structure is fully parametric, so that each system parameter can be changed at any time in order to judge the effects on the whole system. The path assigned to the end-effector can be based on any orbit and therefore on any geometry from Pro/Engineer. Figure 10 shows the prototype with a given orbit, e.g. while working on a wall of a factory hall.

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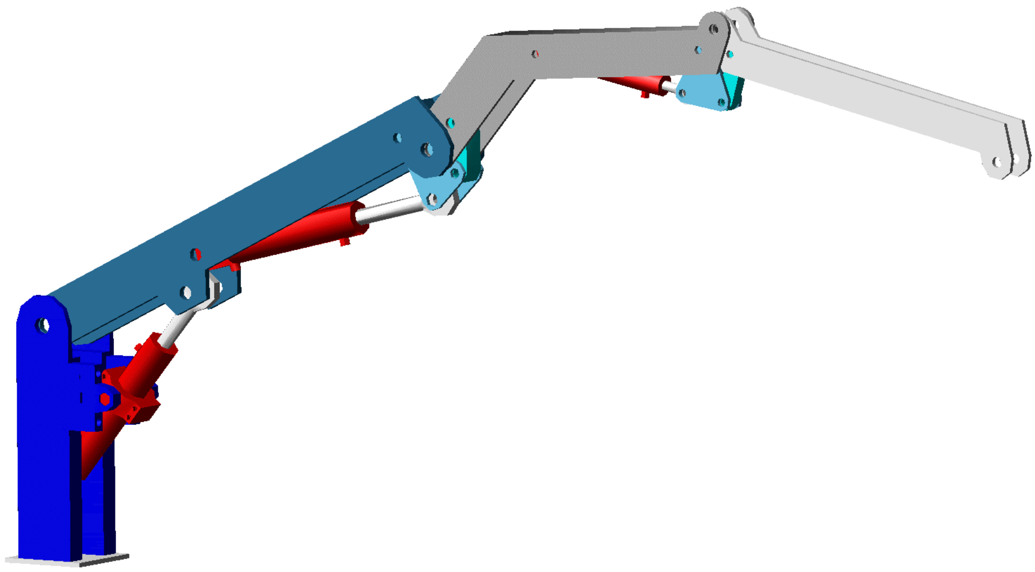

Figure 9: Virtual Prototype, manipulator in working position

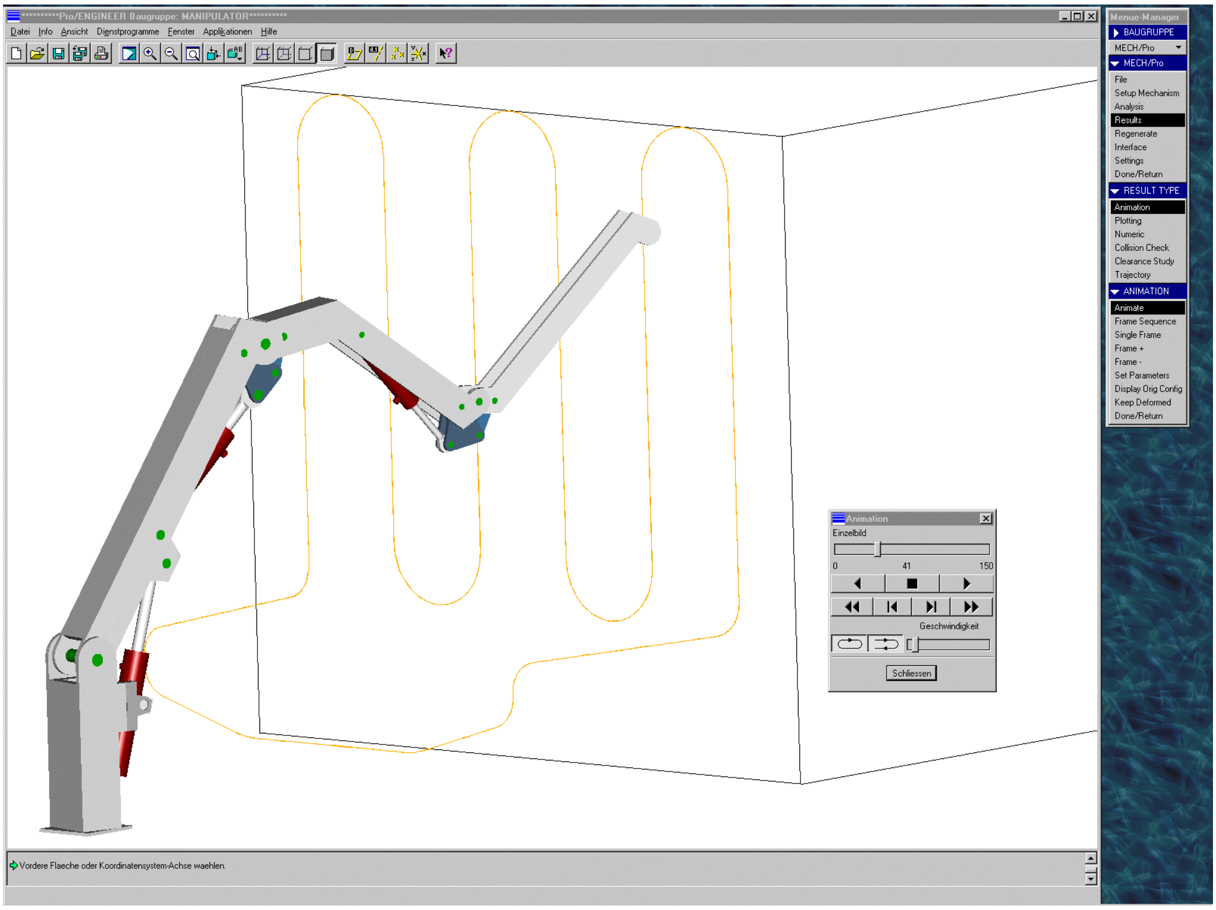

Figure 10: Simulation inside Pro/Engineer using Mechanism/Pro

Steps in Modeling and Simulation

Figure 11 shows the steps to perform, to create, calculate and modify the hydraulic driven manipulator. The steps are divided into sections being done within Pro/Engineer and ADAMS/View.

Pro/E	1.	Create Parts
	2.	Assemble Parts with Pro/Assembly
	3.	Constrain Parts with Mechanism/Pro
	4.	Choose Pro/E Geometry in M/Pro which defines a M/Pro-Curve, acting as path for the hand of the manipulator

↓ transfer to ADAMS/View (*.adm, *.stl or *.slp)

ADAMS	5.	Define Motions (Displacement of time) acting on the Hand of the Manipulator using a user written macro (see below)
	6.	Calculate Manipulator and Perform Simulation
	7.	Measure Displacement of time in the 3 hydraulic cylinders and save as test data

↓ back to Pro/Engineer

Pro/E	8.	Define the hydraulic cylinder Motion by importing the measured test data
	9.	Calculate Manipulator and perform Simulation
	10.	Perform Collision Study
	11.	Generate Plots (Pro/E Drawings)
	12.	Measure Characteristics (e.g. cylinder force)
	13.	Modify or refine the Model

Figure 11: Steps to generate a manipulator with Mechanism/Pro

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The macro in the ADAMS/View section defines the Motions of the manipulators hand in x,y and z-Direction based on the curve choosen in Pro/E.

```
!$Curve_Name:t=data_element
!$Spline_Name_Prefix:t=string
!
variable create variable=tmp1 real=({})
variable create variable=tmp2 real=({})
variable create variable=tmp3 real=({})
variable create variable=tmp4 real=({})
!
for variable=tmp0 start=1 end=(eval($Curve_Name.matrix.row_count))
  variable modify variable=tmp1 real=(eval(0.1*tmp0-0.1)) &
      index=(eval(tmp0))
  variable modify variable=tmp2 real=(eval($Curve_Name.matrix.values[tmp0,1])) &
      index=(eval(tmp0))
  variable modify variable=tmp3 real=(eval($Curve_Name.matrix.values[tmp0,2])) &
      index=(eval(tmp0))
  variable modify variable=tmp4 real=(eval($Curve_Name.matrix.values[tmp0,3])) &
      index=(eval(tmp0))
end
!
if condition=(DB_EXISTS(eval($Curve_Name.parent)//".$'Spline_Name_Prefix'_x"))
  data_element modify spline spline_name=(eval($Curve_Name.parent)//".$'Spline_Name_Prefix'_x") &
    x=(eval(tmp1))  &
    y=(eval(tmp2))  &
    units=length
  data_element modify spline spline_name=(eval($Curve_Name.parent)//".$'Spline_Name_Prefix'_y") &
    x=(eval(tmp1))  &
    y=(eval(tmp3))  &
    units=length
  data_element modify spline spline_name=(eval($Curve_Name.parent)//".$'Spline_Name_Prefix'_z") &
    x=(eval(tmp1))  &
    y=(eval(tmp4))  &
    units=length
else
  data_element create spline spline_name=(eval($Curve_Name.parent)//".$'Spline_Name_Prefix'_x") &
    x=(eval(tmp1))  &
    y=(eval(tmp2))  &
    units=length
  data_element create spline spline_name=(eval($Curve_Name.parent)//".$'Spline_Name_Prefix'_y") &
    x=(eval(tmp1))  &
    y=(eval(tmp3))  &
    units=length
  data_element create spline spline_name=(eval($Curve_Name.parent)//".$'Spline_Name_Prefix'_z") &
    x=(eval(tmp1))  &
    y=(eval(tmp4))  &
    units=length
end
!
variable delete variable=tmp1
variable delete variable=tmp2
variable delete variable=tmp3
variable delete variable=tmp4
```

Figure 12: ADAMS/View Macro

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Overview about Mechanism/Pro

Mechanism/Pro is a easy-to-use mechanism design and simulation tool for designers and engineers who work with Parametric Technology Corporation's Pro/ENGINEER software. One-button transfer to ADAMS enables you to run full kinematic, static, quasi-static and dynamic simulations of your model inside the Pro/E environment. This increase efficiency and productivity since you do not have to learn another software interface. Defining the mechanism, analysing it, and animating the results are all performed within the familiar Pro/ENGINEER interface.
You also have confidence that your assembly will perform as expected without parts colliding once the assembly begins moving. Because MECHANISM/Pro uses your original Pro/ENGINEER geometry for interference and clearance studies, inaccuracies based upon geometric approximation do not occur.
With MECHANISM/Pro, you can easily convert an assembly created in PTC's Pro/ASSEMBLY into a complete mechanical system design by adding constraints, forces and motion generators.
You connect parts from a menu of standard joint and joint primitive types by selecting existing Pro/ENGINEER data and geometry by point-and-click operations, such as At Center and At Vertex. This allows fast and accurate placements of joints, which are fully associative to the Pro/ENGINEER geometry. When the geometry changes, the joints are automatically updated to reflect these changes.
You can create full-system assemblies for all analysis types in the Pro/ENGINEER environment using our embedded MECHANISM/Pro software, then transfer your designs to ADAMS/View within the real Pro/E geometry via Render- (.slp) and Stereolithography (.stl) files including the mass and inertia properties.

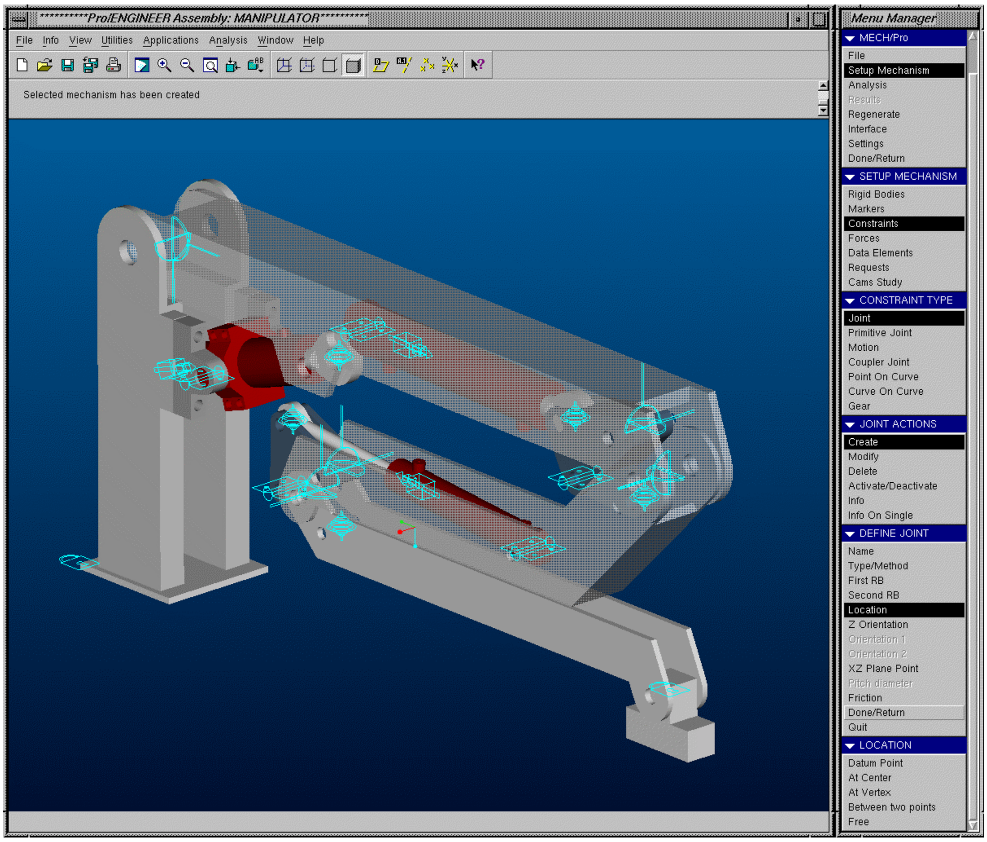

Figure 13: Manipulator with Mechanism

New ADAMS Entities in MECHANISM/Pro 10.1

Markers

Markers are coordinate systems belonging to a rigid body. Markers are fundamental ADAMS entities that you can use to define complex entities. Most of your mechanisms can be defined without creating any marker.

Constraints

- Primitive Joints (Inline, Inplane ,Orientation, Parallel Axis, Perpendicular)
- Coupler Joints (Coupling 2 or 3 joints)
- Gears

Forces

- Multi Components Forces

  A force element that consists of three orthogonal translational force components and three orthogonal torque components. In ADAMS/Solver these types of forces are called GFORCES or General Forces.

- Flexible Beams

  You can define straight beams, beams on Pro/ENGINEER Datum Curves and beams defined picking a list of Pro/ENGINEER Datum Points.

Data Elements

- Curves

  You can define curves referencing geometric edges and datum curves or reading curve points from an external ascii file. Defined curve entities can be used to define **Point On Curve** and **Curve On Curve** constraints. You can simply export curves to ADAMS/View if required.

- Spline, Variable, Array

  You can define ADAMS/Solver SPLINE, VARIABLE, ARRAY entities that you can reference in motion and force functions.

- Measure

  You can define and plot displacement/velocity/acceleration measures between markers. Measures can be defined and plotted also after the simulation has been performed!

Enhancements on existing ADAMS Entities

Joints

You can add Friction to Revolute and Translational joints.

Motions

You can define a motion generator acting between a pair of markers.

Ground Management

MECHANISM/Pro automatically creates the ground rigid body for you and names it as "GROUND". The ground rigid body created by MECHANISM/Pro is "empty"; this means that by default no Pro/ENGINEER assembly/part belongs to it.
You can modify the ground rigid body (adding/removing Pro/ENGINEER assemblies/parts, changing its name) but you can't delete it.

Simulation Enhancements

Run a Custom ADAMS/Solver

You can specify a custom ADAMS/Solver to be used instead of the standard one during the simulation of your mechanism.

Modify ADAMS/Solver Settings

You can modify the settings of each analysis type (Kinematic, Dynamic, Static) entering data in auxiliary dialog boxes.

Mechanism Merging

You can merge a previously defined mechanism into a bigger one. Define a mechanism on a certain "small" assembly being a subassembly (even with multiple instances) of a bigger one. While you are defining your mechanism on the "big" assembly you can merge (import) the already defined small mechanism.

Gui Enhancements

Entity Selection

Rigid bodies and all the entities that are represented with a icon can be selected either by picking or selecting their names from a name list.

Modify the Entities

Entities can be modified, you don't need to delete an entity and create it again.

Activate/Deactivate Entities

Most commonly used entities can be activated/deactivated, you don't need to delete and create an entity if you want to simulate the mechanism without it.

Single Entity Infos

You can show an information window containing the properties of a single selected entity; the entity can be selected also by pick.

Auxiliary Dialog Boxes

A File Browser and Auxiliary dialog boxes appears for entering data.

On The Fly Orientation Flipping

You can flip on the fly the orientation of an entity, just click the right mouse button.

New Filing Method

The state of your mechanism can be saved in mechanism definition file (.mpr extension) having a completely new format; it is not a ADAMS/Solver Dataset file.

The .mpr file containing your mechanism definition includes the following information:

- The name of the Pro/ ENGINEER assembly related to the mechanism defined in the file.
- Various MECHANISM/Pro interface settings such as Icon Size and Icon Visibility.
- The current associativity between your Pro/E parts and subassemblies and your rigid bodies.
- The list of all defined entities with the associativity with your Pro/E features and their properties.
- Analysis settings:

Embedded Plot Editor

The MECHANISM/Pro Plot Editor is a powerful visual tool that allows you to define the plottings you want to see and to examine after your simulations inside the Pro/Engineer environment:

- The Plot Editor allows you to define as many plots you desire and each plot can contain as many curves you want.
- You can define plot curves getting data from different analysis results.
- Defined plots can be drawings inside the Pro/ENGINEER environment or can be exported to the ADAMS/Post Processor tool.

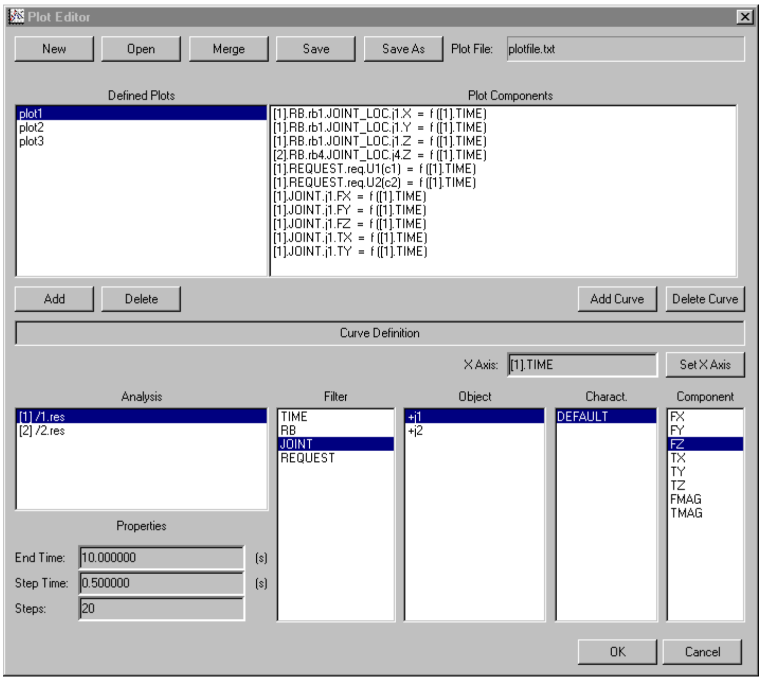

Figure 14: MECHANISM/Pro Plot Editor

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