

Figure 1: Torque-pendulum

Torque-Pendulum Tutorial - Part 1: This is an MSC.ADAMS tutorial that focuses on basic steps in combining a mechanical system model developed in ADAMS with a dynamic system model of an actuator and controller. This part deals with building the basic pendulum model and simulating the initial condition response.

The mechanical model is a simple link used to represent a compound pendulum suspended at a single pivot point. The link is constrained to oscillate in a plane by using a revolute joint at the pivot point.

1. In A/View, create two design points to specify the two end points of the LINK that will be created. By using design points, the length of the LINK can be easily modified later. Name one of the design points POINT_base and the other POINT_tip.
2. Create a LINK using the two design points defined. Use steel as the part material, and name the part 'pendulum'. Make sure the width of the pendulum is 40 mm and the thickness (depth) is 20 mm. Adjust the design point positions so the length from base to tip points is $L_p = 350$ mm (this can be done from the "Tools→Table Editor..." menu, which brings up an editing table that contains database parameters such as points, design variables, etc.).
3. Identify the markers that define the link end points. For example, they may be called MARKER_1 and MARKER_2. Note that these marker orientations may not necessarily line up with the GLOBAL axes. Make note of the marker names.
4. Constrain the LINK to ground by using a revolute joint so that the LINK forms a pendulum that can swing in the current view plan, assumed to be the front view.
5. The pendulum angular deflection about the base, θ_z , is defined positive counterclockwise from the vertical resting position (as shown). In this case, the ATAN2() function is used, so confirm that the proper definition is: $\text{thetaz} = \text{ATAN2}(\text{DY}(\text{MARKER}_2, \text{MARKER_base}), \text{DX}(\text{MARKER}_2, \text{MARKER_base})) + \text{PI}/2$.

The unforced response of the pendulum after it is released from an initial angle, θ_{zo} , will be studied using this model. To set this initial angle, modify the POINT_tip design point so that it has (x,y) coordinates specified by: $x_{tip} = L_p \sin(\theta_{zo})$ and $y_{tip} = L_p \cos(\theta_{zo})$. These values can be changed manually using the Table Editor, but it is preferred to use this example to illustrate how parameterization can be used in ADAMS.

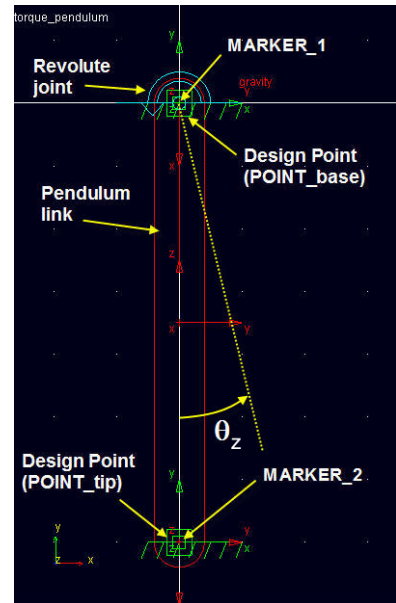


Figure 2: A/View Model

Define the design variables shown in Table 1. By clicking on any of the fields, and then right-clicking on the upper field as shown, the pop-up menu allows parameterization by using the selections indicated. For example, the expression builder was used to define x_{tip} and y_{tip} . Note that these definitions require θ_{zo} to be specified in degrees. Once the initial angle can be modified, the response can be simulated. An example response for $\theta_{zo} = 20$ degrees shown in Figure 3.

End of Part 1. In the next part, a simple model of a hydraulic motor is integrated into the ADAMS model of the pendulum. The objective is to position the pendulum at a desired angle, θ_{zd} , using the hydraulic motor.

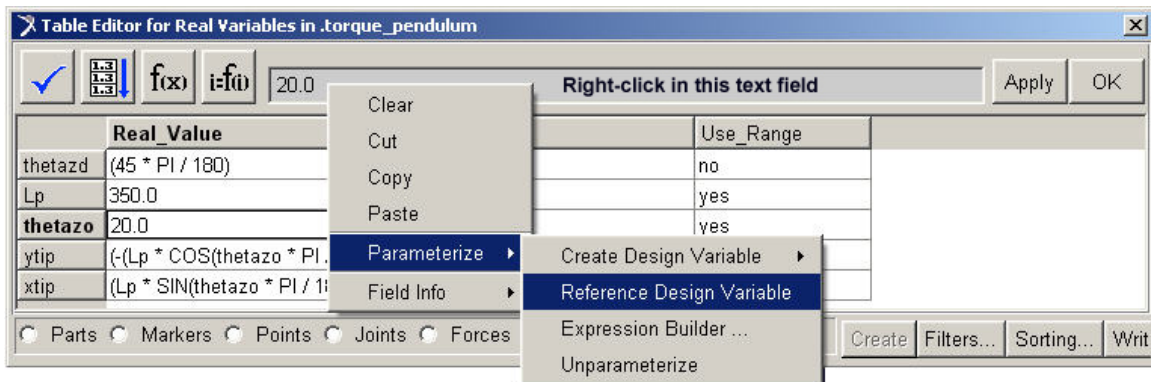


Table 1: Table Editor viewing of design variables.

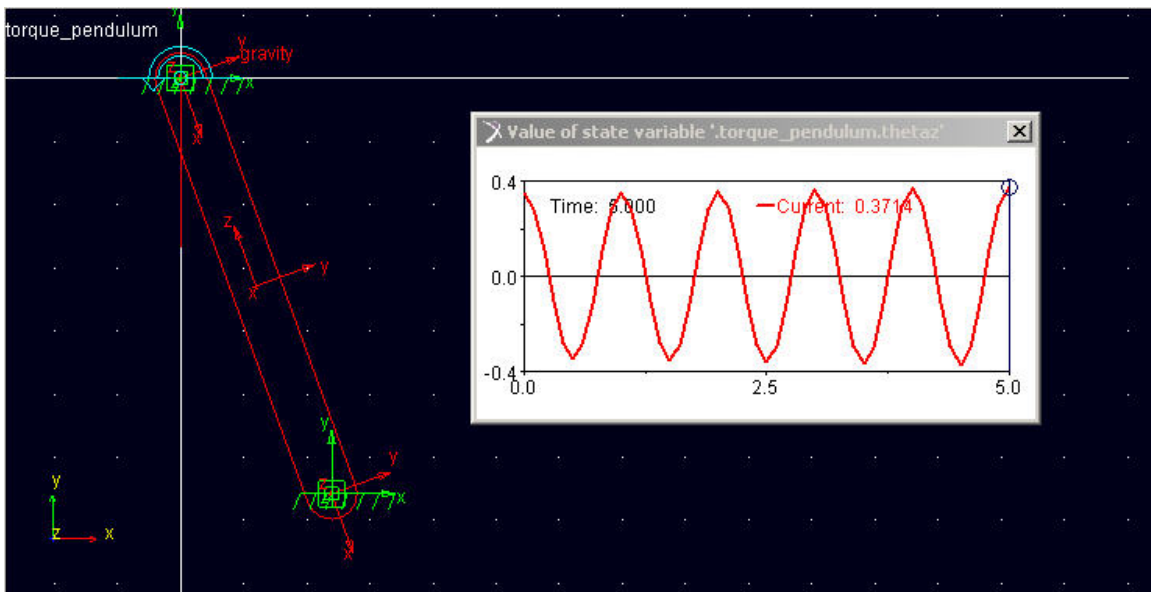


Figure 3: Unforced response of the pendulum given initial angle of 20 degrees.

Torque-Pendulum Tutorial - Part 2: This part of the tutorial focuses on integrating a simple hydraulic motor model and position controller with the pendulum model built in ADAMS.

A hydraulic motor transforms power from hydraulic to mechanical form, ideally following the expressions,

$$\begin{aligned} T_m &= D_m P_m \\ Q_m &= D_m \omega_m \end{aligned}$$

where m refers to ‘motor’ variables, D_m is the motor displacement (e.g., relates amount of fluid displaced per unit revolution). Real motors have friction and leakage, but these effects will be neglected here. Motors may also be influenced by compressibility of the fluid, and this can be accounted for by tracking volumetric fluctuations within the motor housing. This is a dynamic effect that will be included in this model because it allows us to show how a dynamic system model can be integrated within the ADAMS/View modeling environment.

It will be assumed that flow can be specified by a controlled source of flow (a pump) that provides flowrate, Q_p . This flowrate will be modeled as an input (later specified by a controller). We consider Q_p as the flow through the motor, but there is flow induced by the rotational motion, $Q_m = D_m \omega_m$, and the difference flow, $V_f = Q_p - Q_m$ contributes to stored energy in the fluid. This equation provides a differential equation for V_f , which defines the pressure, $P_f = V_f / C_f$. In this model, this is the motor drive pressure, $P_m = P_f$, so the torque is, $T_m = D_m P_m = D_m P_f = D_m V_f / C_f$.

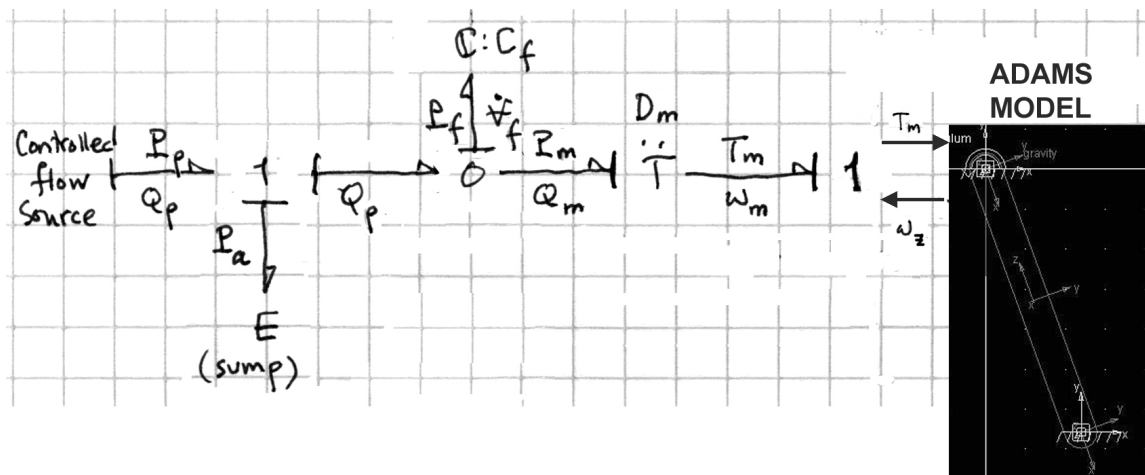


Figure 4: The ADAMS model of the pendulum is now driven at the support pivot by the torque from a hydraulic motor. The diagram indicates how torque is an input to the ADAMS model and angular velocity is an output.

The hydraulic motor output shaft is assumed to be rigid, so the motor output torque is a direct (causal) input into the pendulum model. The pendulum rotates about its support pivot with angle θ_z , and the angular velocity is ω_z . Note that this angular velocity is equal to the motor shaft velocity, so $\omega_m = \omega_z$, as illustrated in Figure 4.

In summary, to build the integrated model, the following is required:

- A measure of the angular velocity, ω_z .
- A model for a controller that can specify the input flowrate, Q_p .

- Representation of the differential equation, \dot{V}_f , which depends on Q_p and on $Q_m = D_m\omega_z$.
- Representation of the torque model equation applied to the pendulum at the support pivot.

1. Form an ADAMS state variable called **omegaz** by using the following variable definition: **omegaz** = WZ(MARKER_1). Since MARKER_1 is fixed in the link and moves relative to the base, it is not necessary to enter any additional marker information. Verify that this variable is correctly generating the angular velocity of interest. For an initial condition response, the output should appear as shown in Figure 5.

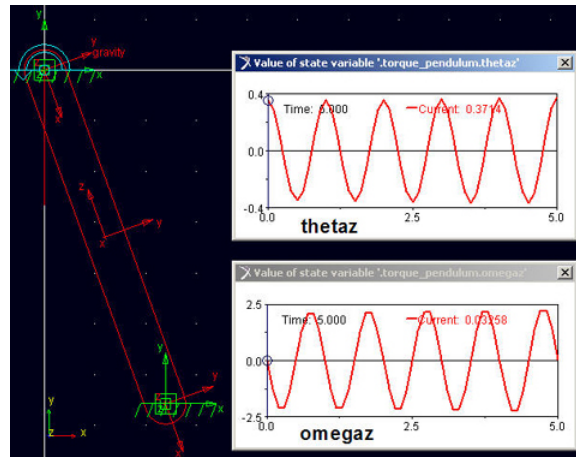


Figure 5: Checking the **omegaz** variable definition.

2. The controlled flow is dictated by a simple proportional (P) control that seeks to control the angular position, θ_z . For simple P-control, $Q_p = K_p(\theta_{zd} - \theta_z)$, where θ_{zd} is the desired position. This controller can be implemented as an ADAMS state variable. The desired or reference angle, θ_{zd} , and the proportional gain, K_p , should be defined as design variables before implementing the Q_p relation as an ADAMS state variable. Use the definitions Kp with value 1.0 and thetazd with a value of 45 (degrees).

3. The next step is to define a differential equation in ADAMS. The differential equation is,

$$\dot{V}_f = Q_p - D_m\omega_z$$

so make sure all the variables on the right-hand side have been defined. Create a design variable for the pump displacement named PDM and set it equal to 2. (note, Dm appears to be a built-in ADAMS variable). Now, from the Build menu go to System Elements and select Differential Equation, and define a new equation as shown in Figure 6.

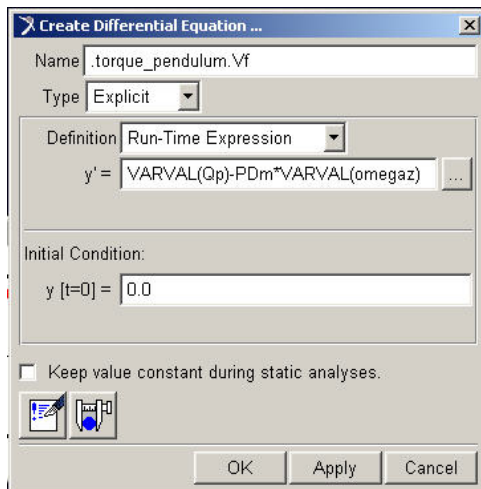


Figure 6: Defining differential equation

This ODE will be solved at each time step with the rest of the ADAMS model, and the value of the volume, V_f , can be called using the ADAMS DIF() function, DIF(Vf). So, to compute the pressure: $P_f = \text{DIF}(V_f)/C_f$. This requires that the design variable for the fluid compliance be defined; use $C_f = 0.0001$. Note also that an initial condition for Vf can also be specified. For this example just leave it as zero.

4. Now that volume is being determined by this dynamic equation, the motor torque can be found by defining a state variable, $T_m = D_m P_m = D_m P_f$. In ADAMS syntax,

$$T_m = PDm * DIF(Vf) / Cf.$$

Once this torque is defined, a torque can be applied to the pendulum with a value determined by VARVAL(T_m). This last step should be completed.

5. If all the steps are completed, the system can be visualized as shown in Figure 7. Run a test simulation with a final time of 10 seconds (500 steps). From Figure 8 it should be clear that there is some work to be done to improve the performance. Make changes as needed to the proportional gain, K_p , and experiment with the initial angle as well. Other variables can be examined to illustrate how this model environment allows you to study both the hydraulics and the mechanics of this control system.

End of Part 2. This tutorial uses a basic compound pendulum example to show how you can integrate auxiliary systems with mechanical systems under study in ADAMS. A hydraulic motor with proportionally-controlled input flow has been used to illustrate this concept. Particular attention has been given to the use of parameterization in the ADAMS model and the application of the Differential Equation system element feature.

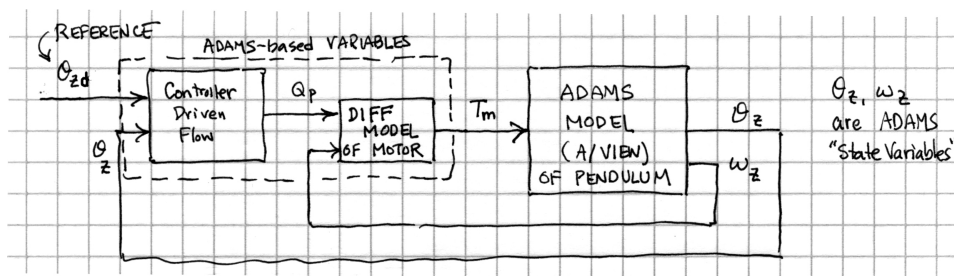


Figure 7: Block diagram of the torque-pendulum system.

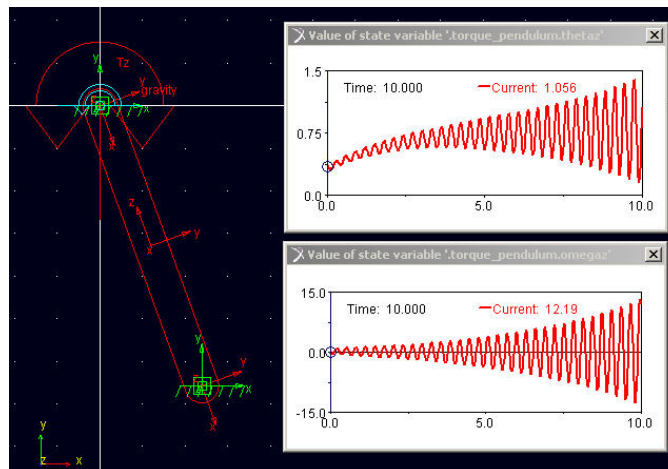


Figure 8: Results for $K_p=1$ and $\theta_{zd} = 45$ deg.