第一章 機構之自由度、位移、速度和加速度的計算與分析

1.1 簡介

一個剛體在二維空間之自由度應爲三,在二維空間是一平面時,這剛體可以沿兩個線性無關之方向作平移,又可以在此平面上作旋轉,而其旋轉軸線與此平面垂直。一個剛體在三維空間之自由度應爲六,即此剛體可以沿三個線性無關之方向作平移,又可圍繞三個線性無關方向之軸線作旋轉。

自由度(Degrees of freedom)的定義是表示一個機構中,每一連桿位置所需之獨立參數的最小數目。由於機構是由機件以接頭連接而成,因此它的自由度是所有機件在尚未連接和固定前的總自由度,扣除所有接頭的總拘束度(Degrees of constraint),再扣除固定機架件的自由度。

1.2 平面機構自由度公式

對平面機構而言,每一根可動的機件其有三個自由度,其中二個自由度爲兩互相垂直軸的平移(Translation),另一個自由度爲繞任意一點的旋轉(Rotation) 。

$$M=3(N-1)-2f_1-f_2$$

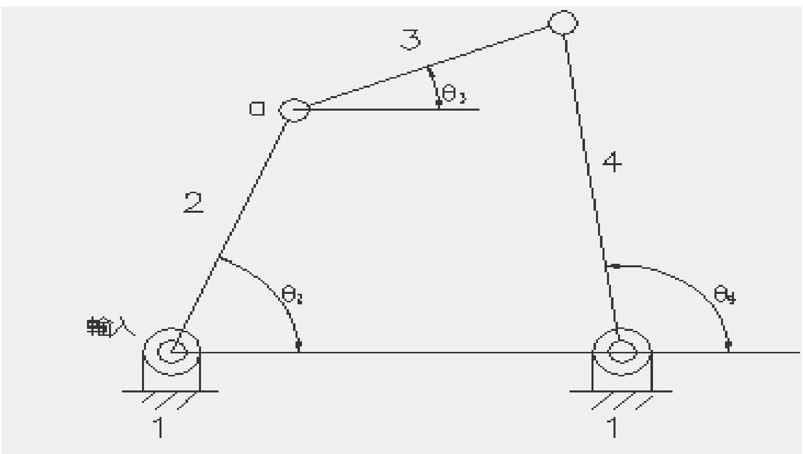
M: 自由度總數

N: 所有連桿數目(包括固定地面之連桿)

f_1: 一個自由度接頭數目(如旋轉軸承)

f_2: 兩個自由度接頭數目(如凸輪、齒輪)

例題一.試求如下圖所示平面四連桿機構的自由度



此四連桿機構,皆爲旋轉接頭,則自由度爲

$$M=3(4-1)-2*4$$
$$=1$$

1.3 空間機構自由度公式

對空間機構而言,每一根可動的機件其有六個自由度,其中三個自由度爲三互相垂直軸的平移,另三個自由度爲對此三軸的旋轉。

$$M=6(N-1)-\Sigma J_iC_i$$

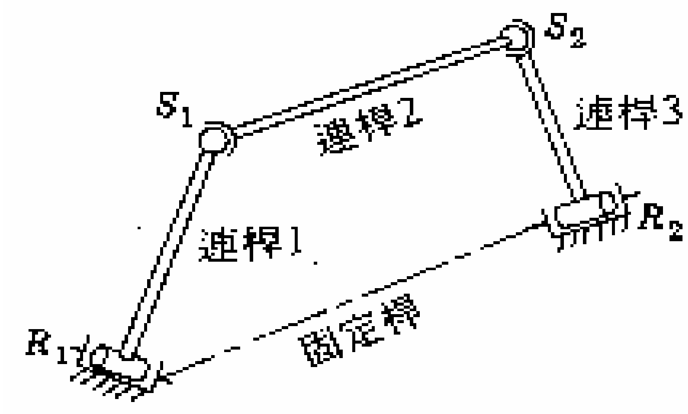
M: 自由度總數

N: 所有連桿數目(包括固定地面之連桿)

J_i: i 型接頭數目

C_i: i 型接頭的拘束度

例題二.試求如下圖所示 RSSR 空間四連桿機構的自由度



此四連桿機構,其中 R_1、R_2 爲旋轉對, S_1、S_2 爲圓球對,則自由度爲

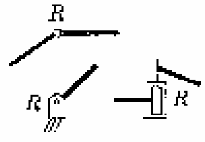
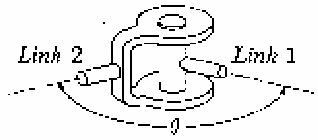
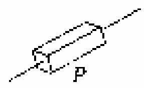
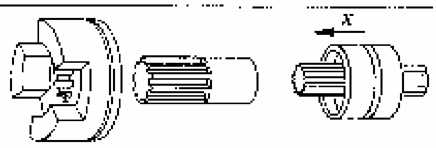
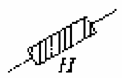
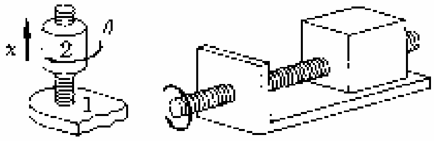
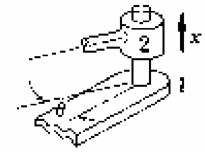
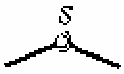
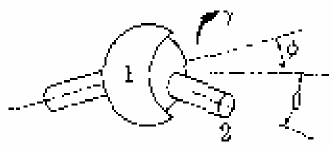
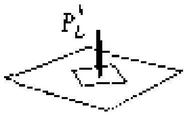
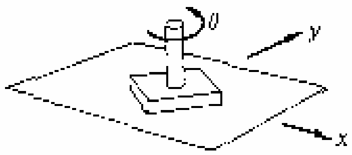
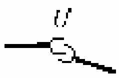
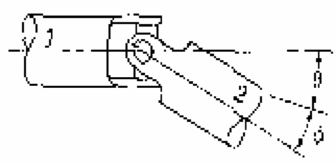
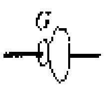
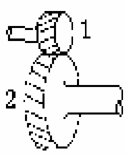
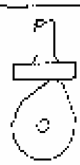
$$M=6(4-1)-5*2-3*2$$
$$=2$$

當 M≧1 時,此爲一個有 M 個自由度機構

M=0 時,此爲一靜定結構

M≦0 時,此爲一靜不定機構

1.4　i 型接頭種類

接頭型式(對偶)	低對(L)或高對(H)	符號	空間連桿組的接頭自由度	圖形表示	可能架構	應用例子
旋軸	L	R	1 θ			銷接頭，僅允許旋轉
稜柱	L	P	1 x			直栓槽，僅允許滑動
螺旋	L	H	1 x or θ			動力螺桿或螺旋栓槽
圓柱	L	C	2 x, θ			套筒，可旋轉與滑動
球	L	S	3 θ, φ, γ			球接頭可做三個角度方向旋轉
平面	L	P_L	3 x, y, θ			平面抑制，可轉動及與該平面平行運動
萬向接頭	L	U	2 θ, φ			虎克萬向接頭，包括兩個旋轉對偶
正齒輪組	H	G	2 (滾動與滑動)			正齒輪，螺旋齒輪，與其他齒數
凸輪組	H	*	2 (滾動與滑動)	*		圓盤凸輪與從動件

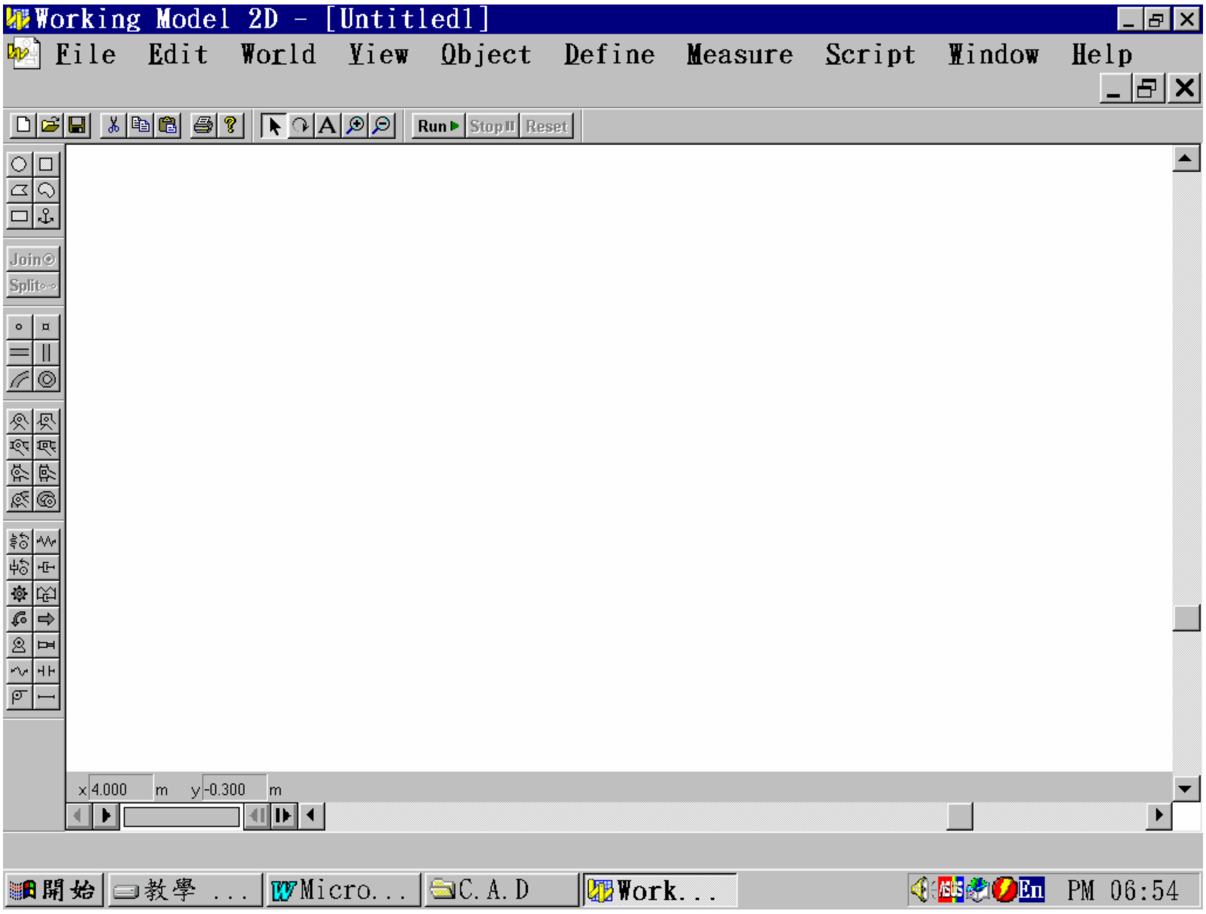
第二章 Working Model 2D 機構應用軟體之實例分析

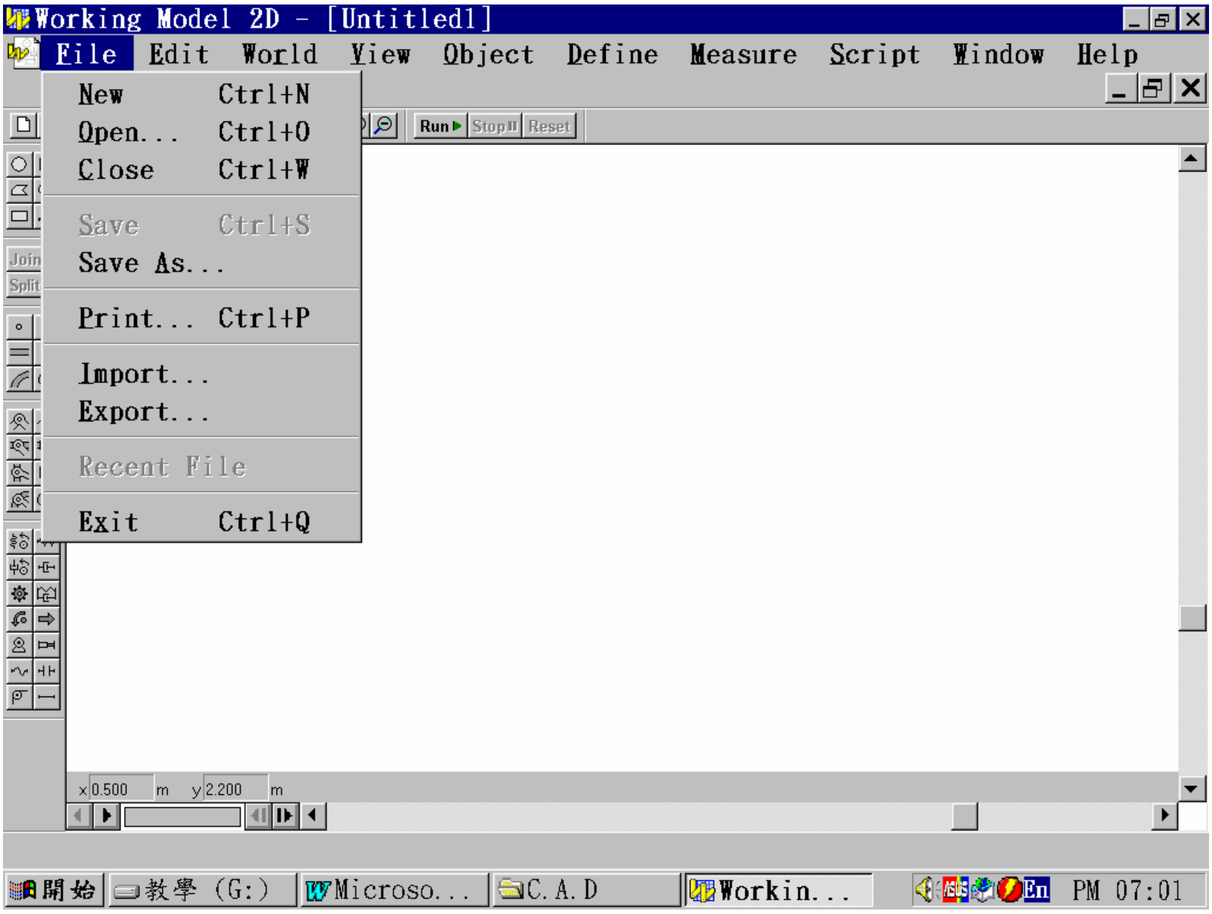
2.1 簡介

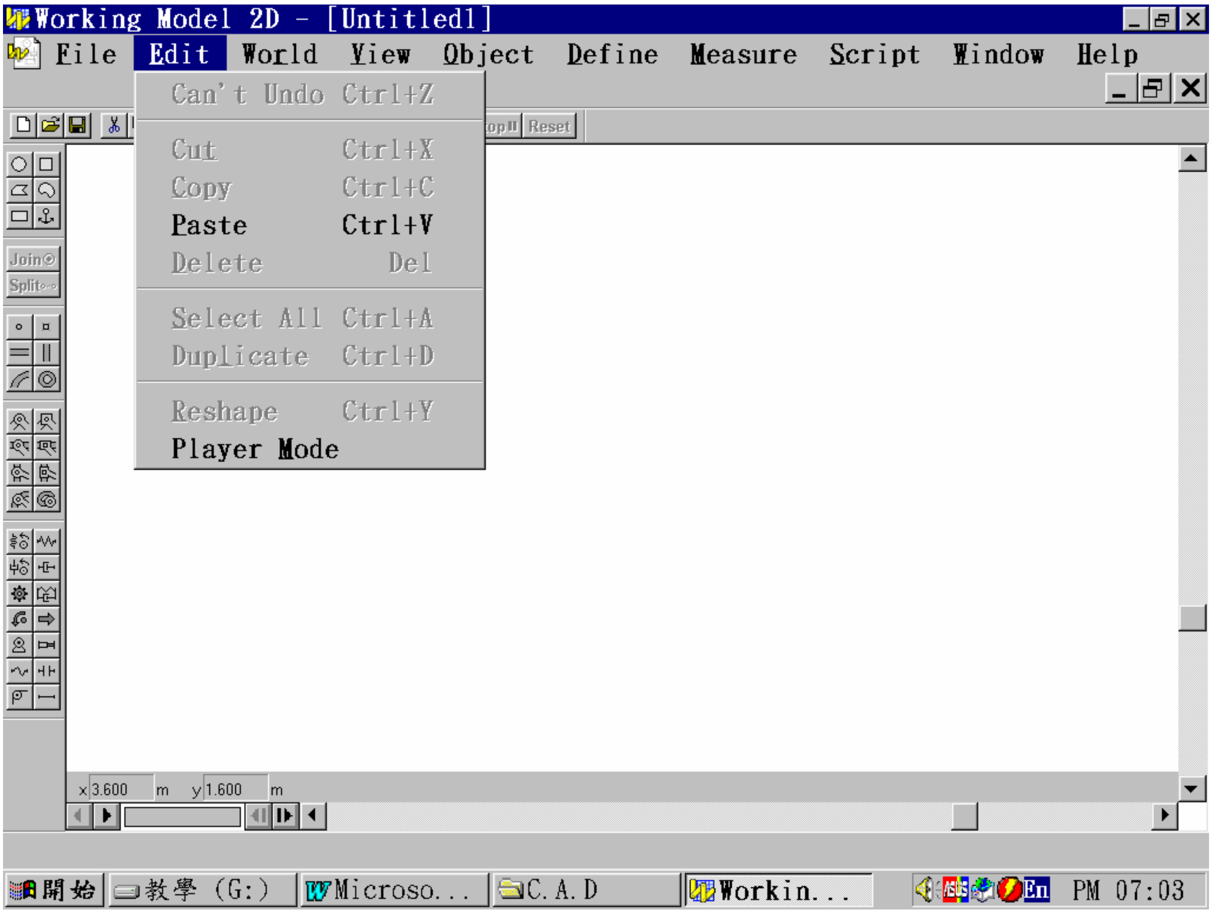
Working Model 2D 為利用複雜的編輯功能來提供一個完整的專業的動態模擬,對於牛頓運動力學上的機構也可以利用 Working Model 2D 在電腦上模擬,它並且提供一些簡易的圖解讓使用者更容易從事實驗,及分析不同的運動情況。

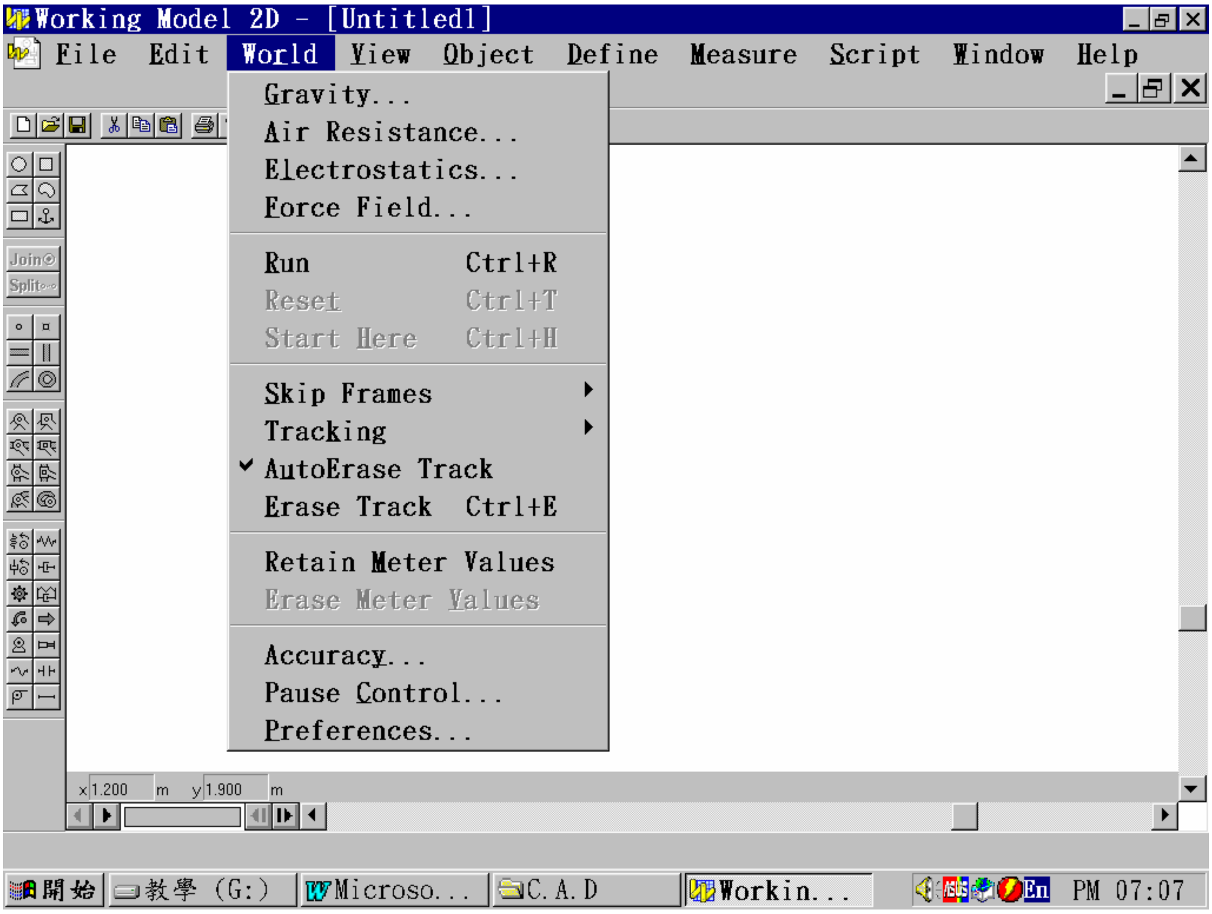
Morking Model 2D 在定義物體和一些約束運動條件(如馬達、彈簧、接頭),只須按滑鼠點選即可,更可以利用 CAD 軟體設計一圖形,然後編輯其資料輸入 Working Model 2D 亦可連接使用,其他可與 Working Model 2D 相連接的軟體亦有 MATLAB、Excel、Microstation、Auto CAD、Design View,Working Model 2D 可計算模擬特定物體上所產生的力量、速度、加速度、扭矩…等等,並且可以預設約束條件,如：重力、摩擦係數，空氣阻力…等狀況,以達到更精確並且接近真實狀態的模擬。

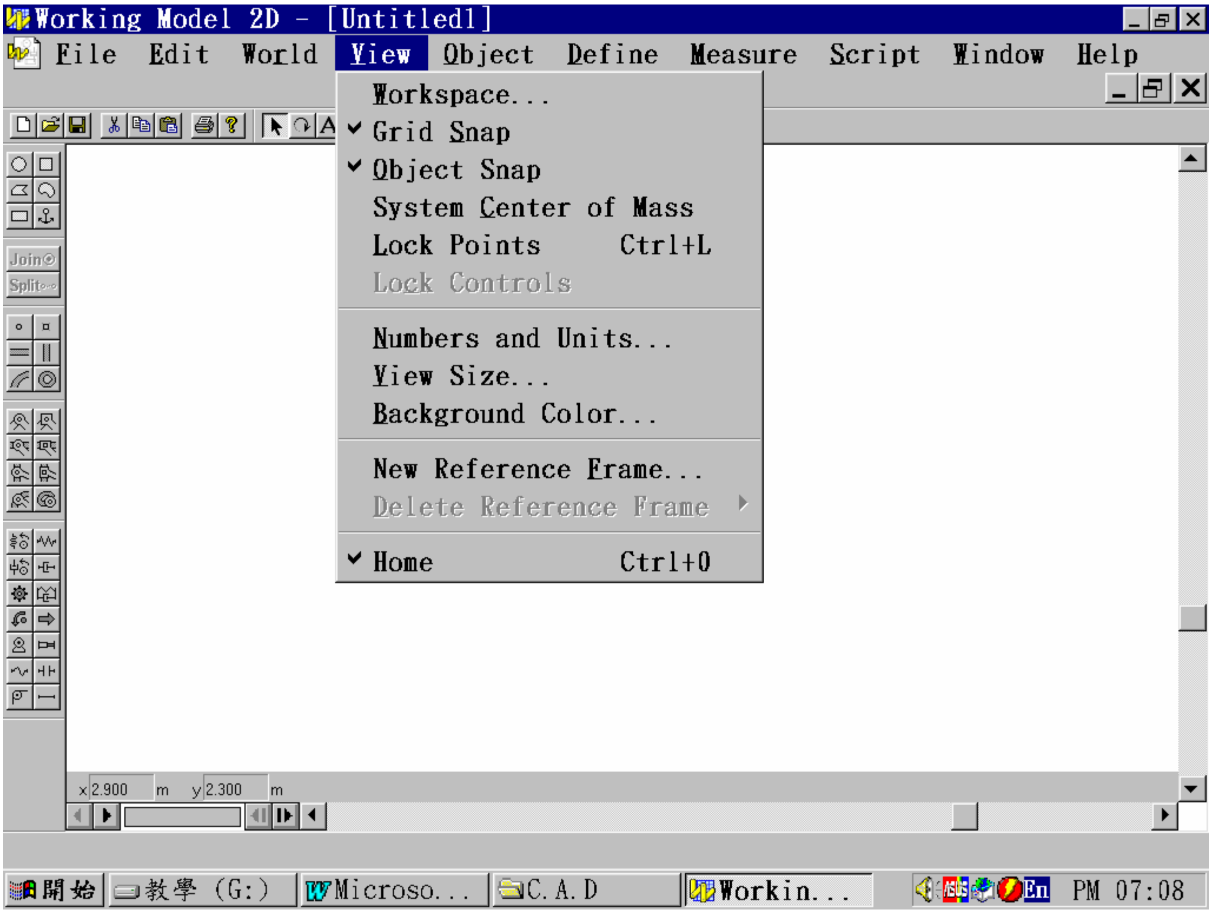
Working Model 2D 機構應用軟體簡介

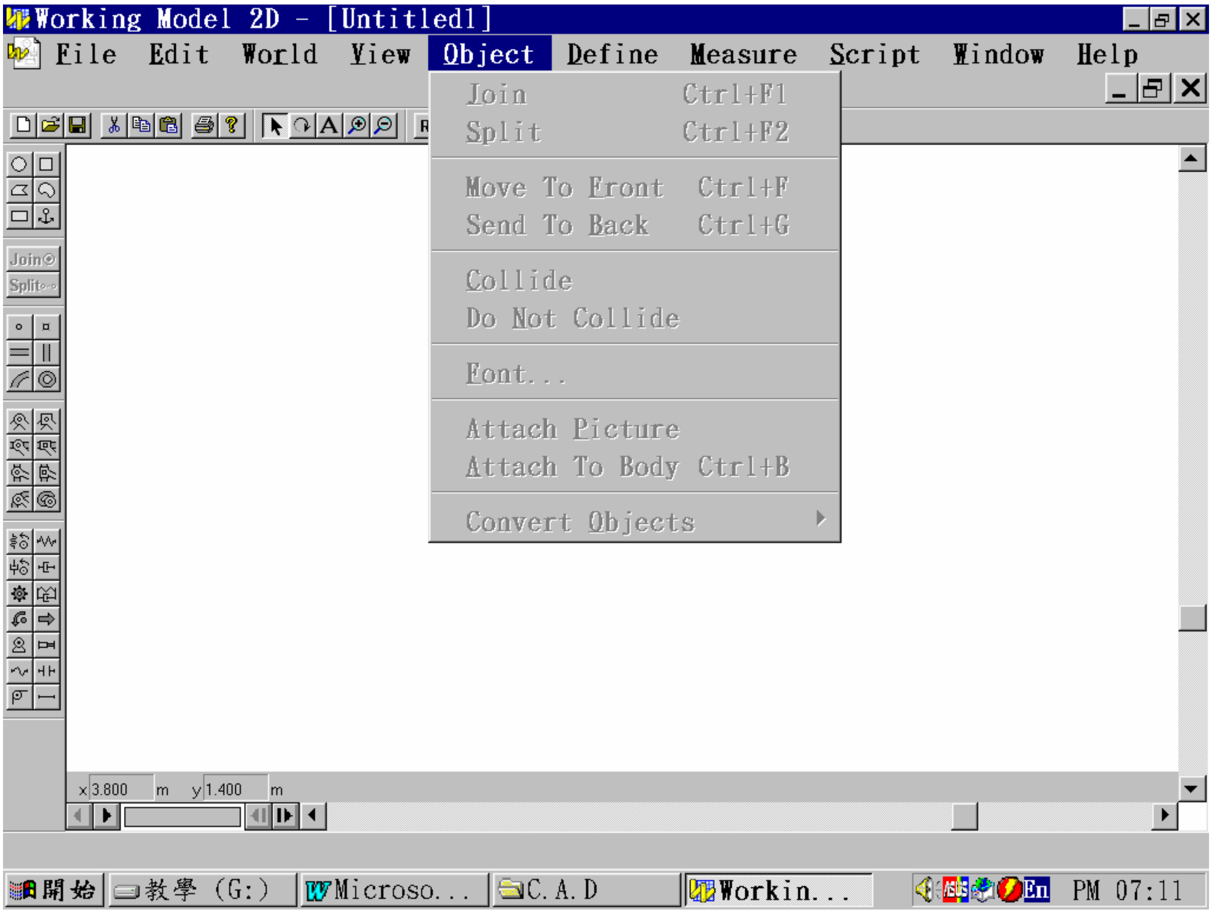


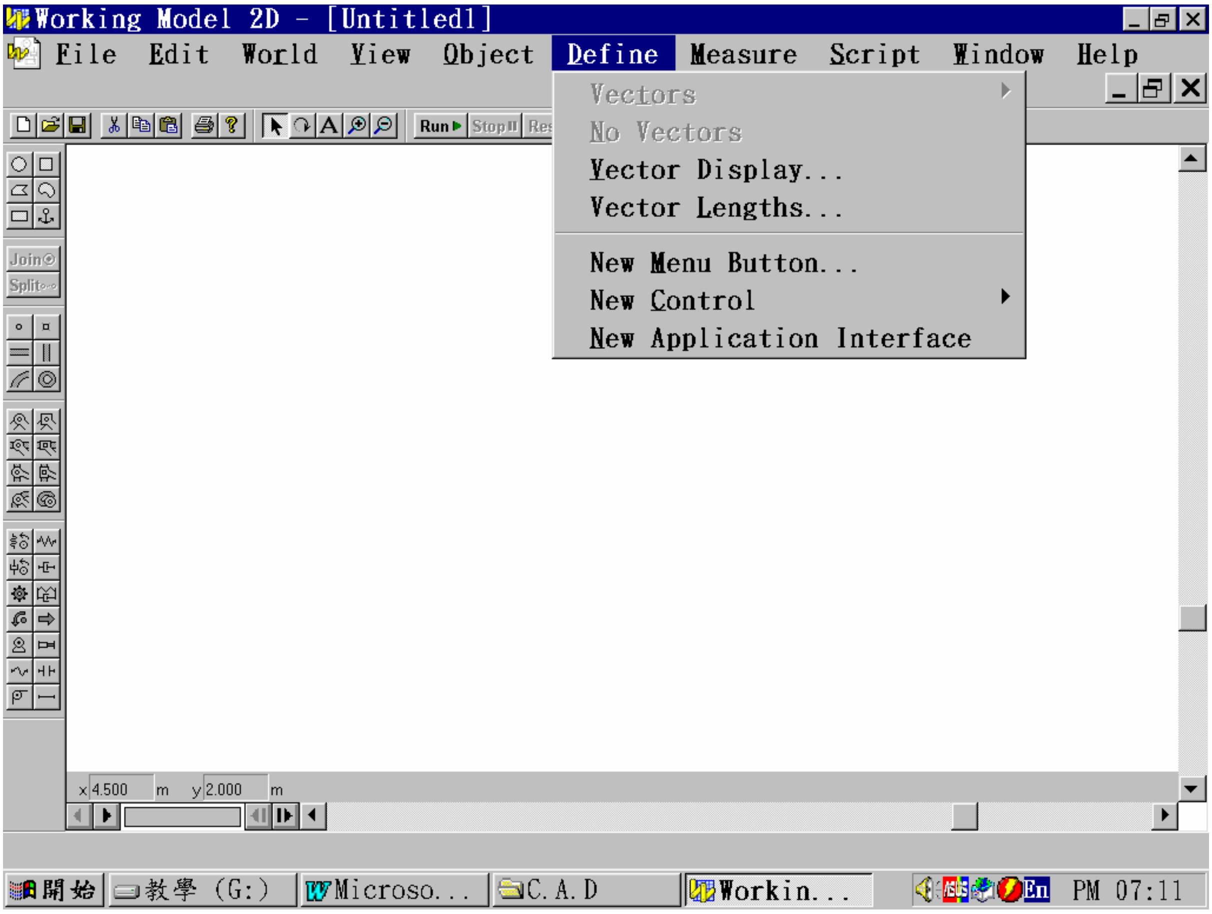

Working Model 2D - [Untitled1]
File Edit World View Object Define Measure Script Window Help
New Ctrl+N
Open... Ctrl+O
Close Ctrl+W
Save Ctrl+S
Save As...
Print... Ctrl+P
Import...
Export...
Recent File
Exit Ctrl+Q
Run Stop Reset
x 0.500 m y 2.200 m
開始 教學 (G:) Microso... C. A. D Workin... PM 07:01

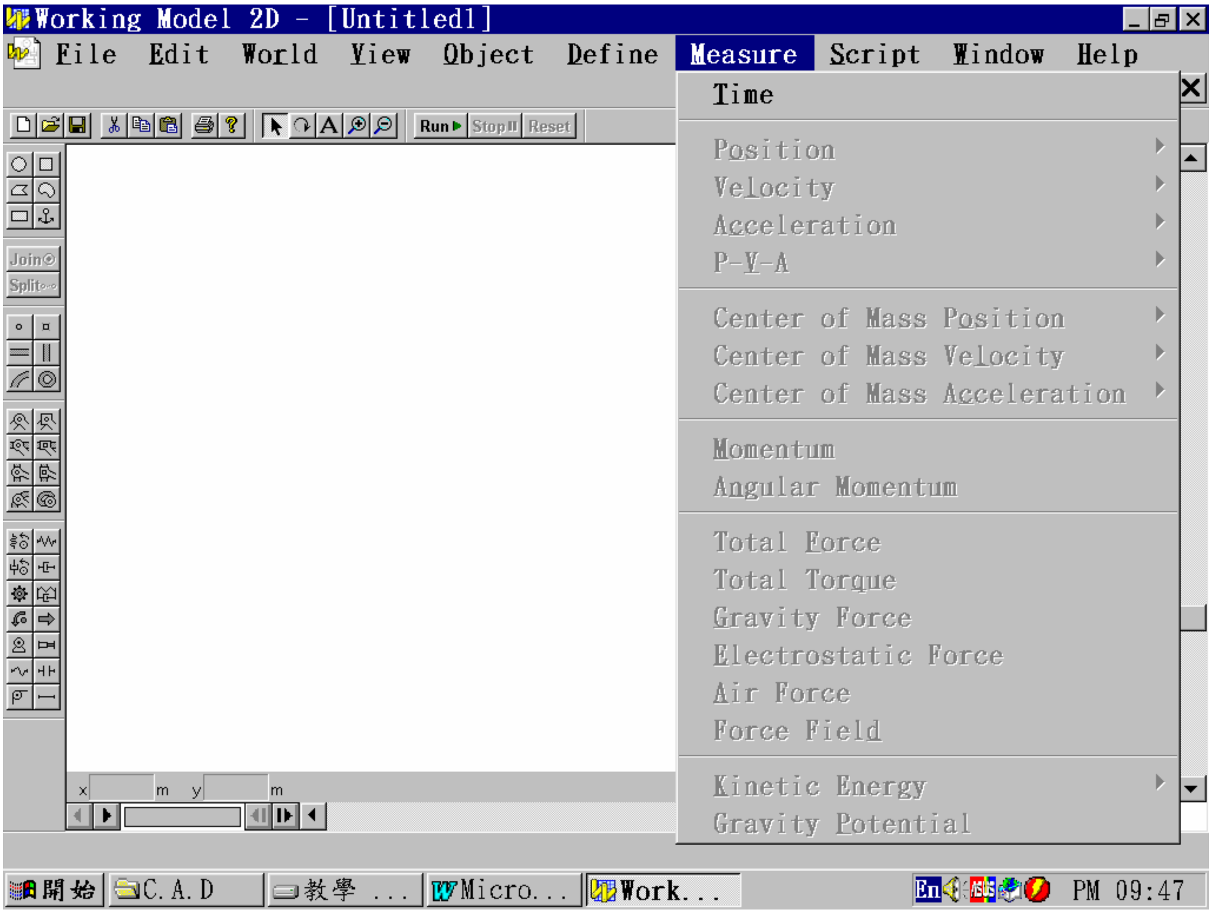

Working Model 2D - [Untitled1]
File Edit World View Object Define Measure Script Window Help
Can't Undo Ctrl+Z
Cut Ctrl+X
Copy Ctrl+C
Paste Ctrl+V
Delete Del
Select All Ctrl+A
Duplicate Ctrl+D
Reshape Ctrl+Y
Player Mode
Reset
x 3.600 m y 1.600 m
開始 教學 (G:) Microso... C. A. D Workin... PM 07:03

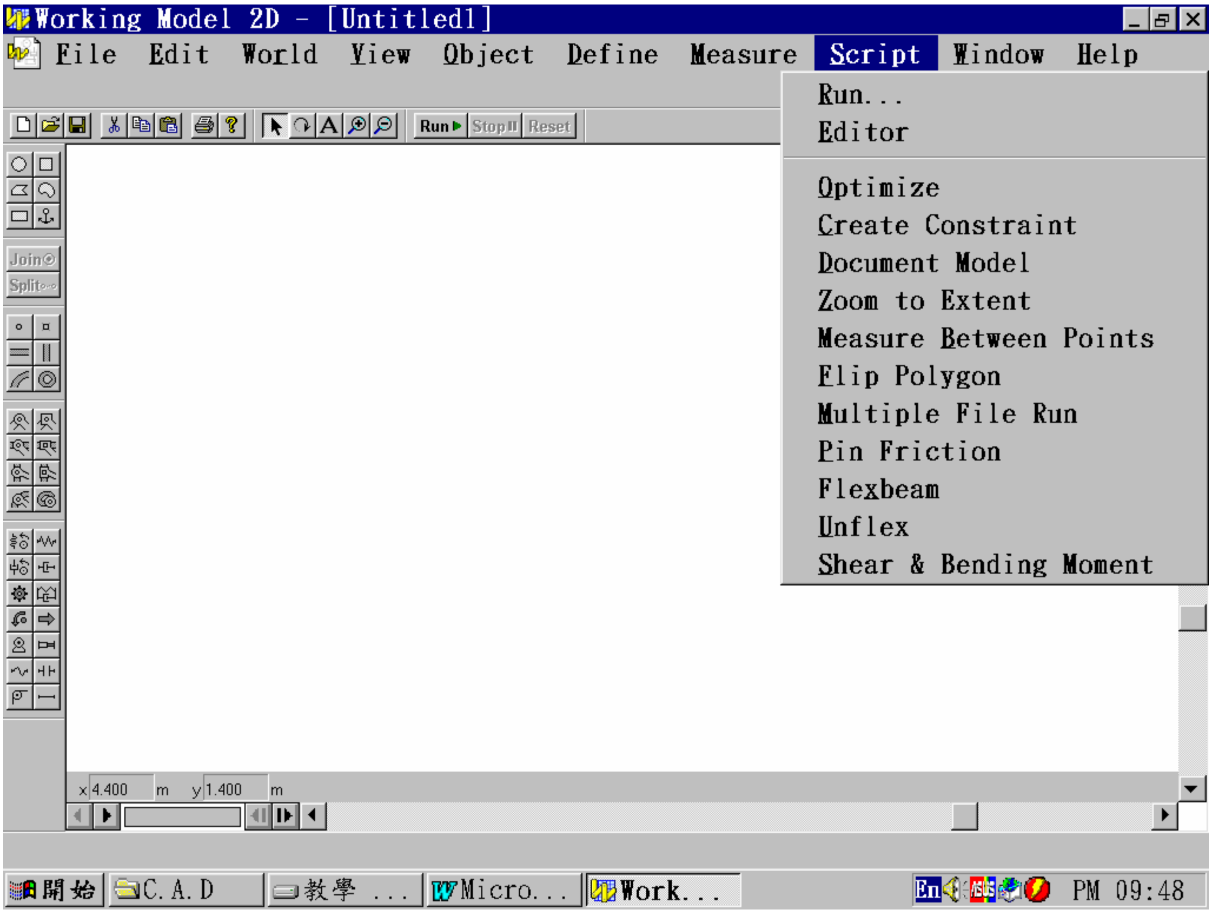

Working Model 2D - [Untitled1]
File
Edit
World
View
Object
Define
Measure
Script
Window
Help
Gravity...
Air Resistance...
Electrostatics...
Force Field...
Run Ctrl+R
Reset Ctrl+T
Start Here Ctrl+H
Skip Frames
Tracking
AutoErase Track
Erase Track Ctrl+E
Retain Meter Values
Erase Meter Values
Accuracy...
Pause Control...
Preferences...
Join
Split
x 1.200 m y 1.900 m
開始
教學 (G:)
Microso...
C.A.D
Workin...
En
PM 07:07

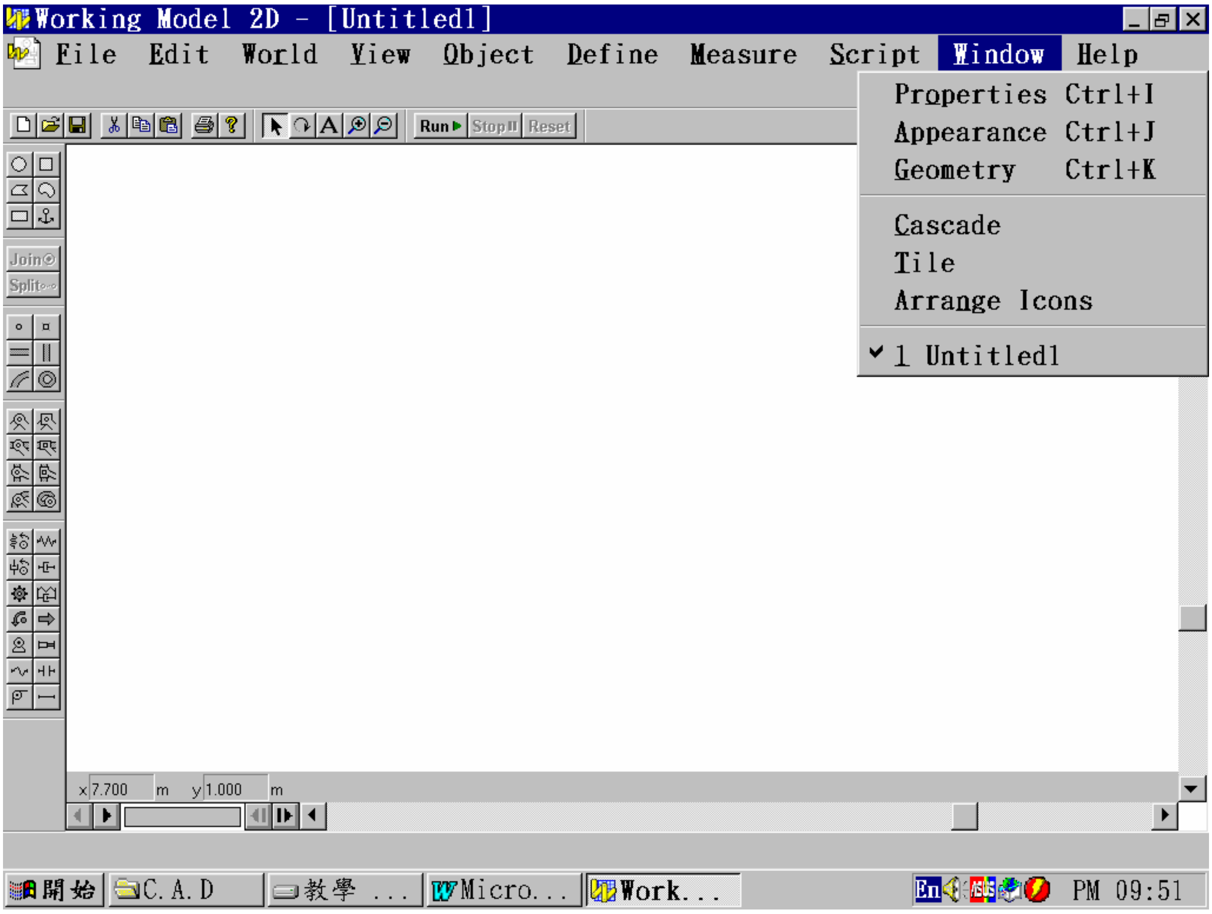

Working Model 2D - [Untitled1]
File
Edit
World
View
Object
Define
Measure
Script
Window
Help
Workspace...
Grid Snap
Object Snap
System Center of Mass
Lock Points Ctrl+L
Lock Controls
Numbers and Units...
View Size...
Background Color...
New Reference Frame...
Delete Reference Frame
Home Ctrl+0
Join
Split
x 2.900 m y 2.300 m
開始
教學 (G:)
Microso...
C.A.D
Workin...
En
PM 07:08

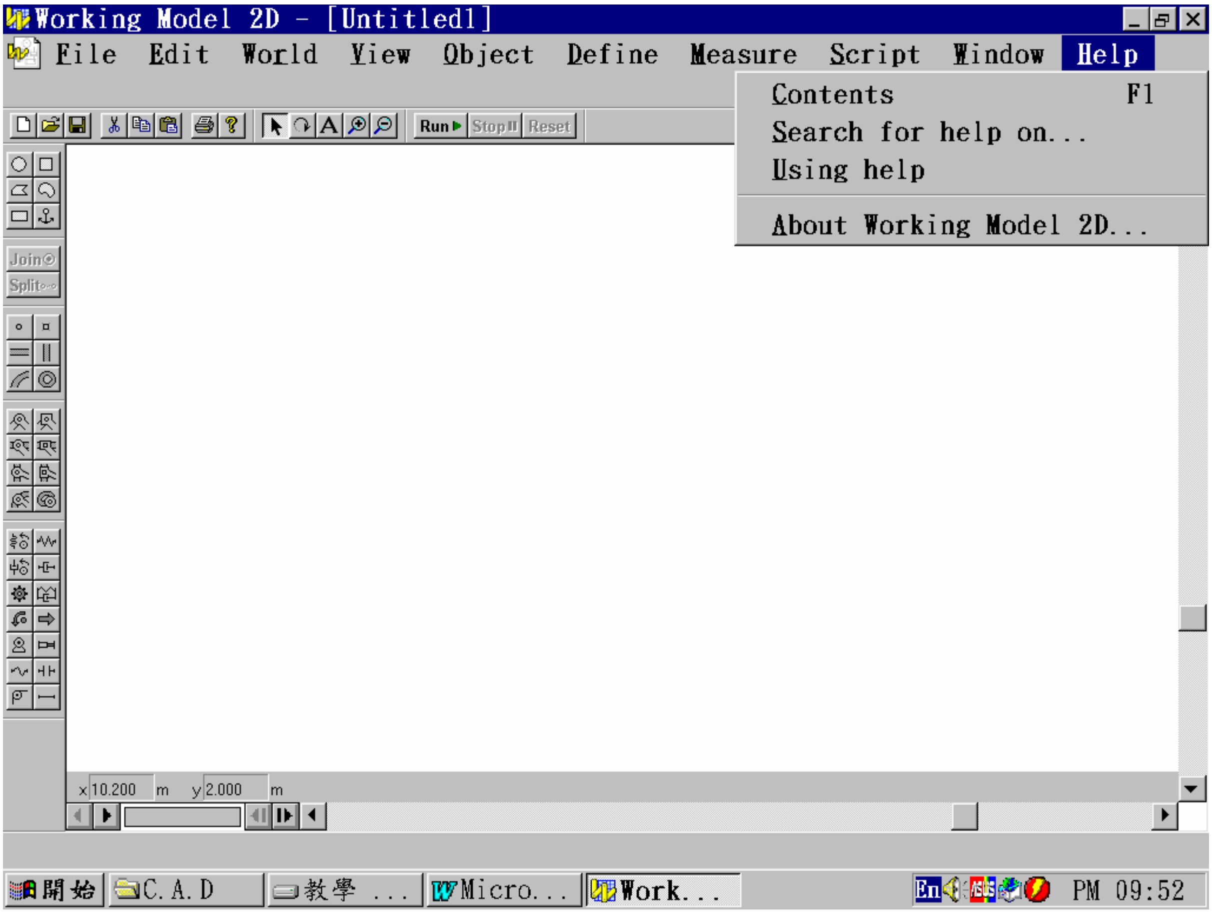

Working Model 2D - [Untitled1]
File Edit World View Object Define Measure Script Window Help
Join Ctrl+F1
Split Ctrl+F2
Move To Front Ctrl+F
Send To Back Ctrl+G
Collide
Do Not Collide
Font...
Attach Picture
Attach To Body Ctrl+B
Convert Objects
x 3.800 m y 1.400 m
開始
教學 (G:)
Microso...
C.A.D
Workin...
PM 07:11

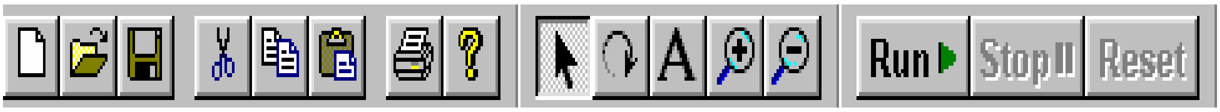

Working Model 2D - [Untitled1]
File Edit World View Object Define Measure Script Window Help
Run Stop
Vectors
No Vectors
Vector Display...
Vector Lengths...
New Menu Button...
New Control
New Application Interface
x 4.500 m y 2.000 m
開始
教學 (G:)
Microso...
C.A.D
Workin...
PM 07:11

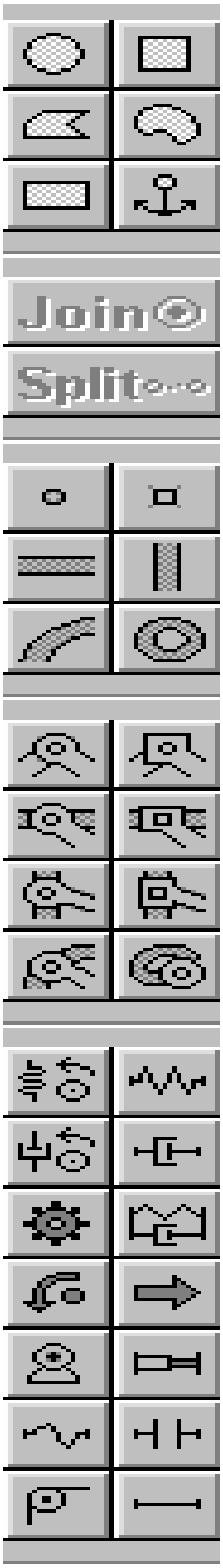

Working Model 2D - [Untitled1]
File Edit World View Object Define Measure Script Window Help
Run Stop Reset
Join
Split
Time
Position
Velocity
Acceleration
P-V-A
Center of Mass Position
Center of Mass Velocity
Center of Mass Acceleration
Momentum
Angular Momentum
Total Force
Total Torque
Gravity Force
Electrostatic Force
Air Force
Force Field
Kinetic Energy
Gravity Potential
x m y m
開始 C.A.D 教學 ... Micro... Work...
PM 09:47


Working Model 2D - [Untitled1]
File Edit World View Object Define Measure Script Window Help
Run Stop Reset
Join
Split
Run...
Editor
Optimize
Create Constraint
Document Model
Zoom to Extent
Measure Between Points
Flip Polygon
Multiple File Run
Pin Friction
Flexbeam
Unflex
Shear & Bending Moment
x 4.400 m y 1.400 m
開始 C.A.D 教學 ... Micro... Work...
PM 09:48


Working Model 2D - [Untitled1]
File Edit World View Object Define Measure Script Window Help
Properties Ctrl+I
Appearance Ctrl+J
Geometry Ctrl+K
Cascade
Tile
Arrange Icons
1 Untitled1
Run Stop Reset
Join
Split
x 7.700 m y 1.000 m
開始 C. A. D 教學 ... Micro... Work...
PM 09:51


Working Model 2D - [Untitled1]
File Edit World View Object Define Measure Script Window Help
Contents F1
Search for help on...
Using help
About Working Model 2D...
Run Stop Reset
Join
Split
x 10.200 m y 2.000 m
開始 C. A. D 教學 ... Micro... Work...
PM 09:52


Run
Stop
Reset


Join
Split

2.2 曲柄搖桿機構(Crank and Rocker Mechanism)

2.2.1 簡介

當四連桿機構中,一連桿可作整個迴轉(即曲柄),而它一連桿僅能作搖擺時(即搖桿),此機構則謂之曲柄搖桿機構,如圖 2.2.1 所示,AD 機件係固定,
AB 曲柄能作整周迴轉,DC 搖桿則繞 D 軸作搖擺運動,欲得此結果,必須合乎下列三條件(依△AC1D 及 AC2D,兩邊和大於第三邊之原理),由下列條件中,得出曲柄 AB 最短。

AD+CD > AB+BC

AD+BC > AB+CD

BC+CD > AB+AD

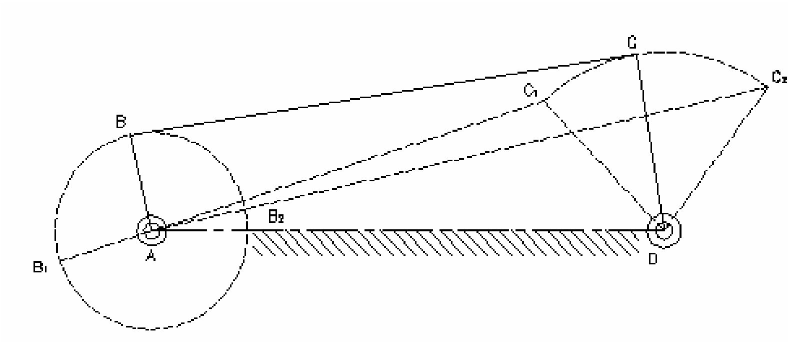


圖 2.2.1 曲柄搖桿機構

2.2.2 分析步驟

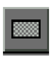
利用 Working Model 分析曲柄搖桿機構,方法如下:

步驟 1: 設定工作環境

(1)從 View 選單下選取 Number and Units ,將 Unit System 改為 SI (degrees),按 More Choices,將 Distances 之單位設定為 Meters,選擇 OK。

(2)在 View 選單下選取 Workspace,開啓 X 和 Y 軸向。

步驟 2: 畫出三根主要連桿

(1)選  畫出一根連桿。

(2)在 Edit 選單中選 Duplicate(複製)出另兩根連桿。

(3)在 Window 選單下選擇 Appearance,將 Body[1]之名稱改為

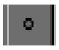
Rod1,Body[2]改名爲 Rod2,Body[3]改名爲 Rod3。

步驟 3: 設定三根連桿之尺寸及質量

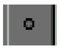
(1)在螢幕下方輸入 Rod1 的尺寸爲 W=1m, H=0.1m, $\phi=0^\circ$,Rod2 的尺寸爲 W=4m,H=0.1m, $\phi=0^\circ$,Rod3 的尺寸爲 W=2.5m,H=0.1m, $\phi=0^\circ$。

(2)在 Window 選單下選取 Properties,更改質量 Rod1=1kg, Rod2=4kg , Rod3=2.5kg。

步驟 4: 給定各個接點

(1)選  在 Rod1 的左右兩端畫出兩個接點,在 Window 選單下選取 Appearance,將左邊的點改名 R1A,右邊改名爲 R1B。

(2)如上之步驟,將 Rod2 左邊的點改爲 R2A,右邊改爲 R2B,將 Rod3 左邊的點改爲 R3A,右邊改爲 R3B。

(3) 選  畫出兩個固定點分別爲 O1,O2。

步驟 5: 將各接點連結起來

(1)用滑鼠點選 Rod1 之左端接點 R1A,按住 Shit 鍵同時點選固定點 O1,再按 

將其連結起來。

(2) 在 Window 選單下選取 Appearance,將其接點命名爲 J1。

(3)如上之步驟,將 Rod1 之右邊接點 R1B 和 Rod2 之左邊接點 R2A 連結起來,將接點命名爲 J2。

(4)將 Rod2 之右邊接點 R2B 和 Rod3 之左邊接點 R3A 連結起來,將其接點命名爲 J3。

(5)將 Rod3 之右邊接點和固定點 O2 連結起來,將其接點命名爲 J4。

步驟 6: 裝上馬達

(1)選  ,將其置於 J1 接點上。

(2)在 Window 選單下選取 Properties,將速度(Value)改爲 5rad/s。

步驟 7: 開始分析

(1)用滑鼠點選 Rod2,在 Measure 選單下選取質量中心之位移(Position)、速度(Velocity)、加速度(Acceleration)圖。

(2)按 

,開始進行分析,如圖 2.2.2 所示。

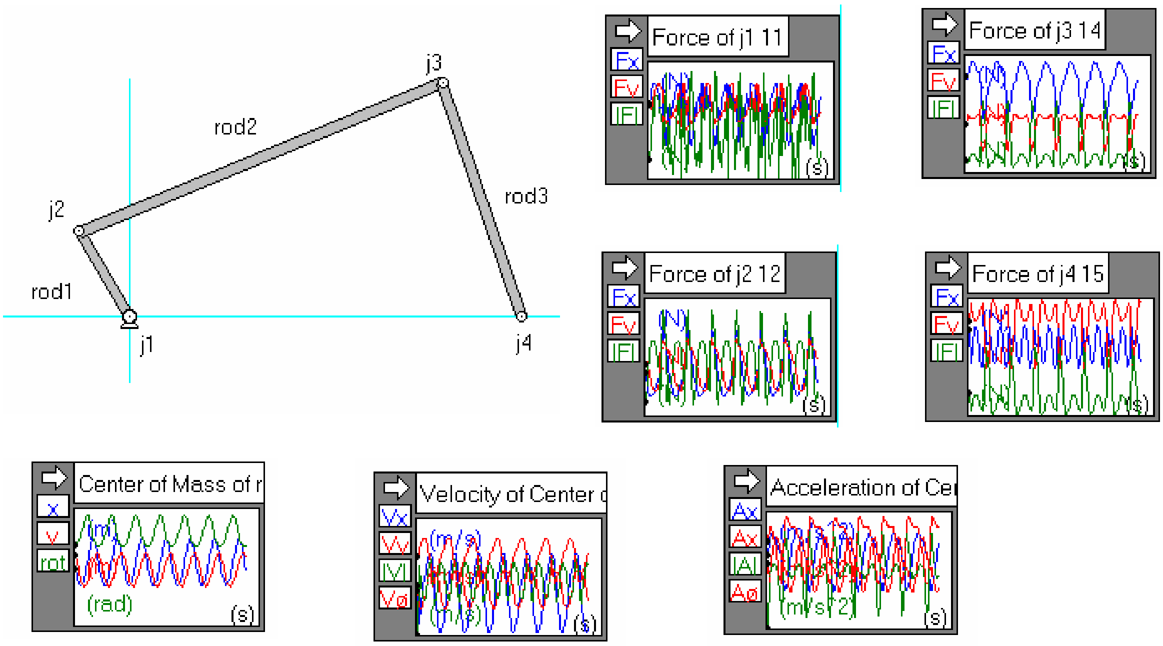


圖 2.2.2 曲柄搖桿之分析圖

2.3 滑塊曲柄機構(Slider-Crank Mechanism)

2.3.1 簡介

滑塊曲柄機構使用最多的是在內燃機上,如圖 3.3.1 所示爲這種機構的簡圖,其連桿 1 爲機架(考慮固定),連桿 2 爲曲柄,連桿 3 爲連接桿,連桿 4 爲滑塊。在內燃機中,連桿 4 就是受到氣體壓力作用的活塞。該力通過連接桿而傳遞到曲柄上。可以看到,在一個循環中將有兩個死點,各在活塞運動的每一極限位置。

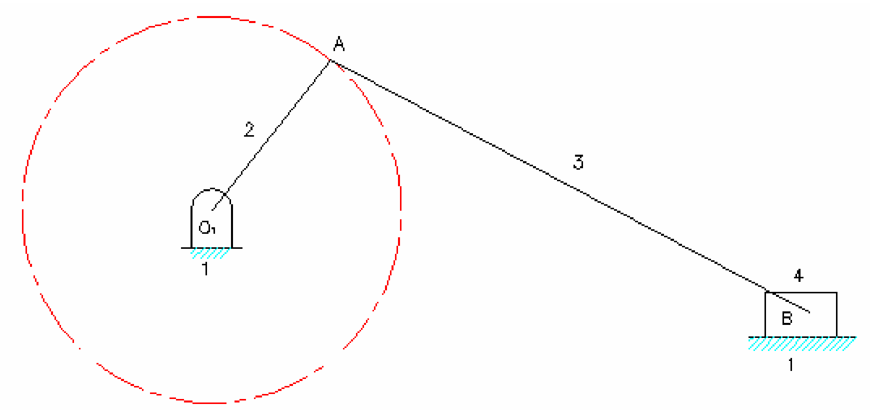


圖 2.3.1 滑塊曲柄機構

2.3.2 分析步驟

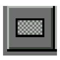
利用 Working Model 來進行分析,方法如下:

步驟 1: 設定工作環境

(1)從 View 選單下選取 Number and Unit,將 Unit System 改爲 SI (degrees),按 More Choices,將 Distance 之單位設定爲 Meters,選擇 OK。

(2)在 View 選單下選取 Workspace,開啓 X 和 Y 軸向。

步驟 2: 畫出兩根主要連桿

(1) 選  畫出一連桿。

(2) 在 Edit 的選單中選擇 Duplicate(複製),畫出第二根連桿。

(3) 在 Window 選單下選擇 Appearance,將 Body[1]之名稱改名爲 Rod1,Body[2]改名爲 Rod2。

步驟 3: 設定連桿之尺寸及質量

(1) 選擇 Rod1 並在螢幕下方輸入尺寸,W=2m,H=0.1m, ϕ=0° 。

(2) 選擇 Rod2 並在螢幕下方輸入尺寸,W=4m,H=0.1m, ϕ=0° 。

(3) 在 Window 選單下選擇 Properties,質量 Rod1=0.5kg, Rod2=1kg。

步驟 4: 畫出一滑塊

(1) 選 畫出一滑塊。

(2) 選擇滑塊,並在螢幕下方輸入尺寸,W=H=0.6m, ϕ=0° 。

(3) 在 Window 選單下選擇 Appearance,將 Body[4]改名 Slider。

(4) 在 Window 選單下選擇 Properties,質量 Slider=0.5kg。

步驟 5: 給定各個接點

(1) 選 在 Rod1 的左右兩端畫出兩個接點,在 Window 選單下選擇 Appearance,將左邊的點改名為 R1A,右邊改名為 R1B。

(2) 如上之步驟,將 Rod2 左邊的點改名為 R2A,右邊改名為 R2B。

(4) 選 在 Slider 的中心畫出一點,在 Window 選單下選取 Appearance,將其命名為 S1。

步驟 6 : 畫出滑槽

(1) 選 畫出一沿軸向之槽。

(2) 在 Window 選單下選取 Appearance,將其命名為 Slot。

步驟 7: 將各點連接起來

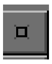
(1) 選 畫出一固定點 O1。

(2) 用滑鼠點選 Rod1 之左端接點 R1A,按住 Shit 鍵同時點選固定點 O1,再按 將其連接起來。

(3) 在 Window 選單下選取 Appearance,將其命名為 J1。

(4) 如上之步驟,將 Rod1 之右端接點 R1B 和 Rod2 之左端接點 R2A 連結,將接點命名為 J2。

(5) 將 Rod2 之右端接點 R2B 和 Slider 之中心點 S1 連結,將接點命名為 J3。

(6) 選  在接點 J3 重複點上一點。

(7) 將 J3 和 Slot 連結。

步驟 8: 裝上馬達

(1) 選  , 將其置於 J1 上。

(2) 在 Window 選單下選取 Properties,將速度(Value)改為 5rad/s。

步驟 9: 開始分析

(1) 用滑鼠點選 Slider,在 Measure 的選單下選取位移(Position)、速度(Velocity)、加速度(Acceleration)圖。

(2) 按 

,開始進行分析,如圖 2.3.2 所示。

(3) 用滑鼠點選 Rod2,在 Measure 的選單下選取位移(Position) 、速度(Velocity)、加速度(Acceleration)圖。

(4) 按 

,開始進行分析,如圖 2.3.3 所示。

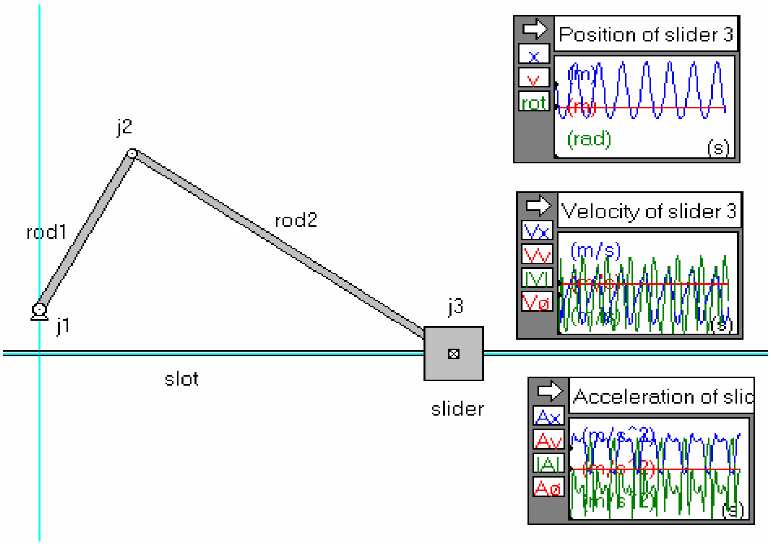


圖 2.3.2 滑塊曲柄機構之滑塊分析圖

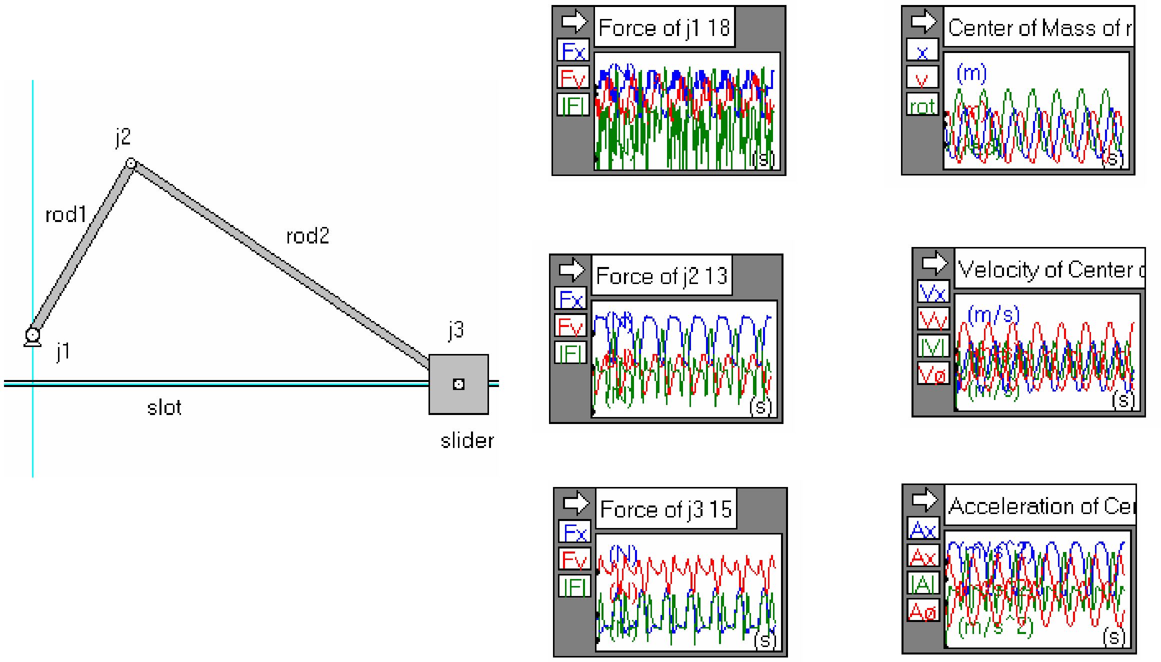


圖 2.3.3 滑塊曲柄之分析圖

2.4 曲柄牛頭鉋床機構(Crank Shaper)

2.4.1 簡介

這種機構是滑塊曲柄機構第二種倒置的一個變型,由連接桿固定而得。如圖 2.4.1 所示機構安排中，連桿 2 作整周迴轉而連桿 4 則作搖擺。如果距離 O_1O_2 縮短時,這種機構就變成惠氏急回機構。

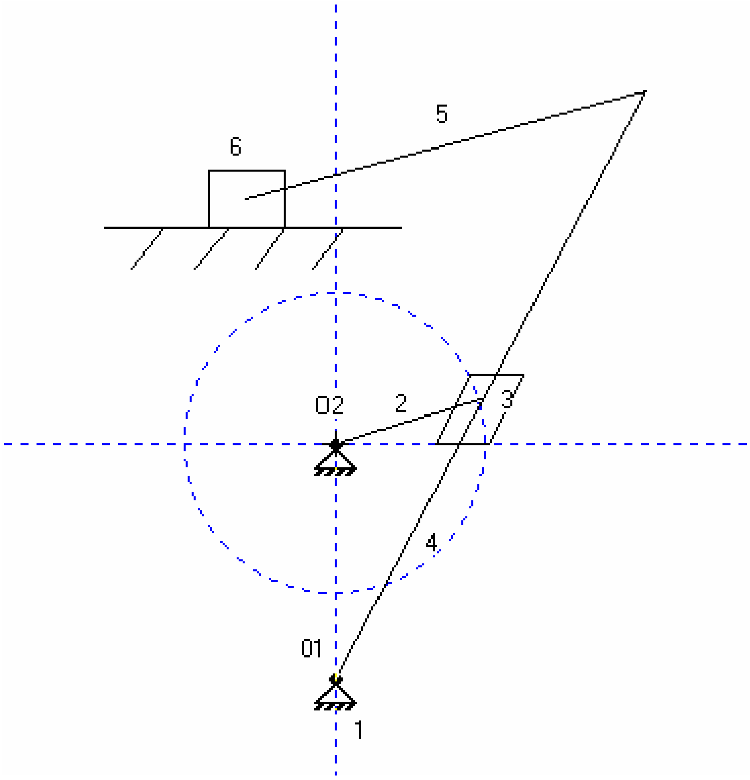


圖 2.4.1 曲柄牛頭鉋床機構

2.4.2 分析步驟

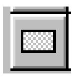
利用 Working Model 分析曲柄牛頭鉋床,方法如下:

步驟 1：設定工作環境

(1)從 View 的選單下選取 Number and Unit,將 Unit System 改爲 SI (degrees),按 More Choices,將 Distance 之單位設定爲 Meter,選擇 OK。

(2)在 View 的選單下選取 Workspace,開啓 X 和 Y 軸向。

步驟 2：畫出三根主要之連桿

(1)選  (rectangle)畫出一連桿。

(2)在 Edit 的選單中選 Duplicate(複製)出另二根連桿。

(3)在 Window 的選單下選擇 Appearance,將 Body[1]之名稱改名爲 Rod1,Body[2]改名爲 Rod2,Body[3]改名爲 Rod3。

步驟 3：設定三根連桿之尺寸及質量

(1)在螢幕下方輸入 Rod1 的尺寸,W=1.5m,H=0.1m,ϕ=0°,Rod2 的尺寸,W=1m,H=0.1m,ϕ=0°,Rod3 的尺寸,W=3m,H=0.1m,ϕ=0°。

(2)在 Window 選單下選取 Properties,更改質量 Rod1=1kg,Rod2=2kg, rod3=0.5kg。

步驟 4：畫出一滑塊

(1) 選 (rectangle),W=0.4m,H=0.2m,ϕ=0°。

(2) 在 Window 的選單下選擇 Appearance,將 Body[4],改名爲 Slider1。

步驟 5：給定各個接點

(1)選(point element)在 Rod1 的左右兩端畫出兩個接點,在 Window 的選單下選取 Appearance,將左邊的 point 改名爲 R1A,右邊改名爲 R1B。

(2)如上之步驟,將 Rod2 左邊的 point 改爲 R2A ,右邊改爲 R2B,將 Rod3 左邊的 point 改爲 R3A ,右邊改爲 R3B。

(3)選(point element)在 Slider1 的中心畫出一 point,在 Window 的選單下選取 Appearance,將其命名爲 S1A。

(4)選 (square point element)在 Slider1 的下端畫出一 point,在 Window 的選單下選取 Appearance,將其命名爲 S1B。

(5)選(point element)給定兩固定端,垂直距離爲 1.5m。

(6)在 Window 的選單下選取 Appearance,將其命名爲 O_1 及 O_2。

步驟 6：畫出滑槽

(1)選(slot element),將它畫在距離上方之固定端爲 1m 之地方,畫出一水平滑槽。

(2)在 Window 的選單下選取 Appearance,將其命名爲 Slot1。

(3)選(slot element),在 Rod3 之桿件上畫出沿桿軸方向之滑槽。

(4)在 Window 的選單下選取 Appearance,將其命名爲 Slot2。

步驟 7：將各接點連結起來

(1)用滑鼠點選 Rod3 之左端接點 R3A,按住 Shift 鍵同時點選固定端 O_1,

再按 將其連結起來。

(2)在 Window 的選單下選取 Appearance,將其接點命名為 J1。

(3)如上之步驟,將 Rod3 之右端接點 R3B 和 Rod1 之接點 R1A 連結,將接點命名為 J2。

(4)將 Rod1 之接點 R1B 和 Slider1 之接點 S1A 連結,將接點命名為 J3。

(5)將 Slider1 之接點 S1B 和 Rod1 之 R1B 接點連結,將接點命名為 J4。

(6)將 Rod2 之左端接點 R2A,和固定端之接點 O_2 連結,將接點命名為 J5。

(7)將 Rod2 之右端接點 R2B,和 Rod3 上之滑槽 Slot2 連結,將接點命名為 J6。

步驟 8：裝上馬達

(1)選 (motor),將其置於 O_2 接點上。

(2)在 Window 選單下選取 Properties,將速度(value) 改為 50rad/s。

步驟 9：開始分析

(1)用滑鼠點選 Slider1,在 Measure 的選單下選取位移(Position)、速度(Velocity)、加速度(Acceleration)圖。

(2)按 ,開始進行分析。(如圖 2.4.2 所示)

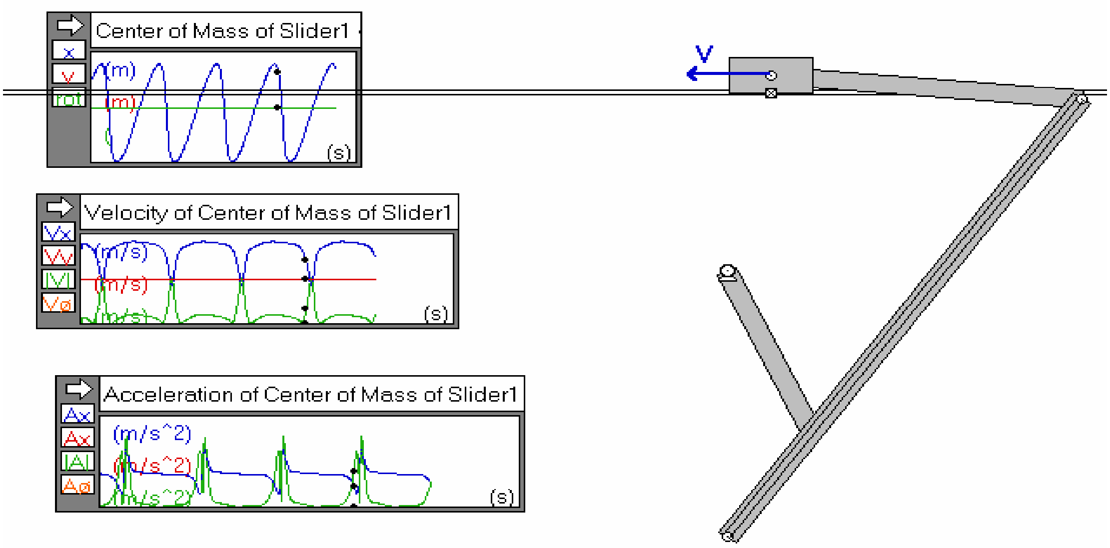


圖 2.4.2　牛頭鉋床之分析

2.5 蘇格蘭軛(Scotch Yoke)

2.5.1 簡介

蘇格蘭軛(Scotch yoke)是作簡諧運動(Simple harmonic motion)的一種機構。它最早用在蒸汽泵(steam pump)上,現在則用在產生振動的試驗機上。另外,它也用爲正弦-餘弦產生器(Sine-cosine generator)供作計算元件。該機構之簡圖如圖 2.5.1 所示。

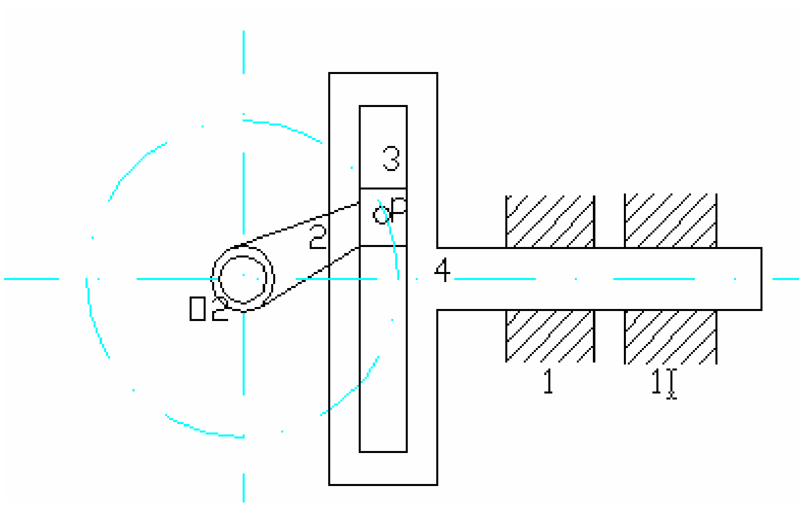


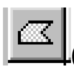
圖 2.5.1 蘇格蘭軛

2.5.2 分析步驟

步驟 1：設定工作環境

(1)進入 Working model 到 View 的選單下選取 Number and Unit,將單位改成 English(pounds)的單位。

步驟 2：畫出從動 T 型元件

(1)選 (Polygon) 畫出一 T 字型的形狀如圖 2.5.2 所示。

(2)在 Window 的選單下選取 Appearance 將物體名稱改爲 T- Slider。

(3)在 Window 的選單下選取 Properties,將質量改爲 3lb。

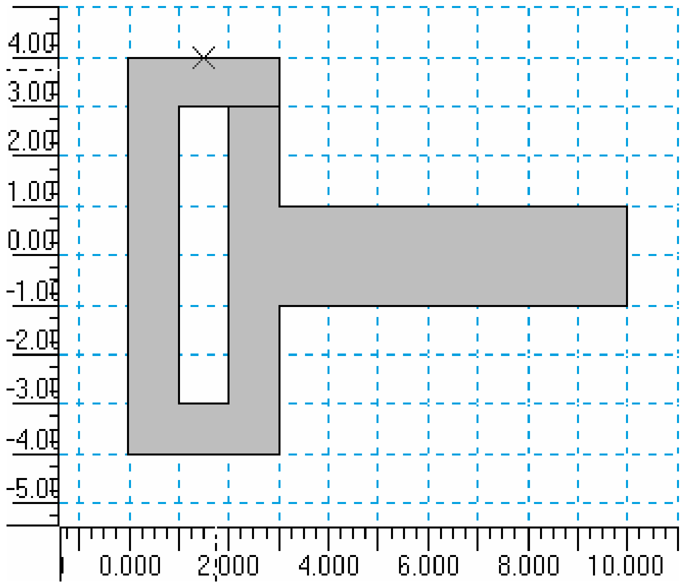


圖 2.5.2

步驟 3：畫出 T 型物件上的滑槽

(1) 選 (Slot element),點選圖 2.5.2 上打 X 的點,在 T 字型上開一滑槽。

(2)在 Window 的選單下選取 Appearance 將物體名稱改爲 Slot1。

步驟 4：畫出滑塊

(1) 選(Square),畫出一滑塊,W=1in,H=1in。

(2) 在 Window 的選單下選取 Appearance 將物體名稱改爲 S-Slider。

(3)在 Window 的選單下選取 Properties,將質量改爲 1lb。

步驟 5：畫出從動曲柄

(1) 選(Rectangle),畫出一矩形爲從動曲柄,W=2.5in，H=0.5in。

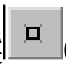
(2) 在 Window 的選單下選取 Appearance 將物體名稱改爲 Crank。

(3)在 Window 的選單下選取 Properties,將質量改爲 2lb。

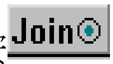
步驟 6：畫出各接點及固定端

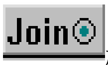
(1) 選(point element),先畫出固定端,將其位置放在 Y 軸=0 的任一點。再將曲柄的左右兩端各畫上兩接點。

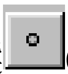
(2) 在 Window 的選單下選取 Appearance 將固定端名稱改爲 O_2,將曲柄的左右兩端名稱改爲 A1 及 A2。

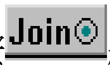
(3) 選(Square point element),在滑塊中心畫出一接點,在 Window 的選單下選取 Appearance 將物體名稱改為 A3。

步驟 7：將各點連接

(1) 先選擇固定端,再按住 Shift 鍵不放,選擇曲柄左端的接點 A1,按將點連接起來,在 Window 的選單下選取 Appearance 將接點名稱改為 J1。

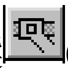
(2) 先選擇 T 型上的滑槽,再按住 Shift 鍵不放,選擇滑塊中心的接點,按將點連接起來,在 Window 的選單下選取 Appearance 將接點名稱改為 J2。

(3)選(point element),滑塊中心畫出一接點,在 Window 的選單下選取 Appearance 將物體名稱改為 A4。

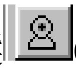
(4)先選擇滑塊中心的接點,再按住 Shift 鍵不放,選擇曲柄右端的接點 A2,按將點連接起來,在 Window 的選單下選取 Appearance 將接點名稱改為 J3。

步驟 8：畫出固定 T 型物件的滑槽

(1) 首先確定 T 型物件的中心要在 Y 軸=0 上,可由下方的座標系統更改。

(2) 選(Keyed slot joint),在 T 型上下各畫出兩滑槽,在 Window 的選單下選取 Appearance 將各滑槽名稱改為 Slot1 及 Slot3。

步驟 9：裝上馬達

(1) 選(Motor),將其放在固定端上。

(2) 在 Window 的選單下選取 Properties,將轉速改為 50rad/s。

步驟 10：最後分析

(1)先點選滑塊(S-Slider),在 Measure 的選單下,做出位移(Position)、速度(Velocity)、加速度(Acceleration)的圖形。(如圖 2.5.3 所示)

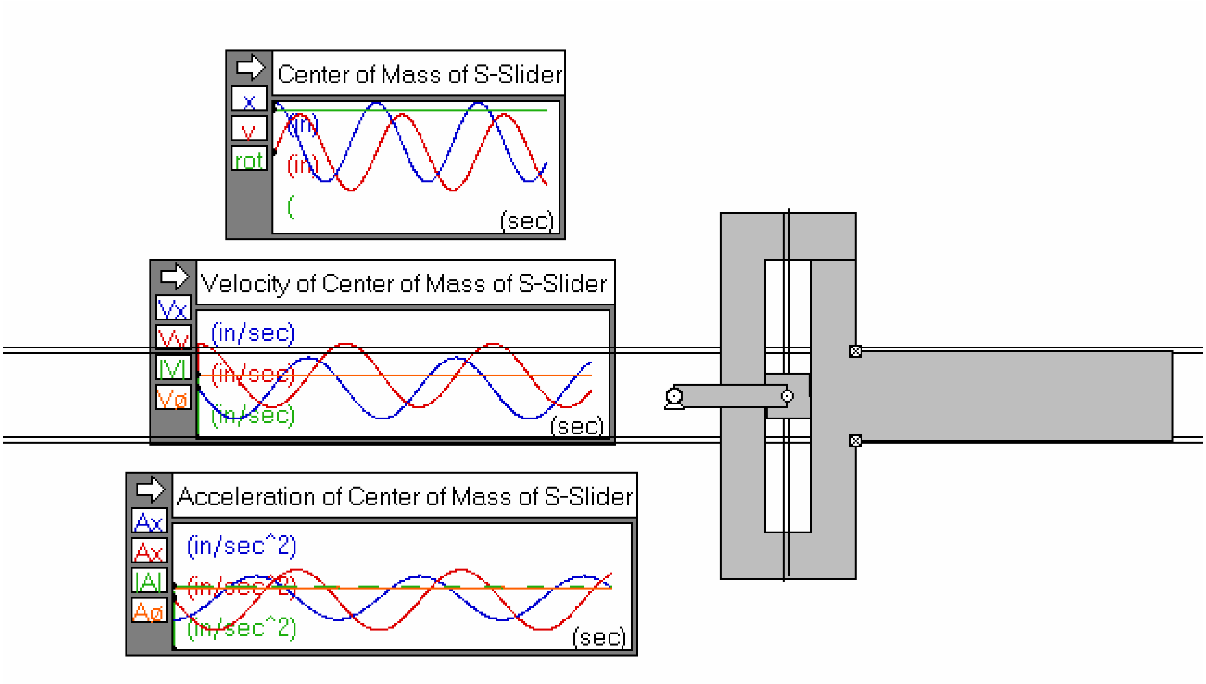


圖 2.5.3　蘇格蘭軛之分析

2.6 彈簧阻尼系統

2.6.1 簡介

探討兩塊不同質量的物體,加上彈簧及阻尼器後,施以一外力,其產生兩個自由度線性振動的分析,如圖 2.6.1 所示。

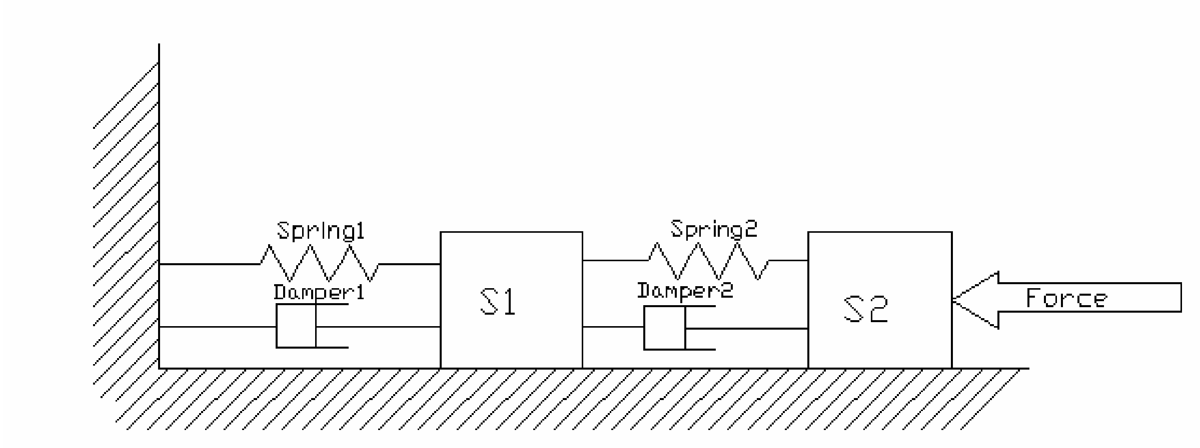
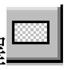


圖 2.6.1　彈簧阻尼系統

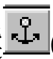
2.6.2 分析步驟

利用 Working Model 軟體,進行動態模擬。

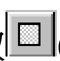
步驟 1:畫出一固定端

(1) 選擇 (rectangle),繪一長方形,並在下方的座標輸入 X=2.5, Y=5,且更改尺寸大小,W=40,H=5。

(2)在 Window 的選單下選擇 Appearance,將其改名為 G1。

(3)選(Anchor),移動滑鼠至 G1 上,任何一處點一下,即可使物體成為固定端。

步驟 2:畫出兩個滑塊

(1)選取(Square),拉出一方滑塊,從 Edit 的選單下選 Duplicate,複製出另一方滑塊。

(2)在 Window 的選單下選擇 Appearance,將兩滑塊分別改名為 S2。

(3)在下方的更改 S1 座標及尺寸,X=25,Y=10,W=10,S2 的座標及尺寸,X=55,Y=10,W=10。

步驟 3：畫出連結點

(1)選取(Point element),在 S1 下方左右兩端各畫出一連結點。

(2)同樣在 S2 的下方左右兩端各畫出一連結點。

(3)在 Window 選單下的 Appearance,將 S1 的連結點名稱改爲 P1A 及 P1B,S2 的改爲 P2A 及 P2B。

步驟 4：設定各物體的質量

(1) 在 Window 下的選單下選擇 Properties,更改質量,S1=100kg, S2= 50kg。

步驟 5：畫出滑槽

(1) 選取(Slot element),在座標原點(0,0)上,畫出一滑槽。

(2) 在 Window 下的選單選擇 Appearance,將其改名爲 Slot1。

(3) 先點選 S1 下的 P1A 點,再按住 Shift 鍵不放,點選 Slot1,按 Join 將兩件連結。

(4) 同上之步驟,將各滑槽重疊,一一將 P1B、P2A、P2B 和 Slot2、Slot3、Slot4 連結。

步驟 6：畫出彈簧

(1) 選取(Spring),移動滑鼠至點(2.5,8),平行拉出彈簧,至 S1 下的一點,在 Window 下的 Appearance,改名爲 Spring1。

(2) 選取(Spring),從 R1 拉出一平行彈簧,至 S2 上一點,在 Window 下的 Appearance,改名爲 Spring2。

步驟 7：畫出阻尼

(1) 選取(Damper),移動滑鼠至點(2.5,2),平行拉出一阻尼器,至 S1 下的一點,在 Window 下的 Appearance,改名爲 Damper1。

(2) 選取(Damper),移動滑鼠至 S1 上的一點,平行拉出一阻尼器,至 S2 上的一點,在 Window 下的 Appearance,改名爲 Damper2。

步驟 8：製造出力量

(1) 選 (Force), 從 S2 上拉出一力量，在下方更改其力量大小,Fx=100N,Fy=0。

步驟 9：開始分析

(1)分別分析 S1、S2 的位移、速度及加速度，所以點選 S1 與 S2,並在 Measure 的選單下選取位移(Position)、速度(Velocity)、加速度(Acceleration)圖。

(2) 按 Run ,開始進行分析。(如圖 2.6.2 所示)

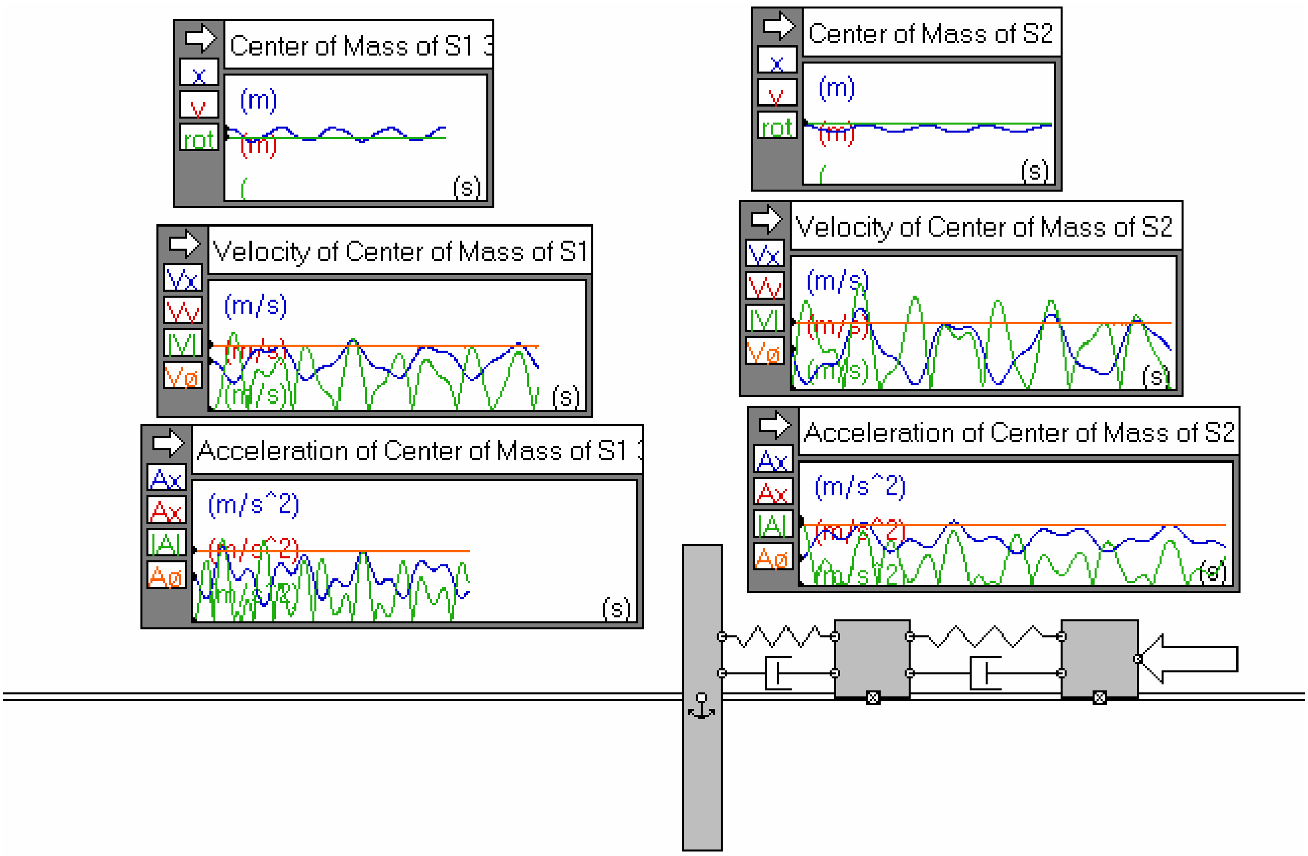
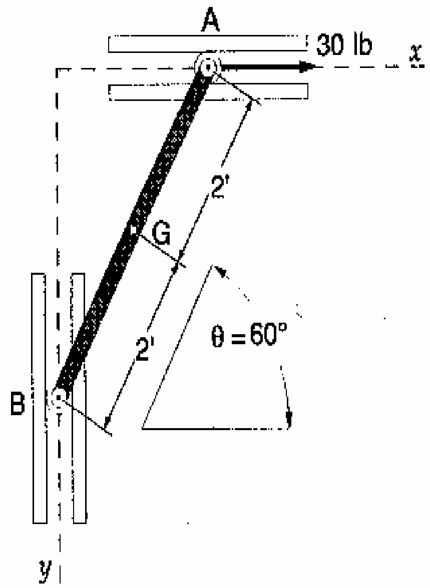


圖 2.6.2 彈簧阻尼系統之分析

A Double-Slotted Rod



The slender bar AB weighs 60 lbs. and moves in the vertical plane with its ends constrained to follow smooth horizontal and vertical guides. The bar is initially at rest in a position such that $\theta = 60°$. A 30 lb. force in the positive x-direction is applied at A. Calculate the initial angular acceleration of the bar and the initial forces on the small end rollers at A and B.

Concepts for Exercise 1:

- Utility windows
- Changing the unit system
- Precise placement of points and slots
- Joining points and slots to create slot joints
- Creating and scaling forces
- Displaying and scaling vectors
- Meters

Setting Up the Workspace

1. Choose Numbers and Units... from the View menu.
2. Choose English (pounds) from the Unit System pop-up menu
3. Click More Choices.
4. Choose Feet from the Distance pop-up menu (Figure 1-2).
5. Click OK.

To display the x-y axes:

1. Choose Workspace from the View menu.
2. On MacOS systems, choose X,Y Axes from the Workspace submenu (Figure 1-3). On Windows systems, check the box next to X,Y Axes in the Workspace dialog (Figure 1-4).

Drawing the Rod

1. Click the Rectangle tool in the Toolbar.
2. Position the pointer in the workspace and click to begin drawing. Move the mouse to size the rectangle. Click again to complete the rectangle.

Sizing the Rod

1. Select the rod (if it is not already selected) by placing the pointer on the object and clicking.
2. Click the height field of the Coordinates bar (labeled h) and enter 4.0. Then press Tab.
3. In the width field, enter the value 0.35 and press Return or Enter.

Zooming In

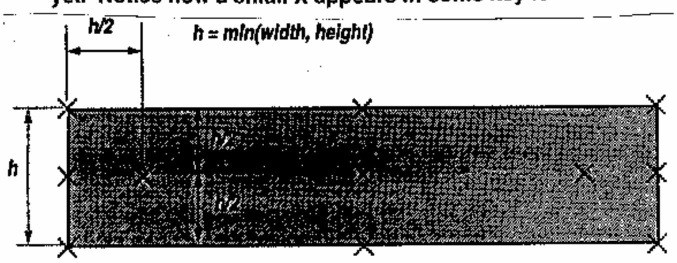
1. Click the Zoom In tool in the Toolbar.
2. Place the pointer on or near the rectangle and click.
3. Click the Arrow tool in the Toolbar or press the spacebar to deselect the Zoom In tool.

Setting the Weight of the Rod

1. Select the rod.
2. Choose Properties from the Window menu.
3. Enter the value 60 in the mass field.

Finding Snap Points on the Rod

1. Double-click the Point tool in the Toolbar.
2. Move the pointer over either end of the rectangle but do not click yet. Notice how a small X appears in some key locations.



Attaching Points to the Rod

We will attach a point element to each end of the rod.

1. Select the Point tool if you have not already done so.
2. Find the snap point at the center of the bottom end of the rod. When the snap point symbol appears, click to attach a point element.
3. Repeat the previous step for the top end of the rod.

Naming Key Elements of the Model

1. Click the point element located at the top end of the rod.
2. Choose Appearance from the Window menu.
3. Click the name field of the Appearance window (see Figure 1-14), and type Top Slot Pin.
4. Click the point element located at the bottom end of the rod.
5. Click the name field of the Appearance window, and type Bottom Slot Pin.

Creating the Slots

1. Click the Horizontal Slot tool in the Toolbar.
2. Bring the pointer near the origin and find its snap point (Figure 1-16). Click when the snap point is visible.
3. Click the Vertical Slot tool in the Toolbar.
4. Find the Snap Point at the origin and click.

Joining the Points to the Slots

1. Select the top point and, while holding the Shift key down, select the horizontal slot.
2. Click the Join button in the Toolbar.
3. Select the bottom point and, while holding the Shift key down, select the vertical slot.
4. Click the Join button in the Toolbar.

Creating the Force

1. Click the Force tool in the Toolbar.
2. Bring the pointer near the top of the rod and look for the Snap Point where the top slot pin is attached.
3. When the snap point on the top slot pin is visible, click once and move the pointer horizontally to the left.
4. Click again to finish creating the force.
5. Click to select the force if it is not already selected.
6. Click in the F_x field of the Coordinates bar and type 30.
7. Click in the F_y field of the Coordinates bar and enter the value 0.

Positioning the Rod

1. Click the rod to select it.
2. Click the Ø field (rotation) of the Coordinates bar and enter the value -30.

Running the Simulation

1. Click the Run button in the Toolbar.
2. Click the Reset button in the Toolbar.

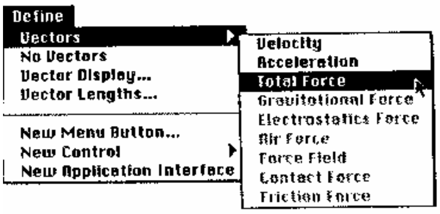
Displaying Vectors

The exercise asks for the initial force on both joints. You can display these forces as vectors for qualitative analysis. To display vectors:

1. **Choose Properties in the Window menu.**

   The Properties window appears.

2. **Click the selection pop-up menu and select "Top Slot Pin"**
3. **Choose Vectors from the Define menu and Total Force from the Vectors submenu (Figure 1-25).**



4. **Go back to the Properties window and select "Bottom Slot Pin".**
5. **Choose Vectors from the Define menu and Total Force from the Vectors submenu.**
6. **Run the simulation.**

   Like the force object, the vectors do not fit on the screen.

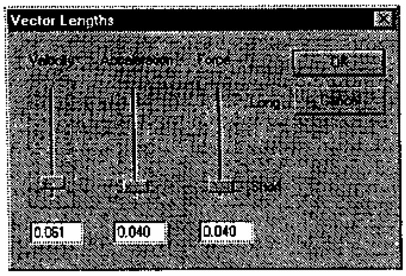
7. **Click Reset.**

Scaling the Vectors

The vectors must be scaled to fit on the screen. To scale the vectors:

1. **Choose Vector Lengths... from the Define menu.**

   The Vector Length dialog (Figure 1-26) appears.



2. **Click in the Force Vector field.**
3. **Enter a smaller value and press Tab to immediately see the change in the simulation window. Repeat until the vectors fit nicely into the window (try 0.0007). Click OK when done.**

Displaying Digital Meters

Three digital meters are required for this exercise: two force meters for the slots and one angular acceleration meter for the rod. To create the slot force digital meters:

1. **Select the horizontal slot and choose Force from the Measure menu.**

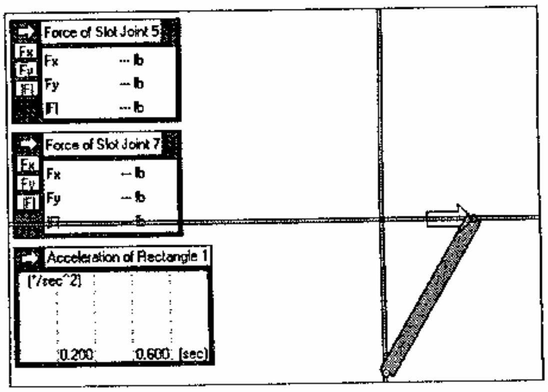
   A force meter is created (Figure 1-28).

2. **Repeat for the vertical slot.**

To create the angular acceleration digital meter:

1. **Select the rod.**
2. **Choose Acceleration from the Measure menu, and Rotation Graph from the Acceleration submenu.**

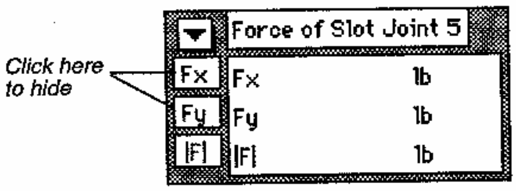
   An x-y graph of the angular acceleration of the rod will appear (see Figure 1-29).



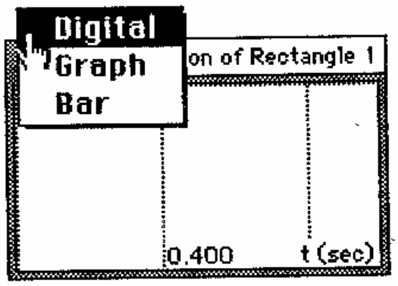
Customizing the Meters

This exercise requires only the magnitudes of the forces on the slots. Thus, some of the properties displayed by the force meters should be hidden. For this example, the total force on the slots, |F|, is the only value of interest; F_x and F_y will be switched off. Also, if a numerical value for the angular acceleration is desired, rather than a graph, it too can be displayed. To modify meter displays:

1. **Click the F_x and F_y buttons on the left side of the Force meters (see Figure 1-30).**

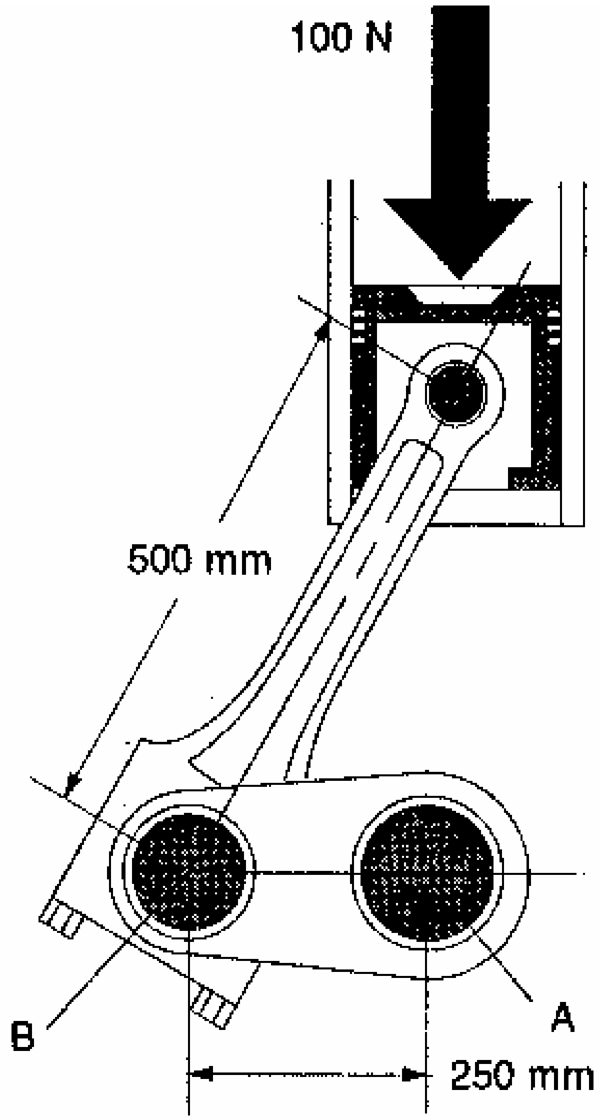


2. **On MacOS systems, click and hold the arrow in the top left corner of the angular acceleration meter and choose the Digital option from the pop-up menu (see Figure 1-31). On Windows systems, click the arrow in top left corner of the meter. With each click, the meter type cycles from Digital, Graph, Bar, and Digital again.**



Checking the Answers

A Piston Engine



In the two cycle piston engine shown, explosive gases are ignited in the combustion chamber above the piston. The explosions apply a force of 100 N for the duration of every downward stroke. The engine is equipped with a speed limiting device (rev limiter) which prevents the rotational speed from exceeding a set value (red-line). The masses of the piston and connecting rod are 1 kg and 2 kg, respectively. The mass of the crankshaft-flywheel assembly is 35 kg. Given that the red-line of the engine is 35 rad/sec (340 rpm), determine the forces at the crankshaft bearing (point A) and connection rod (point B) bearing. Assume the crankshaft-flywheel assembly can be modeled as a circular disk.

Setting Up the Workspace

1. Choose Workspace from the View menu and choose X,Y Axes from the Workspace submenu (MacOS) or the Workspace dialog (Windows).

2. Choose Numbers and Units... from the View menu.

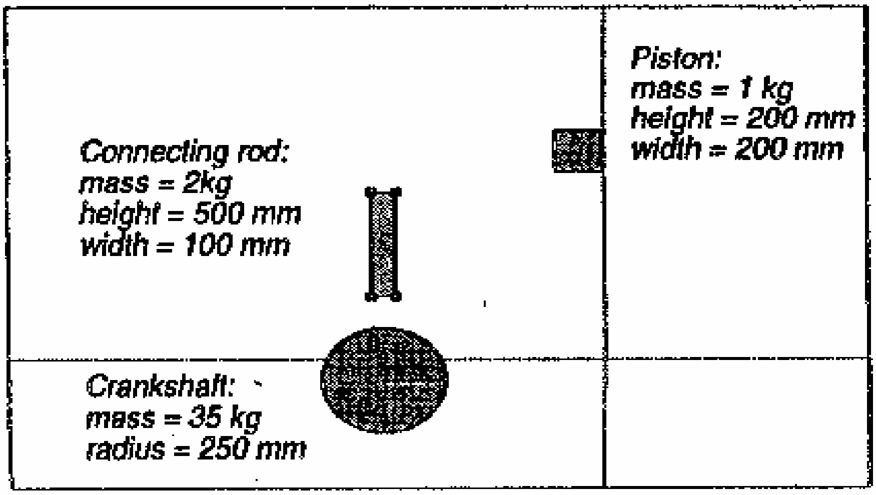
3. Click the More Choices button.

4. Click and hold in the Distance field

5. Choose millimeters from the Distance pop-up menu.

6. Click in the Rotation field and choose Radians from the pop-up menu.

Creating the Components



Creating the Crankshaft

1. Click the Circle tool in the Toolbar.

2. Click once on the background. Move the mouse to expand the circle and click again to complete sketching.

To set the mass of the crankshaft:

1. Choose Properties from the Window menu.

2. Click the mass field and enter the value 35.

To set the size of the crankshaft:

1. Select the crankshaft if it not already selected.

2. Click the Radius field (labeled "r") of the Coordinates bar and enter the value 250

Creating the Piston

1. Choose the Square tool in the Toolbar.
2. Click once on the background, drag to the right, and click again to complete sketching.

To set the size of the piston:

1. Click in the Height or Width field of the Coordinates bar and enter 200.

To set the piston's mass:

1. Select the piston if it not already selected.
2. Choose Properties from the Window menu.
3. Click in the mass field and enter the value 1.

Creating the Connecting Rod

1. Choose the Rectangle tool in the Toolbar.
2. Click once on the background, drag to the right, and click again to complete sketching.

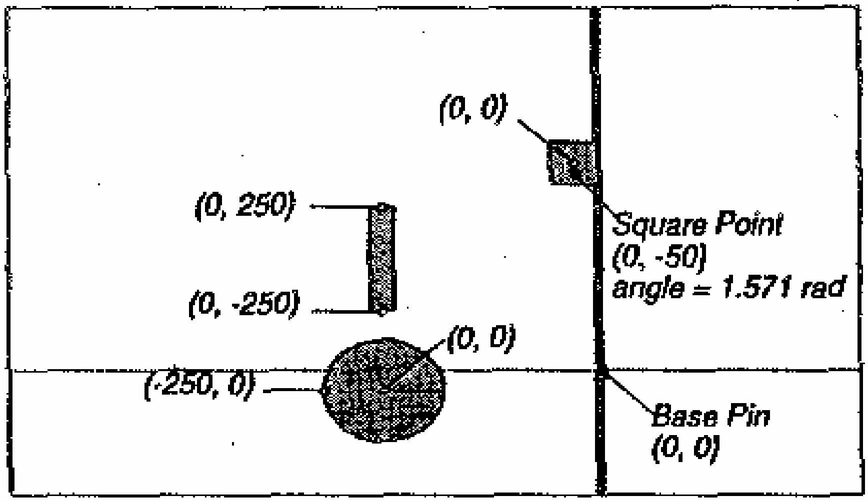
To set the mass of the connecting rod:

1. Select the new rectangle if it not already selected.
2. Choose Properties from the Window menu.
3. Click in the Mass field and enter the value 2.

To set the size of the rod:

1. Click the Height field of the Coordinates bar and enter the value 500.
2. Click the Width field of the Coordinates bar and enter the value 100.

Creating the Points for Joining



Creating Points on the Connecting Rod

1. Double-click the Point tool in the Toolbar.
2. Place the mouse pointer over the connecting rod rectangle. Find the snap point at the top end of the connecting rod.
3. To attach a point element, click when the snap point located at the top end is visible.
4. In the same fashion, attach another point element to the bottom end of the connecting rod.

Attaching Points to the Crankshaft

1. Make sure the Point tool is still selected. Place the mouse pointer over the crankshaft. Find the snap point at the center of the circle.
2. Click when the snap point at the center is visible.
3. Place the mouse pointer near the left quadrant of the circle. Find the snap point at the left quadrant
4. Click when the snap point at the left quadrant is visible.

Attaching Points to the Piston

1. Click the Square Point tool.
2. Click anywhere on the piston.
3. Click in the X field of the Coordinates bar and enter 0.
4. Press the tab key to move to the Y field of the Coordinates bar, and enter -50.
5. Choose the Properties in the Window menu.
6. In the angle field of the Properties window (marked by ø), enter the value 1.571.

To create the point:

1. Click the Point tool.

2. Place the pointer near the center of the square and find the snap point.

3. Click when the snap point at the center is visible.

Attaching a Point to the Background

1. Click the Point tool.

2. Place the mouse pointer near the origin. Find the snap point that appears at the origin.

3. Click when the snap point at the origin is visible.

4. Choose Appearance from the Window menu.

5. In the name field (where it says Point), type Base Pin.

Attaching a Slot to the Background

1. Choose the Vertical Slot tool in the Toolbar.

2. Place the pointer near the point element attached to the origin. Find the snap point.

3. Click when the snap point is visible.

Joining the Piston to the Slot

1. Select the square point on the piston, and while holding down the Shift key, select the slot.
2. Click the Join button in the Toolbar.

Joining the Crankshaft to the Point on the Background

1. Choose Properties in the Window menu.
2. From the selection pop-up menu located at the top of the Properties window, choose Base Pin
3. Hold the Shift key down and select the center point on the crankshaft circle.
4. Click the Join button.

Joining the Components

To join the piston to the connecting rod:

1. **Select the (round) point on the piston and, while holding the Shift key down, select the top point on the connecting rod.**

2. **Click the Join button.**

To join the connecting rod to the crankshaft:

1. **Select the bottom point on the connecting rod and, while holding the Shift key down, select the remaining (left) point on the crankshaft.**

2. **Click the Join button.**

Preventing a Collision

1. **Select the piston and, while holding the Shift key down, select the crankshaft.**

2. **Click and hold on the Object menu title in the menu bar**

3. **Choose Do Not Collide in the Object menu.**

Creating the Force

1. **Click the Force tool in the Toolbar.**

2. **Place the pointer near the midpoint of the top end of the piston. Find the snap point.**

3. **Click when the snap point is visible, drag the mouse upward, and click again to create the force.**

Sizing the Force

1. **Click the force vector to select the force.**

2. **Click the F_y field of the Coordinates bar and type -100.**

3. **Click the F_x field of the Coordinates bar and type 0.**

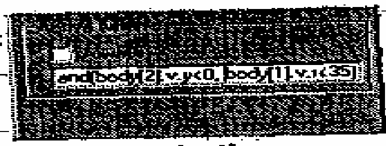
Timing the Force

1. **Select the force.**

2. **Choose Properties from the Window menu.**

3. **Click in the Active When field at the bottom of the Properties window. On Windows systems, you must first un-check the Always button before clicking in the Active When field.**

4. **Type the following formula (see Figure 2-17):**



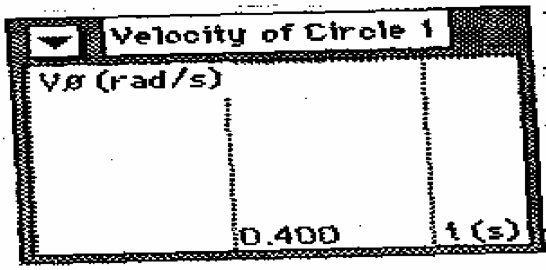
5. **Click the Run button in the Toolbar.**

6. **When you are ready to continue, click the Reset button in the Toolbar.**

Displaying a Graph

1. **Select the crankshaft circle.**

2. **Choose Velocity from the Measure menu and Rotation Graph from the Velocity submenu.**



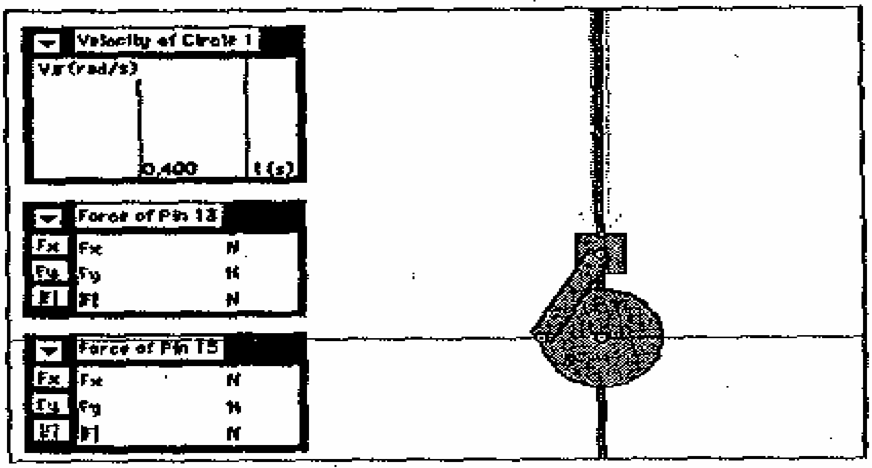
Displaying Digital Force Meters

1. **Select the crankshaft-main bearing joint**
2. **Choose Force from the Measure menu.**
3. **Repeat for the connecting rod-crankshaft joint**

To move the meters:

1. **Select a meter.**
2. **Drag it to any position you wish.**

Your window should resemble Figure 2-20.



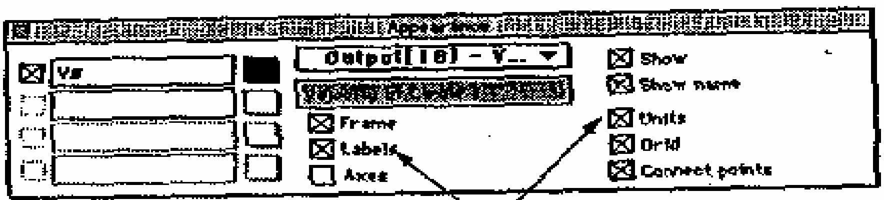
Modifying the Graph Display

1. **Select the velocity meter on the screen.**
2. **Choose Appearance in the Window menu.**

   Alternatively, you could press Control+J (on Windows systems) or Command+J (on MacOS systems) to open the window.

3. **Turn off the options titled "Labels" and "Units" (Figure 2-21)**

   You may wish to try modifying other options and observe the effects on the graph meter.



Remove check marks from these options.

If you wish to show the meter coordinate axes, click the check box labeled Axes.