```
(*Problem I.6.4*)
Off[General::spell];
Off[General::spell1];
Apply [ Clear , Names [ "Global`*" ] ] ;

(* initial data *)
AB = 0.15 ; BC = 0.40 ;  CD = 0.37 ;
CE = 0.23 ; EF = CE   ;  La = 0.30 ;
Lb = 0.45 ; Lc = CD   ;  fi = Pi / 3 ;

DE=CD+CE;

(* position  analysis *)
xD = La ; yD = Lb ;
xB = AB Cos [ fi ] ; yB = AB Sin [ fi ] ;
eq23a = ( xc - xB )^2 + ( yc - yB )^2 - BC^2 ;
eq23b = ( xc - xD )^2 + ( yc - yD )^2 - CD^2 ;
solutionC = Solve [ { eq23a == 0 , eq23b == 0 } , { xc , yc } ] ;
xc1 = xc /. solutionC [ [ 1 ] ] ; yc1 = yc /. solutionC [ [ 1 ] ] ;
xc2 = xc /. solutionC [ [ 2 ] ] ; yc2 = yc /. solutionC [ [ 2 ] ] ;
If [ xc1 < xc2 , xC = xc1 ; yC = yc1 , xC = xc2 ; yC = yc2 ] ;
m = ( yC - yD ) / ( xC - xD ) ; n = yC - m xC ;
eq24 = ( xe - xC )^2 + ( ye - yC )^2 - CE^2 ;
eq27 = ye - m xe - n ;
solutionE = Solve [ { eq24 == 0 , eq27 == 0 } , { xe , ye } ] ;
xe1 = xe /. solutionE [ [ 1 ] ] ; ye1 = ye /. solutionE [ [ 1 ] ] ;
xe2 = xe /. solutionE [ [ 2 ] ] ; ye2 = ye /. solutionE [ [ 2 ] ] ;
If [ xe1 <= xC , xE = xe1 ; yE = ye1 , xE = xe2 ; yE = ye2 ] ;
xF = - Lc ;
eq28 = ( xE - xF )^2 + ( yE - yf )^2 - EF^2 ;
solutionF = Solve [ { eq28 == 0 } , { yf } ] ;
yf1 = yf /. solutionF [ [ 1 ] ] ; yf2 = yf /. solutionF [ [ 2 ] ] ;
If [ yf1 < yE , yF = yf1 , yF = yf2 ] ;

rAB = rB = { xB , yB , 0 } ;
rAC = rC = { xC , yC , 0 } ;
rAD = rD = { xD , yD , 0 } ;
rAE = rE = { xE , yE , 0 } ;
rAF = rF = { xF , yF , 0 } ;

Print["rB = ", rB, " m" ];
Print["rC = ", rC, " m" ];
Print["rD = ", rD, " m" ];
Print["rE = ", rE, " m" ];
Print["rF = ", rF, " m" ];

(* angular velocity of the driver element *)
n = 1600.;(*rpm*)
w10 = n π/30;(*rad/s*)

(* contour 1 *)
omega10  = { 0 , 0 , w10  } ; (* driver element *)
omega21u = { 0 , 0 , w21u } ;
omega32u = { 0 , 0 , w32u } ;
omega03u = { 0 , 0 , w03u } ;

eq323a = omega10 + omega21u + omega32u + omega03u ;
eq323b = Cross [ rAB , omega21u ] + Cross [ rAC , omega32u ] +
         Cross [ rAD , omega03u ] ;

soluC1 = Solve [ { eq323a [ [ 3 ] ] == 0 ,
                   eq323b [ [ 1 ] ] == 0 ,
                   eq323b [ [ 2 ] ] == 0 } ,
                   { w21u , w32u , w03u } ] ;
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w21 = w21u /. soluC1 [ [ 1 ] ] ;
w32 = w32u /. soluC1 [ [ 1 ] ] ;
w03 = w03u /. soluC1 [ [ 1 ] ] ;

w20 = w10 + w21 ;
w30 = - w03 ; (* w30 = w20 + w32; *)

omega21 = { 0 , 0 , w21 } ;
omega32 = { 0 , 0 , w32 } ;
omega03 = { 0 , 0 , w03 } ;
vB = Cross [ omega10 , rAB ] ;
rBC = rAC - rAB ;
omega20 = omega10 + omega21 ;
vC = vB + Cross [ omega20 , rBC ] ;

(* contour 2 *)
w30 = - w03 ;
omega30 = - omega03 ; (* known from the previous contour *)
omega43u = { 0 , 0 , w43u } ;
omega54u = { 0 , 0 , w54u } ;
V05u = { 0 , v05u , 0 } ;

eq324a = omega30 + omega43u + omega54u ;
eq324b = Cross [ rAD , omega30 ] + Cross [ rAE , omega43u ] +
         Cross  [ rAF , omega54u ] + V05u ;

soluC2 = Solve [ { eq324a [ [ 3 ] ] == 0 ,
                   eq324b [ [ 1 ] ] == 0 ,
                   eq324b [ [ 2 ] ] == 0 } ,
                 { w43u , w54u , v05u } ] ;
w43 = w43u /. soluC2 [ [ 1 ] ] ;
w54 = w54u /. soluC2 [ [ 1 ] ] ;
v05 = v05u /. soluC2 [ [ 1 ] ] ;

omega43 = { 0 , 0 , w43 } ;
omega54 = { 0 , 0 , w54 } ;
V05 = { 0 , v05 , 0 } ;

w40 = w30 + w43 ;
rDE = rAE - rAD ;
vE = Cross [ omega30 , rDE ] ;
omega40 = omega30 + omega43 ;
rEF = rAF - rAE ;
vF = Chop[vE + Cross [ omega40 , rEF ]] ;

Print [ "vF = " , vF, " m/s" ] ;

(* contour 1 *)
Alpha21u = { 0 , 0 , alpha21u } ;
Alpha32u = { 0 , 0 , alpha32u } ;
Alpha03u = { 0 , 0 , alpha03u } ;
rCD = rAD - rAC ;

eq410a = Alpha21u + Alpha32u + Alpha03u ;
eq410b = Cross [ rAB, Alpha21u ] + Cross [ rAC, Alpha32u ] +
         Cross [ rAD, Alpha03u ] - w10^2 rAB - w20^2 rBC -
         w03^2 rCD ;
solutC21 = Solve [ { eq410a [ [ 3 ] ] == 0 ,
                     eq410b [ [ 1 ] ] == 0 ,
                     eq410b [ [ 2 ] ] == 0 } ,
                   { alpha21u, alpha32u, alpha03u } ] ;
alpha21 = alpha21u /. solutC21 [ [ 1 ] ] ;
alpha32 = alpha32u /. solutC21 [ [ 1 ] ] ;
alpha03 = alpha03u /. solutC21 [ [ 1 ] ] ;
```

```
Alpha21 = { 0 , 0 , alpha21 } ;
Alpha32 = { 0 , 0 , alpha32 } ;
Alpha03 = { 0 , 0 , alpha03 } ;
alpha20 = alpha21 ;
alpha30 = - alpha03 ; (* =  alpha20 + alpha32 *)
aB = - w10^2 rAB;
Alpha20 = Alpha21;
aC = aB + Cross [ Alpha20, rBC ] - w20^2 rBC ;

(* contour 2 *)

Alpha30 =  { 0, 0, alpha30 } ;
Alpha43u = { 0, 0, alpha43u } ;
Alpha54u = { 0, 0, alpha54u } ;
A05u = { 0, a05u , 0 } ;
eq411a = Alpha30 + Alpha43u + Alpha54u ;
eq411b = Cross [ rAD, Alpha30 ] + Cross [ rAE, Alpha43u ] +
         Cross [ rAF, Alpha54u ] + A05u - w30^2 rDE -
         w40^2 rEF ;

solutC22 = Solve [ { eq411a [ [ 3 ] ] == 0 ,
                     eq411b [ [ 1 ] ] == 0 ,
                     eq411b [ [ 2 ] ] == 0 } ,
                   { alpha43u , alpha54u , a05u } ] ;

alpha43 = alpha43u /. solutC22 [ [ 1 ] ] ;
alpha54 = alpha54u /. solutC22  [ [ 1 ] ] ;
a05 = a05u /. solutC22  [ [ 1 ] ] ;

alpha40 = alpha30 + alpha43 ;
Alpha43 = { 0, 0, alpha43 } ;
aE = Cross [ Alpha30 , rDE ] - w30^2 rDE ;
Alpha40 = Alpha30 + Alpha43 ;
aF =Chop[ aE + Cross [ Alpha40, rEF ] - w40^2 rEF];

markers = Table [ {
            Point [ { 0 , 0 } ] ,
            Point [ { xB , yB } ] ,
            Point [ { xC , yC } ] ,
            Point [ { xD , yD } ] ,
            Point [ { xE , yE } ] ,
            Point [ { xF , yF } ] ,
            Point [ { (xF+xE)/2 , (yF+yE)/2 } ],
            Point [ { (xB+xC)/2 , (yB+yC)/2 } ]
                } ] ;

name = Table [ {
            Text [ "A" ,{0  , 0  },{ 3 , 0 } ] ,
            Text [ "B" ,{xB , yB },{-2 , 0 } ] ,
            Text [ "C" ,{xC , yC },{-2 ,-2 } ] ,
            Text [ "D" ,{xD , yD },{-3 , 0 } ] ,
            Text [ "E" ,{xE , yE },{3  , 0 } ] ,
            Text [ "F" ,{xF , yF },{3  , 0 } ] ,
            Text [ "C4",{(xF+xE)/2,(yF+yE)/2 } ,
                                   {-2 , 0 } ] ,
            Text [ "C2" ,{(xB+xC)/2,(yB+yC)/2} ,
                                   { 2 , 0 } ]
             } ] ;

graph  = Graphics [
        { { RGBColor [ 1 , 0 , 0 ] ,
            Line [ { {0,0},{xB,yB} } ] } ,
          { RGBColor [ 0 , 0 , 1 ] ,
            Line [ { {xB,yB} , {xC,yC}} ] } ,
          { RGBColor [ 1 , 0, 1 ] ,
```

```
          Line [ { {xD,yD},  {xE,yE}} ] } ,
        { RGBColor [ 0 , 0 , 0 ] ,
          Line [ { {xE,yE},{xF,yF} } ] } ,
        { RGBColor [ 0 , 1 , 1 ] ,
          PointSize [ 0.01 ] , markers } ,
        { name } } ] ;

Show [ Graphics [ graph  ] ,
       PlotRange -> { { -.5 , .5 } ,
                      { -.2 , .7 } } ,
      Frame -> True,
      AxesOrigin -> {0,0},
      FrameLabel->{"x","y"},
      Axes -> {True,True},
      AspectRatio -> Automatic ] ;



α1 = α5 = {0,0,0};
α2 = Alpha20;
α3 = Alpha30;
α4 = Alpha40;

Print["α1 = ",α1," rad/s^2"];
Print["α2 = ",α2," rad/s^2"];
Print["α3 = ",α3," rad/s^2"];
Print["α4 = ",α4," rad/s^2"];

h=0.01;
d=0.001;
hSlider=0.02;
wSlider=0.05;
ρ=8000;
g=9.807;

Fext=-Sign[vF]{0,500,0};
Print["Fext = ",Fext,"  N"];

(*Link 1*)
m1=ρ AB h d;
rC1=rB/2;
Print["rC1 = ",rC1,"  m"];
aC1=aB/2;
Print["aC1 = ",aC1,"  m/s^2"];
Fin1=-m1 aC1;
G1={0,-m1 g,0};
F1=(Fin1+G1);
IC1=m1 (AB^2+h^2)/12;
Print["m1 = ",m1,"  kg"];
Print["IC1 = ",IC1,"  kg m^2"];
Print["Fin1 = -m1 aC1 = ",Fin1,"  N "];
Print["G1 = -m1 g = ",G1,"  N "];
Print["F1 = -m1 aC1 + G1 = ",F1,"  N "];
Print["M1 = Min1 = -IC1 α1 = ",{0,0,0},"  N m"];


(*Link 2*)
m2=ρ BC h d;
rC2=(rB+rC)/2;
Print["rC2 = ",rC2,"  m"];
aC2=(aB+aC)/2;
Print["aC2 = ",aC2,"  m/s^2"];
Fin2=-m2 aC2;
G2={0,-m2 g,0};
F2=(Fin2+G2);
```

```
IC2=m2 (BC^2+h^2)/12;
M2=Min2=-IC2 α2;
Print["m2 = ",m2,"  kg"];
Print["IC2 = ",IC2,"  kg m^2"];
Print["Fin2 = -m2 aC2 = ",Fin2,"  N "];
Print["G2 = -m2 g = ",G2,"  N "];
Print["F2 = -m2 aC2 + G2 = ",F2,"  N "];
Print["M2 = Min2 = -IC2 α2 = ",M2,"  N m"];

(*Link 3*)
m3=ρ DE h d;
rC3=(rD+rE)/2;
Print["rC3 = ",rC3,"  m"];
aC3=aE/2;
Print["aC3 = ",aC3,"  m/s^2"];
Fin3=-m3 aC3;
G3={0,-m3 g,0};
F3=(Fin3+G3);
IC3=m3 (DE^2+h^2)/12;
M3=Min3=-IC3 α3;
Print["m3 = ",m3,"  kg"];
Print["IC3 = ",IC3,"  kg m^2"];
Print["Fin3 = -m3 aC3 = ",Fin3,"  N "];
Print["G3 = -m3 g = ",G3,"  N "];
Print["F3 = -m3 aC3 + G3 = ",F3,"  N "];
Print["M3 = Min3 = -IC3 α3 = ",M3,"  N m"];


(*Link 4*)
m4=ρ EF h d;
rC4=(rE+rF)/2;
Print["rC4 = ",rC4,"  m"];
aC4=(aE+aF)/2;
Print["aC4 = ",aC4,"  m/s^2"];
Fin4=-m4 aC4;
G4={0,-m4 g,0};
F4=(Fin4+G4);
IC4=m4 (EF^2+h^2)/12;
M4=Min4=-IC4 α4;
Print["m4 = ",m4,"  kg"];
Print["IC4 = ",IC4,"  kg m^2"];
Print["Fin4 = -m4 aC4 = ",Fin4,"  N "];
Print["G4 = -m4 g = ",G4,"  N "];
Print["F4 = -m4 aC4 + G4 = ",F4,"  N "];
Print["M4 = Min4 = -IC4 α4 = ",M4,"  N m"];

(*Link 5*)
m5=ρ hSlider wSlider d;
Print["aC5 = ",aF,"  m/s^2"];
Fin5=-m5 aF;
G5={0,-m5*g,0};
F5=(Fin5+G5);
IC5=m5 (hSlider^2+wSlider^2)/12;
M5={0,0,0};
Print["m5 = ",m5,"  kg"];
Print["IC5 = ",IC5,"  kg m^2"];
Print["Fin5 = -m5 aC5 = ",Fin5,"  N "];
Print["G5 = -m5 g = ",G5,"  N "];
Print["F5 = -m5 aC5 + G5 = ",F5,"  N "];
Print["M5 = Min5 = -IC5 α5 = ",M5,"  N m"];

Print[" "];
Print[" Ft "];
F05={F05x,0,0};
eqME54=Cross[rF-rE,F05+Fext+F5]+Cross[rC4-rE,F4]+M4;
```

```
solF05=Solve[eqME54[[3]]==0,F05x];
F05s = F05/.solF05[[1]];
Print["F05 = ",F05s,"  N"];

Print[" "];
Print[" Fr "];
F45={F45x,F45y,0};
eqF5y=(F05+F45+F5+Fext)[[2]];
eqME4=(Cross[rF-rE,-F45]+Cross[rC4-rE,F4]+M4)[[3]];
solF45=Solve[{eqF5y==0,eqME4==0},{F45x,F45y}];
F45s = F45/.solF45[[1]];
Print["F45 = ",F45s,"  N"];

Print[" "];
Print[" Er "];
F34={F34x,F34y,0};
eqMF4=(Cross[rE-rF,F34]+Cross[rC4-rF,F4]+M4)[[3]];
eqF45y=(F34+F4+F5+Fext)[[2]];
solF34=Solve[{eqF45y==0,eqMF4==0},{F34x,F34y}];
F34s = F34/.solF34[[1]];
Print["F34 = ",F34s,"  N"];

Print[" "];
Print[" Dr "];
F03={F03x,F03y,0};
eqMC3=(Cross[rD-rC,F03]+Cross[rE-rC,-F34s]+Cross[rC3-rC,F3]+M3)[[3]];
eqMB32=(Cross[rD-rB,F03]+Cross[rE-rB,-F34s]+Cross[rC3-rB,F3]+Cross[rC2-rB,F2]+M3+M2)[[3
]];
solF03=Solve[{eqMC3==0,eqMB32==0},{F03x,F03y}];
F03s = F03/.solF03[[1]];
Print["F03 = ",F03s,"  N"];


Print[" "];
Print[" Cr "];
F32={F32x,F32y,0};
eqMB2=(Cross[rC-rB,F32]+Cross[rC2-rB,F2]+M2)[[3]];
eqMD3=(Cross[rC-rD,-F32]+Cross[rE-rD,-F34s]+Cross[rC3-rD,F3]+M3)[[3]];
solF32=Solve[{eqMB2==0,eqMD3==0},{F32x,F32y}];
F32s = F32/.solF32[[1]];
Print["F32 = ",F32s,"  N"];


Print[" "];
Print[" Br "];
F12={F12x,F12y,0};
eqMC2=(Cross[rB-rC,F12]+Cross[rC2-rC,F2]+M2)[[3]];
eqMD23=(Cross[rB-rD,F12]+Cross[rE-rD,-F34s]+Cross[rC3-rD,F3]+Cross[rC2-rD,F2]+M3+M2)[[3
]];
solF12=Solve[{eqMC2==0,eqMD23==0},{F12x,F12y}];
F12s = F12/.solF12[[1]];
Print["F12 = ",F12s,"  N"];


Print["  "]
(*Link 1*)
F01=-F1+F12s;
Print["F01 = ",F01,"  N"];
Mm=-Cross[rB,-F12s]-Cross[rC1,F1]-M1;
Print["Meq = ",Mm,"  N m"]



rB = {0.075, 0.129904, 0} m
```

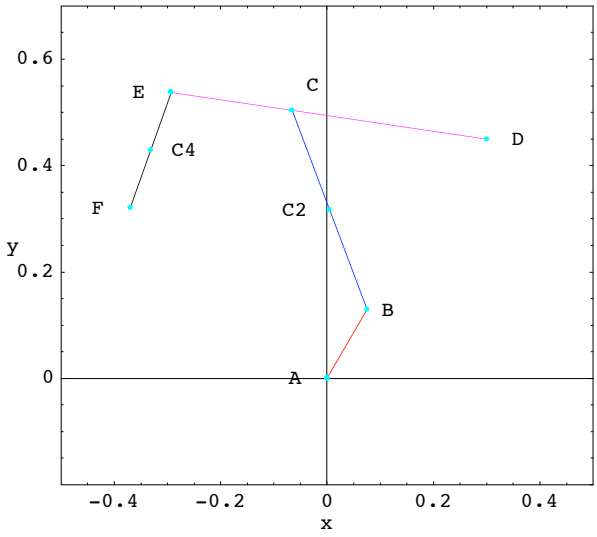
rC = {-0.0660047, 0.504227, 0} m

rD = {0.3, 0.45, 0} m

rE = {-0.293521, 0.537935, 0} m

rF = {-0.37, 0.321023, 0} m

vF = {0, 37.5269, 0} m/s



α1 = {0, 0, 0} rad/s^2

α2 = {0, 0, -5765.48} rad/s^2

α3 = {0, 0, 11778.5} rad/s^2

α4 = {0, 0, -5313.8} rad/s^2

Fext = {0, -500, 0} N

rC1 = {0.0375, 0.0649519, 0} m

aC1 = {-1052.76, -1823.43, 0} m/s^2

m1 = 0.012 kg

IC1 = 0.0000226 kg m^2

Fin1 = -m1 aC1 = {12.6331, 21.8812, 0} N

G1 = -m1 g = {0, -0.117684, 0} N

F1 = -m1 aC1 + G1 = {12.6331, 21.7635, 0} N

M1 = Min1 = -IC1 α1 = {0, 0, 0} N m

rC2 = {0.00449764, 0.317065, 0} m

aC2 = {-711.357, -4076.82, 0.} m/s^2

m2 = 0.032 kg

IC2 = 0.000426933 kg m^2

```
Fin2 = -m2 aC2 = {22.7634, 130.458, 0.}  N

G2 = -m2 g = {0, -0.313824, 0}  N

F2 = -m2 aC2 + G2 = {22.7634, 130.145, 0.}  N

M2 = Min2 = -IC2 α2 = {0, 0, 2.46148}  N m

rC3 = {0.00323941, 0.493968, 0}  m

aC3 = {553.624, -3654.15, 0.}  m/s^2

m3 = 0.048  kg

IC3 = 0.0014404  kg m^2

Fin3 = -m3 aC3 = {-26.5739, 175.399, 0.}  N

G3 = -m3 g = {0, -0.470736, 0}  N

F3 = -m3 aC3 + G3 = {-26.5739, 174.929, 0.}  N

M3 = Min3 = -IC3 α3 = {0, 0, -16.9658}  N m

rC4 = {-0.331761, 0.429479, 0}  m

aC4 = {553.624, -7040.75, 0.}  m/s^2

m4 = 0.0184  kg

IC4 = 0.0000812667  kg m^2

Fin4 = -m4 aC4 = {-10.1867, 129.55, 0.}  N

G4 = -m4 g = {0, -0.180449, 0}  N

F4 = -m4 aC4 + G4 = {-10.1867, 129.369, 0.}  N

M4 = Min4 = -IC4 α4 = {0, 0, 0.431835}  N m

aC5 = {0, -6773.2, 0}  m/s^2

m5 = 0.008  kg

IC5 = 1.93333×10^-6  kg m^2

Fin5 = -m5 aC5 = {0, 54.1856, 0}  N

G5 = -m5 g = {0, -0.078456, 0}  N

F5 = -m5 aC5 + G5 = {0, 54.1071, 0}  N

M5 = Min5 = -IC5 α5 = {0, 0, 0}  N m


 Ft

F05 = {-131.304, 0, 0}  N


 Fr
```

```
F45 = {131.304, 445.893, 0}  N
```

```
 Er
```

```
F34 = {141.49, 316.523, 0}  N
```

```
 Dr
```

```
F03 = {281.548, -237.498, 0}  N
```

```
 Cr
```

```
F32 = {113.484, -379.093, 0}  N
```

```
 Br
```

```
F12 = {-136.247, 248.949, 0}  N
```

```
F01 = {-148.88, 227.185, 0}  N
```

```
Meq = {0. - M1, 0. - M1, 36.3746 - M1}  N m
```