MDA-Project 1 - Problem 3:
Find a Crank-Rocker with Points C and with Attached Slider for Given Slider Positions

Part 1: Graphical solution, plot of the mechanism.

■ crank-rocker mechanismus: Basic functions

```
Clear[par,φ,fψ,ψ1,ψ2,φ0,ψ0,a,b,c,d,k,κ];

σ = ArcTan[a Sin[φ]/(d-a Cos[φ])]
Δ = Simplify[Sqrt[(a Sin[φ])^2 + (d-a Cos[φ])^2]]
λ = Simplify[ArcCos[(Δ^2 + b^2 - c^2) / (2 b Δ)] ]
fψ = π - (σ + λ)
```

$$\text{ArcTan}\left[\frac{a \sin[\varphi]}{d - a \cos[\varphi]}\right]$$

$$\sqrt{a^2 + d^2 - 2\,a\,d \cos[\varphi]}$$

$$\text{ArcCos}\left[\frac{a^2 + b^2 - c^2 + d^2 - 2\,a\,d \cos[\varphi]}{2\,b\,\sqrt{a^2 + d^2 - 2\,a\,d \cos[\varphi]}}\right]$$

$$\pi - \text{ArcCos}\left[\frac{a^2 + b^2 - c^2 + d^2 - 2\,a\,d \cos[\varphi]}{2\,b\,\sqrt{a^2 + d^2 - 2\,a\,d \cos[\varphi]}}\right] - \text{ArcTan}\left[\frac{a \sin[\varphi]}{d - a \cos[\varphi]}\right]$$

```
φi = Pi + ArcCos[(d^2 + (c - a)^2 - b^2) / (2 (c - a) d)];
φa = ArcCos[(d^2 + (c + a)^2 - b^2) / (2 (c + a) d)];
fφ0 = φi - φa
```

$$\pi + \text{ArcCos}\left[\frac{-b^2 + (-a + c)^2 + d^2}{2\,(-a + c)\,d}\right] - \text{ArcCos}\left[\frac{-b^2 + (a + c)^2 + d^2}{2\,(a + c)\,d}\right]$$

```
ψi = Pi - ArcCos[(d^2 + b^2 - (c - a)^2) / (2 b d)];
ψa = Pi - ArcCos[(d^2 + b^2 - (c + a)^2) / (2 b d)];
fψ0 = ψi - ψa
```

$$-\text{ArcCos}\left[\frac{b^2 - (-a + c)^2 + d^2}{2\,b\,d}\right] + \text{ArcCos}\left[\frac{b^2 - (a + c)^2 + d^2}{2\,b\,d}\right]$$

```
μmin1 = ArcCos[(c^2 + b^2 - (d - a)^2) / (2 b c)]
```

$$\text{ArcCos}\left[\frac{b^2 + c^2 - (-a + d)^2}{2\,b\,c}\right]$$

```
μmin2 = Pi - ArcCos[(c^2 + b^2 - (d + a)^2) / (2 b c)]
```

$$\pi - \text{ArcCos}\left[\frac{b^2 + c^2 - (a + d)^2}{2\,b\,c}\right]$$

```
Grashof = Min[a, b, c, d] + Max[a, b, c, d]
```

```
Max[a, b, c, d] + Min[a, b, c, d]
```



```
fδ = ArcTan[(d + b Cos[ψ] - a Cos[φ]), (b Sin[ψ] - a Sin[φ])]
```

```
ArcTan[d - a Cos[φ] + b Cos[ψ], -a Sin[φ] + b Sin[ψ]]
```

point B over B0

```
xB = A0x + b Cos[ψ + γ0] + d Cos[γ0]
yB = A0y + b Sin[ψ + γ0] + d Sin[γ0]
```

```
A0x + d Cos[γ0] + b Cos[γ0 + ψ]
```

```
A0y + d Sin[γ0] + b Sin[γ0 + ψ]
```

point C over A

```
xC = A0x + a Cos[φ + γ0] + kC Cos[κC + δ + γ0]
yC = A0y + a Sin[φ + γ0] + kC Sin[κC + δ + γ0]
```

```
A0x + kC Cos[γ0 + δ + κC] + a Cos[γ0 + φ]
```

```
A0y + kC Sin[γ0 + δ + κC] + a Sin[γ0 + φ]
```

point D of slider

```
γD = ArcSin[yC / lD]
```

$$\text{ArcSin}\left[\frac{A0y + kC \sin[\gamma 0 + \delta + \kappa C] + a \sin[\gamma 0 + \varphi]}{lD}\right]$$

```
xD = xC + lD Cos[γD]
```

$$A0x + kC \cos[\gamma 0 + \delta + \kappa C] + a \cos[\gamma 0 + \varphi] + lD \sqrt{1 - \frac{(A0y + kC \sin[\gamma 0 + \delta + \kappa C] + a \sin[\gamma 0 + \varphi])^2}{lD^2}}$$

■ Test of functions by a par set 1: graphical solution - non-scaled

■ skurv = goal*function*s*phi


```
sfct = {{0, 70.75504456442971`}, {2, 70.69704795174536`},
  {4, 70.60502003432072`}, {6, 70.4798461772672`}, {8, 70.32217732153089`},
  {10, 70.13255888882543`}, {12, 69.9114993466563`}, {14, 69.65950872624644`},
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```

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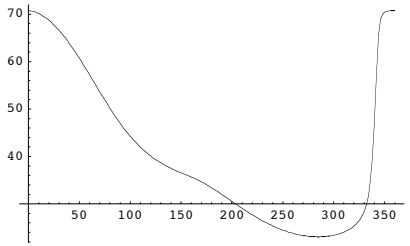
 {342, 57.2151}, {344, 65.5978}, {346, 69.0343}, {348, 70.0208}, {350, 70.3977},
 {352, 70.5927}, {354, 70.7044}, {356, 70.7624}, {358, 70.7776}, {360, 70.755}}
```

```
plokurv1 = ListPlot[skurv, PlotJoined → True];
```



■ Hand solution: par1

```
par1 = {A0x → 0, A0y → 0, γ0 → -15.524110996754258 °, a → 16.5, b → 17, c → 19,
   d → 18.681541692269406, kC → 22, κC → 24.863968303395 Degree , g → 9.3, lD → 28.7}
```

```
{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17,
 c → 19, d → 18.6815, kC → 22, κC → 0.433958, g → 9.3, lD → 28.7}
```

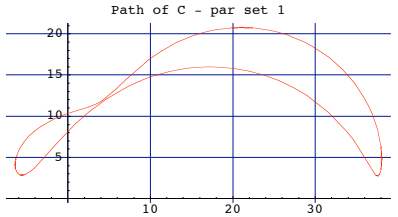


```
ArcCos[(c^2 + kC^2 - g^2) / (2 c kC)] / Degree /. par1 // N
```

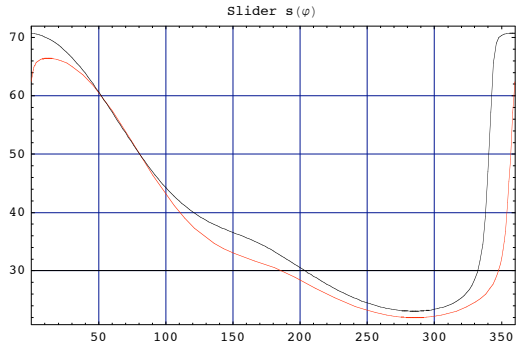
```
24.864
```

■ plot of mechanism

```
xCpar = xC /. δ -> fδ /. ψ -> fψ /. par1;
yCpar = yC /. δ -> fδ /. ψ -> fψ /. par1;
xDpar = xD /. δ -> fδ /. ψ -> fψ /. par1;
plo1C = ParametricPlot[{xCpar, yCpar}, {φ, 0, 2 Pi},
   GridLines → Automatic, PlotLabel → "Path of C - par set 1",
   AspectRatio → Automatic, PlotStyle → {{RGBColor[1, 0, 0]}}];
```

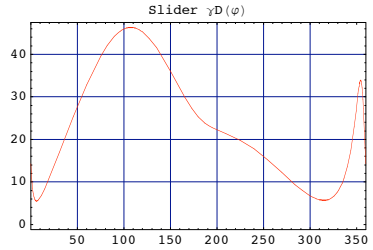



```
φ = phiG * Degree;
plokurv2 = Plot[xDpar, {phiG, 0, 360},
   Frame → True, GridLines → Automatic, PlotLabel → " Slider s(φ) ",
   PlotRange → {{0, 360}, Automatic}, PlotStyle → {{RGBColor[1, 0, 0]}}];
Clear[φ];
Show[plokurv2, plokurv1];
```



Note: there are some errors: Range 40 to300 degrees is fine, after 300 big errors.

```
φ = phiG * Degree;
Plot[γD / Degree /. δ -> fδ /. ψ -> fψ /. par1, {phiG, 0, 360},
  Frame → True, GridLines → Automatic, PlotLabel → " Slider γD(φ) ",
  PlotRange → {{0, 360}, Automatic}, PlotStyle → {{RGBColor[1, 0, 0]}}];
Clear[
  φ];
```



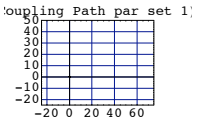
■ Animation of double-rocker mecha par 1 (ψ→fψ)

```
pa = par1
```

```
{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17,
 c → 19, d → 18.6815, kC → 22, κC → 0.433958, g → 9.3, lD → 28.7}
```

```
fψi = fψ;

rA0x = A0x /. pa;
rA0y = A0y /. pa;
rB0x = d Cos[γ0] /. pa;
rB0y = d Sin[γ0] /. pa;
rax = A0x + a Cos[φ + γ0] /. pa;
ray = A0y + a Sin[φ + γ0] /. pa;
rbx = A0x + b Cos[ψ + γ0] + d Cos[γ0] /. ψ → fψi /. pa;
rby = A0y + b Sin[ψ + γ0] + d Sin[γ0] /. ψ → fψi /. pa;
rcx = xC /. δ → fδ /. ψ → fψi /. pa;
rcy = yC /. δ → fδ /. ψ → fψi /. pa;
rdx = xD /. δ → fδ /. ψ → fψi /. pa;
rdy = 0;
lmax = Max[a, b, c, d] /. pa;
Plo0 = Plot[0, {i, 0, 1},
   PlotRange → {{-25, 75}, {-25, 50}}, Frame → True, AspectRatio → Automatic,
   GridLines → Automatic, PlotLabel → "Coupling Path par set 1)"];
```

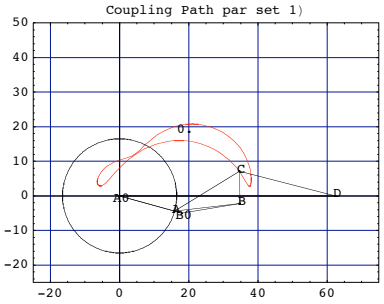



```
Do[
  PloMecha1 = Graphics[{
        Circle  [{rA0x,rA0y},a/.pa],

        Circle  [{rA0x,rA0y},lmax/100],
        Circle  [{rax,ray},lmax/100],
        Circle  [{rbx,rby},lmax/100],
        Circle  [{rcx,rcy},lmax/100],
        Circle  [{rdx,rdy},lmax/100],
        Circle  [{rB0x,rB0y},lmax/100],

        Line  [{{rA0x,rA0y}, {rB0x,rB0y}}],
        Line  [{{rA0x,rA0y}, {rax,ray}}],
        Line  [{{rB0x,rB0y}, {rbx,rby}}],
        Line  [{{rax,ray}, {rbx,rby}, {rcx,rcy}, {rax,ray}}],
        Line  [{{rcx,rcy}, {rdx,rdy}, {rA0x,rA0y}}],

        Text  [φ/Degree//N,{lmax, lmax}],
        Text  [A0,{rA0x+lmax/30, rA0y-lmax/30}],
        Text  [A ,{rax+lmax/30, ray+lmax/30}],
        Text  [B ,{rbx+lmax/30, rby+lmax/30}],
        Text  [C ,{rcx+lmax/30, rcy+lmax/30}],
        Text  [D ,{rdx+lmax/30, rdy+lmax/30}],
        Text  [B0,{rB0x+lmax/30,rB0y-lmax/30}]}];
  Show[Plo0, plo1C,PloMecha1];
,{φ,0, 2 Pi, Pi/10}];
```



Part 2: Parameter-Optimization
ferror(p) -> min, ferror = sum((fct(p) - val)^2)

■ Given are point of B and K

```
par1
```

```
{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17,
 c → 19, d → 18.6815, kC → 22, κC → 0.433958, g → 9.3, lD → 28.7}
```

```
parReq = {A0x → 0, A0y → 0, γ0 → -0.27094685033842053`,
  a → 16.5`, b → 17, c → 19, d → 18.681541692269406`}
```

```
{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17, c → 19, d → 18.6815}
```

```
fct = {
   Simplify[xD /. δ -> fδ /. ψ -> fψ /. φ → 0 Degree /. parReq],
   Simplify[xD /. δ -> fδ /. ψ -> fψ /. φ → 20 Degree /. parReq],
   Simplify[xD /. δ -> fδ /. ψ -> fψ /. φ → 60 Degree /. parReq],
   Simplify[xD /. δ -> fδ /. ψ -> fψ /. φ → 100 Degree /. parReq],
   Simplify[xD /. δ -> fδ /. ψ -> fψ /. φ → 180 Degree /. parReq],
   Simplify[xD /. δ -> fδ /. ψ -> fψ /. φ → 200 Degree /. parReq],
   Simplify[xD /. δ -> fδ /. ψ -> fψ /. φ → 300 Degree /. parReq],
   Simplify[xD /. δ -> fδ /. ψ -> fψ /. φ → 340 Degree /. parReq],
   Simplify[lD - yC /. δ -> fδ /. ψ -> fψ /. φ → 350 Degree /. parReq]

  };

nfct = Length[fct]

9

fct[[8]] //. par1 // N

26.5146
```

Values of s

```
val = {70.8, 68.7, 57.2, 44.3, 33.4, 30.5, 23.4, 47, 5}

{70.8, 68.7, 57.2, 44.3, 33.4, 30.5, 23.4, 47, 5}

nfct = Length[val]

9
```

■ setup the error fct.

```
ferror = Sum[(fct[[i]] - val[[i]])^2, {i, 1, nfct}] // N;

ferror /. par1 // N

618.623
```

■ Find the solution of p

```
par1

{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17,
 c → 19, d → 18.6815, kC → 22, κC → 0.433958, g → 9.3, lD → 28.7}

pinit = {{kC, 30}, {κC, 0.2}, {lD, 24}}

{{kC, 30}, {κC, 0.2}, {lD, 24}}

parOpt = FindMinimum[ferror, pinit]

{392.32, {kC → 22.0795, κC → -0.0846163, lD → 27.4752}}
```


■ Test of functions by a par set 2: optimized solution - non-scaled

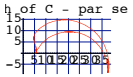
```
par2 = Join[parReq, parOpt[[2]]]

{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17,
 c → 19, d → 18.6815, kC → 22.0795, κC → -0.0846163, lD → 27.4752}

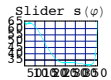
par2 ; (*  we use par1 again! *)
```

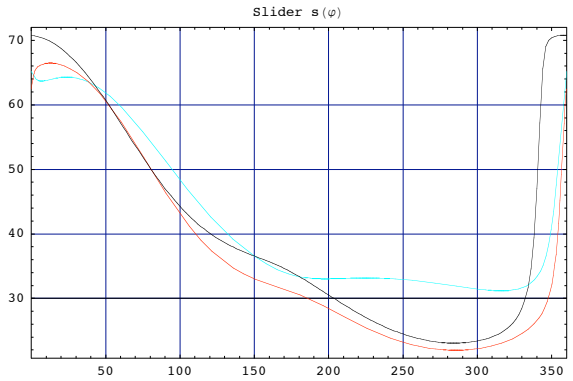
■ plot of mechanism

```
xCpar = xC /. δ -> fδ /. ψ -> fψ /. par2;
yCpar = yC /. δ -> fδ /. ψ -> fψ /. par2;
plo1C = ParametricPlot[{xCpar, yCpar}, {φ, 0, 2 Pi},
   GridLines → Automatic, PlotLabel → "Path of C - par set 1",
   AspectRatio → Automatic, PlotStyle → {{RGBColor[1, 0, 0]}}];
```




```
xDpar = xD /. δ -> fδ /. ψ -> fψ /. par2;
φ = phiG * Degree;
plokurv3 = Plot[xDpar, {phiG, 0, 360},
   Frame → True, GridLines → Automatic, PlotLabel → " Slider s(φ) ",
   PlotRange → {{0, 360}, Automatic}, PlotStyle → {{RGBColor[0, 1, 1]}}];
Clear[φ];
Show[plokurv3, plokurv2, plokurv1];
```





This solution is a few better in the range about 320 and 360 degrees

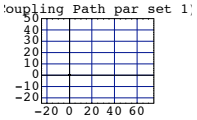
■ Animation of double-rocker mecha par 1 ($\psi \to f\psi$)

```
pa = par2
```

```
{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17,
 c → 19, d → 18.6815, kC → 22.0795, κC → -0.0846163, lD → 27.4752}
```

```
fψi = fψ;

rA0x = A0x /. pa;
rA0y = A0y /. pa;
rB0x = d Cos[γ0] /. pa;
rB0y = d Sin[γ0] /. pa;
rax = A0x + a Cos[φ + γ0] /. pa;
ray = A0y + a Sin[φ + γ0] /. pa;
rbx = A0x + b Cos[ψ + γ0] + d Cos[γ0] /. ψ → fψi /. pa;
rby = A0y + b Sin[ψ + γ0] + d Sin[γ0] /. ψ → fψi /. pa;
rcx = xC /. δ → fδ /. ψ → fψi /. pa;
rcy = yC /. δ → fδ /. ψ → fψi /. pa;
rdx = xD /. δ → fδ /. ψ → fψi /. pa;
rdy = 0;
lmax = Max[a, b, c, d] /. pa;
Plo0 = Plot[0, {i, 0, 1},
   PlotRange → {{-25, 75}, {-25, 50}}, Frame → True, AspectRatio → Automatic,
   GridLines → Automatic, PlotLabel → "Coupling Path par set 1)"];
```

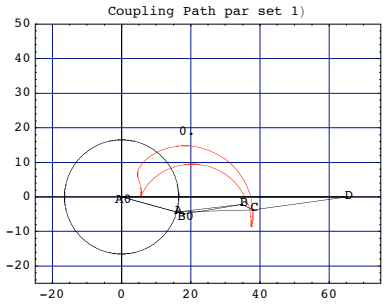



```
Do[
  PloMecha1 = Graphics[{
        Circle  [{rA0x,rA0y},a/.pa],

        Circle  [{rA0x,rA0y},lmax/100],
        Circle  [{rax,ray},lmax/100],
        Circle  [{rbx,rby},lmax/100],
        Circle  [{rcx,rcy},lmax/100],
        Circle  [{rdx,rdy},lmax/100],
        Circle  [{rB0x,rB0y},lmax/100],

        Line  [{{rA0x,rA0y}, {rB0x,rB0y}}],
        Line  [{{rA0x,rA0y}, {rax,ray}}],
        Line  [{{rB0x,rB0y}, {rbx,rby}}],
        Line  [{{rax,ray}, {rbx,rby}, {rcx,rcy}, {rax,ray}}],
        Line  [{{rcx,rcy}, {rdx,rdy}, {rA0x,rA0y}}],

        Text  [φ/Degree//N,{lmax, lmax}],
        Text  [A0,{rA0x+lmax/30, rA0y-lmax/30}],
        Text  [A ,{rax+lmax/30, ray+lmax/30}],
        Text  [B ,{rbx+lmax/30, rby+lmax/30}],
        Text  [C ,{rcx+lmax/30, rcy+lmax/30}],
        Text  [D ,{rdx+lmax/30, rdy+lmax/30}],
        Text  [B0,{rB0x+lmax/30,rB0y-lmax/30}]}];
   Show[Plo0, plo1C,PloMecha1];
 ,{φ,0, 2 Pi, Pi/10}];
```

Further Evaluations of the mechanism using par2

```
par1
```

```
{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17,
 c → 19, d → 18.6815, kC → 22, κC → 0.433958, g → 9.3, lD → 28.7}
```

```
par2
```

```
{A0x → 0, A0y → 0, γ0 → -0.270947, a → 16.5, b → 17,
 c → 19, d → 18.6815, kC → 22.0795, κC → -0.0846163, lD → 27.4752}
```

■ Toggle angle of crank rocker

```
φi = Pi + ArcCos[(d^2 + (c - a)^2 - b^2) / (2 (c - a) d)];
φa = ArcCos[(d^2 + (c + a)^2 - b^2) / (2 (c + a) d)];
fφ0 = φi - φa
```

$$\pi + \text{ArcCos}\left[\frac{-b^2 + (-a+c)^2 + d^2}{2\,(-a+c)\,d}\right] - \text{ArcCos}\left[\frac{-b^2 + (a+c)^2 + d^2}{2\,(a+c)\,d}\right]$$

```
ψi = Pi - ArcCos[(d^2 + b^2 - (c - a)^2) / (2 b d)];
ψa = Pi - ArcCos[(d^2 + b^2 - (c + a)^2) / (2 b d)];
fψ0 = ψi - ψa
```

$$-\text{ArcCos}\left[\frac{b^2 - (-a+c)^2 + d^2}{2\,b\,d}\right] + \text{ArcCos}\left[\frac{b^2 - (a+c)^2 + d^2}{2\,b\,d}\right]$$

```
fφ0 / Degree /. par2
```

```
219.311
```

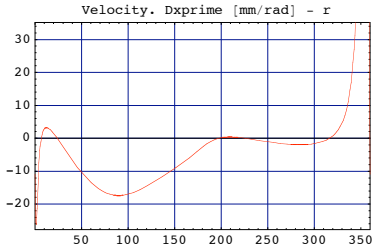
```
fψ0 / Degree /. par2
```

```
162.472
```

■ Toggle angle of slider crank: $\varphi 0$ for stroke s0

```
Dxprime = D[Simplify[xDpar], φ];
```

```
φ = phiG * Degree;
Plot[{Dxprime}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
  PlotLabel → " Velocity. Dxprime [mm/rad] - r", PlotRange → {{0, 360}, Automatic},
  PlotStyle → {{RGBColor[1, 0, 0]}, {RGBColor[0, 1, 0]}, {RGBColor[0, 0, 1]}}];
Clear[
  φ];
```




```
Dxprime /. φ → 25 Degree
```

```
-0.491342
```

```
Dxprime /. φ → 316 Degree
```

```
-0.0730695
```

```
φ0 = 316 - 25
```

```
291
```

```
s0 = xDpar /. φ → 316 Degree - xDpar /. φ → 25 Degree
```

```
33.1472
```

■ Transmission angle of B

```
μmin1 = ArcCos[(c^2 + b^2 - (d - a)^2) / (2 b c)]
```

$$\text{ArcCos}\left[\frac{b^2 + c^2 - (-a + d)^2}{2\,b\,c}\right]$$

```
μmin2 = Pi - ArcCos[(c^2 + b^2 - (d + a)^2) / (2 b c)]
```

$$\pi - \text{ArcCos}\left[\frac{b^2 + c^2 - (a + d)^2}{2\,b\,c}\right]$$

```
μmin1 / Degree /. par2
```

```
2.77792
```

```
180 - μmin2 / Degree /. par2
```

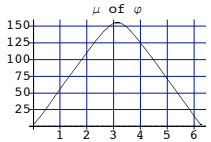
```
155.48
```

Plot of $\mu(\varphi)$

```
μ = ArcCos[(b^2 + c^2 - Δ^2) / (2 b c)]
```

$$\text{ArcCos}\left[\frac{-a^2 + b^2 + c^2 - d^2 + 2\,a\,d\,\text{Cos}[\varphi]}{2\,b\,c}\right]$$

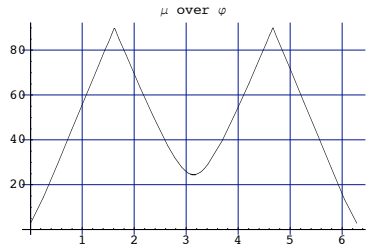

```
Plot[μ / Degree /. par2, {φ, 0, 2 Pi}, GridLines -> Automatic, PlotLabel -> "μ of φ"];
```




```
μfct[φ_, a_, b_, c_, d_] := If[ArcCos[(-a^2 + b^2 + c^2 - d^2 + 2 a d Cos[φ]) / (2 b c)] < 90 Degree,
   ArcCos[(-a^2 + b^2 + c^2 - d^2 + 2 a d Cos[φ]) / (2 b c)], Pi - ArcCos[(-a^2 + b^2 + c^2 - d^2 + 2 a d Cos[φ]) / (2 b c)]];
μfct[0, a /. par2, b /. par2, c /. par2, d /. par2] / Degree
```

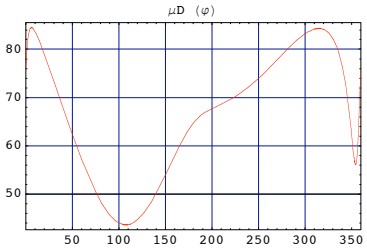
```
2.77792
```

```
Plot[μfct[φ, a /. par2, b /. par2, c /. par2, d /. par2] / Degree,
  {φ, 0, 2 Pi}, GridLines -> Automatic, PlotLabel -> "μ over φ"];
```



■ Transmission angle of D: μD = 90 Degrees - γd

```
φ = phiG * Degree;
Plot[(90 Degree - γD) / Degree /. δ -> fδ /. ψ -> fψ /. par1,
  {phiG, 0, 360}, Frame → True, GridLines → Automatic, PlotLabel → " μD (φ) ",
  PlotRange → {{0, 360}, Automatic}, PlotStyle → {{RGBColor[1, 0, 0]}}];
Clear[
  φ];
```



!!! Note: This are good values

■ Linear Velocity of C and D - scaling: Ms = 4.05/43 or 1/1

```
ω = 2 Pi n / 60 /. n → 300 // N
```

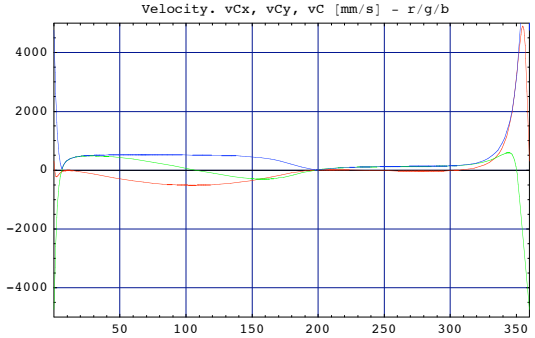
```
31.4159
```

```
Ms = 1 / 1
```

```
1
```

```
vCx = D[Simplify[xCpar / Ms], φ] ω;
vCy = D[Simplify[yCpar / Ms], φ] ω;
vC = Sqrt[vCx^2 + vCy^2];
```

```
φ = phiG * Degree;
Plot[{vCx, vCy, vC}, {phiG, 0, 360}, Frame → True,
  GridLines → Automatic, PlotLabel → " Velocity. vCx, vCy, vC [mm/s] - r/g/b",
  PlotRange → {{0, 360}, {-5000, 5000}},
  PlotStyle → {{RGBColor[1, 0, 0]}, {RGBColor[0, 1, 0]}, {RGBColor[0, 0, 1]}}];
Clear[
  φ];
```



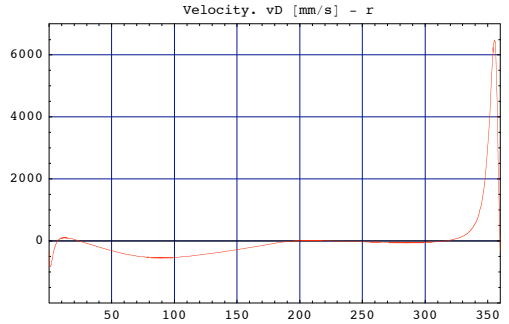

```
vC /. φ → 0
```

```
4754.09
```

```
vDx = D[Simplify[xDpar / Ms], φ] ω;
```



```
φ = phiG * Degree;
Plot[{vDx}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
  PlotLabel → " Velocity. vD [mm/s] - r", PlotRange → {{0, 360}, {-2000, 7000}},
  PlotStyle → {{RGBColor[1, 0, 0]}, {RGBColor[0, 1, 0]}, {RGBColor[0, 0, 1]}}];
Clear[
  φ];
```

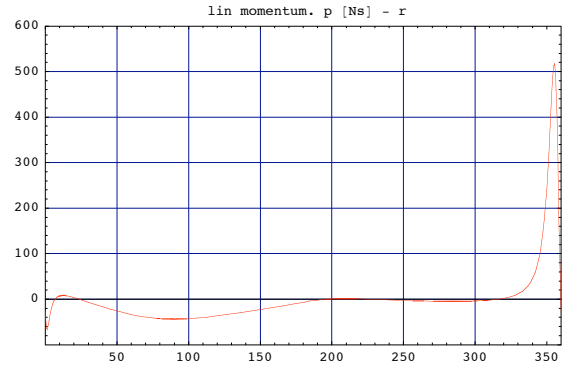



```
vDx /. φ → 355 Degree
```

```
6431.9
```

■ The linear momentum: p = m_Slider vD.

```
φ = phiG * Degree;
Plot[{vDx * 0.080}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
  PlotLabel → " lin momentum. p [Ns] - r", PlotRange → {{0, 360}, {-100, 600}},
  PlotStyle → {{RGBColor[1, 0, 0]}, {RGBColor[0, 1, 0]}, {RGBColor[0, 0, 1]}}];
Clear[
  φ];
```




```
vDx * 0.080 /. φ → 355 Degree
```

```
514.552
```