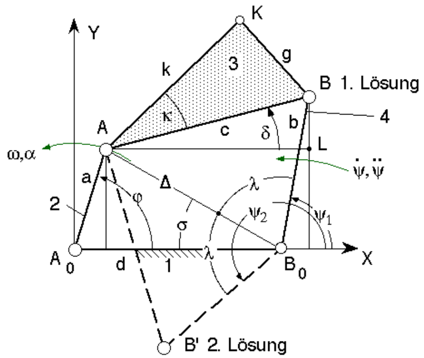
Crank-Rocker mechanism with two coupling points K and H
MDA-Project - Problem 3 - Solution

created (V6) 20.11.2009 / Prof. Dr. Oskar Wallrapp, FK06, UAS Munich
updated 12.12.2009
*****



■ Setup paramters

```
par1 = {A0x → 0, A0y → 0, a → 40, b → 97, c → 98,
  B0x → 100, B0y → 40, k → 60, κ → 49 Degree, h → 30, κH → 49 Degree}
```

```
{A0x → 0, A0y → 0, a → 40, b → 97, c → 98, B0x → 100, B0y → 40, k → 60, κ → 49 °, h → 30, κH → 49 °}
```

```
par2 = {d -> Sqrt[B0x^2 + B0y^2] /. par1 // N, γ0 -> ArcTan[B0y / B0x] /. par1 // N}
```

```
{d → 107.703, γ0 → 0.380506}
```

```
γ0 / Degree /. par2[[2]]
```

```
21.8014
```

```
parErg1 = Join[par1, par2]
```

```
{A0x → 0, A0y → 0, a → 40, b → 97, c → 98, B0x → 100,
 B0y → 40, k → 60, κ → 49 °, h → 30, κH → 49 °, d → 107.703, γ0 → 0.380506}
```

■ 1 Basis Equ of the crank-rocker / double-rocker mechanism

Wir betrachten das Dreick A-B0-Lot von A auf A0,B0: Δ = Strecke A-B0.
ψ1=ψ ist der Winkel der Loesung 1, ψ2 ist der Winkel der Loesung 2.

```
Clear[φ,ψ,ψ1,ψ2];

rax = a Cos[φ];
ray = a Sin[φ];
rbx = d + b Cos[ψ];
rby =     b Sin[ψ];
```



```
X = d - a Cos[φ];
Y = a Sin[φ];
Δ = Sqrt[X^2 + Y^2];
σ = ArcTan[Y/X]
```

$$\mathrm{ArcTan}\left[\frac{a\,\mathrm{Sin}[\varphi]}{d - a\,\mathrm{Cos}[\varphi]}\right]$$

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

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

```
ψf1 = π - (σ + λ)
```

$$\pi - \mathrm{ArcCos}\left[\frac{a^2 + b^2 - c^2 + d^2 - 2\,a\,d\,\mathrm{Cos}[\varphi]}{2\,b\,\sqrt{a^2 + d^2 - 2\,a\,d\,\mathrm{Cos}[\varphi]}}\right] - \mathrm{ArcTan}\left[\frac{a\,\mathrm{Sin}[\varphi]}{d - a\,\mathrm{Cos}[\varphi]}\right]$$

```
ψf2 = π - (σ - λ)
```

$$\pi + \mathrm{ArcCos}\left[\frac{a^2 + b^2 - c^2 + d^2 - 2\,a\,d\,\mathrm{Cos}[\varphi]}{2\,b\,\sqrt{a^2 + d^2 - 2\,a\,d\,\mathrm{Cos}[\varphi]}}\right] - \mathrm{ArcTan}\left[\frac{a\,\mathrm{Sin}[\varphi]}{d - a\,\mathrm{Cos}[\varphi]}\right]$$

```
δf = ArcTan [ b Cos[ψ]+X, b Sin[ψ]-Y ]
```

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

```
μf = ArcCos[(c^2+b^2-Δf^2)/(2 b c)]
```

$$\mathrm{ArcCos}\left[\frac{b^2 + c^2 - \Delta f^2}{2\,b\,c}\right]$$

```
μminI = μf/.Δf->d-a
```

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

```
μminII = Pi - μf/.Δf->d+a
```

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

These fct plots only values smaler 90 Degrees

```
fktmy[f_] := If[f > Pi / 2, Pi - f, f];

fphii = Pi + ArcCos[(d^2 + (c - a)^2 - b^2) / (2 * (c - a) * d)]
fphia = ArcCos[(d^2 + (c + a)^2 - b^2) / (2 * (c + a) * d)]
fphi0 = fphii - fphia
```

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

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

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

```
fpsii = Pi - ArcCos[(d^2 + b^2 - (c - a)^2) / (2 * b * d)]
fpsia = Pi - ArcCos[(d^2 + b^2 - (c + a)^2) / (2 * b * d)]
fpsi0 = fpsii - fpsia
```

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

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

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

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

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

```
xK = A0x + a Cos[φ + γ0] + k Cos[κ + δ + γ0]
yK = A0y + a Sin[φ + γ0] + k Sin[κ + δ + γ0]
```

```
A0x + k Cos[γ0 + δ + κ] + a Cos[γ0 + φ]

A0y + k Sin[γ0 + δ + κ] + a Sin[γ0 + φ]
```

```
xH = A0x + a Cos[φ + γ0] + h Cos[κH + δ + γ0]
yH = A0y + a Sin[φ + γ0] + h Sin[κH + δ + γ0]
```

```
A0x + h Cos[γ0 + δ + κH] + a Cos[γ0 + φ]

A0y + h Sin[γ0 + δ + κH] + a Sin[γ0 + φ]
```

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

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

■ Results calculated by parameter set Erg1

```
par = parErg1
```

```
{A0x → 0, A0y → 0, a → 40, b → 97, c → 98, B0x → 100,
 B0y → 40, k → 60, κ → 49 °, h → 30, κH → 49 °, d → 107.703, γ0 → 0.380506}
```

```
Grashof /. par
```

```
147.703
```

```
b + c /. par
```

```
195
```

```
ψf2 /. par /. φ → 0
ψf2 / Degree /. par /. φ → 0
```

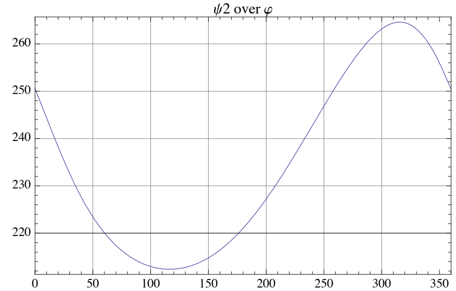
```
4.3717

250.48
```

```
δf /. ψ → ψf2 /. par /. φ → 0
 δf / Degree /. ψ → ψf2 /. par /. φ → 0
```

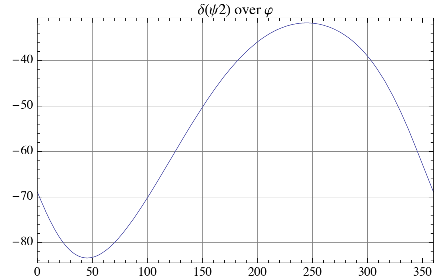
```
-1.2024

-68.8924
```



```
φ = phiG °;
Plot[{ψf2 / Degree /. par}, {phiG, 0, 360}, Frame → True,
 GridLines → Automatic, PlotLabel → "ψ2 over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```




```
φ = phiG °;
Plot[{δf / Degree /. ψ -> ψf2 /. par}, {phiG, 0, 360}, Frame → True,
 GridLines → Automatic, PlotLabel → "δ(ψ2) over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```



■ 2 Find toggle points for $\psi 2$

```
fphii / Degree /. par
fphia / Degree /. par
fphi0 / Degree /. par
```

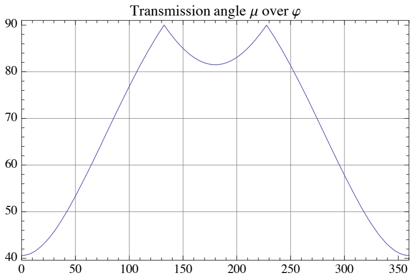
```
243.6

44.4096

199.191
```

```
fpsii / Degree /. par
fpsia / Degree /. par
fpsi0 / Degree /. par
```

```
147.617

95.3963

52.2203
```

▪ 3 Transmission angle mu

```
φ = phiG*Degree;
Plot[fktmy[μf/.Δf->Δ/.par]/Degree,{phiG,0,360},  Frame -> True,GridLines -> Automatic,
    PlotLabel -> "Transmission angle μ over φ", PlotRange -> {{0, 360}, Automatic}]
Clear[φ];
```




```
μminI / Degree /. par
```

```
40.6278
```

```
μminII / Degree /. par
```

```
81.521
```

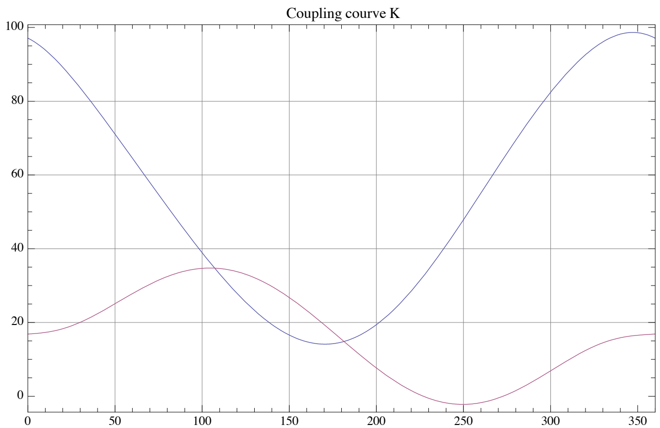
▪ 4 Motion of coupling point K:

```
xK
yK
```

```
A0x + k Cos[γ0 + δ + κ] + a Cos[γ0 + φ]
```

```
A0y + k Sin[γ0 + δ + κ] + a Sin[γ0 + φ]
```

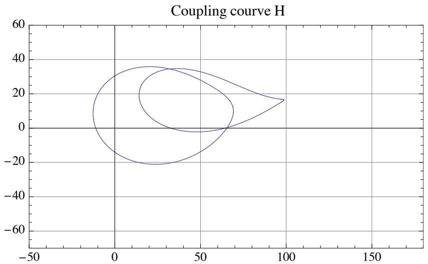
```
φ = phiG °;
Plot[{xK /. δ → δf /. ψ → ψf2 /. par, yK /. δ → δf /. ψ → ψf2 /. par}, {phiG, 0, 360}, Frame → True,
 GridLines → Automatic, PlotLabel → " Coupling courve K", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```




```
φ = phiG °;
ploK = ParametricPlot[{xK /. δ → δf /. ψ → ψf2 /. par, yK /. δ → δf /. ψ → ψf2 /. par},
   {phiG, 0, 360}, Frame → True, GridLines → Automatic,
   PlotLabel → " Coupling courve K", PlotRange → {{-50, 180}, {-70, 60}}];
Clear[
  φ];
```

```
φ = phiG °;
ploH = ParametricPlot[{xH /. δ → δf /. ψ → ψf2 /. par, yH /. δ → δf /. ψ → ψf2 /. par},
   {phiG, 0, 360}, Frame → True, GridLines → Automatic,
   PlotLabel → " Coupling courve H", PlotRange → {{-50, 180}, {-70, 60}}];
Clear[
  φ];
```

```
Show[ploH, ploK]
```



▪ The 6 desired positions of the line HK

```
valKx = {9.7116, 8.3582, 4.5032, 1.4687, 4.1318, 9.8663 } * 10
```

```
{97.116, 83.582, 45.032, 14.687, 41.318, 98.663}
```

```
valKy = { 1.6518, 1.9728, 3.3464, 2.0561, -0.2323, 1.5943} * 10
```

```
{16.518, 19.728, 33.464, 20.561, -2.323, 15.943}
```

```
valHx = {6.7128, 5.4159, 1.5088, -1.2516, 1.7807, 6.9191 } * 10
```

```
{67.128, 54.159, 15.088, -12.516, 17.807, 69.191}
```

```
valHy = {1.5687, 2.5582,  3.5302, 0.7912, -2.0957, 1.0340} * 10
```

```
{15.687, 25.582, 35.302, 7.912, -20.957, 10.34}
```

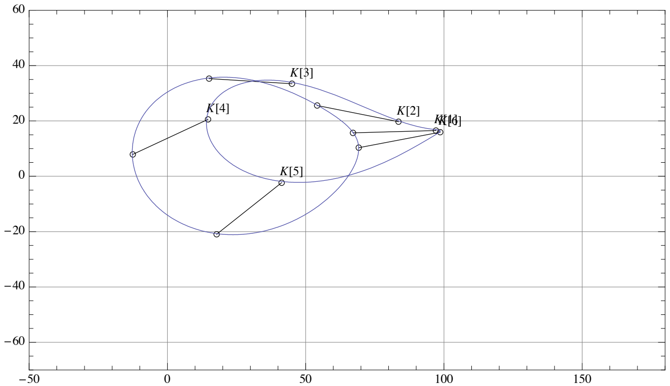
```
valphi = {0, 30, 75, 170, 250, 350}
```

```
{0, 30, 75, 170, 250, 350}
```

```
nfct = Length[valKx]
```

```
6
```

```
lmax = Max[a /. par, b /. par, c /. par, d /. par];
plopos = Table[0, {nfct}];
Do[plopos[[i]] = Graphics[{
    Circle[{valKx[[i]], valKy[[i]]}, 1],
    Circle[{valHx[[i]], valHy[[i]]}, 1] ,
    Line[{{valKx[[i]], valKy[[i]]}, {valHx[[i]], valHy[[i]]}}],
     Text[K[i], {valKx[[i]] + lmax / 30, valKy[[i]] + lmax / 30}]
   }]
 , {i, 1, nfct}]
Print[Show[plopos, ploH, ploK,
  Frame → True, GridLines → Automatic, PlotRange → {{-50, 180}, {-70, 60}}]]
```



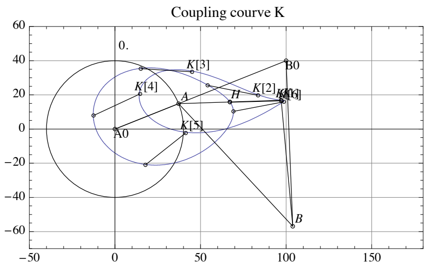
■ 5 Animation of double-rocker mecha par 1 (ψ→fψ2)

```
pa = par
```

```
{A0x → 0, A0y → 0, a → 40, b → 97, c → 98, B0x → 100,
 B0y → 40, k → 60, κ → 49 °, h → 30, κH → 49 °, d → 107.703, γ0 → 0.380506}
```

```
fψi = ψf2;

rA0x = A0x /. pa;
rA0y = A0y /. pa;
rB0x = A0x + d Cos[γ0] /. pa;
rB0y = A0y + 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;
rkx = xK /. δ → δf /. ψ → fψi /. pa;
rky = yK /. δ → δf /. ψ → fψi /. pa;
rhx = xH /. δ → δf /. ψ → fψi /. pa;
rhy = yH /. δ → δf /. ψ → fψi /. pa;

lmax = Max[a, b, c, d] /. pa;
```

```
Do[
  phiText = φ / Degree Degrees // N;
  PloMecha1 =
   Graphics[{Circle[{rA0x, rA0y}, a /. pa], Circle[{rA0x, rA0y}, lmax / 100],
   Circle[{rax, ray}, lmax / 100], Circle[{rbx, rby}, lmax / 100],
     Circle[{rkx, rky}, 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}, {rkx, rky}, {rax, ray}}],
     Circle[{rhx, rhy}, lmax / 100], Text[H, {rhx + lmax / 30, rhy + lmax / 30}],
      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[K, {rkx + lmax / 30, rky + lmax / 30}],
   Text[B0, {rB0x + lmax / 30, rB0y - lmax / 30}], Text[phiText, {5, 48}]}];
  Print[Show[ploK, ploH, plopos, PloMecha1, PlotRange → {{-50, 180}, {-70, 60}}]],
 {φ, 0, 2 Pi, Pi / 180 * 15}];
```



■ 2b) Find a solution done by numerical optimization.

We alredy have :

```
parReq = {A0x → 0, A0y → 0, d → 107.70329614269, γ0 → 0.3805063771123649}
```

```
{A0x → 0, A0y → 0, d → 107.703, γ0 → 0.380506}
```

```
xK
```

```
A0x + k Cos[γ0 + δ + κ] + a Cos[γ0 + φ]
```

```
yK
```

```
A0y + k Sin[γ0 + δ + κ] + a Sin[γ0 + φ]
```

```
xH
```

```
A0x + h Cos[γ0 + δ + κH] + a Cos[γ0 + φ]
```

```
yH
```

```
A0y + h Sin[γ0 + δ + κH] + a Sin[γ0 + φ]
```

desired values of H and K

```
valKx
valKy
```

```
{97.116, 83.582, 45.032, 14.687, 41.318, 98.663}

{16.518, 19.728, 33.464, 20.561, -2.323, 15.943}
```

```
valHx
valHy
```

```
{67.128, 54.159, 15.088, -12.516, 17.807, 69.191}

{15.687, 25.582, 35.302, 7.912, -20.957, 10.34}
```

now, we seup 6 functions for x and y of K and H.

```
nfct
```

```
6
```

```
fctKx = Table[0, {nfct}];
fctKy = Table[0, {nfct}];
fctHx = Table[0, {nfct}];
fctHy = Table[0, {nfct}];
Do[
  fctKx[[i]] = xK /. δ → δf /. ψ → ψf2 /. parReq /. φ → φ[i];
  fctKy[[i]] = yK /. δ → δf /. ψ → ψf2 /. parReq /. φ → φ[i];
  fctHx[[i]] = xH /. δ → δf /. ψ → ψf2 /. parReq /. φ → φ[i];
  fctHy[[i]] = yH /. δ → δf /. ψ → ψf2 /. parReq /. φ → φ[i];
  , {i, 1, nfct}];
fctKx;
```

Build the error function for optimization = sum of errors each function

```
ferror = Sum[
   ((fctKx[[i]] - valKx[[i]]) ^2 +
     (fctKy[[i]] - valKy[[i]]) ^2 +
     (fctHx[[i]] - valHx[[i]]) ^2 +
     (fctHy[[i]] - valHy[[i]]) ^2 )
   , {i, 1, nfct}];
```

Error value for the parErg1 results

```
ferror /. parErg1 /.
 {φ[1] → valphi[[1]] * Degree, φ[2] → valphi[[2]] * Degree, φ[3] → valphi[[3]] * Degree,
  φ[4] → valphi[[4]] * Degree, φ[5] → valphi[[5]] * Degree, φ[6] → valphi[[6]] * Degree}
```

```
295.627
```

```
(fctKx[[5]] /. parErg1 /. φ[5] -> valphi[[5]] * Degree)
```

```
47.877
```

```
valKx[[5]]
```

```
41.318
```

We start the optimization with data found by graphica solution parErg1

```
parErg1
```

```
{A0x → 0, A0y → 0, a → 40, b → 97, c → 98, B0x → 100,
 B0y → 40, k → 60, κ → 49 °, h → 30, κH → 49 °, d → 107.703, γ0 → 0.380506}
```

```
pinit = {
  {φ[1], valphi[[1]] Degree},
  {φ[2], valphi[[2]] Degree},
  {φ[3], valphi[[3]] Degree},
  {φ[4], valphi[[4]] Degree},
  {φ[5], valphi[[5]] Degree},
  {φ[6], valphi[[6]] Degree},
  {a, a /. a → 40}, {b, b /. b → 97}, {c, c /. c → 98},
  {k, k /. k → 60}, {κ, κ /. κ → 49 °}, {h, h /. h → 30}, {κH, κH /. κH → 49 °}}
```

```
{{φ[1], 0}, {φ[2], 30 °}, {φ[3], 75 °}, {φ[4], 170 °}, {φ[5], 250 °},
 {φ[6], 350 °}, {a, 40}, {b, 97}, {c, 98}, {k, 60}, {κ, 49 °}, {h, 30}, {κH, 49 °}}
```



```
parOpt = FindMinimum[ferror, pinit]
```

```
{2.76791×10^-7, {φ[1] → -3.45198×10^-6, φ[2] → 0.523608,
  φ[3] → 1.57079, φ[4] → 2.8798, φ[5] → 4.1888, φ[6] → 6.02137, a → 40.0003,
  b → 99.999, c → 99.9994, k → 59.9999, κ → 0.872653, h → 30., κH → 0.872662}}
```

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

```
{φ[1] → -3.45198×10^-6, φ[2] → 0.523608, φ[3] → 1.57079, φ[4] → 2.8798,
 φ[5] → 4.1888, φ[6] → 6.02137, a → 40.0003, b → 99.999, c → 99.9994, k → 59.9999,
 κ → 0.872653, h → 30., κH → 0.872662, A0x → 0, A0y → 0, d → 107.703, γ0 → 0.380506}
```

```
erg = κ / Degree /. parOpt[[11]]
```

```
49.9994
```

the φ_i values in degrees

```
Do[erg = φ[i] / Degree /. parOpt[[i]]; Print[erg], {i, 1, 6}];
```

```
-0.000197784

30.0005

89.9995

165.

240.001

344.999
```

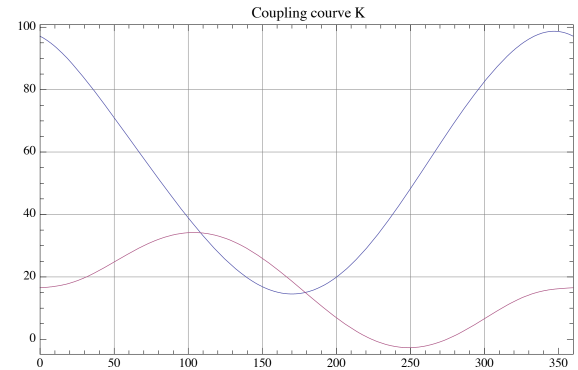
its a very good solution with small a change of parameters!

▪ Motion of coupling point K and H using parOpt

```
par = parOpt
```

```
{φ[1] → -3.45198×10^-6, φ[2] → 0.523608, φ[3] → 1.57079, φ[4] → 2.8798,
 φ[5] → 4.1888, φ[6] → 6.02137, a → 40.0003, b → 99.999, c → 99.9994, k → 59.9999,
 κ → 0.872653, h → 30., κH → 0.872662, A0x → 0, A0y → 0, d → 107.703, γ0 → 0.380506}
```

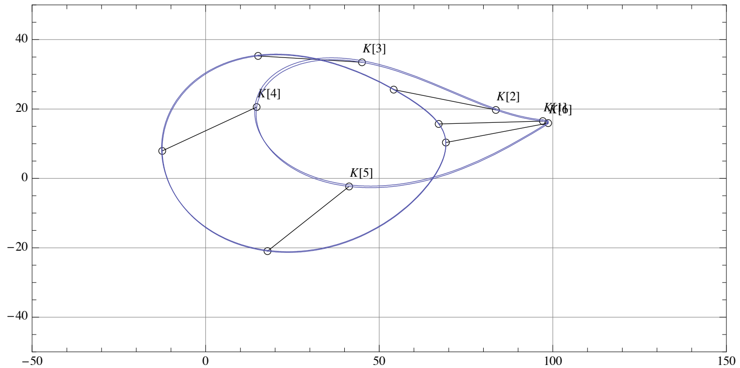
```
φ = phiG °;
Plot[{xK /. δ → δf /. ψ → ψf2 /. par, yK /. δ → δf /. ψ → ψf2 /. par}, {phiG, 0, 360}, Frame → True,
 GridLines → Automatic, PlotLabel → " Coupling courve K", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```



```
φ = phiG °;
ploKOpt = ParametricPlot[{xK /. δ → δf /. ψ → ψf2 /. par, yK /. δ → δf /. ψ → ψf2 /. par},
    {phiG, 0, 360}, Frame → True, GridLines → Automatic,
    PlotLabel → " Coupling courve K", PlotRange → {{-50, 180}, {-70, 60}}];
Clear[
  φ];
```

```
φ = phiG °;
ploHOpt = ParametricPlot[{xH /. δ → δf /. ψ → ψf2 /. par, yH /. δ → δf /. ψ → ψf2 /. par},
    {phiG, 0, 360}, Frame → True, GridLines → Automatic,
    PlotLabel → " Coupling courve H", PlotRange → {{-50, 180}, {-70, 60}}];
Clear[
  φ];
```

```
Print[Show[plopos, ploHOpt, ploKOpt, ploH, ploK,
  Frame → True, GridLines → Automatic, PlotRange → {{-50, 150}, {-50, 50}}]]
```



- **3) further calculations**

```
Grashof /. par
```

147.704

```
b + c /. par
```

199.998

```
ψf2 /. par /. φ → 0
ψf2 / Degree /. par /. φ → 0
```

4.36705

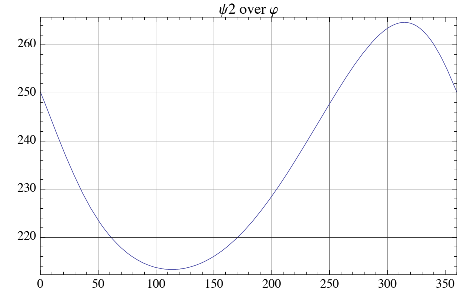
250.214

```
δf /. ψ → ψf2 /. par /. φ → 0
 δf / Degree /. ψ → ψf2 /. par /. φ → 0
```

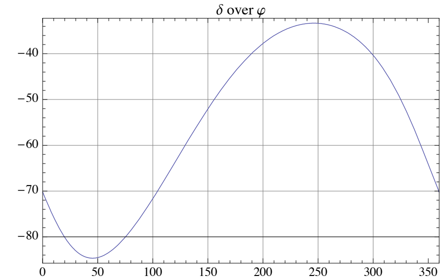
-1.22545

-70.2131


```
φ = phiG °;
Plot[{ψf2 / Degree /. par}, {phiG, 0, 360}, Frame → True,
 GridLines → Automatic, PlotLabel → "ψ2 over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```




```
φ = phiG °;
Plot[{δf / Degree /. ψ -> ψf2 /. par}, {phiG, 0, 360}, Frame → True,
 GridLines → Automatic, PlotLabel → "δ over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```



- **2 Find toggle points for ψ2**

```
fphii / Degree /. par
fphia / Degree /. par
fphi0 / Degree /. par
```

246.275

45.3322

200.942

```
fpsii / Degree /. par
fpsia / Degree /. par
fpsi0 / Degree /. par
```

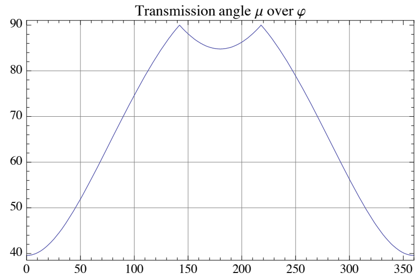
146.682

95.3272

51.3546

3 Transmission angle mu

```
φ = phiG*Degree;
Plot[fktmy[μf/.Δf->Δ/.par]/Degree,{phiG,0,360},  Frame -> True,GridLines -> Automatic,
    PlotLabel -> "Transmission angle μ over φ", PlotRange -> {{0, 360}, Automatic}]
Clear[φ];
```




```
μminI / Degree /. par
```

```
39.5732
```

```
μminII / Degree /. par
```

```
84.7884
```

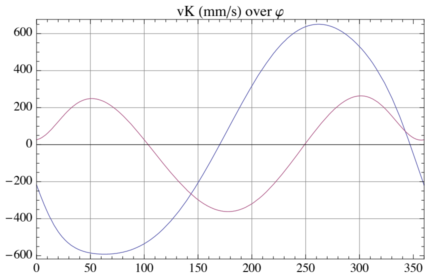
4) Find the velocity of K and H.

```
ωpar = 2 Pi 150 / 60
```

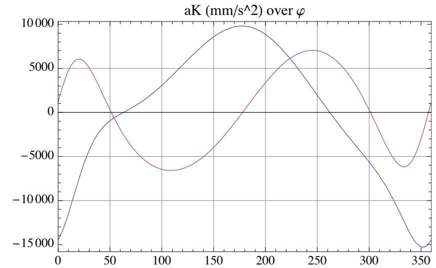
```
5 π
```

```
vKxpar = Simplify[D[xK /. δ → δf /. ψ → ψf2 /. par, φ]] ωpar;
vKypar = Simplify[D[yK /. δ → δf /. ψ → ψf2 /. par, φ]] ωpar;
```

```
φ = phiG °;
Plot[{vKxpar, vKypar}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
 PlotLabel → "vK (mm/s) over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```




```
aKxpar = D[vKxpar, φ] ωpar;
aKypar = D[vKypar, φ] ωpar;
φ = phiG °;
Plot[{aKxpar, aKypar}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
 PlotLabel → "aK (mm/s^2) over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```




```
vKxmax = Chop[vKxpar /. Chop[FindRoot[aKxpar == 0, {φ, 1}]]]
```

```
-591.469
```

```
vKxmax = Chop[vKxpar /. Chop[FindRoot[aKxpar == 0, {φ, 4}]]]
```

```
650.429
```

```
vKymax = Chop[vKypar /. Chop[FindRoot[aKypar == 0, {φ, 1}]]]
```

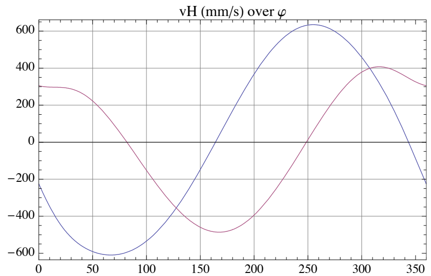
```
248.891
```

```
vKymax = Chop[vKypar /. Chop[FindRoot[aKypar == 0, {φ, 4}]]]
```

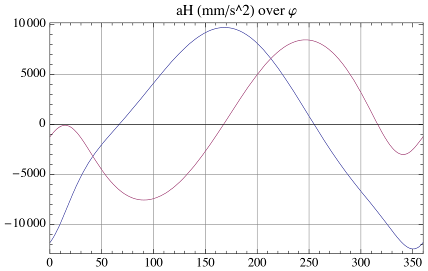
```
-361.448
```

```
vHxpar = D[xH /. δ → δf /. ψ → ψf2 /. par, φ] ωpar;
vHypar = D[yH /. δ → δf /. ψ → ψf2 /. par, φ] ωpar;
```

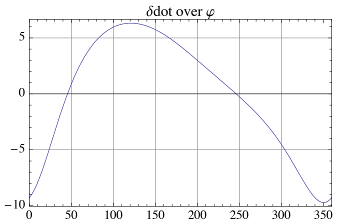
```
φ = phiG °;
Plot[{vHxpar, vHypar}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
 PlotLabel → "vH (mm/s) over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```



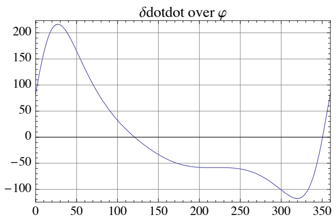
```
aHxpar = D[vHxpar, φ] ωpar;
aHypar = D[vHypar, φ] ωpar;
φ = phiG °;
Plot[{aHxpar, aHypar}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
 PlotLabel → "aH (mm/s^2) over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```




```
δpar = δf /. ψ -> ψf2 /. par;

δpardot = D[δpar, φ] ωpar;

δpardotdot = D[δpardot, φ] ωpar;

φ = phiG °;
Plot[{δpardot}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
 PlotLabel → "δdot over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```




```
φ = phiG °;
Plot[{δpardotdot}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
 PlotLabel → "δdotdot over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```



■ 5) Calculate the input torque M_in of crank

we use units: kg, N = kg m / s^2, Nmm,


```
pardyn = {g → 9.81, mHook → 0.15, IHook → 0.3 / 10000}
```

{g → 9.81, mHook → 0.15, IHook → 0.00003}

```
Tx = mHook aHx / 1000
Ty = mHook aHx / 1000
MT = IHook δdotdot
Fg = mHook g
```

$\frac{\text{aHx mHook}}{1000}$

$\frac{\text{aHx mHook}}{1000}$

IHook δdotdot

g mHook

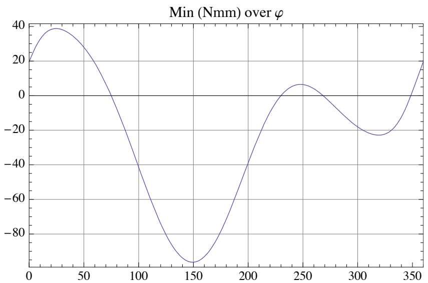
```
MIn = 1 / ω (Tx vHx + Ty vHy + Fg vHy + MT δdot)
```

$$\frac{\frac{\text{aHx mHook vHx}}{1000} + \frac{\text{aHx mHook vHy}}{1000} + \text{g mHook vHy} + \text{IHook } \delta\text{dot } \delta\text{dotdot}}{\omega}$$

```
MInpar = MIn /. {ω → ωpar, vHx → vHxpar, vHy → vHypar,
     aHx → aHxpar, aHy → aHypar, δdot → δpardot, δdotdot → δpardotdot} /. pardyn;

MInpar /. φ → 0
```

19.6142

```
φ = phiG °;
Plot[{MInpar}, {phiG, 0, 360}, Frame → True, GridLines → Automatic,
 PlotLabel → "Min (Nmm) over φ", PlotRange → {{0, 360}, Automatic}]
Clear[φ];
```




```
MInmax = Chop[MInpar /. Chop[FindRoot[D[MInpar, φ] == 0, {φ, 6}]]]
```

-22.8287