Test des courbes terminales

Courbes formées de deux arcs de cercle et d'une droite

Conditions de Keelhoff

Caractéristiques du spiral

Référence :C:\Résonateur (TA)\Data\Bal_spiral cylindrique (ex num).mcd(R)

Référence :C:\Résonateur (TA)\Data\Définition Atan.mcd(R)

Dimensions $\acute{e}p = 0.09\,mm \qquad ha = 0.334\,mm \qquad S = 0.03\,mm^2 \qquad R_0 = 5\,mm \qquad TOL := 10^{-12}$

Elinvar $\rho_s = 8\times 10^3\,m^{-3}\cdot kg \qquad E = 1.7\times 10^{11}\,Pa \qquad G = 6.538\times 10^{10}\,Pa$

Partie cylindrique $n_s := 10.15 \qquad \psi_0 := n_s\cdot 360\cdot deg \qquad \psi_0 = 3.654\times 10^3\,deg \qquad L := R_0\cdot\psi_0 \qquad L = 318.872\,mm$

$r_s(\alpha) := R_0 \qquad s(\alpha) := R_0\cdot(\alpha-\pi) \qquad x_{0s}(\alpha) := R_0\cdot\cos(\alpha) \qquad y_{0s}(\alpha) := R_0\cdot\sin(\alpha)$

Courbe terminale externe $r_t := 0.5\cdot R_0 \qquad l_t := R_0 + \pi\cdot r_t \qquad \alpha_A := \pi$

$x_{0t1}(\alpha_t) := r_t\cdot(1+\cos(\alpha_t)) \qquad y_{0t1}(\alpha_t) := r_t\cdot\sin(\alpha_t) \qquad x_{0t2}(x) := x \qquad y_{0t2}(x) := r_t$

$x_{0t3}(\beta_t) := -r_t\cdot(1+\sin(\beta_t)) \qquad y_{0t3}(\beta_t) := r_t\cdot\cos(\beta_t)$

Courbe terminale interne $\alpha_B := mod(\psi_0+\pi, 2\cdot\pi) \qquad \alpha_B = 234\,deg$

$x_{0t'1}(\alpha_{t'}) := x_{0t1}(\alpha_{t'})\cdot\cos(\alpha_B) - y_{0t1}(\alpha_{t'})\cdot\sin(\alpha_B) \qquad x_{0t'2}(x) := x_{0t2}(x)\cdot\cos(\alpha_B) - y_{0t2}(x)\cdot\sin(\alpha_B)$

$y_{0t'1}(\alpha_{t'}) := x_{0t1}(\alpha_{t'})\cdot\sin(\alpha_B) + y_{0t1}(\alpha_{t'})\cdot\cos(\alpha_B) \qquad y_{0t'2}(x) := x_{0t2}(x)\cdot\sin(\alpha_B) + y_{0t2}(x)\cdot\cos(\alpha_B)$

$x_{0t'3}(\beta_{t'}) := x_{0t3}(\beta_{t'})\cdot\cos(\alpha_B) - y_{0t3}(\beta_{t'})\cdot\sin(\alpha_B)$

$y_{0t'3}(\beta_{t'}) := x_{0t3}(\beta_{t'})\cdot\sin(\alpha_B) + y_{0t3}(\beta_{t'})\cdot\cos(\alpha_B) \qquad L_t := 2\cdot l_t + L$

Position du piton $R_P := R_0 \qquad \alpha_P := 0 \qquad x_P := R_0 \qquad y_P := 0\cdot mm$

Position du point d'attache à la virole $R_V := R_0 \qquad \alpha_V(\theta) := mod(\alpha_B+\pi+\theta, 2\cdot\pi) \qquad \alpha_V(0) = 54\,deg$

$x_V(\theta) := R_V\cdot\cos(\alpha_V(\theta)) \qquad y_V(\theta) := R_V\cdot\sin(\alpha_V(\theta))$

Amplitude stationnaire du balancier $\theta_0 = 270\,deg \qquad \theta := 270\cdot deg$

Référence :C:\Résonateur (TA)\Tables\Modules J, I et W des barres élastiques.mcd(R)

$I_{33} := I_{f\_rect}(\acute{e}p, ha) \qquad W_{f3} := W_{f\_rect}(\acute{e}p, ha)$

Graphe des courbes et du spiral

$n_t := 201 \qquad j := 0\,..\,n_t-1 \qquad \Delta\alpha_t := \dfrac{\pi}{2\cdot(n_t-1)} \qquad \alpha_{t_j} := j\cdot\Delta\alpha_t \qquad x_{t1_j} := x_{0t1}(\alpha_{t_j}) \qquad y_{t1_j} := y_{0t1}(\alpha_{t_j})$

$x_j := r_t - j\cdot\dfrac{2\cdot r_t}{n_t-1} \qquad x_{t2_j} := x_{0t2}(x_j) \qquad y_{t2_j} := y_{0t2}(x_j) \qquad x_0 := pile(x_{t1}, x_{t2}) \qquad y_0 := pile(y_{t1}, y_{t2})$

$\beta_{t_j} := j\cdot\Delta\alpha_t \qquad x_{t3_j} := x_{0t3}(\beta_{t_j}) \qquad y_{t3_j} := y_{0t3}(\beta_{t_j}) \qquad x_t := pile(x_0, x_{t3}) \qquad y_t := pile(y_0, y_{t3})$

$n := 50\cdot n_s + 1 \qquad i := 0\,..\,n-1 \qquad \Delta\alpha := \dfrac{\psi_0}{n-1} \qquad \alpha_i := \pi + i\cdot\Delta\alpha \qquad \pi+\psi_0-20\cdot\pi = 234\,deg$

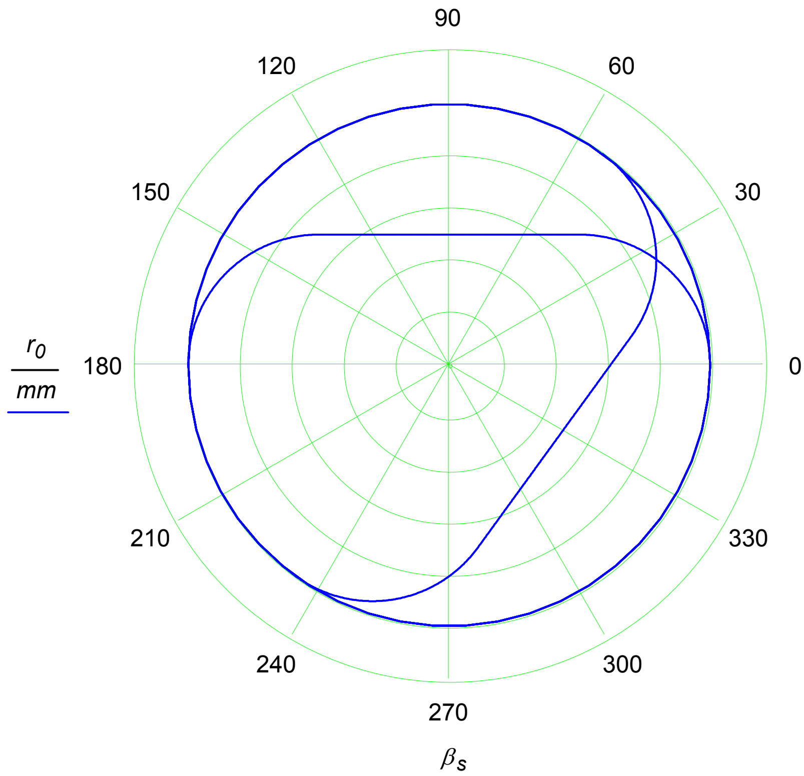
$x_{s_i} := x_{0s}(\alpha_i) \qquad y_{s_i} := y_{0s}(\alpha_i) \qquad x_0 := pile(x_t, x_s) \qquad y_0 := pile(y_t, y_s)$

$\alpha_{t'_j} := j \cdot \Delta\alpha_t$ $\quad x_{t'1} := \overrightarrow{x_{0t'1}(\alpha_{t'})}$ $\quad y_{t'1} := \overrightarrow{y_{0t'1}(\alpha_{t'})}$ $\quad x_0 := pile(x_0, x_{t'1})$ $\quad y_0 := pile(y_0, y_{t'1})$

$x_{t'2} := \overrightarrow{x_{0t'2}(x)}$ $\quad y_{t'2} := \overrightarrow{y_{0t'2}(x)}$ $\quad x_0 := pile(x_0, x_{t'2})$ $\quad y_0 := pile(y_0, y_{t'2})$

$\beta_{t'_j} := j \cdot \Delta\alpha_t$ $\quad x_{t'3} := \overrightarrow{x_{0t'3}(\beta_{t'})}$ $\quad y_{t'3} := \overrightarrow{y_{0t'3}(\beta_{t'})}$ $\quad x_0 := pile(x_0, x_{t'3})$ $\quad y_0 := pile(y_0, y_{t'3})$

$r_0 := \overrightarrow{\sqrt{x_0^2 + y_0^2}}$ $\qquad \beta_s := \overrightarrow{Atan(x_0, y_0)}$



Vérification de la condition de Phillips

Partie cylindrique $\qquad z_{0s}(\alpha) := x_{0s}(\alpha) + i \cdot y_{0s}(\alpha)$

$$\zeta_{0s} := \frac{R_0}{L} \cdot \int_{\pi}^{\psi_0 + \pi} z_{0s}(\alpha)\, d\alpha \qquad \xi_{0s} := Re(\zeta_{0s}) \qquad \eta_{0s} := Im(\zeta_{0s}) \qquad \xi_{0s} = -0.063\,mm \qquad \eta_{0s} = -0.032\,mm$$

Courbe terminale externe

$z_{0t1}(\alpha_t) := x_{0t1}(\alpha_t) + i \cdot y_{0t1}(\alpha_t)$ $\qquad z_{0t2}(x) := x_{0t2}(x) + i \cdot y_{0t2}(x)$ $\qquad z_{0t3}(\beta_t) := x_{0t3}(\beta_t) + i \cdot y_{0t3}(\beta_t)$

$$\zeta_{0t} := \frac{1}{l_t} \cdot \left(\int_0^{\frac{\pi}{2}} z_{0t1}(\alpha_t) \cdot r_t \, d\alpha_t - \int_{r_t}^{-r_t} z_{0t2}(x)\, dx + \int_0^{\frac{\pi}{2}} z_{0t3}(\beta_t) \cdot r_t \, d\beta_t \right)$$

Vérification

$\xi_{0t} := Re(\zeta_{0t})$ $\qquad \eta_{0t} := Im(\zeta_{0t})$ $\qquad \xi_{0t} = 0\,mm$ $\qquad \eta_{0t} = 1.945\,mm$ $\qquad \frac{R_0^2}{l_t} = 1.945\,mm$

Courbe terminale interne

$z_{0t'1}(\alpha_{t'}) := x_{0t'1}(\alpha_{t'}) + i \cdot y_{0t'1}(\alpha_{t'})$ $\qquad z_{0t'2}(x') := x_{0t'2}(x') + i \cdot y_{0t'2}(x')$ $\qquad z_{0t'3}(\beta_{t'}) := x_{0t'3}(\beta_{t'}) + i \cdot y_{0t'3}(\beta_{t'})$

$$\zeta_{0t'} := \frac{1}{l_t} \cdot \left(\int_0^{\frac{\pi}{2}} z_{0t'1}(\alpha_{t'}) \cdot r_t \, d\alpha_{t'} - \int_{r_t}^{-r_t} z_{0t'2}(x') \, dx' + \int_0^{\frac{\pi}{2}} z_{0t'3}(\beta) \cdot r_t \, d\beta \right)$$

$\xi_{0t'} := Re(\zeta_{0t'})$ $\eta_{0t'} := Im(\zeta_{0t'})$ $\xi_{0t'} = 1.573\,mm$ $\eta_{0t'} = -1.143\,mm$

Condition de Phillips $l_t \cdot \zeta_{0t} + L \cdot \zeta_{0s} + l_t \cdot \zeta_{0t'} = 0\,mm^2$

Vérification de la condition de Moulin

Partie cylindrique $s_s(\alpha) := R_0 \cdot (\alpha - \pi) + l_t$

$$Z_{2s} := \frac{2}{L_t^2} \cdot \int_{\pi}^{\psi_0 + \pi} s_s(\alpha) \cdot z_{0s}(\alpha) \cdot R_0 \, d\alpha \qquad Z_{2s} = -0.112 + 0.075i\,mm$$

Courbe terminale externe

$$Z_{2t} := \frac{2}{L_t^2} \cdot \left[\int_0^{\frac{\pi}{2}} r_t \cdot \alpha_t \cdot z_{0t1}(\alpha_t) \cdot r_t \, d\alpha_t - \int_{r_t}^{-r_t} \left(r_t \cdot \frac{\pi}{2} + r_t - x \right) \cdot z_{0t2}(x) \, dx \right]$$

$$Z_{2t} := Z_{2t} + \frac{2}{L_t^2} \cdot \int_0^{\frac{\pi}{2}} \left(r_t \cdot \frac{\pi}{2} + 2 \cdot r_t + r_t \cdot \beta_t \right) \cdot z_{0t3}(\beta_t) \cdot r_t \, d\beta_t$$

$$Z_{2t} = -2.704 \times 10^{-3} + 2.706i \times 10^{-3}\,mm$$

Courbe terminale interne

$$Z_{2t'1} := \frac{2}{L_t^2} \cdot \int_0^{\frac{\pi}{2}} (l_t + L + r_t \cdot \alpha_{t'}) \cdot z_{0t'1}(\alpha_{t'}) \cdot r_t \, d\alpha_{t'} \qquad Z_{2t'2} := \frac{-2}{L_t^2} \cdot \int_{r_t}^{-r_t} \left(l_t + L + r_t \cdot \frac{\pi}{2} + r_t - x' \right) \cdot z_{0t'2}(x') \, dx'$$

$$Z_{2t'3} := \frac{2}{L_t^2} \cdot \int_0^{\frac{\pi}{2}} \left(l_t + L + r_t \cdot \frac{\pi}{2} + 2 \cdot r_t + r_t \cdot \beta_{t'} \right) \cdot z_{0t'3}(\beta_{t'}) \cdot r_t \, d\beta_{t'} \qquad Z_{2t'} := Z_{2t'1} + Z_{2t'2} + Z_{2t'3}$$

$$Z_{2t'} = 0.117 - 0.082i\,mm$$

Condition de Moulin $Z_2 := Z_{2t} + Z_{2s} + Z_{2t'}$ $\boxed{|Z_2| = 4.279 \times 10^{-3}\,mm}$