Test des courbes terminales

Courbes formées de deux arcs de cercle

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 $ép = 0.09\,mm$ $ha = 0.334\,mm$ $S = 0.03\,mm^2$ $R_0 = 5\,mm$ $TOL := 10^{-12}$

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

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

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

Courbe terminale externe

$r_{t1} := 0.8$ $r_{t1} := racine\left[(2 \cdot r_{t1} - 1)^4 - 4 \cdot (1 - r_{t1})^4 - \pi^2 \cdot r_{t1}{}^2 \cdot (1 - r_{t1})^2, r_{t1}\right] \cdot R_0$ $r_{t1} = 0.832\,R_0$

$r_{t2} := 2 \cdot r_{t1} - R_0$ $r_{t2} = 0.665\,R_0$ $\beta_0 := arctan\left[\dfrac{\pi \cdot r_{t1}}{2 \cdot (R_0 - r_{t1})}\right]$ $\beta_0 = 82.695\,deg$ $l_t := r_{t2} \cdot \beta_0 + \pi \cdot r_{t1}$

$x_{0t1}(\alpha_t) := -R_0 + r_{t1} \cdot (1 + cos(\alpha_t))$ $y_{0t1}(\alpha_t) := r_{t1} \cdot sin(\alpha_t)$

$x_{0t2}(\beta_t) := r_{t2} \cdot cos(\beta_t)$ $y_{0t2}(\beta_t) := r_{t2} \cdot sin(\beta_t)$

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

$x_{0t'1}(\alpha_{t'}) := (R_0 - r_{t1} + r_{t1} \cdot cos(\alpha_{t'})) \cdot cos(\alpha_B) - r_{t1} \cdot sin(\alpha_{t'}) \cdot sin(\alpha_B)$

$y_{0t'1}(\alpha_{t'}) := (R_0 - r_{t1} + r_{t1} \cdot cos(\alpha_{t'})) \cdot sin(\alpha_B) + r_{t1} \cdot sin(\alpha_{t'}) \cdot cos(\alpha_B)$

$x_{0t'2}(\beta_{t'}) := r_{t2} \cdot cos(\beta_{t'}) \cdot cos(\alpha_B + \pi) - r_{t2} \cdot sin(\beta_{t'}) \cdot sin(\alpha_B + \pi)$

$y_{0t'2}(\beta_{t'}) := r_{t2} \cdot cos(\beta_{t'}) \cdot sin(\alpha_B + \pi) + r_{t2} \cdot sin(\beta_{t'}) \cdot cos(\alpha_B + \pi)$

Positions du piton $r_P := r_{t2}$ $\alpha_P := -\beta_0$ $\alpha_P = -82.695\,deg$ $x_P := x_{0t2}(\alpha_P)$ $y_P := y_{0t2}(\alpha_P)$

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

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

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

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

$I_{33} := I_{f\_rect}(ép, ha)$ $W_{f3} := W_{f\_rect}(ép, ha)$

Graphe des courbes et du spiral

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

$\Delta\beta_t := \dfrac{\beta_0}{n_t - 1}$ $\beta_{t_j} := j \cdot \Delta\beta_t - \beta_0$ $x_{t2_j} := x_{0t2}(\beta_{t_j})$ $y_{t2_j} := y_{0t2}(\beta_{t_j})$

$x_t := pile(x_{t2}, x_{t1})$ $y_t := pile(y_{t2}, y_{t1})$

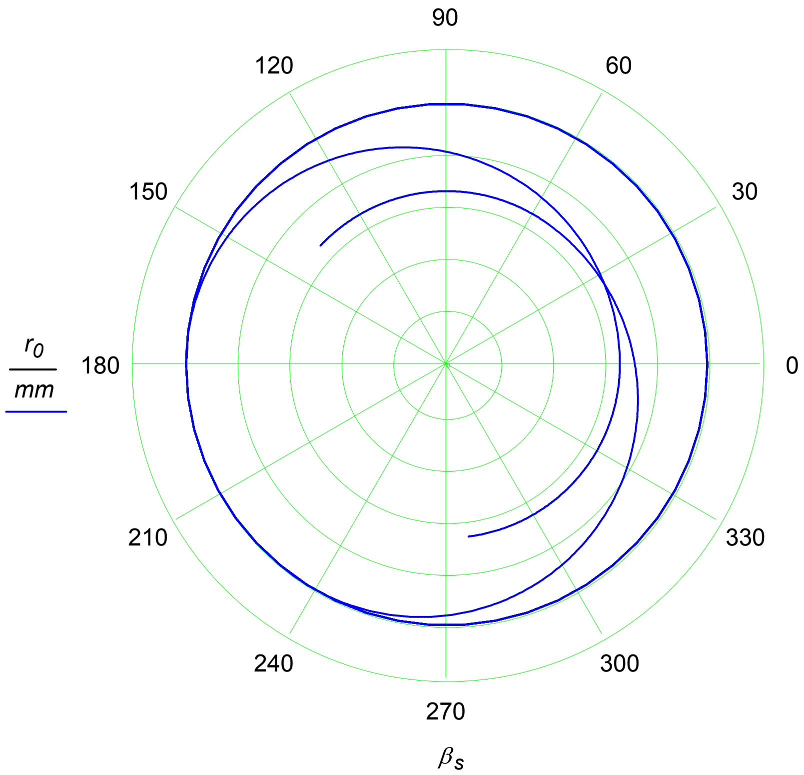
$n := 50 \cdot n_s + 1 \qquad i := 0 .. n-1 \qquad \Delta\alpha := \dfrac{\psi_0}{n-1} \qquad \alpha_i := \pi + i \cdot \Delta\alpha \qquad \pi + \psi_0 - 20 \cdot \pi = 234\,deg$

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

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

$\beta_{t'_j} := j \cdot \Delta\beta_t \qquad x_{t'2_j} := x_{0t'2}(\beta_{t'_j}) \qquad y_{t'2_j} := y_{0t'2}(\beta_{t'_j}) \qquad x_0 := pile(x_0, x_{t'2}) \qquad y_0 := pile(y_0, y_{t'2})$

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



Vérification de la condition de Phillips

Partie cylindrique

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

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

Courbe terminale externe

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

$\zeta_{0t} := \dfrac{1}{l_t} \cdot \left(\displaystyle\int_0^{\pi} z_{0t1}(\alpha_t) \cdot r_{t1}\, d\alpha_t + \int_{-\beta_0}^{0} z_{0t2}(\beta_t) \cdot r_{t2}\, d\beta_t \right)$

Vérification

$\xi_{0t} := Re(\zeta_{0t}) \qquad \eta_{0t} := Im(\zeta_{0t}) \qquad \xi_{0t} = 0\,mm \qquad \eta_{0t} = 1.399\,mm \qquad \dfrac{R_0^{\,2}}{l_t} = 1.399\,mm$

Courbe terminale interne

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

$$\zeta_{0t'} := \frac{1}{l_t}\cdot\left(\int_0^{\pi} z_{0t'1}(\alpha_{t'})\cdot r_{t1}\,d\alpha_{t'} + \int_0^{\beta_0} z_{0t'2}(\beta_{t'})\cdot r_{t2}\,d\beta_{t'}\right)$$

$\xi_{0t'} := Re(\zeta_{0t'})$ $\quad\eta_{0t'} := Im(\zeta_{0t'})$ $\quad\xi_{0t'} = 1.132\,mm$ $\quad\eta_{0t'} = -0.822\,mm$

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

Vérification de la condition de Moulin

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

$$Z_{2s} := \frac{2}{L_t^2}\cdot\int_{\pi}^{\psi_0+\pi} s_s(\alpha)\cdot z_{0s}(\alpha)\cdot R_0\,d\alpha \qquad Z_{2s} = -0.108 + 0.07i\,mm$$

Courbe terminale externe $\quad s_{t2}(\beta_t) := r_{t2}\cdot(\beta_0 + \beta_t) \quad s_{t1}(\alpha_t) := (r_{t2}\cdot\beta_0 + r_{t1}\cdot\alpha_t)$

$$Z_{2t} := \frac{2}{L_t^2}\cdot\left(\int_0^{\pi} s_{t1}(\alpha_t)\cdot z_{0t1}(\alpha_t)\cdot r_{t1}\,d\alpha_t + \int_{-\beta_0}^{0} s_{t2}(\beta_t)\cdot z_{0t2}(\beta_t)\cdot r_{t2}\,d\beta_t\right)$$

$$Z_{2t} = -3.759\times 10^{-3} + 5.981i\times 10^{-3}\,mm$$

Courbe terminale interne $\quad s_{t'1}(\alpha_{t'}) := r_{t1}\cdot\alpha_{t'} + L + l_t \quad s_{t'2}(\beta_{t'}) := s_{t'1}(\pi) + r_{t2}\cdot\beta_{t'}$

$$Z_{2t'1} := \frac{2}{L_t^2}\cdot\int_0^{\pi} s_{t'1}(\alpha_{t'})\cdot z_{0t'1}(\alpha_{t'})\cdot r_{t1}\,d\alpha_{t'}$$

$$Z_{2t'2} := \frac{2}{L_t^2}\cdot\int_0^{\beta_0} s_{t'2}(\beta_{t'})\cdot z_{0t'2}(\beta_{t'})\cdot r_{t2}\,d\beta_{t'} \qquad Z_{2t'} := Z_{2t'1} + Z_{2t'2}$$

$$Z_{2t'} = 0.111 - 0.076i\,mm$$

Condition de Moulin $\quad Z_2 := Z_{2t} + Z_{2s} + Z_{2t'} \quad \boxed{|Z_2| = 3.963\times 10^{-4}\,mm}$