Test des courbes terminales

Courbes formées d'un arc 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 $\quad ép = 0.09\,mm \quad ha = 0.334\,mm \quad S = 0.03\,mm^2 \quad R_0 = 5\,mm \quad TOL := 10^{-9}$

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

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

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

Courbe terminale externe $\quad \beta := 121\cdot deg \quad \beta_0 := racine\left[\beta\cdot\left(\sqrt{2}\cdot sin(\beta)-1\right)+sin(\beta)\cdot cos(\beta),\beta\right] \quad \beta_0 = 121.21\,deg$

$\alpha_A := \pi \quad r_t := \dfrac{R_0}{\sqrt{2}\cdot sin(\beta_0)} \quad x_{0t}(\alpha_t) := -R_0 + r_t\cdot(1+cos(\alpha_t)) \quad y_{0t}(\alpha_t) := r_t\cdot sin(\alpha_t) \quad l_t := r_t\cdot 2\cdot\beta_0$

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

$x_{0t'}(\alpha_{t'}) := \left[R_0 + r_t\cdot(-1+cos(\alpha_{t'}))\right]cos(\alpha_B) - r_t\cdot sin(\alpha_{t'})\cdot sin(\alpha_B)$

$y_{0t'}(\alpha_{t'}) := \left[R_0 + r_t\cdot(-1+cos(\alpha_{t'}))\right]sin(\alpha_B) + r_t\cdot sin(\alpha_{t'})\cdot cos(\alpha_B) \quad L_t := 2\cdot l_t + L$

Position du piton $\quad \alpha_{tP} := \pi - 2\cdot\beta_0 \quad \alpha_{tP} = -62.426\,deg \quad x_P := x_{0t}(\alpha_{tP}) \quad y_P := y_{0t}(\alpha_{tP})$

$z_P := x_P + i\cdot y_P \quad r_P := |z_P| \quad r_P = 3.811\,mm \quad arg(z_P) = -74.047\,deg$

Position du point d'attache à la virole $\quad r_V := r_P \quad \alpha_V(\theta) := Atan\left(x_{0t'}(2\cdot\beta_0), y_{0t'}(2\cdot\beta_0)\right)+\theta \quad \alpha_V(0) = 128.047\,deg$

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

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

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

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

Graphe des courbes et du spiral

$n_t := 201 \quad j := 0..n_t-1 \quad \Delta\alpha_t := \dfrac{2\cdot\beta_0}{n_t-1} \quad \alpha_{t_j} := \pi - 2\cdot\beta_0 + j\cdot\Delta\alpha_t \quad x_{t_j} := x_{0t}(\alpha_{t_j}) \quad y_{t_j} := y_{0t}(\alpha_{t_j})$

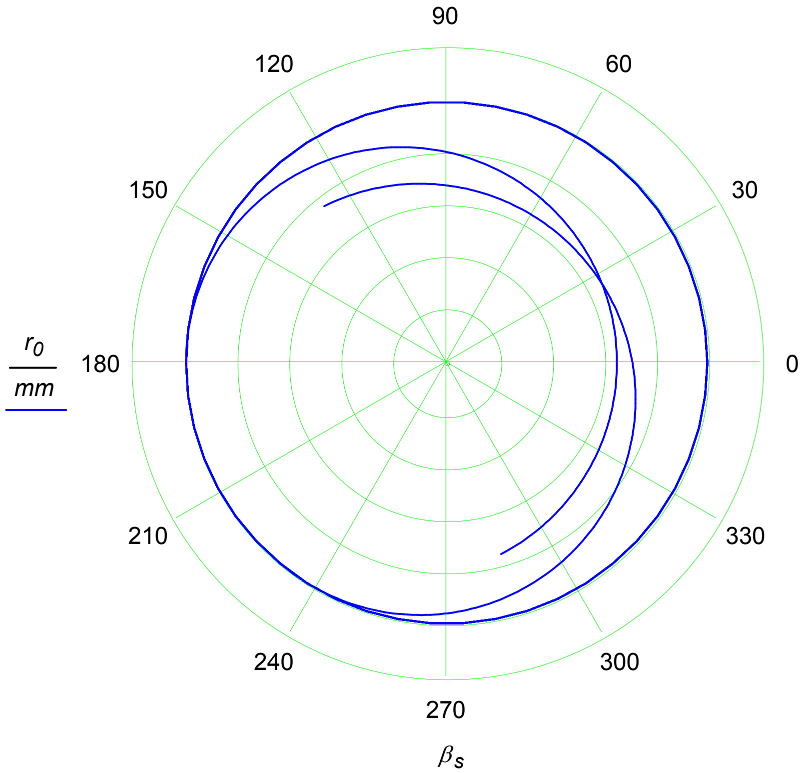
$n := 50\cdot n_s + 1 \quad i := 0..n-1 \quad \Delta\alpha := \dfrac{\psi_0}{n-1} \quad \alpha_i := \pi + i\cdot\Delta\alpha \quad \pi + \psi_0 - 20\cdot\pi = 234\,deg$

$\alpha_{t'_j} := j\cdot\Delta\alpha_t \quad x_{t'_j} := x_{0t'}(\alpha_{t'_j}) \quad y_{t'_j} := y_{0t'}(\alpha_{t'_j})$

$x_{s_i} := x_{0s}(\alpha_i) \quad y_{s_i} := y_{0s}(\alpha_i) \quad x_0 := pile(x_t, x_s) \quad y_0 := pile(y_t, y_s) \quad x_0 := pile(x_0, x_{t'}) \quad y_0 := pile(y_0, y_{t'})$

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

Test des courbes terminales



Vérification de la condition de Phillips

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

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

Courbe terminale externe $\quad z_{0t}(\alpha_t) := x_{0t}(\alpha_t) + i \cdot y_{0t}(\alpha_t)$

$$\zeta_{0t} := \frac{r_t}{l_t} \cdot \int_{\alpha_{tP}}^{\pi} z_{0t}(\alpha_t)\, d\alpha_t \qquad \xi_{0t} := Re(\zeta_{0t}) \qquad \eta_{0t} := Im(\zeta_{0t})$$

Vérification

$$\xi_{0t} = 0\, mm \qquad \eta_{0t} = 1.429\, mm \qquad \frac{R_0^{\,2}}{l_t} = 1.429\, mm$$

Courbe terminale interne $\quad z_{0t'}(\alpha_{t'}) := x_{0t'}(\alpha_{t'}) + i \cdot y_{0t'}(\alpha_{t'})$

$$\zeta_{0t'} := \frac{r_t}{l_t} \cdot \int_{0}^{2 \cdot \beta_0} z_{0t'}(\alpha_{t'})\, d\alpha_{t'} \qquad \xi_{0t'} := Re(\zeta_{0t'}) \qquad \eta_{0t'} := Im(\zeta_{0t'}) \qquad \xi_{0t'} = 1.156\, mm \qquad \eta_{0t'} = -0.84\, mm$$

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

$$Z_{2t} := \frac{2}{L_t^{\,2}} \cdot \int_{\alpha_{tP}}^{\pi} r_t \cdot \left(\alpha_t - \alpha_{tP}\right) \cdot z_{0t}\left(\alpha_t\right) \cdot r_t \, d\alpha_t$$

$$Z_{2t} = -3.767 \times 10^{-3} + 5.775i \times 10^{-3}\,mm$$

Courbe terminale interne

$$Z_{2t'} := \frac{2}{L_t^{\,2}} \cdot \int_{0}^{2 \cdot \beta_0} \left(l_t + L + r_t \cdot \alpha_{t'}\right) \cdot z_{0t'}\left(\alpha_{t'}\right) \cdot r_t \, d\alpha_{t'}$$

$$Z_{2t'} = 0.112 - 0.077i\,mm$$

Condition de Moulin

$$Z_2 := Z_{2t} + Z_{2s} + Z_{2t'}$$

$$\boxed{\left|Z_2\right| = 5.485 \times 10^{-4}\,mm}$$