Test des courbes terminales d'un spiral plat

Courbes externe et interne

Conditions de Keelhoff

Caractéristiques du spiral

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

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

Dimensions $\quad ép = 0.03\,mm \quad ha = 0.15\,mm \quad S = 4.5\times 10^{-3}\,mm^2 \quad TOL := 10^{-12}$

$d2_{sp} = 4.52\,mm \quad d_V := 1.1\cdot mm \quad d_B := 1.312\cdot d1_{sp} \quad p_{sp} = 0.135\,mm \quad n_{sp} := \dfrac{d2_{sp} - d_B}{2\cdot p_{sp}}$

$L := \pi\cdot\dfrac{n_{sp}}{2}\cdot\left(d2_{sp} + d_B\right) \quad L = 10.674\,cm \quad \psi_0 := 2\cdot\pi\cdot n_{sp} \quad \psi_0 = 4.102\times 10^3\,deg$

Position du point de raccordement sur le spiral $\quad \alpha_A := \pi \quad r_A := 0.5\cdot d2_{sp} \quad z_A := r_A\cdot e^{i\cdot\alpha_A}$

Forme initiale du spiral

$a := \dfrac{p_{sp}}{2\cdot\pi} \quad r_s(\alpha) := r_A - a\cdot\left(\alpha - \alpha_A\right) \quad x_{0s}(\alpha) := r_s(\alpha)\cdot cos(\alpha) \quad y_{0s}(\alpha) := r_s(\alpha)\cdot sin(\alpha)$

$s(\alpha) := \dfrac{1}{2\cdot a}\cdot\left(r_A{}^2 - r_s(\alpha)^2\right) \quad s(\alpha) := r_A\cdot\left(\alpha - \alpha_A\right) - \dfrac{a}{2}\cdot\left(\alpha - \alpha_A\right)^2$

Courbe terminale externe

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

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

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

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

Courbe terminale interne $\quad \alpha_B := mod\left(\psi_0 + \pi, 2\cdot\pi\right) \quad \alpha_B = 322.4\,deg \quad r_B := 0.5\cdot d_B$

$\beta := 121\cdot deg \quad \beta'_0 := racine\left[\beta\cdot\left(\sqrt{2}\cdot sin(\beta) - 1\right) + sin(\beta)\cdot cos(\beta), \beta\right] \quad \beta'_0 = 121.21\,deg$

$r_{t'} := \dfrac{r_B}{\sqrt{2}\cdot sin\left(\beta'_0\right)} \quad r_{t'} = 0.827\,r_B \quad x_{0t}\left(\alpha_t\right) := -r_B + r_{t'}\cdot\left(1 + cos\left(\alpha_t\right)\right) \quad y_{0t}\left(\alpha_t\right) := r_{t'}\cdot sin\left(\alpha_t\right)$

$x_{0t'}\left(\alpha_{t'}\right) := \left[r_B + r_{t'}\cdot\left(-1 + cos\left(\alpha_{t'}\right)\right)\right]cos\left(\alpha_B\right) - r_{t'}\cdot sin\left(\alpha_{t'}\right)\cdot sin\left(\alpha_B\right) \quad l_{t'} := r_{t'}\cdot 2\cdot\beta'_0$

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

Position des goupilles de raquettes $\quad r_{GR} := r_{t2} \quad \alpha_{GR} := -\beta_0 \quad \alpha_{GR} = -82.695\,deg$

$x_{GR} := x_{0t2}\left(\alpha_{GR}\right) \quad y_{GR} := y_{0t2}\left(\alpha_{GR}\right)$

Position du point d'attache à la virole $\quad r_V := \sqrt{x_{0t'}\left(2\cdot\beta'_0\right)^2 + y_{0t'}\left(2\cdot\beta'_0\right)^2} \quad \alpha_V(\theta) := Atan\left(x_{0t'}\left(2\cdot\beta'_0\right), y_{0t'}\left(2\cdot\beta'_0\right)\right) + \theta$

$r_V = 0.55\,mm \quad \alpha_V(0) = 216.447\,deg \quad x_V(\theta) := r_V\cdot cos\left(\alpha_V(\theta)\right) \quad y_V(\theta) := r_V\cdot sin\left(\alpha_V(\theta)\right)$

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

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 terminales et du spiral

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

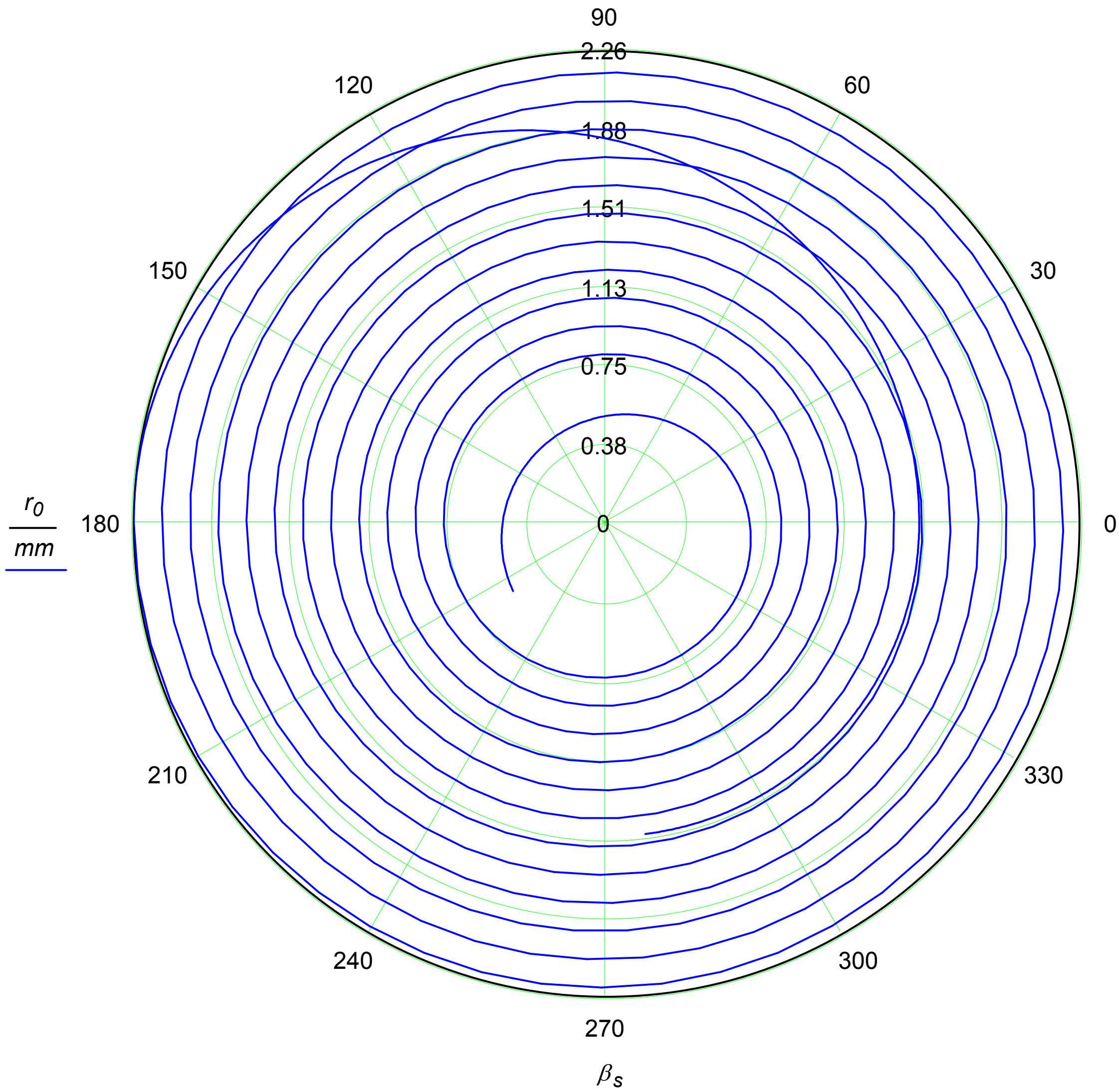
$\Delta\beta_t := \dfrac{\beta_0}{n_t - 1}$ $\quad \beta_{t_j} := j \cdot \Delta\beta_t - \beta_0$ $\quad x_{t2_j} := x_{0t2}\left(\beta_{t_j}\right)$ $\quad y_{t2_j} := y_{0t2}\left(\beta_{t_j}\right)$ $\quad x_t := pile\left(x_{t2}, x_{t1}\right)$ $\quad y_t := pile\left(y_{t2}, y_{t1}\right)$

$n := 50 \cdot partentière\left(n_{sp}\right) + 1$ $\quad i := 0 .. n - 1$ $\quad \Delta\alpha := \dfrac{\psi_0}{n - 1}$ $\quad \alpha_i := \pi + i \cdot \Delta\alpha$

$x_{s_i} := x_{0s}\left(\alpha_i\right)$ $\quad y_{s_i} := y_{0s}\left(\alpha_i\right)$ $\quad x_0 := pile\left(x_t, x_s\right)$ $\quad y_0 := pile\left(y_t, y_s\right)$ $\quad mod\left(\psi_0 + \pi, 2 \cdot \pi\right) = 322.4\,deg$

$\Delta\alpha_{t'} := \dfrac{2 \cdot \beta'_0}{n_t - 1}$ $\quad \alpha_{t'_j} := j \cdot \Delta\alpha_{t'}$ $\quad x_{t'1_j} := x_{0t'}\left(\alpha_{t'_j}\right)$ $\quad y_{t'1_j} := y_{0t'}\left(\alpha_{t'_j}\right)$ $\quad x_0 := pile\left(x_0, x_{t'1}\right)$ $\quad y_0 := pile\left(y_0, y_{t'1}\right)$

$r_0 := \overrightarrow{\sqrt{x_0^{\,2} + y_0^{\,2}}}$ $\quad \beta_s := \overrightarrow{Atan\left(x_0, y_0\right)}$ $\quad n_{pt} := dernier\left(\beta_s\right)$ $\quad \beta_{s_{npt}} = 216.4\,deg$ $\quad \alpha_V(0) = 216.4\,deg$



Vérification de la condition de Phillips

Partie cylindrique

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

$$\zeta_{0s} := \frac{1}{L} \cdot \int_{\pi}^{\pi+\psi_0} z_{0s}(\alpha) \cdot r_s(\alpha)\, d\alpha \qquad \xi_{0s} := Re(\zeta_{0s}) \qquad \eta_{0s} := Im(\zeta_{0s})$$

$$\xi_{0s} = -4.111 \times 10^{-3}\, mm \qquad \eta_{0s} = -0.052\, mm$$

Courbe terminale externe

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

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

$$\xi_{0t} := Re(\zeta_{0t}) \qquad \eta_{0t} := Im(\zeta_{0t}) \qquad \xi_{0t} = 0\, mm \qquad \eta_{0t} = 0.632\, mm$$

Courbe terminale interne

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

$$\zeta_{0t'} := \frac{r_{t'}}{l_{t'}} \cdot \int_0^{2 \cdot \beta'_0} z_{0t'}(\alpha_{t'})\, d\alpha_{t'} \qquad \xi_{0t'} := Re(\zeta_{0t'}) \qquad \eta_{0t'} := Im(\zeta_{0t'}) \qquad \xi_{0t'} = 0.126\, mm \qquad \eta_{0t'} = 0.163\, mm$$

Condition de Phillips

$$l_t \cdot \zeta_{0t} + L \cdot \zeta_{0s} + l_{t'} \cdot \zeta_{0t'} = -0.121 + 0.021i\, mm^2$$

Vérification de la condition de Moulin

Partie cylindrique

$$s_s(\alpha) := r_A \cdot (\alpha - \alpha_A) - \frac{a}{2} \cdot (\alpha - \alpha_A)^2 + l_t$$

$$Z_{2s} := \frac{2}{L_t^2} \cdot \int_{\pi}^{\psi_0+\pi} s_s(\alpha) \cdot z_{0s}(\alpha) \cdot r_s(\alpha)\, d\alpha \qquad Z_{2s} = -4.1 \times 10^{-3} - 0.013i\, mm$$

Courbe terminale externe

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

$$Z_{2t} = -3.17 \times 10^{-3} + 5.044i \times 10^{-3}\, mm$$

Courbe terminale interne

$$Z_{2t'} := \frac{2}{L_t^2} \cdot \int_0^{2 \cdot \beta'_0} (l_t + L + r_{t'} \cdot \alpha_{t'}) \cdot z_{0t'}(\alpha_{t'}) \cdot r_{t'}\, d\alpha_{t'}$$

Condition de Moulin

$$Z_2 := Z_{2t} + Z_{2s} + Z_{2t'} \qquad \boxed{|Z_2| = 2.134 \times 10^{-3}\, mm}$$