# Calcul des déformations des fils élastiques

## Fils élastiques en arc de cercle - Couple concentré normal à l'axe du fil

### Flexion et torsion

#### Fil rond en acier

$d := 1 \cdot mm$ $\quad S := \pi \cdot \frac{d^2}{4}$ $\quad E := 2.0 \cdot 10^5 \cdot N \cdot mm^{-2}$ $\quad G := \frac{E}{2.6}$ $\quad \rho := 7.85 \cdot 10^3 \cdot kg \cdot m^{-3}$

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

$J_t := J_{t\_circ}(d)$ $\quad I_{22} := I_{f\_circ}(d)$ $\quad I_{33} := I_{22}$

$W_t := W_{t\_circ}(d)$ $\quad W'_t := W_t$ $\quad W_{f2} := W_{f\_circ}(d)$ $\quad W_{f3} := W_{f2}$

Caractéristiques de l'arc de cercle $\quad R := 13.25 \cdot mm$ $\quad \psi_{AB} := 75 \cdot deg$

Forces extérieures en bout d'arc $\quad C := 6 \cdot N \cdot mm$ $\quad \lambda_C := 45 \cdot deg$

$F_x := 0 \cdot N$ $\quad F_y := 0 \cdot N$ $\quad F_z := 0 \cdot N$ $\quad C_x := C \cdot cos(\lambda_C)$ $\quad C_y := C \cdot sin(\lambda_C)$ $\quad C_z := 0 \cdot N \cdot mm$

Valeur de tests transitoires $\quad \alpha_m := 20 \cdot deg$

Référence :E:\Résonateur (TA)\Fils et lames en arc de cercle\Arc de cercle E_L - F&C.mcd(R)

### Torseur des forces de cohésion

$\mathbf{M_c}(\psi_{AB}, \alpha_m)^T = (4.243 \quad 4.243 \quad 0)\, N \cdot mm$

### Sollicitations

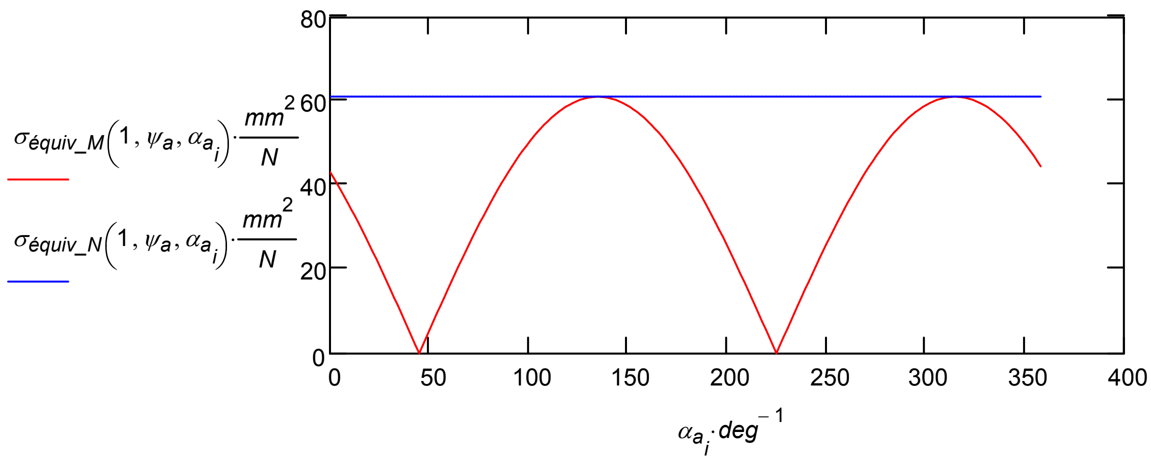
$\mathbf{e'_1}(\alpha_m)^T = (-0.342 \quad 0.94 \quad 0)$ $\quad \mathbf{e'_2}(\alpha_m)^T = (-0.94 \quad -0.342 \quad 0)$ $\quad \mathbf{e'_3}(\alpha_m)^T = (0 \quad 0 \quad 1)$

Moment de torsion $\quad M_t(\psi_{AB}, \alpha_m) = 2.536\, N \cdot mm$

Moments de flexion $\quad M_{f2}(\psi_{AB}, \alpha_m) = -5.438\, N \cdot mm$ $\quad M_{f3}(\psi_{AB}, \alpha_m) = 0\, N \cdot mm$

### Contraintes

Cas d'un anneau fendu $\quad n := 201$ $\quad i := 1 .. n-1$ $\quad \psi_a := 360 \cdot deg$ $\quad \alpha_{a_i} := (i-1) \cdot \frac{\psi_a}{n-1}$



## *Calcul des déplacements par les intégrales de Mohr*

Position du déplacement désiré $\alpha_M := 40 \cdot deg$

### Calcul des déplacements linéiques

Déplacement dans la direction de Ox $\lambda := 0 \cdot deg$ $\gamma := 90 \cdot deg$ $|\mathbf{v}(\lambda, \gamma)| = 1$

$\delta_{tv}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 0\,mm$ $\delta_{fv2}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 0\,mm$ $\delta_{fv3}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 0\,mm$

$\delta_x(\psi_{AB}, \alpha) := \delta_v(\psi_{AB}, \alpha, \lambda, \gamma)$ $\boxed{\delta_x(\psi_{AB}, \alpha_M) = 0\,mm}$

Déplacement dans la direction de Oy $\lambda := 90 \cdot deg$ $\gamma := 90 \cdot deg$ $|\mathbf{v}(\lambda, \gamma)| = 1$

$\delta_{tv}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 0\,mm$ $\delta_{fv2}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 0\,mm$ $\delta_{fv3}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 0\,mm$

$\delta_y(\psi_{AB}, \alpha) := \delta_v(\psi_{AB}, \alpha, \lambda, \gamma)$ $\boxed{\delta_y(\psi_{AB}, \alpha_M) = 0\,mm}$

Déplacement dans la direction de Oz $\lambda := 0 \cdot deg$ $\gamma := 0 \cdot deg$ $|\mathbf{v}(\lambda, \gamma)| = 1$

$\delta_{tv}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 4.381 \times 10^{-3}\,mm$ $\delta_{fv2}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 0.021\,mm$ $\delta_{fv3}(\psi_{AB}, \alpha_M, \lambda, \gamma) = 0\,mm$

$\delta_z(\psi_{AB}, \alpha) := \delta_v(\psi_{AB}, \alpha, \lambda, \gamma)$ $\boxed{\delta_z(\psi_{AB}, \alpha_M) = 0.026\,mm}$

### Calcul des déplacements angulaires

Déplacement angulaire autour de Ox $\lambda_c := 0 \cdot deg$ $\gamma_c := 90 \cdot deg$ $|\mathbf{cv}(\lambda, \gamma)| = 1$

$\theta_{tcv}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = -0.044\,deg$ $\theta_{fcv2}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0.263\,deg$ $\theta_{fcv3}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0\,deg$

$\theta_x(\psi_{AB}, \alpha) := \theta_{cv}(\psi_{AB}, \alpha, \lambda_c, \gamma_c)$ $\boxed{\theta_x(\psi_{AB}, \alpha_M) = 0.219\,deg}$

Déplacement angulaire autour de Oy $\lambda_c := 90 \cdot deg$ $\gamma_c := 90 \cdot deg$ $|\mathbf{cv}(\lambda, \gamma)| = 1$

$\theta_{tcv}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0.166\,deg$ $\theta_{fcv2}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0.102\,deg$ $\theta_{fcv3}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0\,deg$

$\theta_y(\psi_{AB}, \alpha) := \theta_{cv}(\psi_{AB}, \alpha, \lambda_c, \gamma_c)$ $\boxed{\theta_y(\psi_{AB}, \alpha_M) = 0.267\,deg}$

Déplacement angulaire autour de Oz $\lambda_c := 0 \cdot deg$ $\gamma_c := 0 \cdot deg$ $|\mathbf{cv}(\lambda, \gamma)| = 1$

$\theta_{tcv}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0\,deg$ $\theta_{fcv2}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0\,deg$ $\theta_{fcv3}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0\,deg$

$\theta_z(\psi_{AB}, \alpha) := \theta_{cv}(\psi_{AB}, \alpha, \lambda_c, \gamma_c)$ $\boxed{\theta_z(\psi_{AB}, \alpha_M) = 0\,deg}$

Déplacement angulaire de flexion $\lambda_c := \alpha_M$ $\gamma_c := 90 \cdot deg$ $|\mathbf{cv}(\lambda, \gamma)| = 1$

$\theta_{tcv}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0.073\,deg$ $\theta_{fcv2}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0.267\,deg$ $\theta_{fcv3}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0\,deg$

$\theta_f(\psi_{AB}, \alpha) := \theta_{cv}(\psi_{AB}, \alpha, \lambda_c, \gamma_c)$ $\boxed{\theta_f(\psi_{AB}, \alpha_M) = 0.339\,deg}$

Déplacement angulaire de torsion $\lambda_c := \alpha_M + \frac{\pi}{2}$ $\gamma_c := 90 \cdot deg$ $|\mathbf{cv}(\lambda, \gamma)| = 1$

$\theta_{tcv}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0.155\,deg$ $\theta_{fcv2}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = -0.091\,deg$ $\theta_{fcv3}(\psi_{AB}, \alpha_M, \lambda_c, \gamma_c) = 0\,deg$

$\theta_t(\psi_{AB}, \alpha) := \theta_{cv}(\psi_{AB}, \alpha, \lambda_c, \gamma_c)$ $\boxed{\theta_t(\psi_{AB}, \alpha_M) = 0.064\,deg}$

## *Solution analytique*

Moment de torsion $M_t(\psi_{AB},\alpha') := -C_x \cdot sin(\alpha') + C_y \cdot cos(\alpha')$

Moment fléchissant $M_{f2}(\psi_{AB},\alpha') := -C_x \cdot cos(\alpha') - C_y \cdot sin(\alpha')$

Déplacement selon Oz $M_{tv}(\alpha,\alpha') := R\cdot(1 - cos(\alpha - \alpha'))$ $M_{fv}(\alpha,\alpha') := -R\cdot sin(\alpha - \alpha')$

$$\delta_{t3}(\psi_{AB},\alpha) := \frac{R}{G\cdot J_t}\cdot\int_0^{\alpha} M_t(\psi_{AB},\alpha')\cdot M_{tv}(\alpha,\alpha')\, d\alpha' \qquad \delta_{f3}(\psi_{AB},\alpha) := \frac{R}{E\cdot I_{22}}\cdot\int_0^{\alpha} M_{f2}(\psi_{AB},\alpha')\cdot M_{fv}(\alpha,\alpha')\, d\alpha'$$

$$\delta_{t3}(\psi_{AB},\alpha) := \frac{C_x\cdot R^2}{2\cdot G\cdot J_t}\cdot[\alpha\cdot sin(\alpha) - 2\cdot(1 - cos(\alpha))] + \frac{C_y\cdot R^2}{2\cdot G\cdot J_t}\cdot(sin(\alpha) - \alpha\cdot cos(\alpha))$$

$$\delta_{f3}(\psi_{AB},\alpha) := \frac{C_x\cdot R^2}{2\cdot E\cdot I_{22}}\cdot(\alpha\cdot sin(\alpha)) - \frac{C_y\cdot R^2}{2\cdot E\cdot I_{22}}\cdot(\alpha\cdot cos(\alpha) - sin(\alpha)) \qquad \delta_3(\psi_{AB},\alpha) := \delta_{t3}(\psi_{AB},\alpha) + \delta_{f3}(\psi_{AB},\alpha)$$

$\delta_{t3}(\psi_{AB},\alpha_M) = 4.381\times 10^{-3}\, mm$ $\delta_{f3}(\psi_{AB},\alpha_M) = 0.021\, mm$ $\delta_3(\psi_{AB},\alpha_M) = 0.026\, mm$

Déplacement angulaire de flexion $M_{tv}(\alpha,\alpha') := sin(\alpha - \alpha')$ $M_{fv}(\alpha,\alpha') := -cos(\alpha - \alpha')$

$$\theta_{ft}(\psi_{AB},\alpha) := \frac{R}{G\cdot J_t}\cdot\int_0^{\alpha} M_t(\psi_{AB},\alpha')\cdot M_{tv}(\alpha,\alpha')\, d\alpha' \qquad \theta_{ff}(\psi_{AB},\alpha) := \frac{R}{E\cdot I_{22}}\cdot\int_0^{\alpha} M_{f2}(\psi_{AB},\alpha')\cdot M_{fv}(\alpha,\alpha')\, d\alpha'$$

$$\theta_{ft}(\psi_{AB},\alpha) := \frac{C_x\cdot R}{2\cdot G\cdot J_t}\cdot(\alpha\cdot cos(\alpha) - sin(\alpha)) + \frac{C_y\cdot R}{2\cdot G\cdot J_t}\cdot(\alpha\cdot sin(\alpha))$$

$$\theta_{ff}(\psi_{AB},\alpha) := \frac{C_x\cdot R}{2\cdot E\cdot I_{22}}\cdot(\alpha\cdot cos(\alpha) + sin(\alpha)) + \frac{C_y\cdot R}{2\cdot E\cdot I_{22}}\cdot(\alpha\cdot sin(\alpha)) \qquad \theta_f(\psi_{AB},\alpha) := \theta_{ft}(\psi_{AB},\alpha) + \theta_{ff}(\psi_{AB},\alpha)$$

$\theta_{ff}(\psi_{AB},\alpha_M) = 0.267\, deg$ $\theta_{ft}(\psi_{AB},\alpha_M) = 0.073\, deg$ $\theta_f(\psi_{AB},\alpha_M) = 0.339\, deg$

Déplacement angulaire de torsion $M_{tv}(\alpha,\alpha') := cos(\alpha - \alpha')$ $M_{fv}(\alpha,\alpha') := sin(\alpha - \alpha')$

$$\theta_{tt}(\psi_{AB},\alpha) := \frac{R}{G\cdot J_t}\cdot\int_0^{\alpha} M_t(\psi_{AB},\alpha')\cdot M_{tv}(\alpha,\alpha')\, d\alpha' \qquad \theta_{tf}(\psi_{AB},\alpha) := \frac{R}{E\cdot I_{22}}\cdot\int_0^{\alpha} M_{f2}(\psi_{AB},\alpha')\cdot M_{fv}(\alpha,\alpha')\, d\alpha'$$

$$\theta_{tt}(\psi_{AB},\alpha) := \frac{-C_x\cdot R}{2\cdot G\cdot J_t}\cdot(\alpha\cdot sin(\alpha)) + \frac{C_y\cdot R}{2\cdot G\cdot J_t}\cdot(\alpha\cdot cos(\alpha) + sin(\alpha))$$

$$\theta_{tf}(\psi_{AB},\alpha) := \frac{-C_x\cdot R}{2\cdot E\cdot I_{22}}\cdot(\alpha\cdot sin(\alpha)) + \frac{C_y\cdot R}{2\cdot E\cdot I_{22}}\cdot(\alpha\cdot cos(\alpha) - sin(\alpha)) \qquad \theta_t(\psi_{AB},\alpha) := \theta_{tt}(\psi_{AB},\alpha) + \theta_{tf}(\psi_{AB},\alpha)$$

$\theta_{tf}(\psi_{AB},\alpha_M) = -0.091\, deg$ $\theta_{tt}(\psi_{AB},\alpha_M) = 0.155\, deg$ $\theta_t(\psi_{AB},\alpha_M) = 0.064\, deg$

## *Cas particuliers*

Référence :E:\Résonateur (TA)\Fils et lames en arc de cercle\Définition Atan.mcd(R)

### Quart de cercle

$\psi_{AB} := 90\cdot deg \qquad L := R\cdot\psi_{AB} \qquad L = 20.813\,mm$

$\delta_3(\psi_{AB},\psi_{AB}) = 0.126\,mm \qquad \theta_t(\psi_{AB},\psi_{AB}) = -0.543\,deg \qquad \theta_f(\psi_{AB},\psi_{AB}) = 0.543\,deg$

$$\Delta_{90} := \frac{R^2}{2}\cdot\left[\frac{0}{m}\quad\frac{0}{m}\quad\left[\frac{1}{E\cdot I_{22}}\cdot\left(\frac{\pi}{2}\cdot C_x + C_y\right) + \frac{1}{G\cdot J_t}\cdot\left[\left(\frac{\pi}{2}-2\right)\cdot C_x + C_y\right]\right]\right]^T \qquad \Delta_{90} = \begin{pmatrix}0\\0\\0.126\end{pmatrix} mm$$

$$\Theta_t := \frac{R}{2}\cdot\left[\left[\frac{1}{E\cdot I_{22}}\cdot\left(\frac{-\pi}{2}\cdot C_x - C_y\right) + \frac{1}{G\cdot J_t}\cdot\left(\frac{-\pi}{2}\cdot C_x + C_y\right)\right]\right] \qquad \Theta_t = -0.543\,deg$$

$$\Theta_f := \frac{R}{2}\cdot\left[\left[\frac{1}{E\cdot I_{22}}\cdot\left(C_x + \frac{\pi}{2}\cdot C_y\right) + \frac{1}{G\cdot J_t}\cdot\left(-C_x + \frac{\pi}{2}\cdot C_y\right)\right]\right] \qquad \Theta_f = 0.543\,deg$$

### Graphe de la déformation

$x_0(\alpha) := R\cdot cos(\alpha) \qquad y_0(\alpha) := R\cdot sin(\alpha) \qquad z_0(\alpha) := 0$

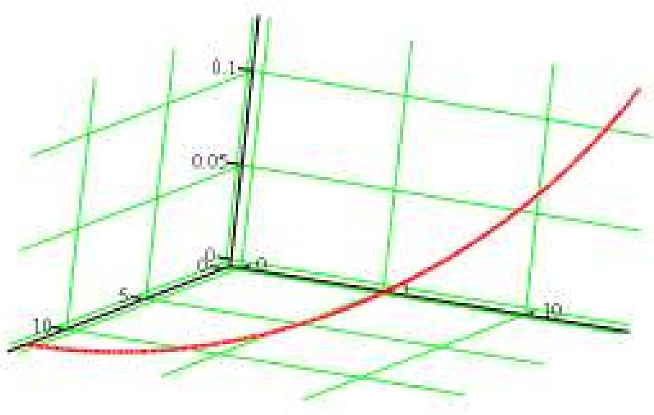
$z_d(\alpha) := \delta_3(\psi_{AB},\alpha) \quad \theta_d(\alpha) := arctan\left(\frac{z_d(\alpha)}{R}\right) \quad x_d(\alpha) := R\cdot cos(\theta_d(\alpha))\cdot cos(\alpha) \quad y_d(\alpha) := R\cdot cos(\theta_d(\alpha))\cdot sin(\alpha)$

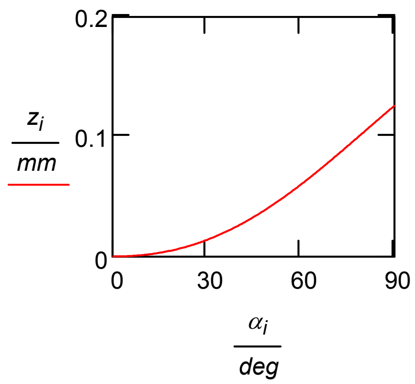
$x'_d(\alpha) := \frac{d}{d\alpha}x_d(\alpha) \qquad y'_d(\alpha) := \frac{d}{d\alpha}y_d(\alpha) \qquad z'_d(\alpha) := \frac{d}{d\alpha}z_d(\alpha)$

$L = 20.813\,mm$

$\alpha_0 := 0 \qquad \alpha_{max} := \psi_{AB} \qquad L_d := \int_{\alpha_0}^{\alpha_{max}} \sqrt{x'_d(\alpha)^2 + y'_d(\alpha)^2 + z'_d(\alpha)^2}\,d\alpha \qquad L_d = 20.813\,mm$

$n := 201 \qquad i := 1..n \qquad \alpha_i := \frac{\psi_{AB}}{n-1}\cdot(i-1) \qquad z_i := z_d(\alpha_i) \qquad x_i := x_d(\alpha_i) \qquad y_i := y_d(\alpha_i)$




$\left(\frac{x}{mm}, \frac{y}{mm}, \frac{z}{mm}\right)$

## Demi-cercle

$\psi_{AB} := 180 \cdot deg \qquad L := R \cdot \psi_{AB} \qquad L = 41.626\, mm$

$\delta_3(\psi_{AB}, \psi_{AB}) = 0.077\, mm \qquad \theta_t(\psi_{AB}, \psi_{AB}) = -1.185\, deg \qquad \theta_f(\psi_{AB}, \psi_{AB}) = -1.185\, deg$

$$\Delta_{180} := \frac{R^2}{2} \cdot \left[ \frac{0}{m} \quad \frac{0}{m} \quad \left[ \frac{1}{E \cdot I_{22}} \cdot (0 + \pi \cdot C_y) + \frac{1}{G \cdot J_t} \cdot (-4 \cdot C_x + \pi \cdot C_y) \right] \right]^T \qquad \Delta_{180} = \begin{pmatrix} 0 \\ 0 \\ 0.077 \end{pmatrix} mm$$

$$\Theta_t := \frac{R}{2} \cdot \left[ \left[ \frac{1}{E \cdot I_{22}} \cdot (0 - \pi \cdot C_y) + \frac{1}{G \cdot J_t} \cdot (0 - \pi \cdot C_y) \right] \right] \qquad \Theta_t = -1.185\, deg$$

$$\Theta_f := \frac{R}{2} \cdot \left[ \left[ \frac{1}{E \cdot I_{22}} \cdot (-\pi \cdot C_x + 0) + \frac{1}{G \cdot J_t} \cdot (-\pi \cdot C_x + 0) \right] \right] \qquad \Theta_f = -1.185\, deg$$

### Graphe de la déformation

$x_0(\alpha) := R \cdot \cos(\alpha) \qquad y_0(\alpha) := R \cdot \sin(\alpha) \qquad z_0(\alpha) := 0$

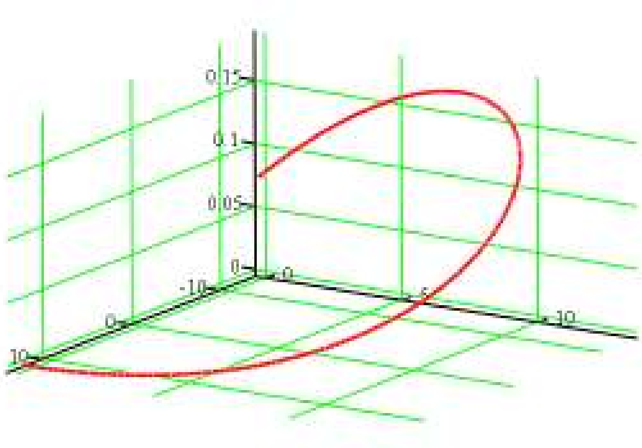
$$z_d(\alpha) := \delta_3(\psi_{AB}, \alpha) \quad \theta_d(\alpha) := \arctan\left(\frac{z_d(\alpha)}{R}\right) \quad x_d(\alpha) := R \cdot \cos(\theta_d(\alpha)) \cdot \cos(\alpha) \quad y_d(\alpha) := R \cdot \cos(\theta_d(\alpha)) \cdot \sin(\alpha)$$

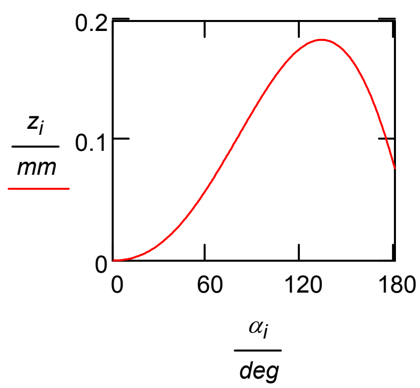
$$x'_d(\alpha) := \frac{d}{d\alpha} x_d(\alpha) \qquad y'_d(\alpha) := \frac{d}{d\alpha} y_d(\alpha) \qquad z'_d(\alpha) := \frac{d}{d\alpha} z_d(\alpha)$$

$L = 41.626\, mm$

$$\alpha_0 := 0 \qquad \alpha_{max} := \psi_{AB} \qquad L_d := \int_{\alpha_0}^{\alpha_{max}} \sqrt{x'_d(\alpha)^2 + y'_d(\alpha)^2 + z'_d(\alpha)^2}\, d\alpha \qquad L_d = 41.626\, mm$$

$$n := 201 \qquad i := 1 .. n \qquad \alpha_i := \frac{\psi_{AB}}{n-1} \cdot (i - 1) \qquad z_i := z_d(\alpha_i) \qquad x_i := x_d(\alpha_i) \qquad y_i := y_d(\alpha_i)$$




$$\left( \frac{x}{mm}, \frac{y}{mm}, \frac{z}{mm} \right)$$

## Anneau fendu

$\psi_{AB} := 360 \cdot deg \qquad L := R \cdot \psi_{AB} \qquad L = 83.252\,mm$

$\delta_3(\psi_{AB}, \psi_{AB}) = -0.548\,mm \qquad \theta_t(\psi_{AB}, \psi_{AB}) = 2.371\,deg \qquad \theta_f(\psi_{AB}, \psi_{AB}) = 2.371\,deg$

$$\Delta_{360} := \frac{R^2}{2} \cdot \left[ \frac{0}{m} \quad \frac{0}{m} \quad \left[ \frac{1}{E \cdot I_{22}} \cdot (0 - 2 \cdot \pi \cdot C_y) + \frac{1}{G \cdot J_t} \cdot (0 - 2 \cdot \pi \cdot C_y) \right] \right]^T \qquad \Delta_{360} = \begin{pmatrix} 0 \\ 0 \\ -0.548 \end{pmatrix} mm$$

$$\Theta_t := \frac{R}{2} \cdot \left[ \left[ \frac{1}{E \cdot I_{22}} \cdot (0 + 2 \cdot \pi \cdot C_y) + \frac{1}{G \cdot J_t} \cdot (0 + 2 \cdot \pi \cdot C_y) \right] \right] \qquad \Theta_t = 2.371\,deg$$

$$\Theta_f := \frac{R}{2} \cdot \left[ \left[ \frac{1}{E \cdot I_{22}} \cdot (2 \cdot \pi \cdot C_x + 0) + \frac{1}{G \cdot J_t} \cdot (2 \cdot \pi \cdot C_x + 0) \right] \right] \qquad \Theta_f = 2.371\,deg$$

### Graphe de la déformation

$x_0(\alpha) := R \cdot cos(\alpha) \qquad y_0(\alpha) := R \cdot sin(\alpha) \qquad z_0(\alpha) := 0$

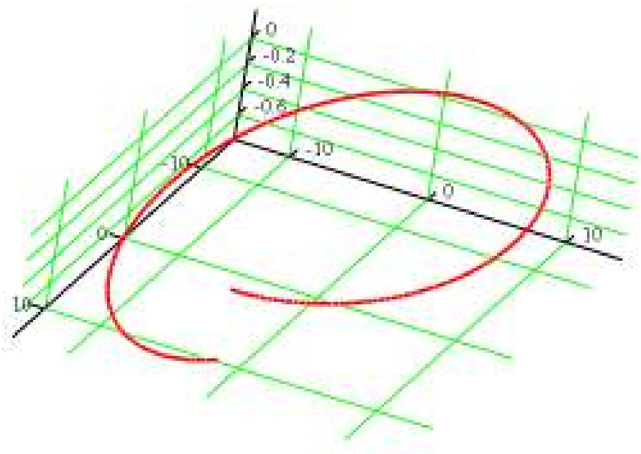
$z_d(\alpha) := \delta_3(\psi_{AB}, \alpha) \quad \theta_d(\alpha) := arctan\left(\frac{z_d(\alpha)}{R}\right) \quad x_d(\alpha) := R \cdot cos(\theta_d(\alpha)) \cdot cos(\alpha) \quad y_d(\alpha) := R \cdot cos(\theta_d(\alpha)) \cdot sin(\alpha)$

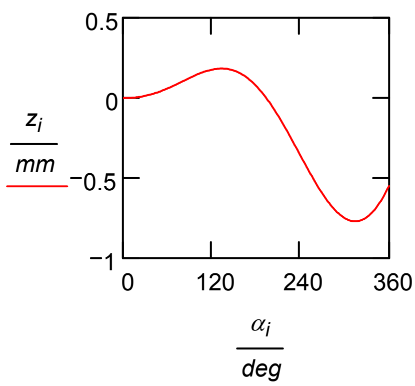
$x'_d(\alpha) := \frac{d}{d\alpha} x_d(\alpha) \qquad y'_d(\alpha) := \frac{d}{d\alpha} y_d(\alpha) \qquad z'_d(\alpha) := \frac{d}{d\alpha} z_d(\alpha)$

$L = 83.252\,mm$

$\alpha_0 := 0 \qquad \alpha_{max} := \psi_{AB} \qquad L_d := \int_{\alpha_0}^{\alpha_{max}} \sqrt{x'_d(\alpha)^2 + y'_d(\alpha)^2 + z'_d(\alpha)^2}\, d\alpha \qquad L_d = 83.233\,mm$

$n := 201 \qquad i := 1..n \qquad \alpha_i := \frac{\psi_{AB}}{n-1} \cdot (i - 1) \qquad z_i := z_d(\alpha_i) \qquad x_i := x_d(\alpha_i) \qquad y_i := y_d(\alpha_i)$




$\left(\frac{x}{mm}, \frac{y}{mm}, \frac{z}{mm}\right)$