Nonlinear interactions between a cable with no axial preload and its casing. Application to automotive gearshift command systems

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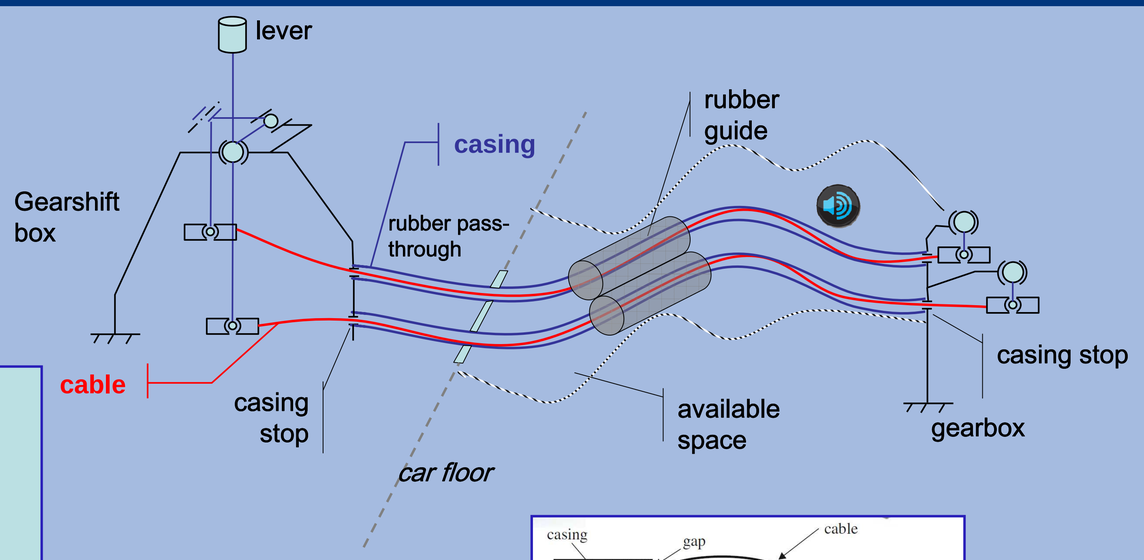
Technological and Scientific contexts

Driving comfort requires to reduce:
- Drag friction force during gear shifting,
- Gearbox vibration transmission to the gearshift lever
- cable-casing vibro-impacting noise

Main scientific challenges
- cable-casing spatially curved geometry simulation,
- non-linearities: cable-casing contact, large displacement,
- vibrations and dynamic instabilities, parametric excitations



Research steps

Cable and casing mechanical properties (E, EI, ρ), geometry characteristics

Boundary conditions and surrounding components (start, end, intermediate, points)

Elementary Drag force and efficiency experimental identification

Non linear FE Computation, large displacements, co-rotational formulation, cable-casing contact problem solved with penalty method

Spatially curved cable-casing path, contact points and forces

Drag force and efficiency models integration

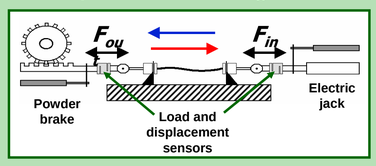
Drag force and efficiency calculation on real car gearshift mechanism

Dynamic Ananysis
- Modes and frequencies computation around static equilibrium position
- Forced response to:
  - Cable axial excitation
  - Casing transverse excitation
- Vibration instabilities prediction

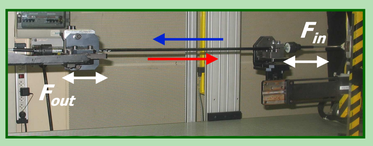
Experimental validation

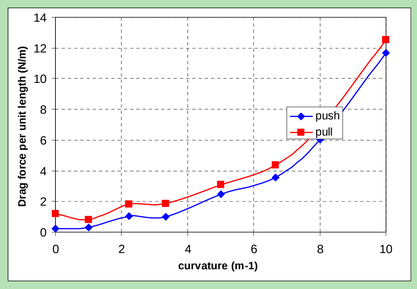
Drag force and Efficiency analysis

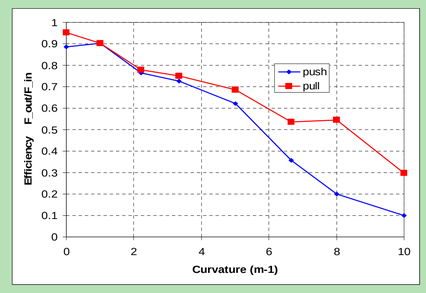
- **Drag force:** threshold load to move the cable into the casing
- **Efficiency:** ratio between In/Out forces
- Experimental design influence analysis → Drag and Efficiency per unit length

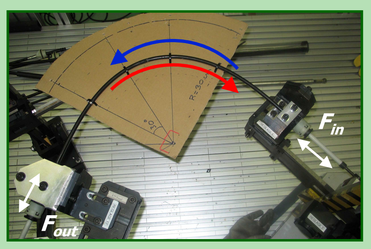


Curvature C	Temperature T	Force F
∞	-30°C	50 N
5 m^{-1}	0°C	100 N
6.25 m^{-1}	40°C	150 N
	85°C	









$$Drag_{push} = 4,41 - 1251,6.C - 0,038.T + 327950.C^2 + 5,4.10^{-4}.T^2 - 7,4.C.T \quad (N/m)$$

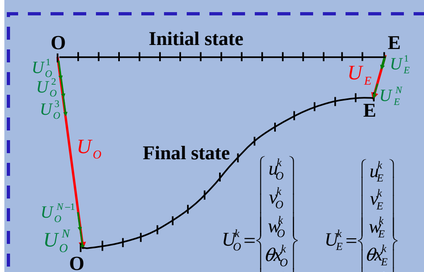
$$Drag_{pull} = 3,957 - 336,8.C - 0,087.T + 221783.C^2 + 10,1.10^{-4}.T^2 - 8,09.C.T \quad (N/m)$$

$$\rho_{push} = 0,559 + 0,006.F - 39,11.C + 0,001.T - 2,38.10^{-5}.F^2 - 520,4.C^2 - 3,1.10^{-6}.T^2 - 0,06.F.C + 6,6.10^{-7}.F.T + 0,019.C.T$$

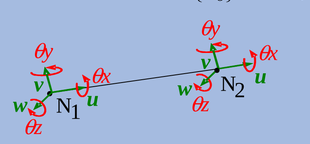
$$\rho_{pull} = 0,693 + 0,003.F - 27,03.C + 0,002.T - 1,03.10^{-5}.F^2 - 3083,6.C^2 - 11,3.10^{-6}T^2 - 0,02.F.C + 44,5.10^{-7}.F.T + 0,079.C.T$$

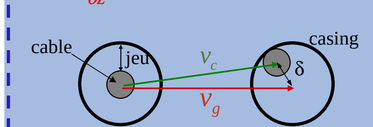
Curvilinear casing geometry and contact points prediction

- ***Incremental method + co –rotationnal FE formulation + contact penalty-barrier method***

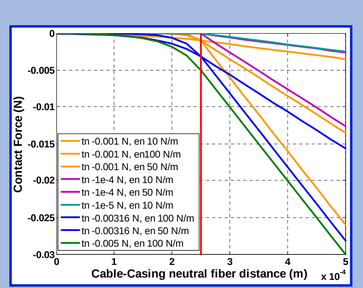


$$U_O^k = \begin{Bmatrix} u_O^k \\ v_O^k \\ w_O^k \\ \theta x_O^k \\ \theta y_O^k \\ \theta z_O^k \end{Bmatrix} \quad U_E^k = \begin{Bmatrix} u_E^k \\ v_E^k \\ w_E^k \\ \theta x_E^k \\ \theta y_E^k \\ \theta z_E^k \end{Bmatrix}$$





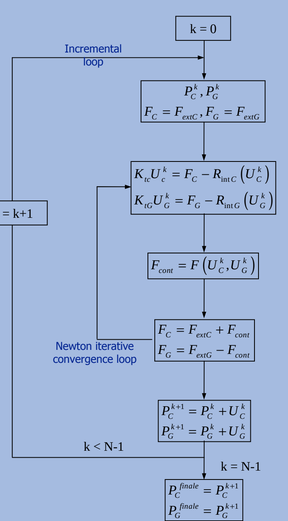
FE modeling, cable-casing contact interaction



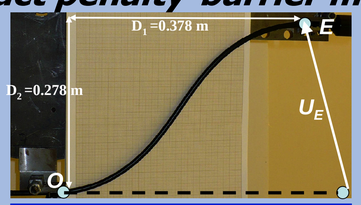
$$g_n = jeu - \overrightarrow{C_iM}.\vec{n}$$

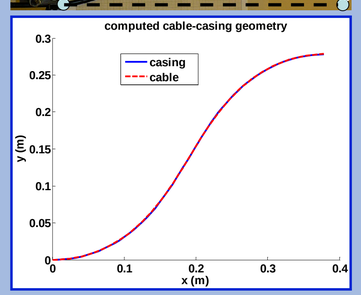
$$\begin{cases} F_{cont} = t_n + e_n.g_n & si\ g_n < 0 \\ F_{cont} = t_n.e^{a_n.g_n} & si\ g_n \geq 0 \end{cases}$$

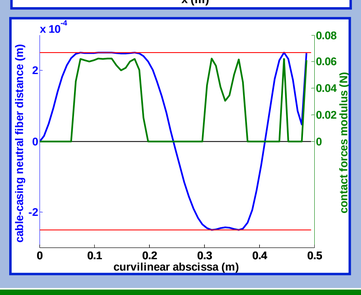
$$\begin{cases} \vec{F}_{casing/cable} = -F_{cont}.\vec{n} \\ \vec{F}_{cable/casing} = F_{cont}.\vec{n} \end{cases}$$



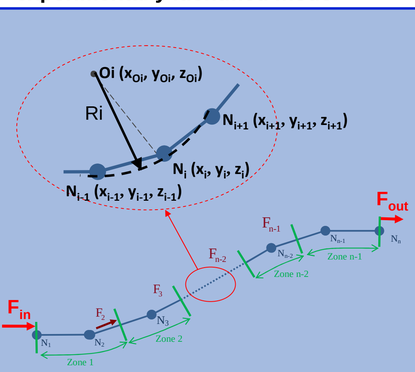
Computation algorithm







- Drag force an efficiency computation from cable-casing path decomposition and experimentally identified model



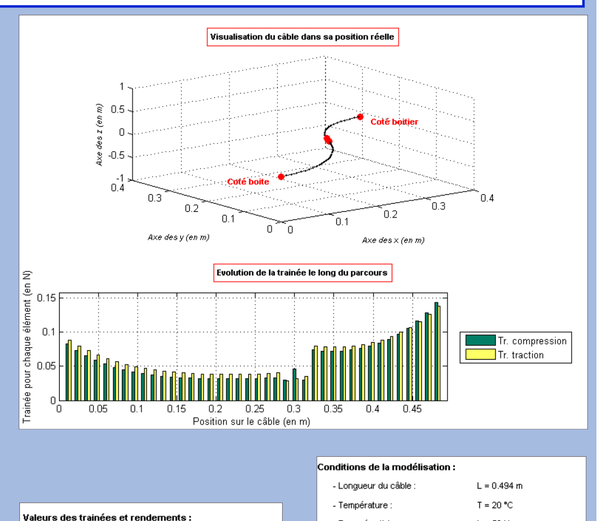
$$Drag = \sum_{i=1}^{i=Nb\_z} Drag_{lin}(R_i).L_{zone\_i}$$

$$\eta_{global} = \frac{F_{out}}{F_{in}} = 1 - \frac{F_{in} - F_{out}}{F_{in}} = 1 - \frac{\Delta F_{total}}{F_{in}}$$

$$\Delta F_{total} = \sum_{i=1}^{n-1} \Delta F_{zone\_i} \qquad \eta_{lin\_i} = 1 - \frac{\Delta F_{lin\_i}}{F_i}$$

$$\Delta F_{zone\_i} = \Delta F_{lin\_i}.L_{zone\_i} \qquad \Delta F_{lin\_i} = F_i(\eta_{lin\_i} - 1)$$

$$(F_{in}, C_1) \rightarrow \eta_{lin\_1} \rightarrow \Delta F_{zone\_1} \rightarrow F_2 = F_{in} - \Delta F_{zone\_1} \rightarrow \ldots.$$



Valeurs des traînées et rendements :

- Traînée en compression :	**Tc = 2.5 N**
- Traînée en traction :	**Tt = 2.7 N**
- Rendement en compression :	**Rc = 0.82**
- Rendement en traction :	**Rt = 0.85**

Conditions de la modélisation :

- Longueur du câble :	L = 0.494 m
- Température :	T = 20 °C
- Force émettrice :	L = 50 N
- Rayon int/ext :	Ri = 0.0000 /Re = 0.0016 m
- Module d'Young :	E = 1.9e+010 Pa
- Coefficient de Poisson :	v = 0.3
- Masse volumique :	Ro = 7495 kg/m3

Dynamic and Vibration transmission analysis

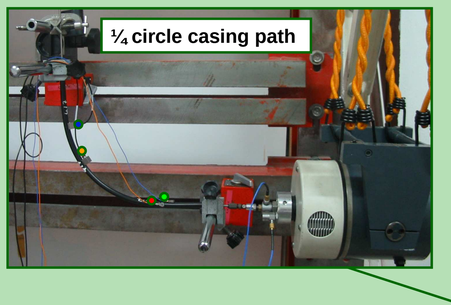
- **Time response around static equilibrium position**
  - **cable axial harmonic excitation**
  - **casing transverse excitation**
- **Time integration to predict dynamic response**
- **Experimentation-Validation on**
  - **basic casing curved geometry**
  - **car cable-casing geometry**

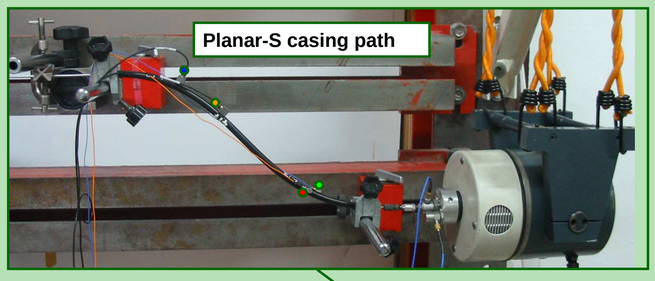
Computed cable-casing spatially curved geometry

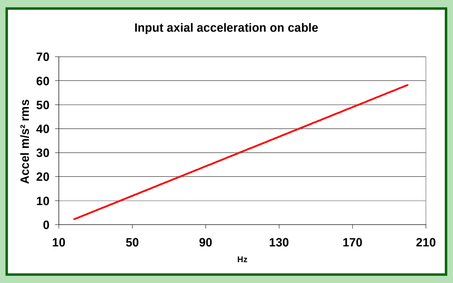
$K_{cable-casing}$, $M_{cable-casing}$

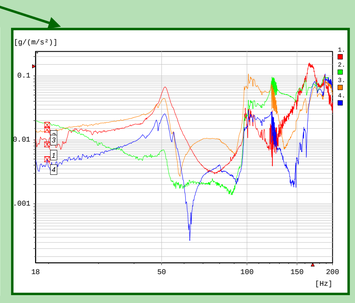
$F(t)=F_1\sin(\omega t)$ Or $\gamma(t)=\gamma_1\sin(\omega t)$ → **Newmark scheme Time response computation**

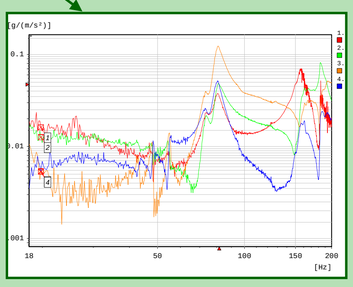
u(t)
$P(t)=P_0 + u(t)$

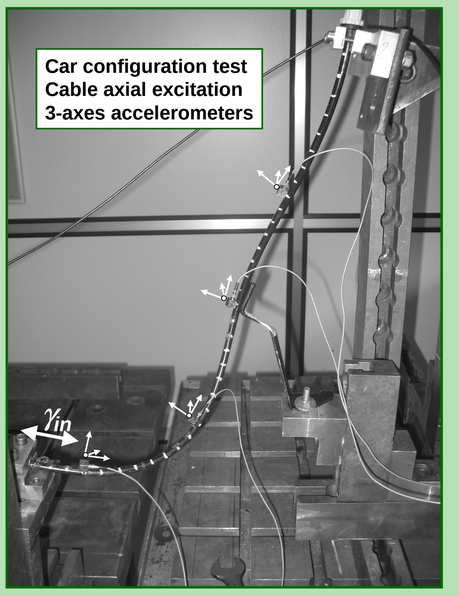












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