Tribology of a CVT traction drive

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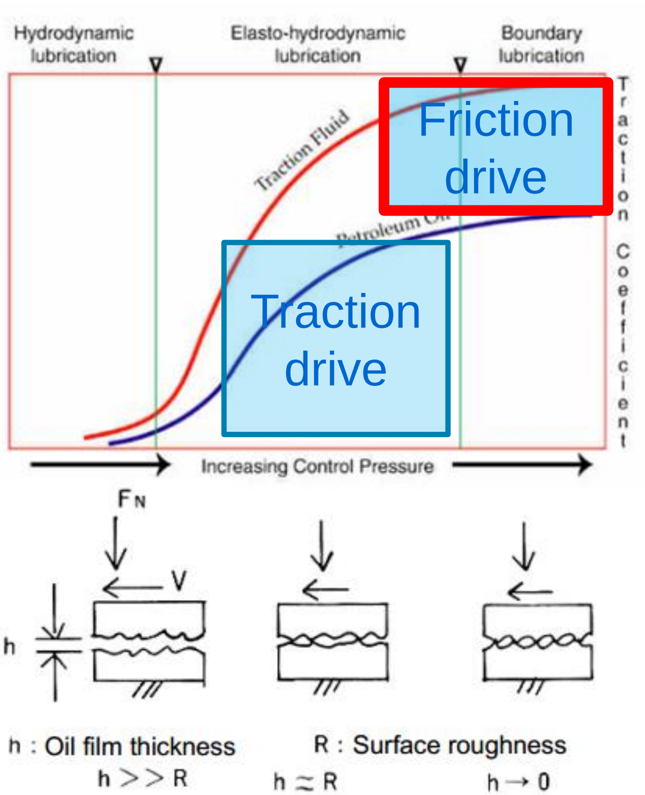
Where innovation starts

Structure

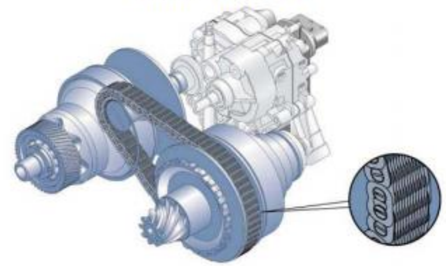
- **Background**
- **Introduction**
- **Traction drive modeling**
- **NuVinci analysis with model**

Aim: predict efficiency of NuVinci transmission, which works as a traction drive

Background: CVT types



Manuel E. Joaquim. Ehls: The secret behind cvts. Technical report, Findett Corporation.

Types	Product	
Pulley based CVTs	LuK chain CVT 	Bosch pushbelt CVT 
Toroidal CVT	Nissan Extroid toroidal CVT 	
Ball based CVTs	Kopp Variator 	NuVinci CVP 

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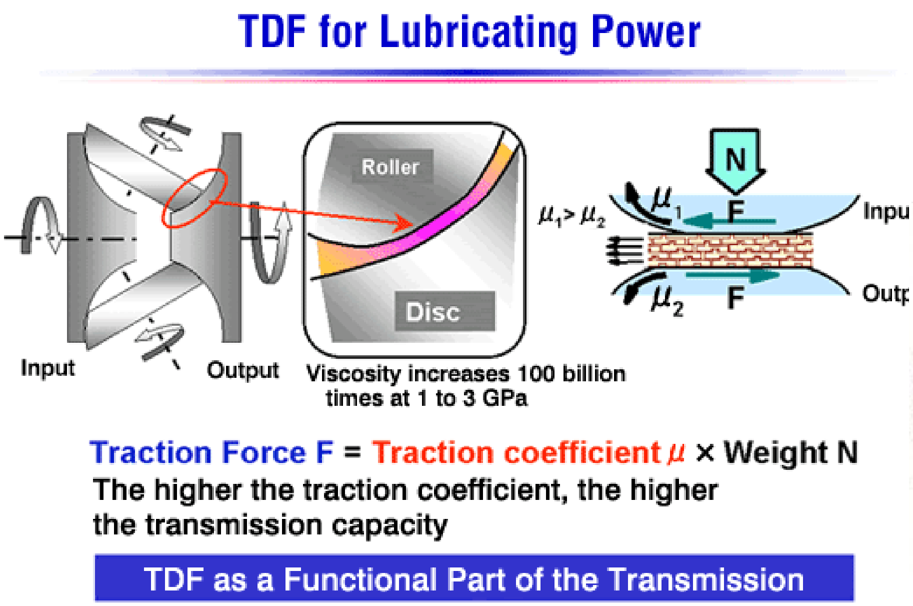
Introduction: traction drive fluid



LTD Nissan Motor Co. Extroid cvt: for application to rear-wheel-drive cars powered by large engines.

Traction fluid behaves in a **solid** like manner under high contact stress
(order of 1 [GPa], 10,000 times atmospheric pressure)

The mountains flowed before the Lord

relaxation time

$$De = \frac{t_c}{t_p}$$

Observation time

Deborah (1200BC – 1124 BC):
a prophetess of the God of the Israelites

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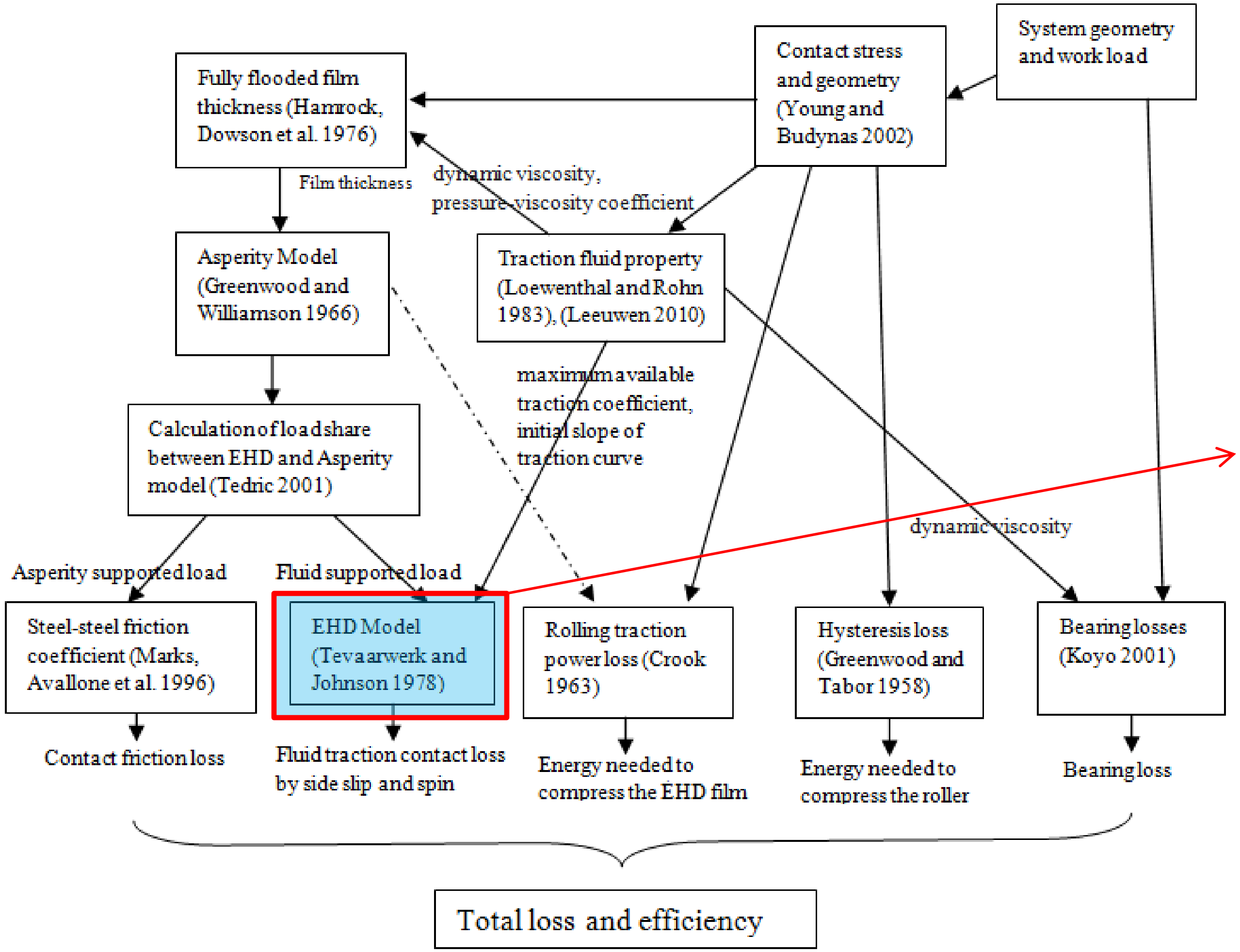
Modeling



Johnson-Tevaarwerk model gives good predictions at **large Deborah number**:

- Large contact pressure
- Short transit time

Modeling: Johnson-Tevaarwerk model

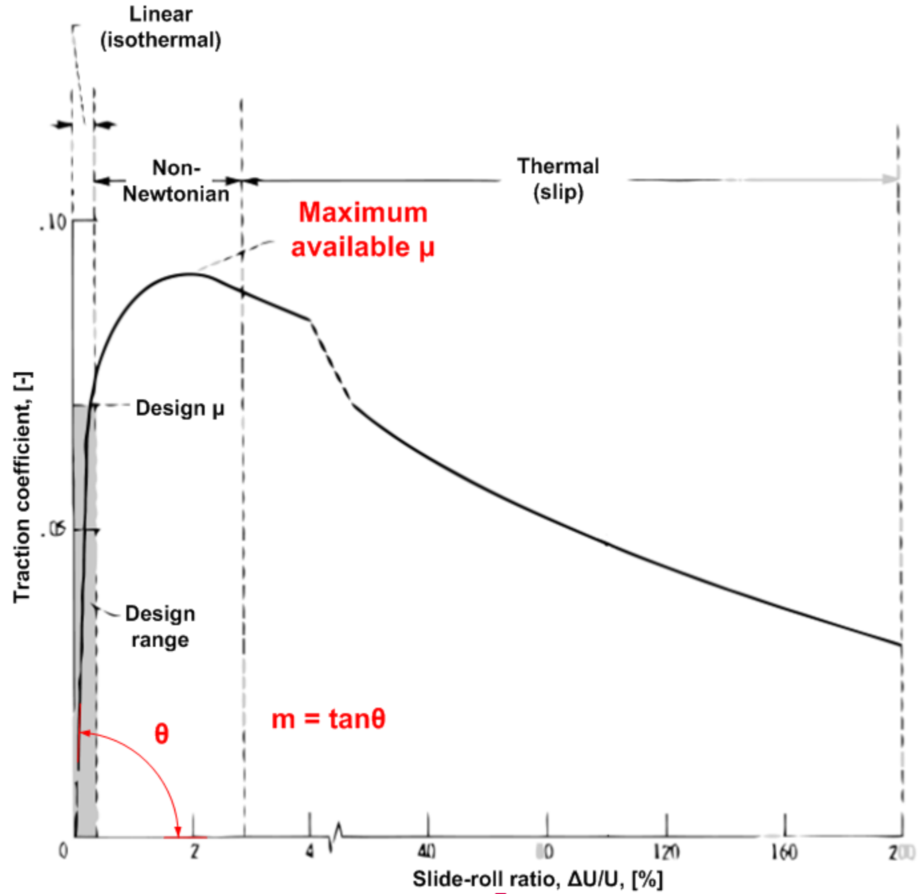
- Developed in 1978
- Based on limited shear stress theory
- Describing the elastic and plastic behavior in traction drive
- Two key parameters:

$$G = \frac{3}{8}\frac{mNh}{a^2 b}$$

elastic shear modulus

$$\tau_c = \frac{\mu N}{\pi a b}$$

average limiting shear strength



Modeling: Johnson-Tevaarwerk model

Dimensionless parameters

- Dimensionless slip in rolling direction: $J_1 = C\frac{\Delta U}{U}$
- Dimensionless slip in transverse direction: $J_2 = C\frac{\Delta V}{U}$
- Dimensionless spin: $J_3 = C\frac{\omega_s\sqrt{ab}}{U}$
- Dimensionless traction force in rolling direction: $J_4 = \frac{F_x}{\tau_c \pi ab} = \frac{F_x}{\mu N}$
- Dimensionless traction force in transverse direction: $J_5 = \frac{F_y}{\tau_c \pi ab} = \frac{F_y}{\mu N}$
- Dimensionless torque perpendicular to contact area: $J_6 = \frac{T_s}{\mu N\sqrt{ab}}$

$$C = \frac{G\sqrt{ab}}{\tau_c h_c} = \frac{3\pi}{8}\frac{m}{\mu}\sqrt{k}$$

Loewenthal and Rohn investigated 334 traction drives experimental results, a regression model was given based on Santotrac 50.

Losses

Slip loss: $P_{slip} = \Delta U F_x = J_1 J_4 \frac{U\mu N}{C}$

Spin loss: $P_{spin} = \omega_s T = J_3 J_6 \frac{U\mu N}{C}$

Transferred power: $P_{in} = U F_x = \frac{J_4 U \mu N}{sf}$

$$\frac{P_{slip} + P_{spin}}{P_{in}} = \frac{J_1 J_4 + J_3 J_6}{J_4 C} sf$$

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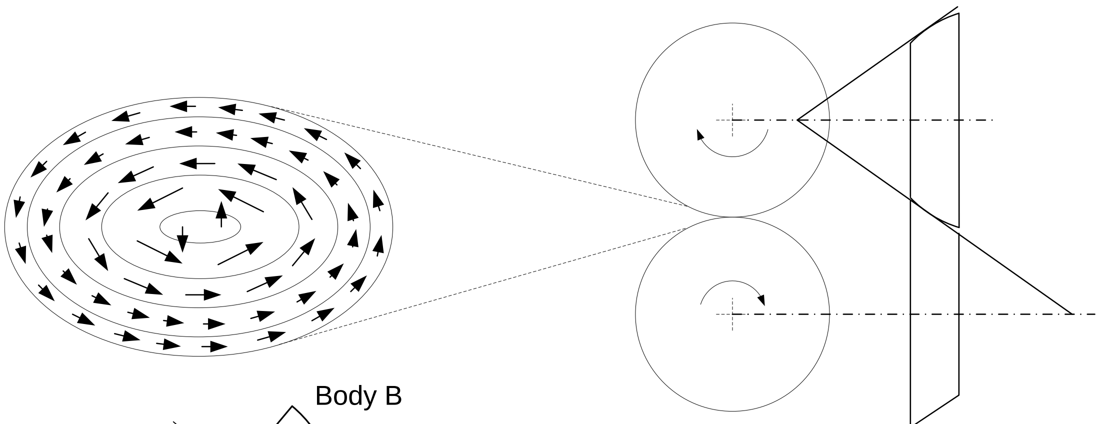
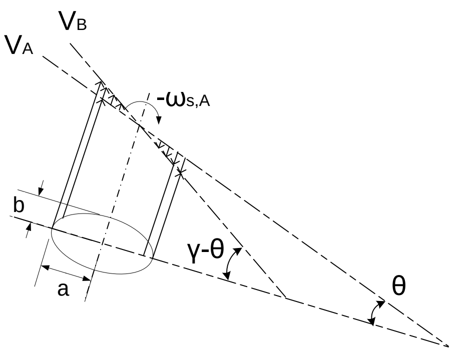
Model parameter: Spin, critical factor

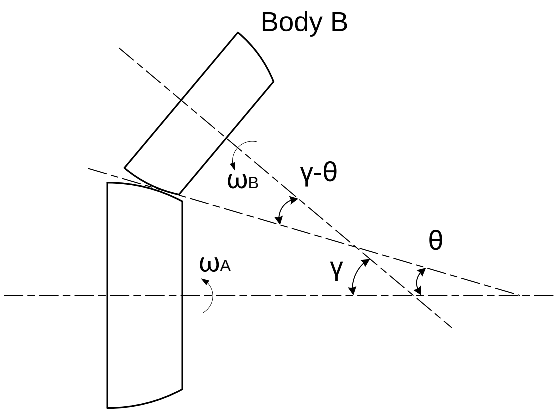
Spin:

“a difference in the angular velocity vector between the bodies in the direction normal to the contact”

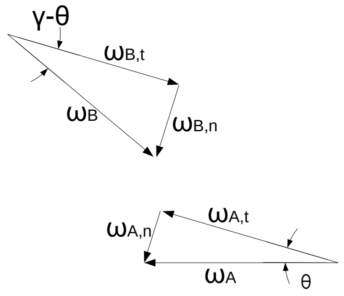




Spin contact pattern on roller A



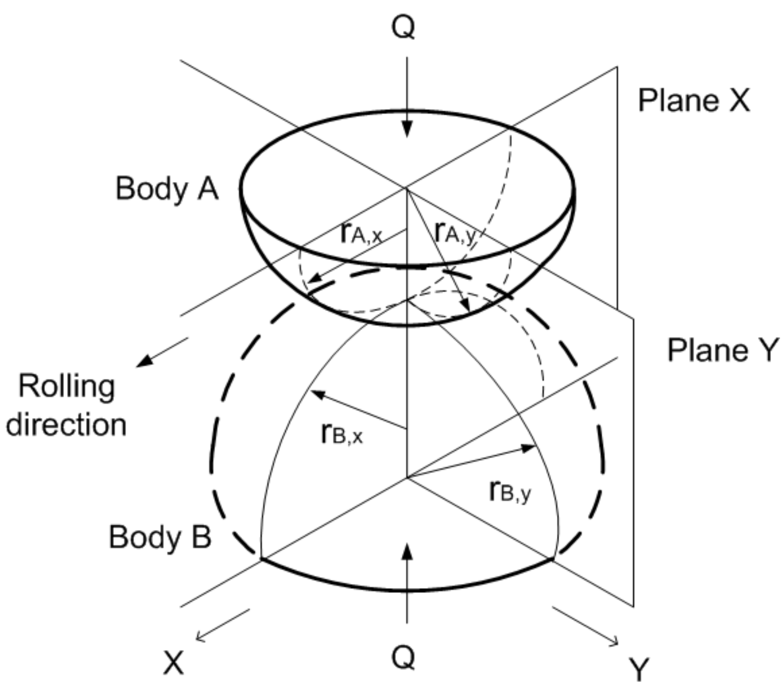
Contact geometry for spin calculations

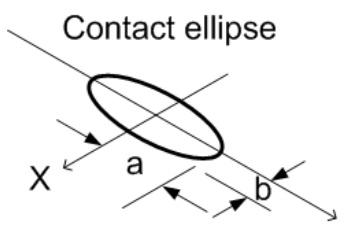


Angular velocity diagram

Model parameter: contact size and stress

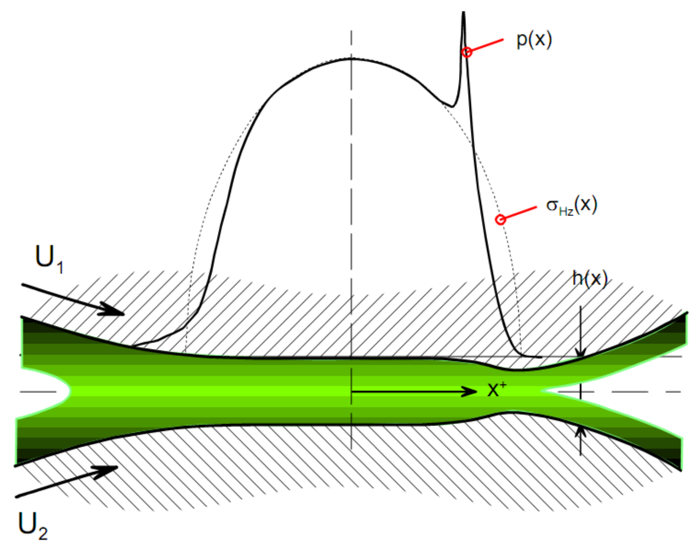
Hertzian contact





$$k = \frac{a}{b}$$

Film thickness



$$H_c = 2.69 U^{0.67} G^{0.53} W^{-0.067} (1 - 0.61 e^{-0.73k})$$

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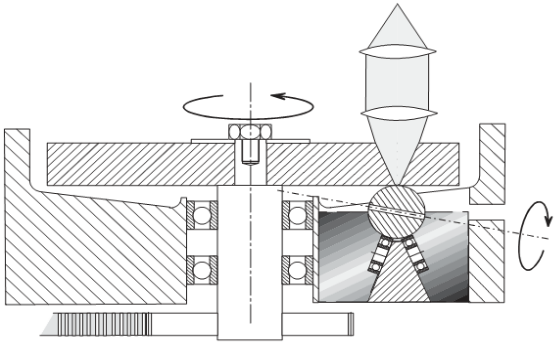
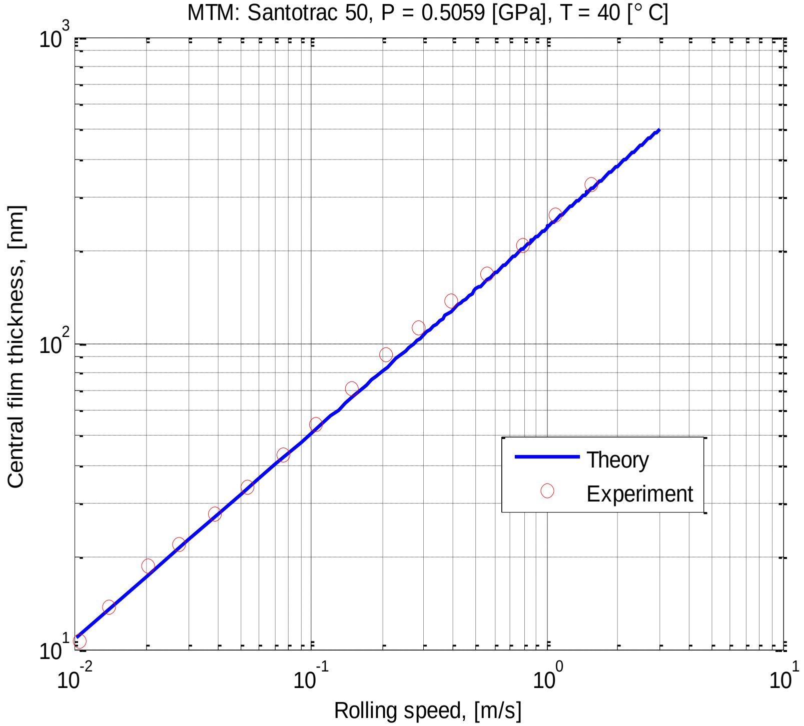
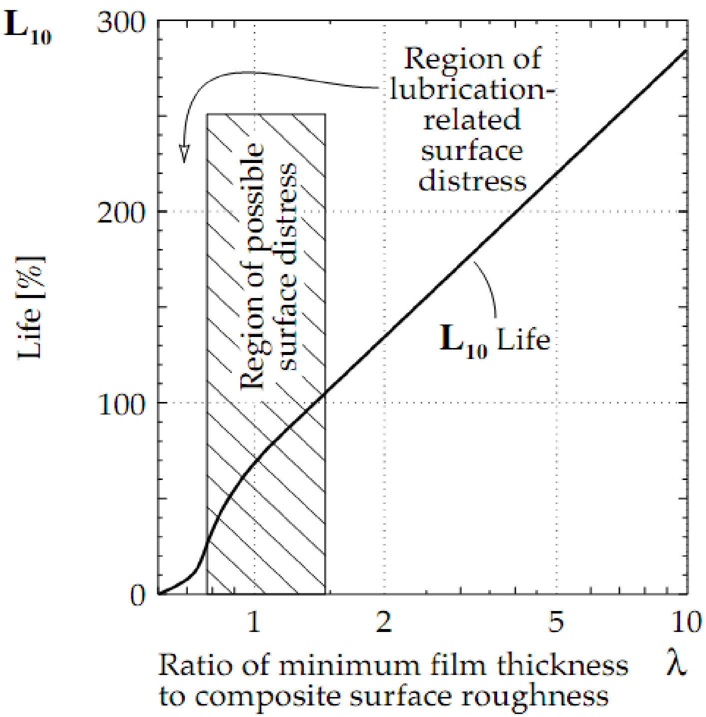
Modeling: film thickness and surface roughness







$$\lambda = \frac{h_c}{\sqrt{\sigma_A^2 + \sigma_B^2}}$$

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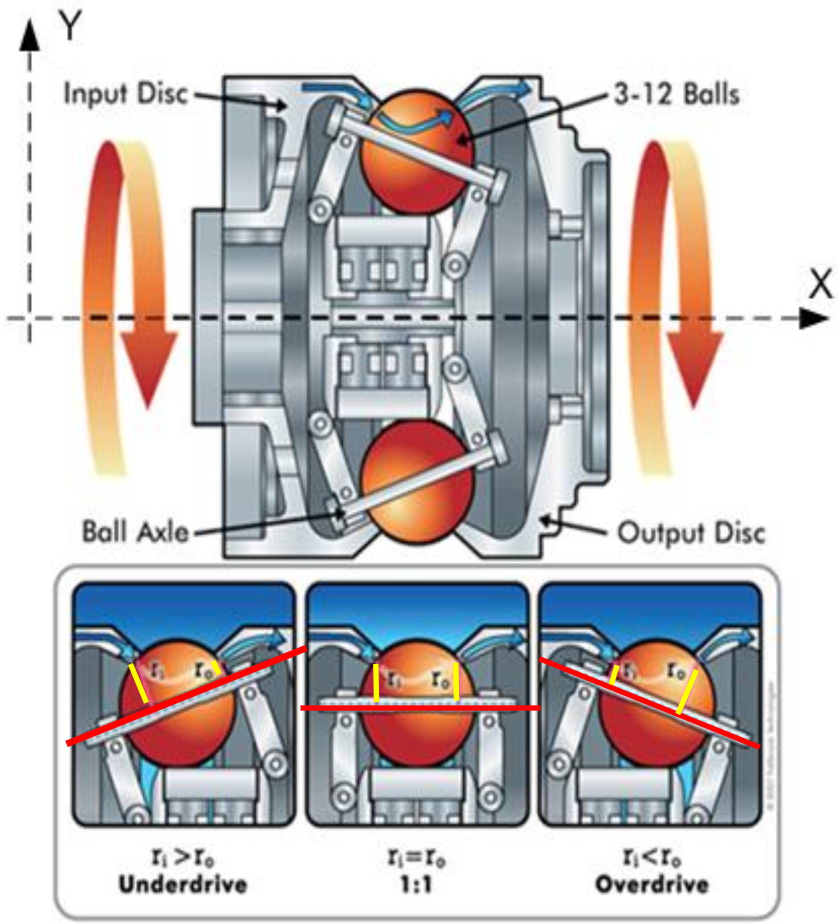
NuVinci analysis: Introduction

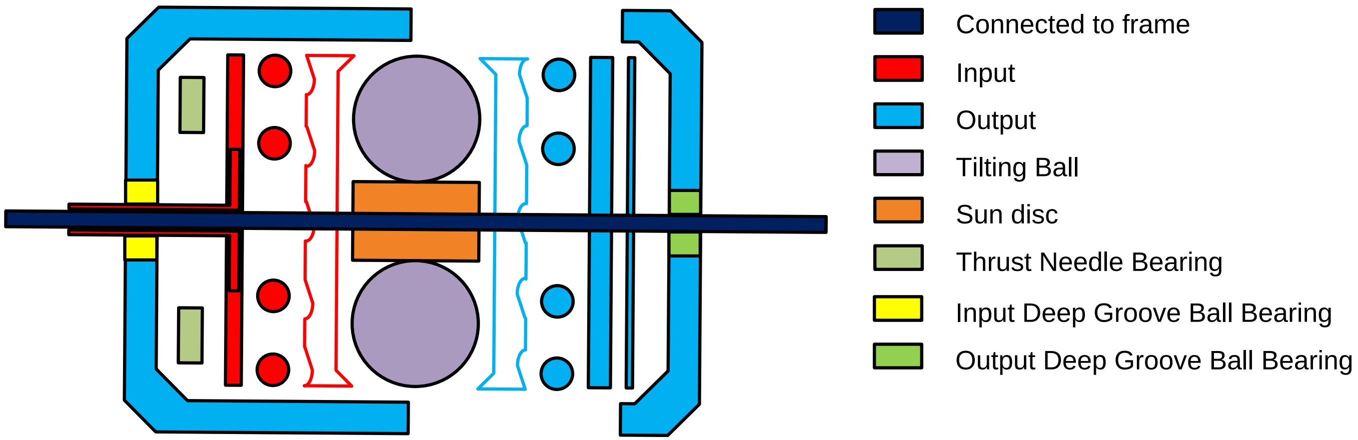
The NuVinci hub is a new concept introduced in 2007:

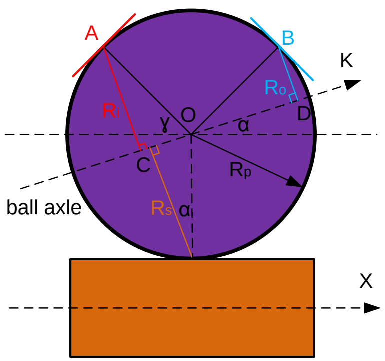
- Simple
- Compact
- Continuous shifting
- Non-hydraulic

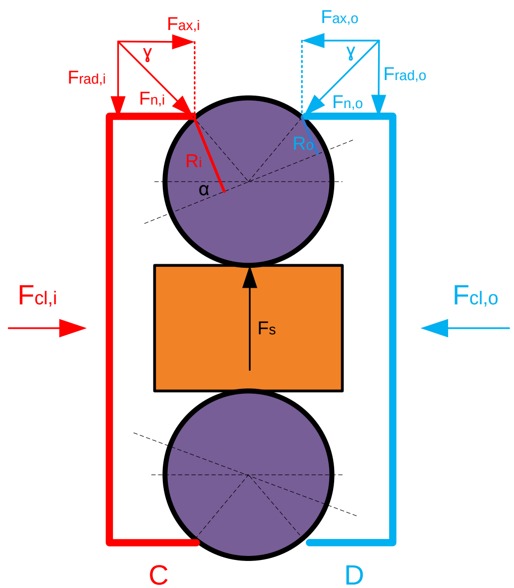
Batavus' bike catalog 2012: Vivente NuVinci

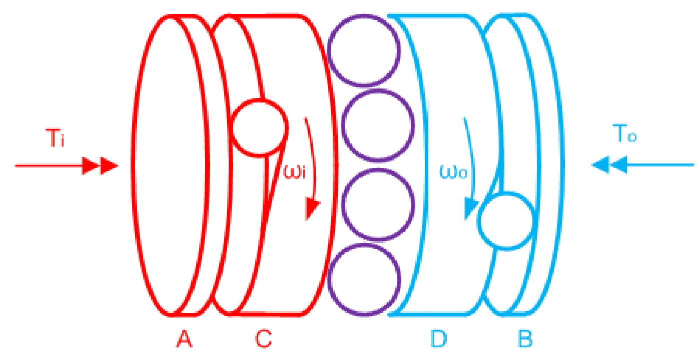


NuVinci analysis: geometry and force









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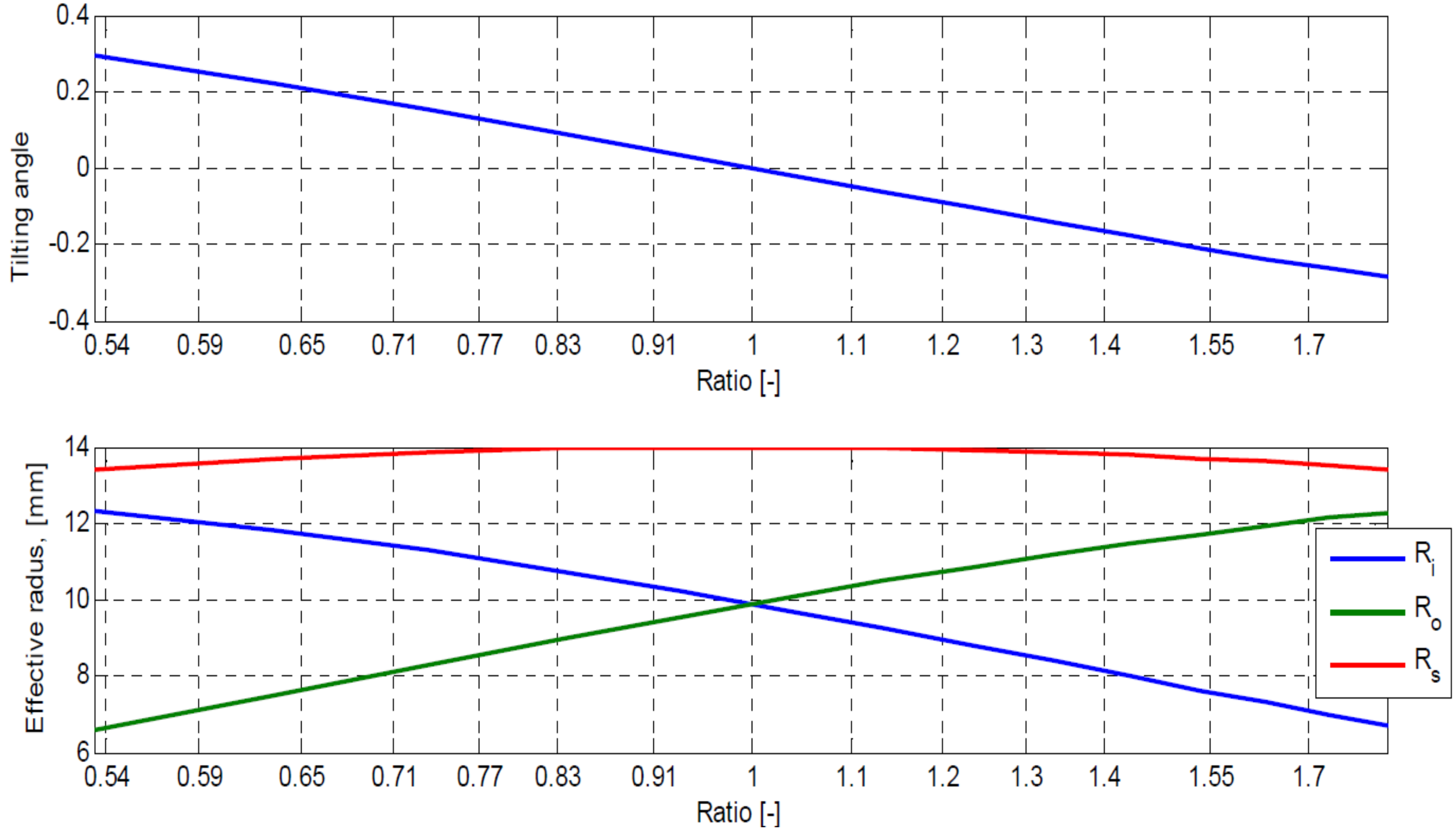
NuVinci analysis: ratio and tilting angle



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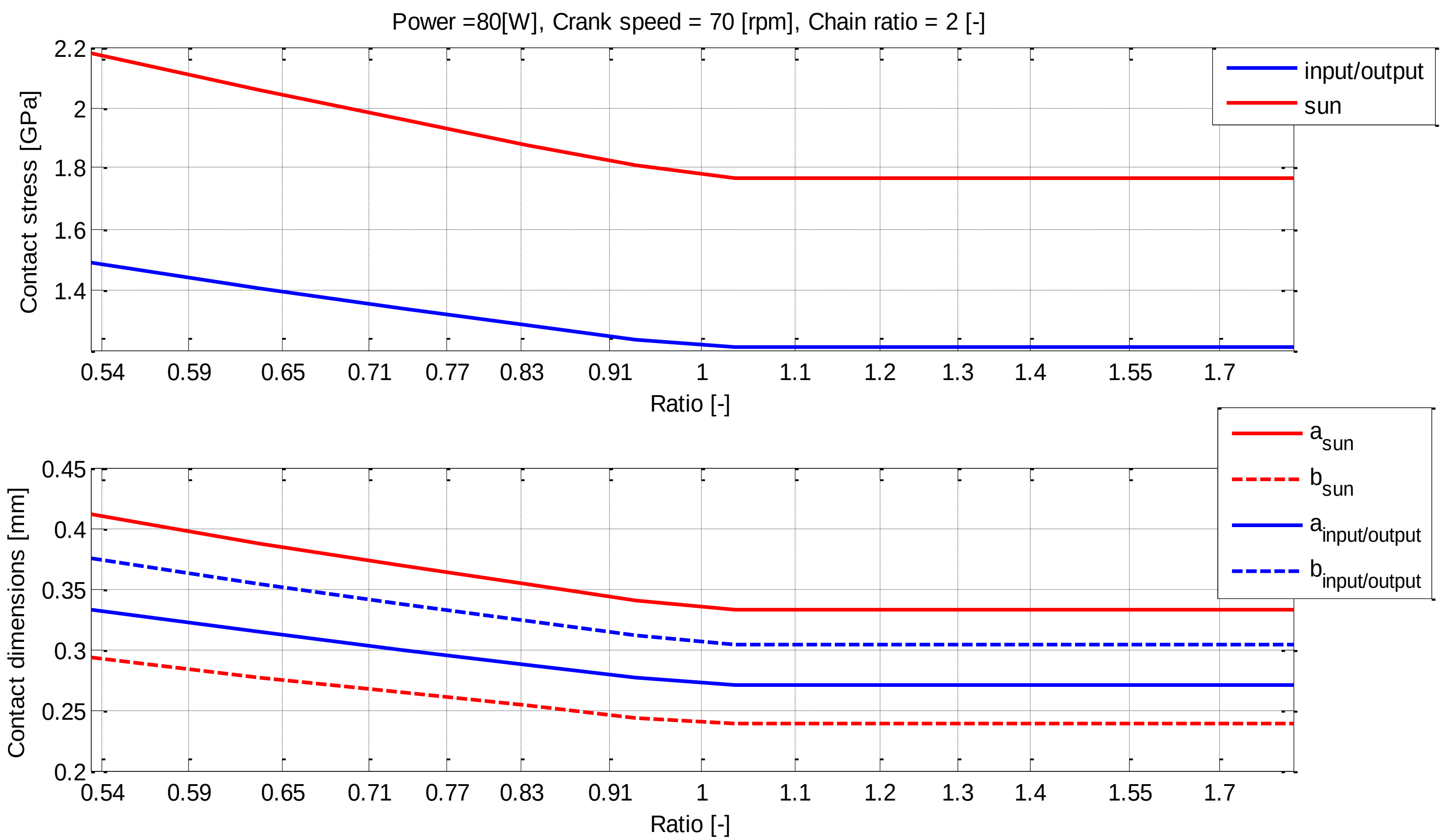
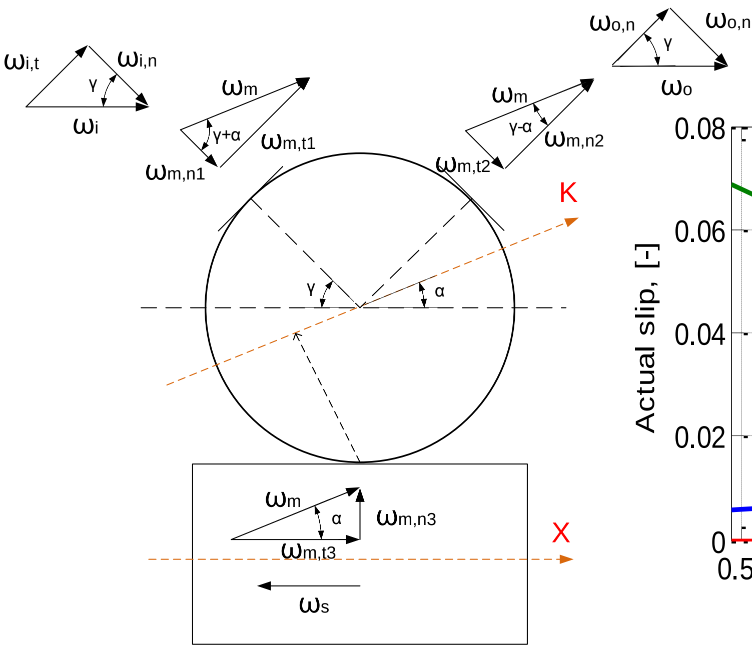
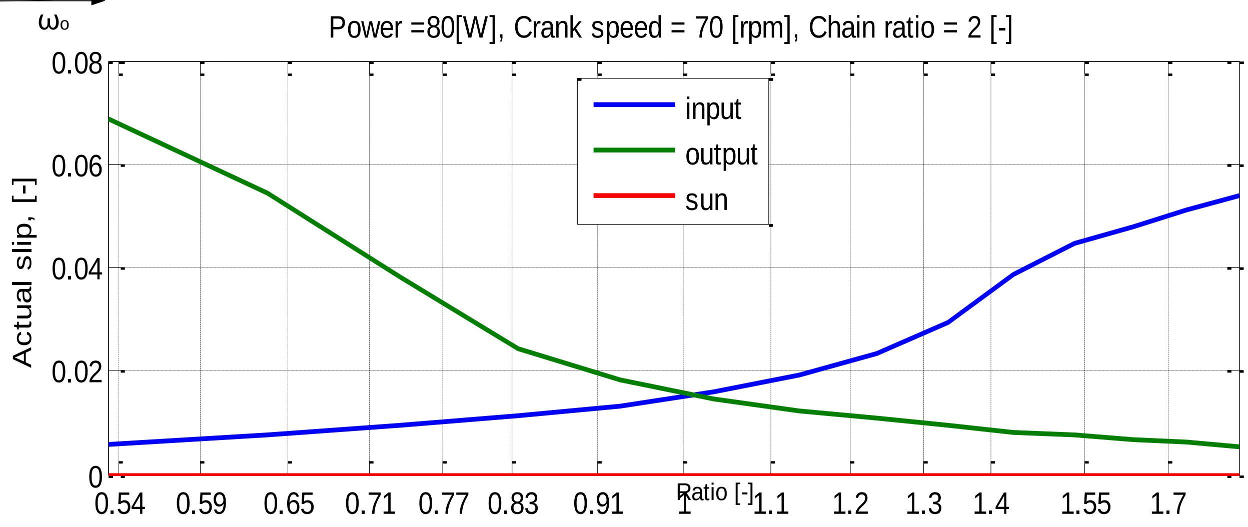
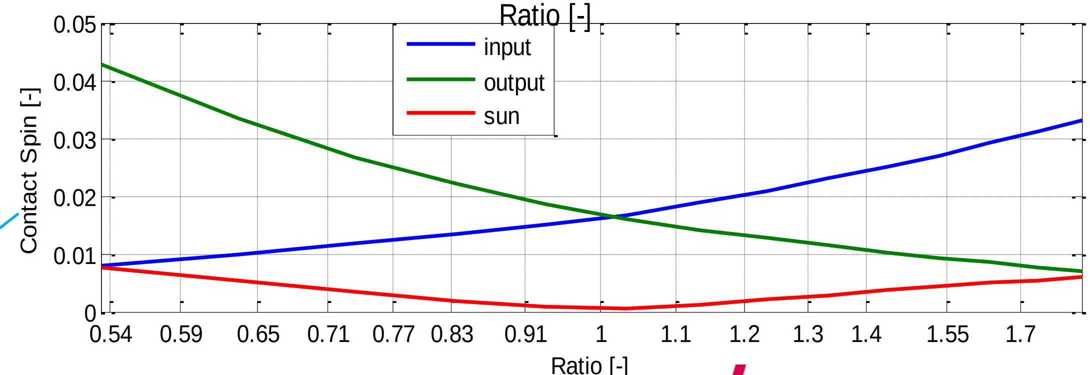
NuVinci analysis: contact stress and size



NuVinci analysis: Spin and slip

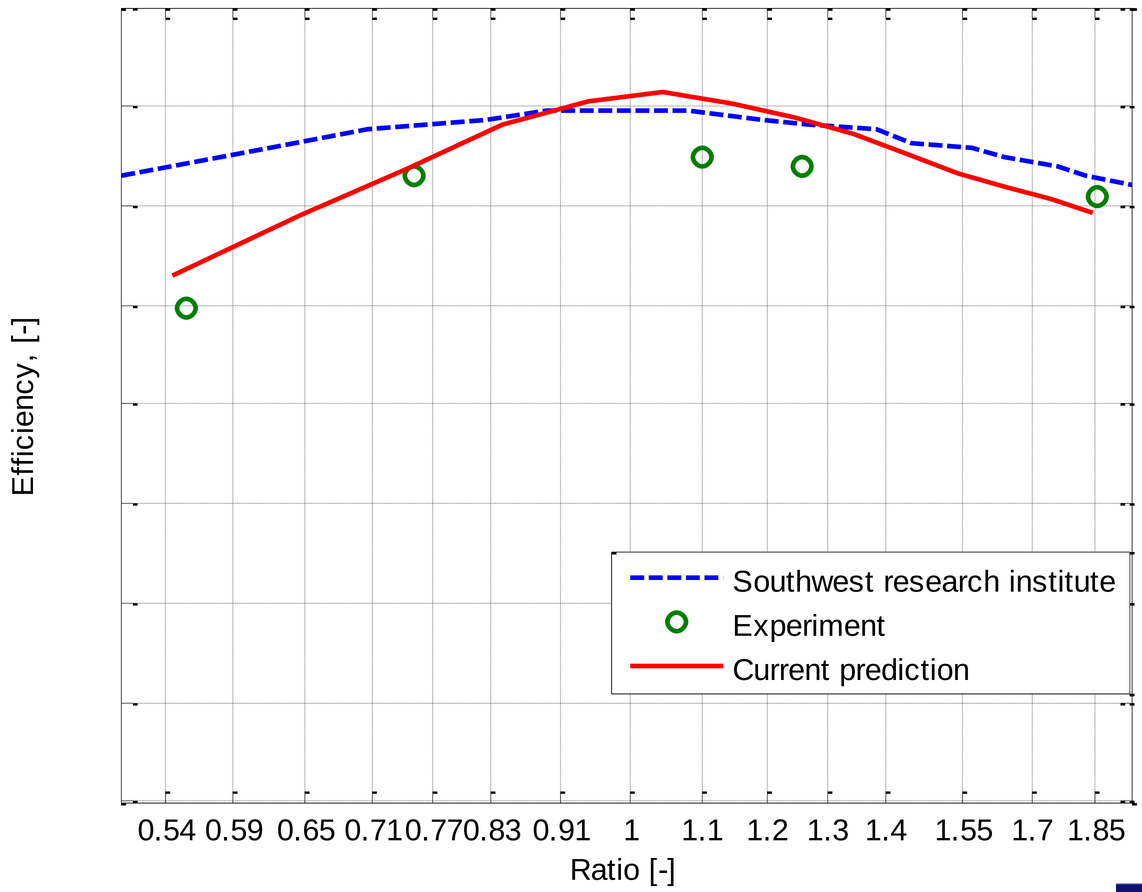




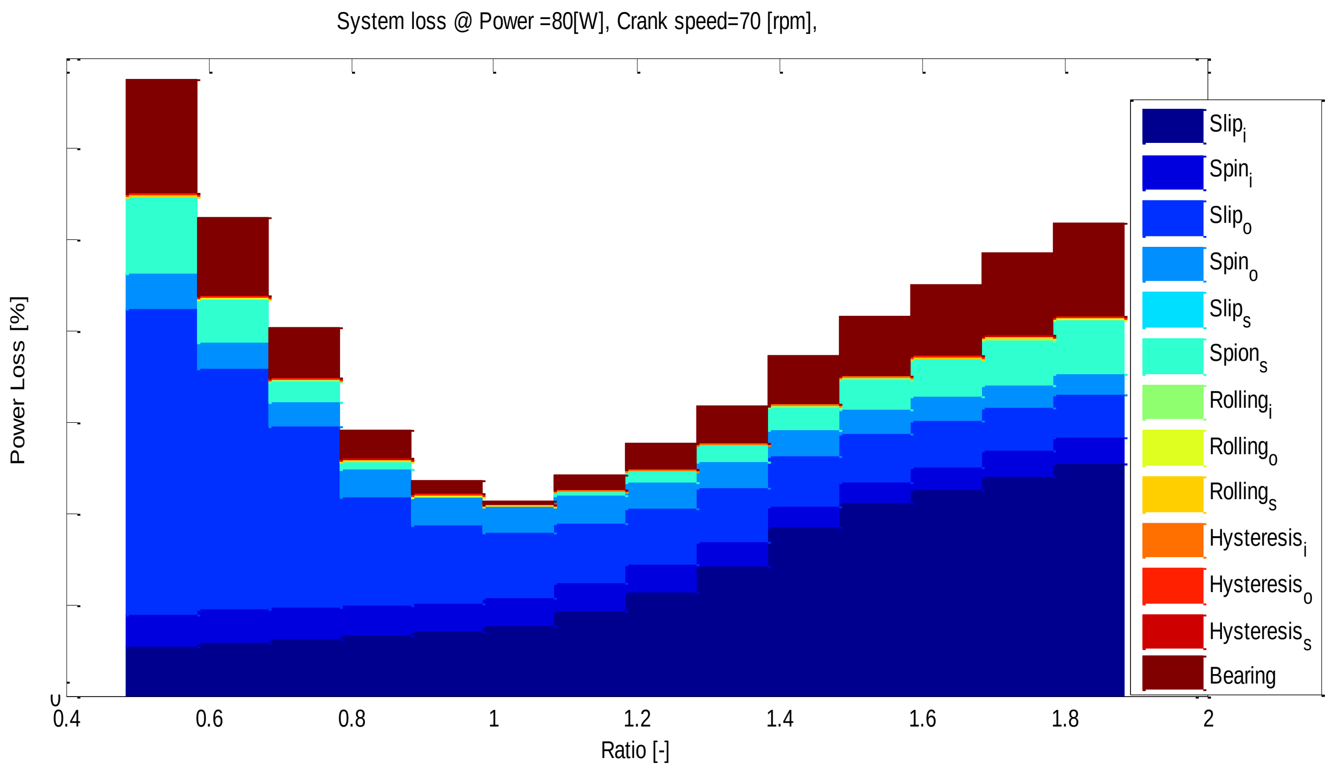


$\frac{\omega_s \sqrt{ab}}{U}$, non-dimensional

NuVinci analysis: system efficiency



NuVinci analysis: system efficiency



NuVinci analysis: Conclusion

- **Slip losses are the main source of system losses;**
- **However, they are very sensitive to contact spin level;**

➢**Thus eliminating the spin on contact interface is the key point to improve a traction drive efficiency.**

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Questions?