

Università degli Studi di Modena e Reggio Emilia
Facoltà di Ingegneria Informatica
Corso di Laurea in Ingegneria Informatica

Sviluppo in ambiente Matlab e Simulink di modelli dinamici ridotti per un sistema CVT su macchine agricole

Relatore:

Prof. Roberto Zanasi

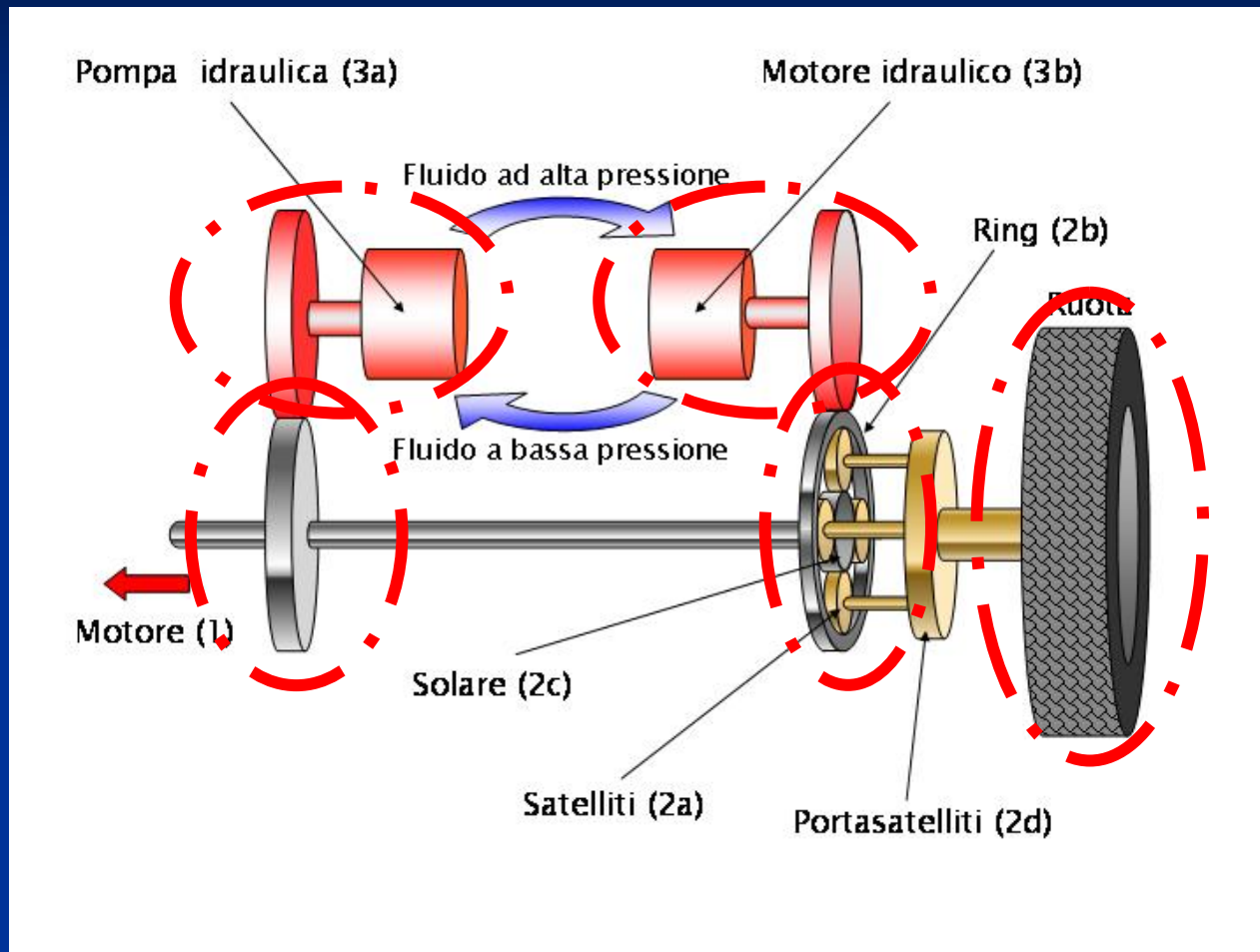
Correlatori:

Dott.ssa Ing. Federica Grossi

Tesi di Laurea di:

Walter Galati

Schema funzionale CVT



✓ Motore Endotermico

✓ Pompa Idraulica

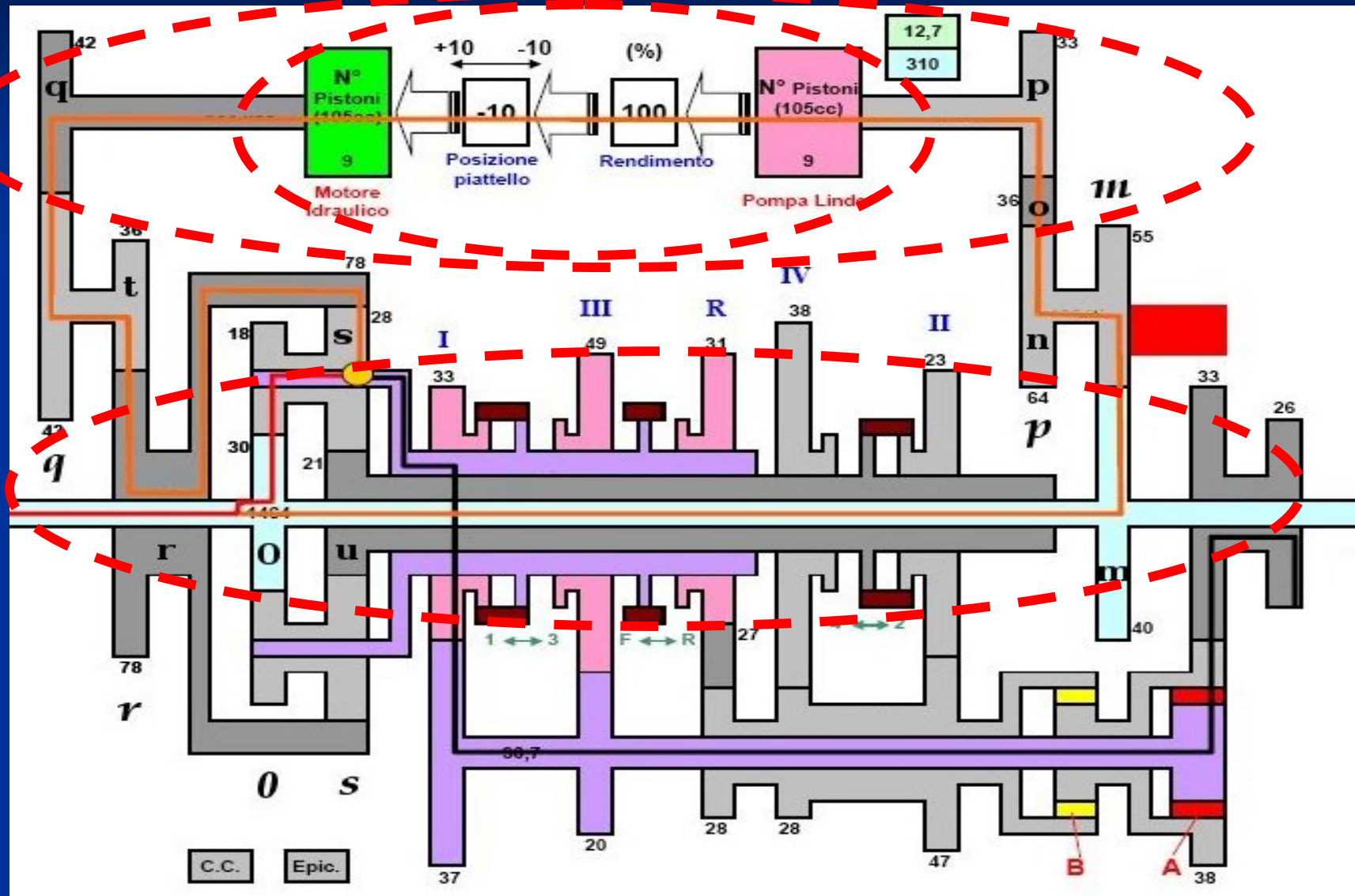
✓ Motore Idraulico

✓ Gruppo Epicicloidale

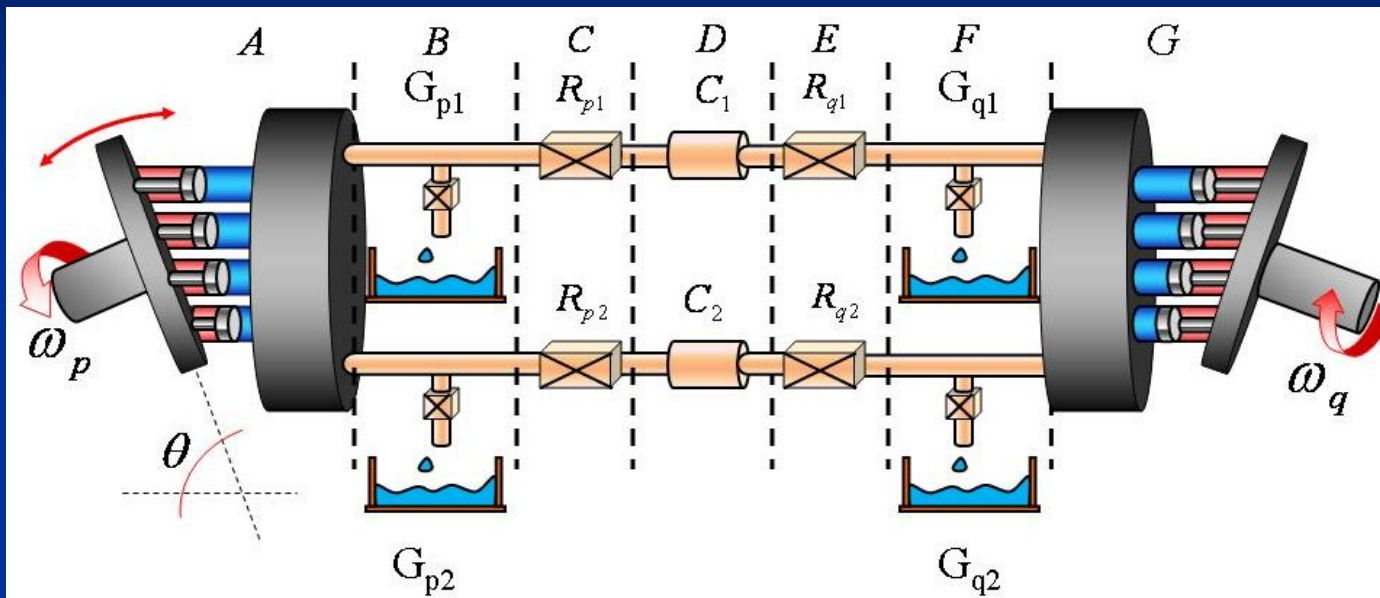
✓ Ruota

(Continuously Variable Transmission)

Schema Reale del Sistema CVT



Semplificazione Schema Idraulico



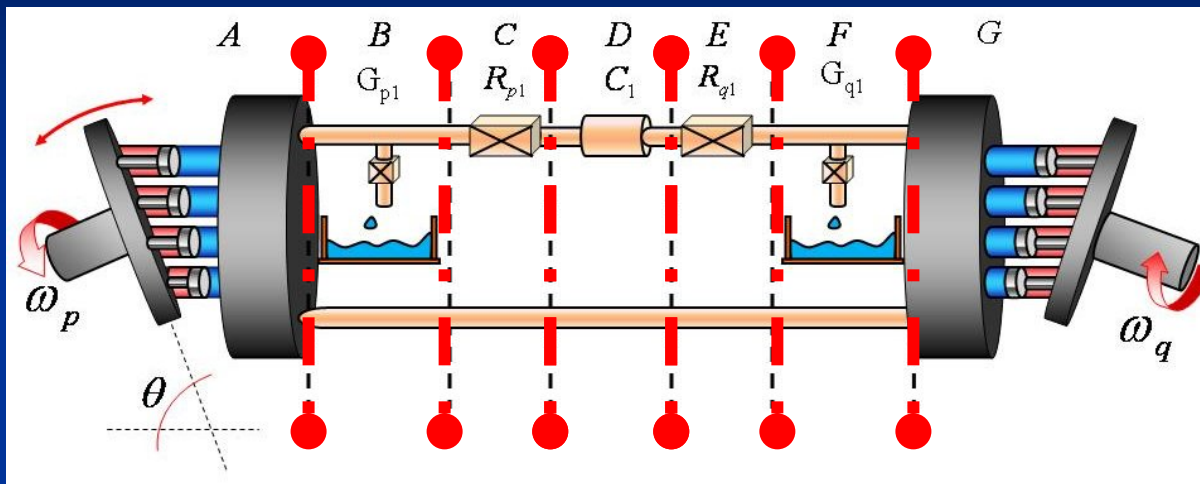
Circuito
Idraulico

La matrice trasformata T permette di ridurre il circuito idraulico da due ad una dimensione

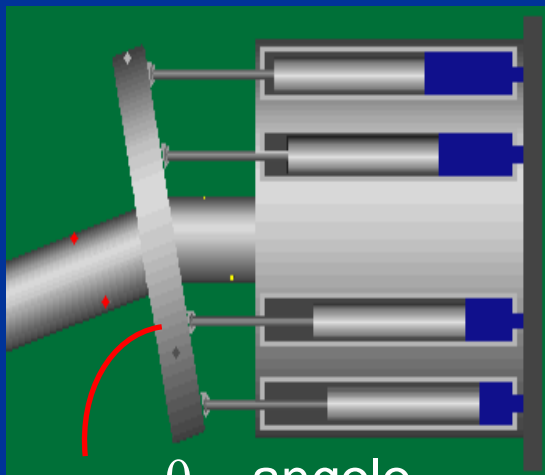
$$\begin{bmatrix} P_d \\ P_s \end{bmatrix} = \begin{bmatrix} 1 & -1 \\ \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = \begin{bmatrix} P_1 - P_2 \\ \frac{(P_1 + P_2)}{2} \end{bmatrix}$$

$$T = \begin{bmatrix} \frac{1}{2} & 1 \\ -\frac{1}{2} & 1 \end{bmatrix}$$

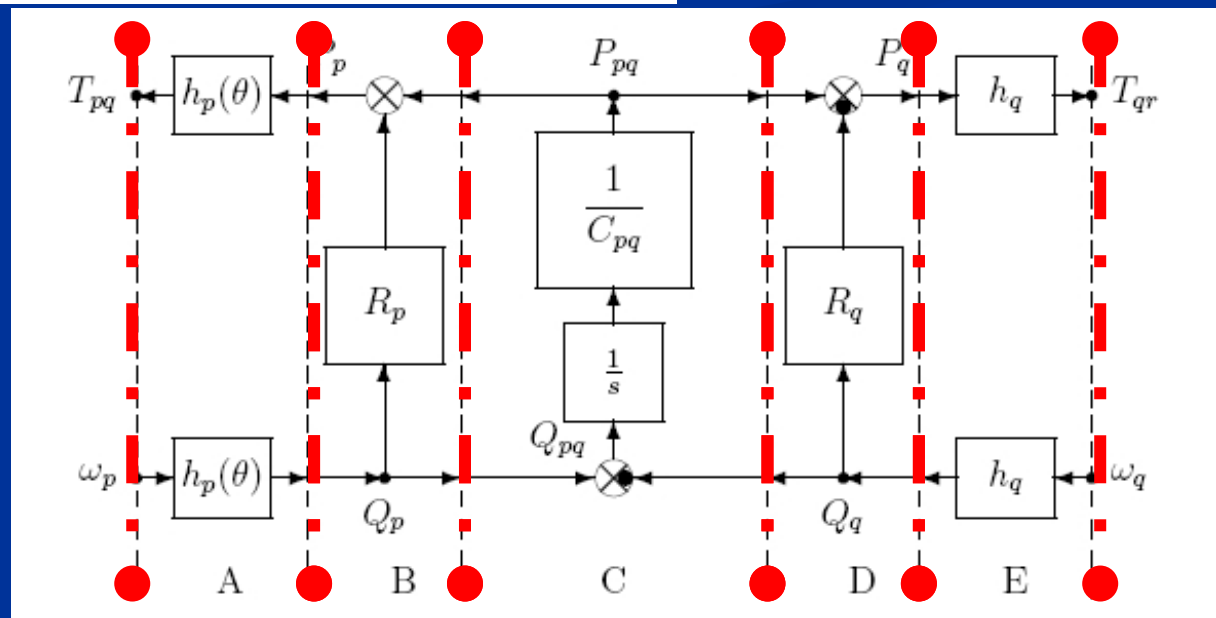
Schema POG Semplificato



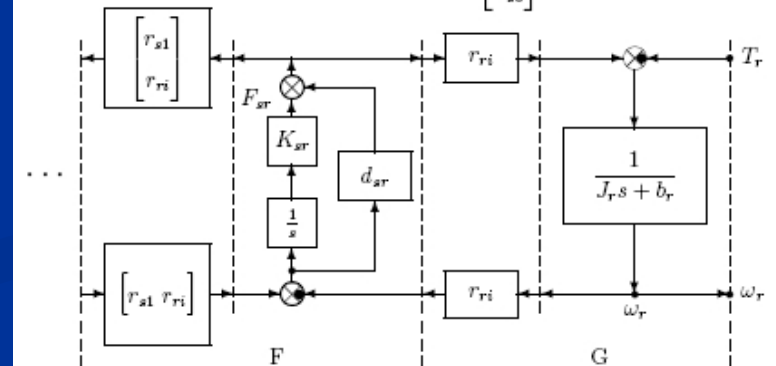
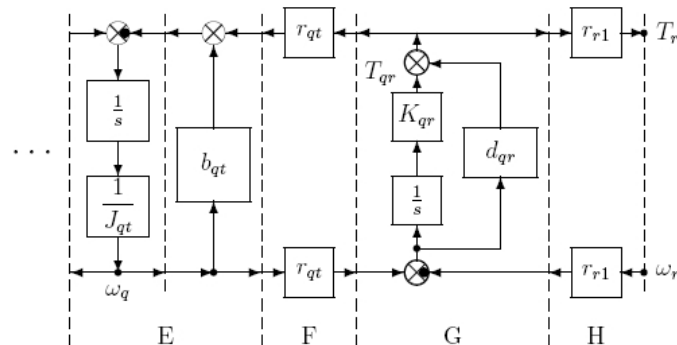
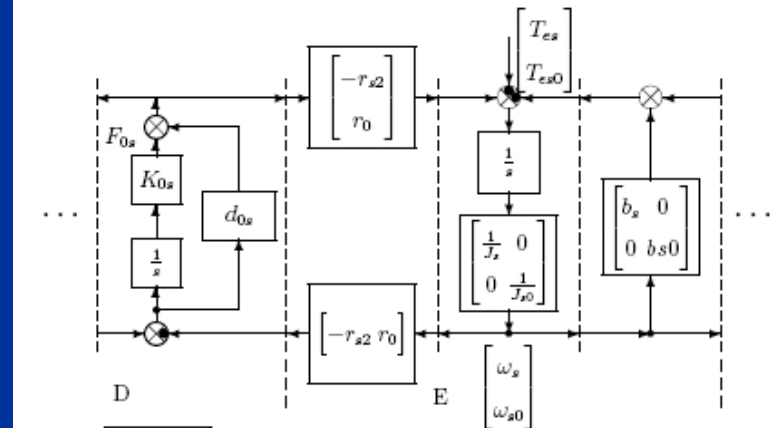
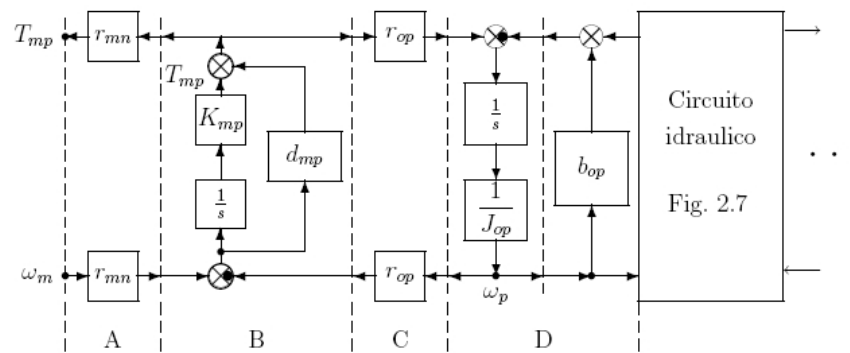
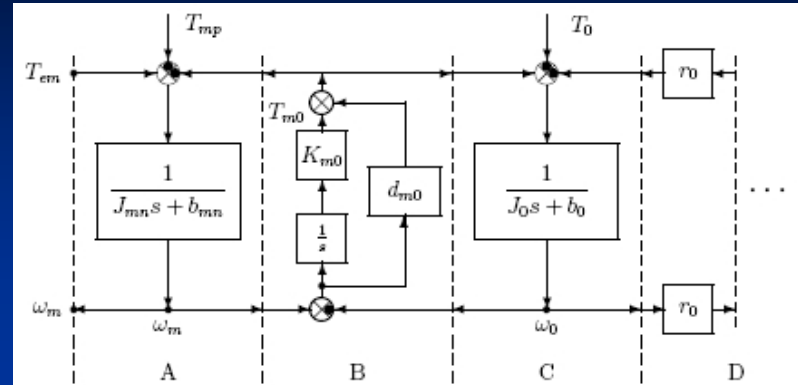
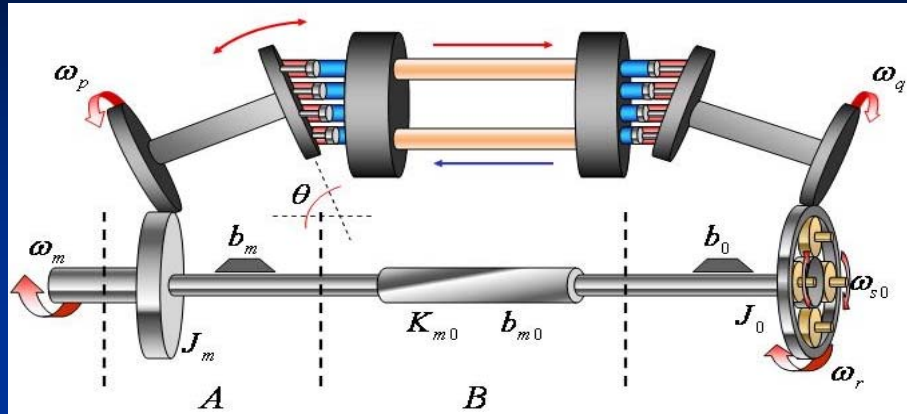
Circuito Idraulico Semplificato



θ = angolo
piattello



Schema POG Completo



Riduzione del Sistema

Relazione descrittiva degli schemi a blocchi nello spazio degli stati

$$L \dot{x} = A x + B u$$

$$\begin{bmatrix} \omega_m \\ \omega_0 \\ \omega_s \\ \omega_{s0} \\ \omega_r \\ \omega_p \\ \omega_q \\ T_{m0} \\ F_{s0} \\ F_{sr} \\ T_{mp} \\ P_{pq} \\ T_{qr} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ \frac{h_p(\theta)r_0r_{mn}r_{qt}r_{ri}-h_qr_0r_{op}r_{r1}r_{ri}}{h_qr_0r_{op}r_{r1}r_{s1}+h_qr_{op}r_{r1}r_{ri}r_{s2}} \\ \frac{h_p(\theta)r_{mn}r_{qt}r_{ri}r_{s2}+h_qr_0r_{op}r_{r1}r_{s1}}{h_qr_{op}r_{r1}r_{s1}r_0+h_qr_{op}r_{r1}r_{ri}r_{s1}} \\ \frac{h_p(\theta)r_{mn}r_{qt}}{h_qr_{op}r_{r1}} \\ -\frac{r_{mn}}{r_{op}} \\ -\frac{h_p(\theta)r_{mn}}{h_qr_{op}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad \omega_m, \leftrightarrow \tilde{x} = \mathbf{T}_t \omega_m$$

Trasformazione in coordinate applicata al sistema

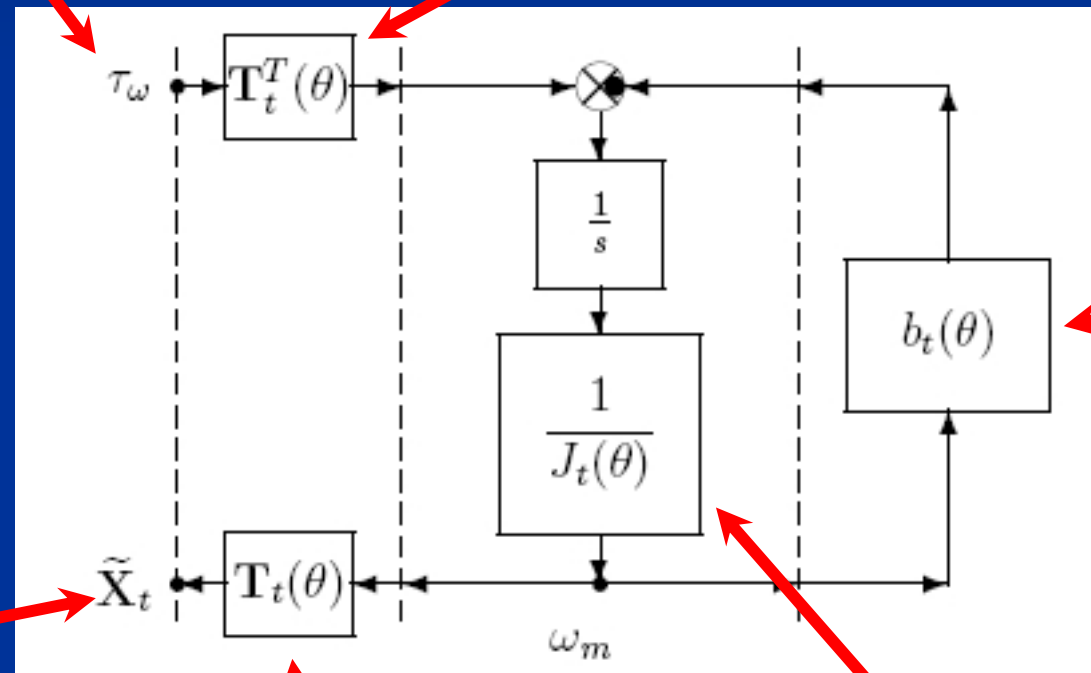
Sistema Trasformato Ridotto

$$J_t(\theta) \dot{\omega}_m = -b_t(\theta) \omega_m + \mathbf{T}_t^T \tau_\omega$$

Sistema Ridotto CVT

Vettore di Stato
Coniugato in Potenza

Matrice Trasposta
di Trasformazione



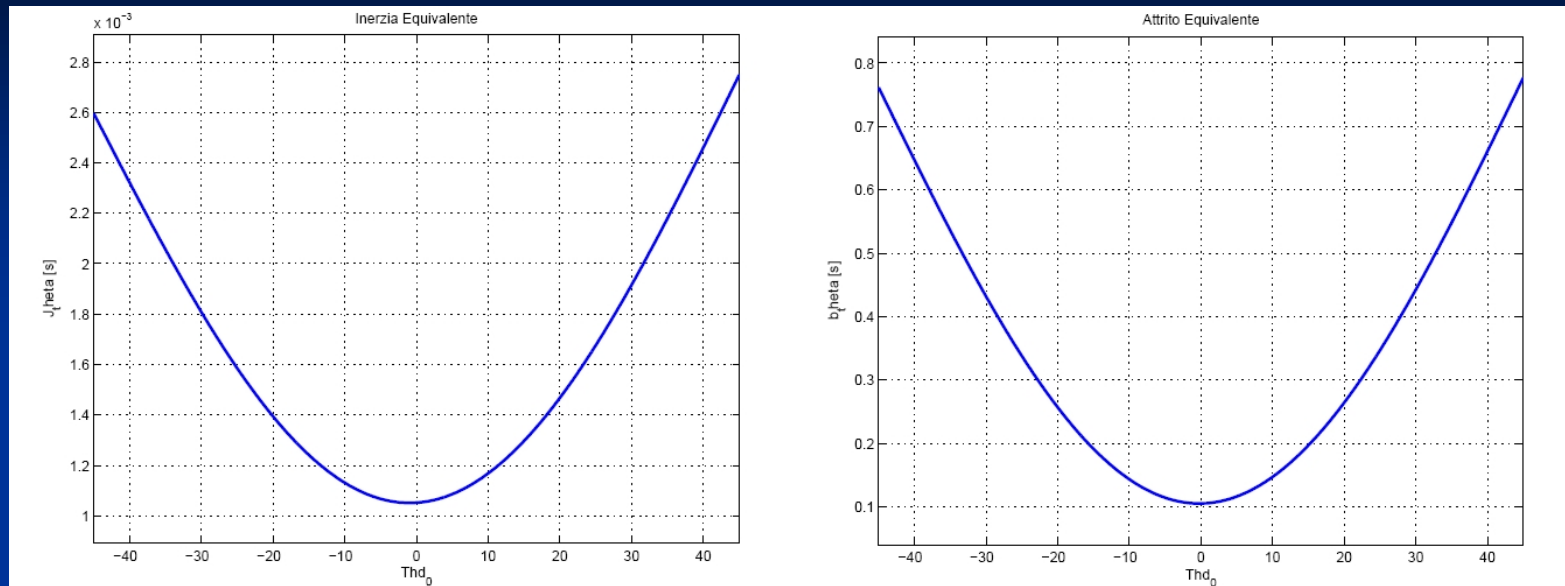
Coefficiente
di Attrito
Equivalente

Vettore di
Stato

Matrice di
Trasformazione

Coefficiente di Inerzia
Equivalente

Inerzia e Attrito equivalente



$$J_t(\theta) = J_0 + J_{mn} + \frac{J_{op} r_{mn}^2}{r_{op}^2} + \frac{(h_p(\theta))^2 J_{qt} r_{mn}^2}{h_q^2 r_{op}^2} + \frac{(h_p(\theta))^2 J_r r_{mn}^2 r_{qt}^2}{h_q^2 r_{op}^2 r_{r1}^2} +$$

$$+ \frac{J_s (h_q r_0 r_{op} r_{r1} r_{ri} - h_p(\theta) r_0 r_{mn} r_{qt} r_{ri})^2}{(h_q r_0 r_{op} r_{r1} r_{s1} + h_q r_{op} r_{r1} r_{ri} r_{s2})^2} + \frac{J_{s0} (h_q r_0 r_{op} r_{r1} r_{s1} + h_p(\theta) r_{mn} r_{qt} r_{ri} r_{s2})^2}{(h_q r_0 r_{op} r_{r1} r_{s1} + h_q r_{op} r_{r1} r_{ri} r_{s2})^2}$$

$$b_t(\theta) = \frac{1}{(h_q^2 r_{op}^2 r_{r1}^2 (r_0 r_{s1} + r_{ri} r_{s2})^2)} (b_s r_0^2 r_{ri}^2 (h_q r_{op} r_{r1} - h_p(\theta) r_{mn} r_{qt})^2 + b_0 h_q^2 r_{op}^2 r_{r1}^2$$

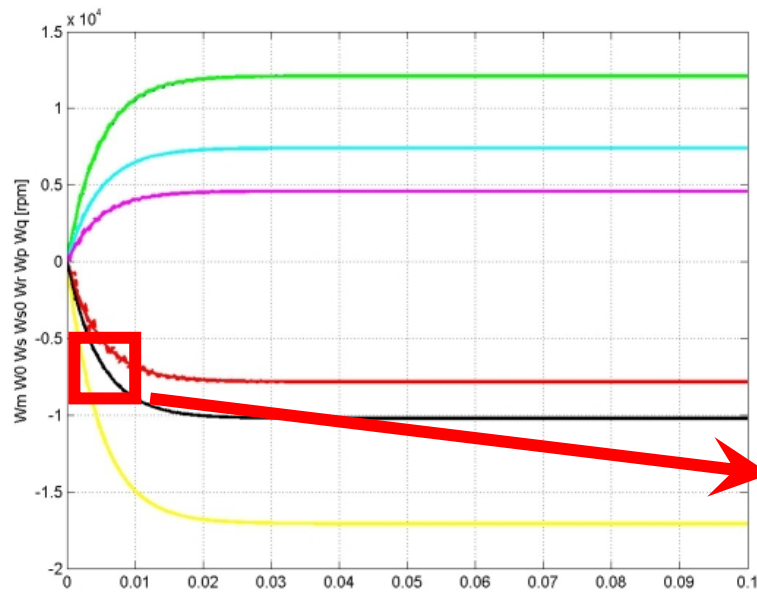
$$(r_{s2} r_{ri} + r_{s1} r_0)^2 + b_{s0} (h_q r_{op} r_{r1} r_{s1} r_0 + h_p(\theta) r_{mn} r_{qt} r_{ri} r_{s2}) +$$

$$R_p h_p(\theta)^2 r_{mn}^2 r_{r1}^2 h_q^2 (r_{s2} r_{ri} + r_{s1} r_0)^2 + R_q h_p(\theta)^2 r_{mn}^2 r_{r1}^2 h_q^2 (r_{s2} r_{ri} +$$

$$r_{s1} r_0)^2 + b_{qt} h_p(\theta)^2 r_{mn}^2 r_{r1}^2 (r_{s2} r_{ri} + r_{s1} r_0)^2 + b_r h_p(\theta)^2 r_{mn}^2 r_{qt}^2 (r_{s2} r_{ri} +$$

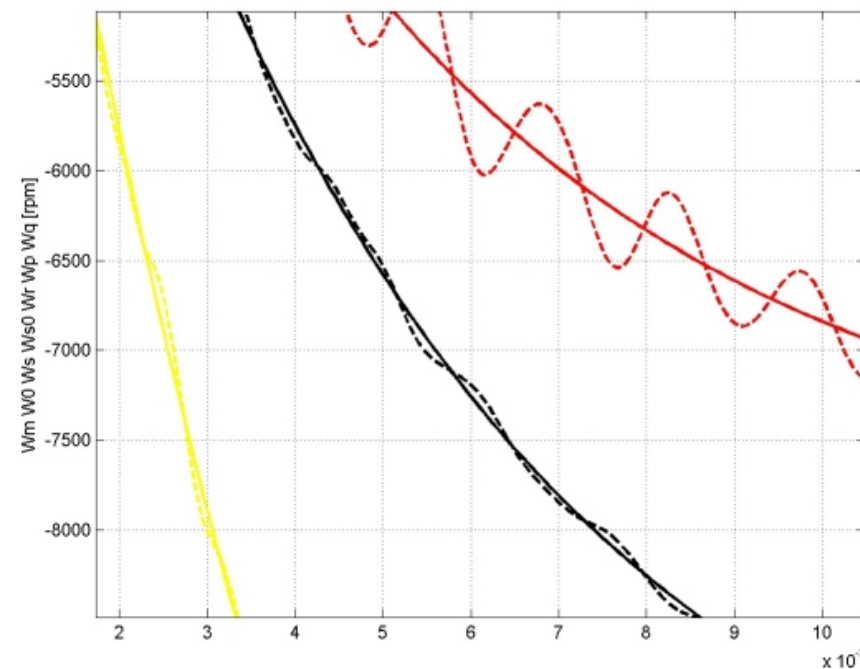
$$r_{s1} r_0)^2 + b_{mn} h_q^2 r_{op}^2 r_{r1}^2 (r_{s2} r_{ri} + r_{s1} r_0)^2 + b_{op} h_q^2 r_{mn}^2 r_{r1}^2 (r_{s2} r_{ri} + r_{s1} r_0)^2)$$

Simulazioni con θ Costante

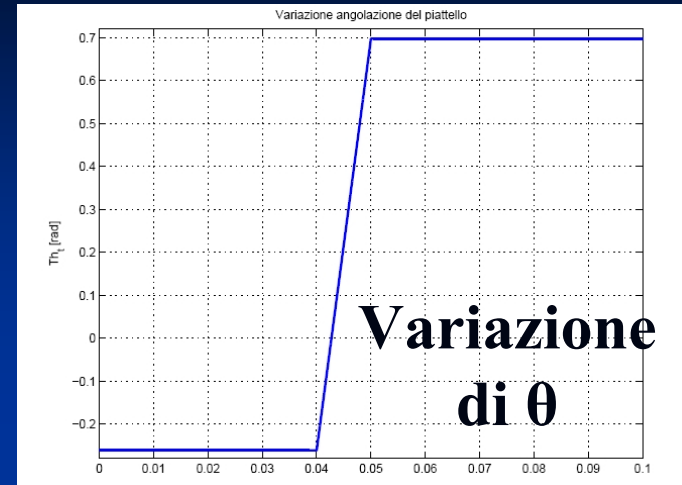
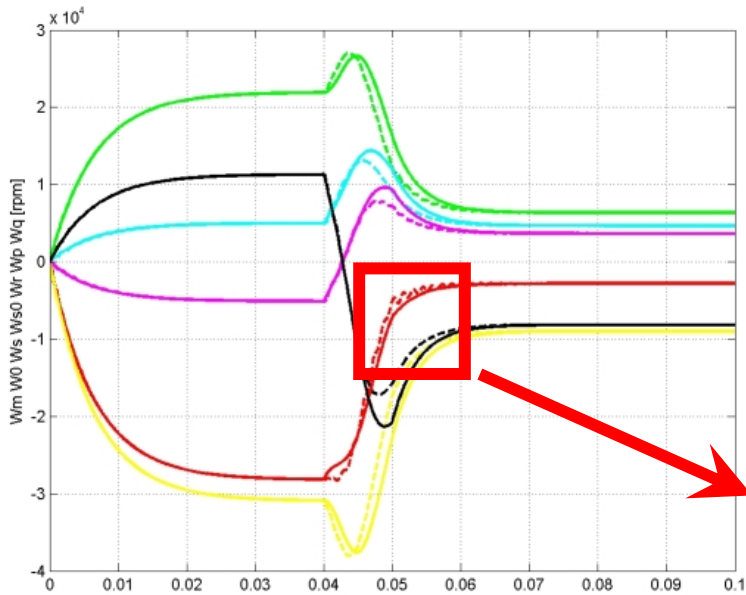


Confronto
Schema Ridotto
e Schema Reale

Particolare del
Confronto



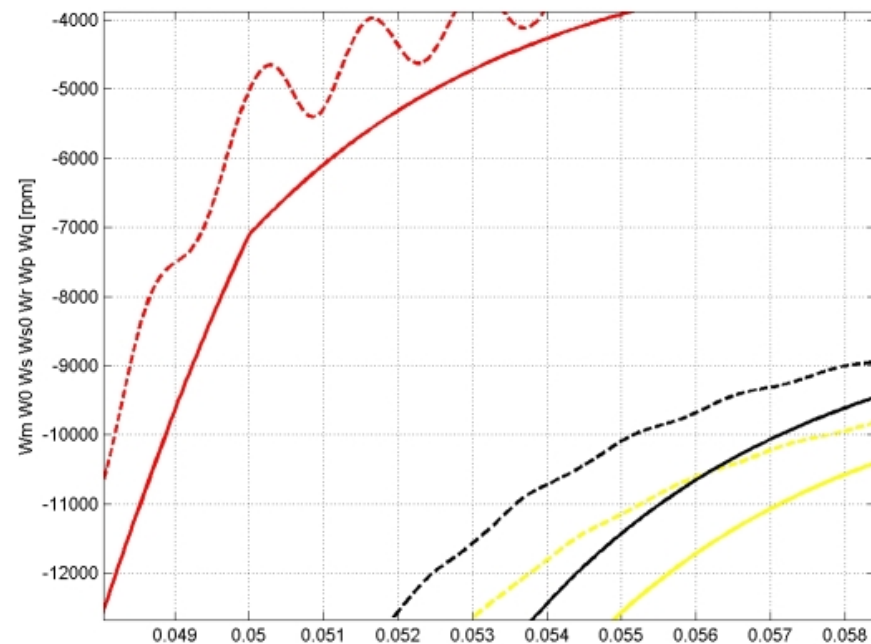
Simulazioni con θ variabile



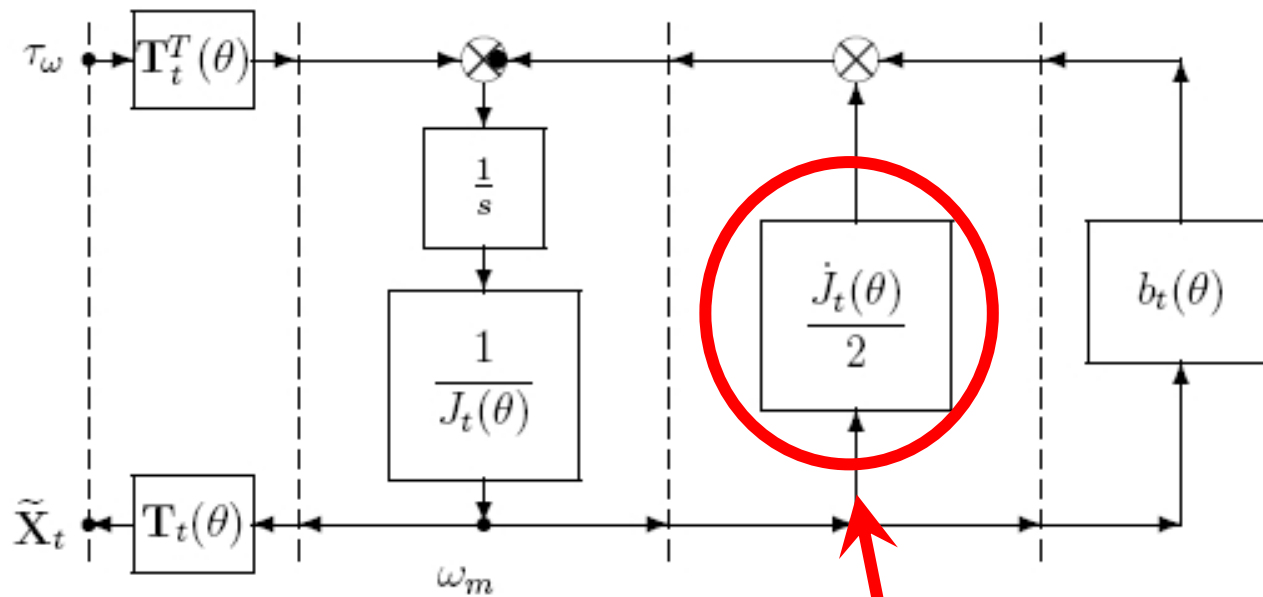
**Variazione
di θ**

**Confronto
Schema Ridotto
e Schema Reale**

**Particolare del
Confronto**

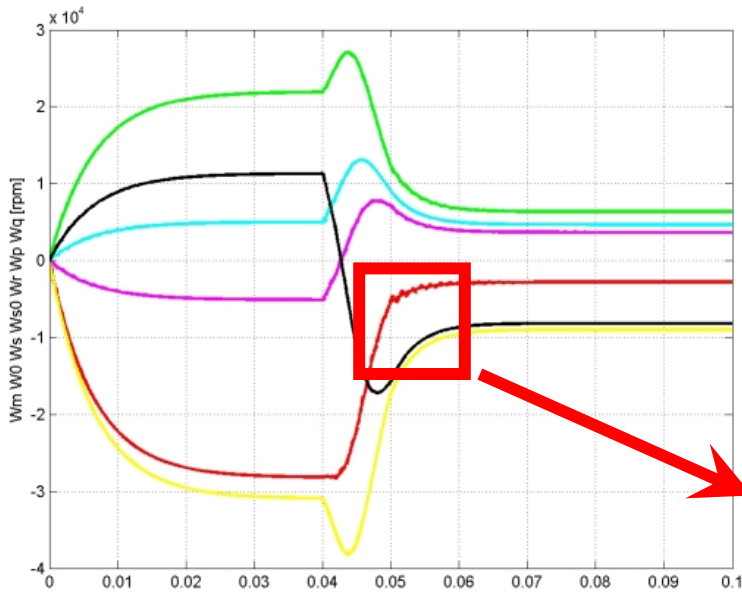


Sistema Ridotto Completo



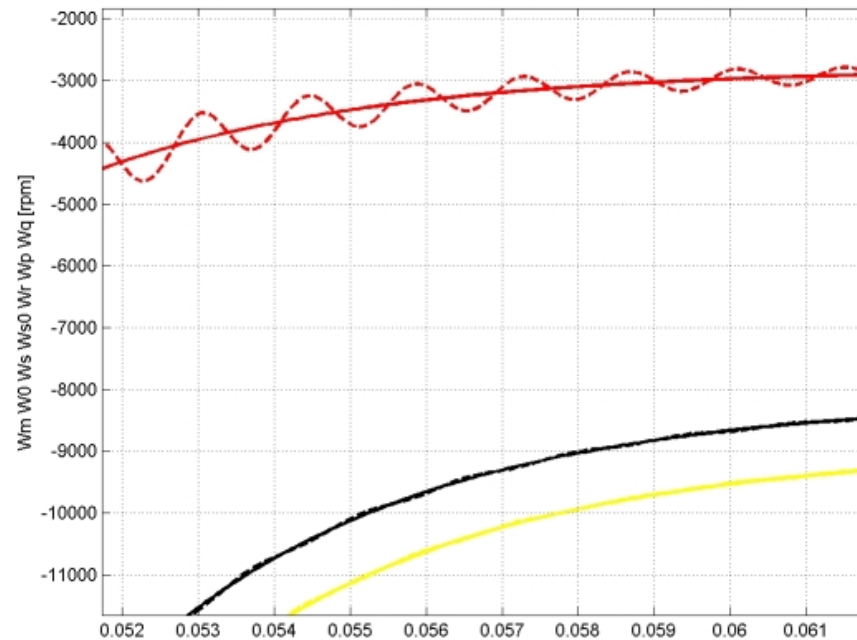
$$\frac{d}{d(\theta)}(J_t(\theta)\dot{\omega}_m) = \tau_\omega \mathbf{T}_t^T + \frac{\dot{J}_t(\theta)\dot{\omega}_m}{2} + b_t(\theta)\dot{\omega}_m$$

Simulazioni con θ variabile

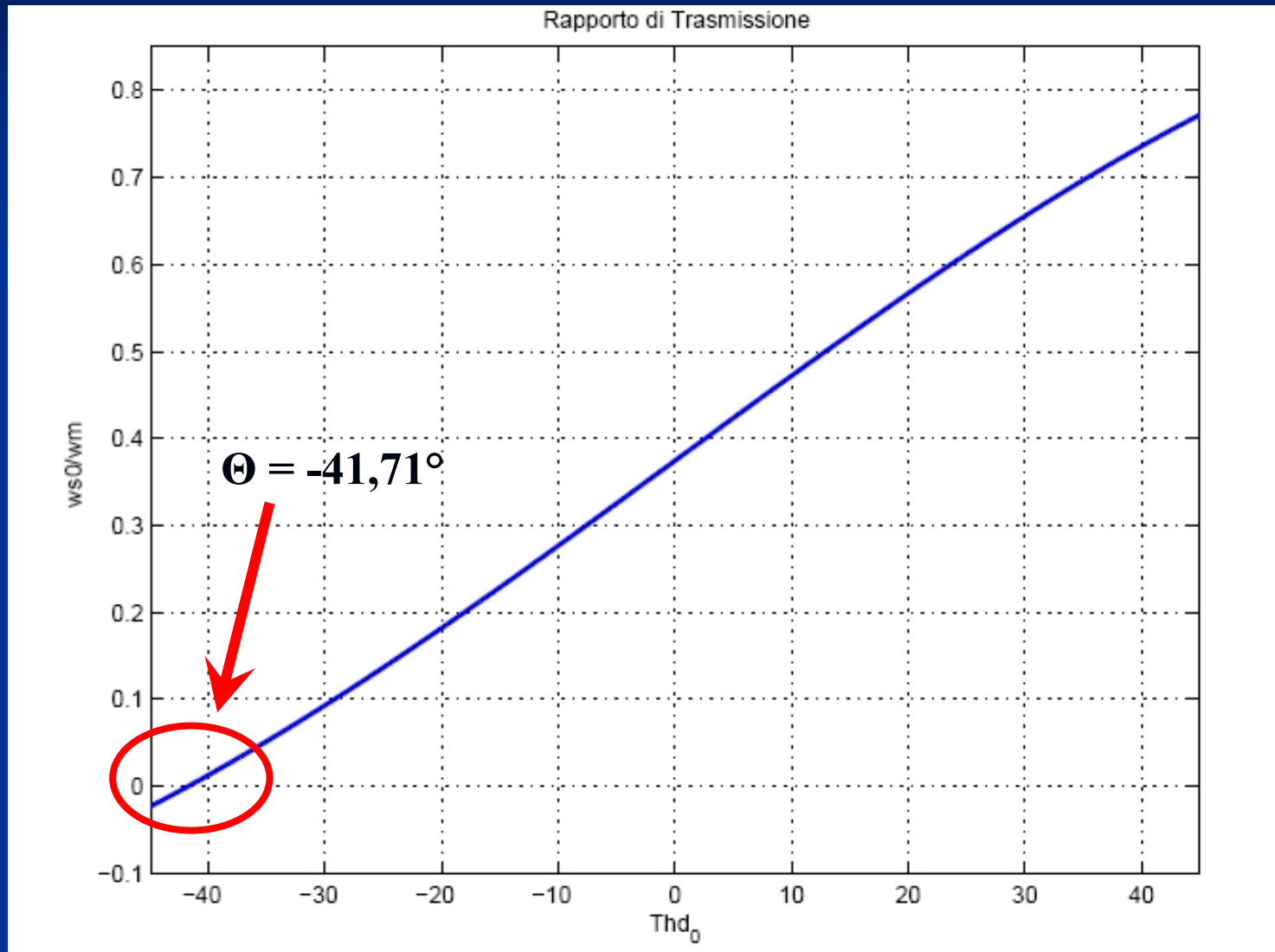


**Confronto
Schema Ridotto
e Schema Reale**

**Particolare del
Confronto**



Rapporto di Trasmissione



Conclusioni

- ✓ **Ottimizzazione circuito idraulico**
- ✓ **Realizzazione del modello dinamico e del modello dinamico ridotto del sistema CVT in ambiente Matlab e Simulink**