

Dipartimento di Ingegneria Meccanica e Industriale
Corso di Laurea Automazione Industriale



UNIVERSITÀ
DEGLI STUDI
DI BRESCIA

LABORATORIO DI ROBOTICA INDUSTRIALE E MACCHINE LABORATORIO DI AUTOMATICA

Docente: **Prof. Beschi Manuel**

Studenti: **Fares Peter William – 721654**
Mirandola Edoardo – 723993
Pennacchio Manuele – 721965

Anno Accademico 2022-2023



1

Introduzione

2

Identificazione

3

Modellizzazione

4

Controllo

5

Taratura

6

Risultati

7

Conclusioni



1

Introduzione

2

Identificazione

3

Modellizzazione

4

Controllo

5

Taratura

6

Risultati

7

Conclusioni



**Controllo SCARA
partendo da
Black Box**



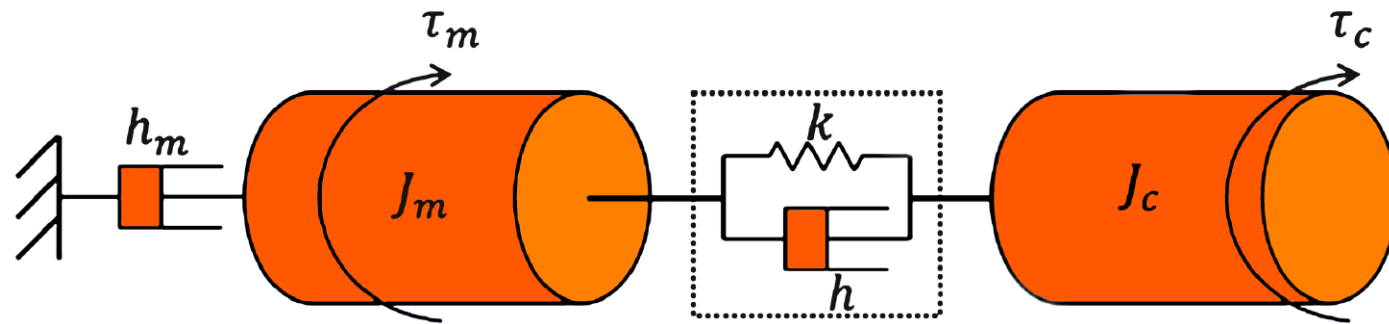
**Identificazione in
frequenza del
modello**



**Progettazione del
sistema di controllo
attraverso il modello**



MODELLIZZAZIONE DELLO SCARA - TRASMISSIONE ELASTICA



$$\begin{cases} J_m \cdot \ddot{q}_m = \tau_m - k(q_m - q_c) - h(\dot{q}_m - \dot{q}_c) - h_m \dot{q}_m \\ J_c \cdot \ddot{q}_c = \tau_c + k(q_m - q_c) + h(\dot{q}_m - \dot{q}_c) \end{cases}$$

$$\frac{V_m(s)}{T_m(s)} = \frac{J_c \cdot s^2 + h \cdot s + k}{J_m J_c s^3 + (J_c h + J_m h + J_c h_m) s^2 + (J_c k + J_m k + h h_m) s + h_m k}$$



1

Introduzione

2

Identificazione

3

Modellizzazione

4

Controllo

5

Taratura

6

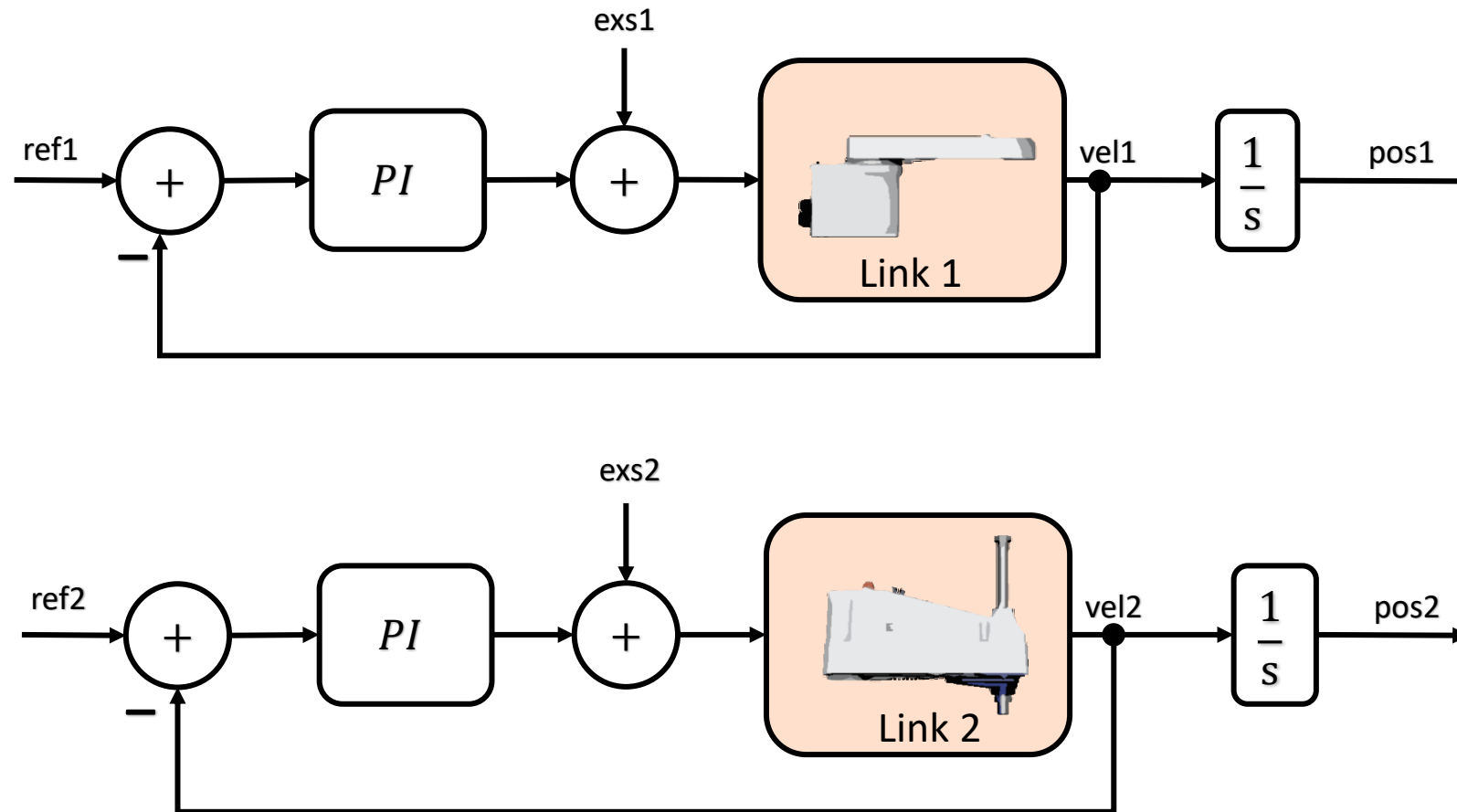
Risultati

7

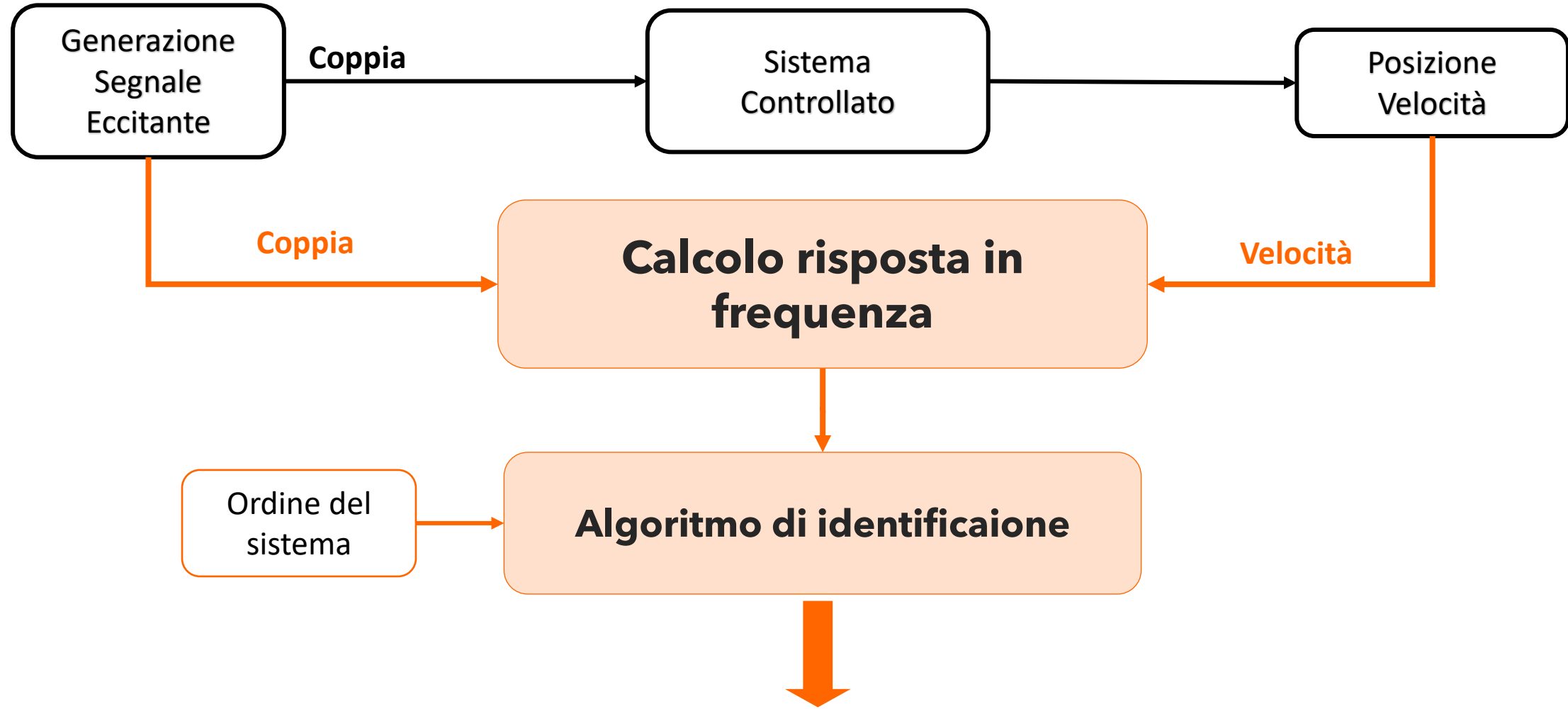
Conclusioni

CONTROLLO PER L'IDENTIFICAZIONE - CLOSED LOOP

ARCHITETTURA DECENTRALIZZATA



PROCESSO

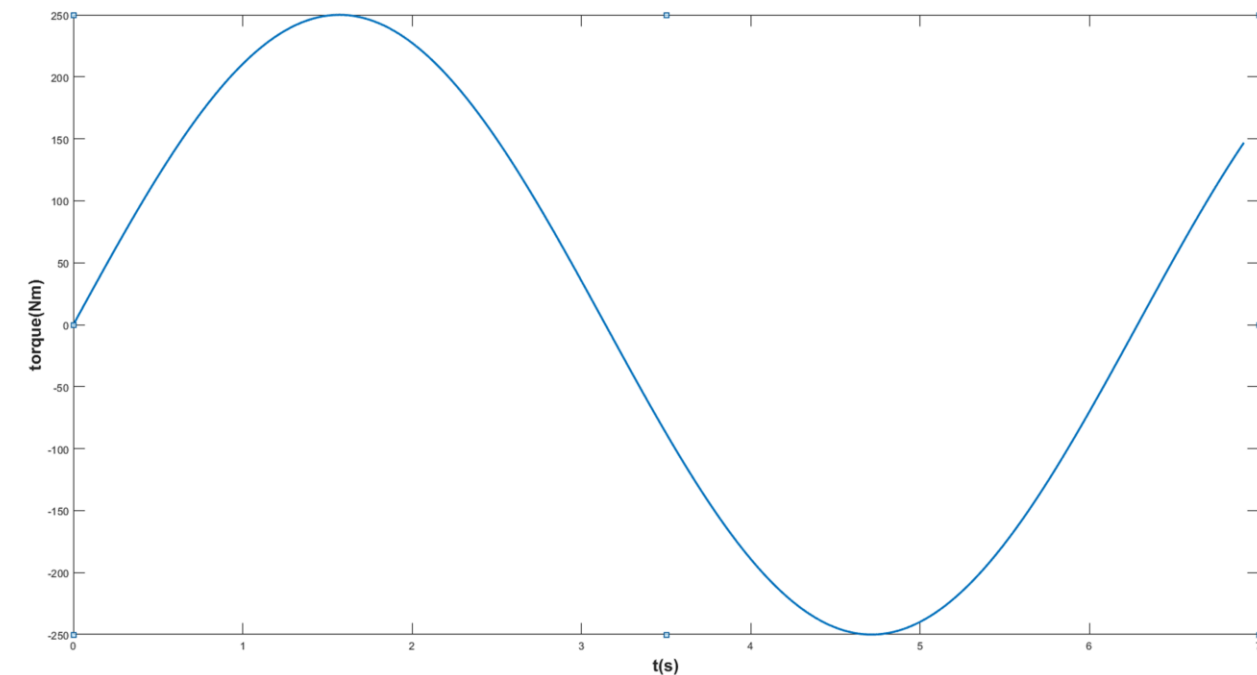


MODELLO DEL SISTEMA COPPIA-VELOCITÀ

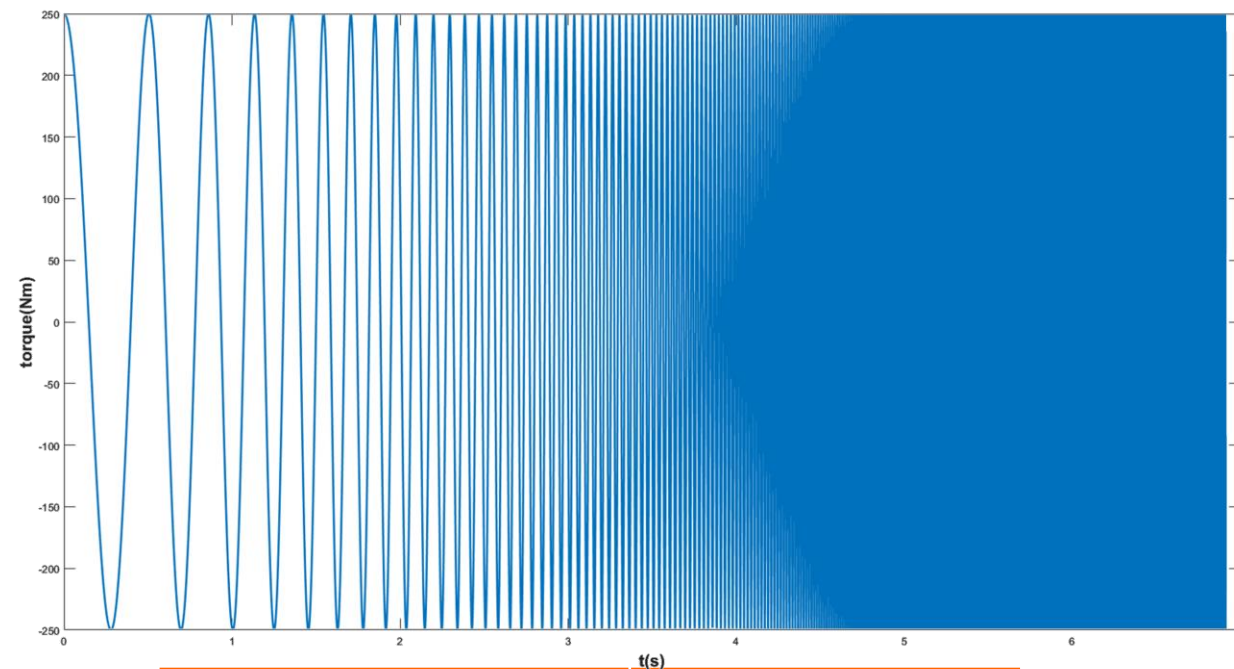
SEGNALE ECCITANTE

PORTANTE

CHIRP

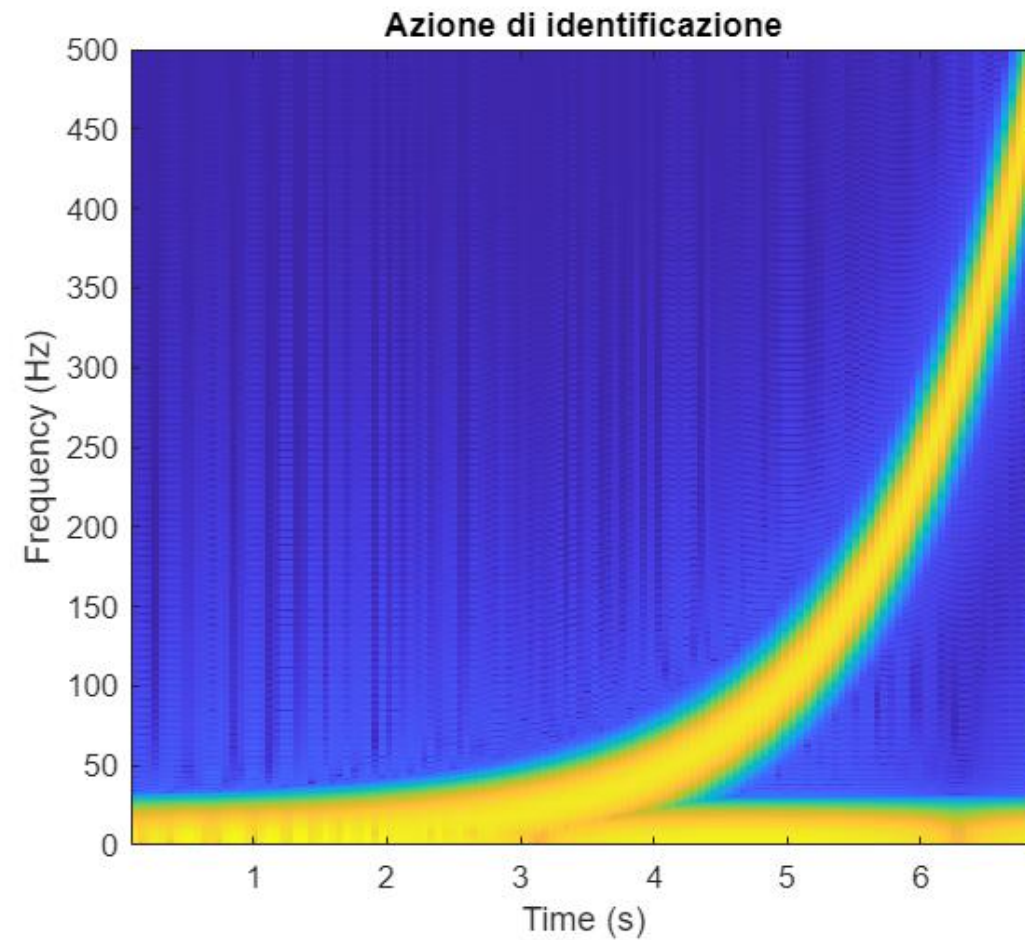
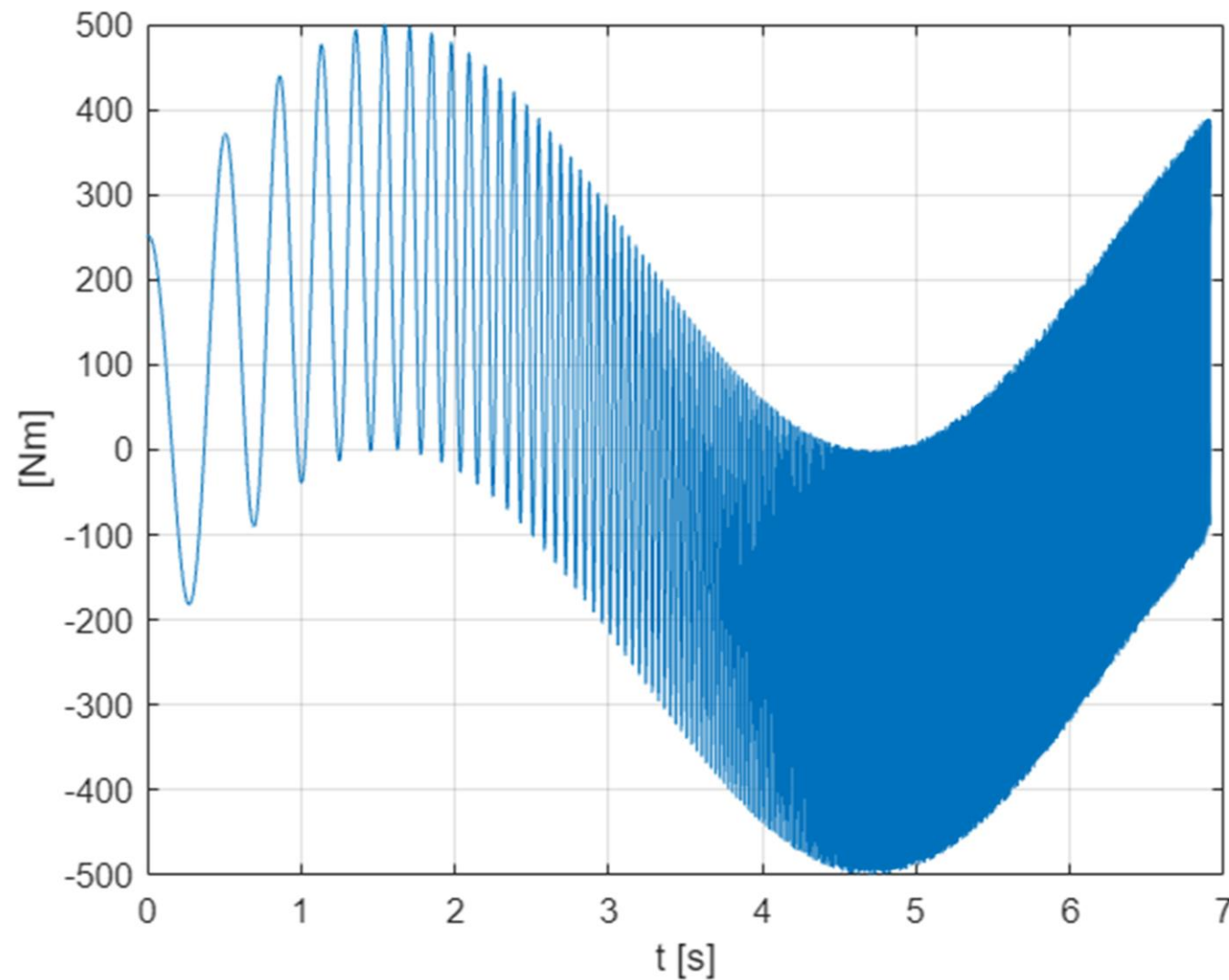


PARAMETRI	VALORE
Pulsazione	1 [rad/s]
Ampiezza	250[Nm]

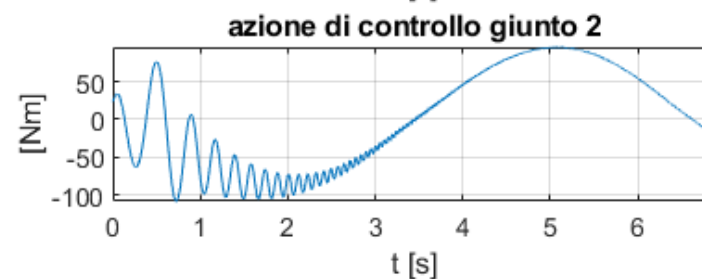
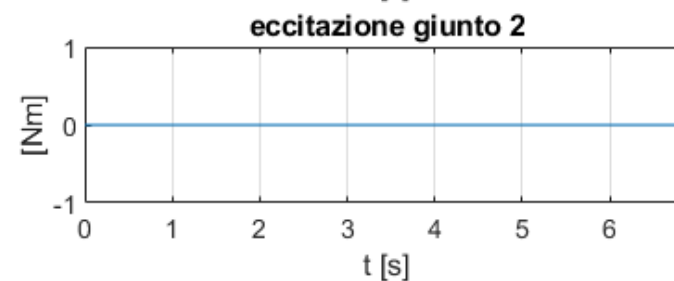
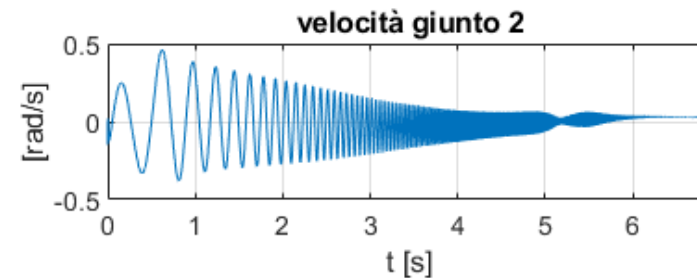
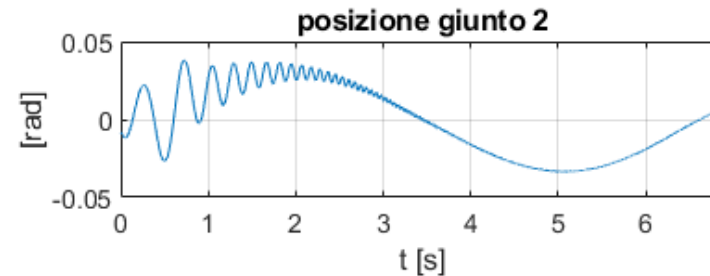
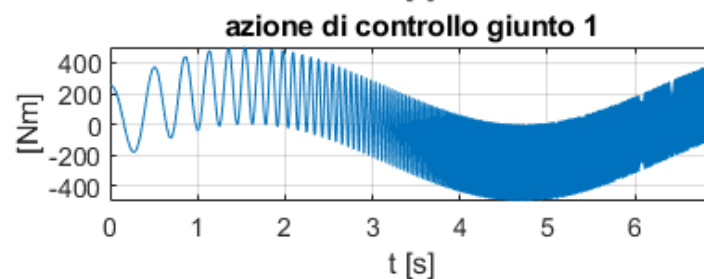
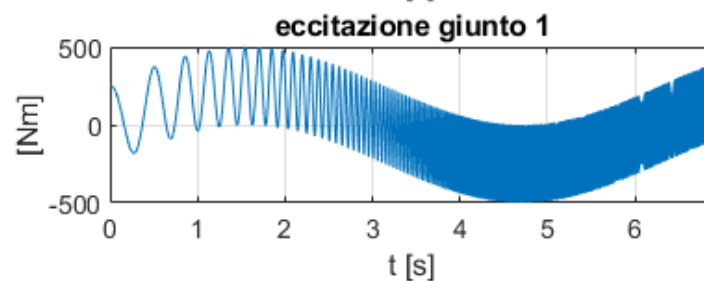
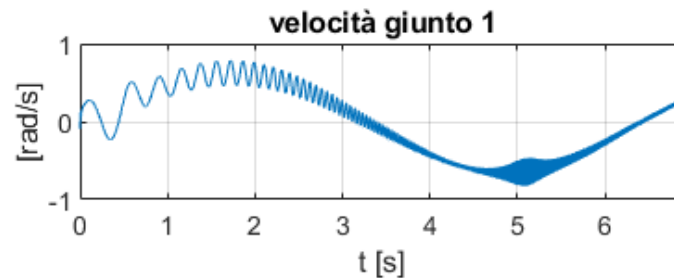
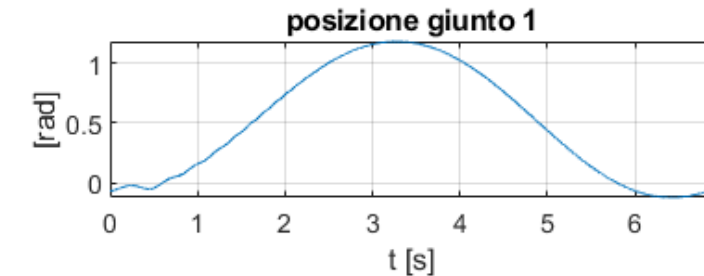


PARAMETRI	VALORE
Pulsazione iniziale	10 [rad/s]
Pulsazione finale	3141[rad/s]
Ampiezza	250[Nm]

SEGNALE ECCITANTE (chirp + portante)



GIUNTO 1



CHIRP

- $\omega = 20 \div 3141 \frac{rad}{s}$
- $A = 250Nm$

Portante

- $\omega = 1 \frac{rad}{s}$
- $A = 250Nm$

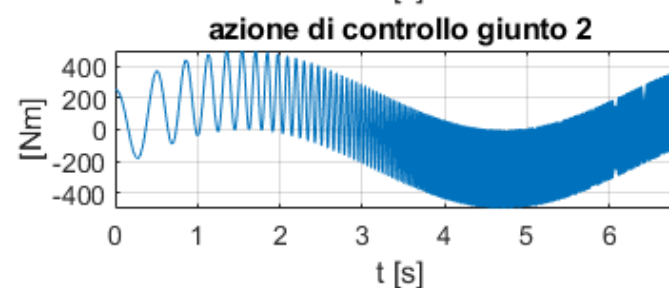
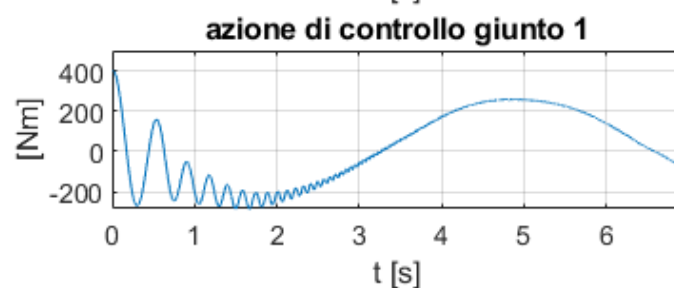
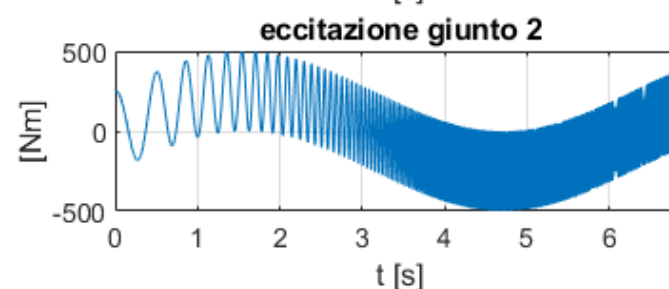
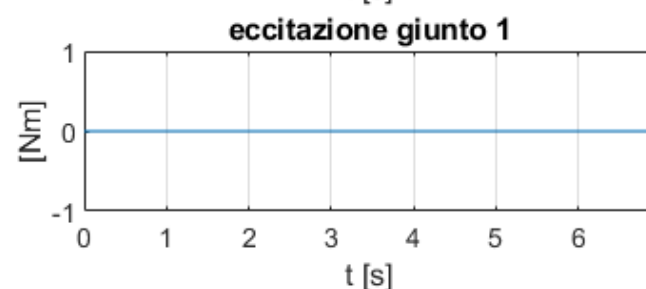
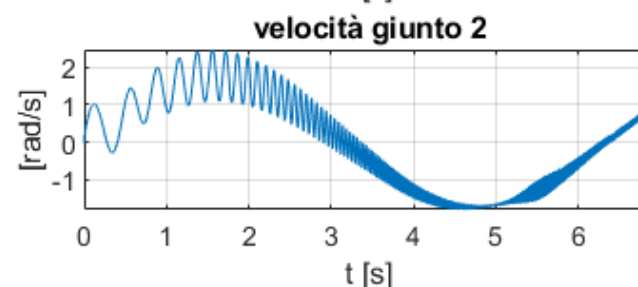
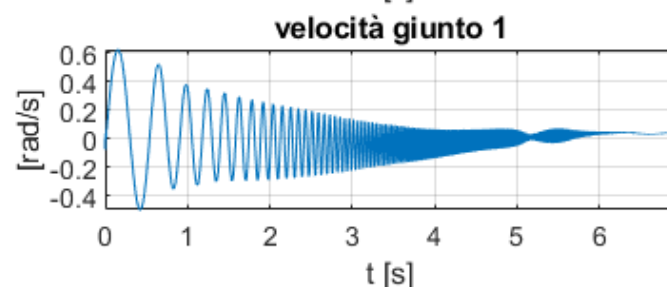
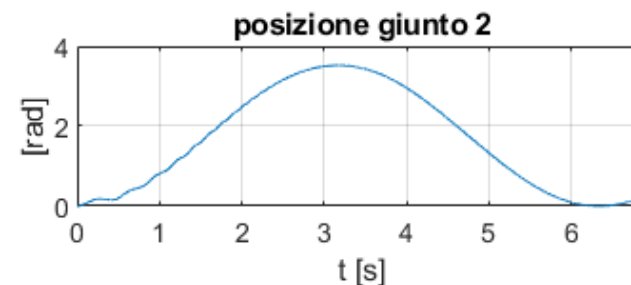
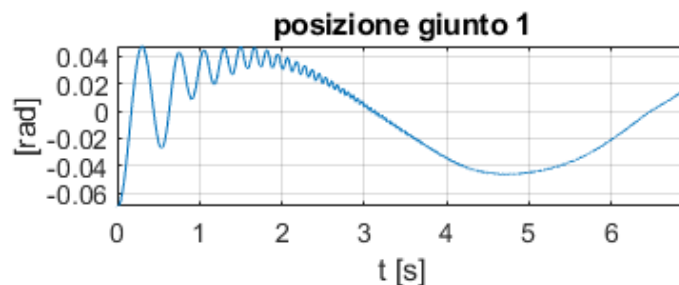
Controllore PI giunto 2

- $K_p = 2864$
- $K_i = 10$

Controllore PI giunto 1

- $K_p = 0.01$
- $K_i = 0.1$

GIUNTO 2



CHIRP

- $\omega = 20 \div 3141 \frac{rad}{s}$
- $A = 250 Nm$

Portante

- $\omega = 1 \frac{rad}{s}$
- $A = 250 Nm$

Controllore PI giunto 2

- $K_p = 0.01$
- $K_i = 0.1$

Controllore PI giunto 1

- $K_p = 5729$
- $K_i = 10$



1

Introduzione

2

Identificazione

3

Modellizzazione

4

Controllo

5

Taratura

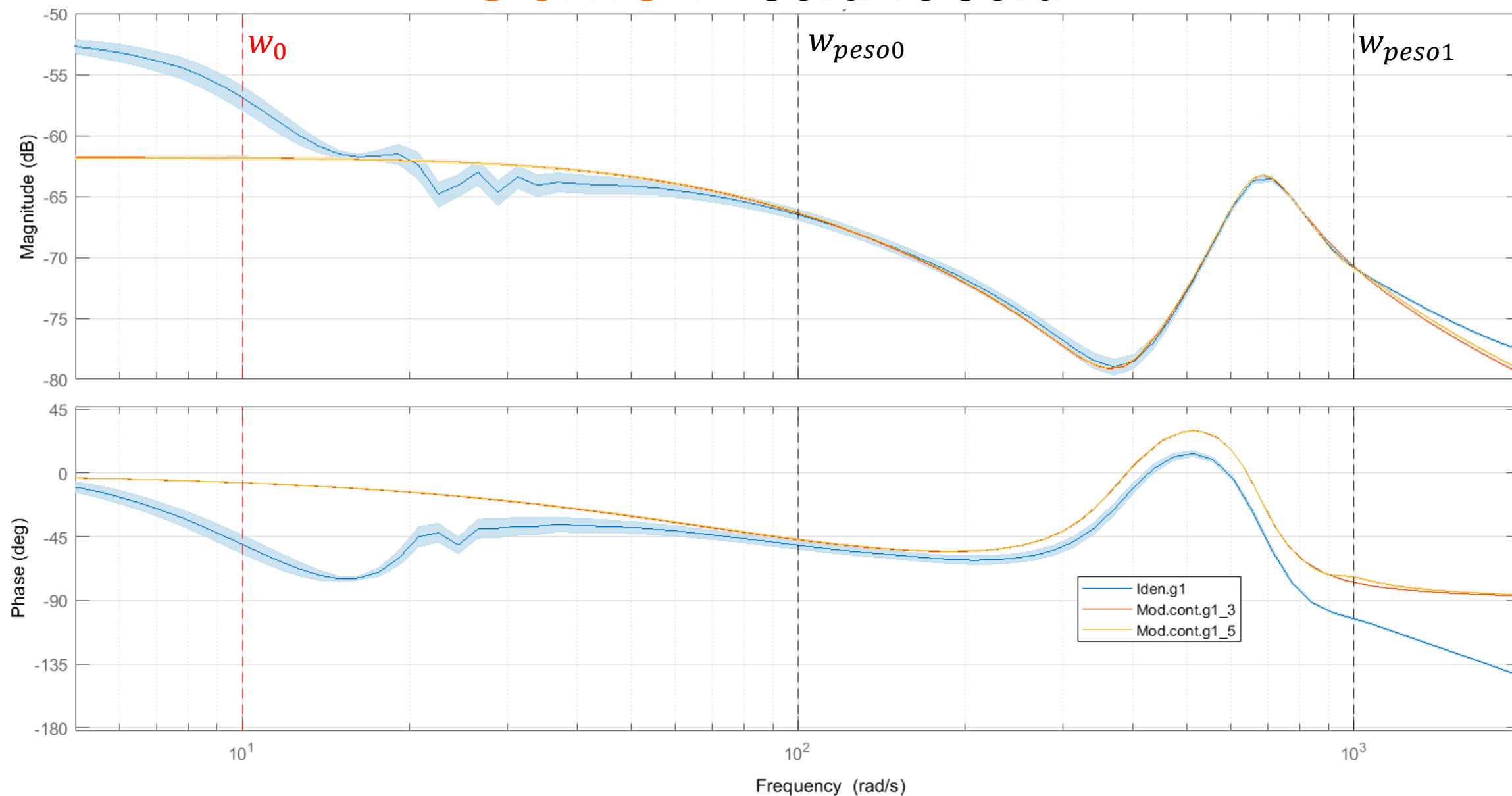
6

Risultati

7

Conclusioni

GIUNTO 1 - 3ord Vs 5ord



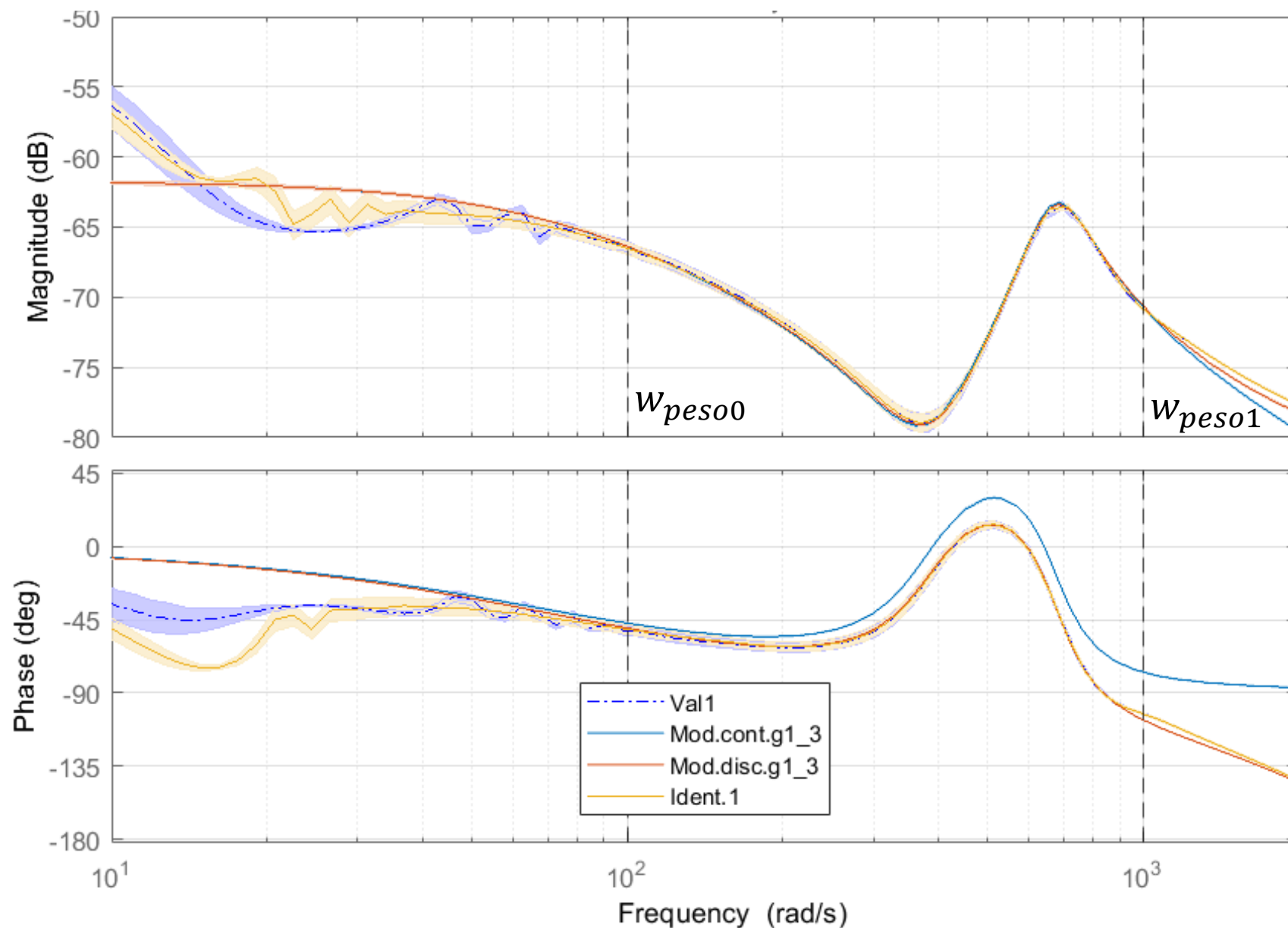
VALIDAZIONE GIUNTO 1

CHIRP

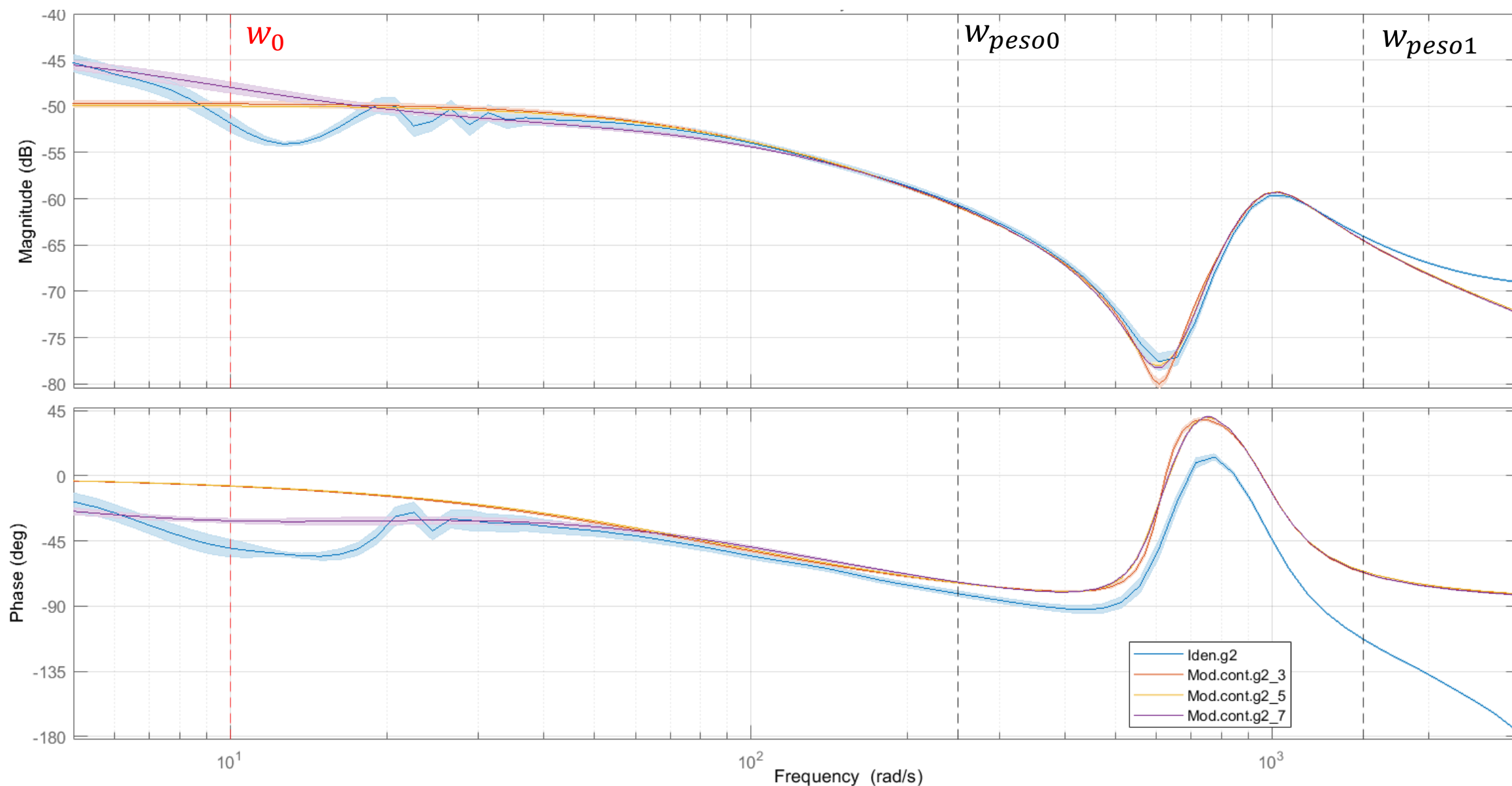
- $\omega = 20 \div 3141 \frac{\text{rad}}{\text{s}}$
- $A = 300 \text{Nm}$

Portante

- $\omega = 2 \frac{\text{rad}}{\text{s}}$
- $A = 130 \text{Nm}$



GIUNTO 2 - 3ord Vs 5ord Vs 7ord



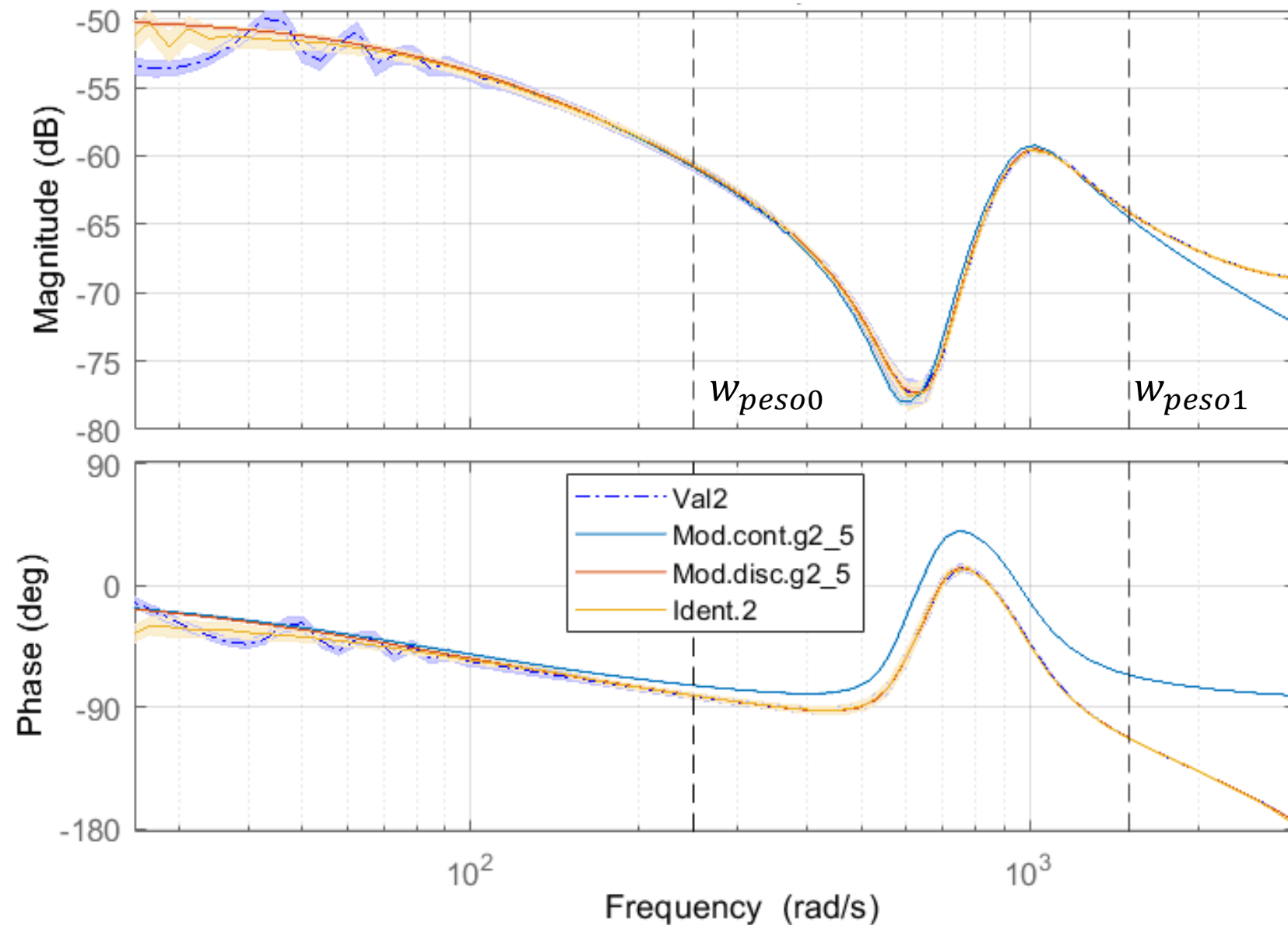
VALIDAZIONE GIUNTO 2

CHIRP

- $\omega = 20 \div 3141 \frac{\text{rad}}{\text{s}}$
- $A = 300 \text{Nm}$

Portante

- $\omega = 2 \frac{\text{rad}}{\text{s}}$
- $A = 130 \text{Nm}$





1

Introduzione

2

Identificazione

3

Modellizzazione

4

Controllo

5

Taratura

6

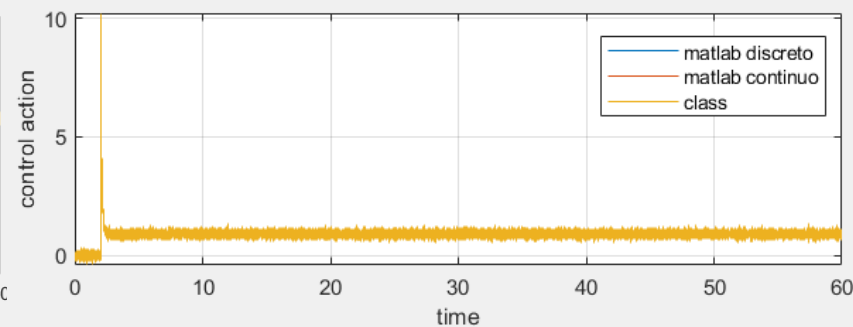
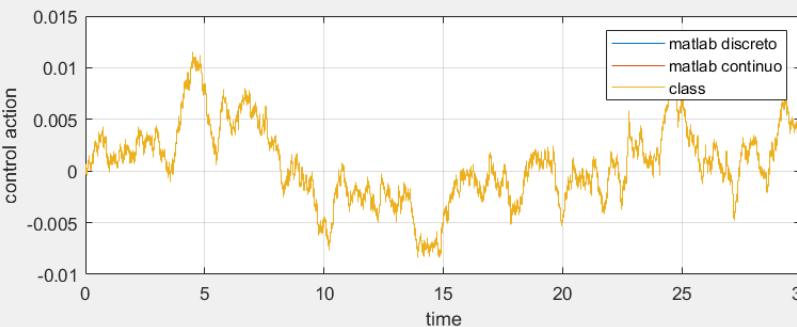
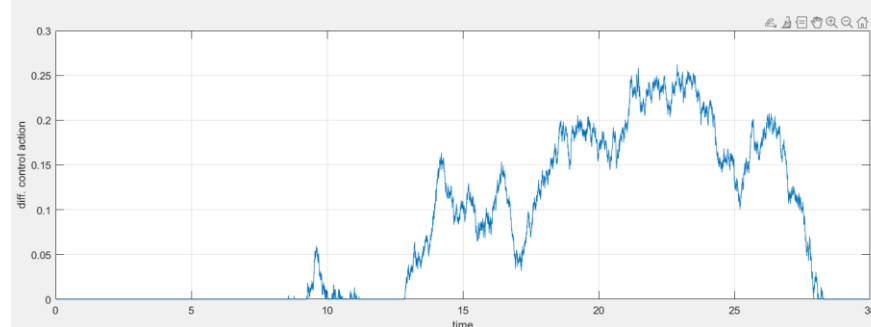
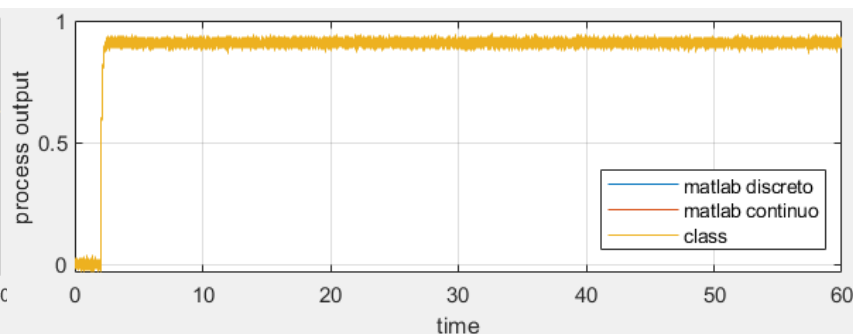
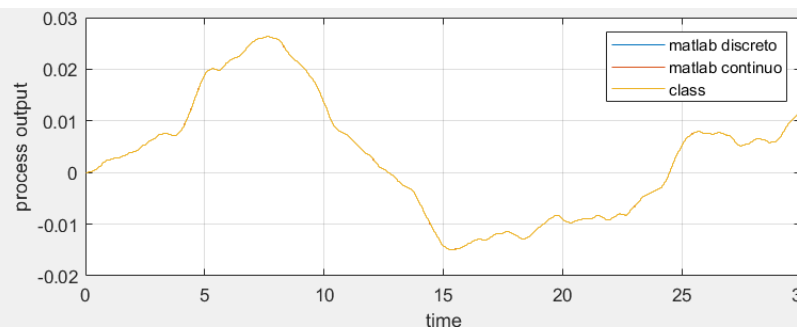
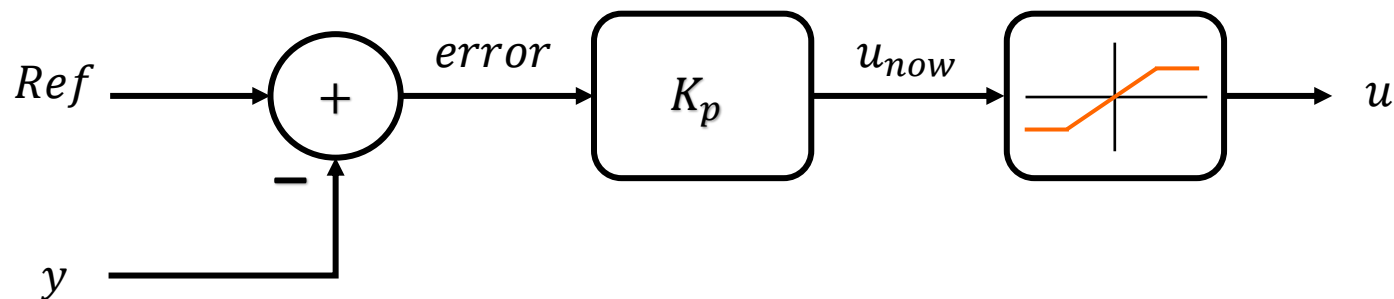
Risultati

7

Conclusioni



CONTROLLORE P - TEST



Test 2

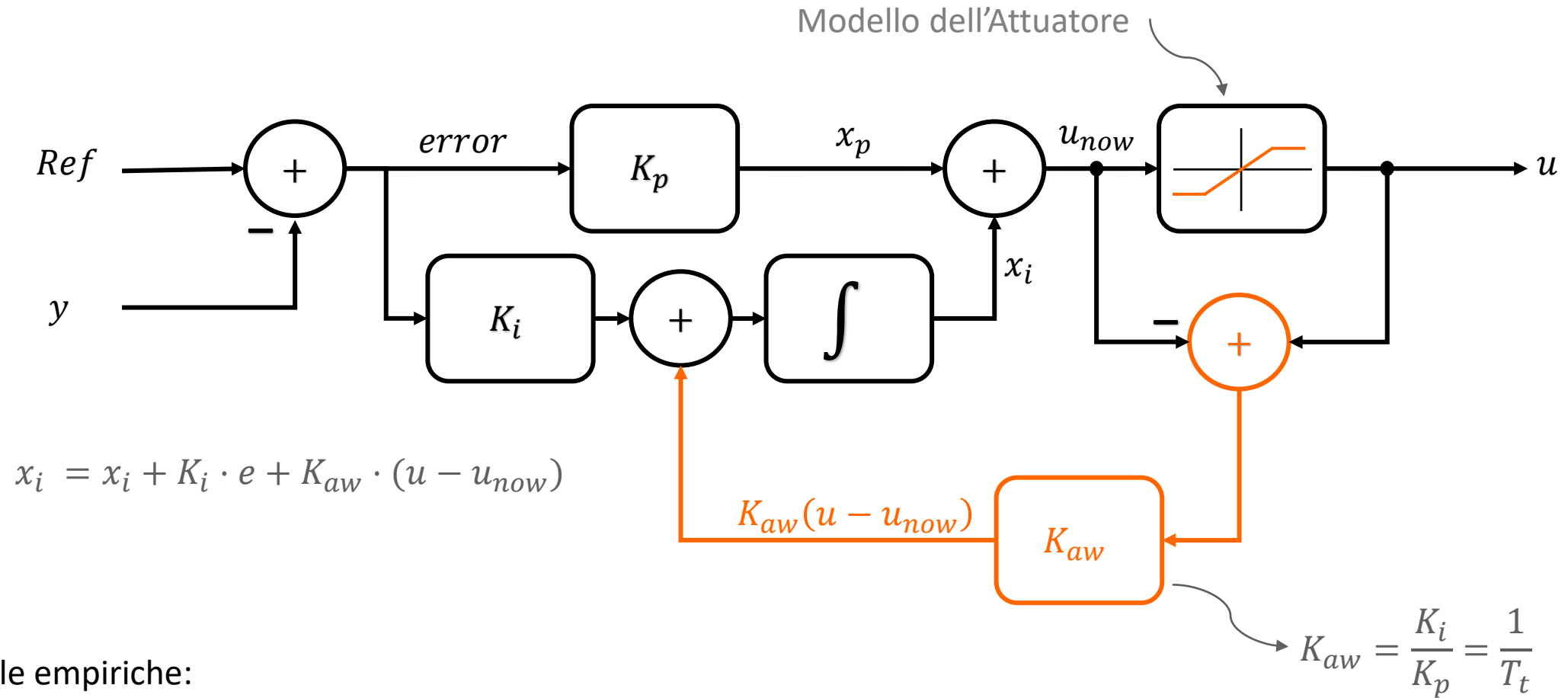


Test 3



Test 4

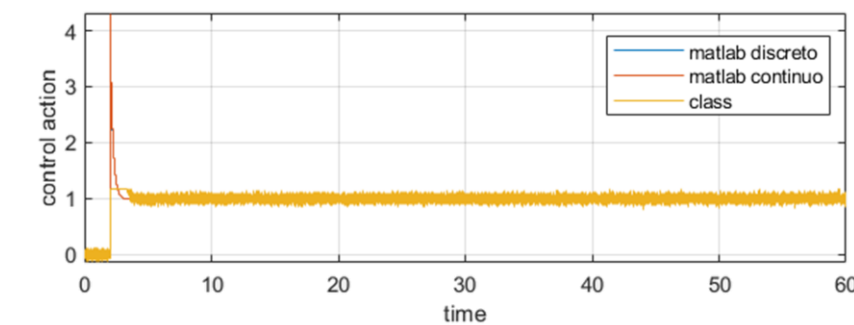
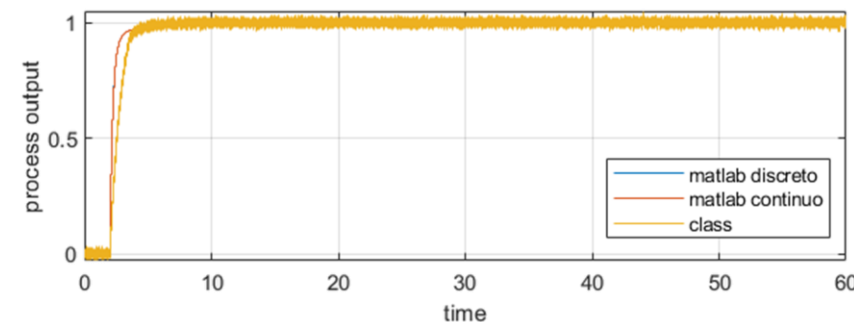
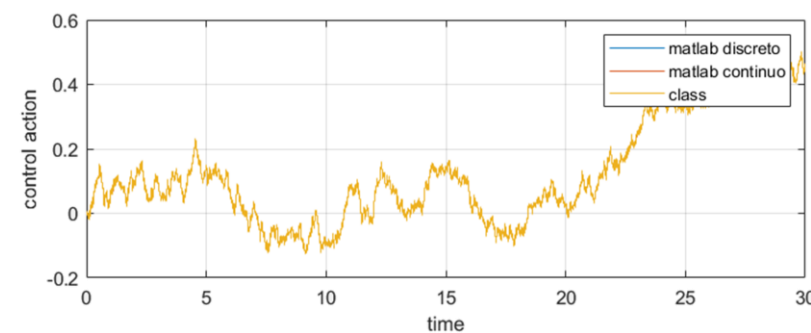
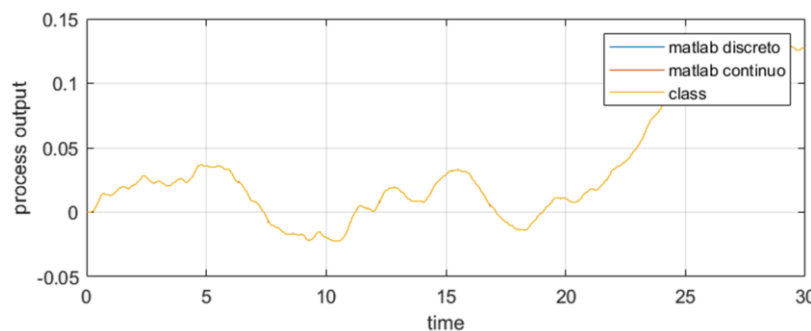
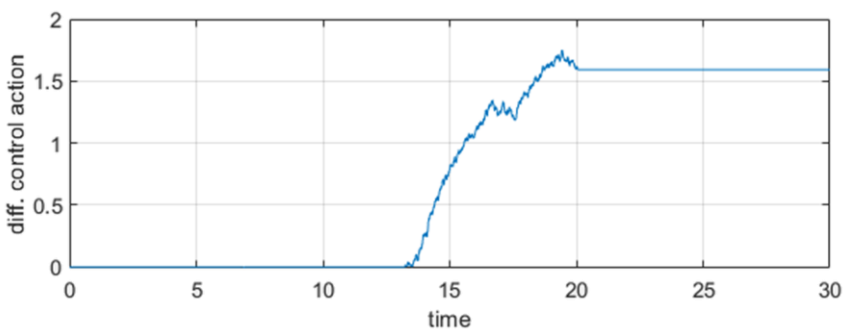
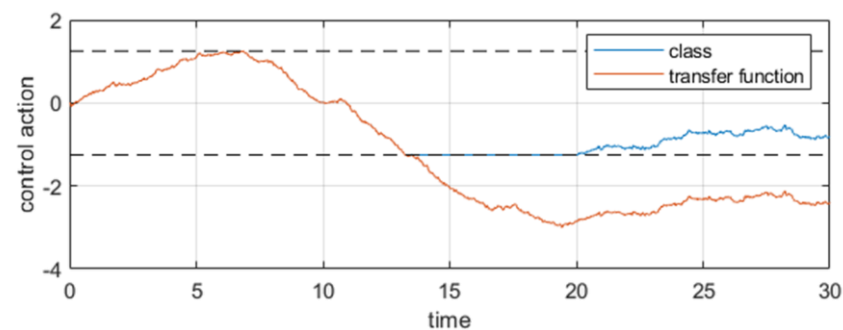
CONTROLLORE PI - Back Calculation



Per regole empiriche:

- $K_{aw} \rightarrow$ guadagno di anti wind-up
- $T_t = T_i \rightarrow$ costante di tempo di tracciamento

CONTROLLORE PI - TEST



✓ **Test 2**

✓ **Test 3**

✓ **Test 4**

FILTRO PASSA BASSO - IMPLEMENTAZIONE

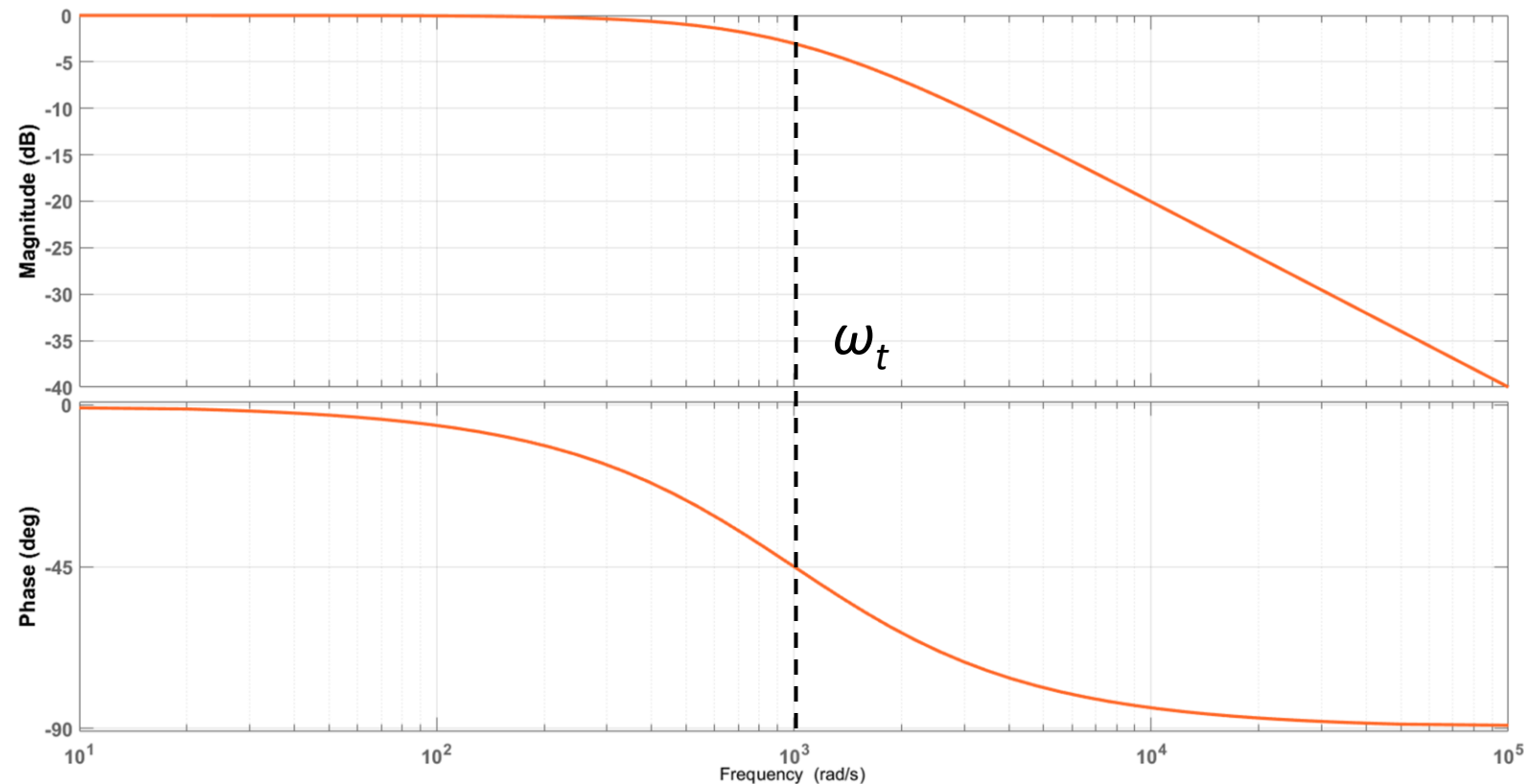
$$F_{PB}(s) = \frac{1}{1 + \tau \cdot s}$$

$c2d(F_{PB}, st, 'tustin')$

$$F_{PB_d}(z) = \frac{0.3333 \cdot z + 0.3333}{z - 0.3333}$$

da Z alle differenze

$$V_o(k) = (0.3333 \cdot V_i(k) + 0.3333 \cdot V_i(k-1) - 0.3333 \cdot V_o(k-1))$$

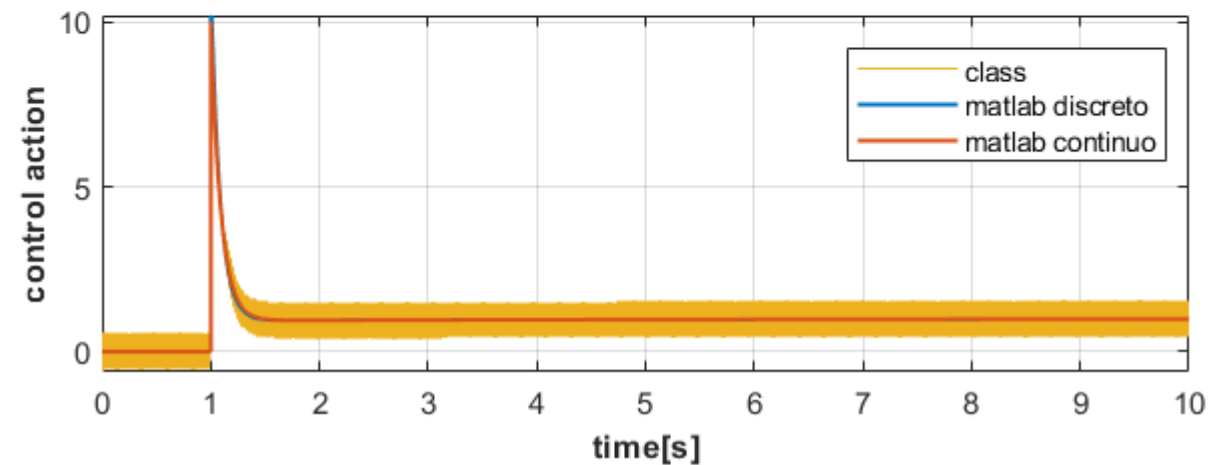
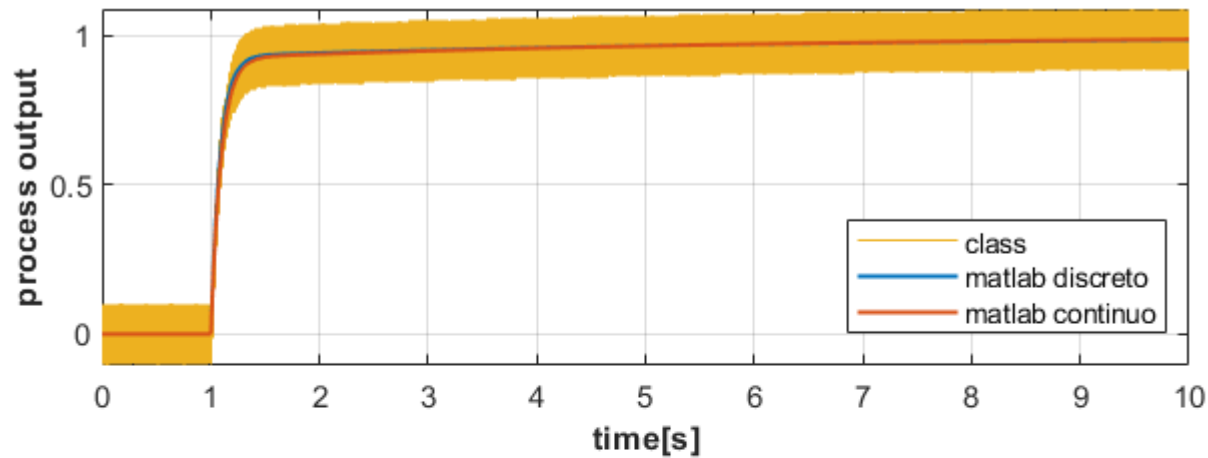


$$\tau = 0.001s \rightarrow \omega_\tau = \frac{1}{\tau} = 1000 \frac{rad}{s}$$

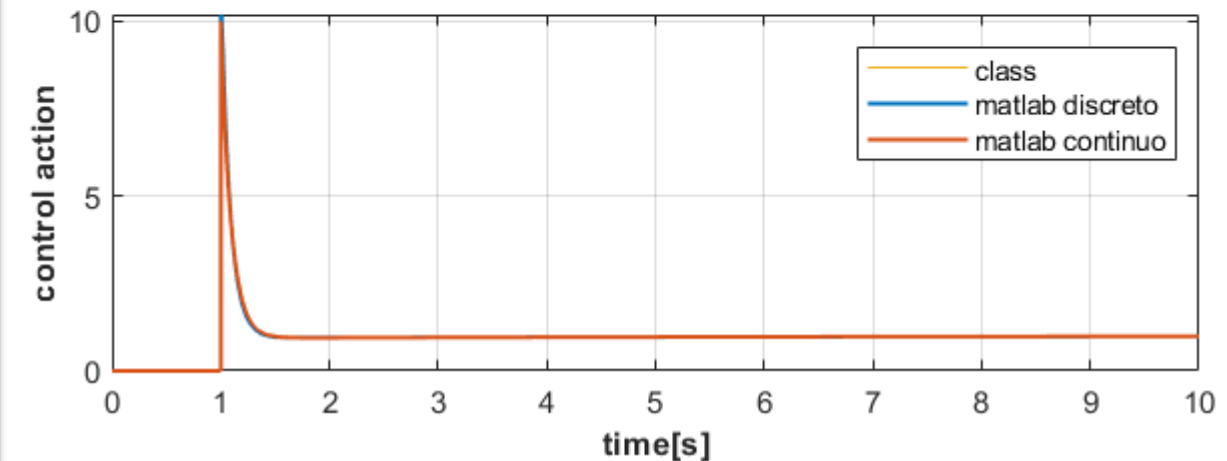
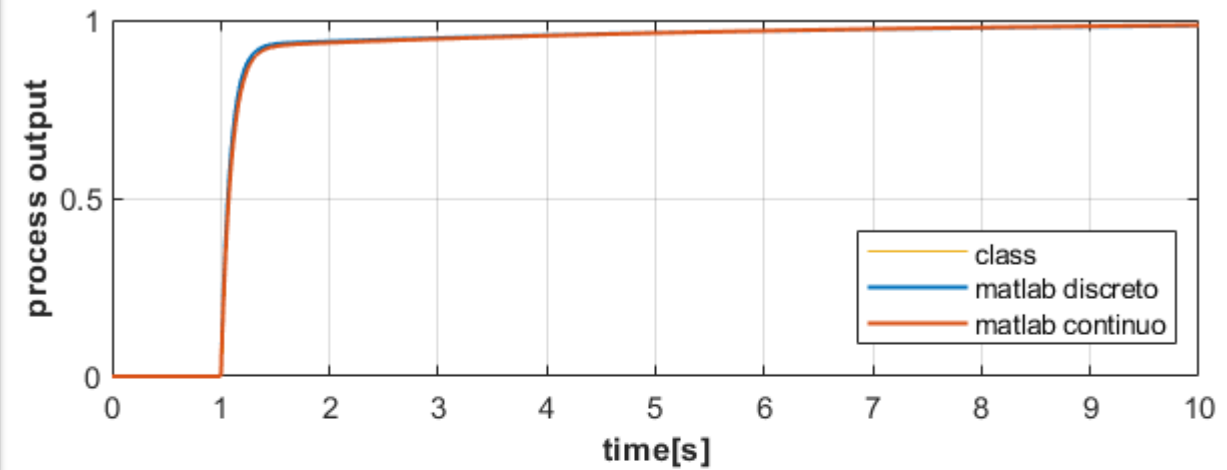
FILTRO PASSA BASSO - TEST



Test4-1: $noise(t) = 0.1 \cdot \sin(100 \cdot t)$



Test4-2: $noise(t) = 0.1 \cdot \sin(2000 \cdot t)$



FILTRO NOTCH - IMPLEMENTAZIONE

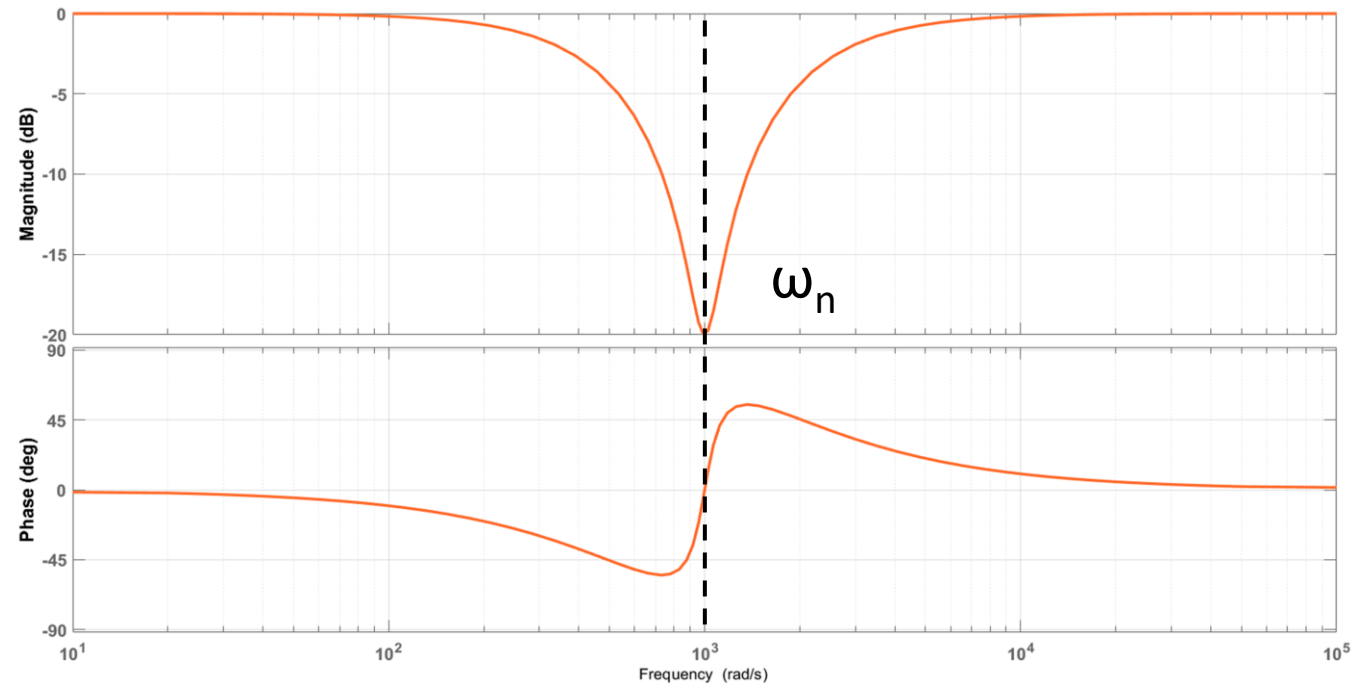
$$F_N(s) = \frac{s^2 + 2 \cdot \omega_n \cdot xci_z \cdot s + \omega_n^2}{s^2 + 2 \cdot \omega_n \cdot xci_p \cdot s + \omega_n^2}$$

c2d(F_N, st, 'tustin')

$$F_{Nd}(z) = \frac{0.6 \cdot z^2 - 0.6667 \cdot z + 0.5111}{z^2 - 0.6667 \cdot z + 0.1111}$$

da z alle differenze

$$V_o(k) = 0.6 \cdot V_i(k) - 0.6667 \cdot V_i(k-1) + 0.5111 \cdot V_i(k-2) + \dots \\ + 0.6667 \cdot V_o(k-1) - 0.1111 \cdot V_o(k-2)$$



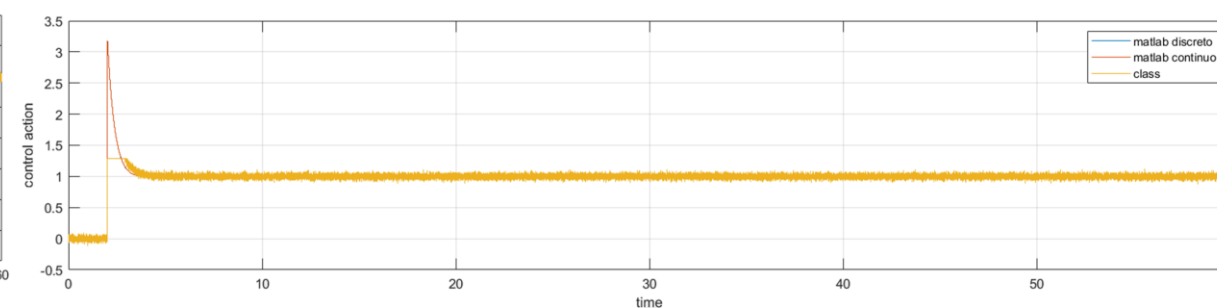
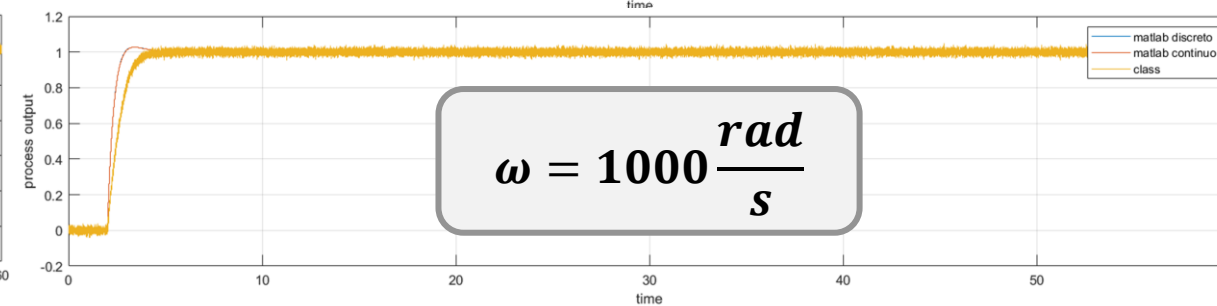
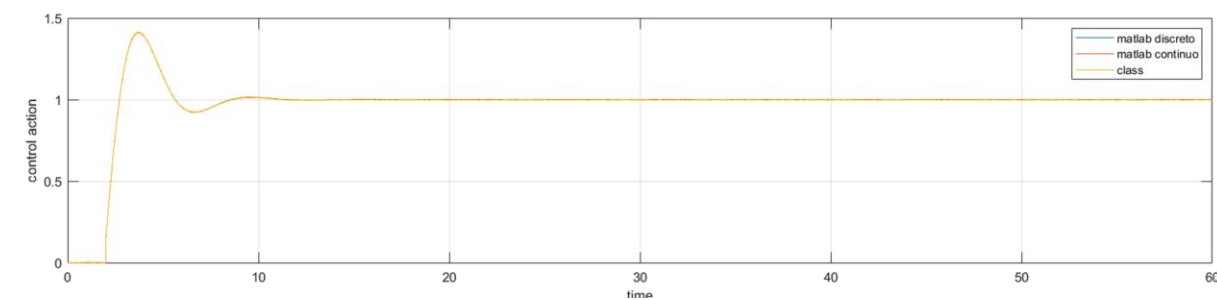
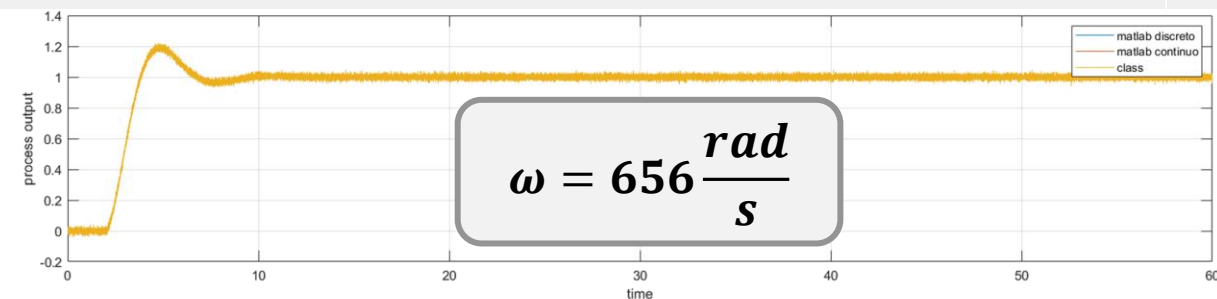
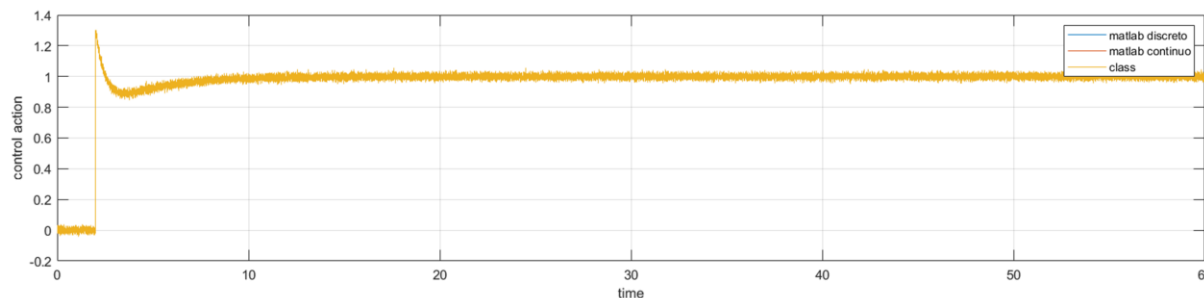
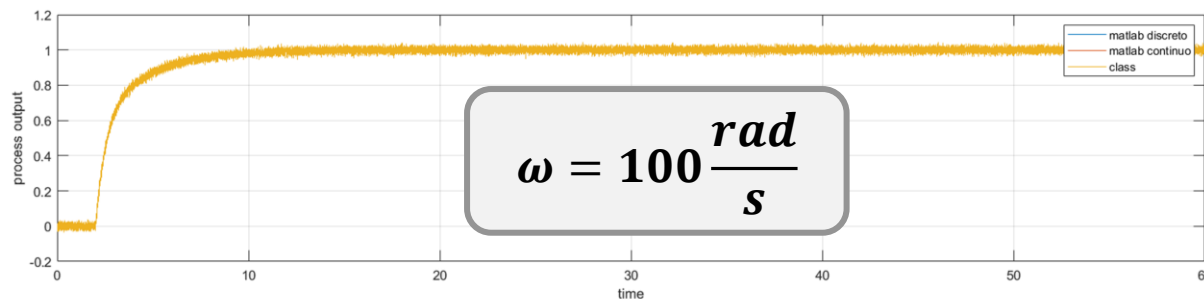
$$\omega_n = 1000 \frac{\text{rad}}{\text{s}} \\ xci_p = 1 \\ xci_z = 0.1$$

FILTRO NOTCH - TEST



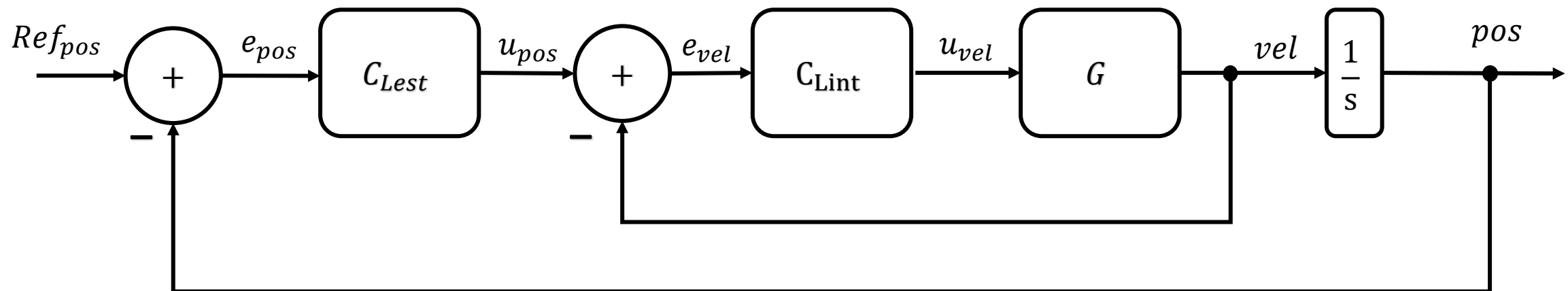
Test4 $noise(t) = 0.1 \cdot \sin(\omega \cdot t)$

- $Xci_p = 1$
- $Xci_z = 0.09$
- $\omega_n = 656 \frac{rad}{s}$



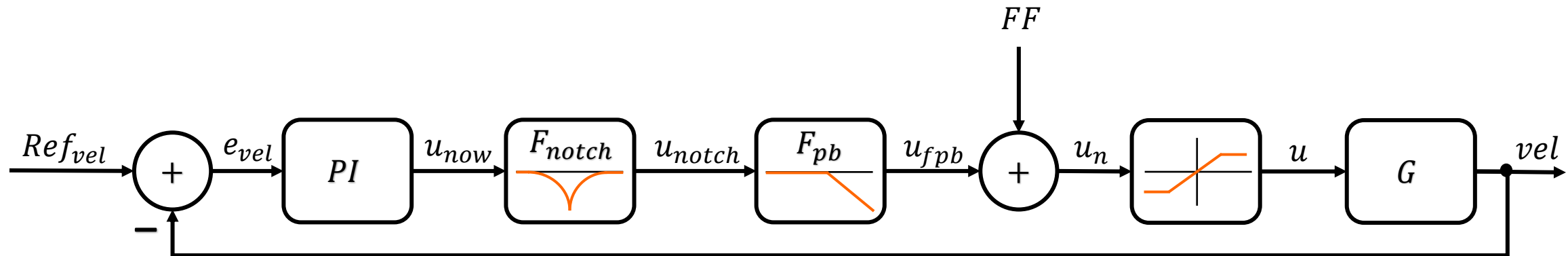
SCHEMA DI CONTROLLO

CASCADE CONTROL



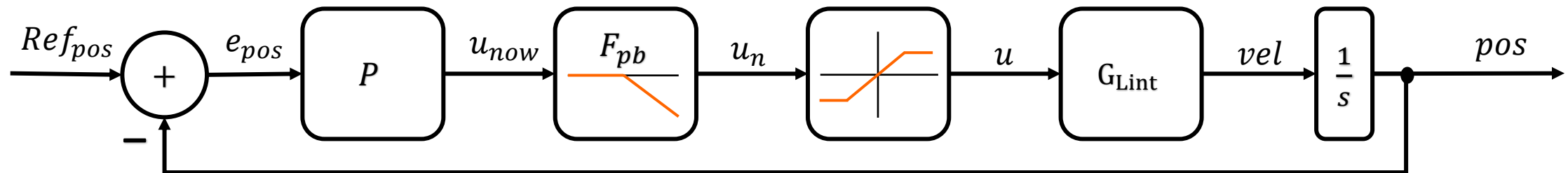
CASCADE CONTROL

LOOP INTERNO



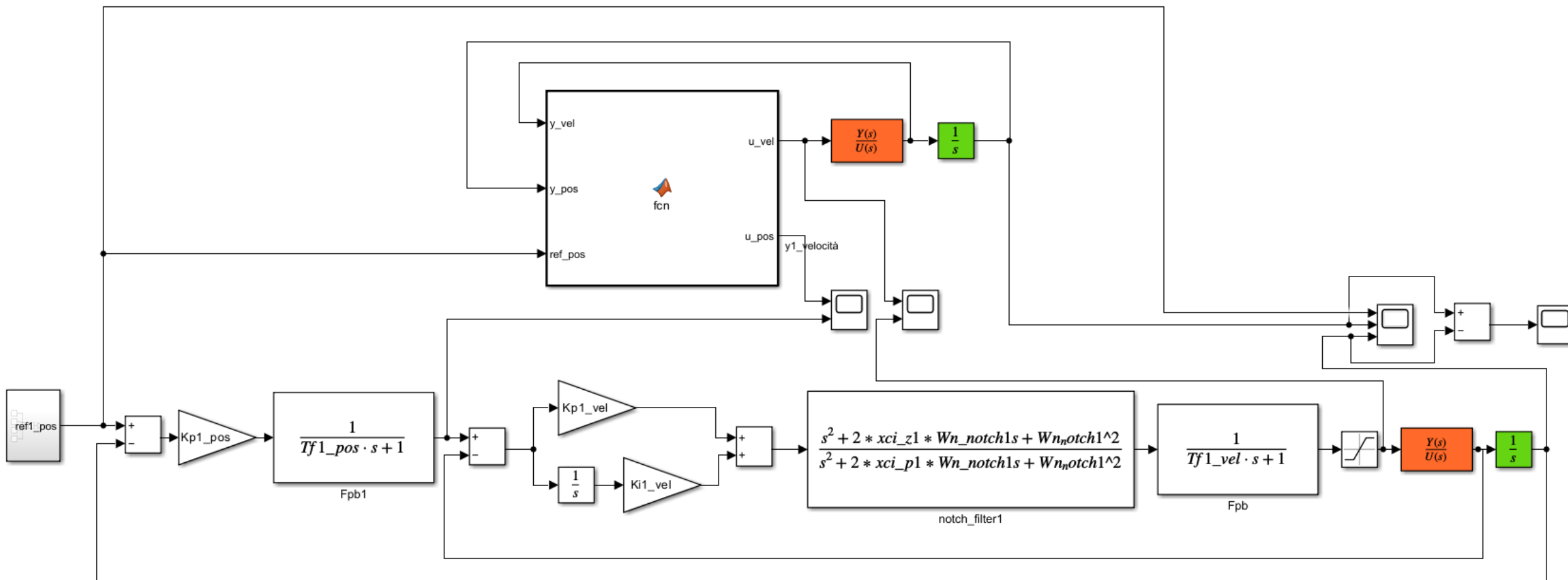
CASCADE CONTROL

LOOP ESTERNO

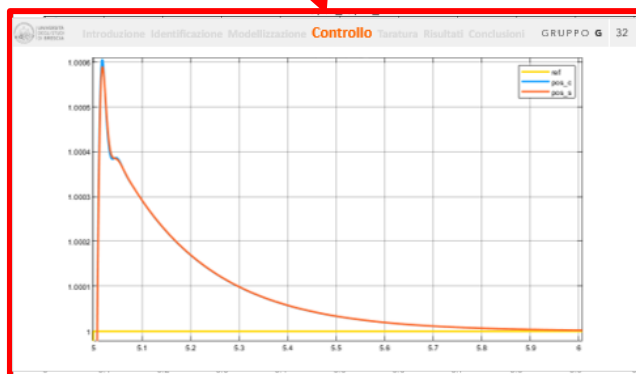
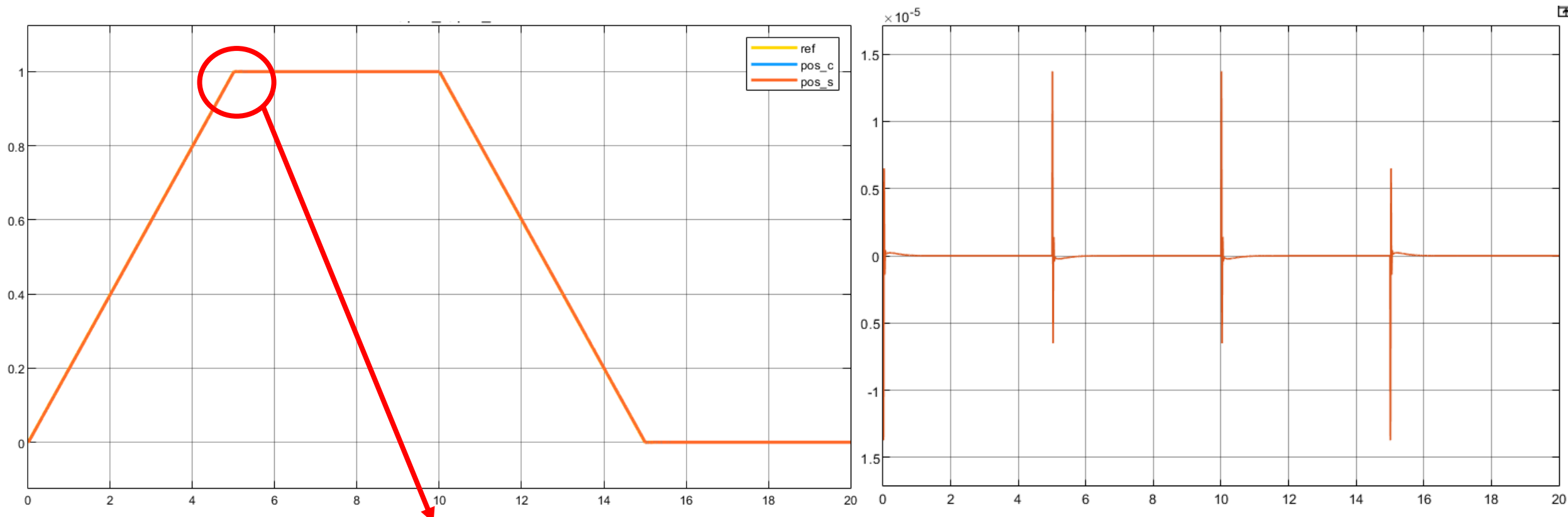


CASCADE CONTROL

TEST 5



CASCADE CONTROL - TEST



**Errore sulla posizione
< 10^{-5}**



1

Introduzione

2

Identificazione

3

Modellizzazione

4

Controllo

5

Taratura

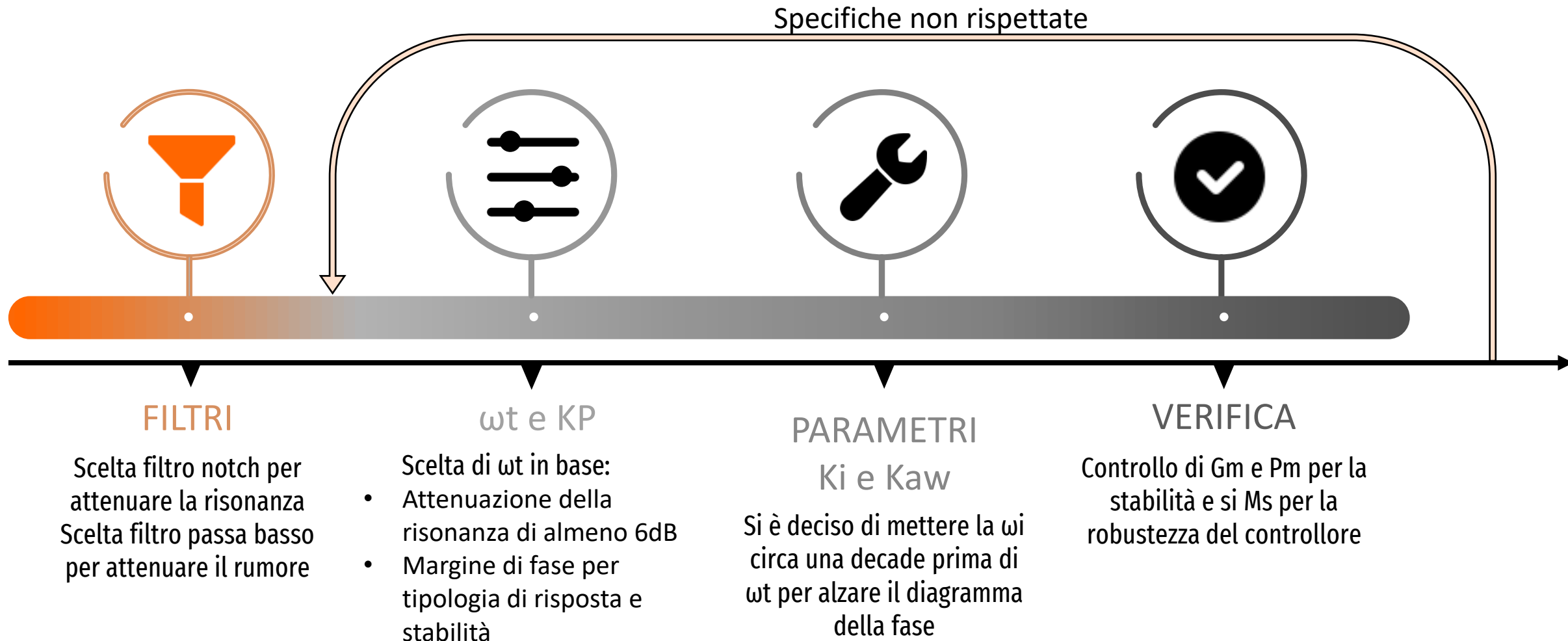
6

Risultati

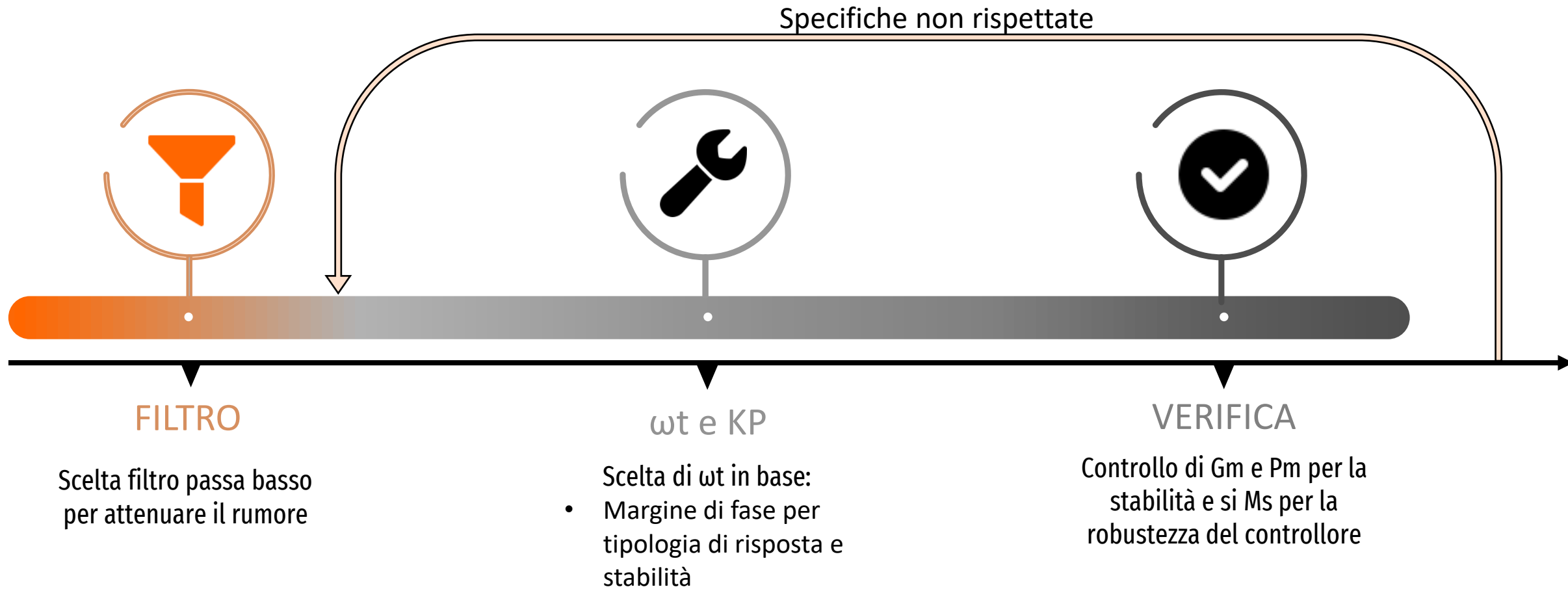
7

Conclusioni

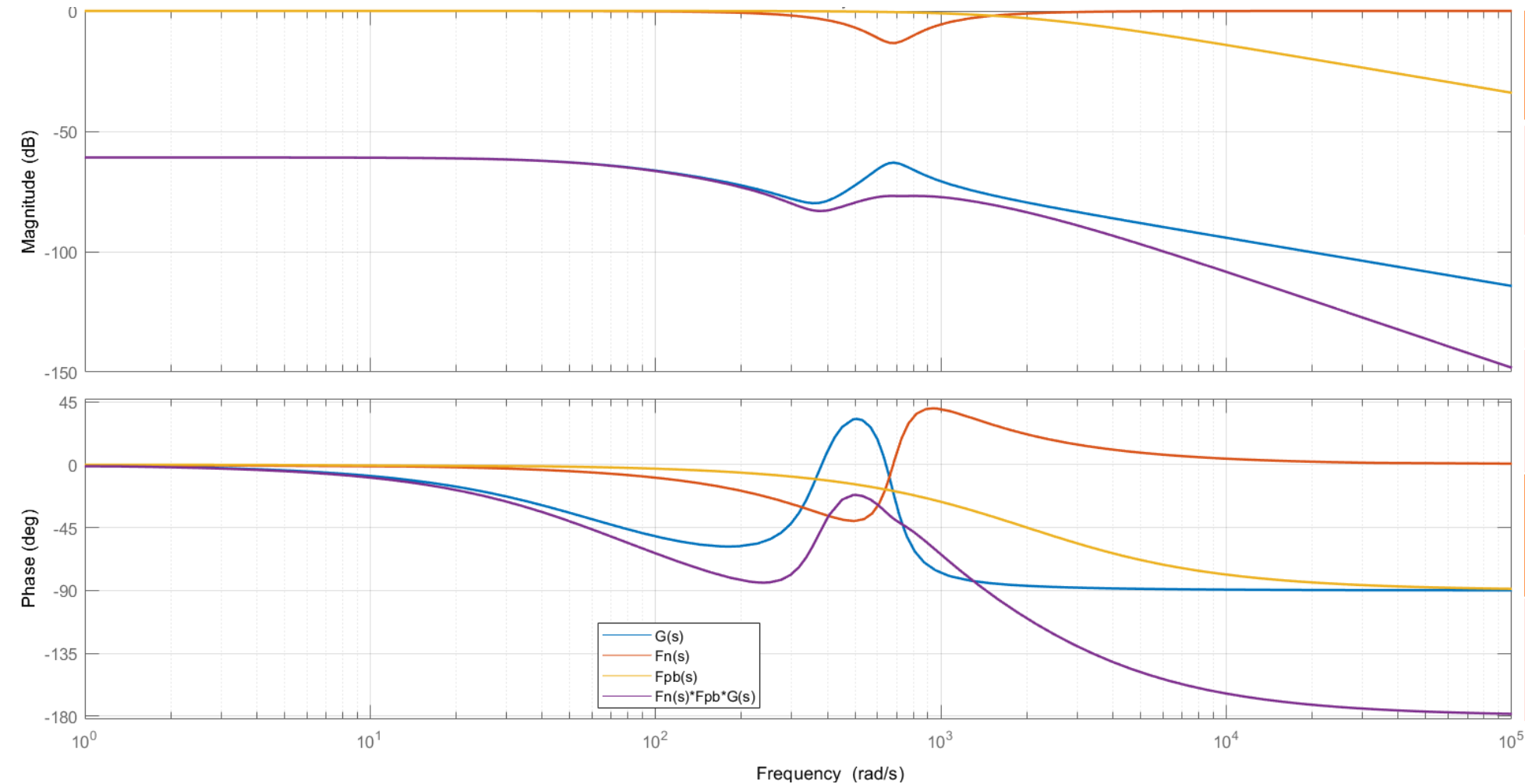
TARATURA LOOP INTERNO



TARATURA LOOP ESTERNO



GIUNTO 1 - loop interno - filtri



FILTRO NOTCH

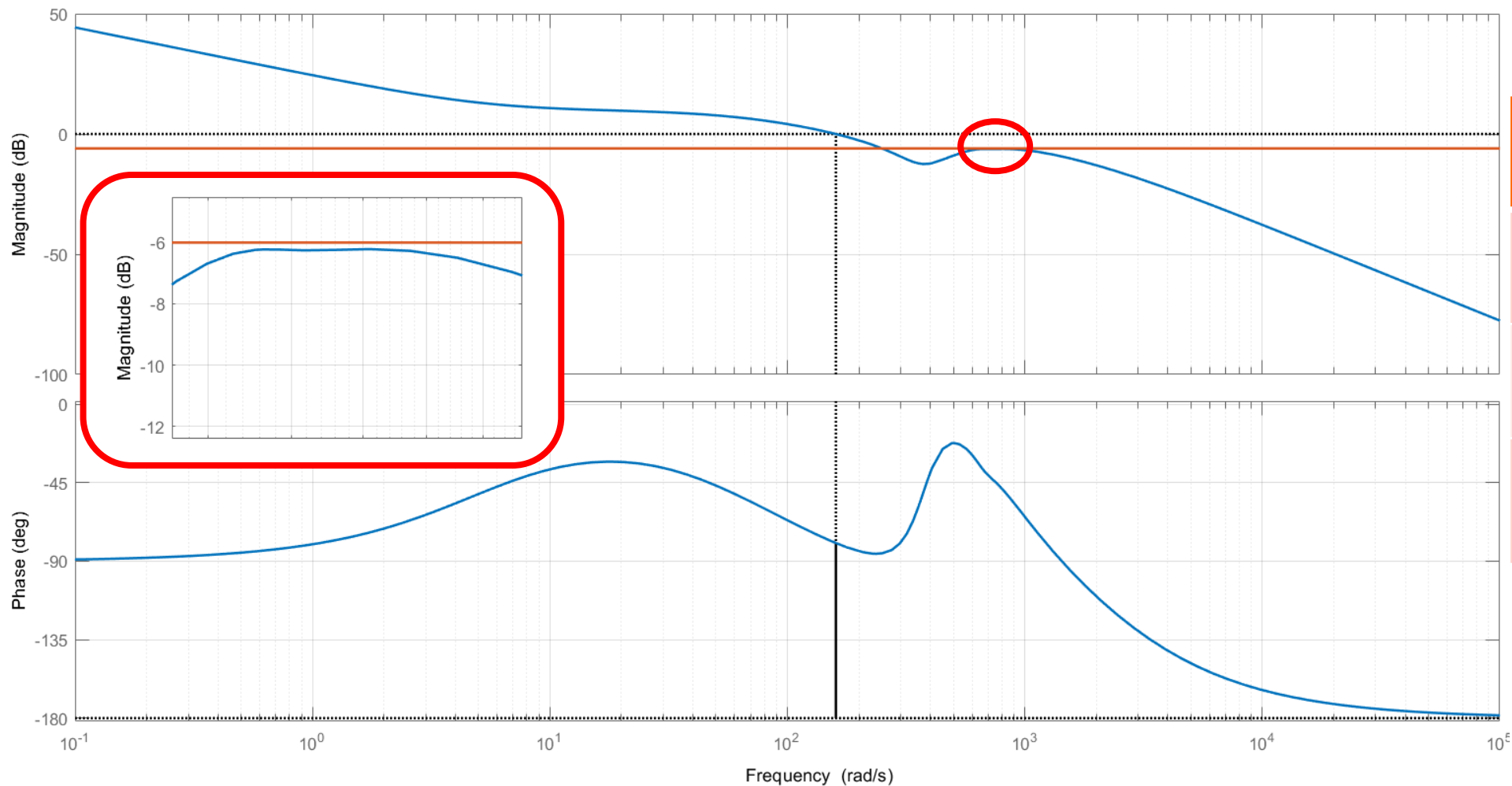
Wn**680 [rad/s]****Xci_p****0.7****Xci_z****0.15**

FILTRO PASSA BASSO

Wpb**2000**

GIUNTO 1 - loop interno - controllore

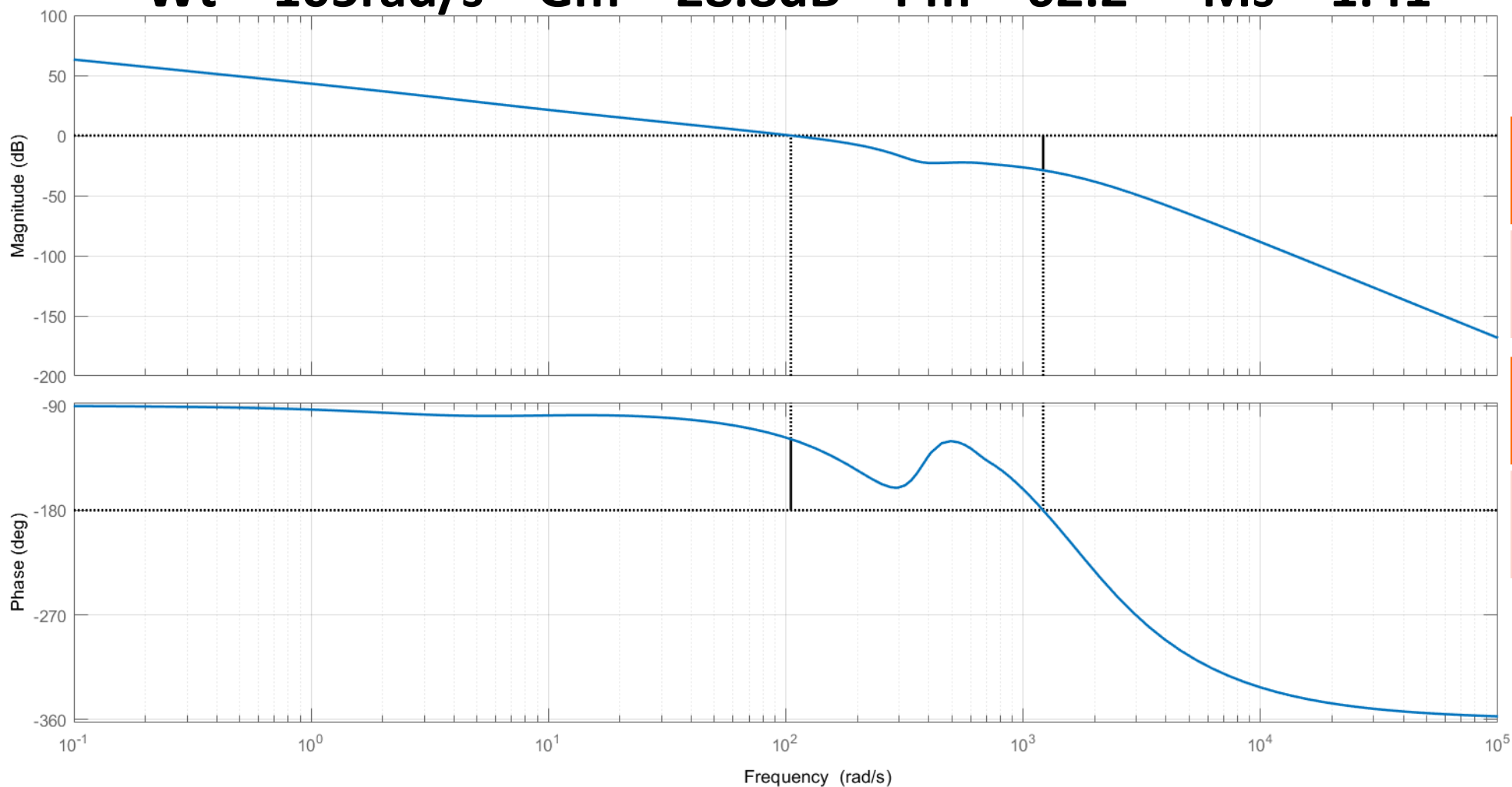
$W_t = 160 \text{ rad/s}$ $G_m = \text{Inf}$ $P_m = 104^\circ$ $M_s = 1.08$



PI	
Kp	3401
Ki	18142
Kaw	5.33

GIUNTO 1 - loop esterno

$W_t = 105 \text{ rad/s}$ $G_m = 28.8 \text{ dB}$ $P_m = 62.2^\circ$ $M_s = 1.41$

**PI** **K_p** **149.78****FILTRO PASSA BASSO** **W_{pb}** **2000**

GIUNTO 2 - loop interno - filtri

FILTRO NOTCH

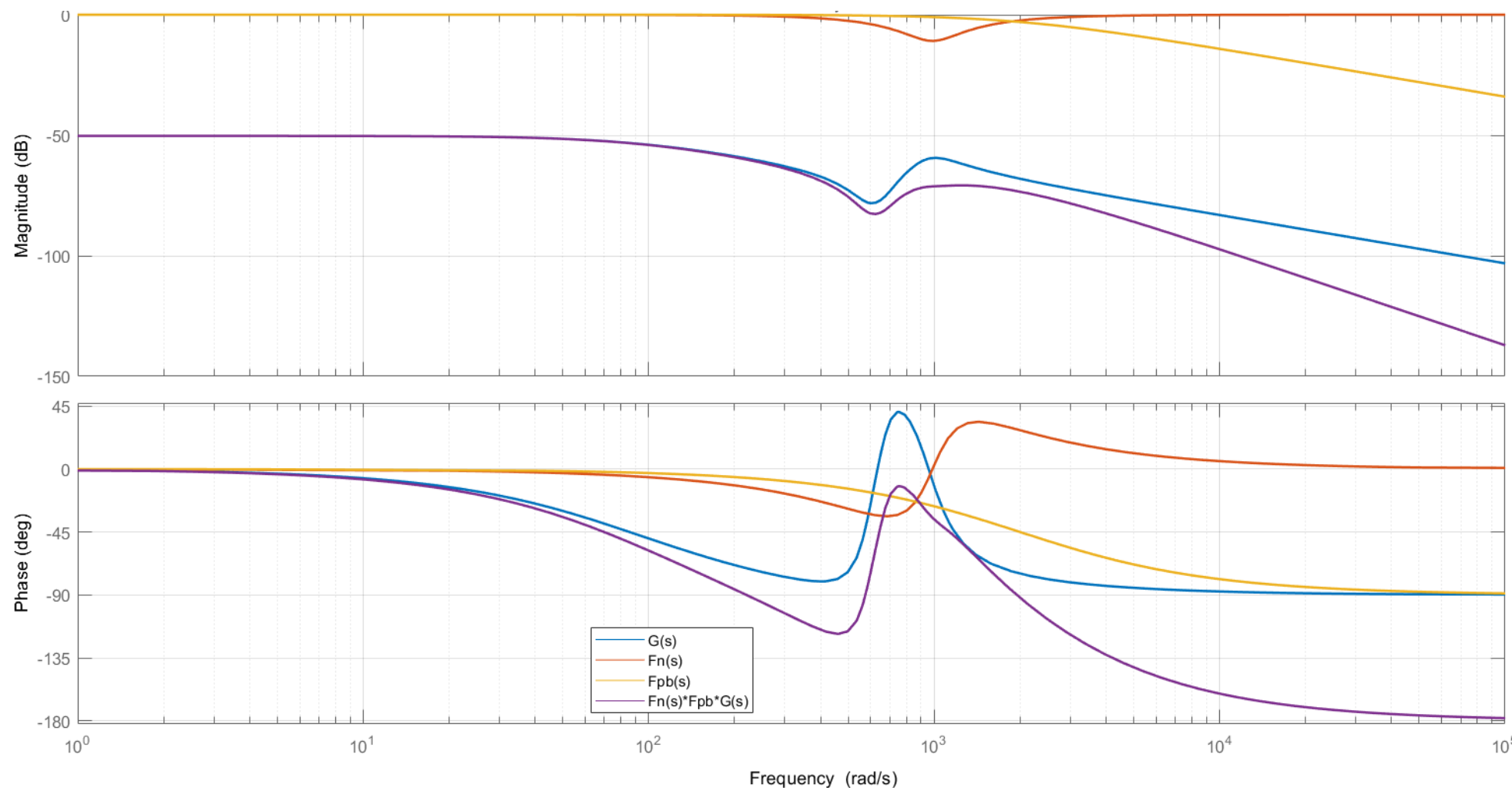
W_n 986 [rad/s]

X_{ci_p} 0.7

X_{ci_z} 0.2

FILTRO PASSA BASSO

W_{pb} 2000



GIUNTO 2 - loop interno - controllore

$W_t = 300 \text{ rad/s}$ $G_m = \text{Inf}$ $P_m = 75^\circ$ $M_s = 1.06$

PI

Kp

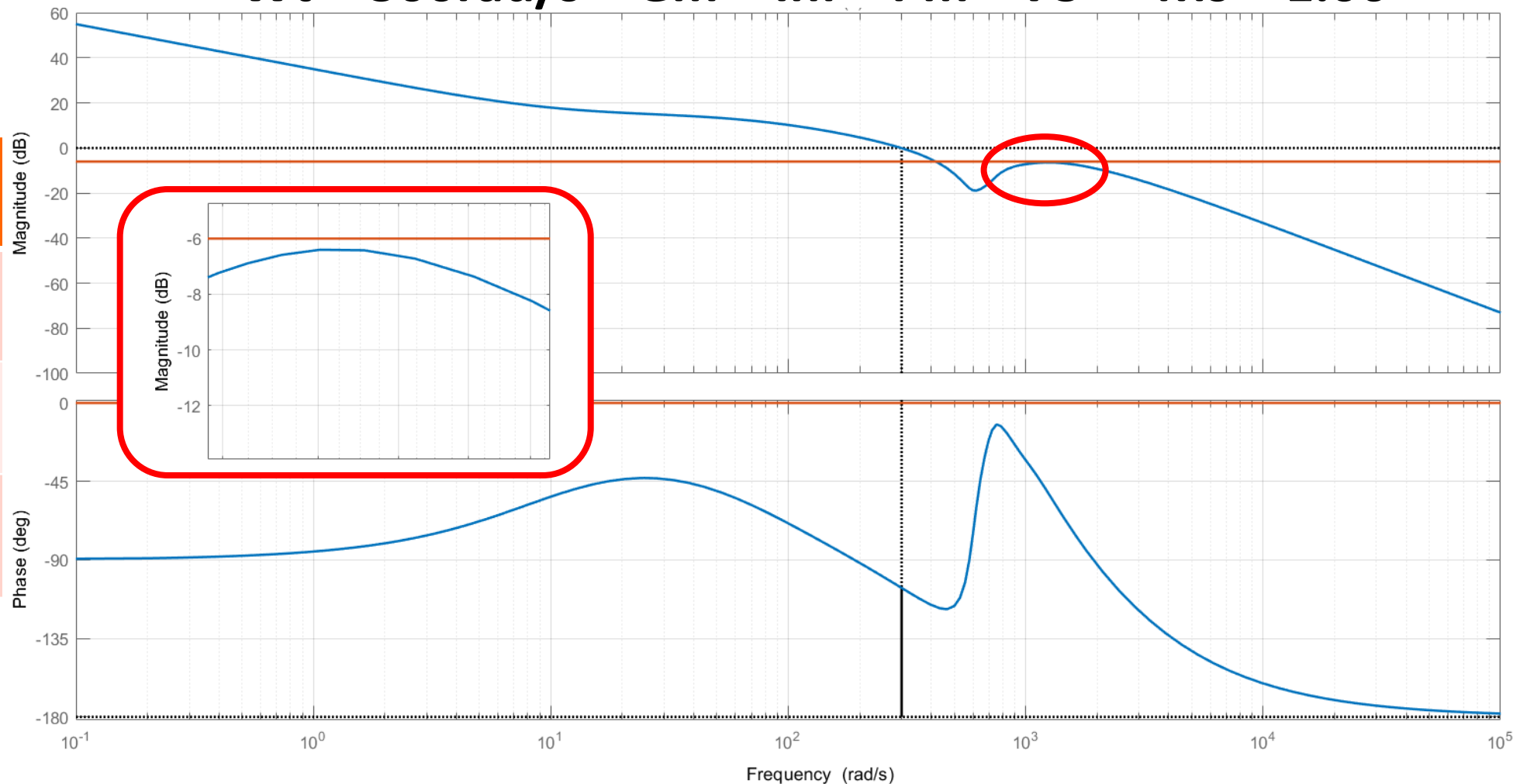
1587.4

Ki

15874

Kaw

10



GIUNTO 2 - loop esterno

$W_t = 105 \text{ rad/s}$ $G_m = 13.8 \text{ dB}$ $P_m = 72^\circ$ $M_s = 1.29$

P

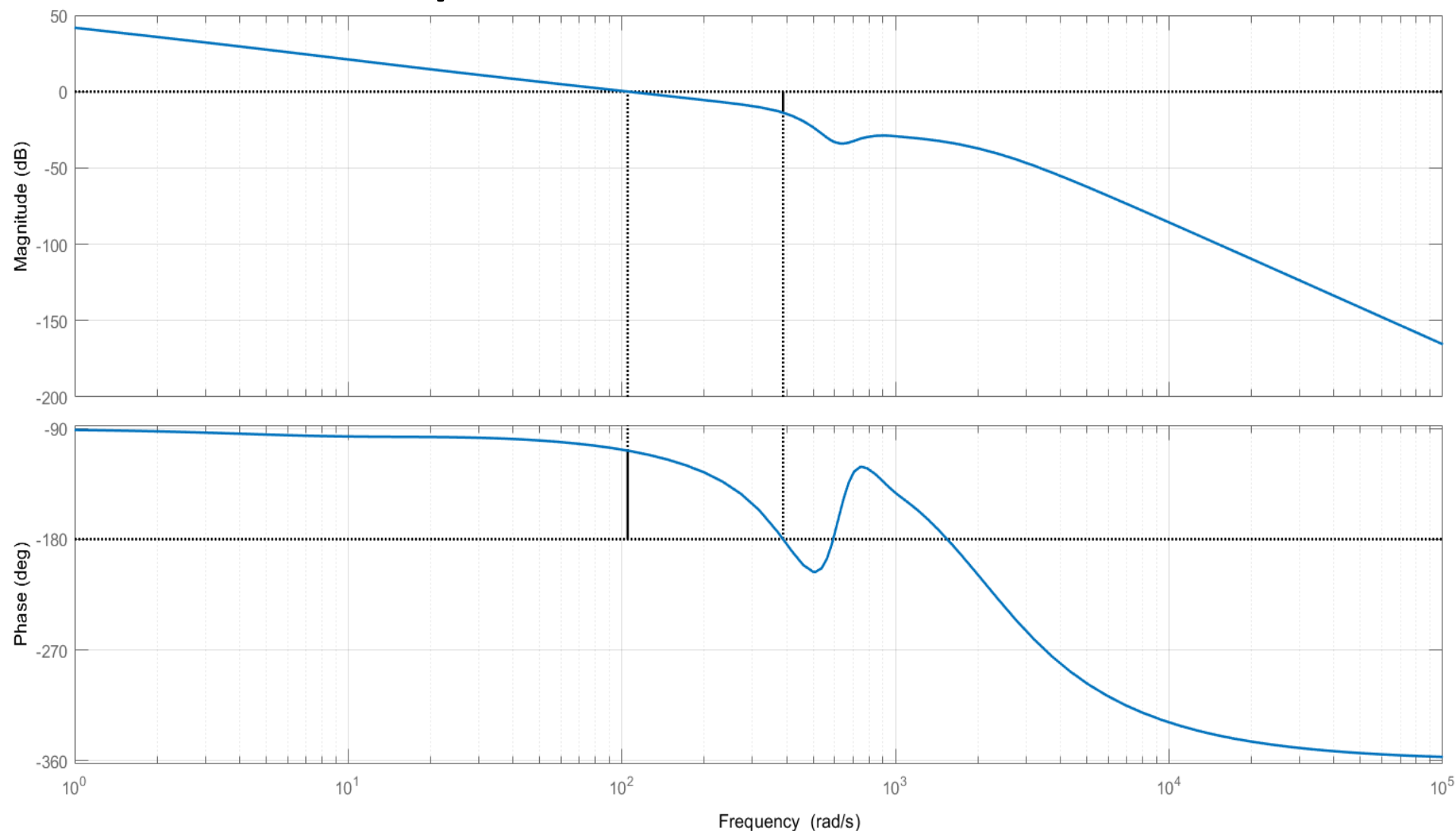
K_p

120.47

FILTRO PASSA BASSO

W_{pb}

2000





1

Introduzione

2

Identificazione

3

Modellizzazione

4

Controllo

5

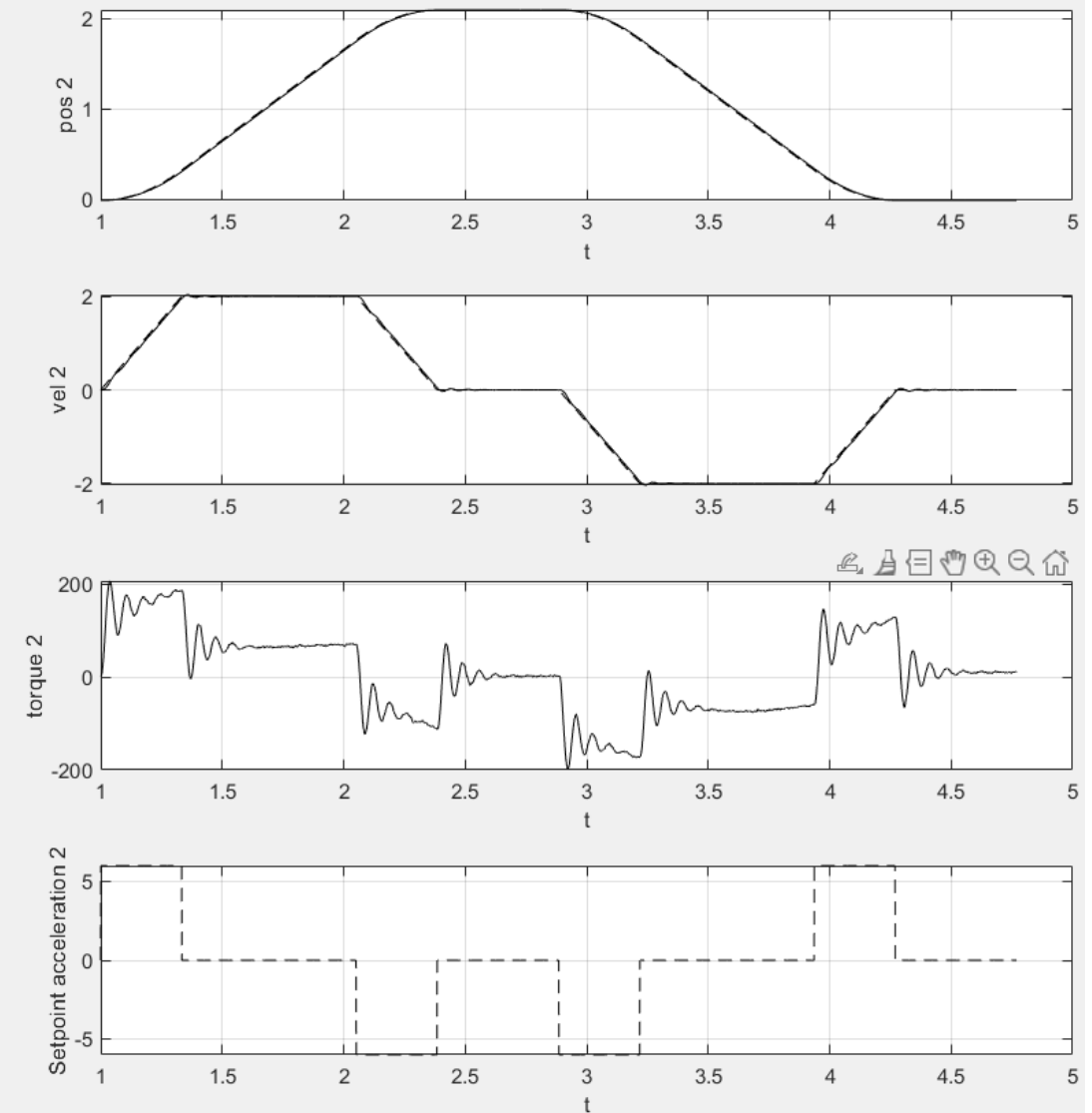
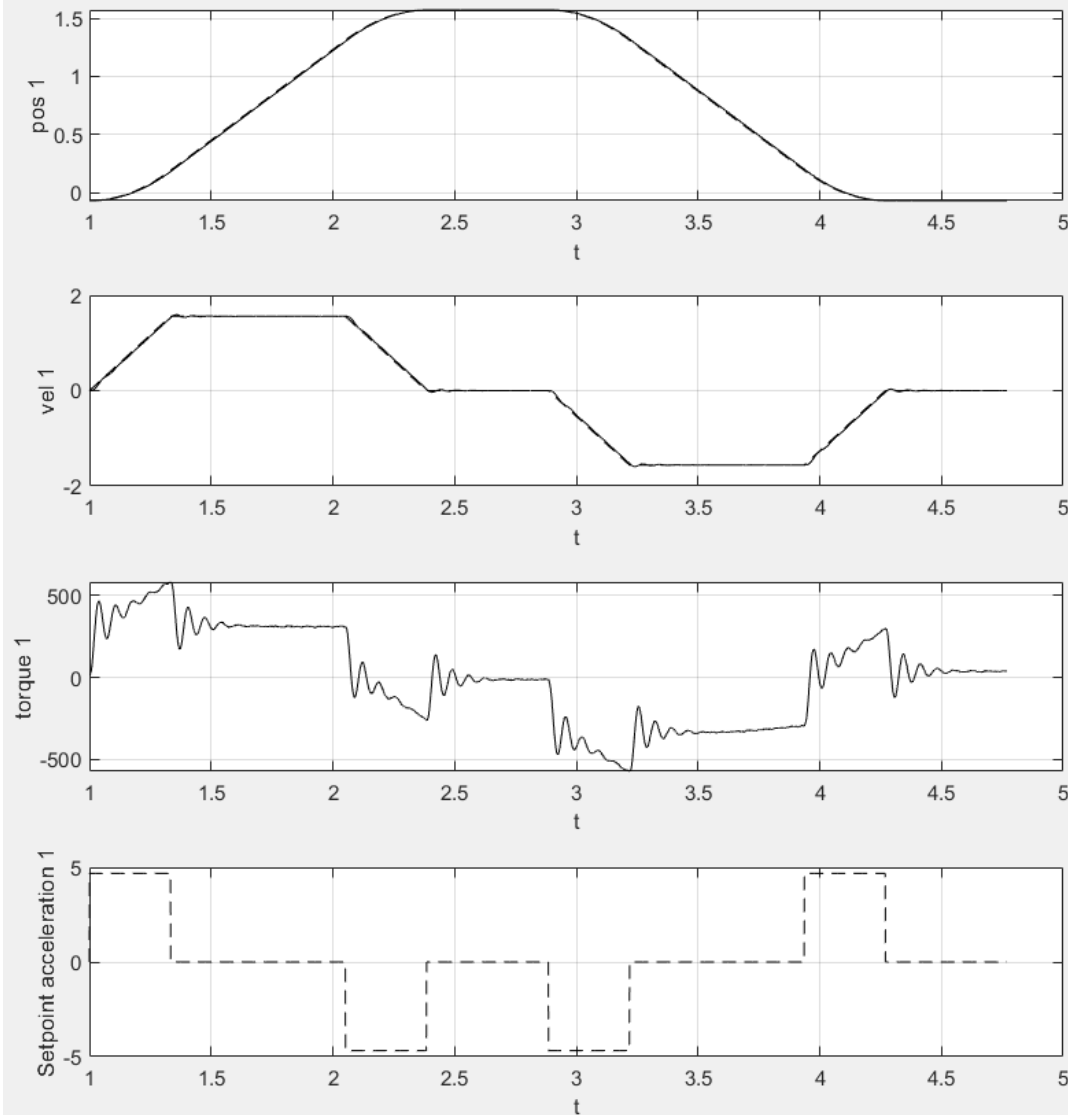
Taratura

6

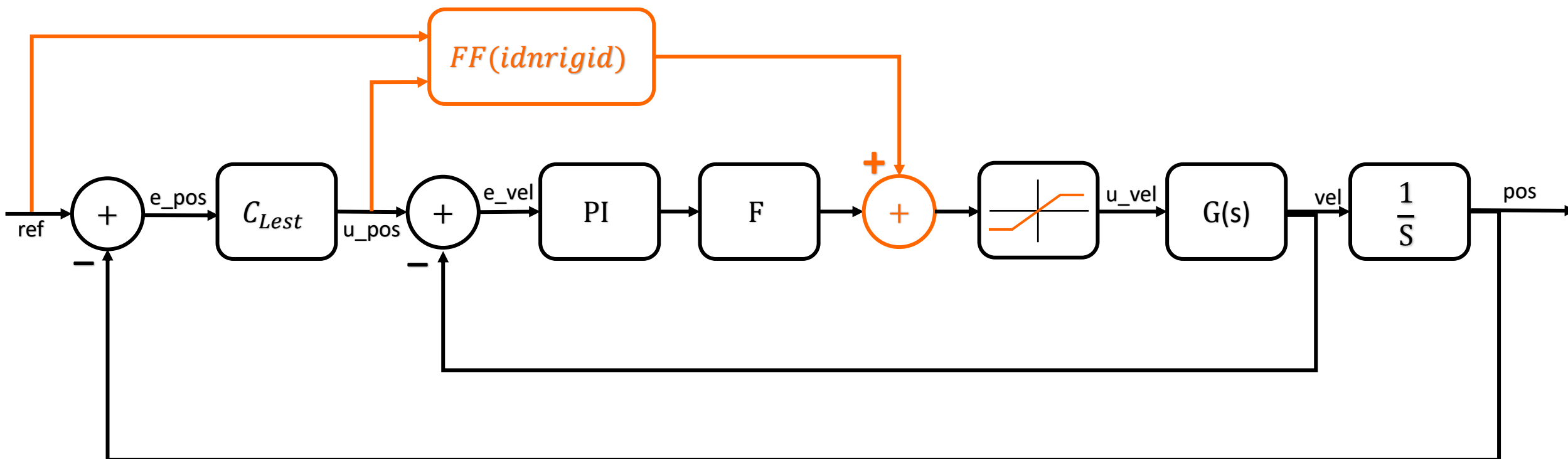
Risultati

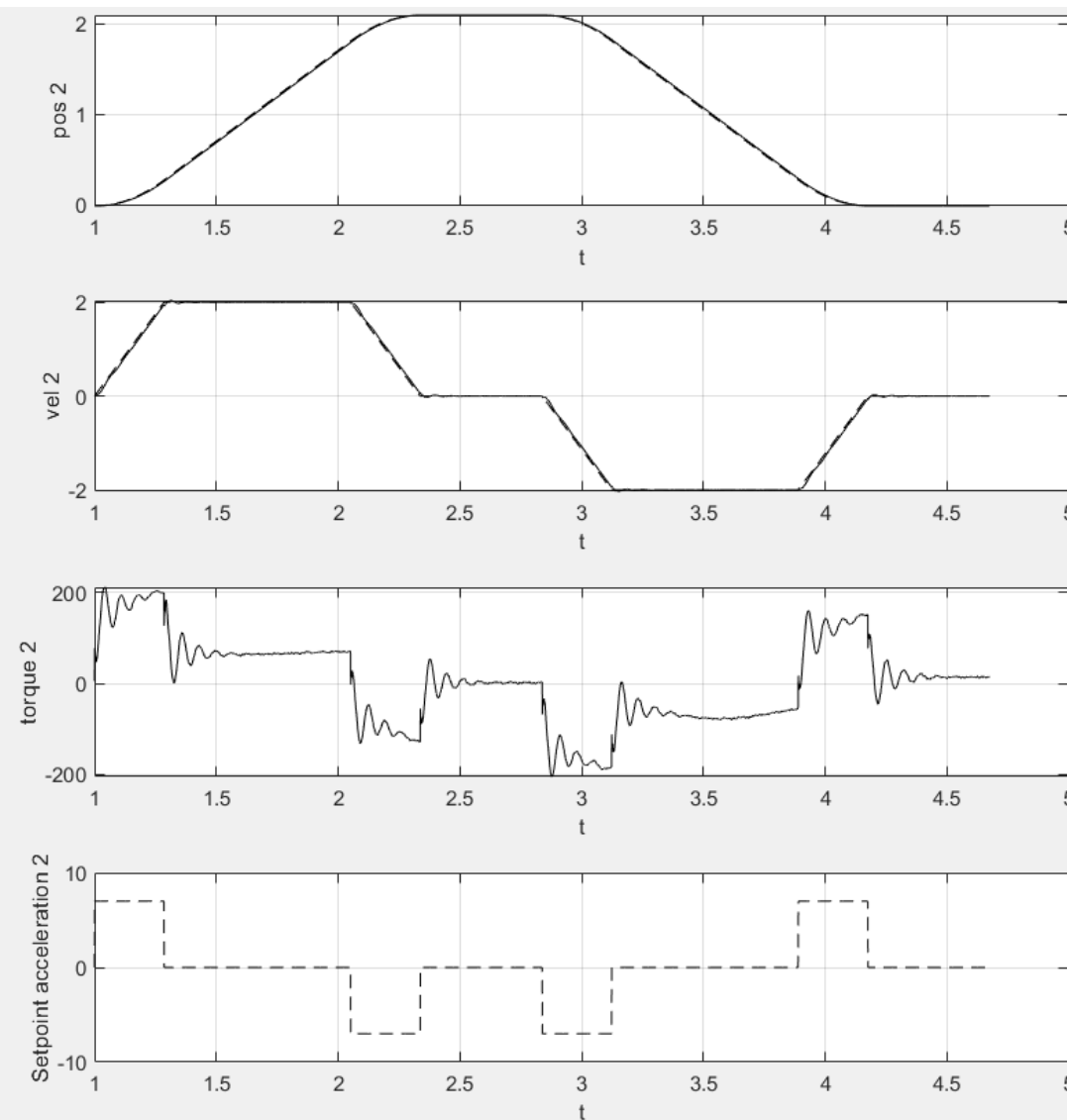
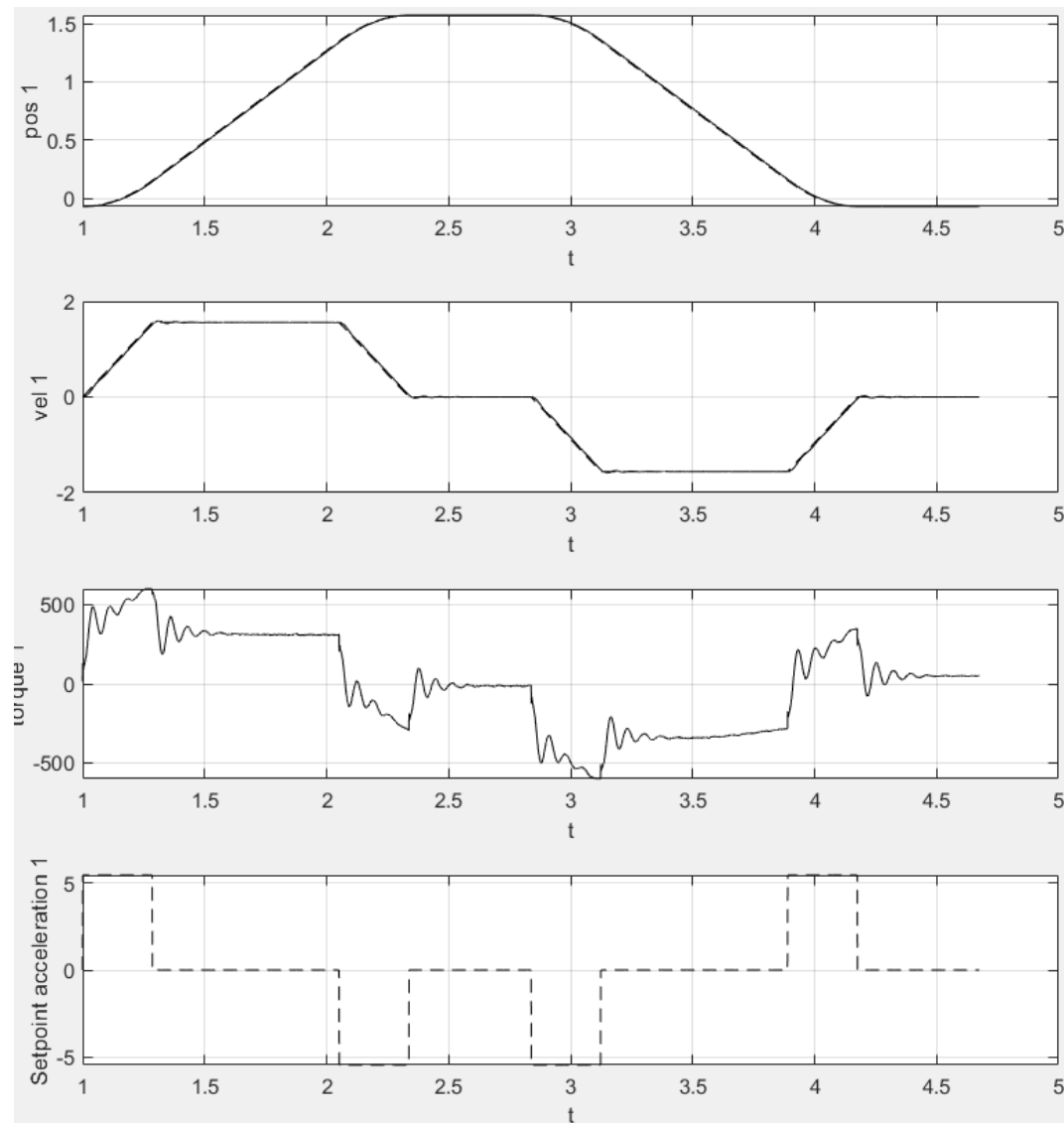
7

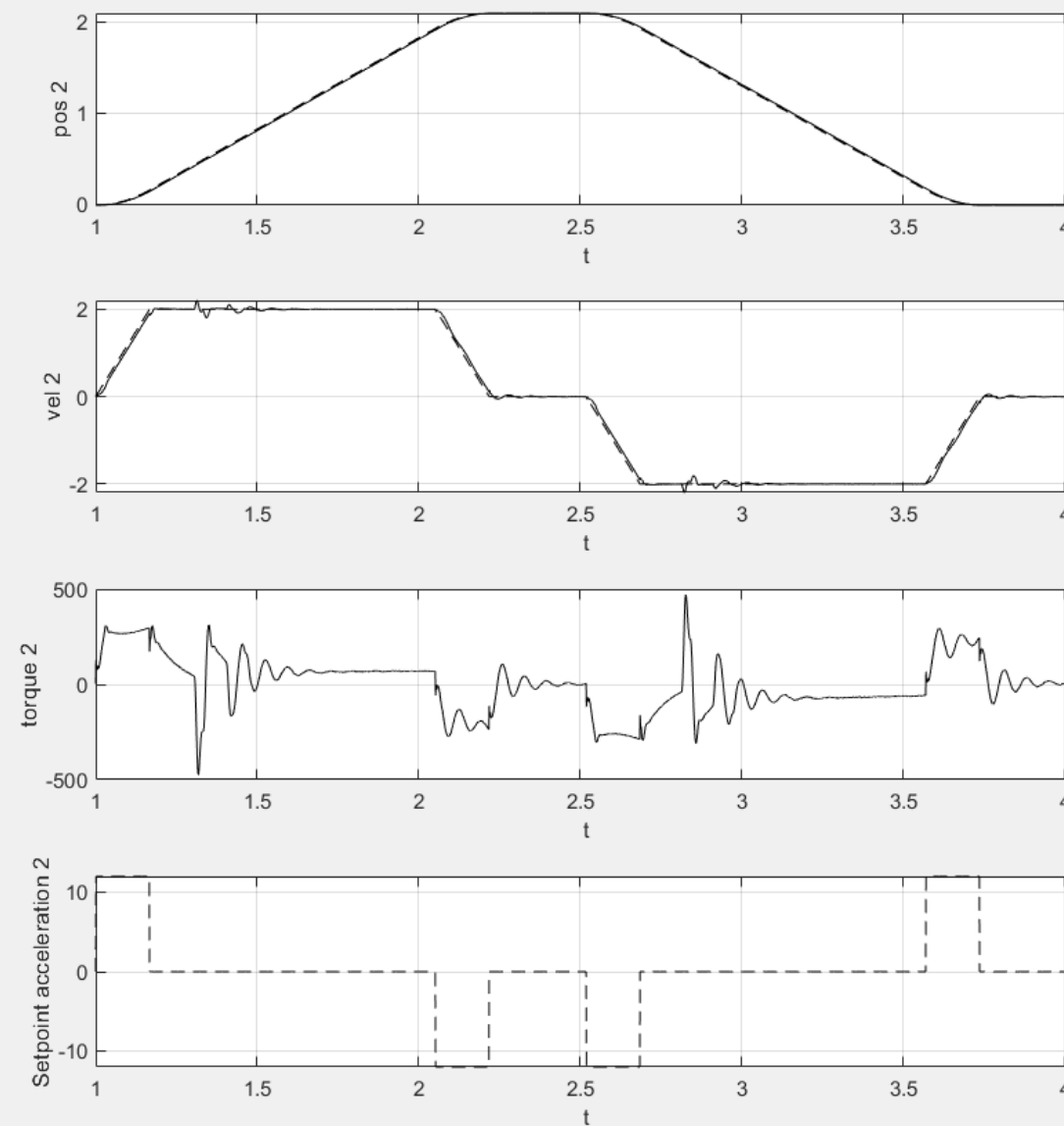
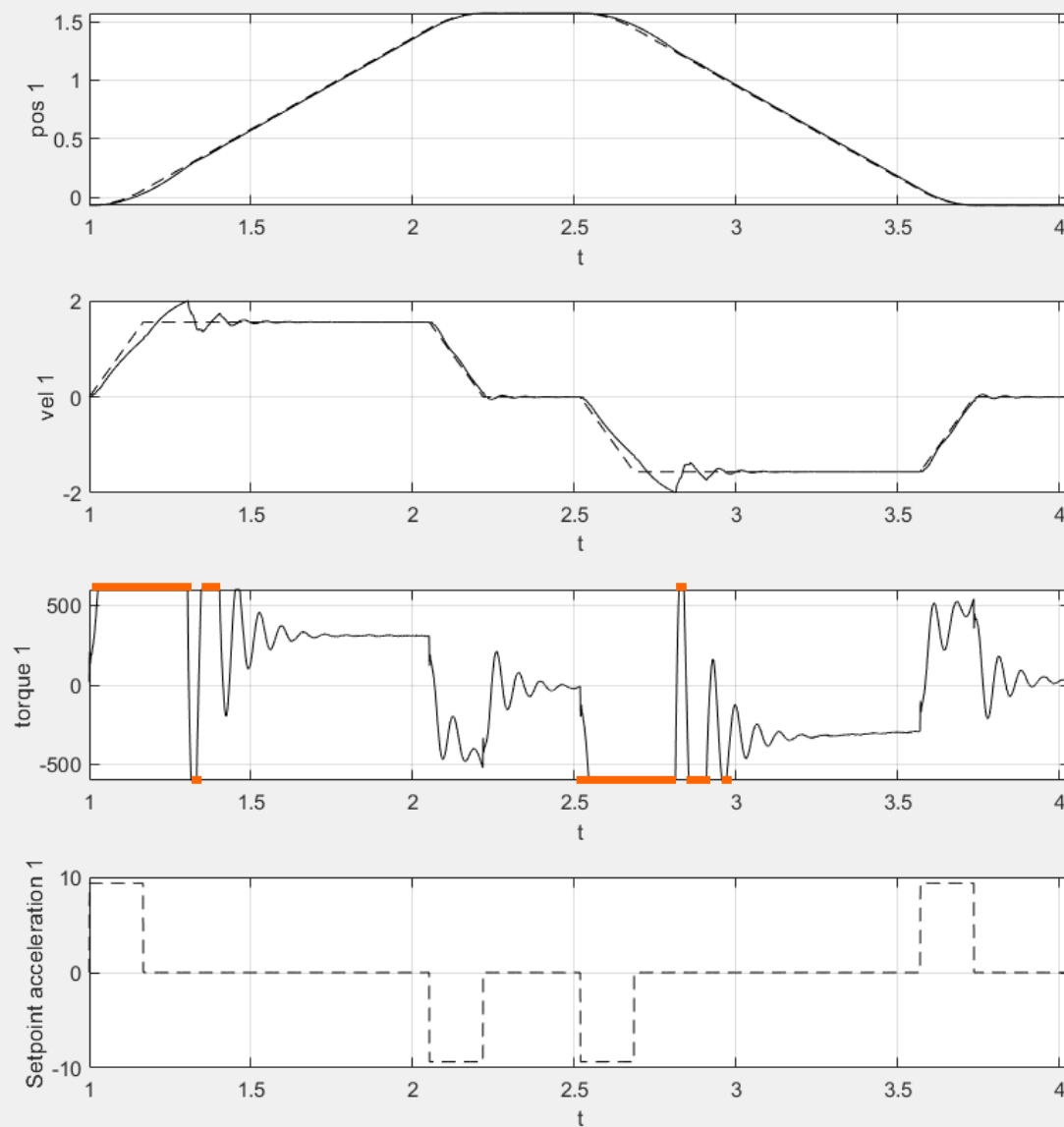
Conclusioni

REST_TIME = 0.5**MAX_ACC = 5****SCORE = 32.18**

AGGIUNTA AZIONE FEEDFORWARD COPPIA



REST_TIME = 0.5**MAX_ACC = 7****SCORE = 32.42**

REST_TIME = 0.3**MAX_ACC = 12****SCORE = 33.77**



1

Introduzione

2

Identificazione

3

Modellizzazione

4

Controllo

5

Taratura

6

Risultati

7

Conclusioni



TARATURA

- Introduzione di algoritmi per la taratura per una migliore che considerano M_s , G_m e P_m
- Basare la funzione di costo non solo sul modello ma anche sulla risposta della simulazione per tener conto anche delle azioni di feedforward e saturazione del sistema



FEEDFORWARD

Si potrebbe pensare di inserire il feedforward anche nell'anelo esterno per aumentare le prestazioni del controllore, e di inserire all'interno della funzione anche il già esistente il peso dello oggetto spostato



IDENTIFICAZIONE

Introdurre un controllore che nella fase di identificazione si occupi di inserire i freni nel caso il sistema diverga e annulli il test

Dipartimento di Ingegneria Meccanica e Industriale
Corso di Laurea Automazione Industriale



UNIVERSITÀ
DEGLI STUDI
DI BRESCIA

GRAZIE PER L'ATTENZIONE

Per ulteriori informazioni visitare : https://github.com/EdoGitMira/Progetto_LAB_Automatica.git

Anno Accademico 2022-2023