

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

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Pennacchio Manuele – 721965

Anno Accademico 2022-2023



- 1 Introduzione**
- 2 Identificazione**
- 3 Modellizzazione**
- 4 Controllo**
- 5 Taratura**
- 6 Risultati**
- 7 Conclusioni**



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Introduzione

Identificazione

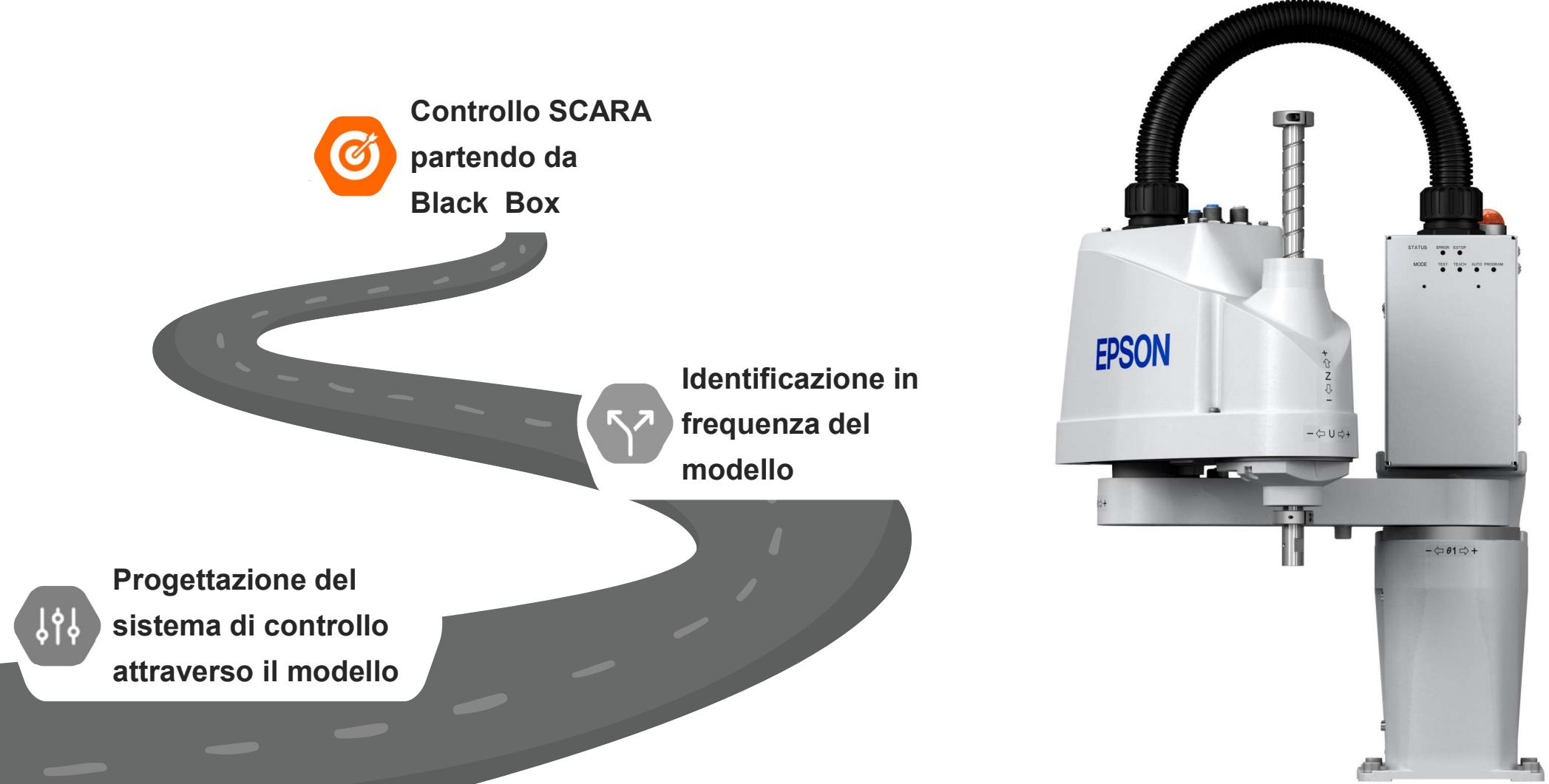
Modellizzazione

Controllo

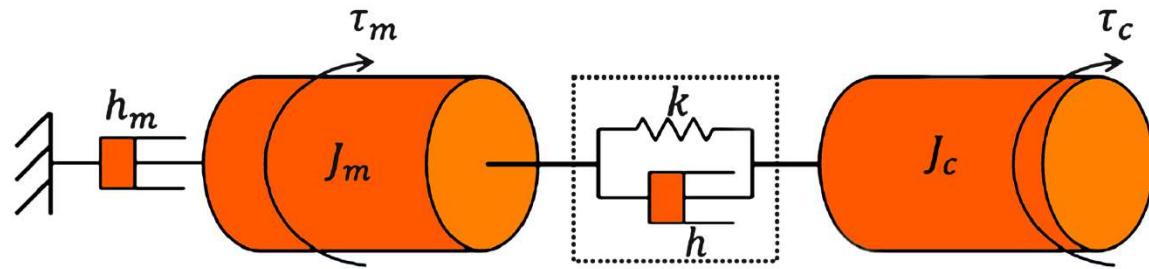
Taratura

Risultati

Conclusioni



MODELLIZZAZIONE DELLO SCARA - TRASMISSIONE ELASTICA



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

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



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Taratura

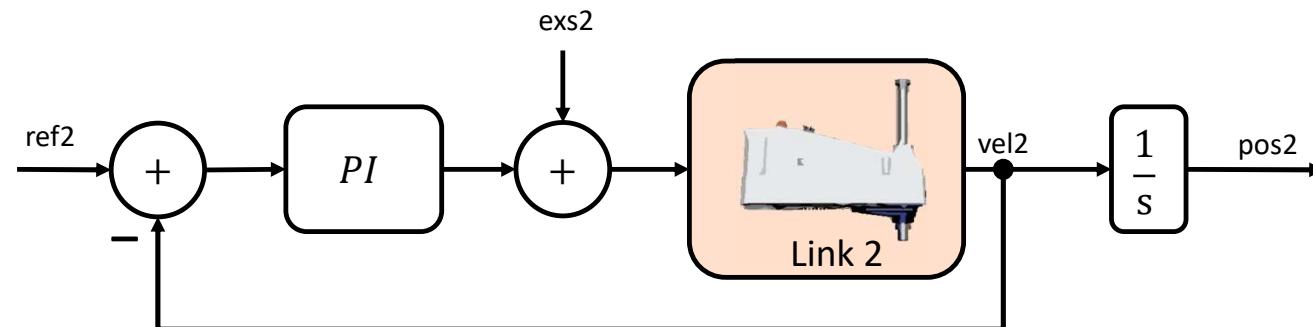
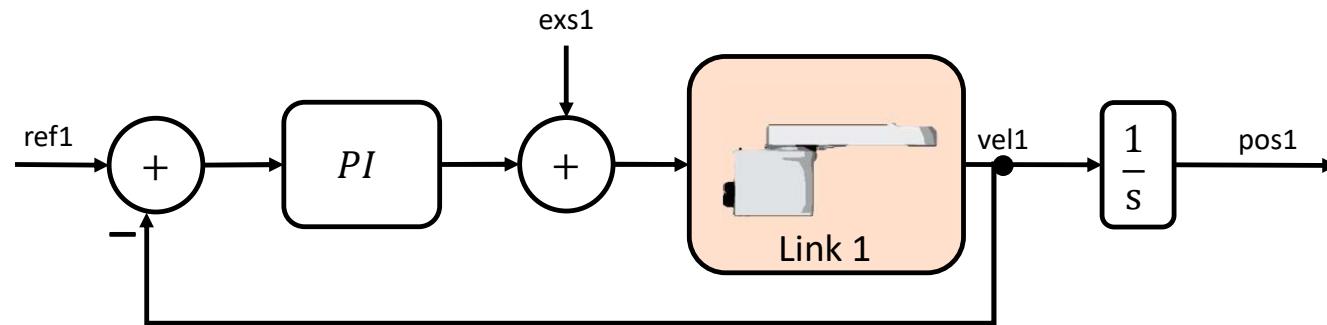
6

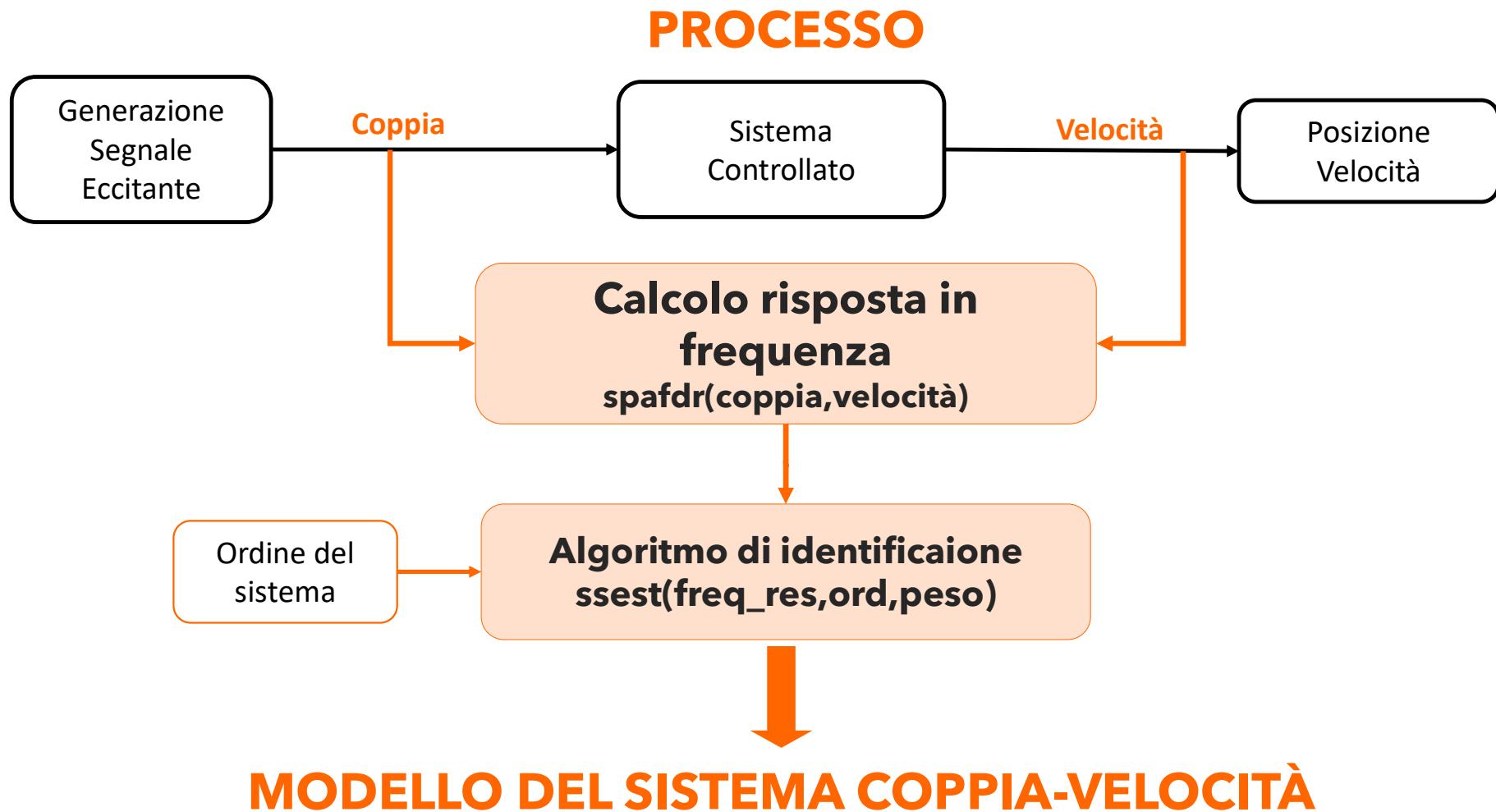
Risultati

7

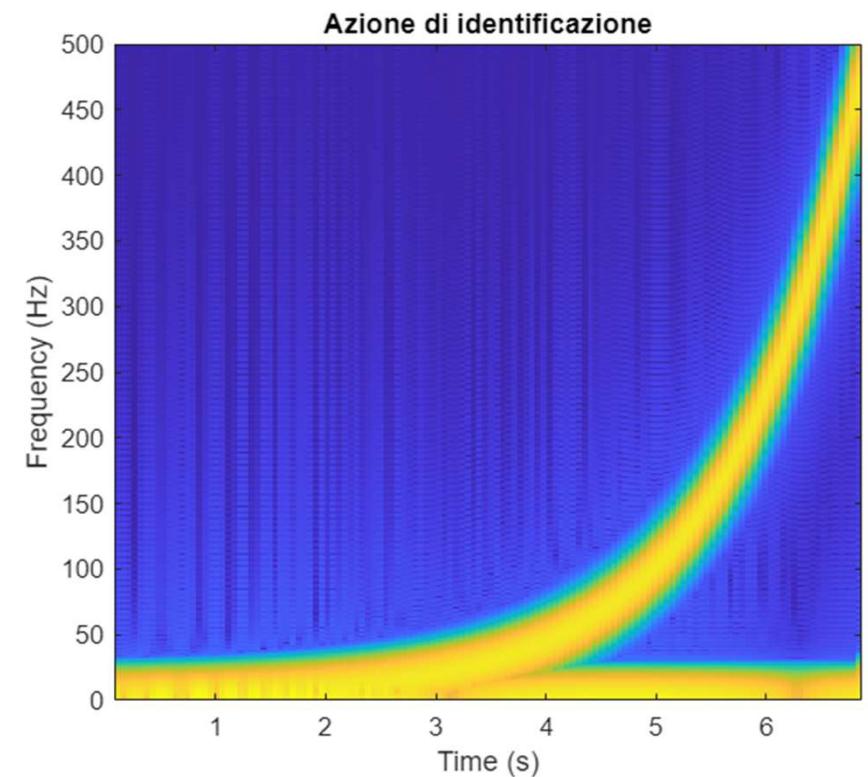
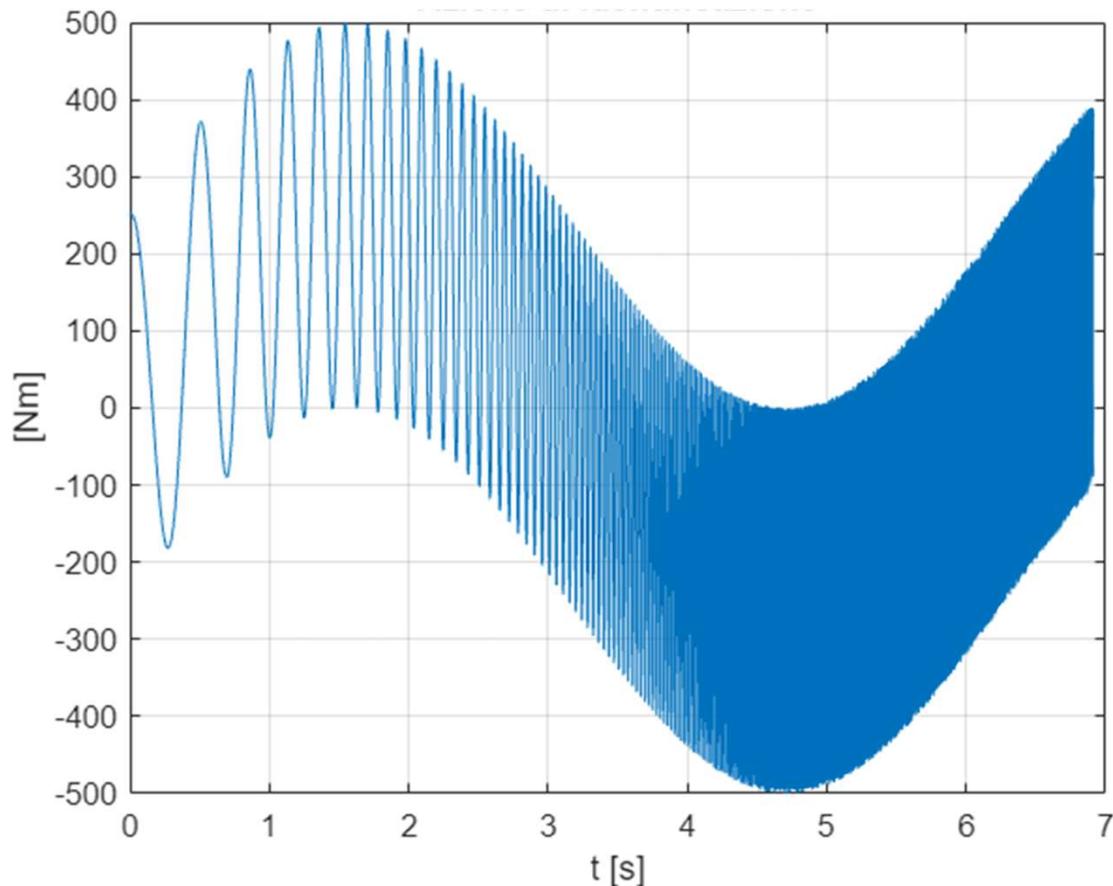
Conclusioni

CONTOLLO PER L'IDENTIFICAZIONE - CLOSED LOOP ARCHITETTURA DECENTRALIZZATA





SEGNALE ECCITANTE

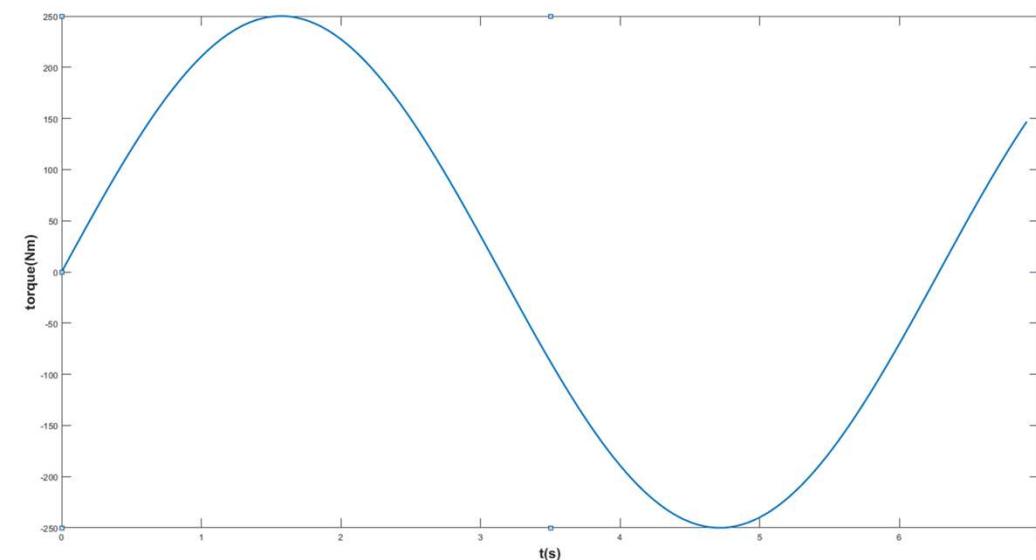


CHIRP + PORTANTE

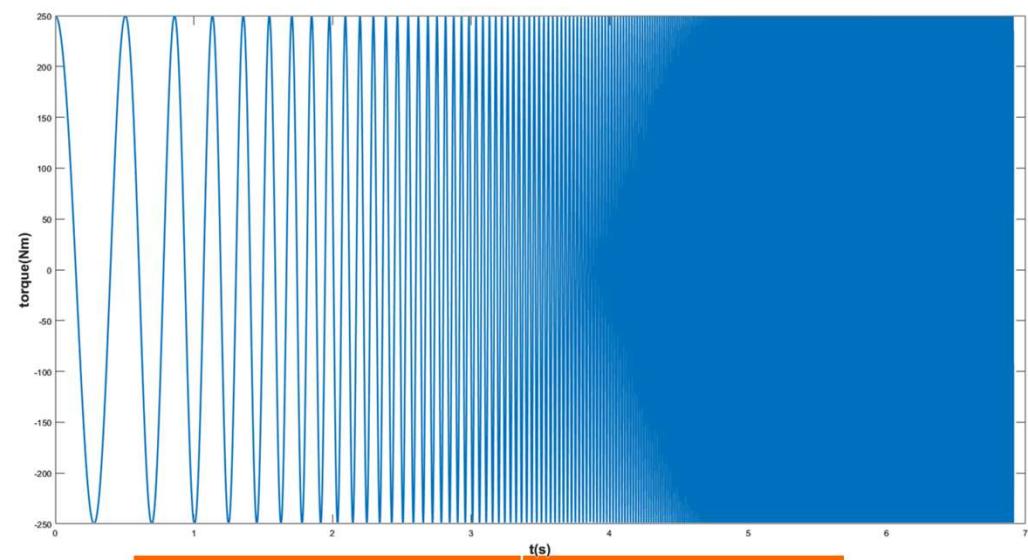
SEGNALE ECCITANTE

PORTANTE

CHIRP

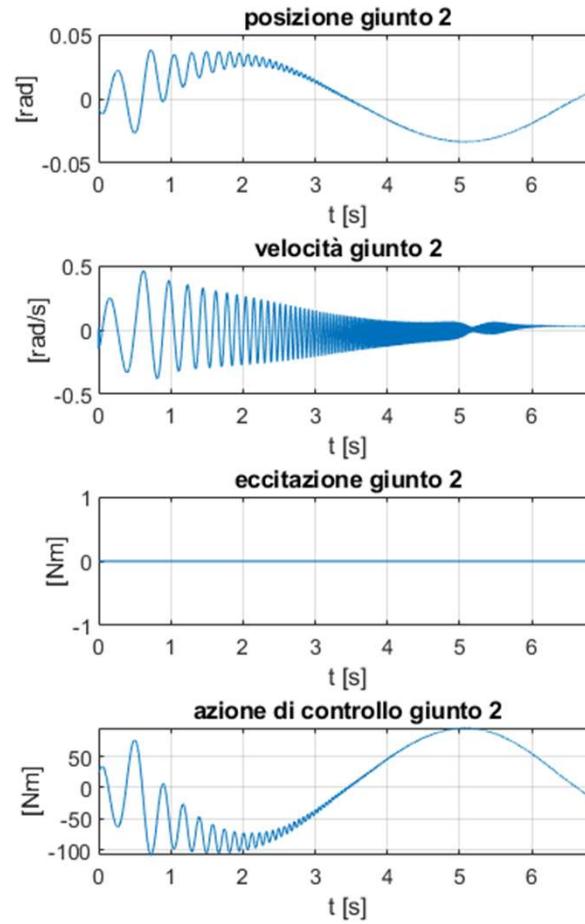
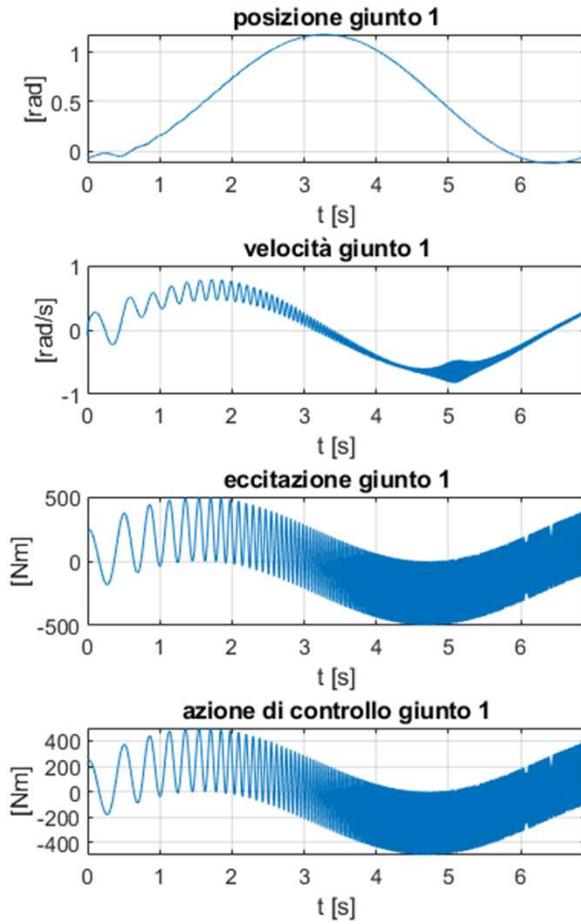


PARAMETRI	VALORE
Pulsazione	1 [rad/s]
Aampiezza	250[Nm]



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

GIUNTO 1



CHIRP

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

Portante

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

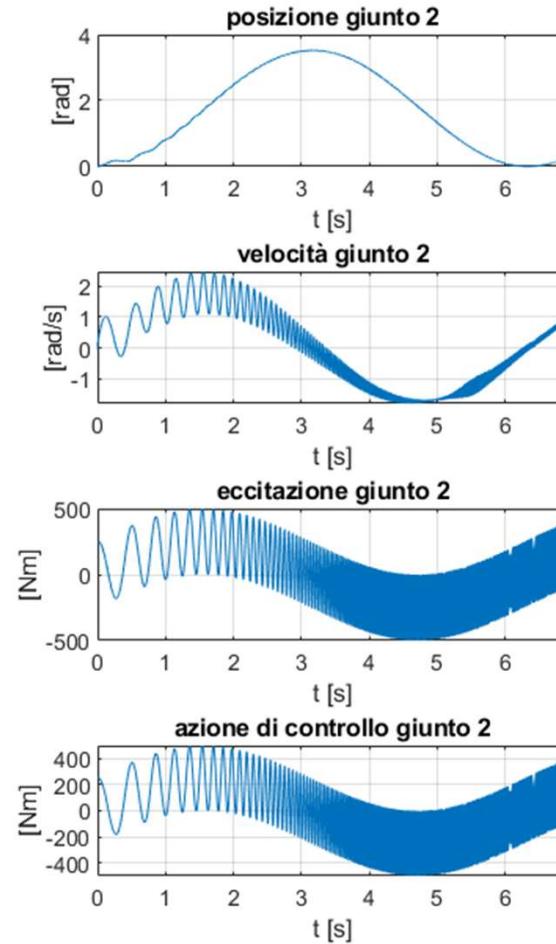
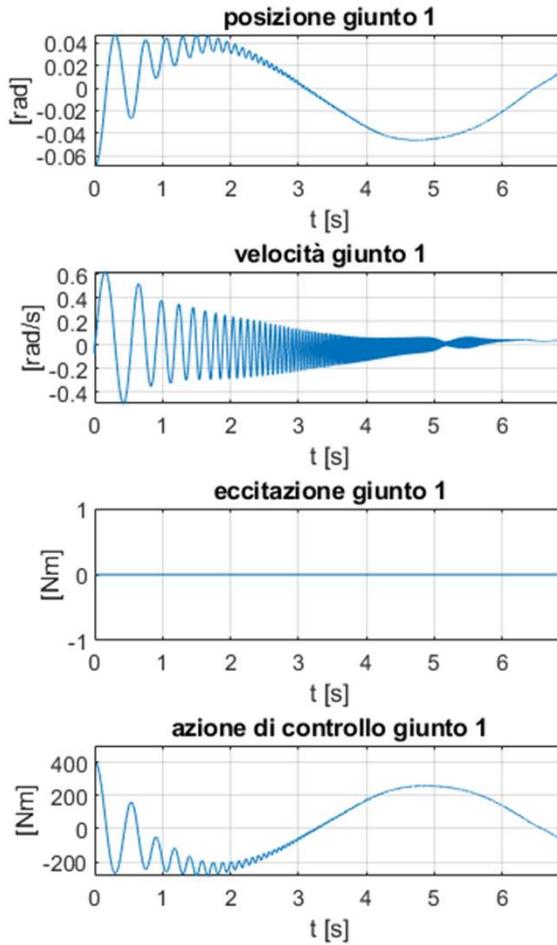
Controllore PI giunto 2

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

Controllore PI giunto 1

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

GIUNTO 2



CHIRP

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

Portante

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

Controllore PI giunto 2

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

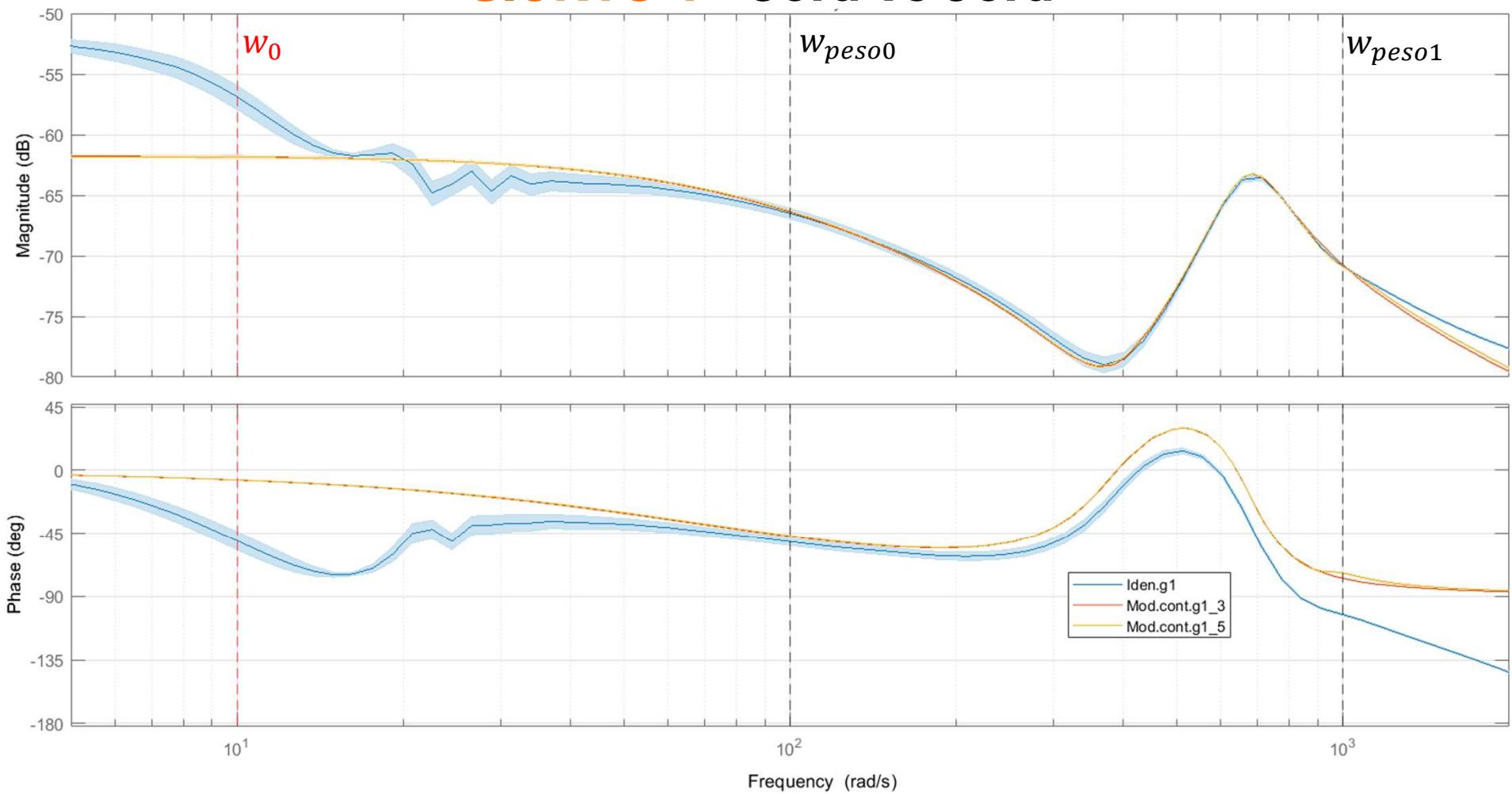
Controllore PI giunto 1

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



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GIUNTO 1 - 3ord Vs 5ord



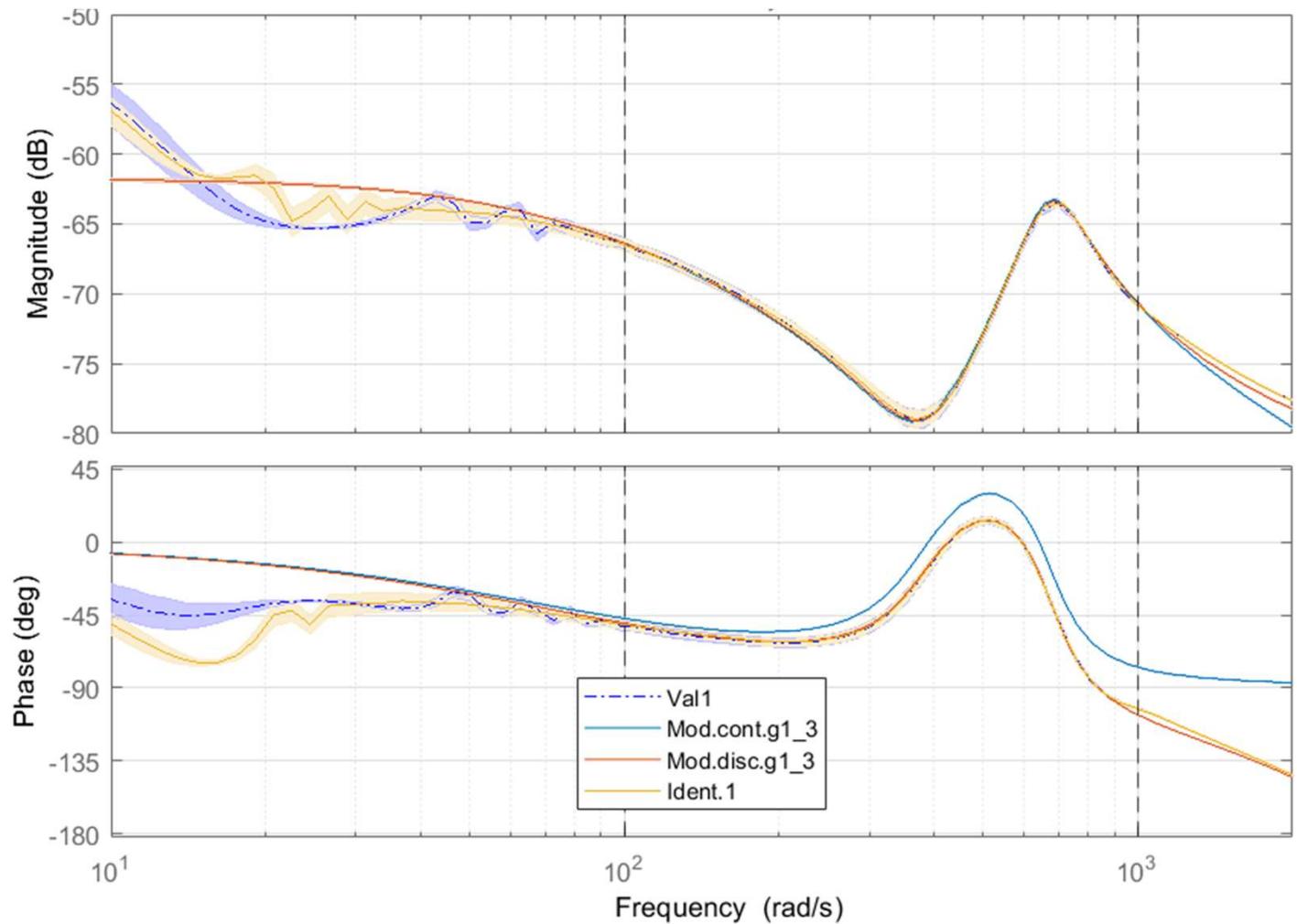
VALIDAZIONE GIUNTO 1

CHIRP

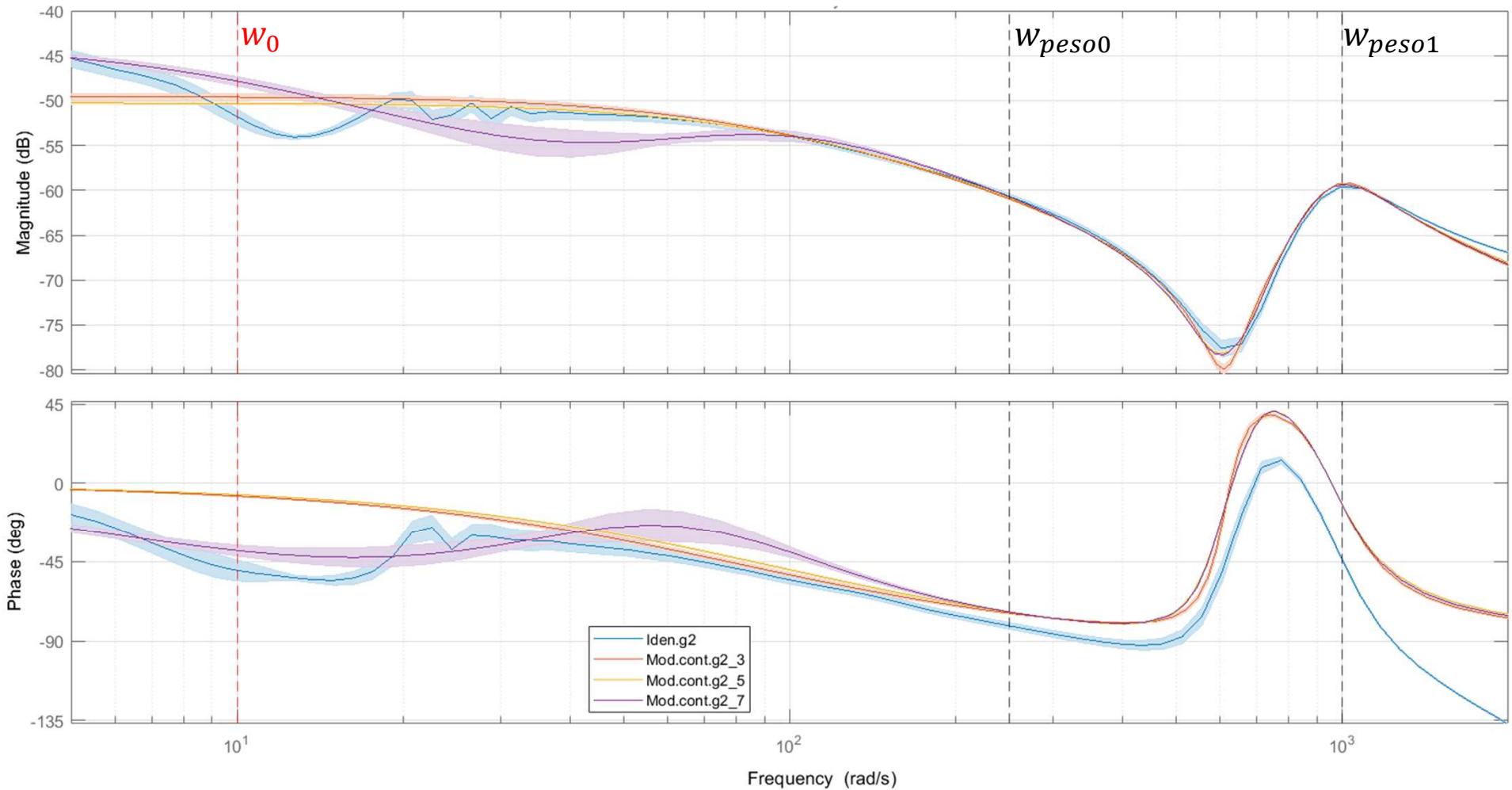
- $\omega = 20 \div 3141 \frac{rad}{s}$
- $A = 300Nm$

Portante

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



GIUNTO 2 - 3ord Vs 5ord Vs 7ord



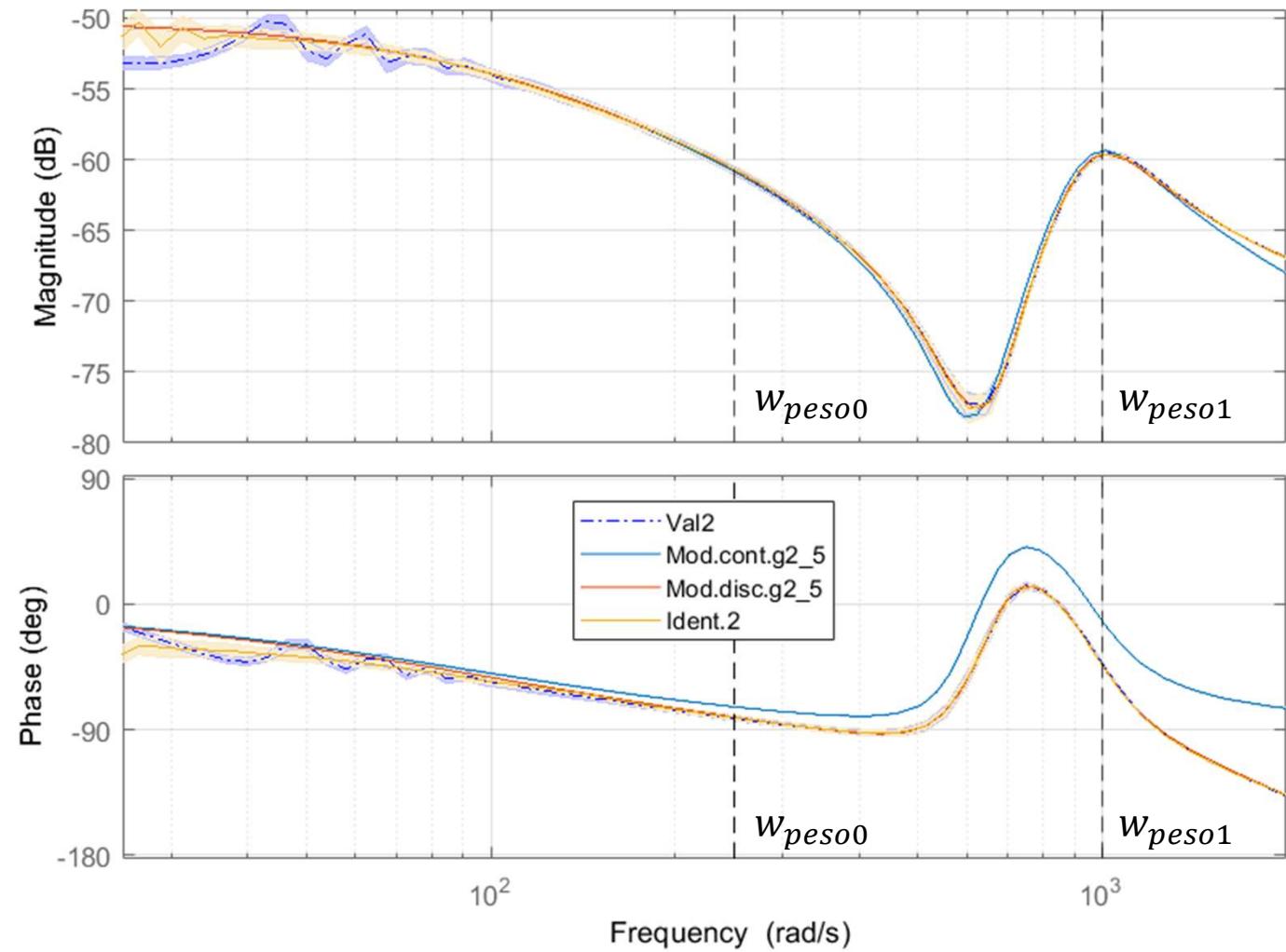
VALIDAZIONE GIUNTO 2

CHIRP

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

Portante

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

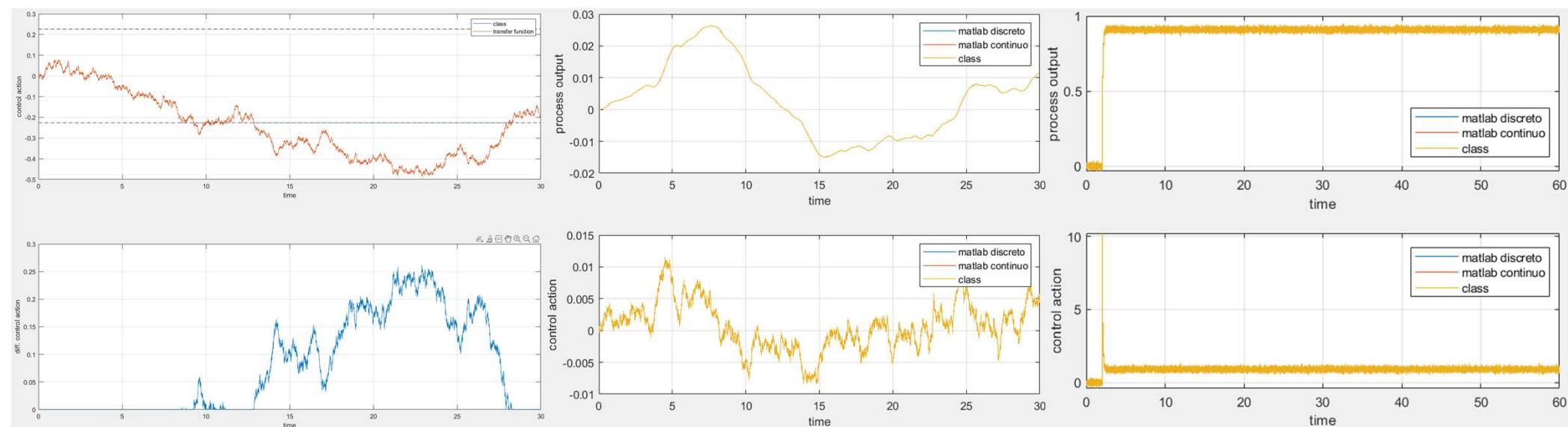
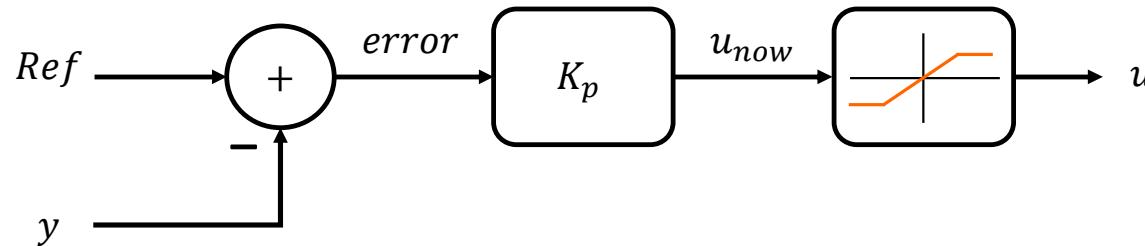




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CONTROLLORE P - TEST



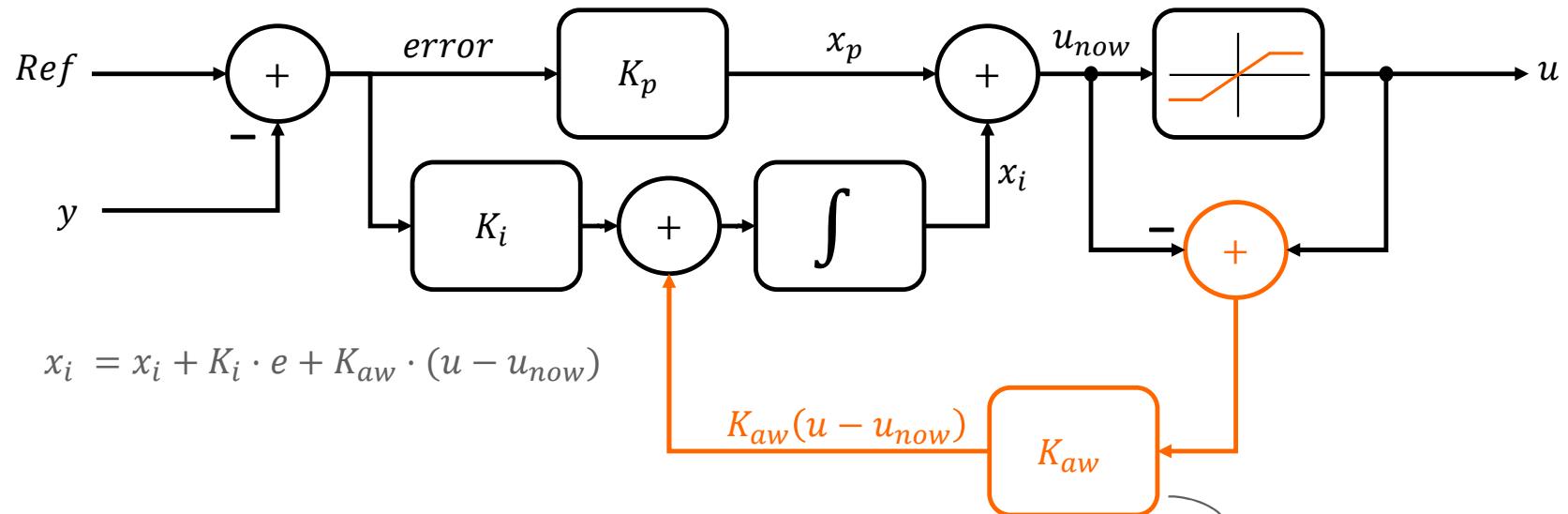
 **Test 2**

 **Test 3**

 **Test 4**

CONTROLLORE PI - Back Calculation

L'azione integrale viene ricalcolata quando avviene una saturazione dell'attuatore,
si usa il blocco di saturazione come modello dell'attuatore

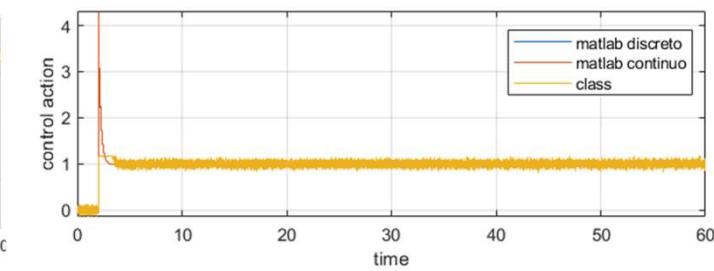
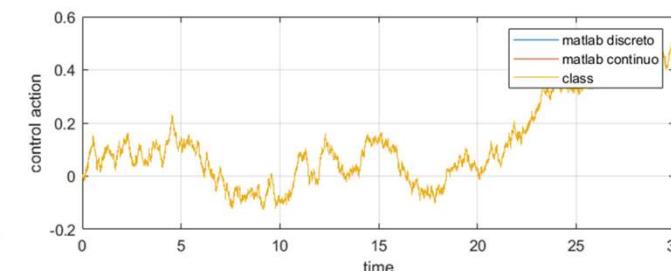
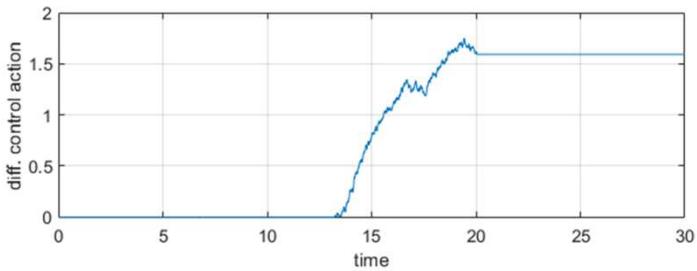
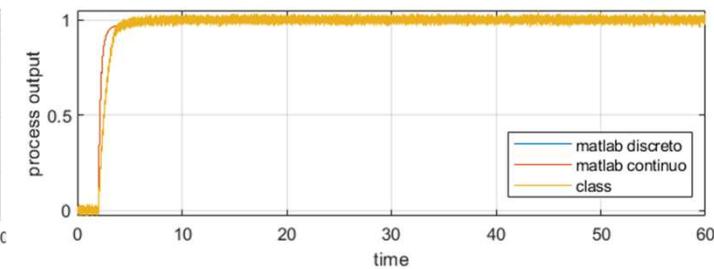
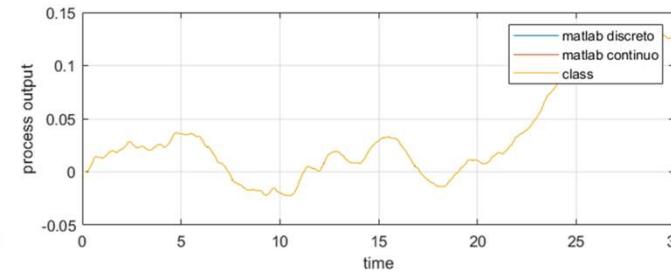
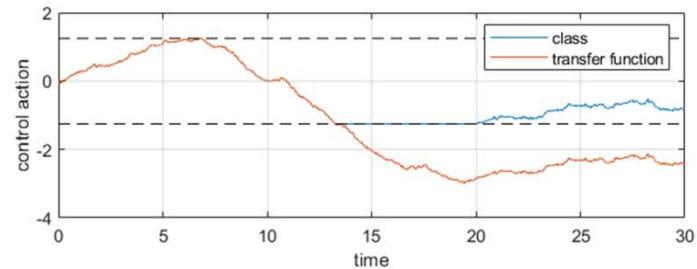


Per regole empiriche:

- $K_{aw} \rightarrow$ guadagno di anti wind-up
- $T_t = T_i \rightarrow$ costante di tempo di tracciamento, velocità di decremento dell'azione integrale

$$K_{aw} = \frac{K_i}{K_p} = \frac{1}{T_i}$$

CONTROLLORE PI - TEST



Test 2

Test 3

Test 4

FILTRO PASSA BASSO - IMPLEMENTAZIONE

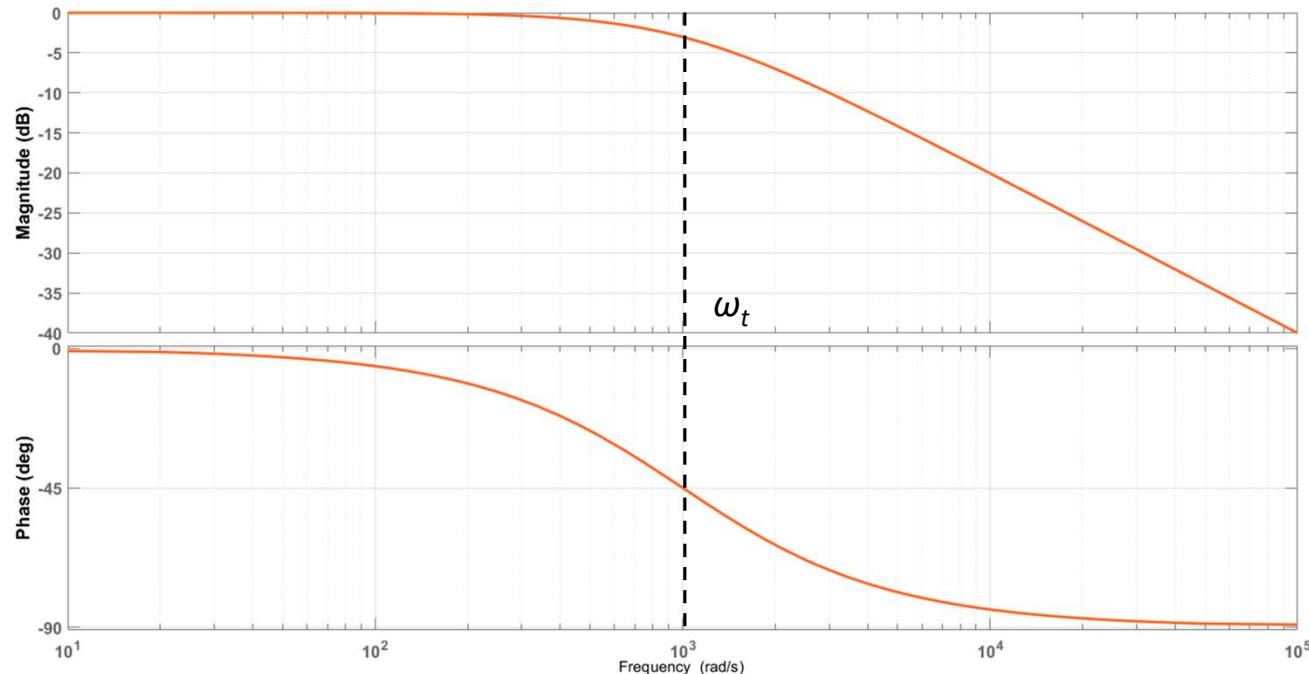
$$F_{PB} = \frac{1}{1 + \tau \cdot s}$$

\downarrow
c2d(F_{PB} , st, 'tustin')

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

\downarrow
da z alle differenze

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

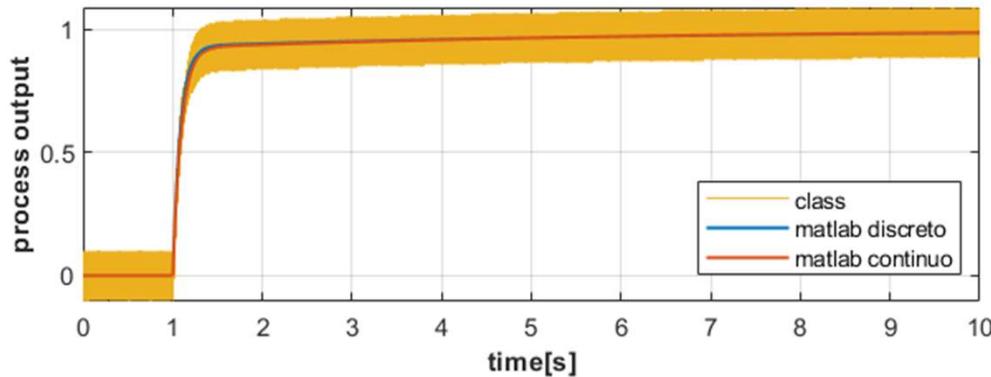


$$\tau = 0.001s \rightarrow \omega_\tau = \frac{1}{\tau} = 1000 \frac{rad}{s}$$

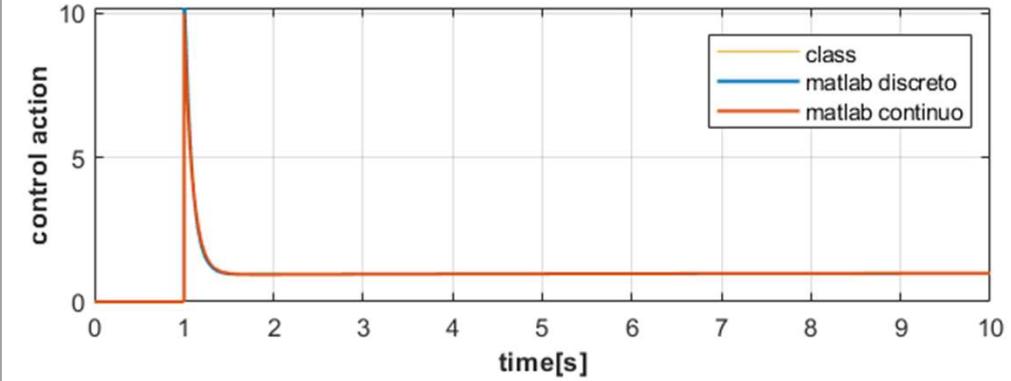
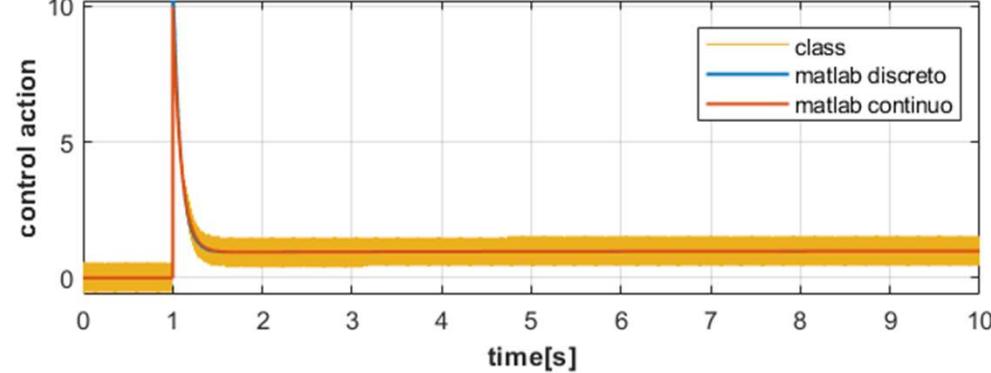
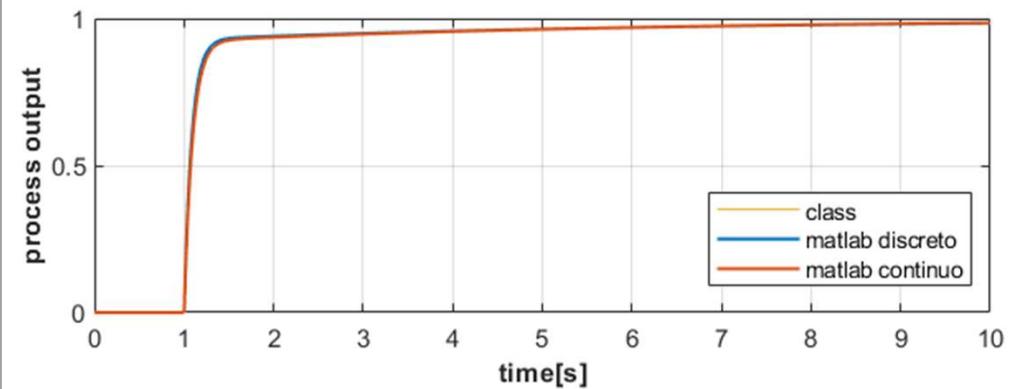
FILTRO PASSA BASSO - TEST



Test1 $noise(t) = 0.1 \cdot \sin(2\pi \cdot 50 \cdot t)$



Test2 $noise(t) = 0.1 \cdot \sin(2\pi \cdot 1000 \cdot t)$



FILTRO NOTCH - IMPLEMENTAZIONE

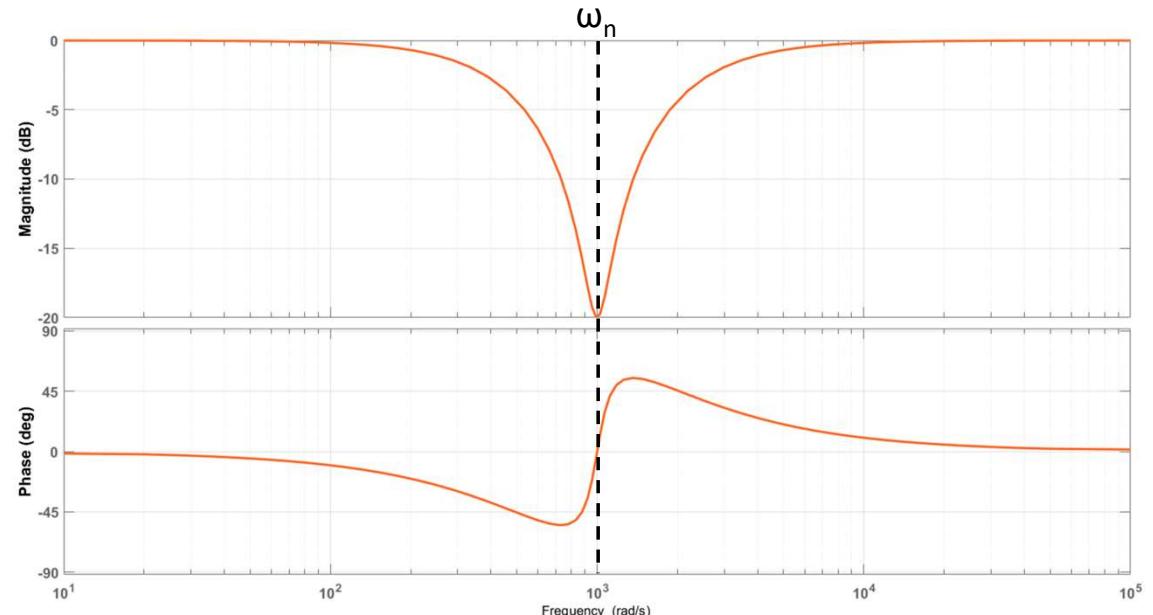
$$F_N = \frac{s^2 + 2 \cdot \omega_n \cdot xci_z \cdot s + \omega_n^2}{s^2 + 2 \cdot \omega_n \cdot xci_p \cdot s + \omega_n^2}$$

c2d(F_N, st, 'tustin')

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

da z alle differenze

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



$$\omega_n = 1000 \frac{\text{rad}}{\text{s}}$$

$$xci_p = 1$$

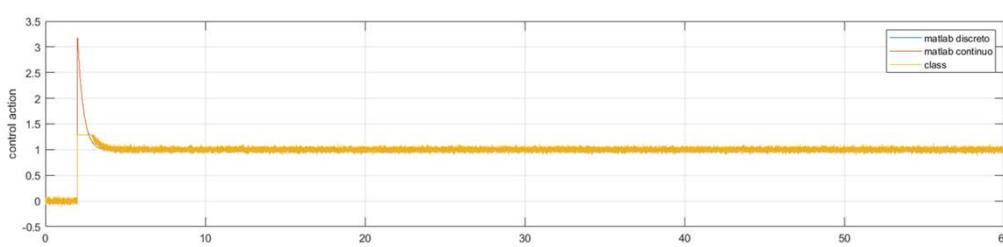
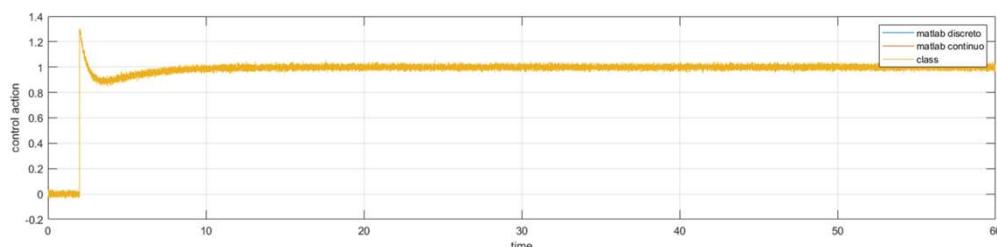
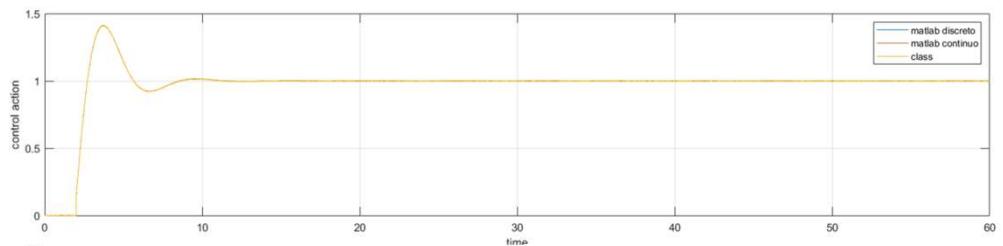
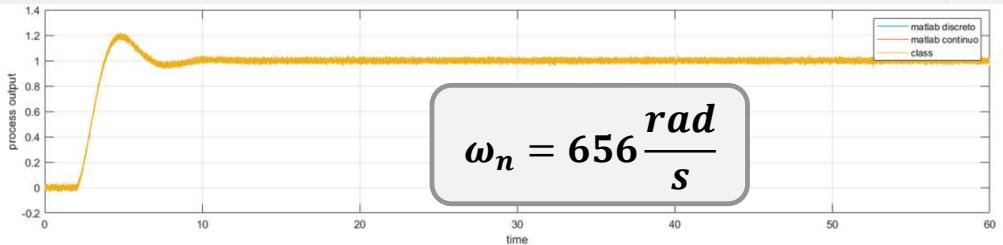
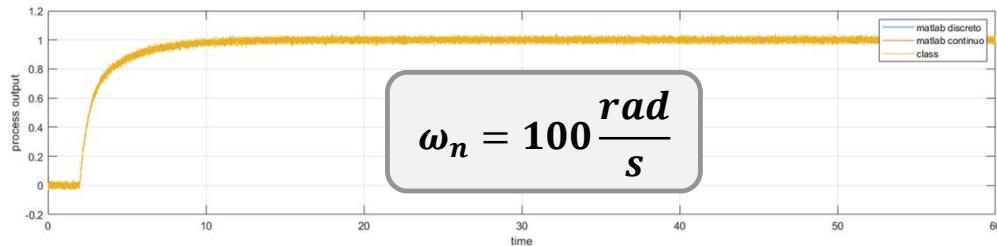
$$xci_z = 0.1$$

FILTRO NOTCH - TEST



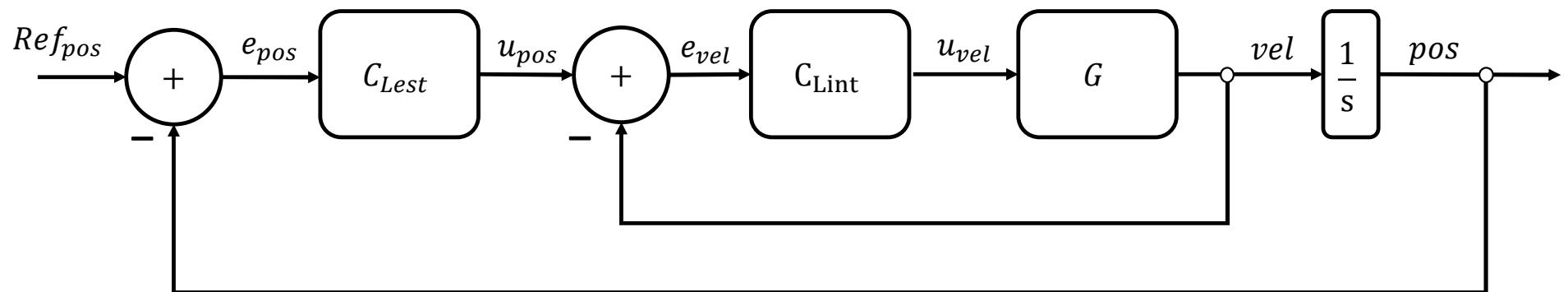
Test4 $noise(t) = 0.1 \cdot \sin(\omega \cdot t)$

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



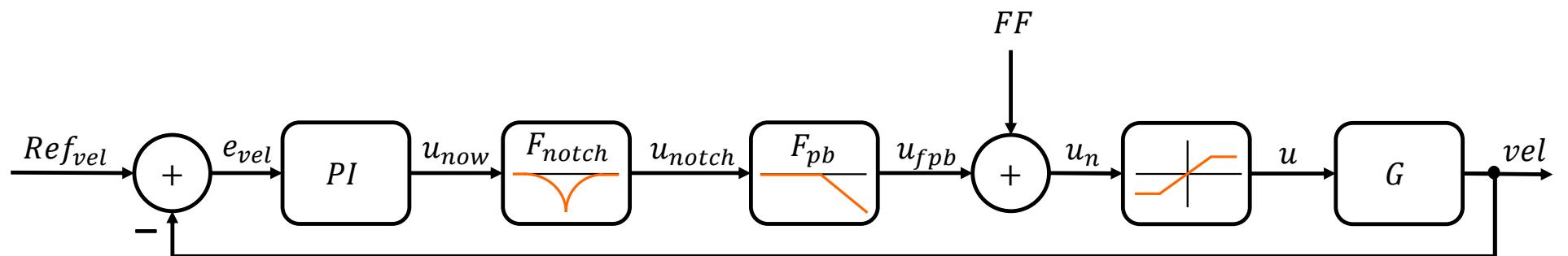
SCHEMA DI CONTROLLO

CASCADE CONTROL



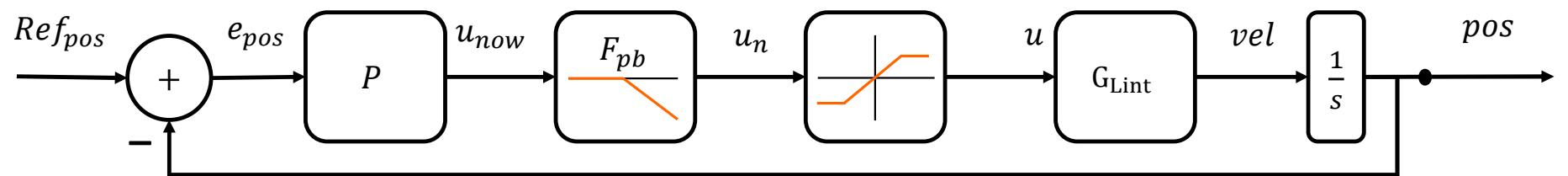
CASCADE CONTROL

LOOP INTERNO

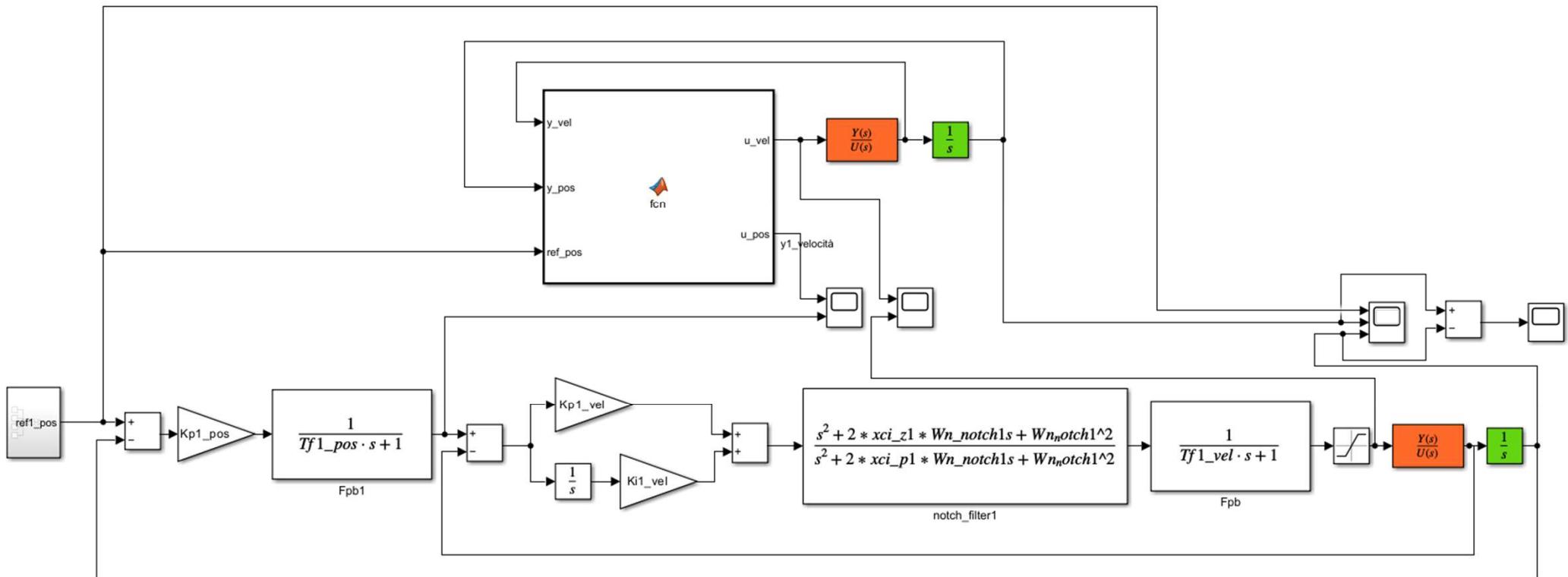


CASCADE CONTROL

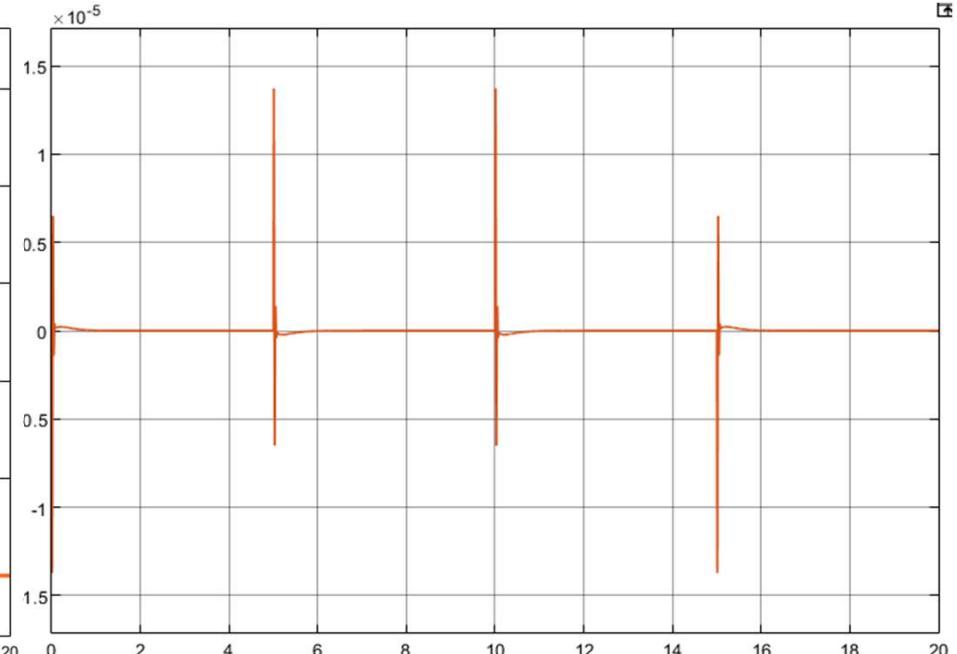
LOOP ESTERNO



CASCADE CONTROL TEST

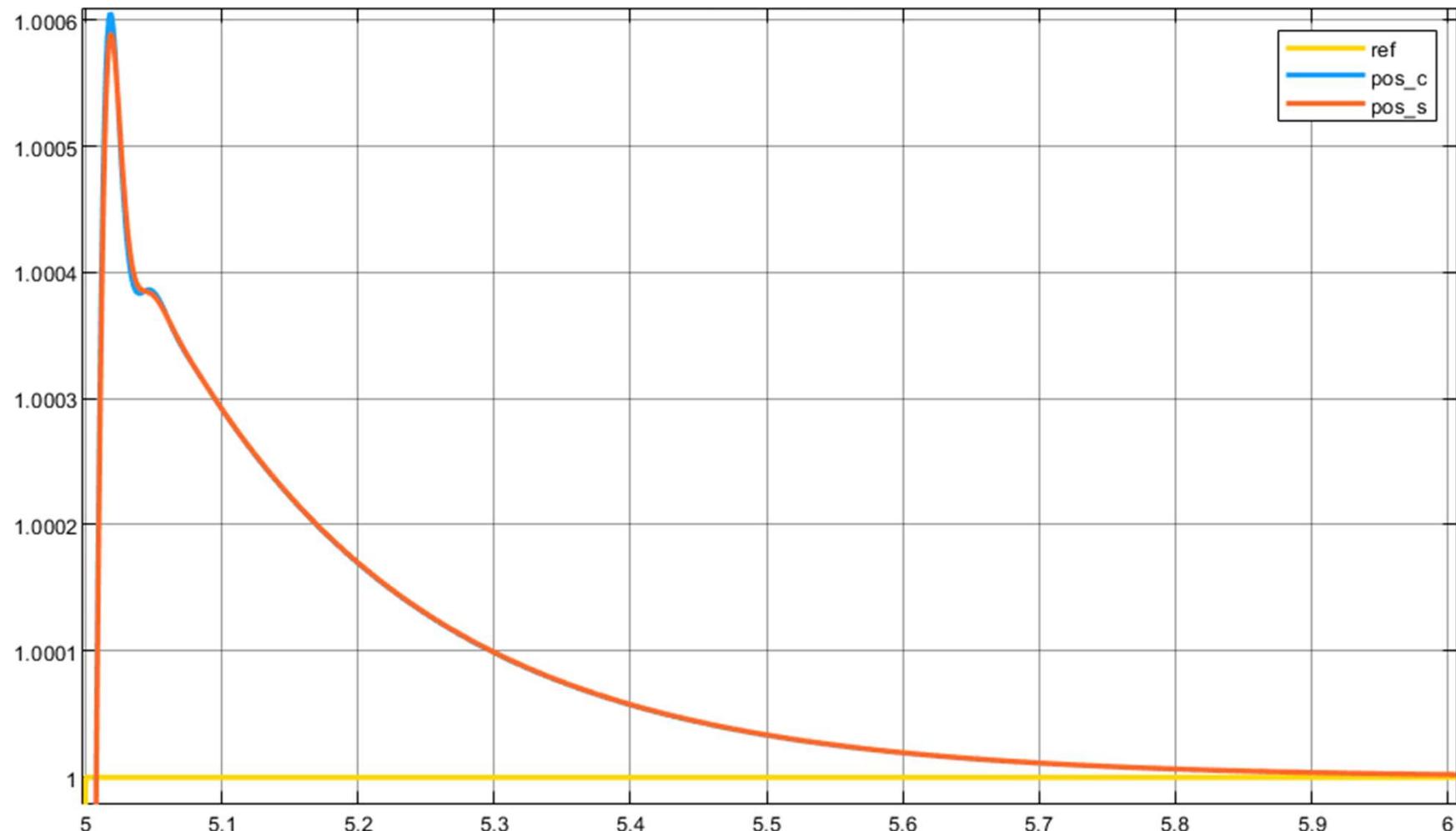


CASCADE CONTROL - TEST



Errore su $y < 10^{-5}$

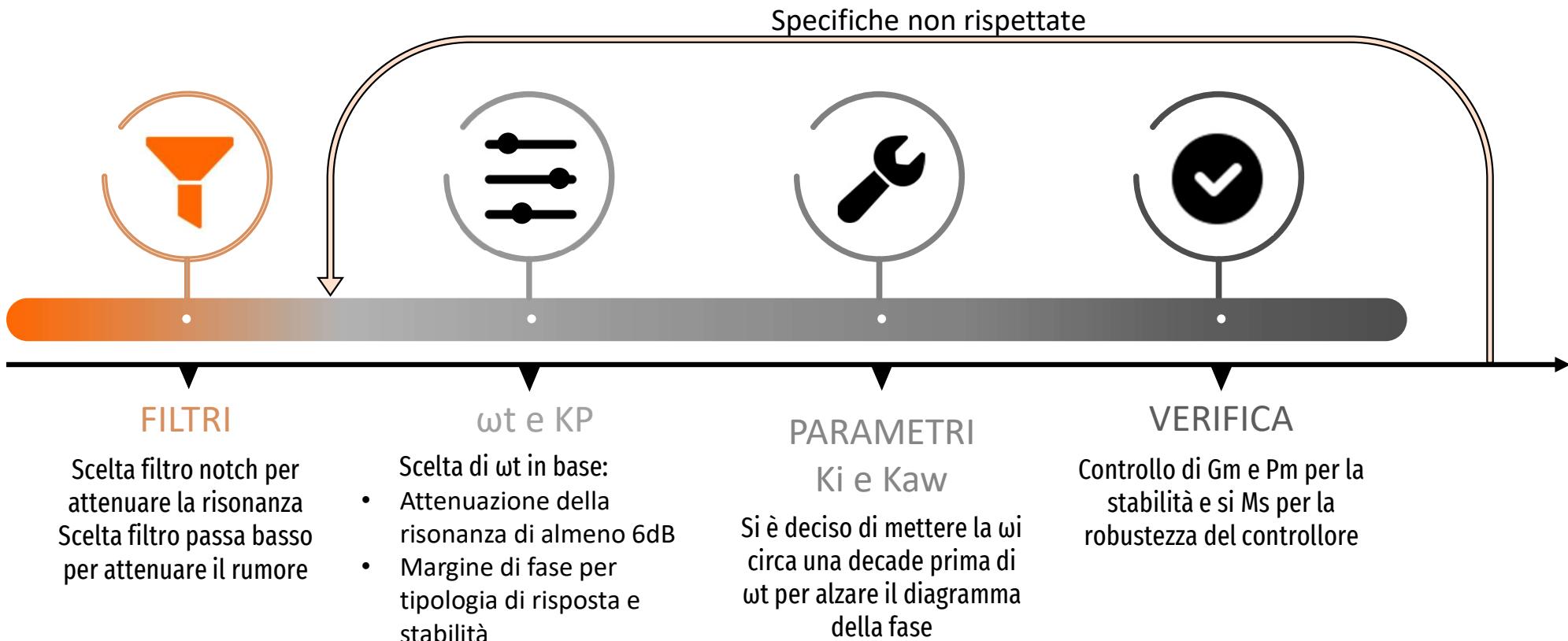




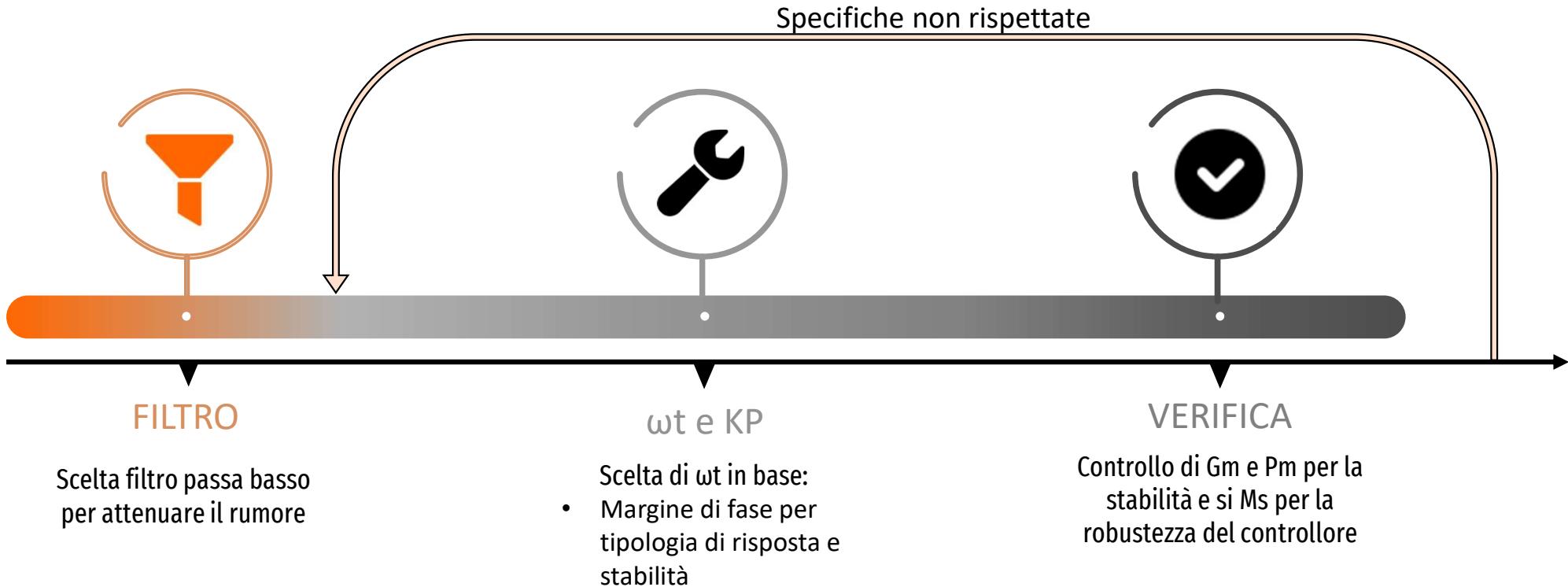


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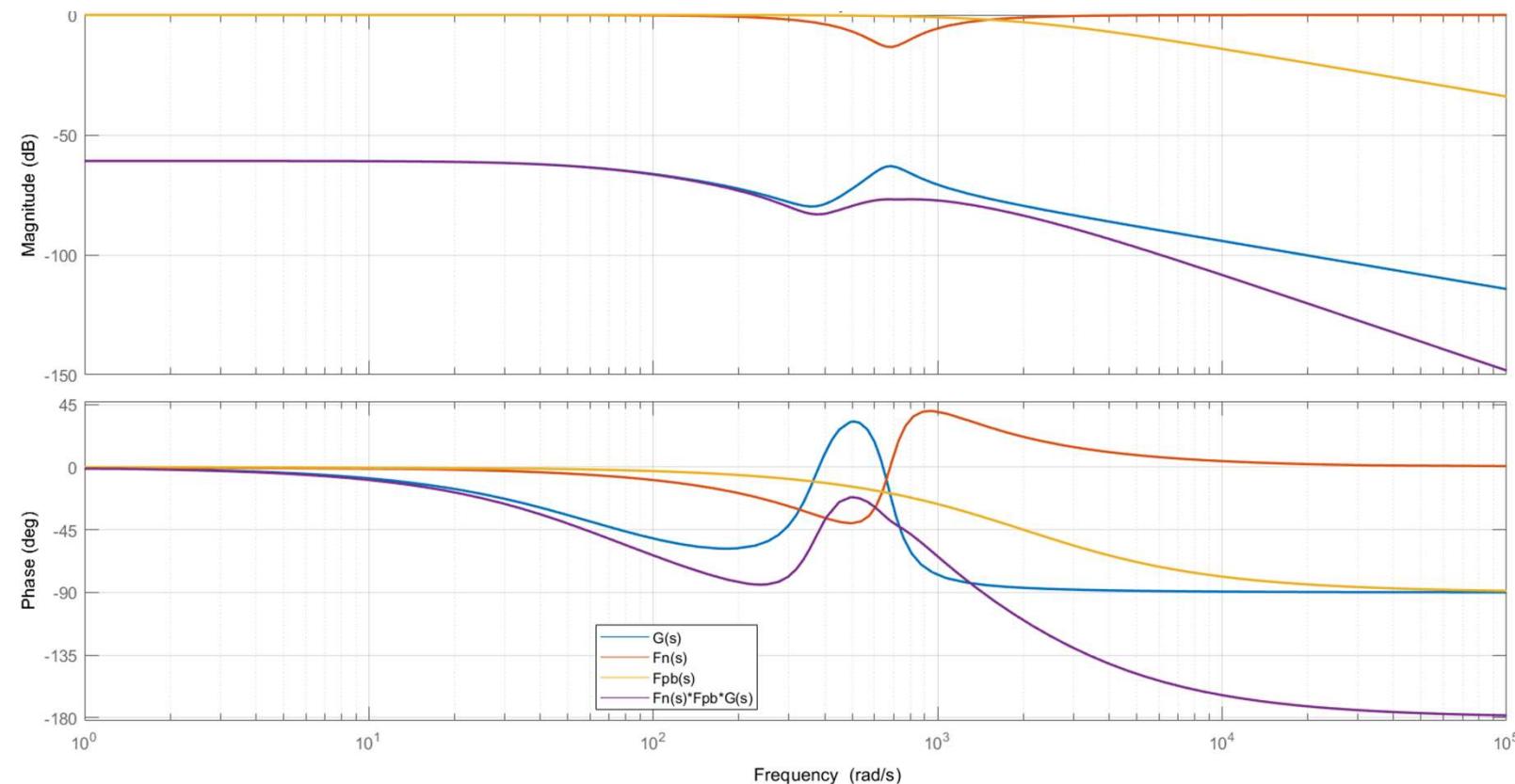
TARATURA LOOP INTERNO



TARATURA LOOP ESTERNO



GIUNTO 1 - loop interno - filtri



FILTRO NOTCH

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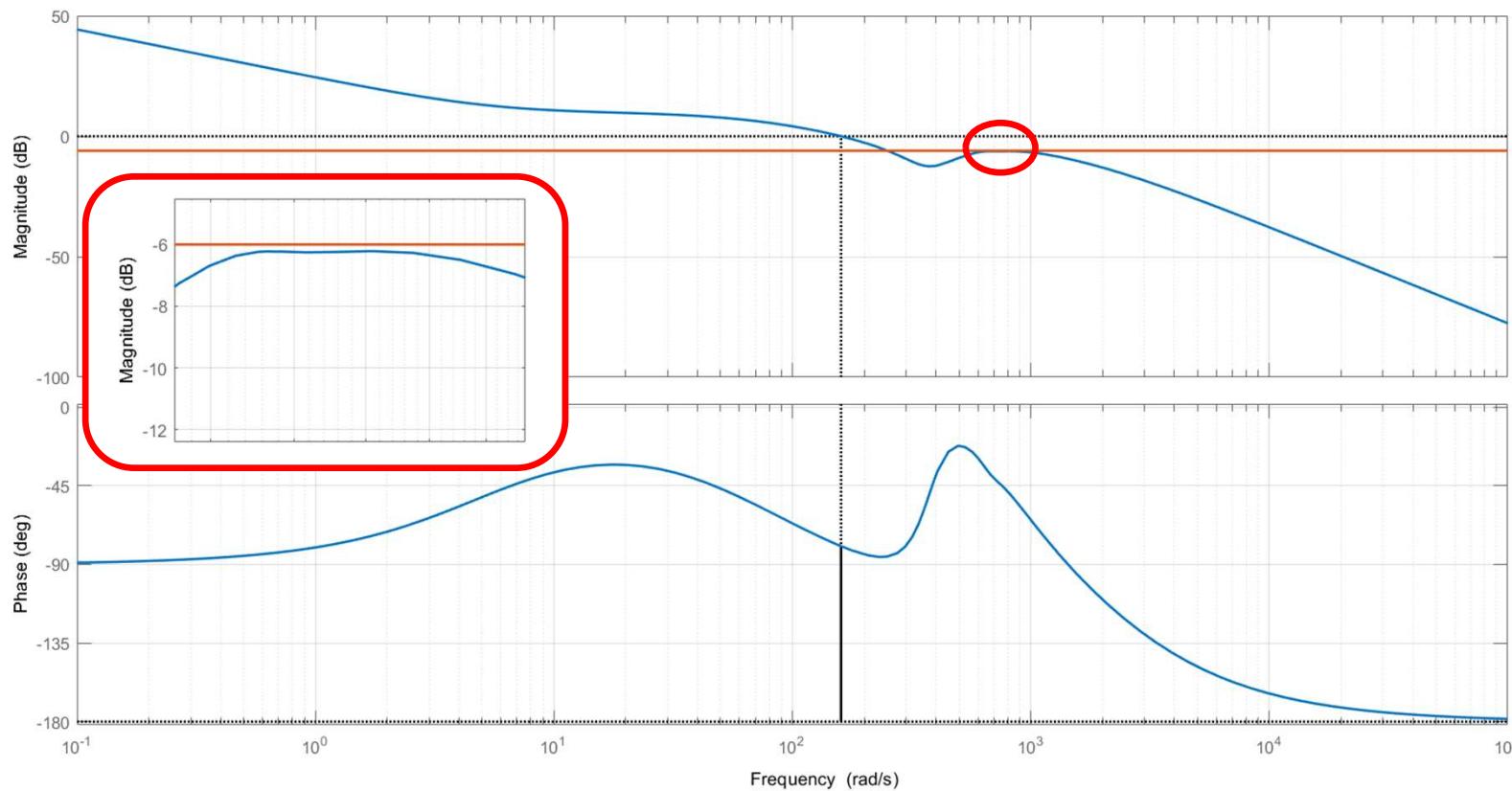
Xci_z	0.15
-------	------

FILTRO PASSA BASSO

Wpb	2000
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GIUNTO 1 - loop interno - controllore

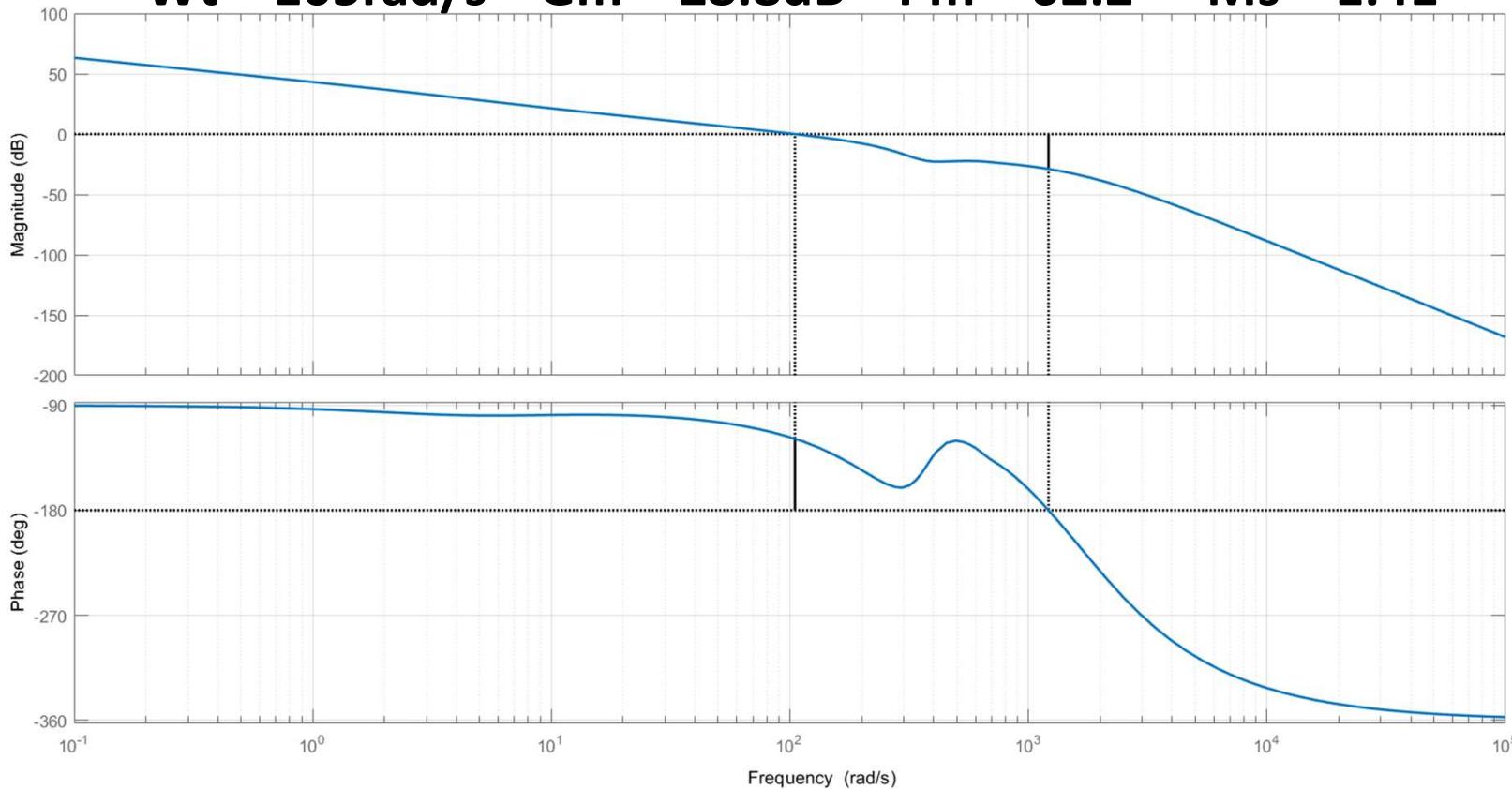
$W_t = 160\text{rad/s}$ $G_m = \text{Inf}$ $P_m = 104^\circ$ $M_s = 1.08$



PI	
Kp	3401
Ki	18142
Kaw	5.33

GIUNTO 1 - loop esterno

W_t = 105rad/s G_m = 28.8dB P_m = 62.2° M_s = 1.41



PI	
K_p	149.78
FILTRO PASSA BASSO	
W_{pb}	2000

GIUNTO 2 - loop interno - filtri

FILTRO NOTCH

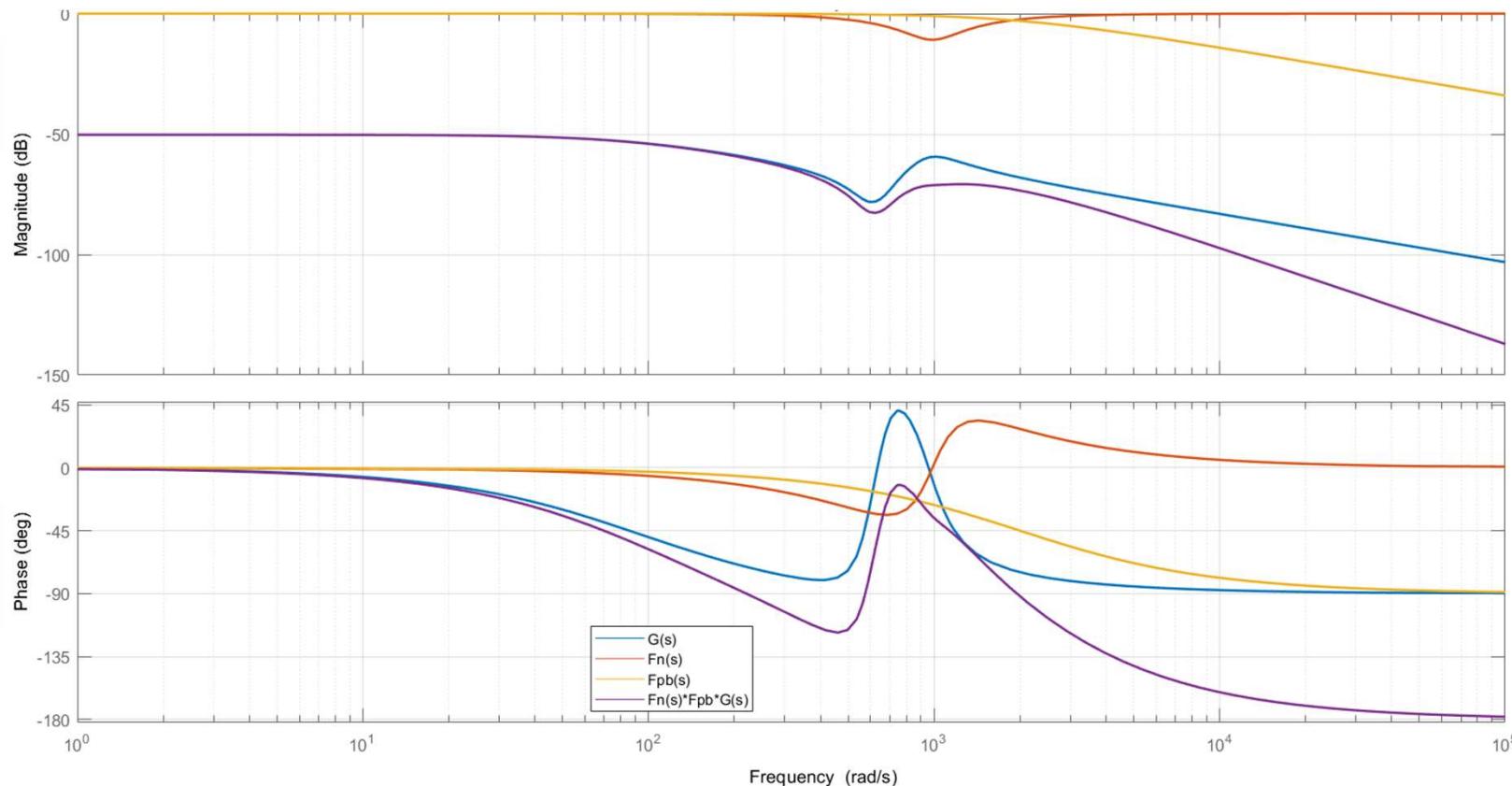
Wn	986 [rad/s]
-----------	--------------------

Xci_p	0.7
--------------	------------

Xci_z	0.2
--------------	------------

FILTRO PASSA BASSO

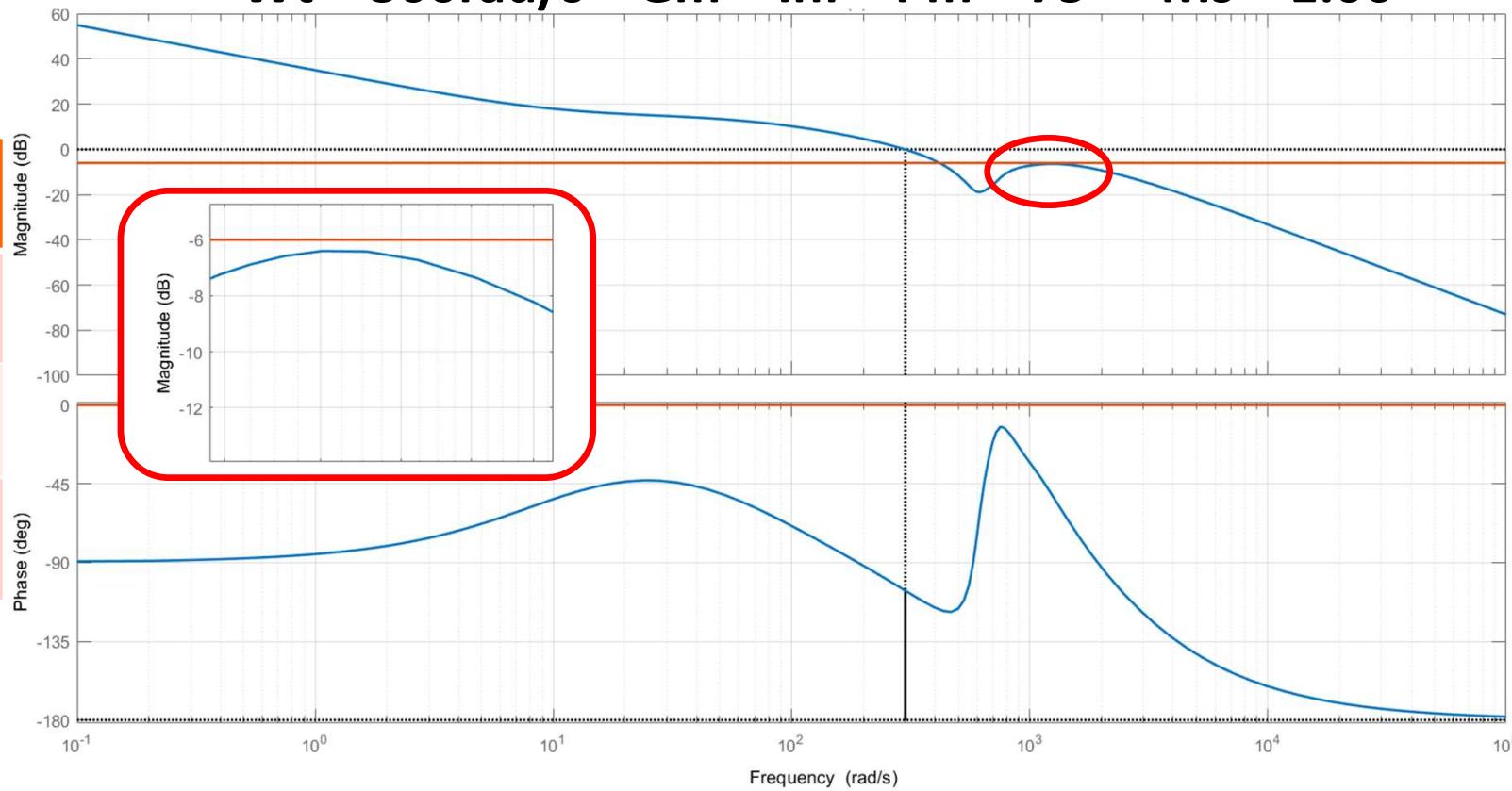
Wpb	2000
------------	-------------



GIUNTO 2 - loop interno - controllore

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

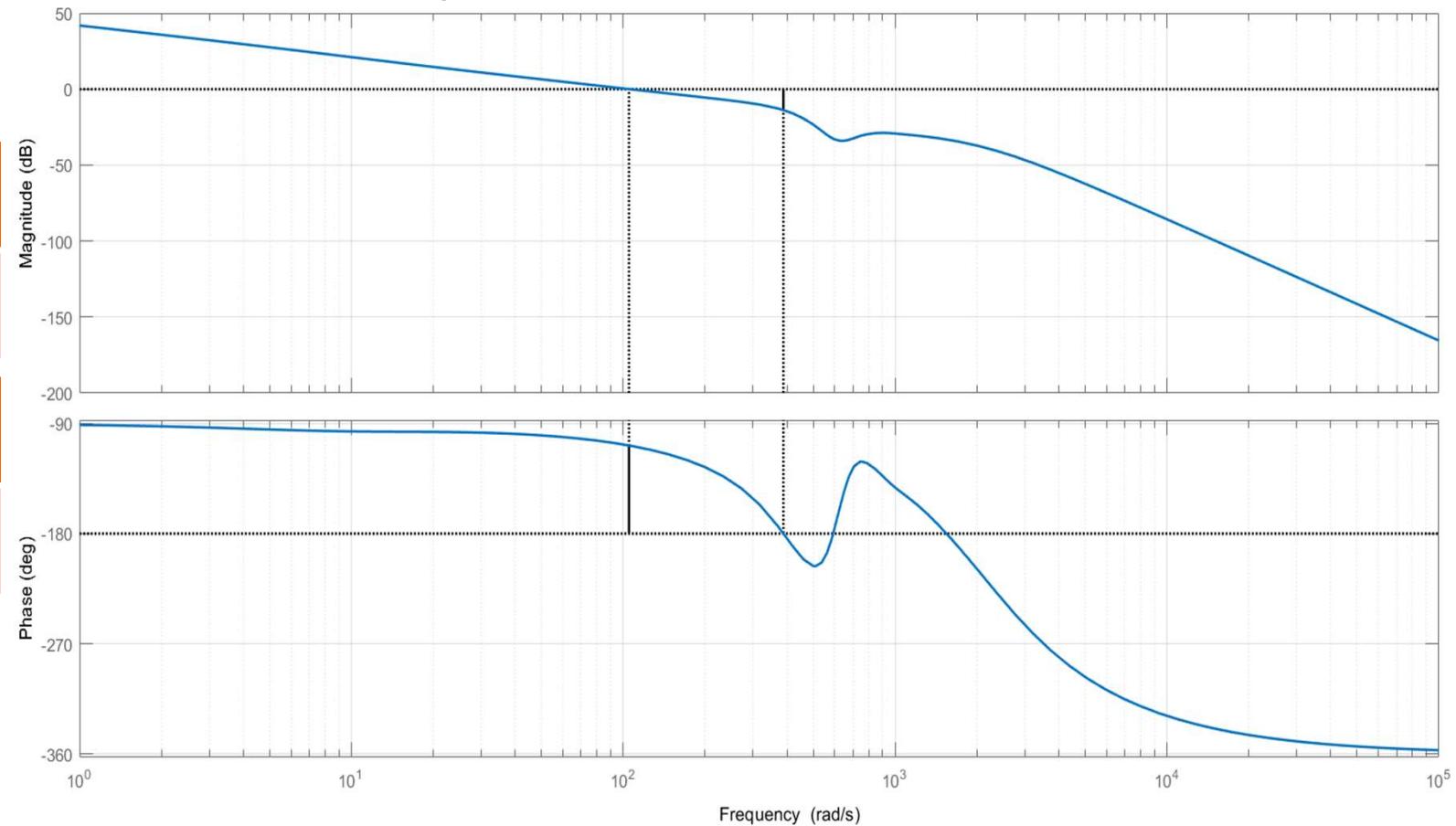
PI	
K_p	1587.4
K_i	15874
K_{aw}	10



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

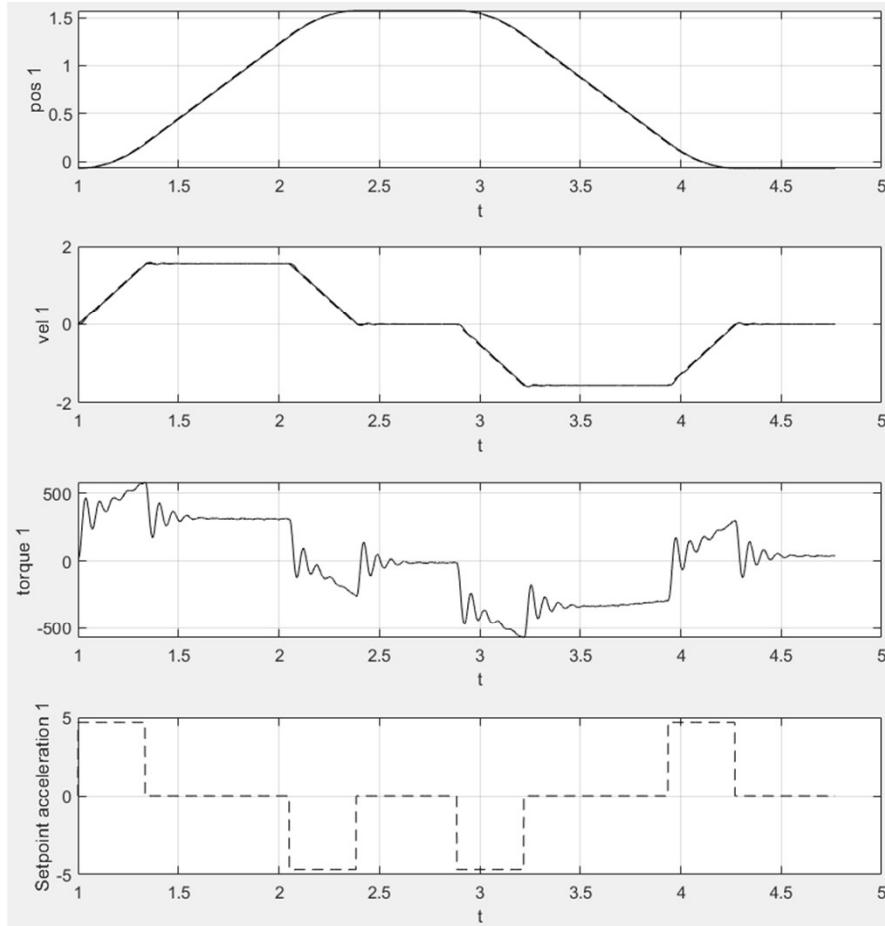




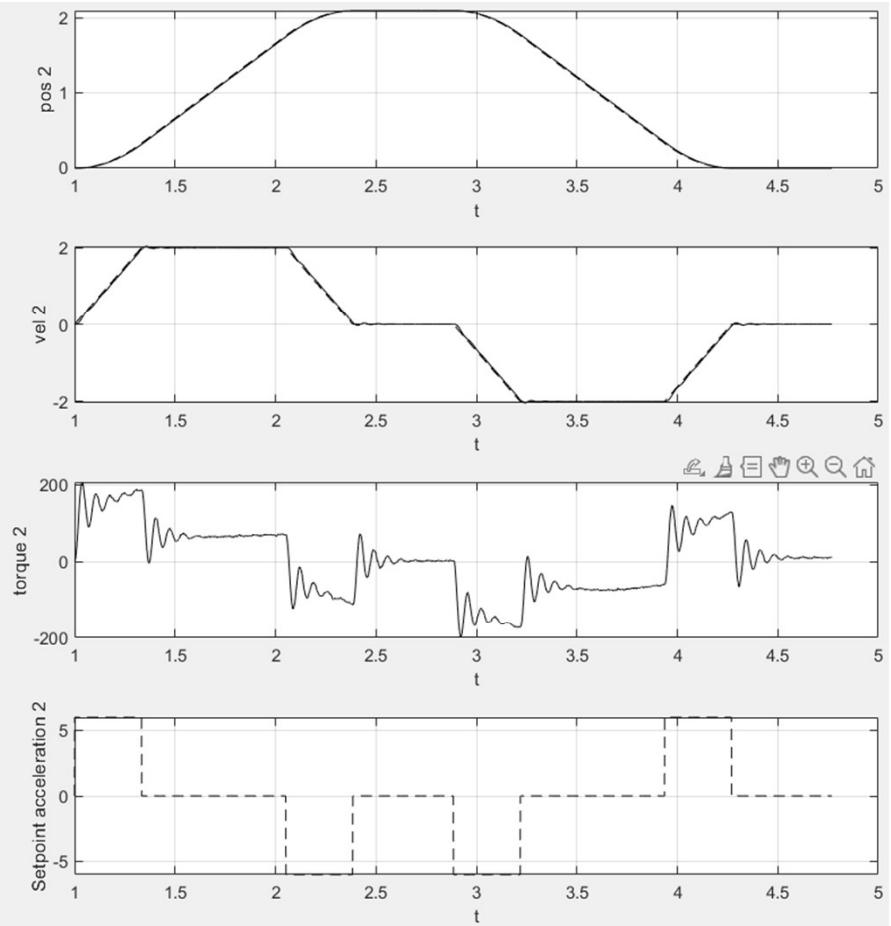
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REST_TIME = 0.5

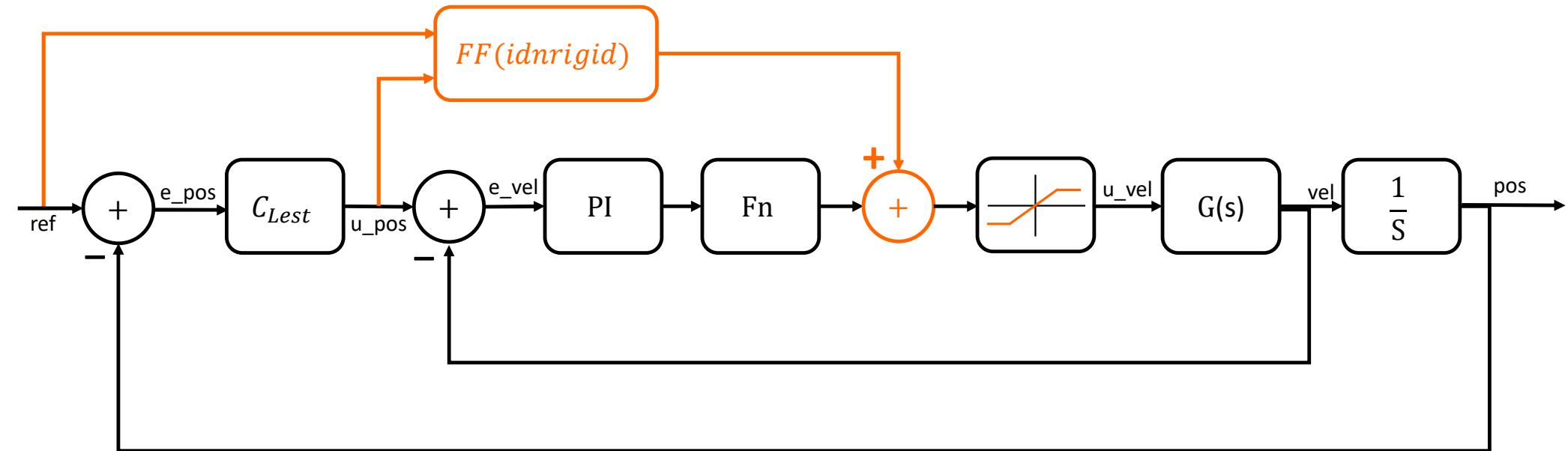
MAX ACC = 5



SCORE = 32.18

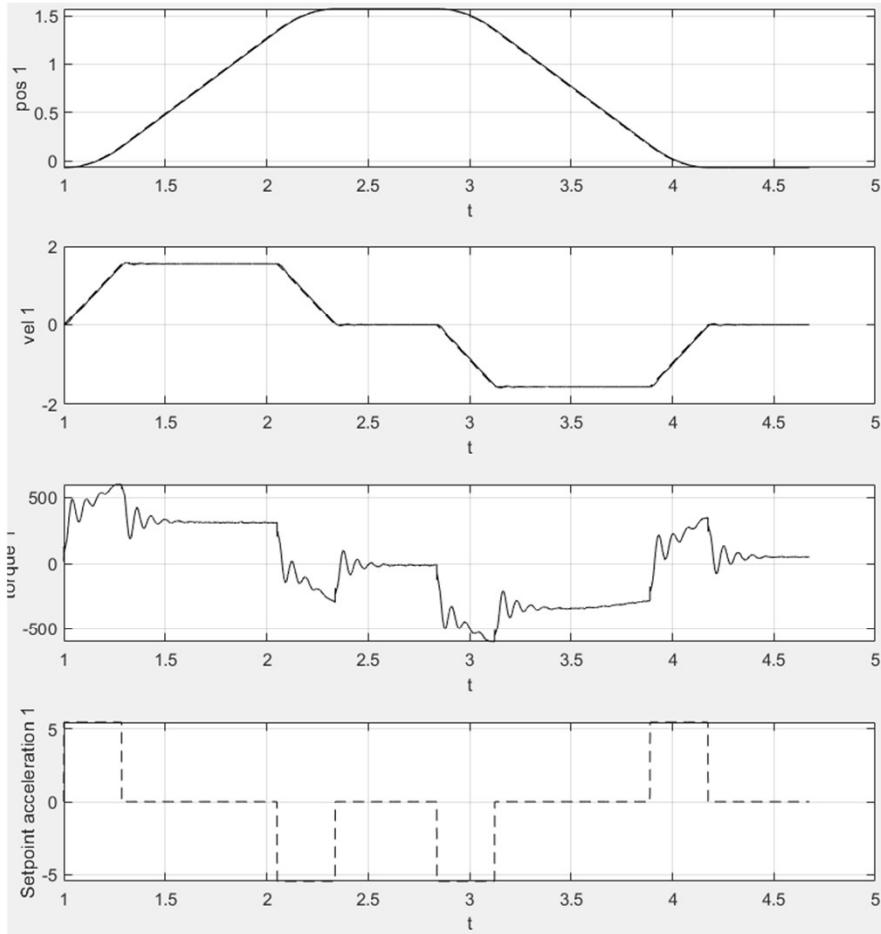


AGGIUNTA AZIONE FEEDFORWARD COPPIA

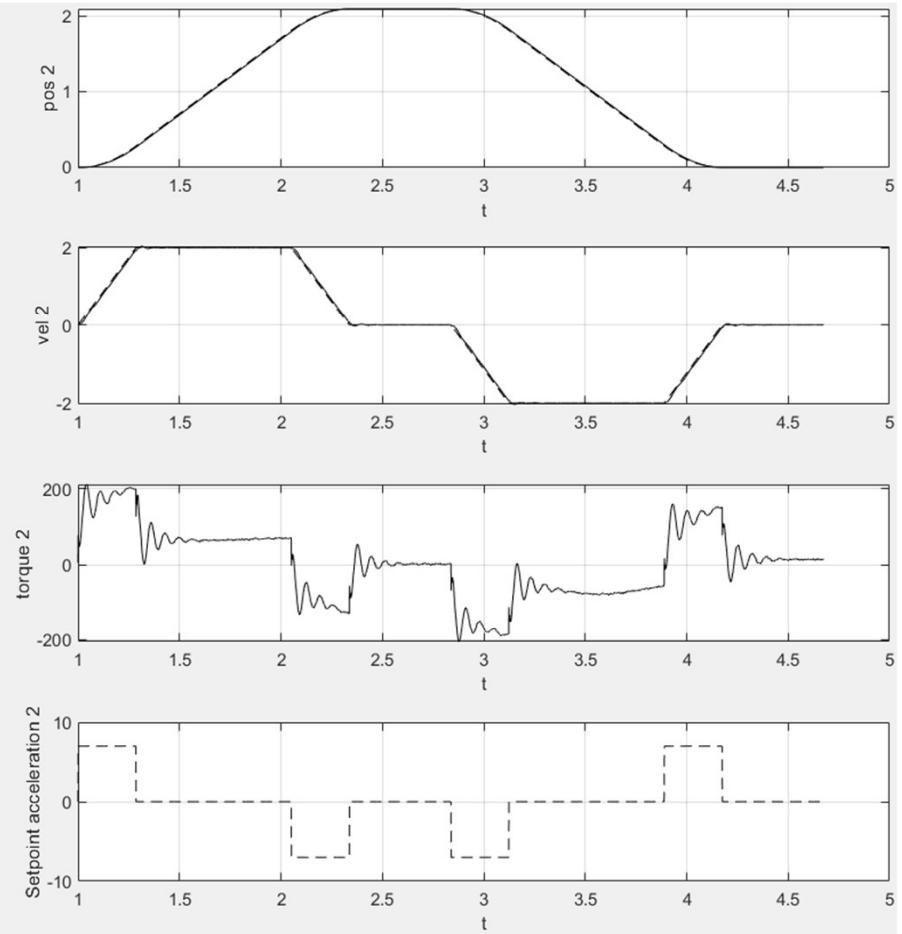


REST_TIME = 0.5

MAX ACC = 7

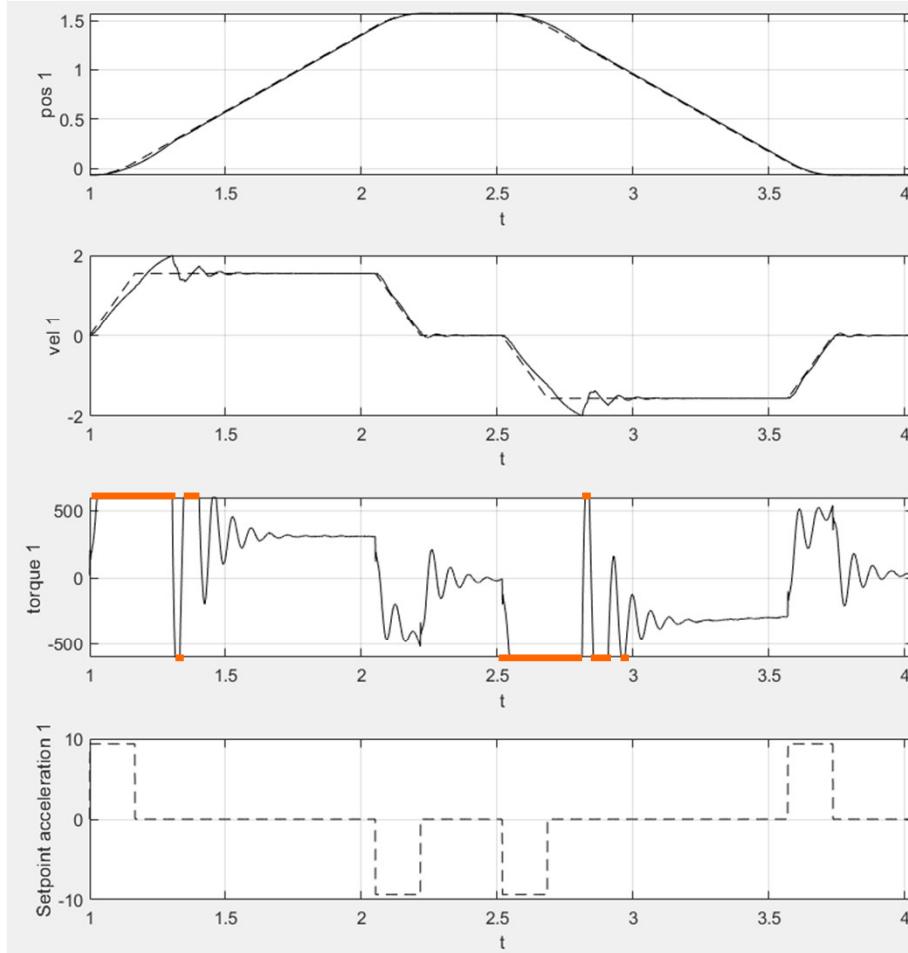


SCORE = 32.42

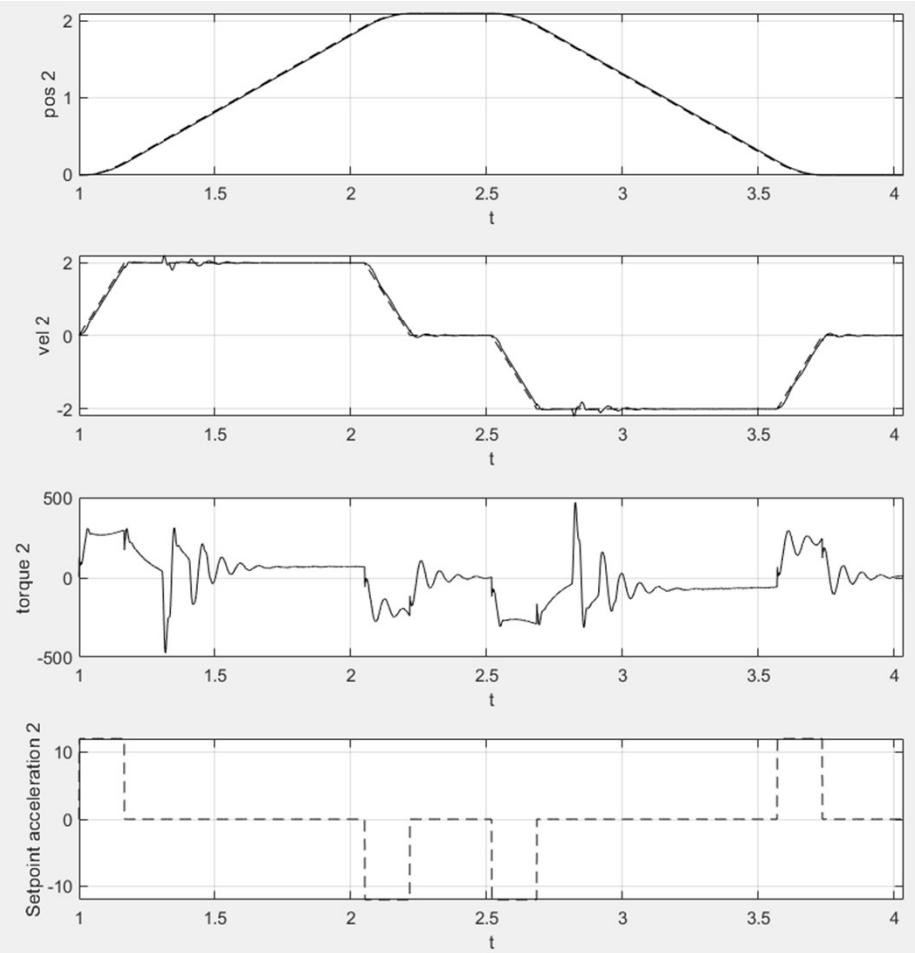


REST_TIME = 0.3

MAX ACC = 12



SCORE = 33.77





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TARATURA

- Introduzione di algoritmi per la taratura per una migliore che considerano Ms, Gm e Pm
- 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

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GRAZIE PER L'ATTENZIONE

Anno Accademico 2022-2023