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UNIVERSITÀ DI PAVIA
Dipartimento di
Ingegneria Industriale
e dell'Informazione

Automated Mechanical System Design

Motion curve planning 02

Prof. Hermes Giberti

Develop an test motion curve modules

Develop Matlab functions and scripts in order to collect and test the following motion curve modules:

- Cubic curve
- Cycloidal curve
- Asymmetric trapezoidal speed profile (s-shape)
- Modified trapezoidal (acceleration) curve (seven parameters)

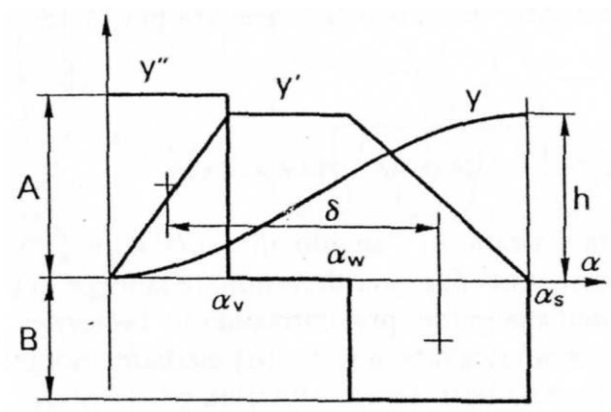
Develop an test motion curve modules

From first propriety of the acceleration diagram

$$\frac{A}{B} = \frac{\alpha_s - \alpha_w}{\alpha_v}$$

While, from the second propriety of the acceleration diagram

$$\begin{cases} y'_{max}\delta = h = A\alpha_v\delta \\ \delta = \dfrac{\alpha_s}{2} - \dfrac{\alpha_v}{2} + \dfrac{\alpha_w}{2} \end{cases}$$



From the previous equations it is possible to evaluate the values of the maximum acceleration

$$\begin{cases} A = \dfrac{2h}{\alpha_v(\alpha_s - \alpha_v + \alpha_w)} \\ B = \dfrac{2h}{(\alpha_s - \alpha_w)(\alpha_s - \alpha_v + \alpha_w)} \end{cases}$$

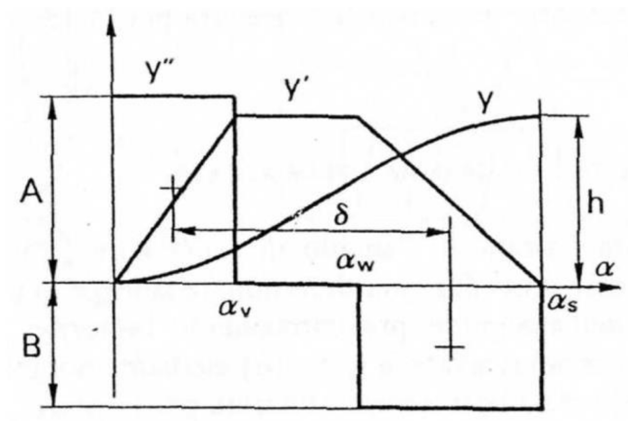
Develop an test motion curve modules

It is possible, integrating the acceleration diagram, to define the motion curve in terms of velocity and displacement

$$0 < \alpha < \alpha_v \quad \begin{cases} y'' = A \\ y' = A\alpha \\ y = \frac{1}{2}A\alpha^2 \end{cases}$$

$$\alpha_v < \alpha < \alpha_w \quad \begin{cases} y'' = 0 \\ y' = A\alpha_v \\ y = A\alpha_v\left(\alpha - \frac{\alpha_v}{2}\right) \end{cases}$$

$$\alpha_w < \alpha < \alpha_s \quad \begin{cases} y'' = -B \\ y' = A\alpha_v - B(\alpha - \alpha_w) \\ y = A\alpha_v\left(\alpha - \frac{\alpha_v}{2}\right) - \frac{B}{2}(\alpha - \alpha_w)^2 \end{cases}$$



Develop an test motion curve modules

Regarding the “Modified trapezoidal (acceleration) curve” (seven parameters) please referred to kiro website:

- Modified Trapezoidal Trajectory_eng.pdf
- Modified Trapezoidal Trajectory_ita.pdf

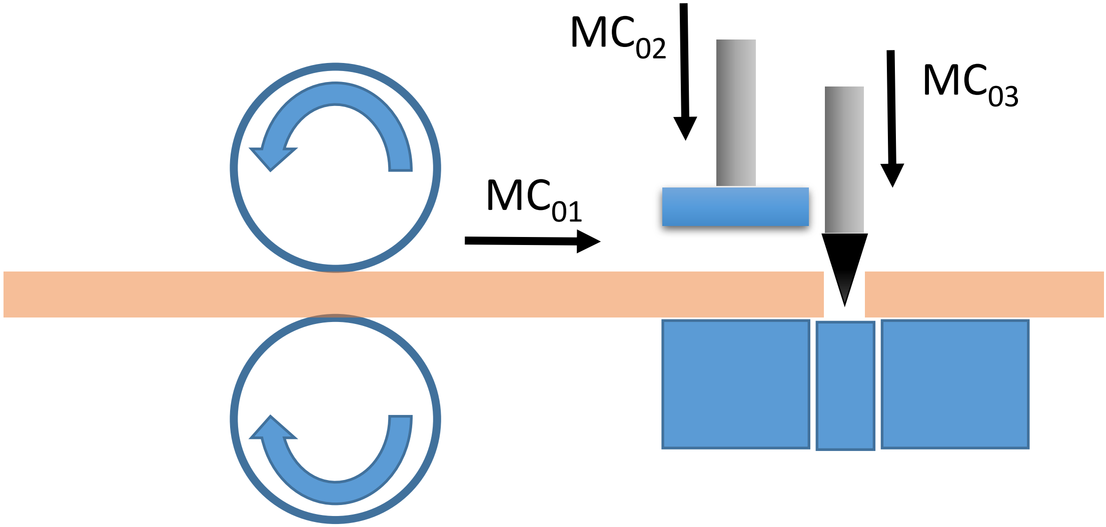
Note:

Use this profile in order to develop the project for the exam.

Timing diagram for a cutting machine

Design the timing diagram for a functional group of a cutting machine made up of three mechanism:

- Feeding group → motion curve MC_{01}
- Pressing group → motion curve MC_{02}
- Cutting group → motion curve MC_{03}



Rise for each curve:

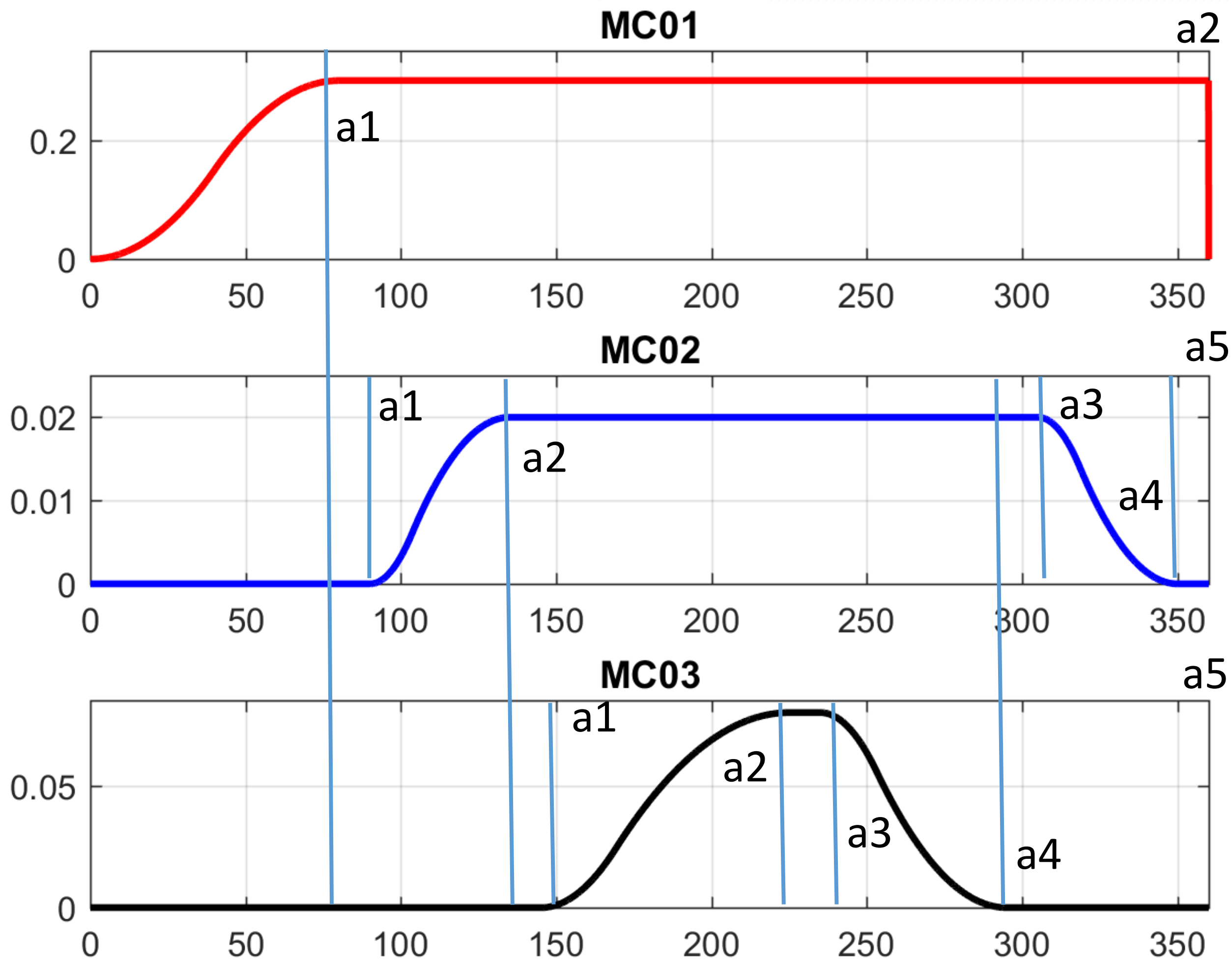
- h_{01} = 300mm
- h_{02} = 20 mm
- h_{03} = 80 mm

Timing diagram for a cutting machine

MC_{01}:
a1=80; a2=360;

MC_{02}
a1=90; a2=135;
a3=305; a4=350;
a5=360;

MC_{03}
a1=145; a2=225;
a3=235; a4=295;
a5=360;



Timing diagram for a cutting machine

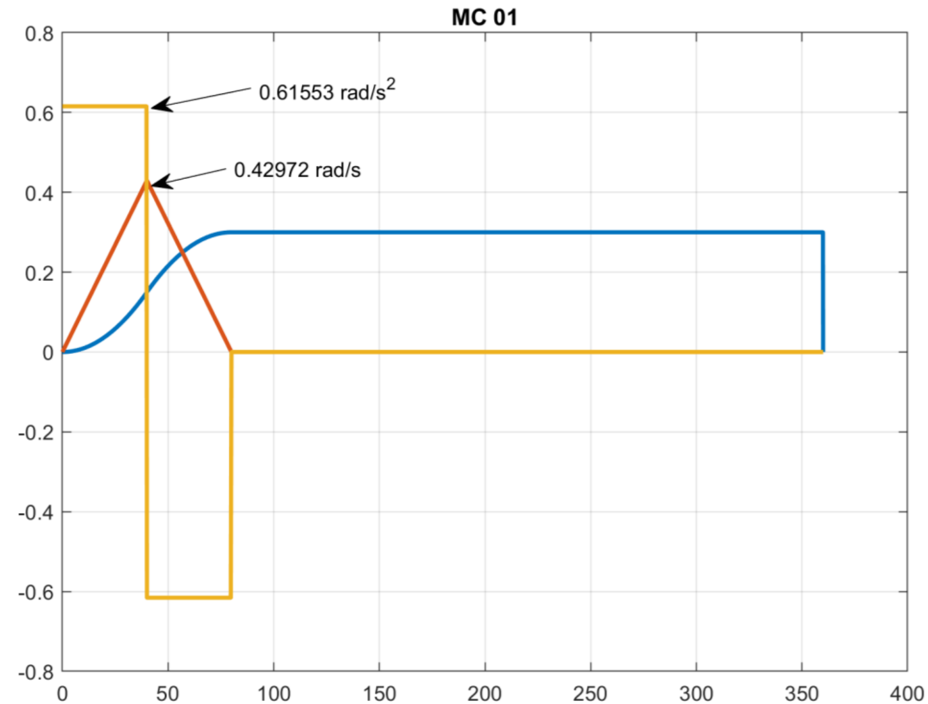
Using the motion curve module that you developed, calculate:

- Maximum geometrical acceleration and speed values for each movement
- If the machine cut 200 pieces per minute, what is the maximum acceleration value of each movement?

Timing diagram for a cutting machine

200 pieces per minute → 200 rpm of the master shaft

$$\begin{cases} \dfrac{200}{60} = 3.33 \text{ turns per second} \\ \dfrac{60}{200} = 0.3 \text{ sec. for each turn/product} \\ \omega = \dfrac{200 \cdot 2\pi}{60} = 20.944 \text{ rad/s} \end{cases}$$

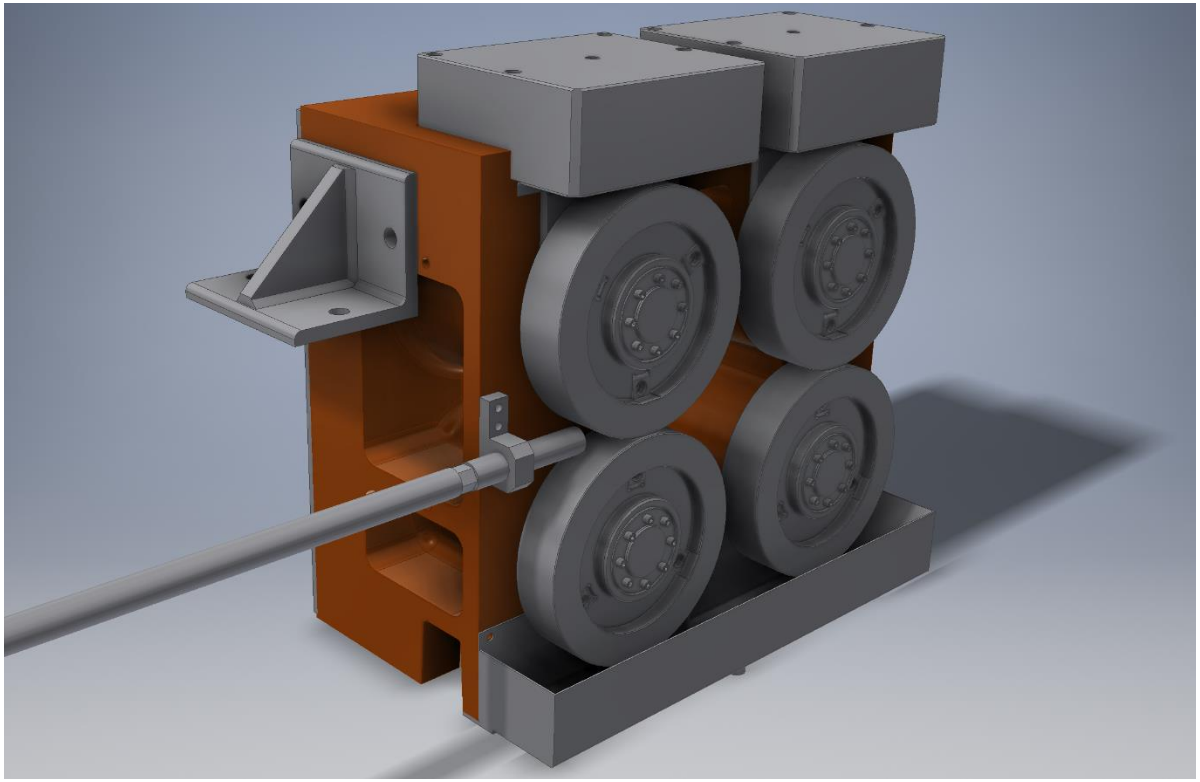


$$\begin{cases} \dot{y} = y'\omega = 0.43 \cdot 20.94 = 9m/s \\ \ddot{y} = y''\omega^2 = 0.61 \cdot 20.94^2 = 270m/s^2 \end{cases}$$

$$\ddot{y}_{max} = c_a \frac{h}{t_a^2} = 4 \frac{0.3}{(0.3 \frac{80}{360})^2} = 270 \text{ m/s}^2$$

Feeding group layout

Study the feeding group, shown in the figure, and determine the torque required by the motor to follow the designed motion curve when the production is <u>100 pieces/minutes</u>.



Import in inventor the file:

P6-16-00-ASSIEME GENERALE.STEP

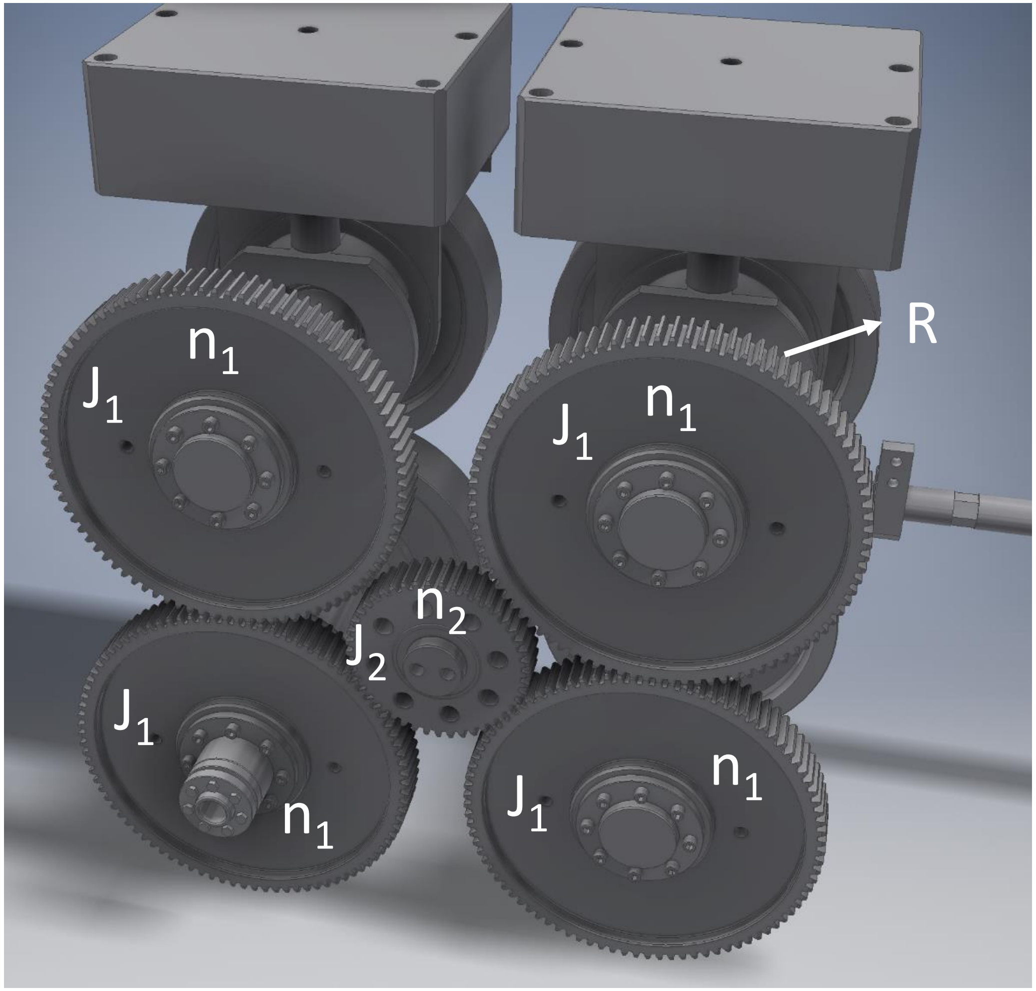
All the components are steel made.

Feeding group layout

Calculate:

- the equivalent J of all the actuated axes
- the inverse dynamic problem writing a simple Matlab script
- plot the values of speed and torque on a Cartesian plan where rpm is on the abscissa axis and torque on the ordinate one.

Feeding group layout



Input data:

n_1=90 teeth

n_2=45 teeth

The resistance force is:
F_r=500 N

Mass & geometrical analysis:

J_1=0,284 kg m^2

J_2=0,007 kg m^2

R=0.134 m

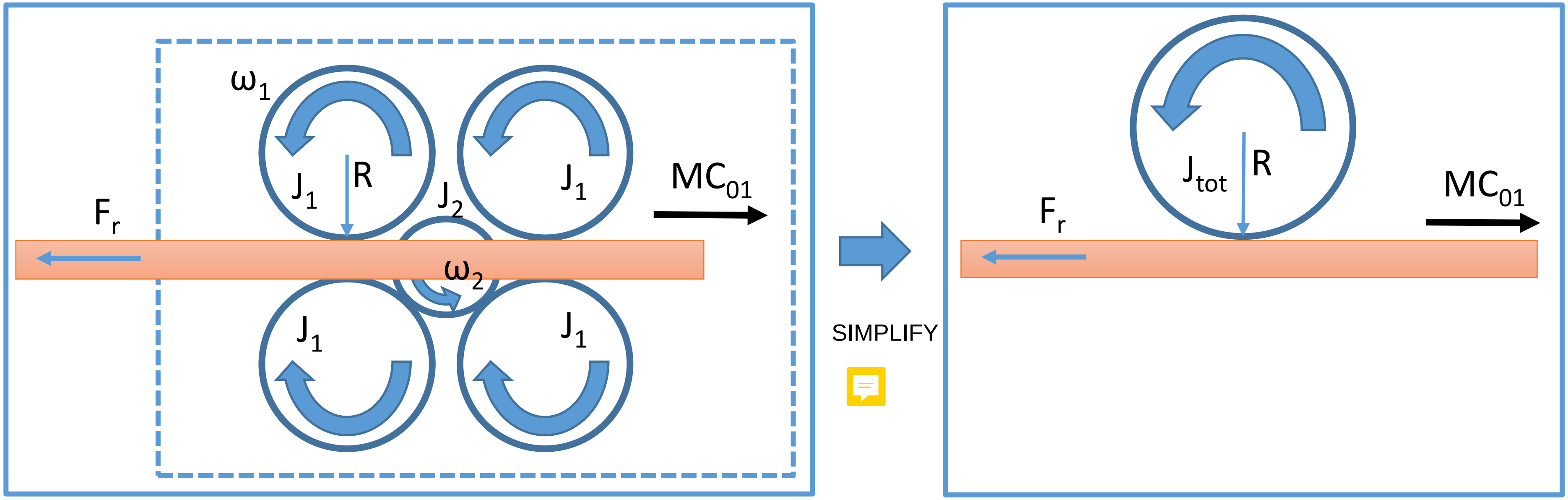
Feeding group layout

Calculate the equivalent J of all the actuated axes

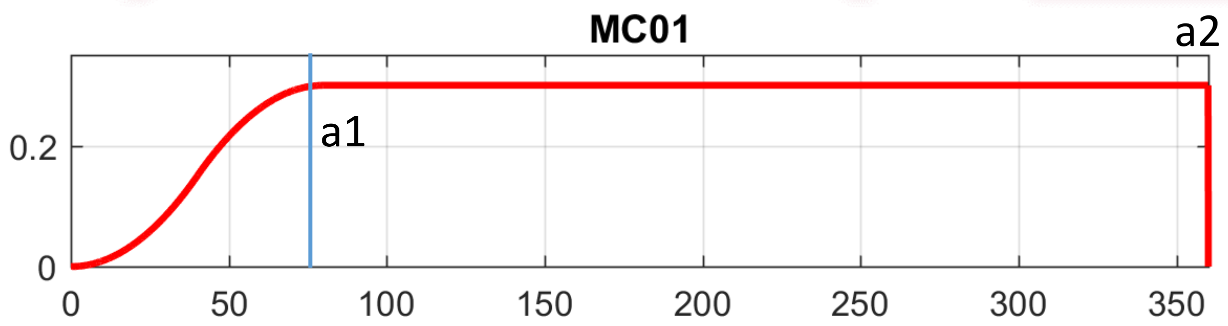
$$\omega_1 \tau_g = \omega_2 \rightarrow \boxed{\tau_g = \frac{\omega_2}{\omega_1} = \frac{n_1}{n_2} = \frac{90}{45} = 2}$$

$$\frac{1}{2} J_2 \omega_2^2 = \frac{1}{2} J^* \omega_1^2 \rightarrow \boxed{J^* = J_2 \left(\frac{\omega_2}{\omega_1}\right)^2 = 4J_2}$$

$$J_{\mathrm{tot}} = 4J_1 + 4J_2$$



Feeding group



MC_{01}:

a1=80; a2=360;

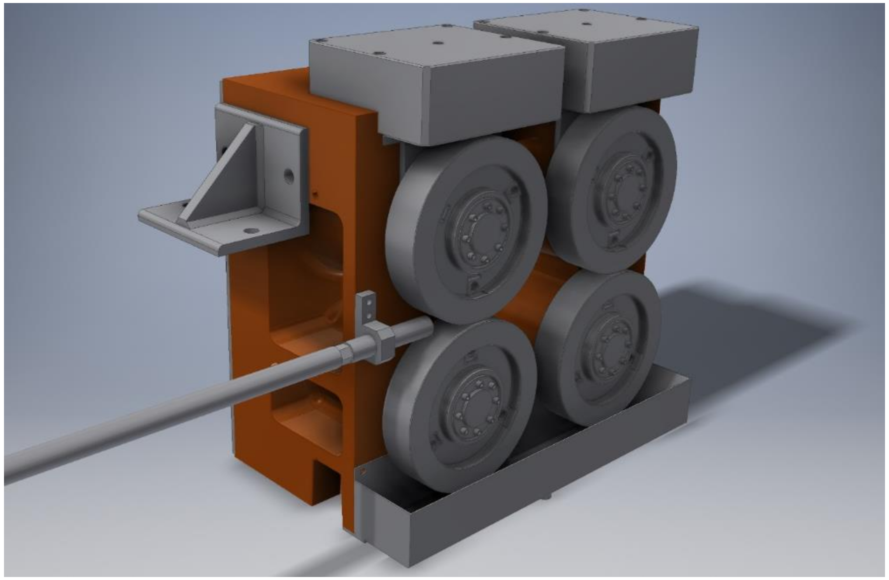
Production

→ 100 pieces per minute

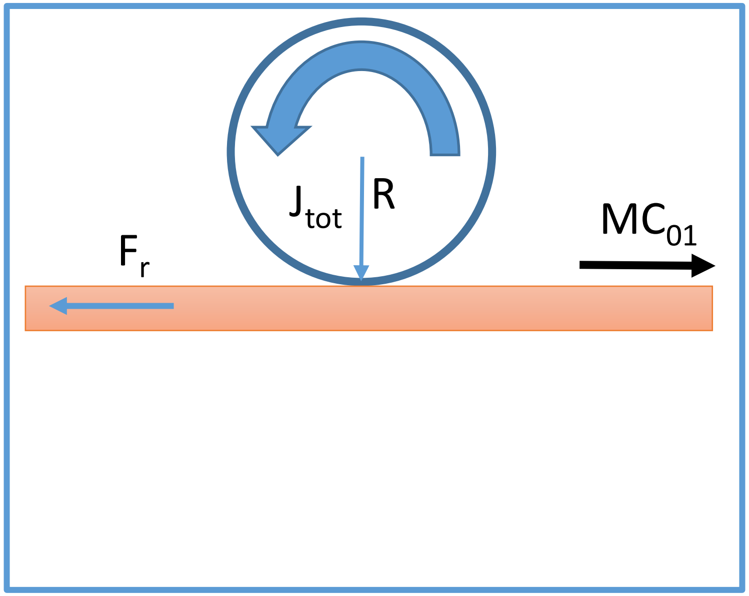
→ $t_c = t_{a2} = 60/100 = 0.6$ s

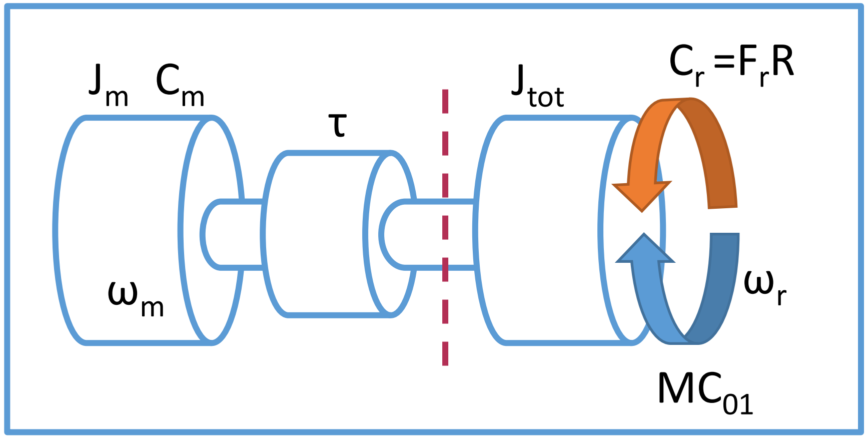
→ $t_{a1} = 0.6*(80/360) = 0.133$ s

→ $\omega=100*2*pi/60$



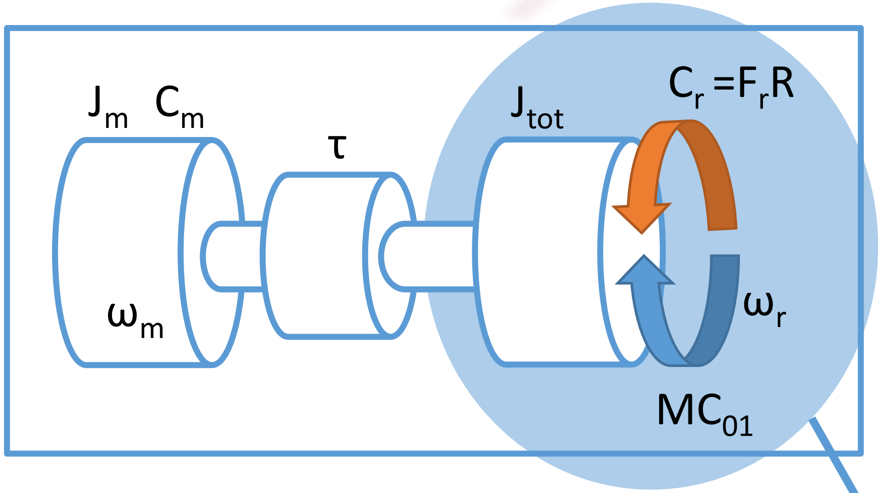
Feeding group layout





$$
\begin{cases}
J_{\text{tot}} = 4J_1 + 4J_2 \\
C_r = F_r R = 500 \cdot 0.134 = 67Nm \\
\omega_r = \dfrac{v}{R}
\end{cases}
$$

Feeding group



$$C_m \omega_m - J_m \dot{\omega}_m \omega_m = C_r \omega_r + J_{tot} \dot{\omega}_r \omega_r$$

$$\frac{C_m}{\tau} - \frac{J_m}{\tau^2} \dot{\omega}_r = C_r + J_{tot} \dot{\omega}_r$$

$$C_m = \frac{J_m}{\tau} \dot{\omega}_r + \tau (C_r + J_{tot} \dot{\omega}_r) = \frac{J_m}{\tau} \dot{\omega}_r + \tau C_r^*$$

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Thank you for your attention