Vehicle Dynamics

Synchronous mechanism modeling

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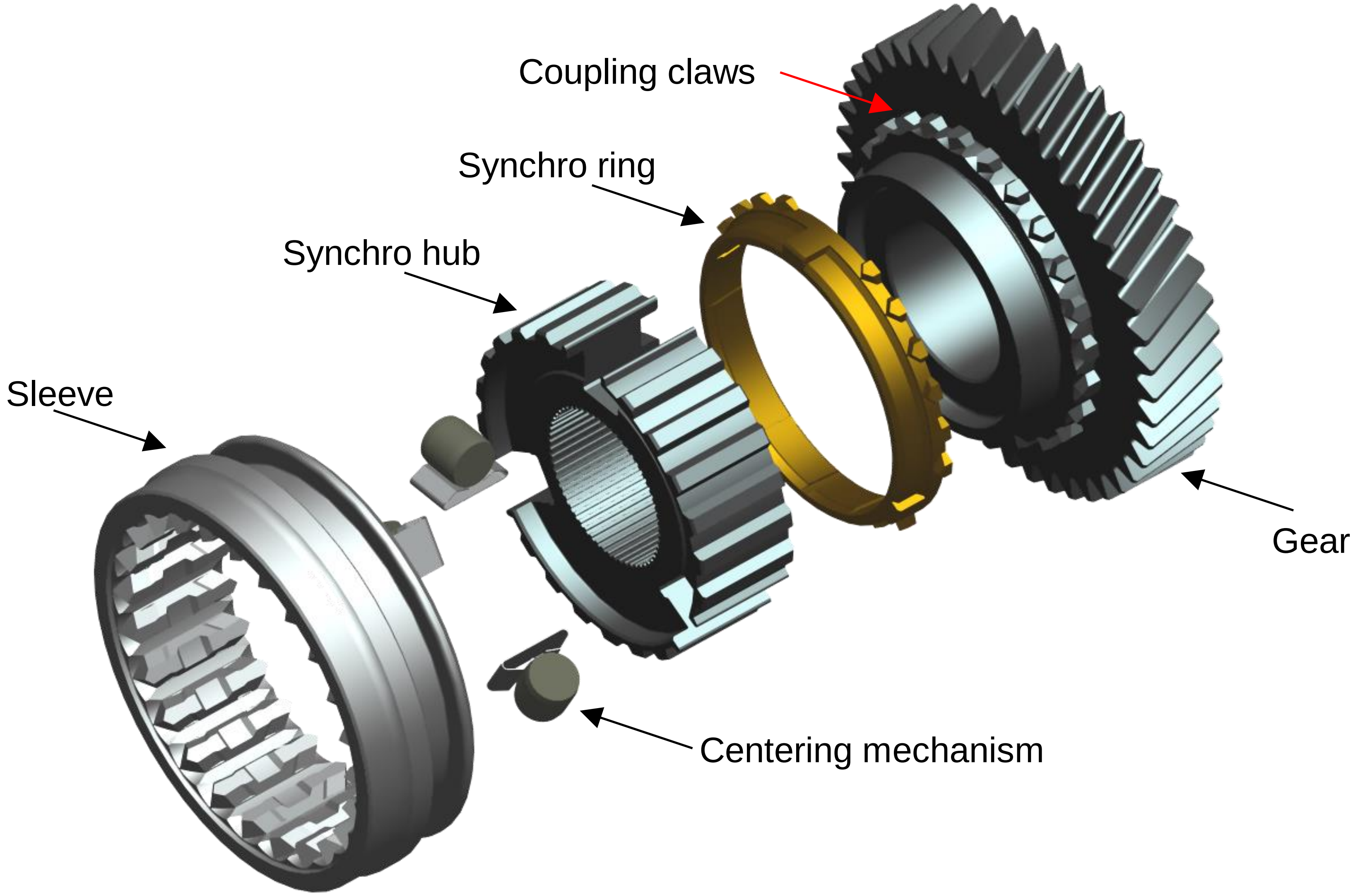
Contents

- **Buildup of a synchronous mechanism, the synchronization process**
- Stressing of a synchronous mechanism
- State flow chart based synchronous mechanism model

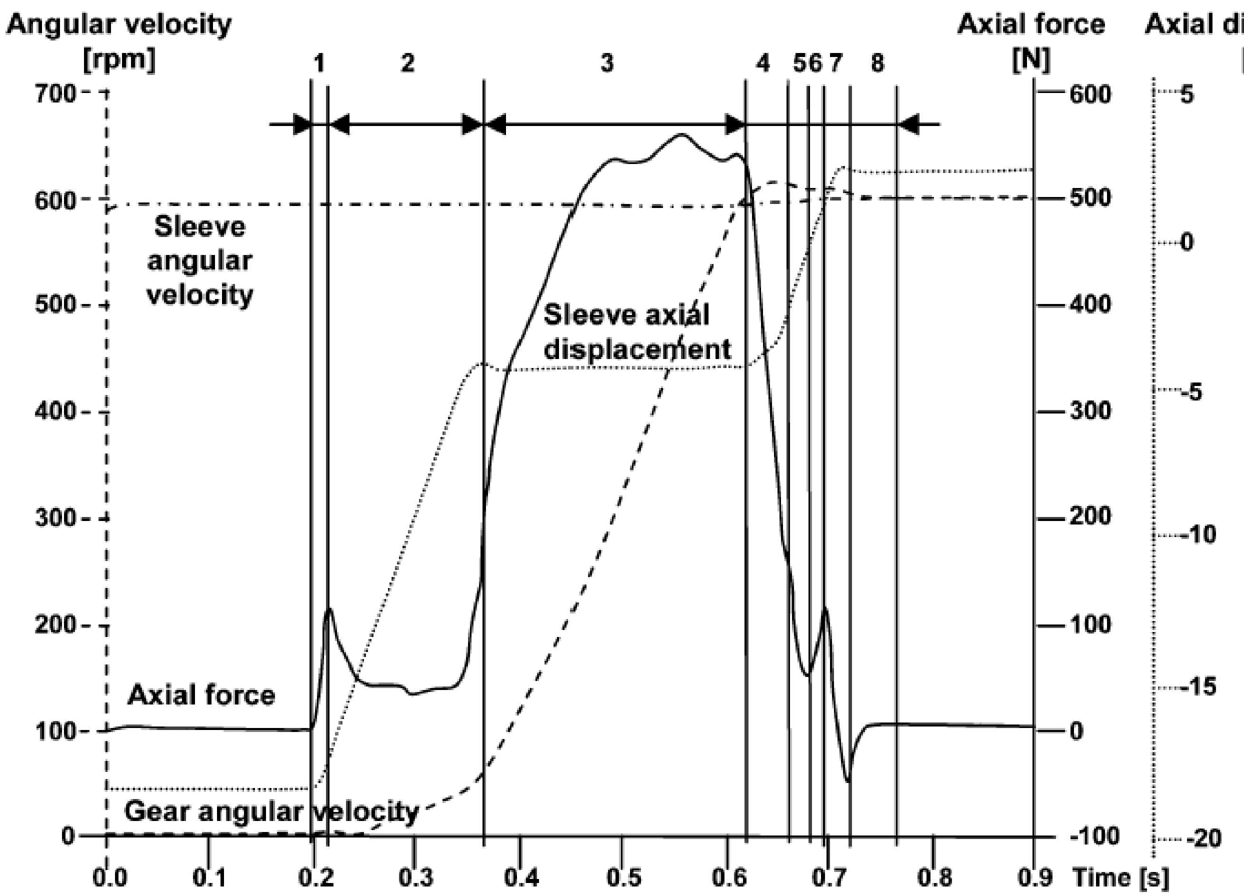
Synchronous mechanism modeling

Buildup of a synchronous mechanism (Borg-Warner type)



Synchronous mechanism modeling

A szinkronszerkezet kapcsolási folyamat szakaszai *[1]*



Working phases:

- **1 – First free fly**
- **2 – Start of angular velocity synchronization**
- **3 – Angular velocity synchronization**
- **4 – Turning the synchro ring**
- **5 – Second free fly**
- **6 – Start of the second bump**
- **7 – Turning the gear**
- **8 – Final free fly**

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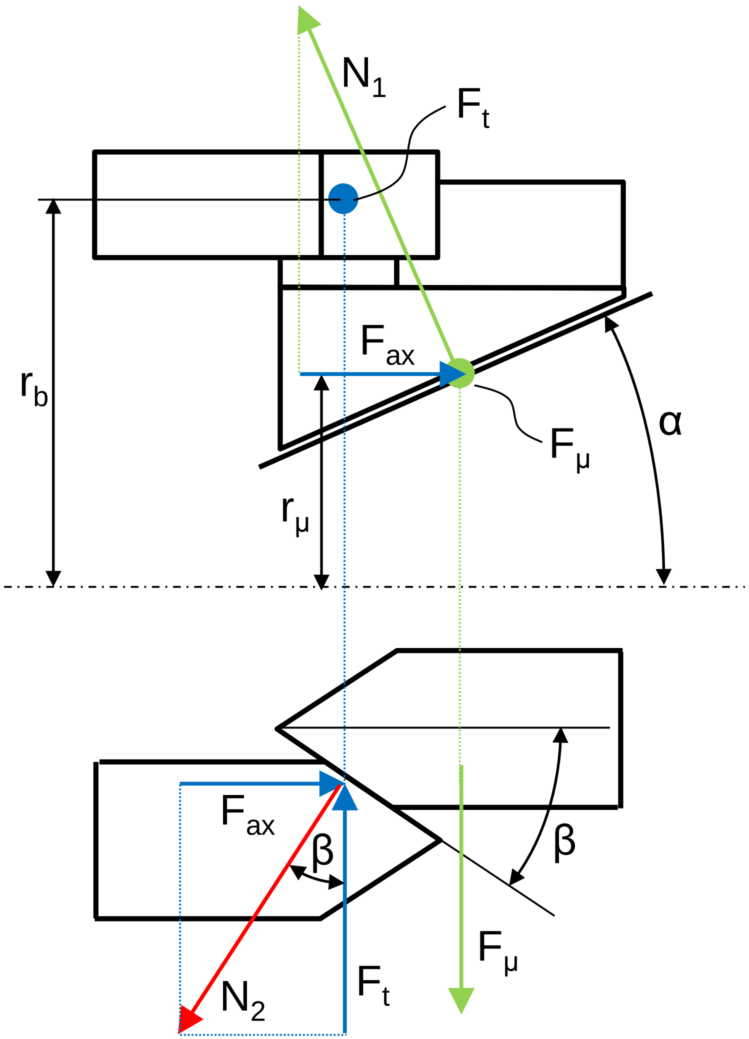
Designing the locking mechanism (approximate)



Tangential force on the synchronizing cone:

$$F_\mu = \mu N_1 = \mu \frac{F_{ax}}{sin\alpha}$$

Slipping limit on the coupling claws:

$$\left.\begin{matrix} F_{ax} = N_2 sin\beta \\ F_t = N_2 cos\beta \end{matrix}\right\} \Rightarrow F_t = \frac{F_{ax}}{tg\beta}$$

Criterion for coupling/locking: $M_\mu > M_t$

$$r_\mu F_\mu > r_b F_t$$

$$r_\mu \mu \frac{F_{ax}}{sin\alpha} > r_b \frac{F_{ax}}{tg\beta}$$

$$tg\beta > \frac{r_b sin\alpha}{r_\mu \mu}$$

From locking point of view a blunter claw is preferable, while a sharper claw makes synchronisation process faster. Charasteristic values:

α ≈ 6-8° > arctg(μ), to avoid self-locking
β ≈ 46 –64°, the least value, which is able to lock

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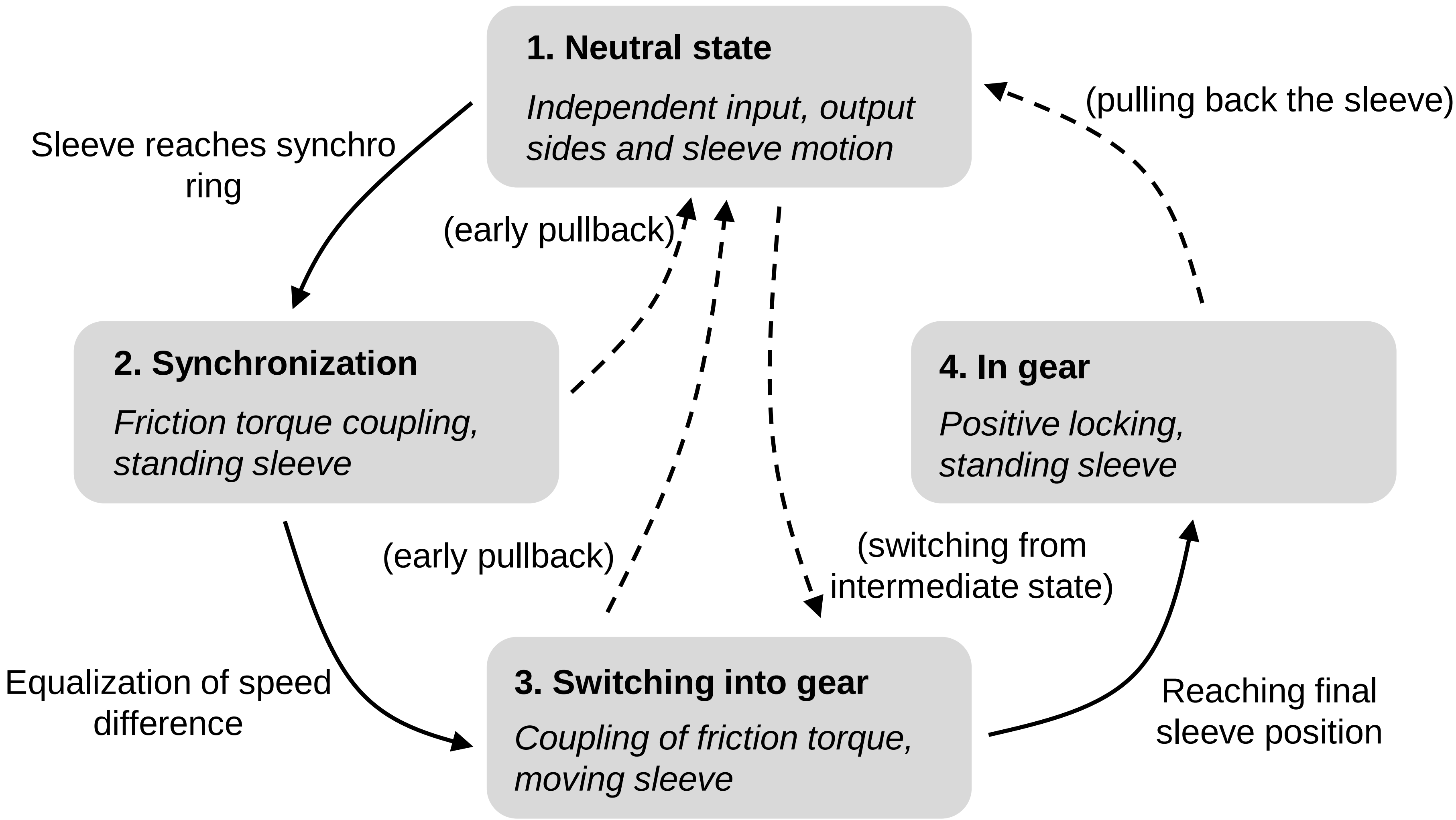
MŰEGYETEM GÉPJÁRMŰVEK TANSZÉK

Model characteristics and assumptions

Modeled parts of the system:	input reduced inertia (rotation) output reduced inertia (rotation) sleeve (progression)
Assumptions:	simplified, rotationally symmetric parts process divided to four main parts only swtching only from neautral position frictional losses neglected
Model input:	axial switching force

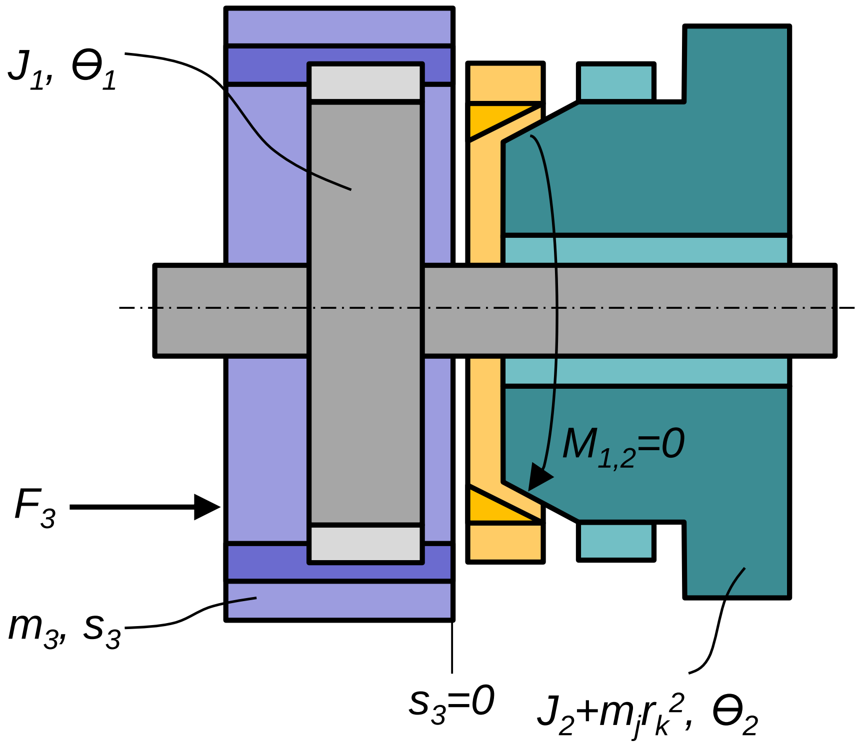
Synchronous mechanism modeling

Definition of states and trasitions of the system



MŰEGYETEM GÉPJÁRMŰVEK TANSZÉK

Equations of motion in state 1 (neutral position)



Equations of motion:

$$J_1\ddot{\theta}_1 = M_{1,2}$$

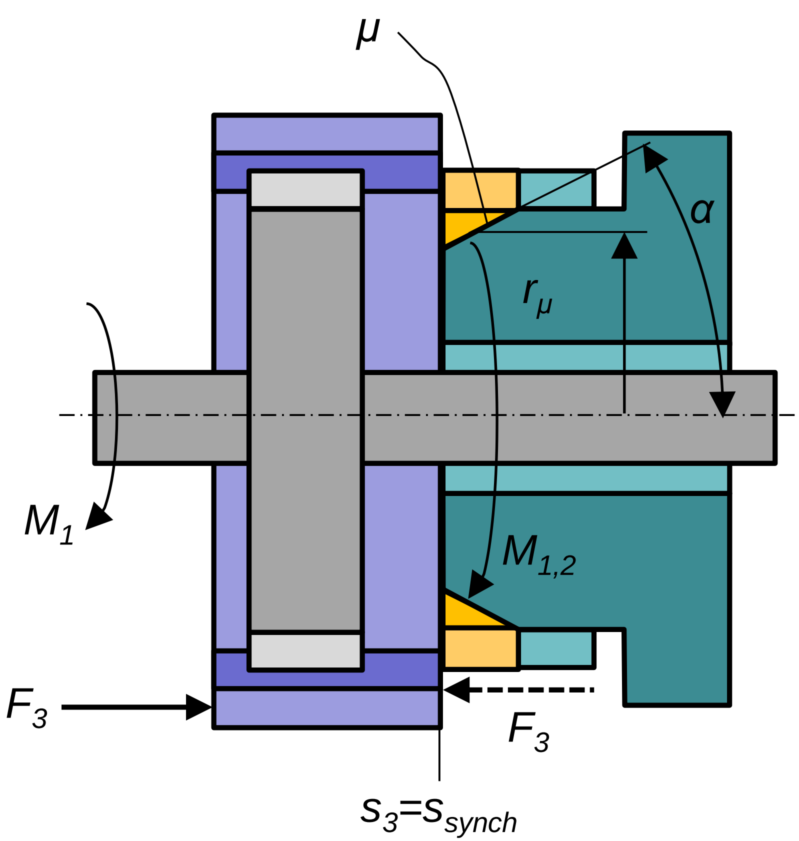
$$\left(J_2 + m_j r_k^2\right)\ddot{\theta}_2 = -M_{1,2}$$

$$m_3\ddot{s}_3 = F_3$$

Additional equations:

$$M_{1,2} = 0$$

Equations of motion in state 2 (synchronization)



Equations of motion:

$$J_1\ddot{\theta}_1 = M_{1,2}$$

$$\left(J_2 + m_j r_k^2\right)\ddot{\theta}_2 = -M_{1,2}$$

$$\ddot{s}_3 = 0$$

Additional equations:

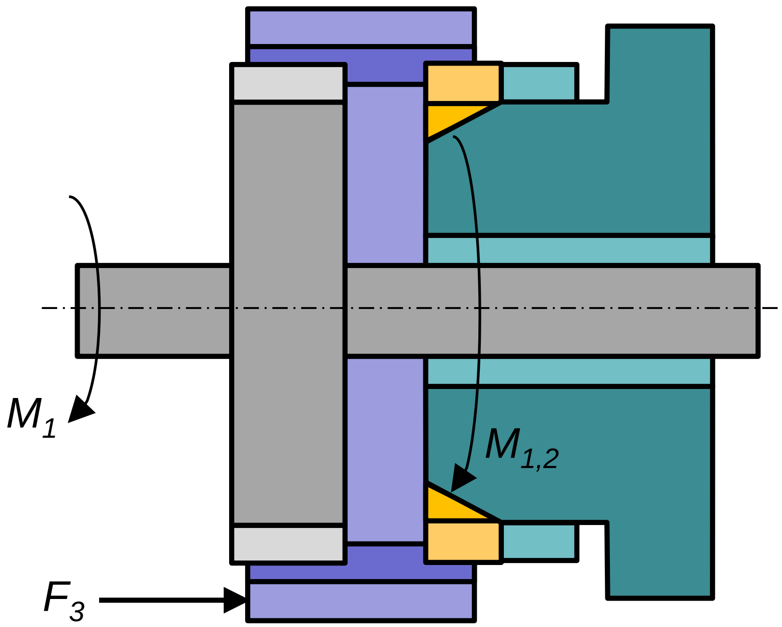
$$s_3 = s_{synch} = const.$$

$$M_{1,2} = sgn\left(\dot{\theta}_2 - \dot{\theta}_1\right)\frac{\mu r_\mu}{sin\alpha}F_3$$

$$sgn(u) \approx \frac{2}{1+e^{-\sigma u}} - 1$$

Synchronous mechanism modeling

Equations of motion in state 3 (switching to gear)



Equations of motion:

$$J_1\ddot{\theta}_1 = M_{1,2}$$

$$\left(J_2 + m_j r_k^2\right)\ddot{\theta}_2 = -M_{1,2}$$

$$m_3\ddot{s}_3 = F_3$$

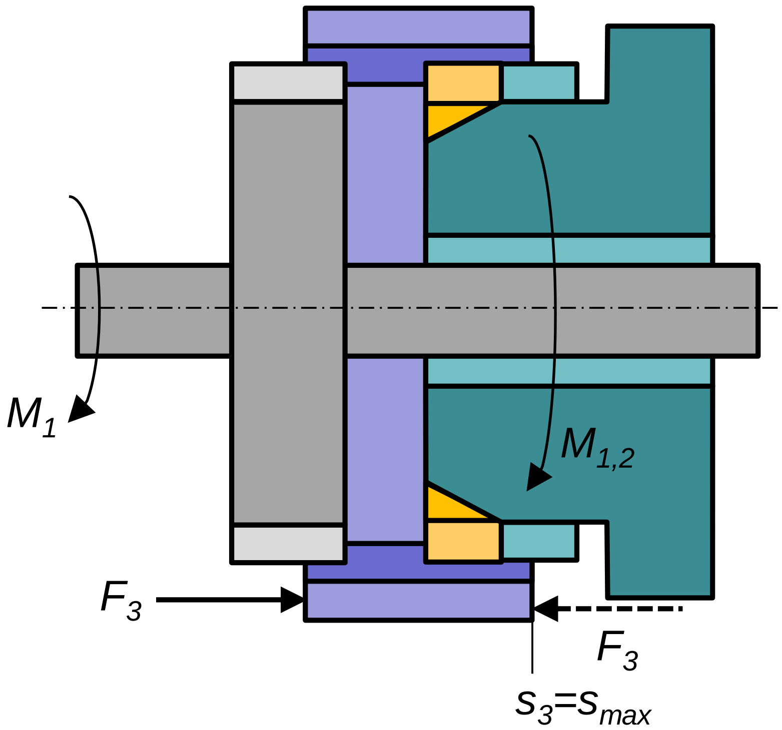
Additional equations:

$$M_{1,2} = sgn\left(\dot{\theta}_2 - \dot{\theta}_1\right)\frac{\mu r_\mu}{sin\alpha}F_3$$

$$sgn(u) \approx \frac{2}{1+e^{-\sigma u}} - 1$$

Synchronous mechanism modeling

Equations of motion in state 4 (in gear)



Equations of motion:

$$J_1\ddot{\theta}_1 = M_{1,2}$$

$$(J_2 + m_j r_k^2)\ddot{\theta}_2 = -M_{1,2}$$

$$\ddot{s}_3 = 0$$

Additional equations:

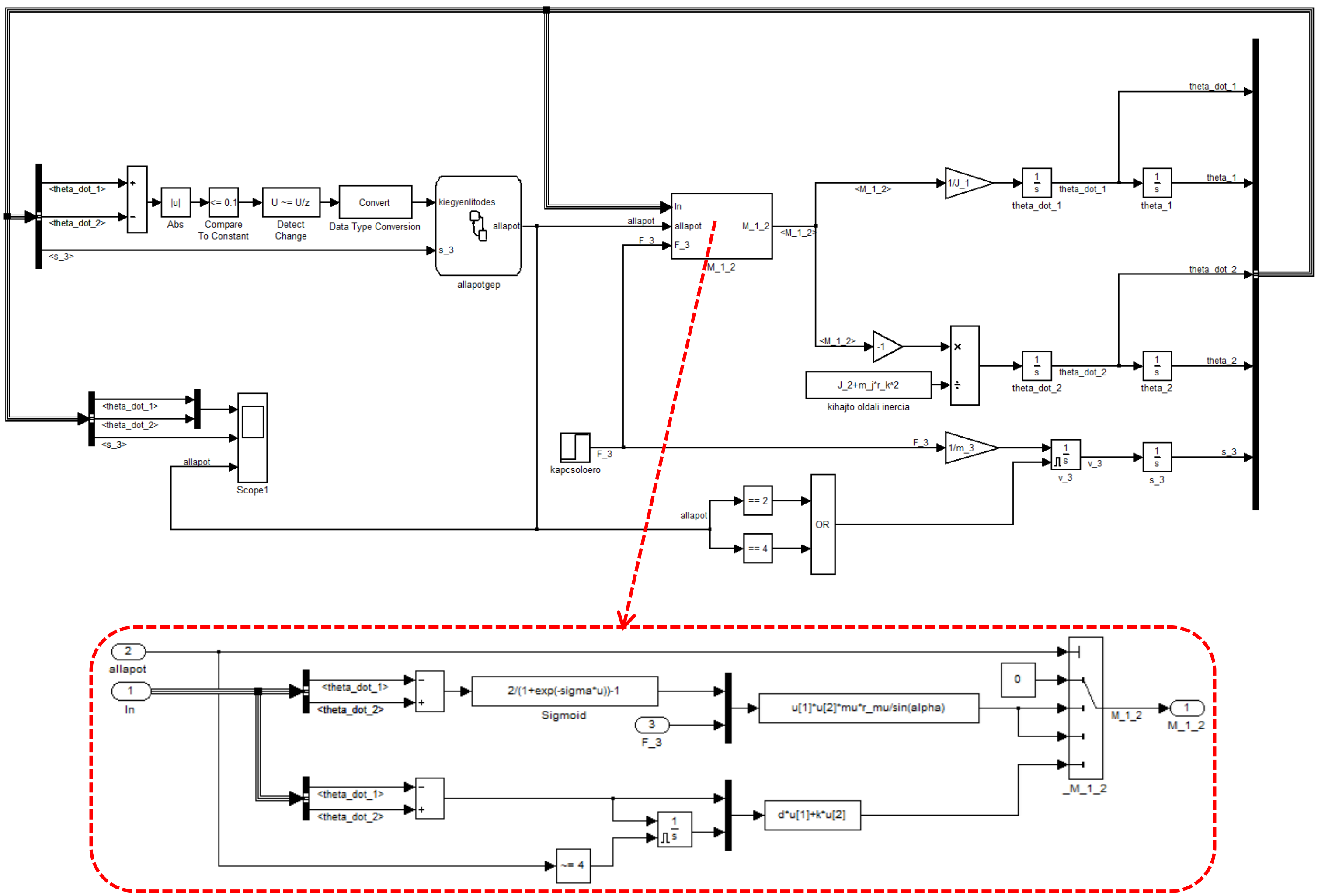
$$s_3 = s_{max} = const.$$

$$M_{1,2} = d(\dot{\theta}_2 - \dot{\theta}_1) + k\int(\dot{\theta}_2 - \dot{\theta}_1)dt$$

Deformation-free status at the beginning of state

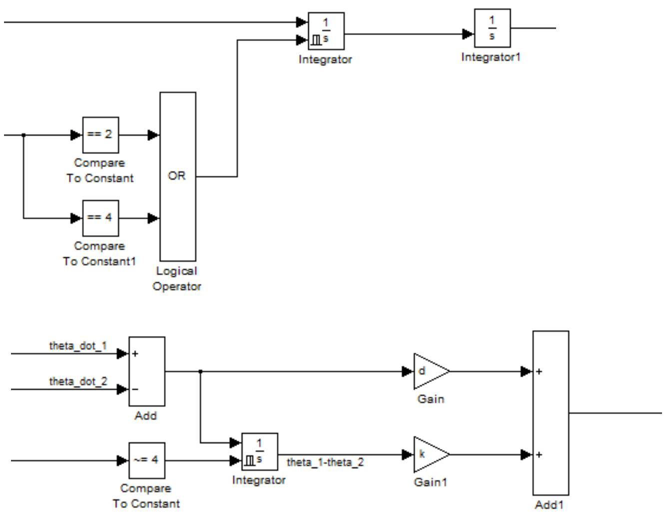
MŰEGYETEM GÉPJÁRMŰVEK TANSZÉK

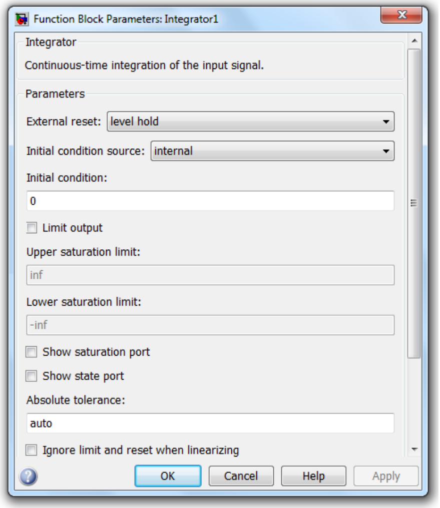
Implementation of the model in Simulink



Synchronous mechanism modeling

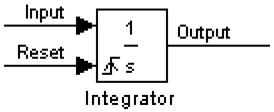
Integrator reset





Resetting the State

The block can reset its state to the specified initial condition based on an external signal. To cause the block to reset its state, select one of the **External reset** choices. A trigger port appears below the block's input port and indicates the trigger type.



- Select `rising` to reset the state when the reset signal rises from a zero to a positive value or from a negative to a positive value.
- Select `falling` to reset the state when the reset signal falls from a positive value to zero or from a positive to a negative value.
- Select `either` to reset the state when the reset signal changes from a zero to a nonzero value or changes sign.
- Select `level` to reset the state when the reset signal is nonzero at the current time step or changes from nonzero at the previous time step to zero at the current time step.
- Select `level hold` to reset the state when the reset signal is nonzero at the current time step.

Synchronous mechanism modeling

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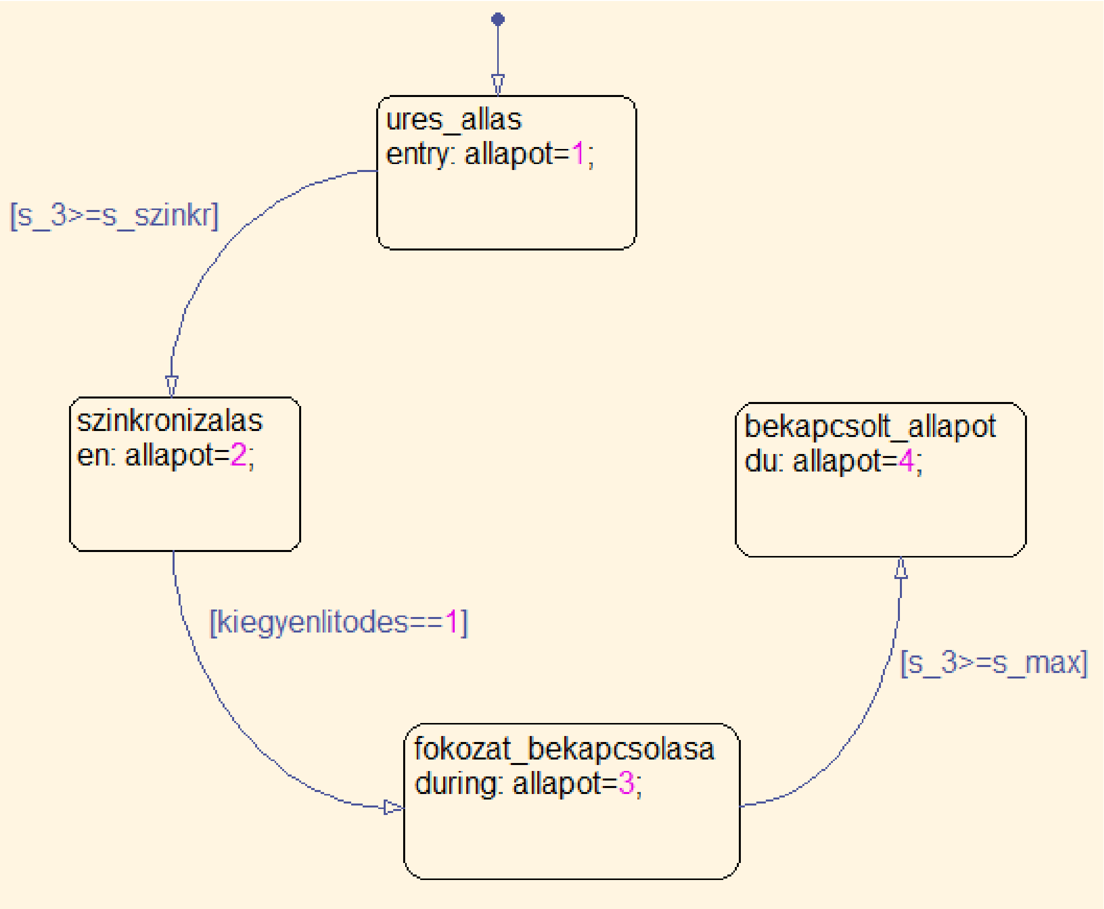
Implementing the state flow chart



Contents of: szinkronszerkezet/allapotgep

Name	Scope	Port	Resolve Signal	DataType
allapot	Output	1	☐	double
kiegyenlitodes	Input	1		double
s_3	Input	2		double
s_szinkr	Parameter			double
s_max	Parameter			double

MŰEGYETEM GÉPJÁRMŰVEK TANSZÉK

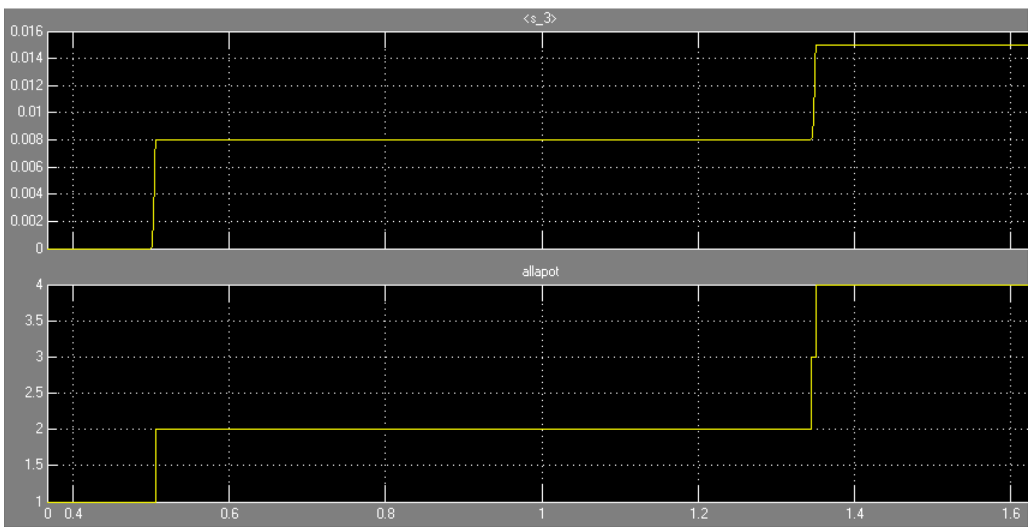
Model parameters

```
J_1=1;      % [kgm^2] behajtó oldali inercia
J_2=5;      % [kgm^2] kihajtó oldali inercia
m_j=1000; % [kg] járműtömeg
r_k=0.315;  % [m] gördülési sugár
m_3=2;      % [kg] tolókerék tömeg

F_3=1000;   % [N] kapcsolóerő

s_szinkr=8e-3; % [m] szinkronizálási helyzet
s_max=15e-3;   % [m] max. bekapcsolt helyzet

mu=0.1;         % [-] súrlódási tényező
r_mu=45e-3;     % [m] súrlódási középsugár
alpha=8*pi/180; % [rad] szinkron félkúpszög

k=1e6; % [Nm/rad] kapcsolószerkezet merevség
d=1e3; % [Nms/rad] kapcsolószerkezet csillapítás

sigma=1000; % [-] sigmoid formatényező

theta_dot_1_0=1500*2*pi/60; % [rad/s] kezdeti behajtó oldali szögsebesség
theta_dot_2_0=1000*2*pi/60; % [rad/s] kezdeti kihajtó oldali szögsebesség
s_3_0=0;                    % [m] kezdeti tolókerék pozíció
```

Synchronous mechanism modeling

Solver settings

Solver: ode45 (Dormand-Prince)
Relative tolerance: 1e-3
Absolute tolerance: auto



Solver: ode15s (stiff/NDF)
Relative tolerance: 1e-9
Absolute tolerance: auto
Maximum order: 5

References

[1] **Lovas**, **L.**, **Play, D**., **Márialigeti, J.** and **Rigal, J.-F.** Mechanical behaviour simulation for synchromesh mechanism improvements, Proc. IMechE, Part D: J. Automobile Engineering, 2006, Vol. 220, pp. 919–945 (2006)