Mechatronic Actuators

Lecture 7b

Mechanical drives

Linear systems

- Acceleration : $\ddot{x} = \frac{F}{m}$
- Motor power : $F_m = F_L + m_{tot}\ddot{x} + B_L\dot{x}$
- Change in kinetic energy : $\Delta E_k = \frac{m_{tot}(\dot{x}_2^2 - \dot{x}_1^2)}{2}$

Systems with wheels

The choice of drive motors for wheeled systems depends on two factors:

- Can the wheels provide enough torque to handle all tasks including acceleration and riding uphill?
- Can the required torque be transferred to the surface without slipping?

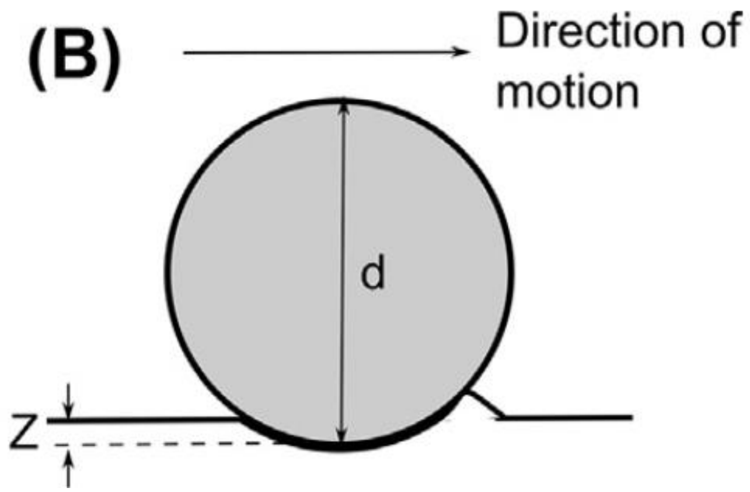
Torque requirement

- A sum: $E_t = R_r + G_r + F_a$
- R_r rolling resistance
- G_r influence of slope
- F_a acceleration force

Rolling resistance

- Equation: $R_r = C_{rr} mg\ cos\alpha$

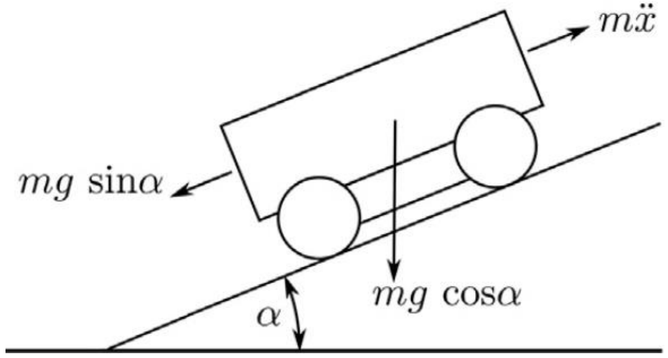
- Coefficient of rolling friction : $C_{rr} = \sqrt{\frac{z}{d}}$



Wheel surface combination	Coefficient of rolling resistance, C_{rr}	Static coefficient of friction, μ
Steel on steel	0.0005	0.5
Hard rubber on concrete	0.01–0.02	0.6–0.8
BMX bicycle tires on road surface	0.0055	0.9

Influence of slope

- The force is determined by the weight of the vehicle and the slope
  $G_r = mg\ sin\alpha$



Acceleration force

- Equation: $F_a = m\ddot{x}$

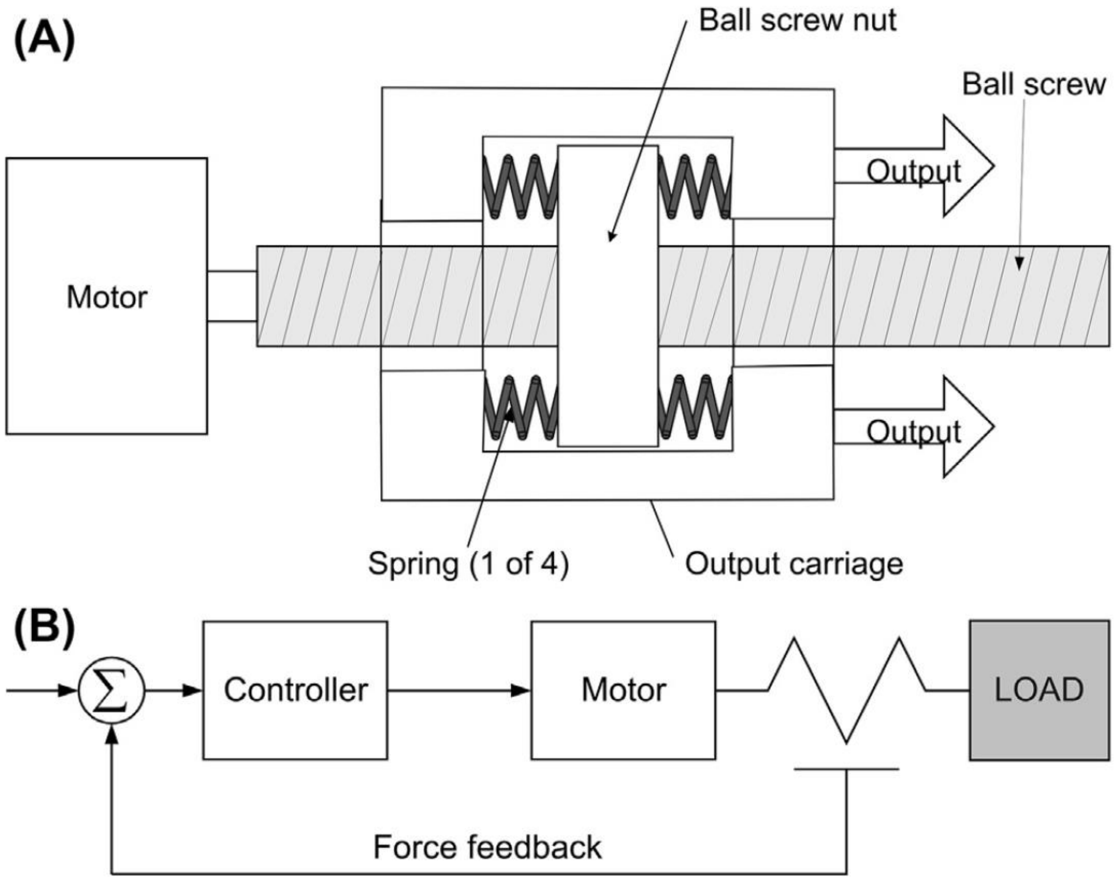
The sum of all three influences and torques on the wheel

- Sum: $E_t = R_r + G_r + F_a$ must be provided as the sum of the forces of all wheels.
- So: $T_d = \frac{E_t}{n_d} r$, where r is the diameter of the wheels and n_d is the number of driven wheels

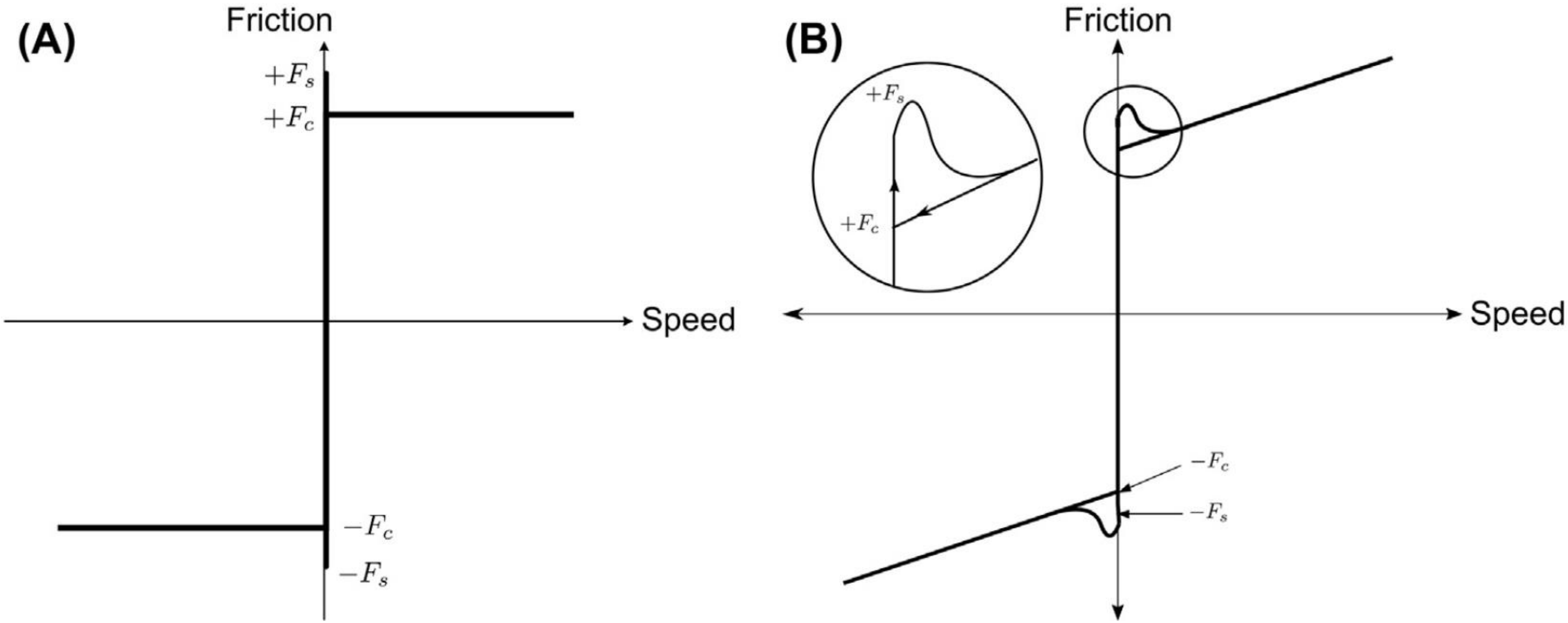
Does it slip?

- Condition: $T_e^{max} = \frac{mg\mu r\ cos\alpha}{n_{tot}} > T_d$, where μ is the coefficient of static friction and n_{tot} is the number of all wheels (driven and non-driven).

Force-based systems



Friction



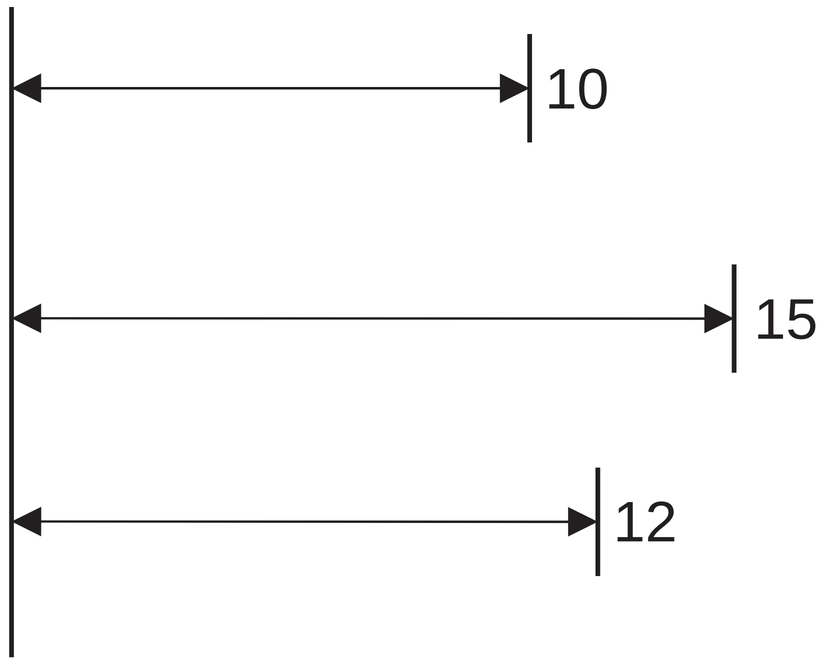
Equations

- $F_f = \mu N$
- $F_f = \begin{cases} F_f(\dot{x}) & \dot{x} \neq 0 \\ F_e & \dot{x} = 0, \ddot{x} = 0, |F_e| < F_s \\ F_s \operatorname{sgn}(F_e) & \dot{x} = 0, \ddot{x} \neq 0, |F_e| < F_s \end{cases}$
- $F_f \dot{x} = F_c \operatorname{sgn} \dot{x} + B\dot{x}$
- $\operatorname{sgn} \dot{x} = \begin{cases} +1 & \dot{x} > 0 \\ 0 & \dot{x} = 0 \\ -1 & \dot{x} < 0 \end{cases}$

Friction coefficient

Material pairs	Coefficient of friction
Aluminium and Aluminium	1.05–1.35
Aluminium and Mild steel	0.61
Mild steel and Brass	0.51
Mild steel and Mild steel	0.74
Tool steel and Brass	0.24
Tool steel and PTFE	0.05–0.3
Tool steel and Stainless steel	0.53
Tool steel and Polyethylene	0.65
Tungsten carbide and Mild steel	0.4–0.6

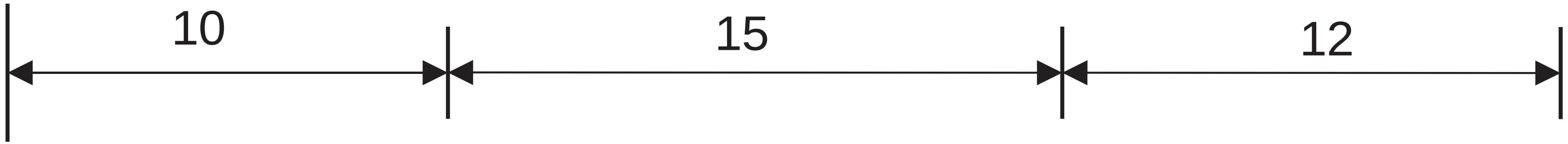
Absolute displacement



Vedno povemo, na kakšen položaj se želimo postaviti. Prva vrednost je 10. V drugem koraku se postavimo na vrednost 15 (premaknemo se torej 5 pulzov v desno). V tretjem koraku se postavimo na vrednost 12 (premaknemo se torej tri pulse v levo).

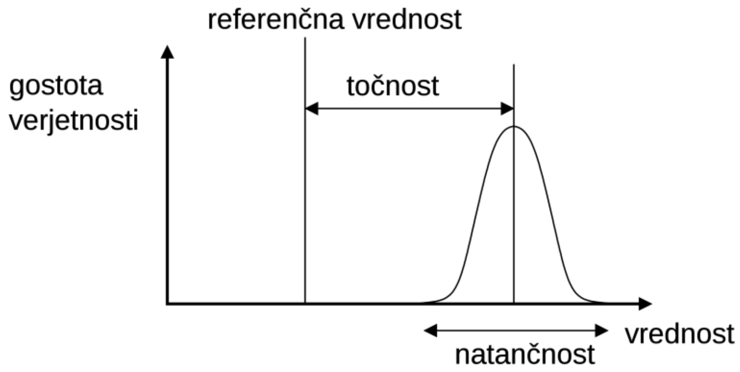
Takšno premikanje je najbolj točno.

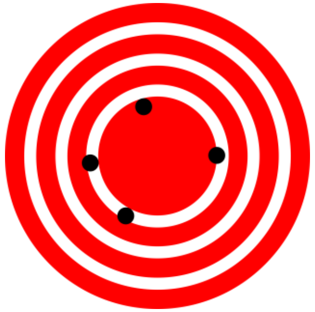
Relative displacement



In the first step, we move 10 pulses to the right. In the second step, a further 15 pulses to the right (absolute value 25). In the third step for another 12 pulses to the right. Such movement is less accurate.

Accuracy / precision





Good accuracy, poor precision

Good precision, poor accuracy

Accuracy

Accuracy can mean several things. Among others:

- Resolution
- Positioning accuracy
- repetition accuracy

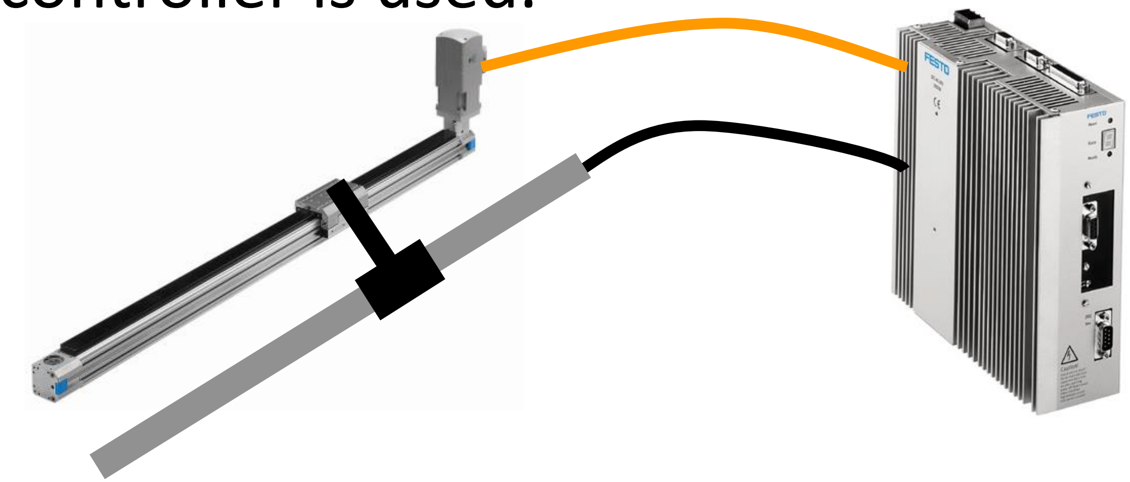
Resolution

Resolution is (theoretically) the smallest displacement we can achieve.

Let's say we use a stepper electric motor with a step of 1.8^o. If the motor is connected to a toothed belt of size 25, which has a displacement of 63 mm per revolution, then the resolution is 63 mm $*(1.8^o/360^o) = 0.315$ mm.

Positioning accuracy (1)

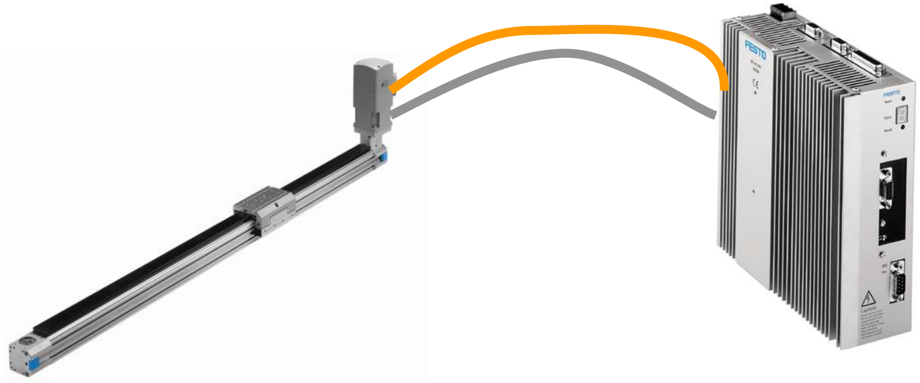
Positioning accuracy means the accuracy with which the positioning system can move to a certain position in a controlled manner, regardless of the direction from which the position is reached. A controller is used.



This method is the most accurate, as all tolerances in the system are taken into account in the control loop.

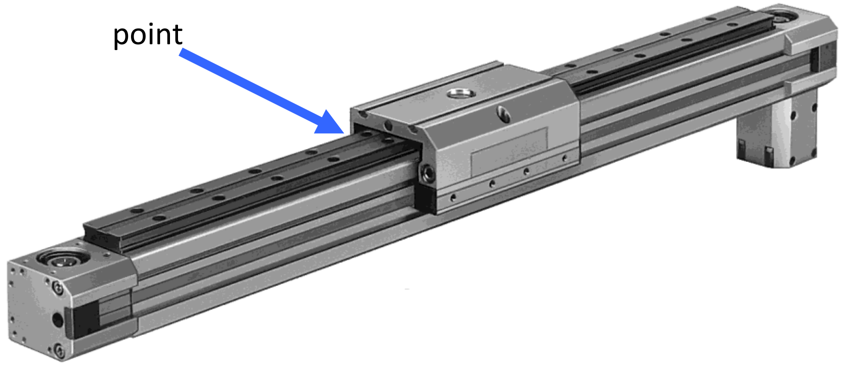
Positioning accuracy (2)

An alternative is a system with a resolver on an electric motor. Axis tolerances are not taken into account. Still, the system is good enough for most applications.



Repeatability

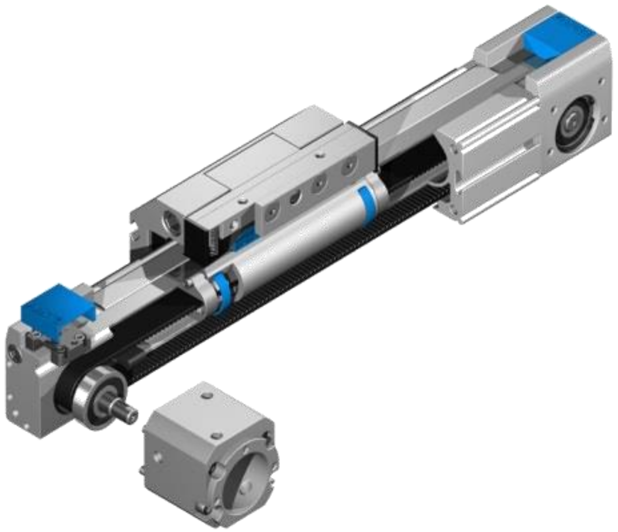
Repeatability refers to the accuracy with which an axis position can be achieved when repeating a task.



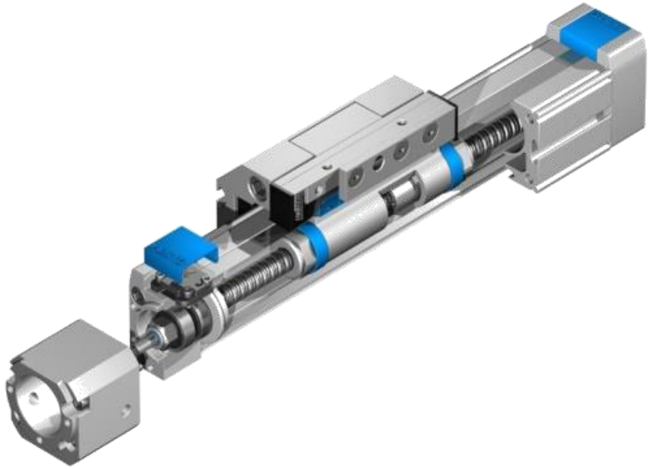
In practice, this is the most important data, as it takes into account all tolerances.

Axis types

- toothed belt



- spindle



Comparison

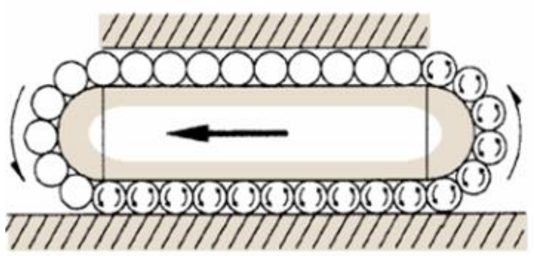
	Toothed belt	Spindle
Length	5000 mm	2000 mm
Displacement per rev.	32 – 176 mm	4 – 30 mm
Max. rotational speed		3000 rpm
Max. speed	1 – 5 m/s	0.2 – 1.2 m/s
Max. acceleration	15 – 50 m/s^2	
Max. torque	0.08 – 42 Nm	0.1 – 8.5 Nm
Max. axial force	15 – 1500 N	140 – 1600 N
Repetition accuracy	0.08 – 0.1 mm	± 0.02 mm

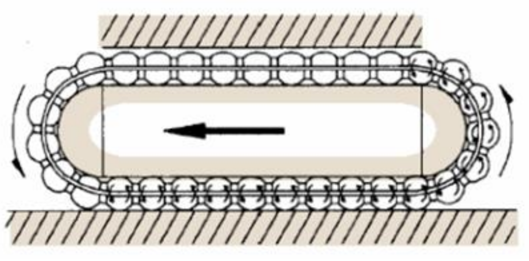
Types of sliders / bearings

- No purposeful bearing
- With balls (recirculating ball bearing slide) (mark KF)
- With wheels (roller bearing) (mark RF)
- For increased loads (heavy duty) (mark HD)

Types of sliders / bearings

With balls (KF)

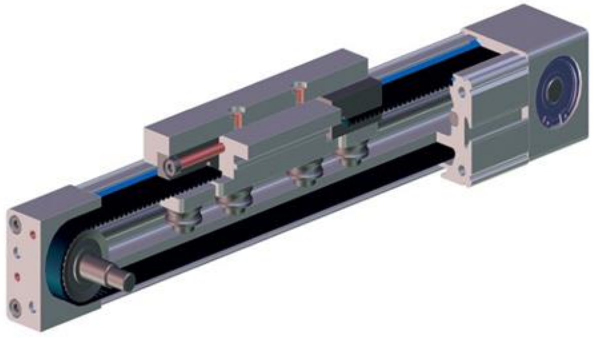


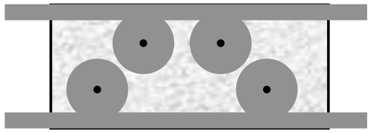


Since the balls are in contact, such a system is quite noisy and has a fairly high level of wear. Movement speed is fairly limited. In the case of a cage, this is improved. A large number of balls means a lot of contact surfaces and consequently possible higher loads.

With wheels (RF)

The wheels are mounted inside the axle, so maintenance is almost impossible. Since the wheels have a larger diameter than the balls, there are fewer of them and they do not touch, higher speeds are possible, but therefore the loads are lower.

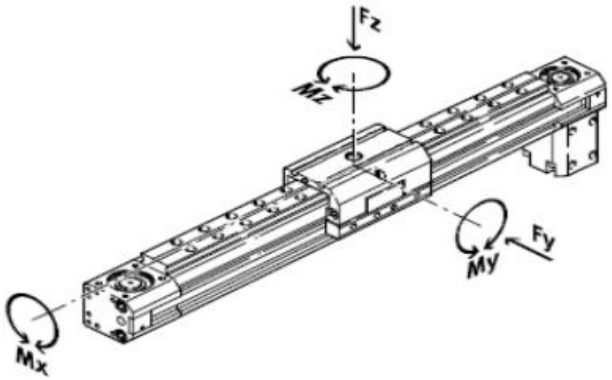




For increased loads(HD)

Consisting of two sets of balls and intended for very high loads

Overview of types



						Forces and torques				
	Size	stroke length	velocity	repet. acc.	Feed force	Fy	Fz	Mx	My	Mz
	mm	mm	m/s	mm	N	N	N	Nm	Nm	Nm
ZR	25	3,000	5	±0.1	260	-	330	1	20	3
ZR-KF	25	3,000	3	±0.1	260	3080	3080	45	170	170
ZR-RF	25	5,000	10	±0.1	260	260	150	7	30	30
ZR-HD	25	1,000	3	±0.1	260	5400	5600	260	415	400

Types of clutches

- Soft clutch

- hoof clutch