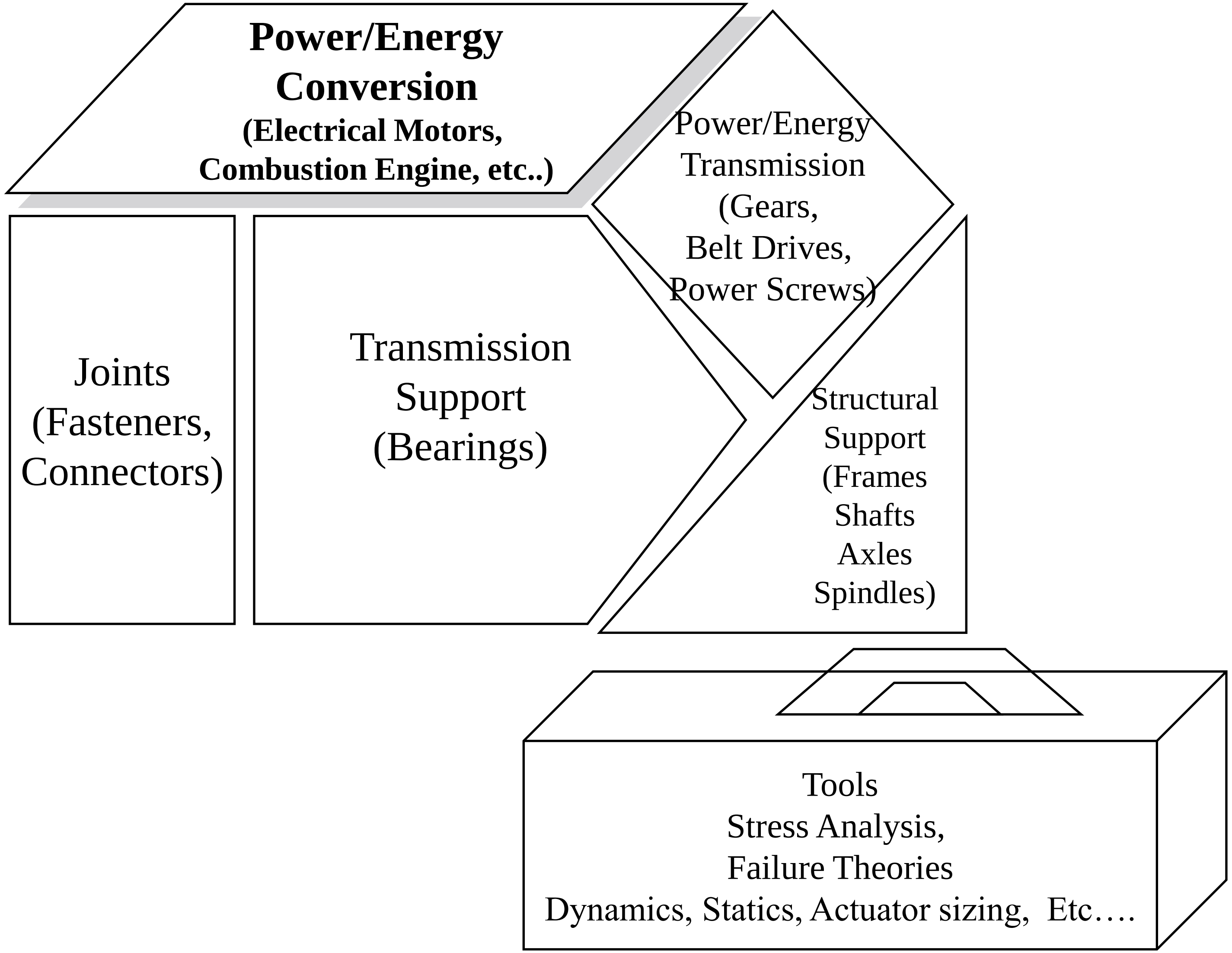
MCT333: Mechatronic Systems Design
Lecture 4: Actuator Selection

Presented by : Dr. Mohammed Ibrahim



Power/Energy
Conversion
(Electrical Motors,
Combustion Engine, etc..)
Power/Energy
Transmission
(Gears,
Belt Drives,
Power Screws)
Joints
(Fasteners,
Connectors)
Transmission
Support
(Bearings)
Structural
Support
(Frames
Shafts
Axles
Spindles)
Tools
Stress Analysis,
Failure Theories
Dynamics, Statics, Actuator sizing, Etc….

How to Engineer a bio-inspired Robot

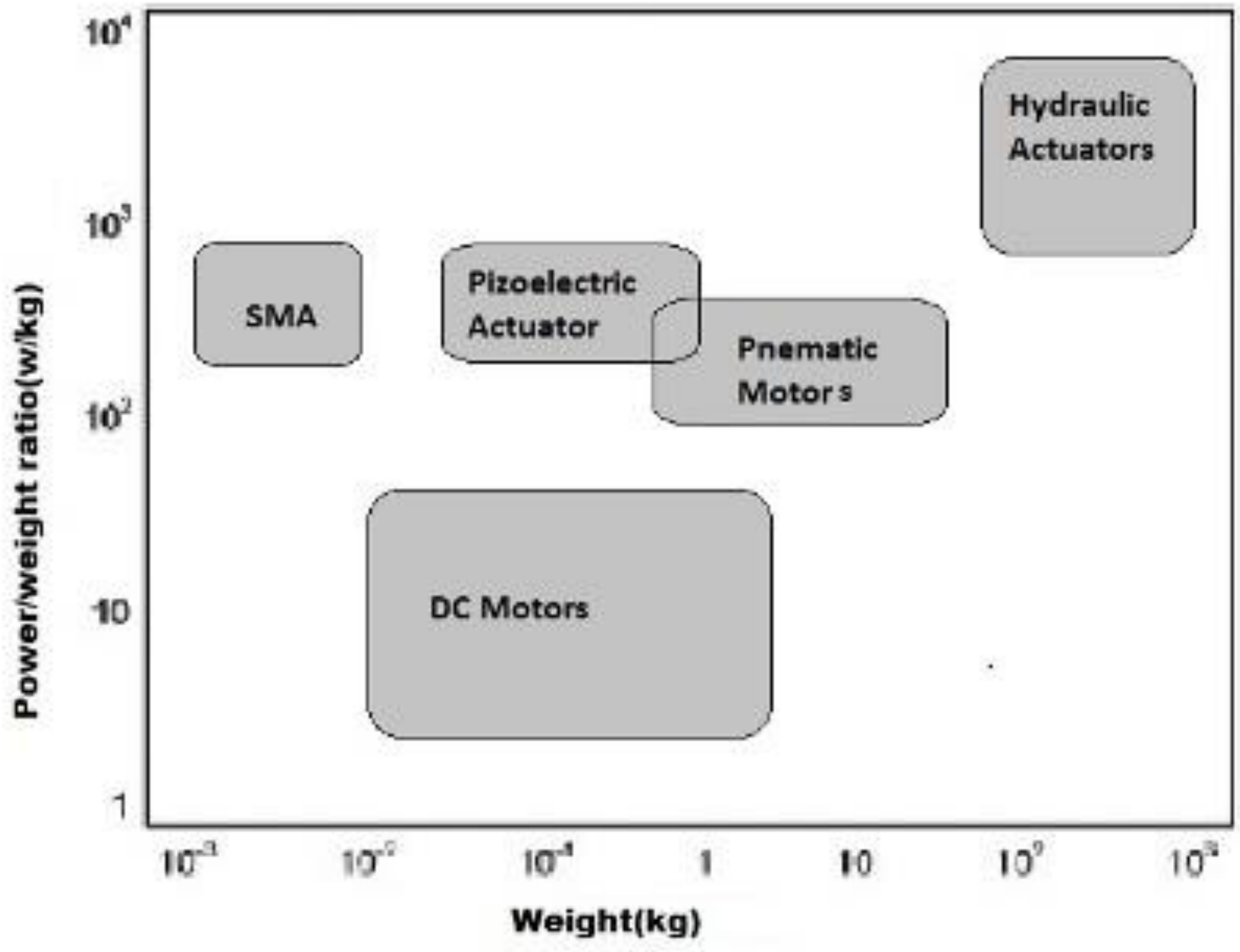
MicroLecture

robotics Swiss National Centre of Competence in Research

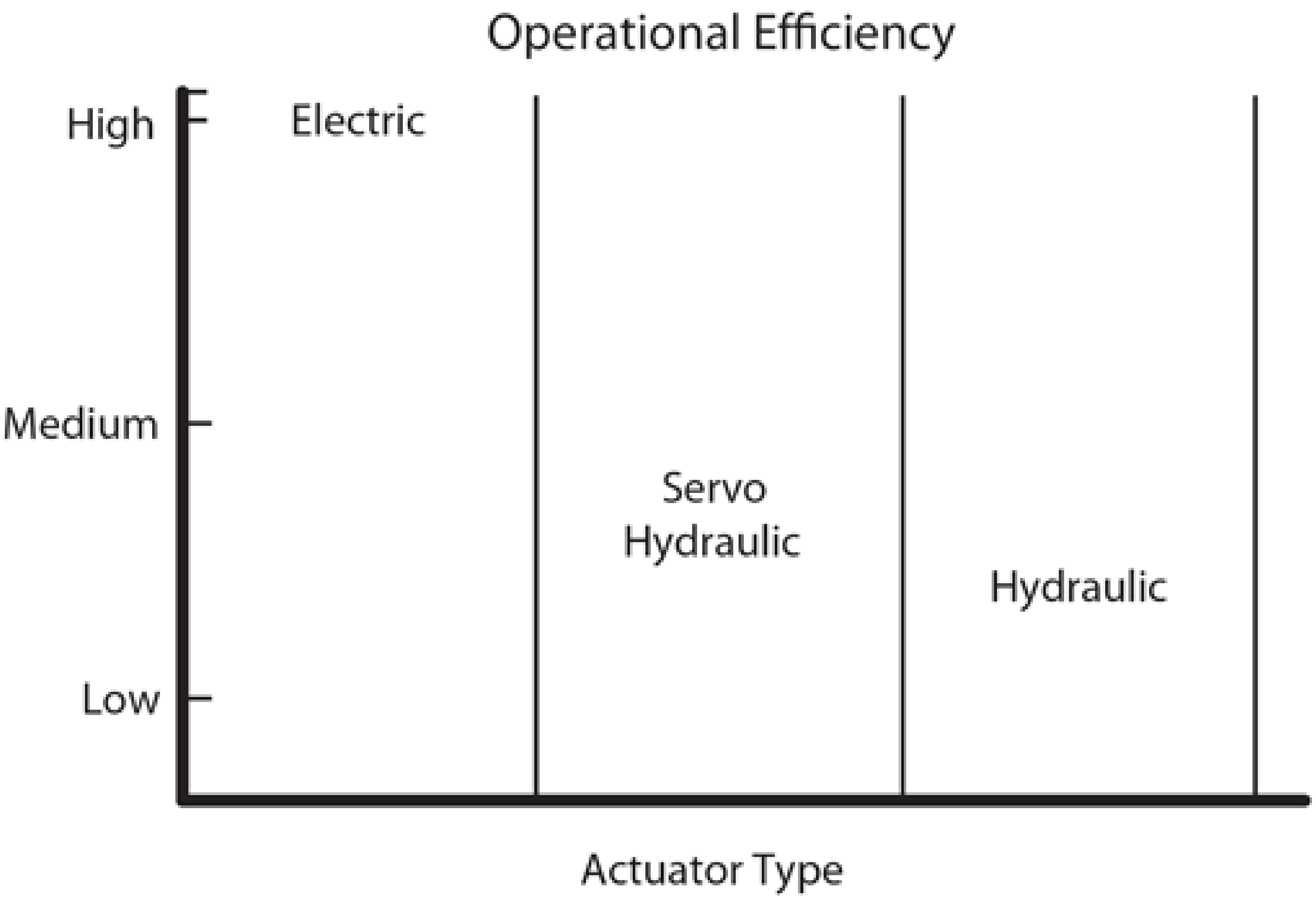
Robohub

- https://www.youtube.com/watch?v=6igNZiVtbxU

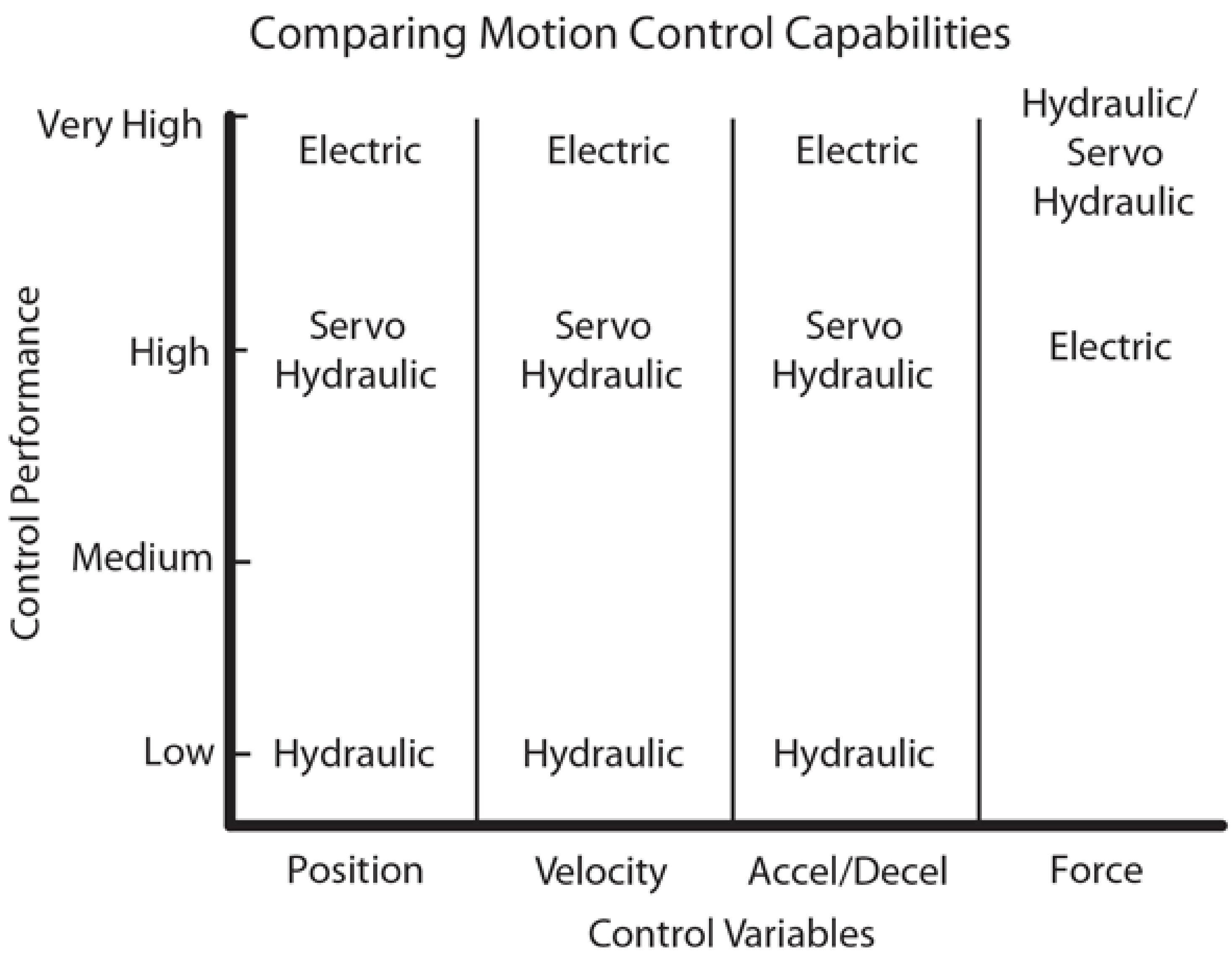
Actuators Power-to-weight Ratio



Operational Efficiency



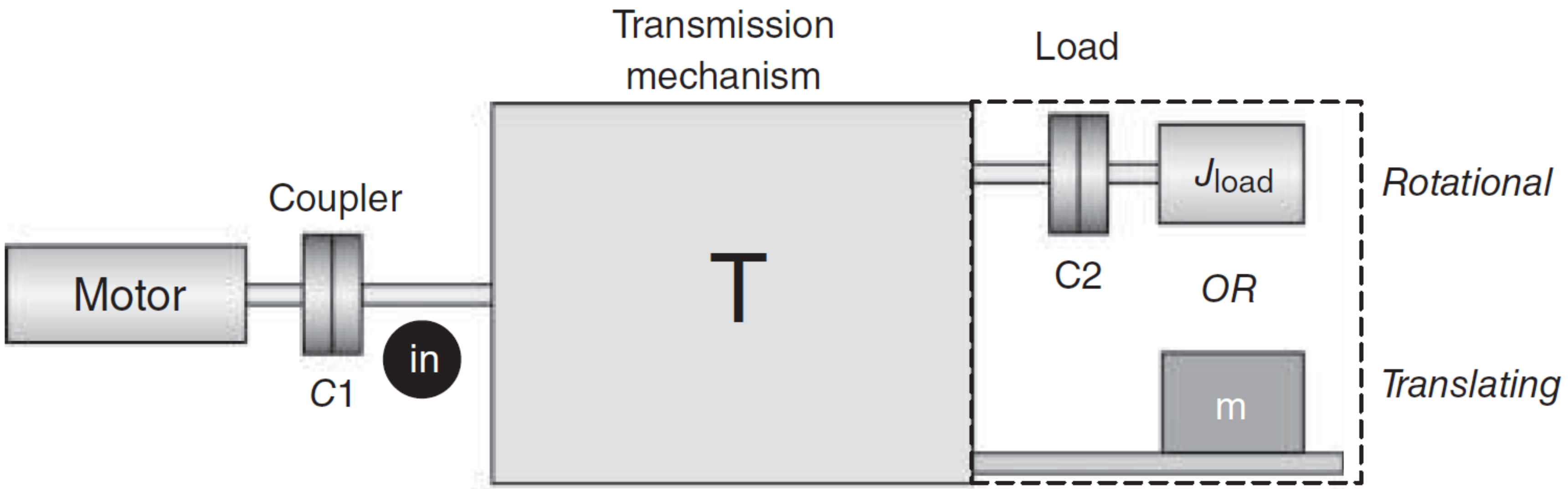
Motion Control Capabilities



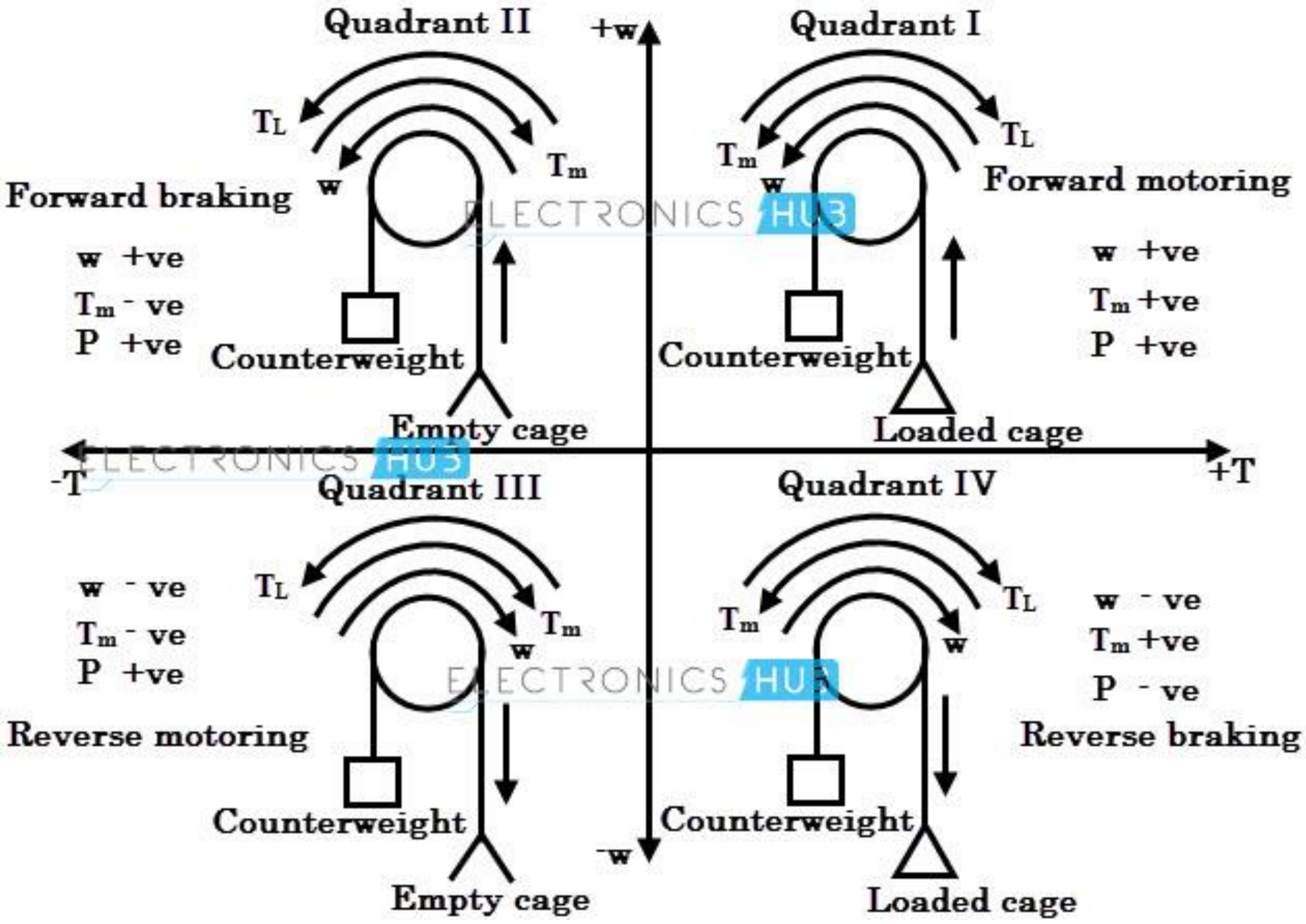
Power Transmission Comparison

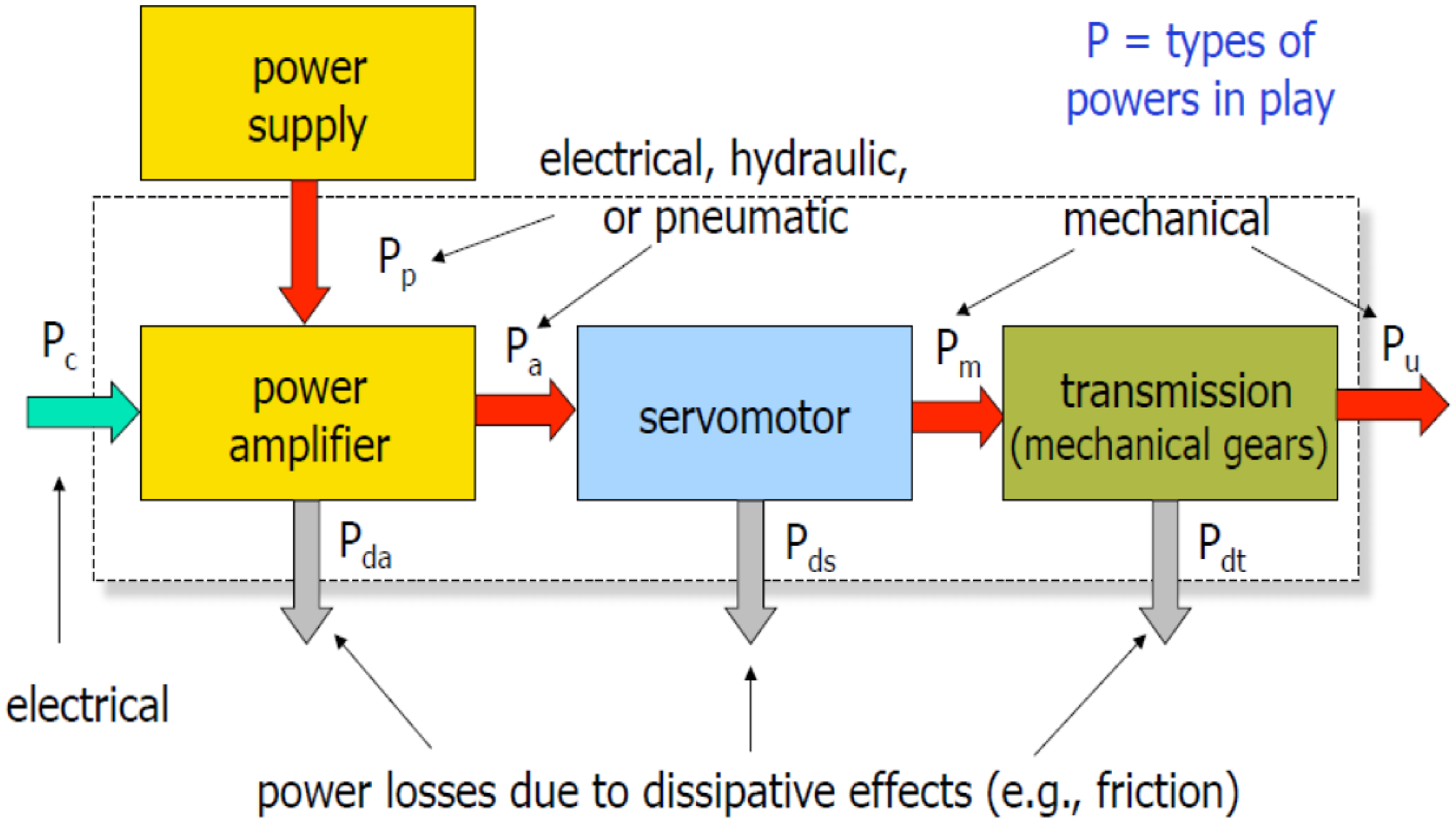
Characteristics	Pneumatic	Hydraulic	Electric
Complexity	Simple	Medium	Medium/High
Peak power	High	Very high	High
Size	Low size/force	Very low size/force	Medium size/force
Control	Simple valves	Simple valves	Electronic controller
Position accuracy	Good	Good	Better
Speed	Fast	Slow	Fast
Purchase cost	Low	High	High
Operating cost	Medium	High	Low
Maintenance cost	Low	High	Low
Utilities	Compressor/power/pipes	Pump/power/pipes	Power only
Efficiency	Low	Low	High
Reliability	Excellent	Good	Good
Maintenance	Low	Medium	Medium

Transmission Mechanisms

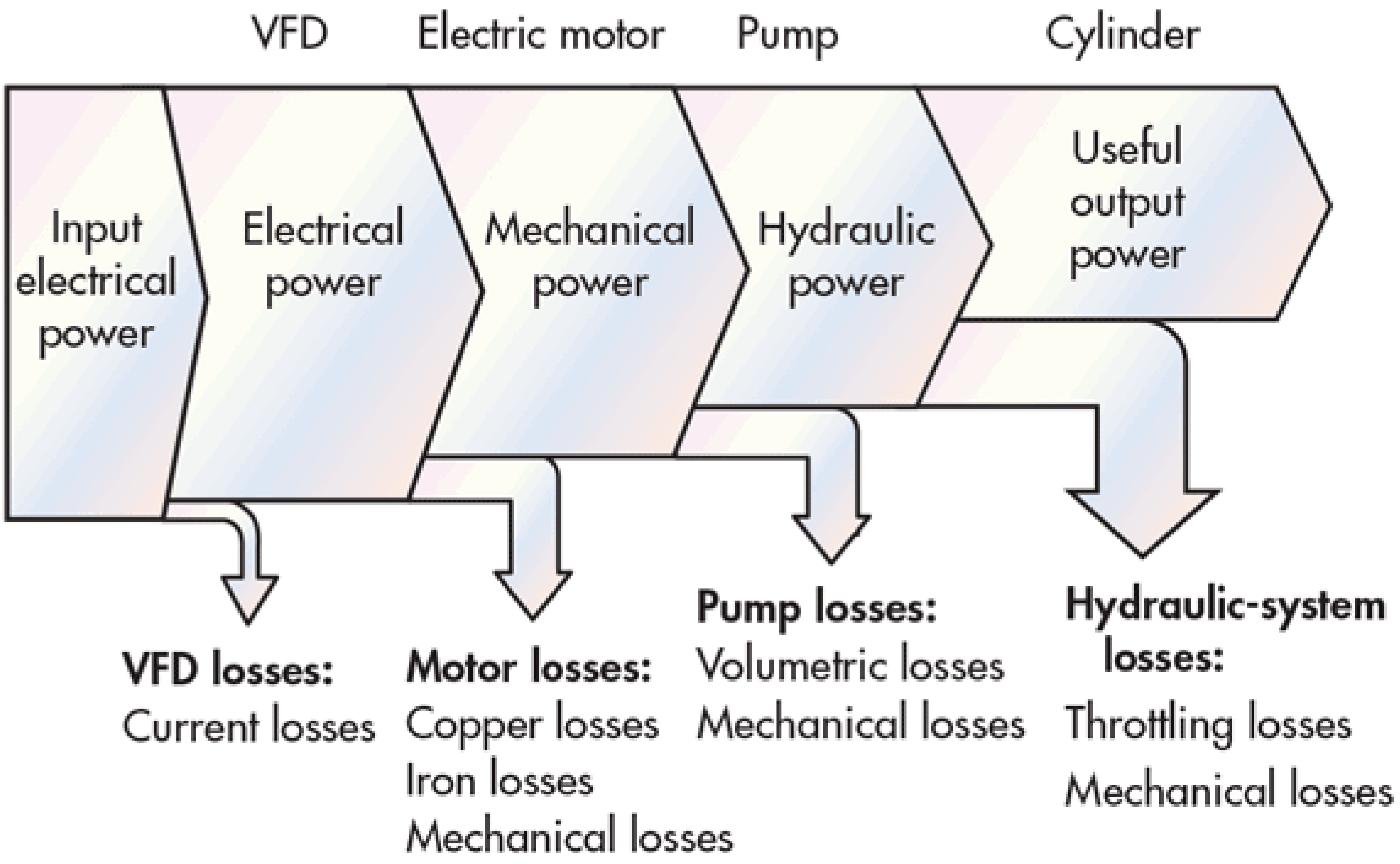


Operating Modes (Four Quadrant)

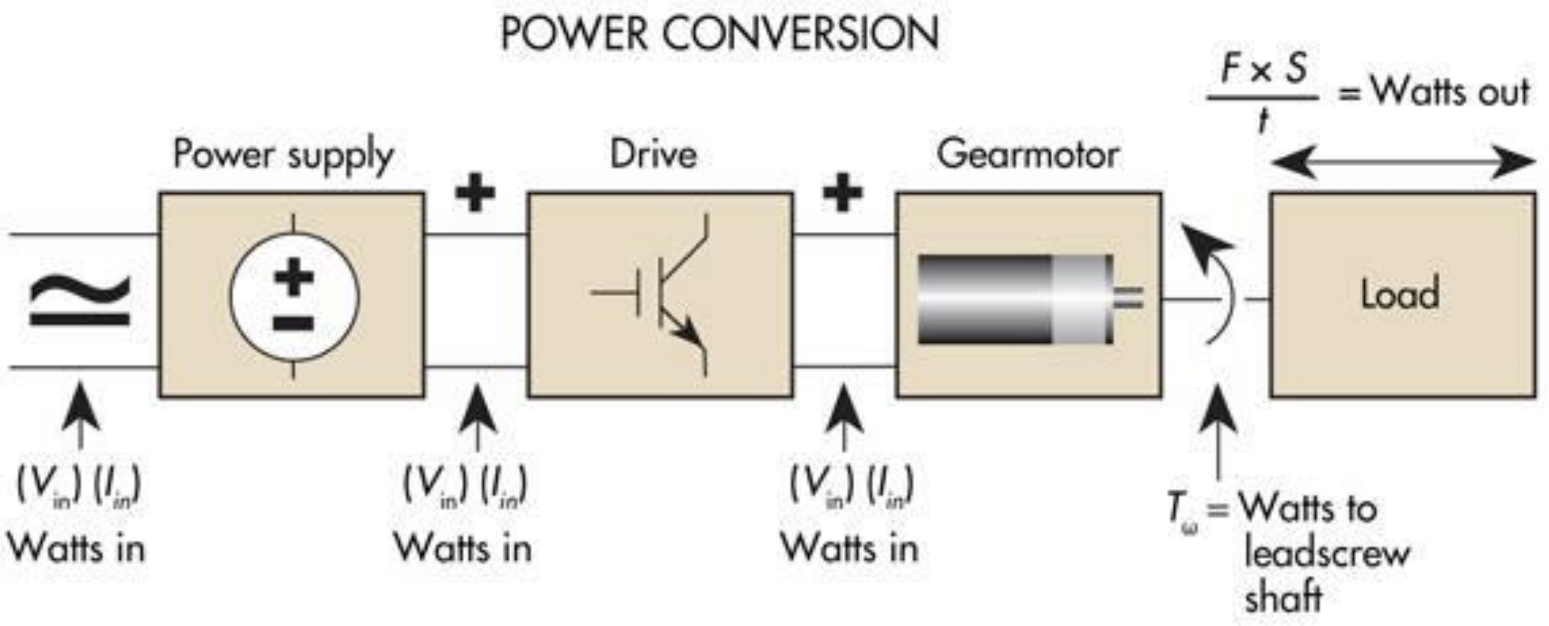



power supply
P = types of powers in play
electrical, hydraulic, or pneumatic
mechanical
P_p
P_c
power amplifier
P_a
servomotor
P_m
transmission (mechanical gears)
P_u
P_{da}
P_{ds}
P_{dt}
electrical
power losses due to dissipative effects (e.g., friction)

Operational Efficiency and Energy Conversion (Hydraulic System)



Operational Efficiency and Energy Conversion (Electrical Motor Actuation System)



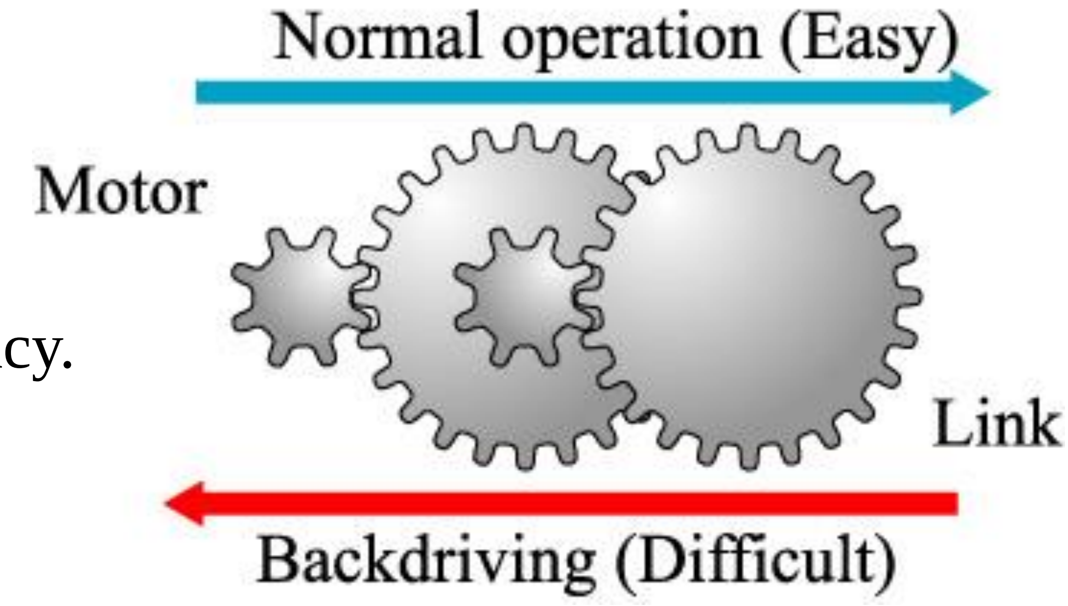
Backdrivability (Passive behavior)

$$\eta_{back-drive} = 2 - \frac{1}{\eta_{forward}}$$

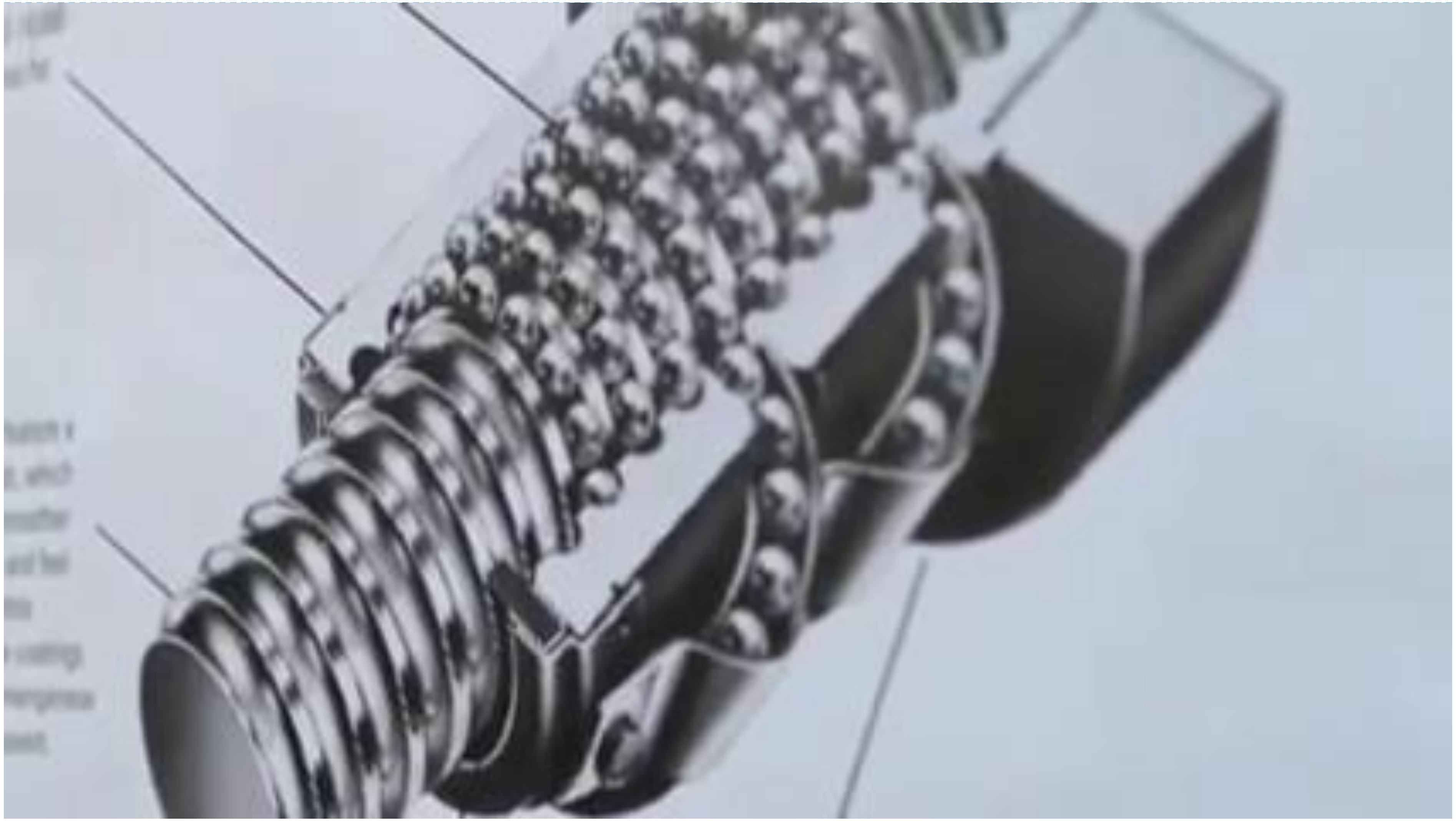
Where:

$\eta_{back\text{-}drive}$, back-driving or reverse efficiency.

$\eta_{forward}$, driving or forward efficiency.

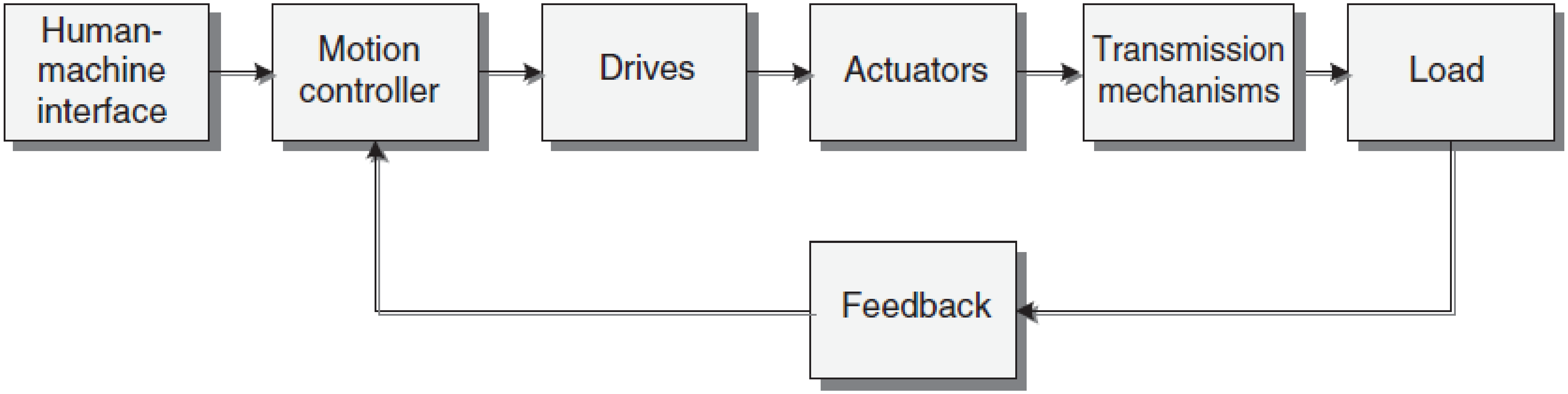


Backdrivability (Passive behavior)

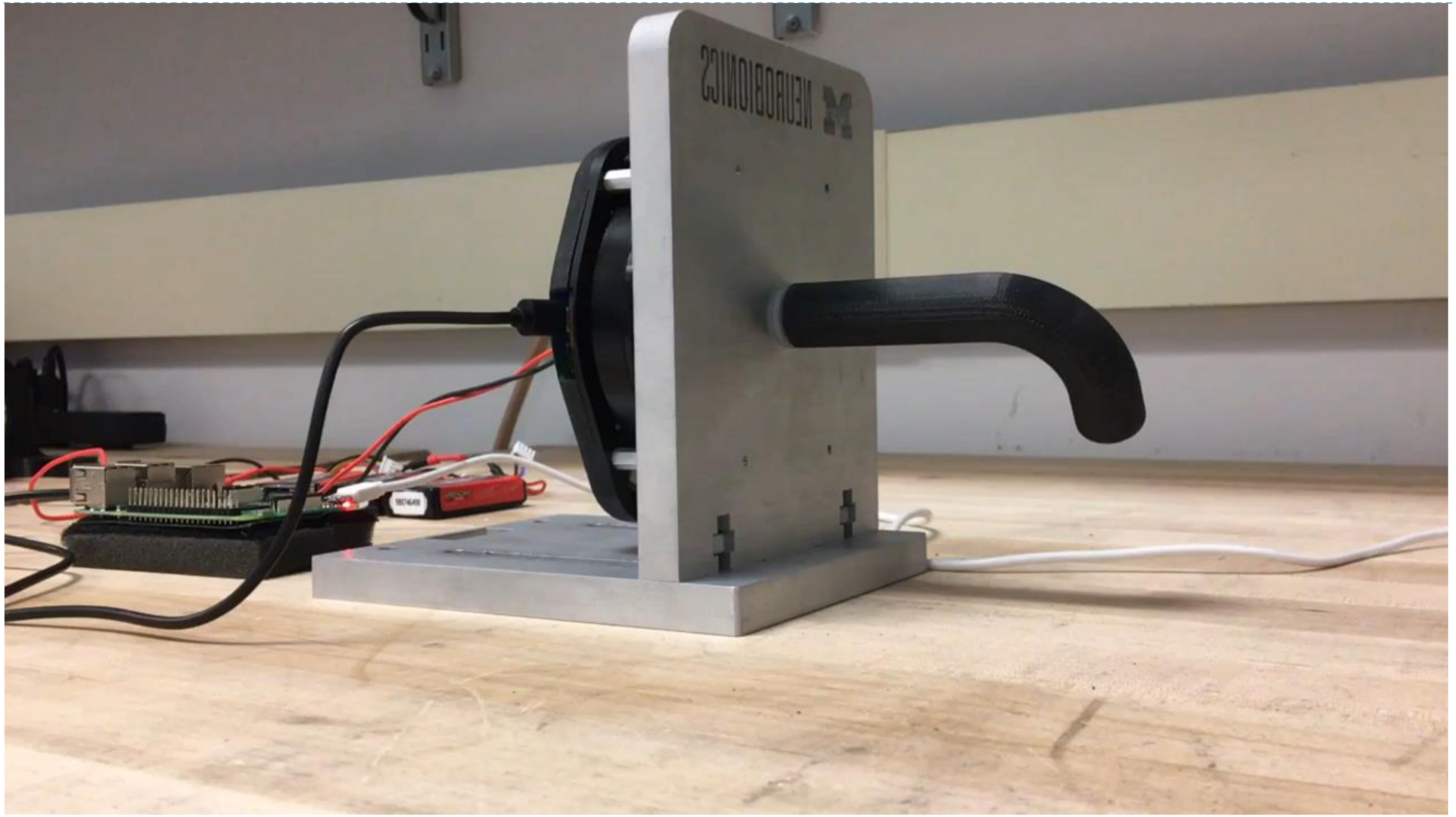


- https://youtu.be/wgs1eCOf6ag?t=95

Components of a motion control system

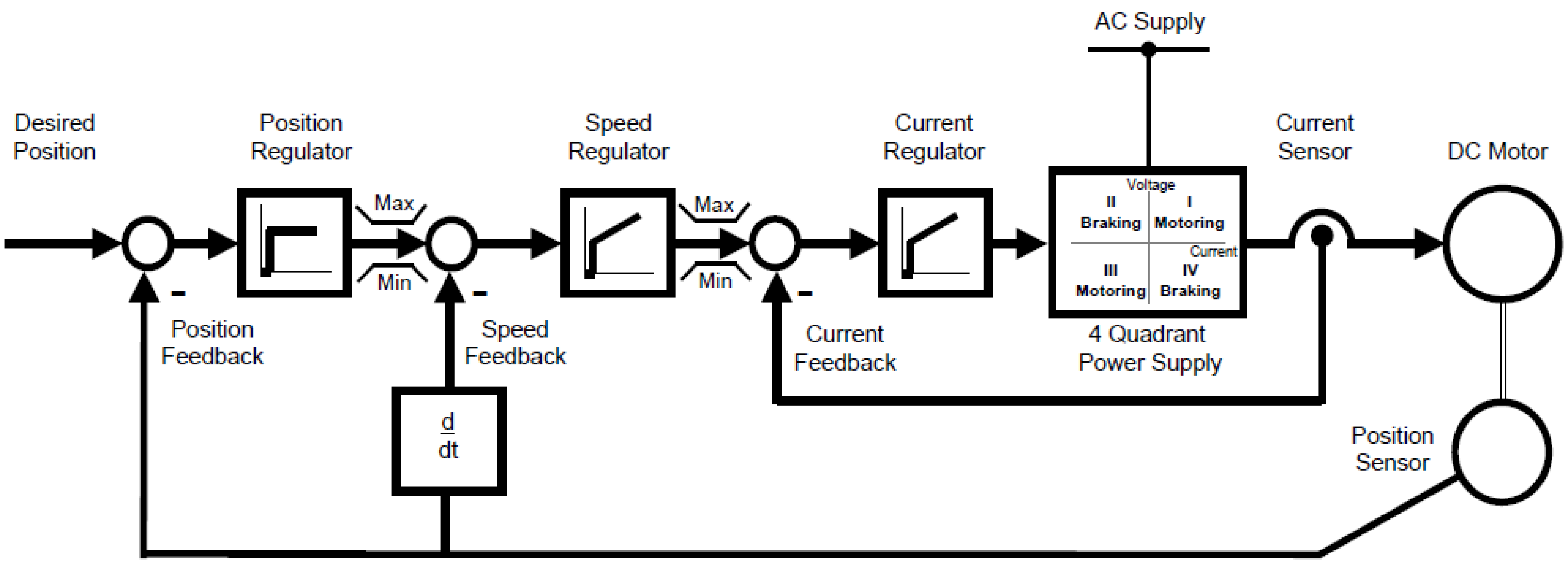


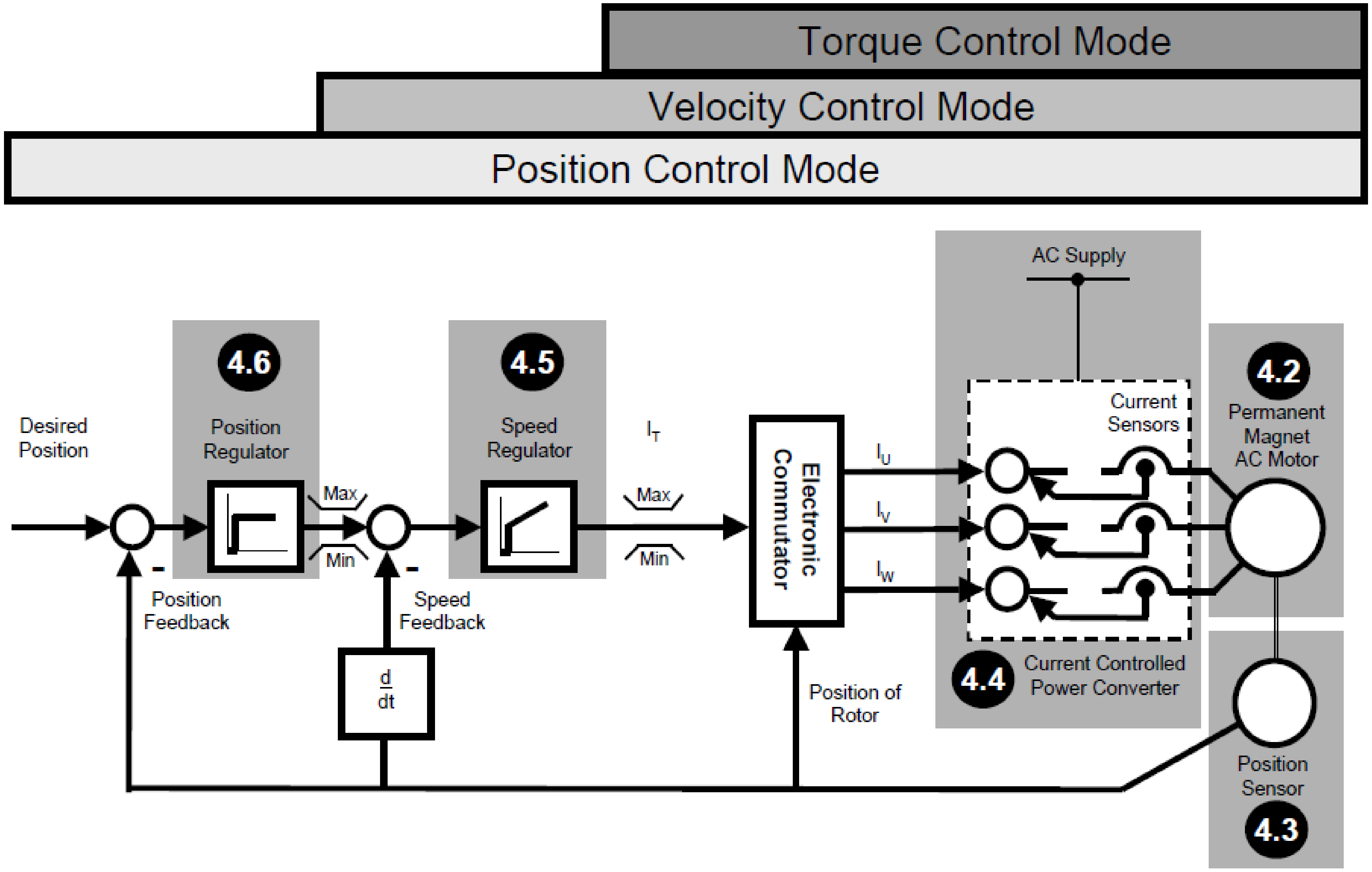
Open Loop Speed Control



- https://www.youtube.com/watch?v=uMUelwLQzhw

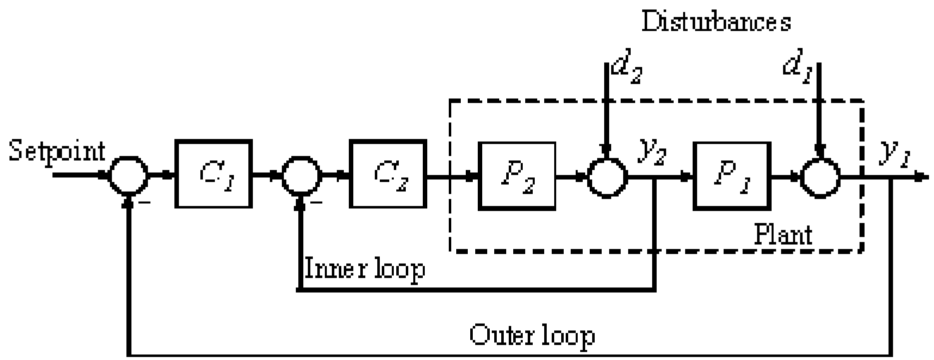
Cascade Control Structure of High Performance DC Servo System (Review)

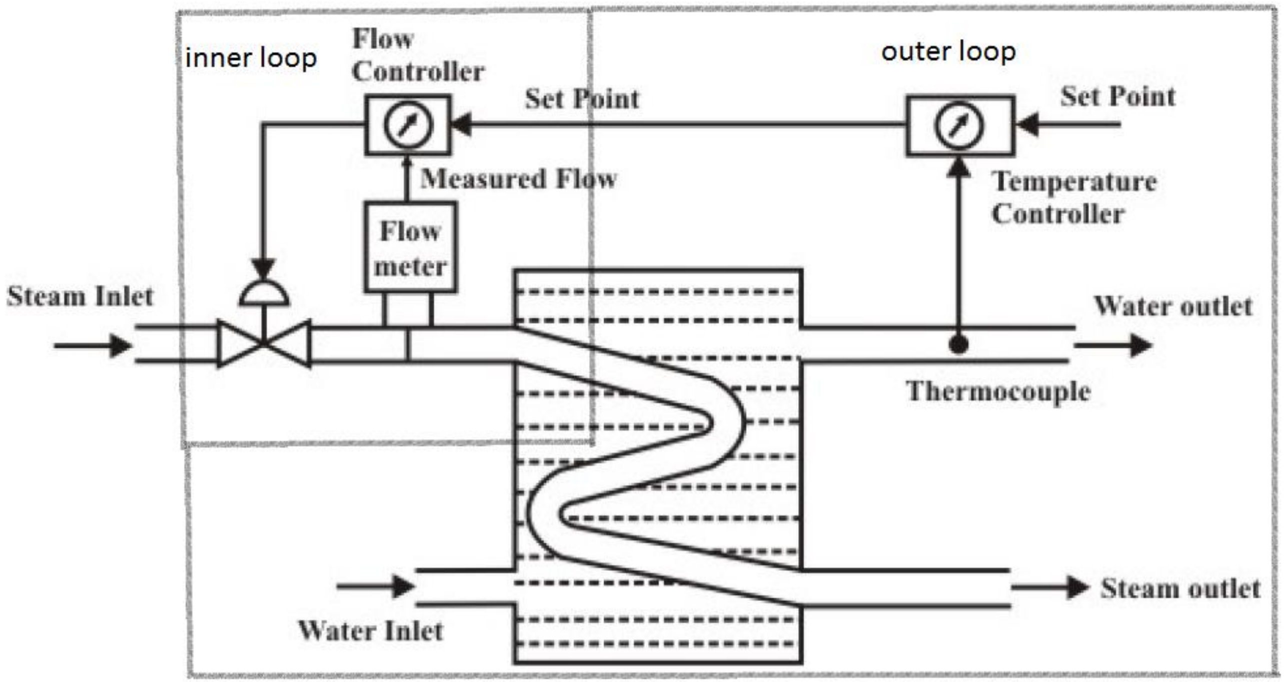




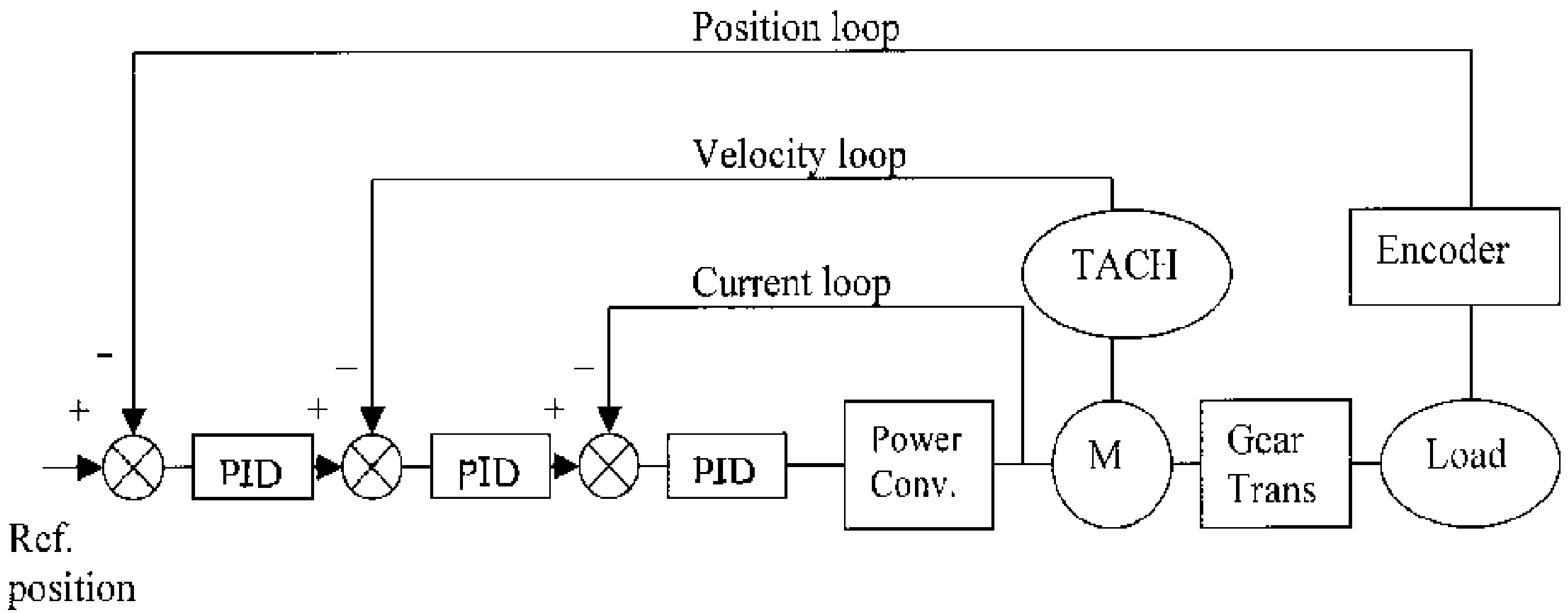
Block Diagram of AC Servo System

cascading control loop





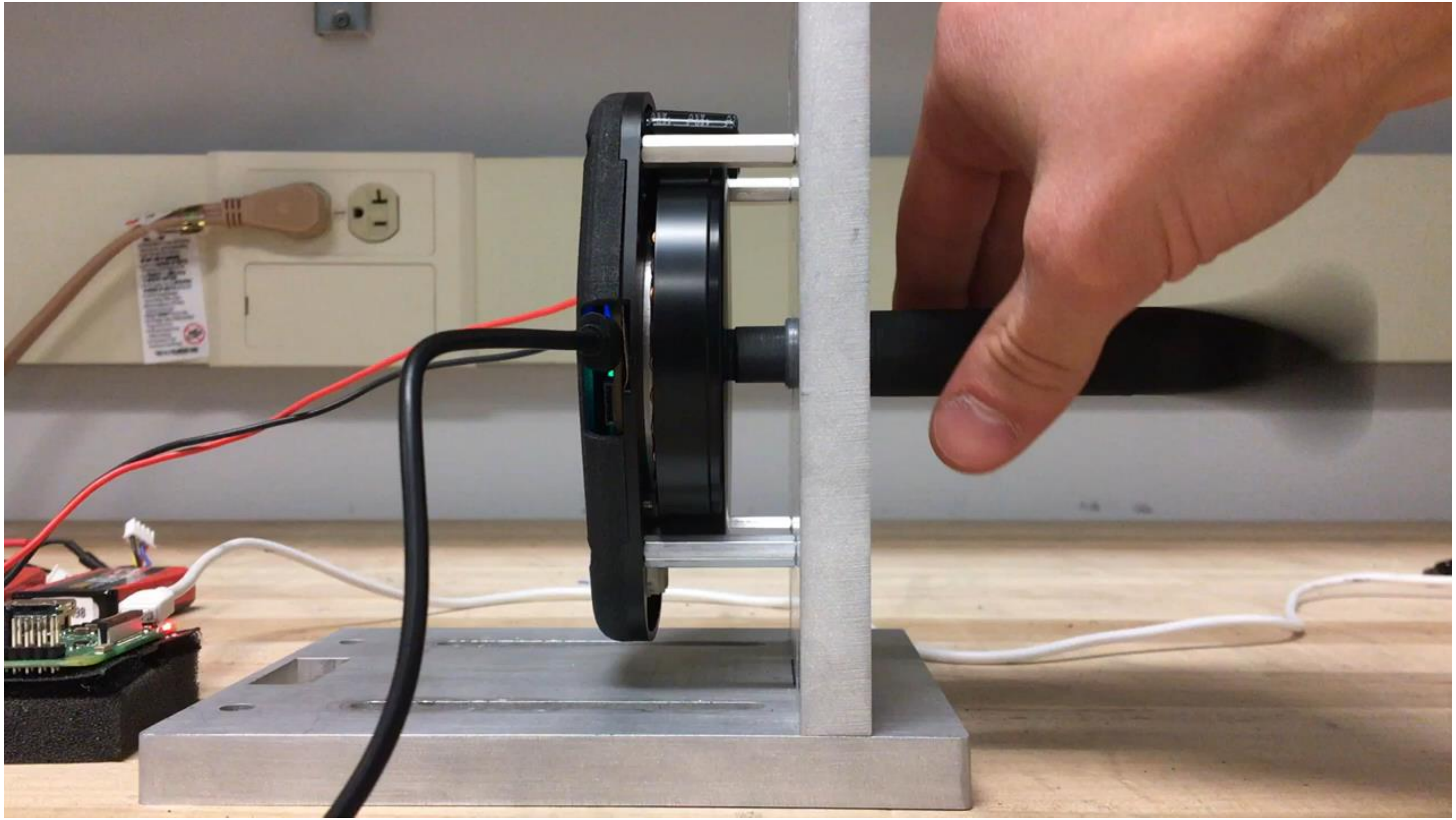
Control of Electric Machines



CASCADE CONTROL SYSTEM

- In cascade control a process is controlled by two controllers in such way that both are acting for each other.
- Cascade control is technique which contains two or more closed loop control cascade to each other in such way that first loop controller output will be set point for second loop controller. It is called remote set point for second controller.
- In cascade control First Loop called Master Controller and second loop called Slave Controller. Master controller generate the set point for the slave controller.
- Finally slave controller control the process depends upon the remote set point provide by the master controller

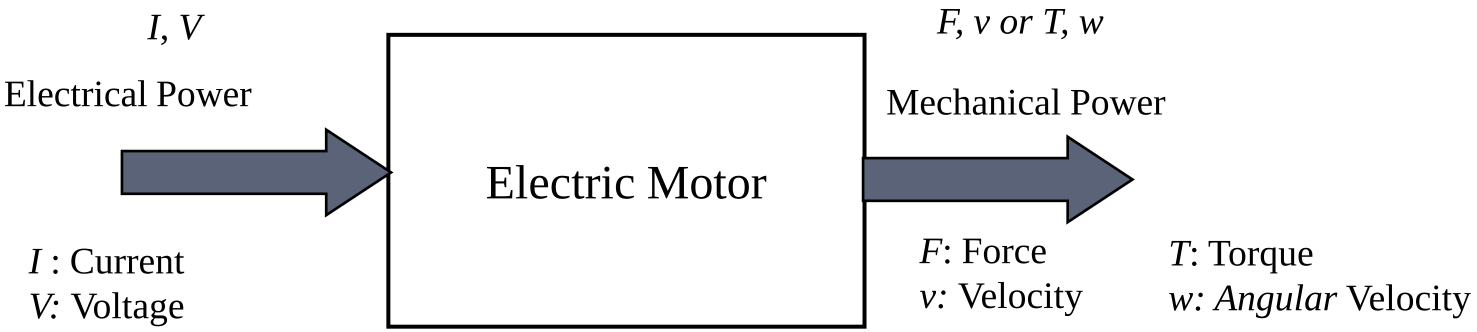
Current Control



- https://www.youtube.com/watch?v=z_4NXcOQf6s

Analysis of Electric Motors

- Electric Motors convert electrical power to mechanical power.

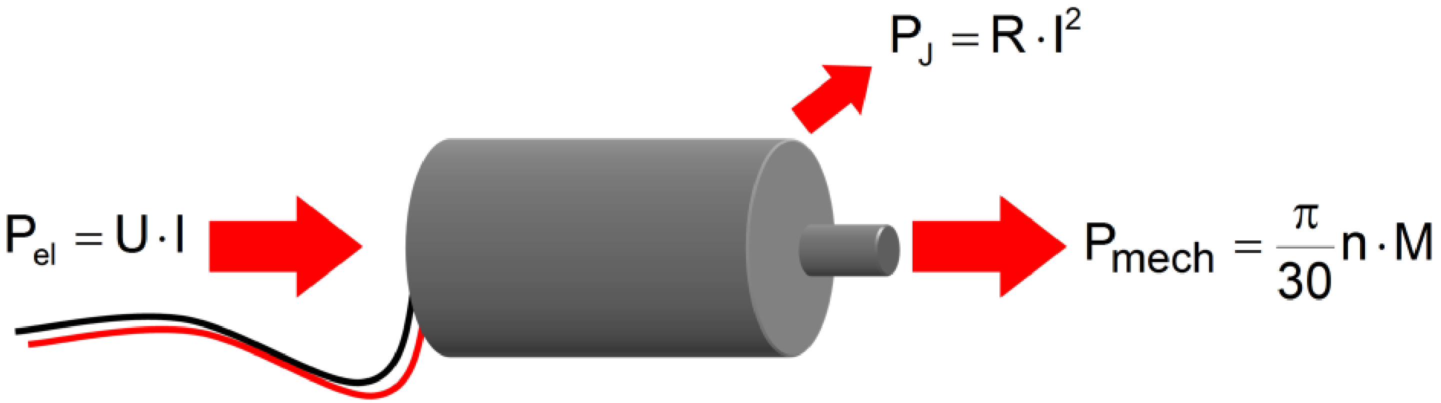


*Electrical Power = I*V*

*Mechanical Power = F*v* for linear motor

$= T*\omega$ for rotary motor

Analysis of Electric Motors



Data Sheet and Operating Ranges

Motor Data

			110061	110062	110063	110064	110065	110066	110067	110068	110069	110070
	Values at nominal voltage											
1	Nominal voltage	V	1.5	3.0	6.0	9.0	12.0	14.0	15.0	18.0	21.0	30.0
2	No load speed	rpm	10200	11700	9620	11800	11800	11800	11200	11200	11600	10800
3	No load current	mA	201	117	46.7	39.1	29.3	25.1	22.2	18.5	16.5	10.7
4	Nominal speed	rpm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4160
5	Nominal torque (max. continuous torque)	mNm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.35
6	Nominal current (max. continuous current)	A	0.720	0.720	0.494	0.394	0.294	0.253	0.225	0.186	0.162	0.105
7	Stall torque	mNm	4.93	4.51	4.02	4.82	4.76	4.81	4.53	4.47	4.48	4.03
8	Starting current	A	3.76	1.97	0.721	0.700	0.519	0.450	0.377	0.310	0.275	0.164
9	Max. efficiency	%	58	57	56	58	58	58	58	57	57	55
	Characteristics											
10	Terminal resistance	Ω	0.399	1.52	8.32	12.8	23.1	31.1	39.8	58.0	76.2	183
11	Terminal inductance	mH	0.017	0.0519	0.306	0.467	0.831	1.13	1.42	2.05	2.61	6.01
12	Torque constant	mNm / A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.7
13	Speed constant	rpm / V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	387
14	Speed / torque gradient	rpm / mNm	2220	2770	2560	2600	2630	2600	2630	2670	2750	2880
15	Mechanical time constant	ms	24.5	23.7	23.2	23.2	23.2	23.2	23.4	23.3	23.4	23.8
16	Rotor inertia	gcm^2	1.05	0.816	0.864	0.854	0.844	0.854	0.848	0.834	0.811	0.788

Values at nominal voltage

Characteristic motor data

Specifications

Thermal data

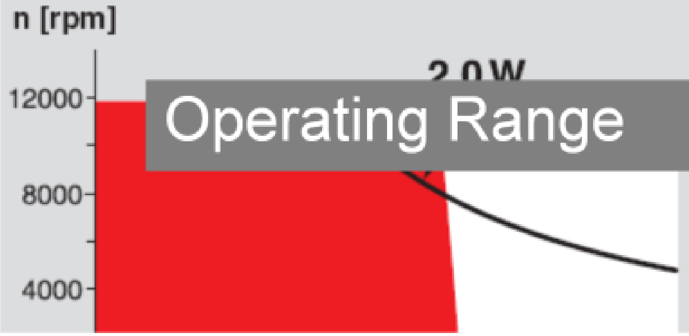
17	Thermal resistance housing-ambient	29.8 K / W
18	Thermal resistance winding-housing	5.5 K / W
19	[illegible]	[illegible] s
20	[illegible]	[illegible] s
21	Ambient temperature	-30 ... +85°C
22	Max. permissible winding temperature	+125°C

Mechanical data (sleeve bearings)

23	Max. permissible speed	11900 rpm

Further Specifications

Operating Range



Operating Range

Comments

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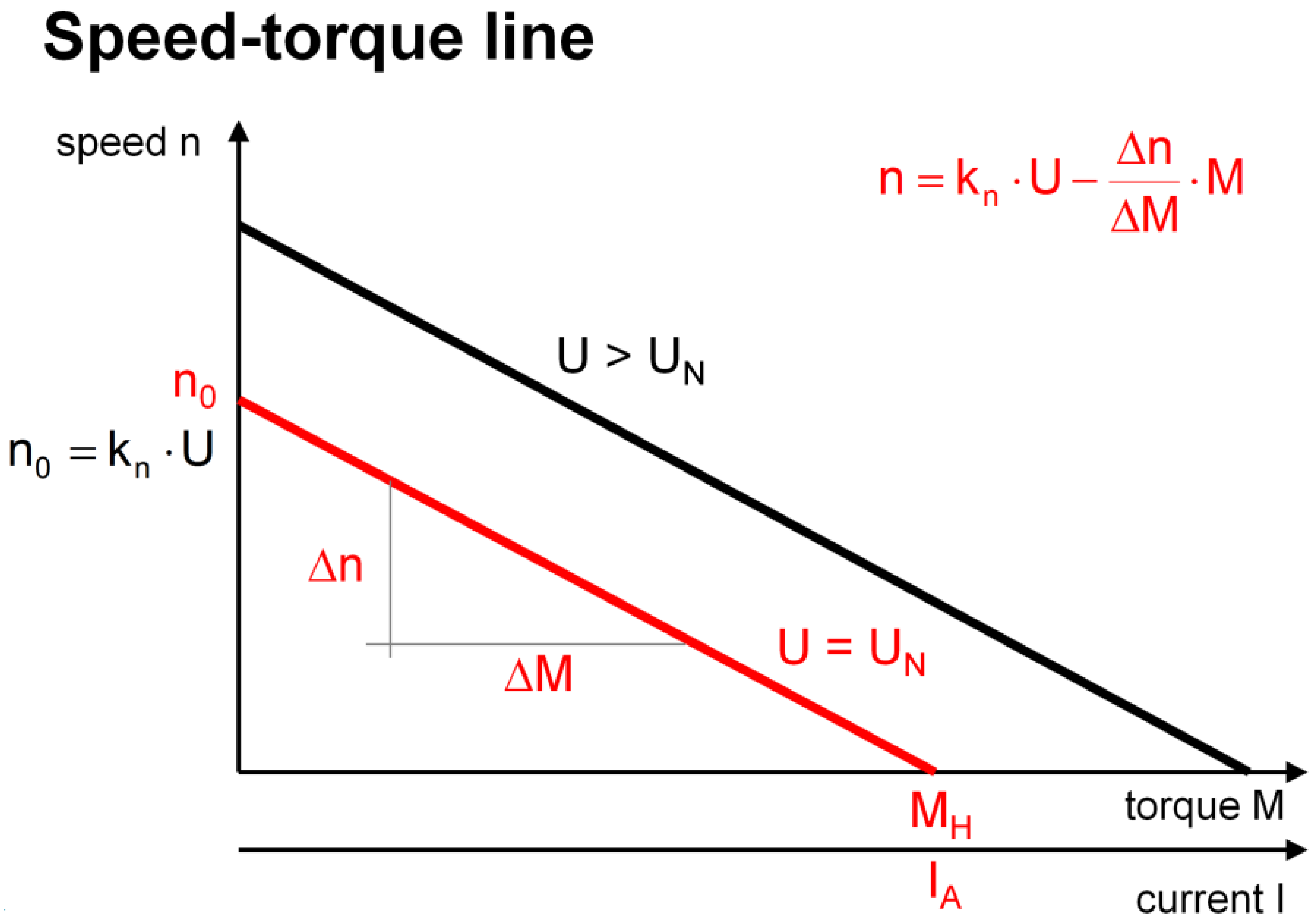
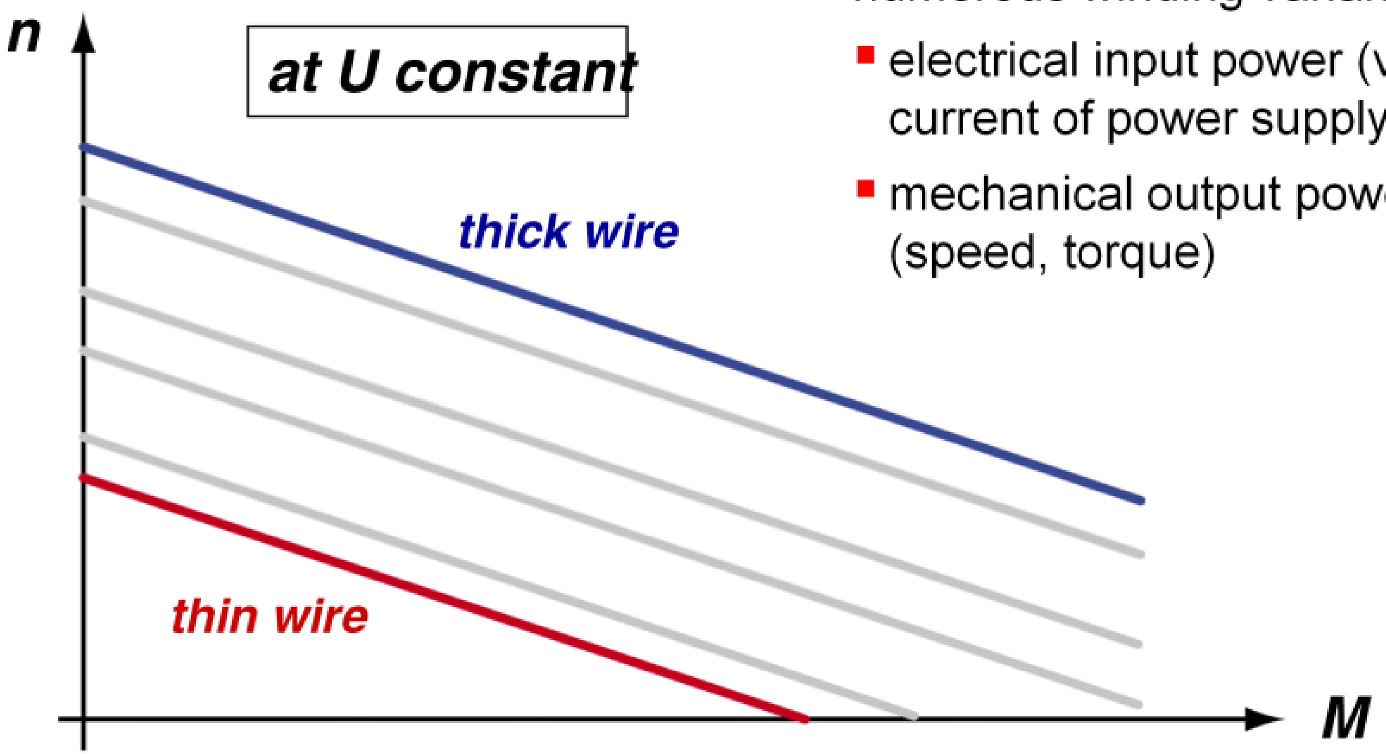
Speed-Torque Curve



Winding

Winding series



numerous winding variants adjust

- electrical input power (voltage, current of power supply)
- mechanical output power (speed, torque)

speed-torque gradient

- basically constant for the winding series
- constant filling factor: a constant amount of copper fills the air gap

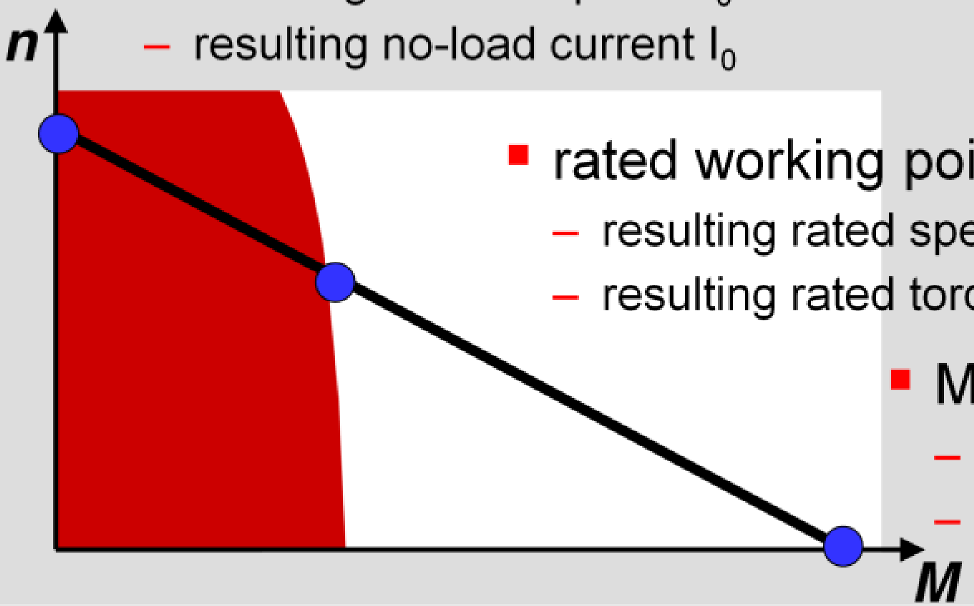
Nominal Voltages

Values at nominal voltage

describe the special working points:

- at rated voltage U_N
- at rated current I_N

- No-load operating point
  - resulting no-load speed n_0
  - resulting no-load current I_0



- rated working point
  - resulting rated speed n_N
  - resulting rated torque M_N
- Motor at stall
  - resulting stall torque M_H
  - resulting starting current I_A

Friction and no-load

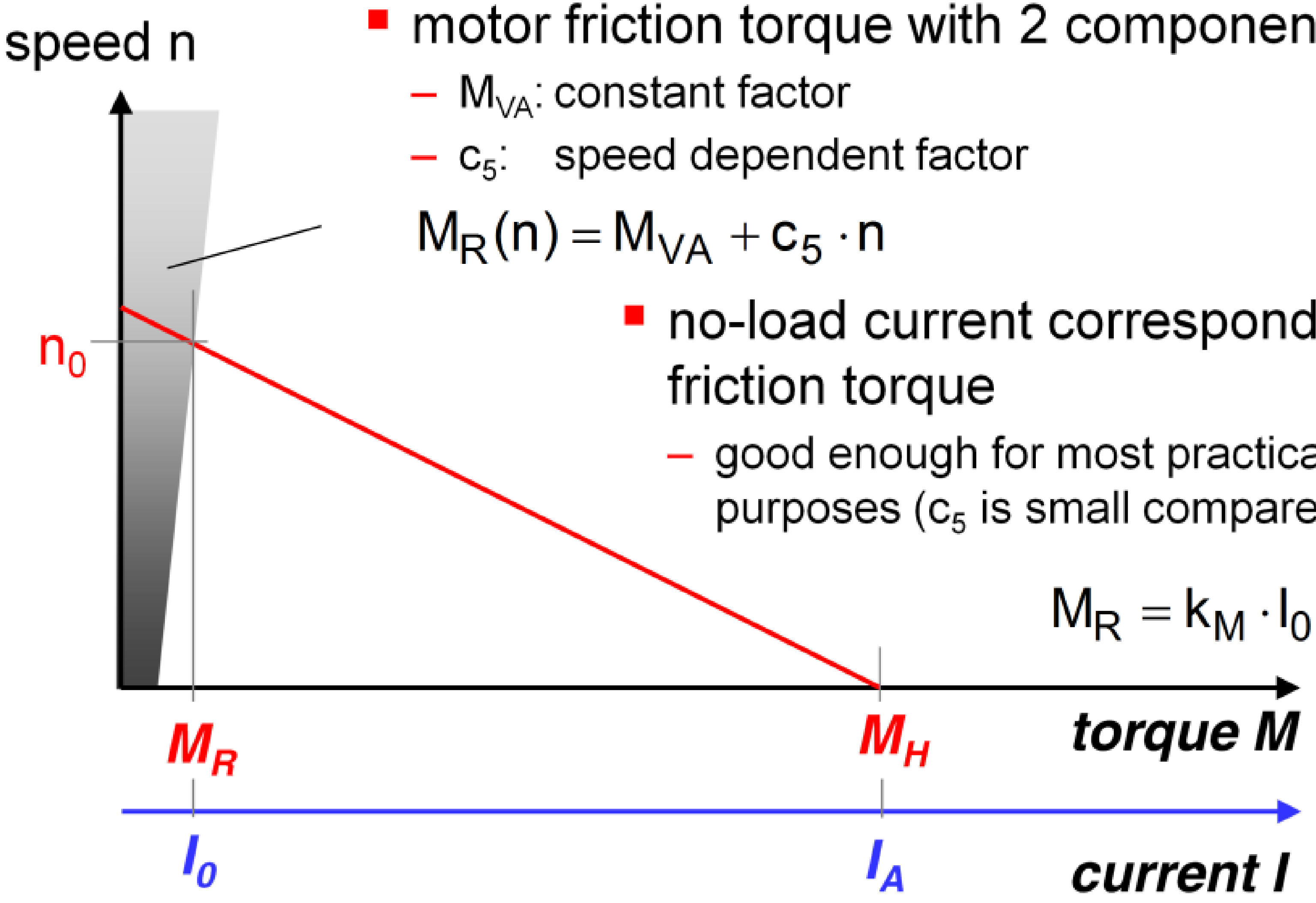
Friction and no-load

- motor friction torque with 2 components
  - M_{VA}: constant factor
  - c_5: speed dependent factor

$$M_R(n) = M_{VA} + c_5 \cdot n$$

- no-load current corresponds to the friction torque
  - good enough for most practical purposes (c_5 is small compared to M_{VA})

$$M_R = k_M \cdot I_0$$



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4	Nominal speed	rpm	867[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]70	4160
5	Nominal torque (max. continuous torque)	mNm	0.68[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]39	2.35
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Values at nominal voltage

Characteristic motor data

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18 Thermal resistance winding-housing 5.5 K / W

19 3 s

20 3 s

21 Ambient temperature -30 ... +85°C

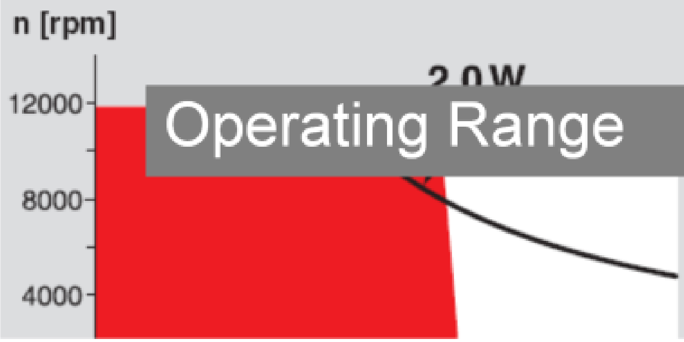
22 Max. permissible winding temperature +125°C

Further Specifications

Mechanical data (sleeve bearings)

23 Max. permissible speed 11900 rpm

Operating Range



Comments

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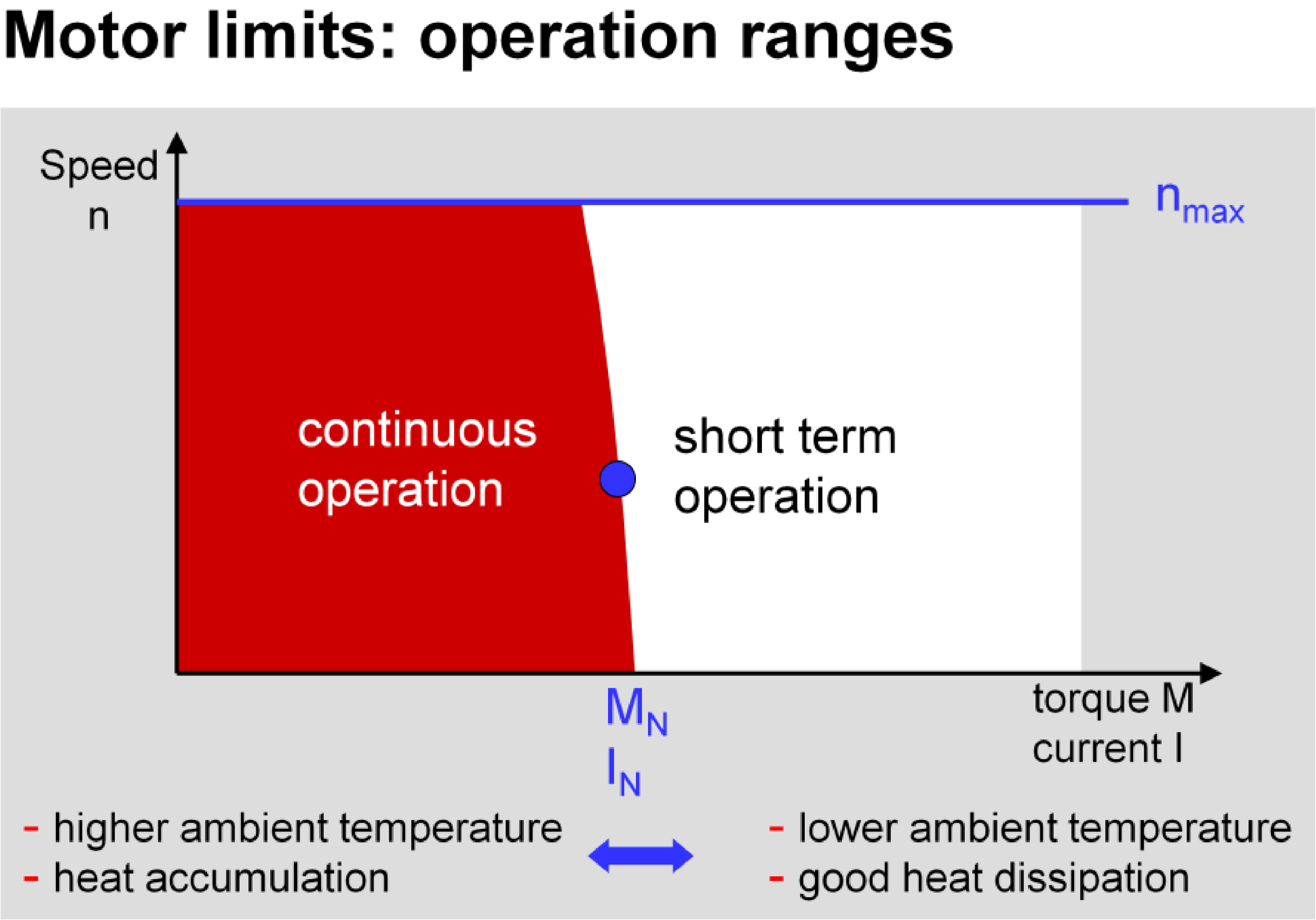
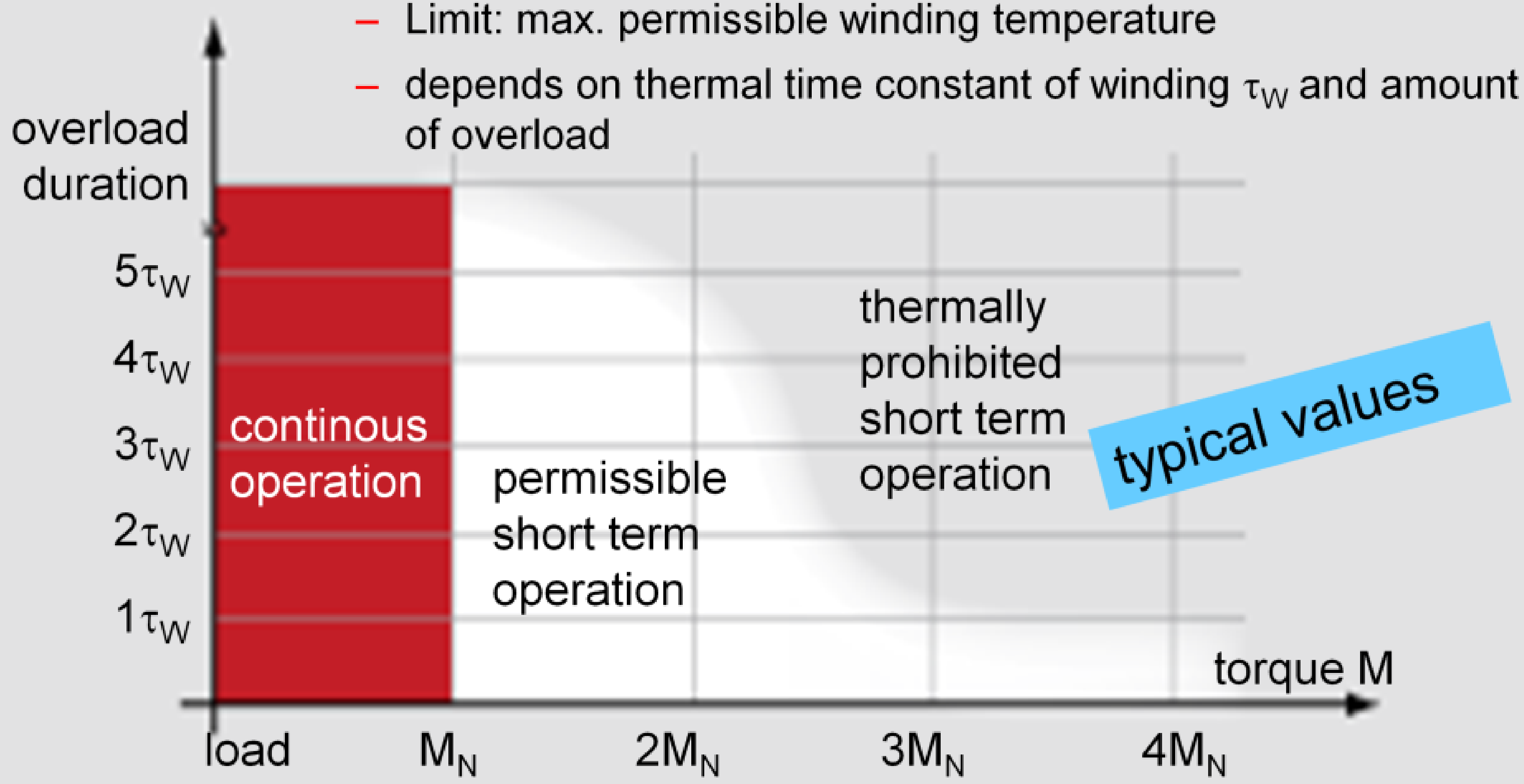
Operation Ranges



Operation Ranges

Short-term operation at overload

- motor may be overloaded for a short time and repeatedly
  - Limit: max. permissible winding temperature
  - depends on thermal time constant of winding τ_W and amount of overload



thermal time constant of the winding τ_W.

Influence of temperature

temperature coefficients

Cu	+ 0.39 % per K	AlNiCo	- 0.02	% per K
		Ferrite	- 0.2	% per K
		NdFeB	- 0.1	% per K

temperature | **resistance** | **magnetic properties**

- example: RE motor

ΔT = + 50K

R: + 19.5 %

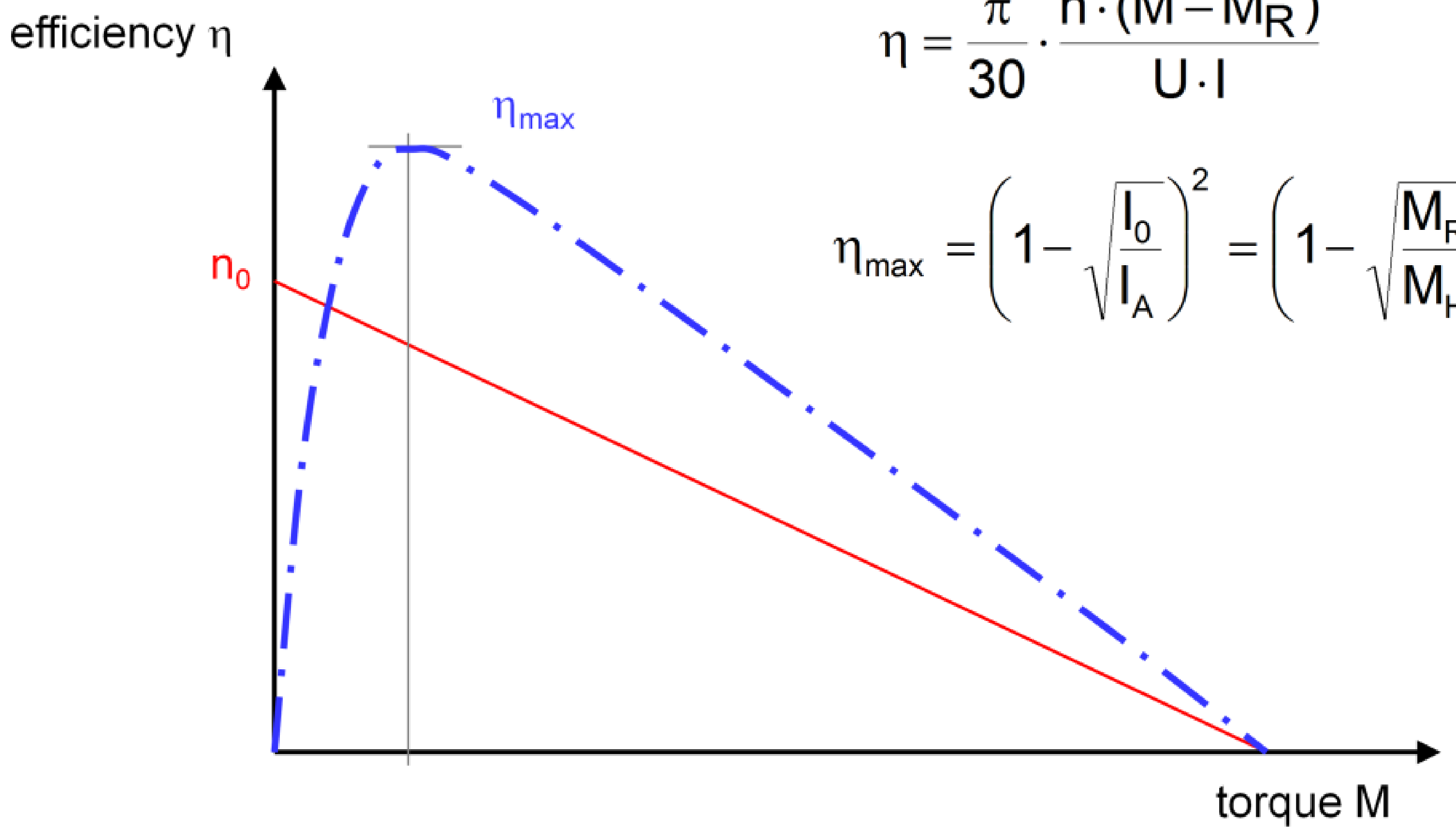
k_n + 5 % (no-load speed)

k_M - 5 % (more current!)

stall torque M_H : - 22 %

Efficiency

Max. efficiency



$$\eta = \frac{\pi}{30} \cdot \frac{n \cdot (M - M_R)}{U \cdot I}$$

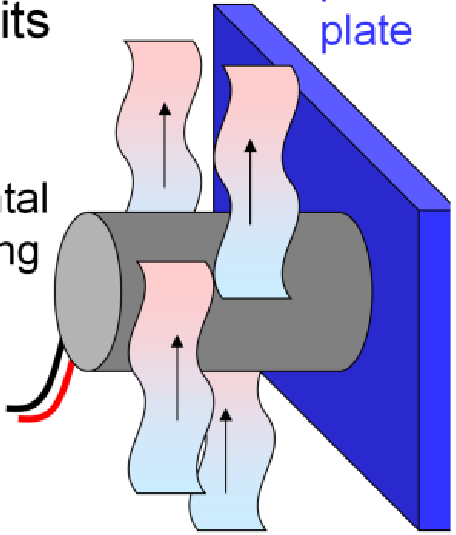
$$\eta_{max} = \left(1 - \sqrt{\frac{I_0}{I_A}}\right)^2 = \left(1 - \sqrt{\frac{M_R}{M_H}}\right)^2$$

Thermal motor data

Thermal motor data

describe the motor heating and thermal limits

- depend strongly on mounting conditions
- standard mounting:



- heating and cooling
  - thermal resistance housing-ambient R_{th2}
  - thermal resistance winding-housing R_{th1}
  - thermal time constant of winding τ_{thW}
  - thermal time constant of motor τ_{thS}
- temperature limits
  - ambient temperature range
  - max. winding temperature T_{max}

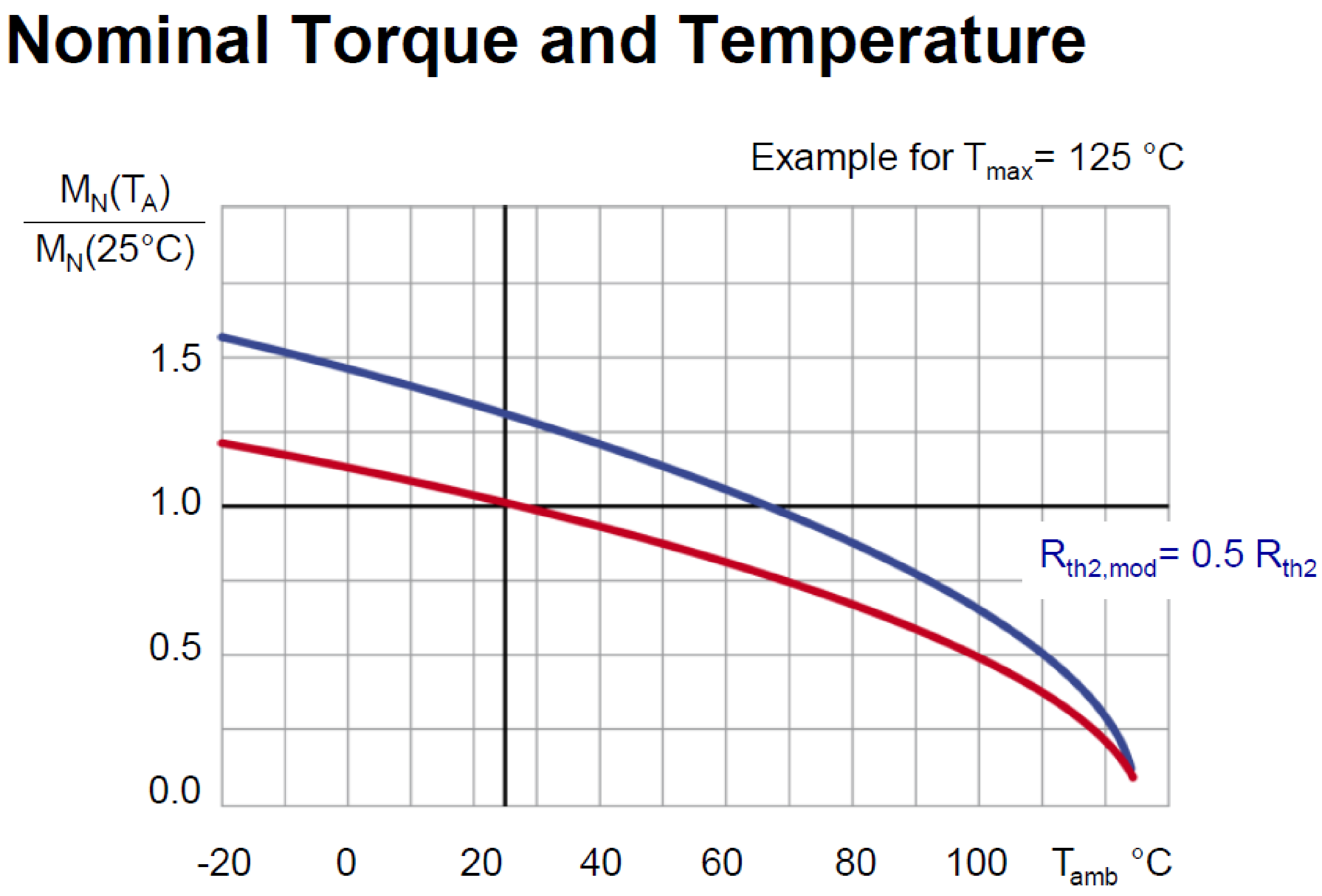
Motor Thermal Information

- The thermal data are needed to evaluate and calculate the thermal response of the motor. Thermal data depend on the details of heat dissipation. Thus, the values on the data sheet are given for **standard conditions** which are defined as follows
  - Ambient temperature of 25°C
  - Motor mounted horizontally on plastic plate: There is not much heat dissipation through the flange.
  - Free air convection, no additional cooling. Free air convection is quite effective for heat dissipation.

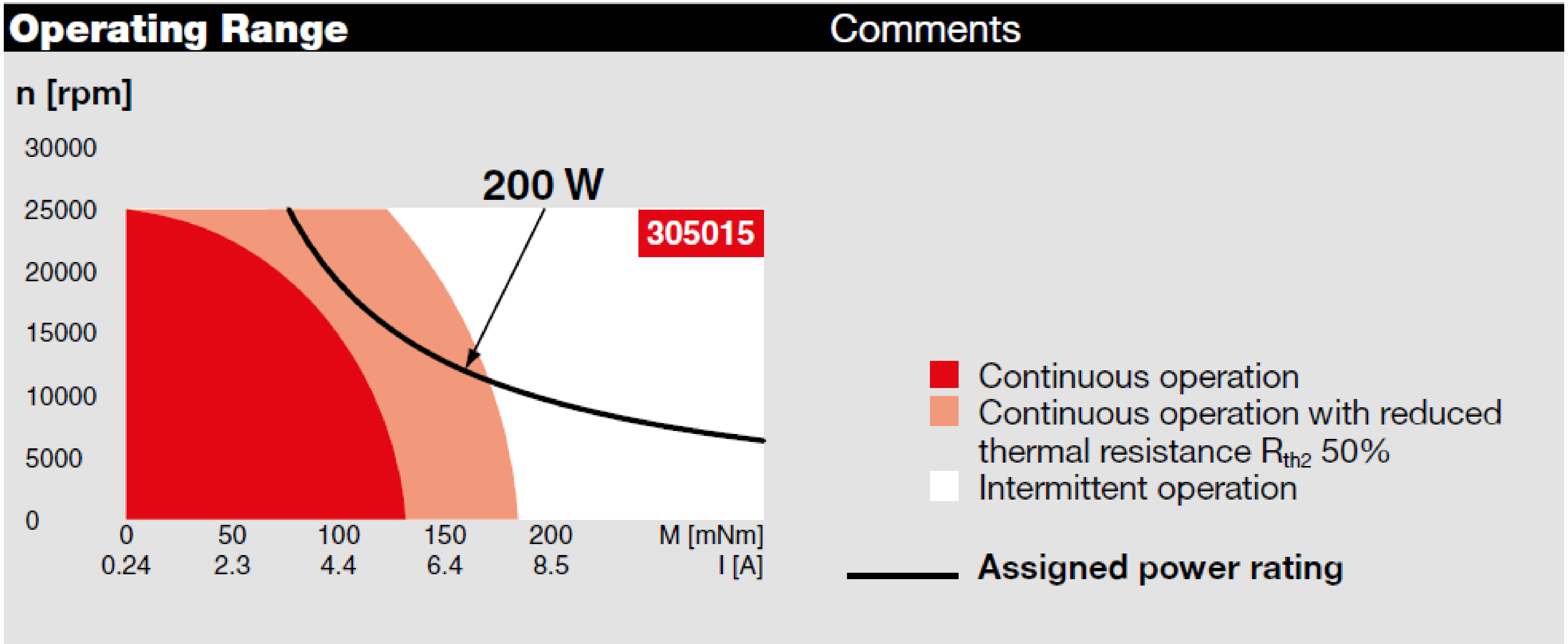
- These standard conditions represent **average mounting conditions**. Mounting the motor on a metallic frame (heat sink) will increase heat dissipation and hence there is more current allowed (see next slide). When the motor is encapsulated, there is no air convection, the ambient temperature increases and less current is permitted.
- The **thermal resistances** describe how well heat can flow from winding to housing and from the housing to the ambient. It's this second parameter which is influenced by the mounting conditions.
- The **thermal time constants** give the typical time frames for the heating of the winding and of the motor as a whole. While the winding temperature reacts with in a few seconds it takes several minutes to heat up – or even longer for bigger motors. Measuring the housing temperature will not give short term information about the winding temperature. The housing will have reached its thermal equilibrium after typically half an hour or more.

Nominal Torque and Temperature

- This diagram shows the **influence of the ambient temperature** on the maximal permissible torque (**red curve**). One can see that at temperatures below 25° the permissible torque is higher, while it decreases at higher ambient temperatures.
- The influence of an **improved heat dissipation** is shown in the **blue curve**. Reducing the thermal resistance between housing and ambient by 2 leads to a maximum permissible current (or torque) which is about 30% higher at standard ambient conditions. Such a reduction of the thermal resistance is easily obtained, e.g. by mounting the motor on a metallic chassis.



Motor Limit Lines for Motor selections



Questions

Thank You