8 Final example

An autonomous vehicle is to transport loads in a production hall. The following data are known for the drive task:

- Dimensions of the hall: $100\,\mathrm{m}$ x $200\,\mathrm{m}$
- Max. speed of the robot: $10\,\mathrm{km/h}$
- Weight of the vehicle m_V: $5\,\mathrm{kg}$
- Max. weight of the load m_L: $60\,\mathrm{kg}$
- 2 wheels with diameter D: $150\,\mathrm{mm}$
- One gearbox-motor system is used per wheel.
- Gear ratio: 1:10 ($i = 10$)
- Only rolling resistance is considered as load force: $F_L = c_R * F_{weight}$
- Rolling resistance coefficient c_R for car tyres on concrete: 0.02
- Total moment of inertia referenced to motor shaft is $\approx J_{Tot,Mot} = \frac{1}{i^2} \cdot (m_L + m_V) * (D/2)^2$.

Drive characteristic data

1. What is the maximum load torque of the motors at constant speed?
2. What is the maximum acceleration time at maximum load and starting from standstill when four-times the maximum load torque is available for the acceleration process? Calculate also the braking time.
3. If operation at maximum load and maximum speed can be assumed to be continuous and a safety factor of 2 is used, what is the rated torque and rated speed required for the drive motors?

Motor choice

In the catalogue of a motor manufacturer [1], which specialises in automation and robotics applications, a DC motor and a synchronous motor (both with permanent magnet excitation) are available for the calculated rated torque and speed.

DC Motor with permanent magnet excitation

The following data are known from the data sheet of the permanent magnet excited DC motor:

- rated voltage $U_N = 24\,\mathrm{V}$
- rated armature current $I_{AN} = 2.3\,\mathrm{A}$
- rated torque $M_N = 0.1\,\mathrm{Nm}$
- rated speed $n_N = 3600\,\mathrm{min}$
- no-load current $I_{A0} = 0.28\,\mathrm{A}$

The voltage drop per brush is $0.7\,\mathrm{V}$ and saturation is neglected. The frictional torque can be assumed to be constant.

4. What is the efficiency at the rated point?
5. Calculate all values of the equivalent circuit at the rated point.
6. What armature voltage and armature current are required when the motor is operated at half the rated speed and a quarter of the rated torque (vehicle with $5\,\mathrm{km/h}$ and $11\,\mathrm{kg}$ load)?

Synchronous motor with permanent magnet excitation

The following data are known from the data sheet of the permanent magnet excited synchronous motor:

- rated voltage $U_N = \frac{24}{\sqrt{2}}\mathrm{V}$
- rated stator current $I_{SN} = 2.1\,\mathrm{A}$
- rated torque $M_N = 0.106\,\mathrm{Nm}$
- rated speed $n_N = 3610\,\mathrm{min}$
- efficiency at rated point $\eta_N = 80\,\%$

Only losses in the stator winding and operation with only q-current (stator current in phase with the induced voltage) are assumed.

7. Calculate all values of the equivalent circuit at the nominal point and draw the phasor diagram qualitatively.

[1] Here, for practical reasons, slightly modified data from the catalogue of Dunkermotoren taken as a basis. Other alternatives: Wittenstein, Nidec, Maxon, Faulhaber, ...

8. What stator voltage and stator current are required if the motor is operated at half the rated speed and a quarter of the rated torque (vehicle with $5\,\mathrm{km/h}$ and $11\,\mathrm{kg}$ load)?
9. And if the motor could be operated at $2 \cdot n_N$ (or the vehicle at $20\,\mathrm{km/h}$) with the same load? In this case, the stator resistance can be neglected.

Power electronics

The power electronic motor control is fed from a DC voltage source:

10. What circuit is required for 4-quadrant operation of the DC motor? Draw the circuit with the most important components.
11. And for the synchronous motor?
12. What duty cycle (D) does the DC motor require for the operation from point 6, if the battery voltage is $U_{Bat} = 24\,\mathrm{V}$?