Mechatronics for elevator installers and drive technicians, Part 3

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1 Introduction

When designing and engineering elevators it is important to have available every possible item of mechanical and electrical data describing the elevator system. The more exactly these data can be ascertained during the planning phase, the more economically the system can be planned-at the very best quality. Moreover, the amount of work required during commissioning is reduced since the manufacturer can set the relevant parameters at the frequency converter prior to dispatch. The technicians on site can then assume that they already have a properly functioning drive and that only fine tuning will be required

Many system specifications (e.g. weights, drive sheave diameter, gear transmission ratio etc.) can be determined quite precisely; others (e.g. efficiency, travel cycles etc.) can hardly be determined with any real degree of accuracy. Experience and estimated allowances for the required torque are the only aids available. In the sample calculations which follow, express mention is made of any estimated assumptions. Whenever you plan and mass produce series with identical specifications, you should verify your assumptions by way of measurements made on site. A small amount of effort invested here can often save money and improve ride comfort in the elevator system.

In the interest of clarity and understanding we are disregarding the rope weights (aramid ropes are, for example, assumed) and are inserting some closely approximated magnitudes as constants.

2 Mechanical and electrical system data

A brief survey of the major electrical and mechanical designations and definitions of the associated physical magnitudes and units of measure is provided in the table below. The units of measure may be included to help verify calculations. We recommend the use of standardised SI units; consequently the diameter of the drive sheave is, for example, given in meter and rotation speeds, where they occur, are converted into revolutions per second.

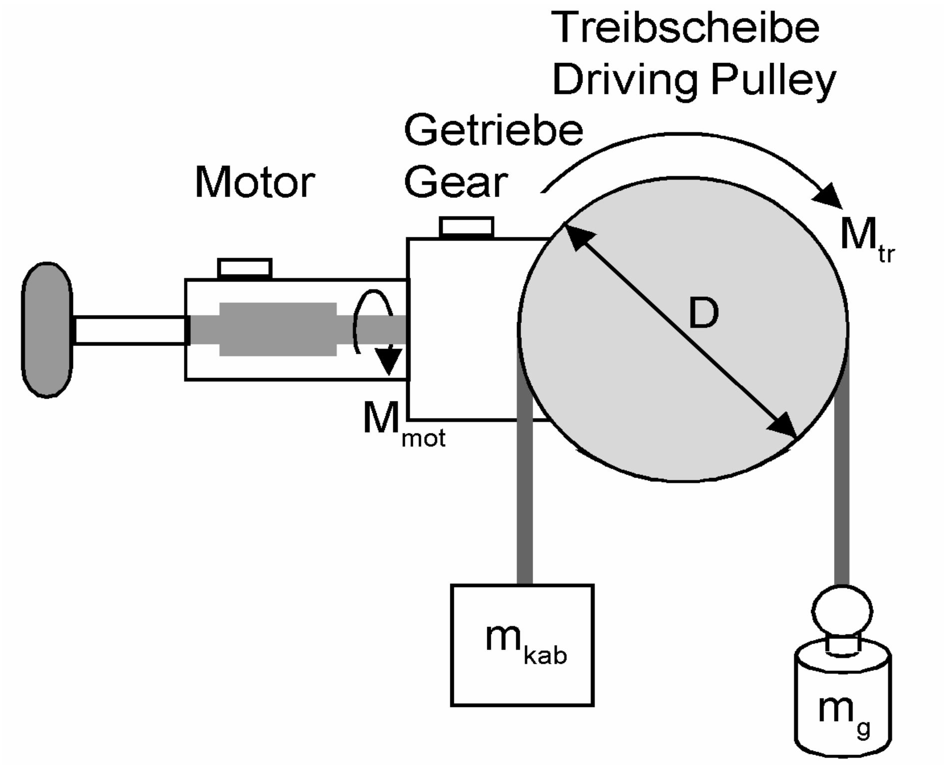
Designation	Symbol	Comments
Weights, masses	m, Q, ...	Weights in [kg] e. g. Cabs, counterweights payload
Velocity	v	Velocity in [m*s^{-1}] meter/second
Acceleration	a, g	Acceleration in [m*s^{-2}], g acc. due to gravity 9,81 m/s^2
Force	F	Force F=m*a, mass times acceleration, in [N] Newtons
Torque	M	Torque M=F*r, force times radius, in [Nm] Newtonmeters
Rotation speed	n	Speed in revolutions per min; n/60=revolutions per second
Power	P	Electrical power [VA, W, kW...], mechanical [kg*m^2*s^{-3}]
Gear ratio, transmission ratio	i	Factor "i" contains the numerator and denominator in the Gear ratio, e.g. 57:2, for reeving 1:1
Drive sheave diameter	D	Diameter in [mm, m], radius r=D/2, circumference U= л *D
Voltage	U	Voltage measured in [V] Volts
Current	I	Current measured in [A] Amperes
Inertia	J	Inertia of mass in [m*r^2]

3 Sample calculation

We will demonstrate the layout, calculation and manipulation of the above-mention mechanical and electrical data using an elevator system exhibiting the following specifications:

Payload m_n:	1000 kg	Velocity v:	1,6 m/s
Cab weight m_{kab}:	500 kg	Gear ratio i:	57:2
Counterweight m_g:	1000 kg	Drive sheave diameter D:	600 mm, 0,6 m
Reeving:	1:1	Inertia J_g:	0,3 kg*m^2
max. acceleration a:	1,4 m/s^2	(referenced to motor shaft)	

Figure 8: A sketch illustrating our example:



(figure 8)

Using the data given above and the formula for velocity, we can now select a motor:

$$V = \frac{n_n * D * \text{л}\ [m]}{60 * i\ \ [s]}$$

The nominal motor speed which results is n = 1450rpm. Thus a standard, 4-pole asynchronous motor operating at a nominal 50 Hz may be selected. Since, at nominal speed and frequency, the machine is also operated at nominal speed, estimating the power is easy using the following formula:

$$P_{mot} = \frac{m_h * g * V\ \ [kg*m^2*s^{-3}]}{\eta}$$

Recalling the table above we see that the unit of measure "[kg*m^2*s^{-3}]" also corresponds to the desired unit for output in watts [W]; we define m_h as the payload being hoisted; this is the difference between the empty and full cab weights. Always select the worst case when making this assessment. The data above result in m_h = 500 kg. We estimate efficiency " η" to 0,7; this takes the gearing and hoistway into consideration. If you already have more exact values available for the gearing and the hoistway, then please insert these.

P_{mot} = 11,2 kW

Now we select a motor appropriate to the mechanical system at hand and find for example, the following specifications in the motor manufacturer's data sheet:

Rated power	P_n: 15 kW	Rated speed	n_n:	1450/min
Rated torque	M_n: 98 Nm	Rated current:	33 A	
cosφ	0,83	Efficiency	η_{mot}:	0,9
Nom. frequency	f_n: 50 Hz	Nom. voltage	U_n:	360 V
Inertia	J_{mot}: 0,1 kg*m^2			

There are a few additional points which should be noted:

- The motor's rated power may deviate somewhat from the required hoisting power. An overly large motor drams more reactive current for magnetisation and thus can unnecessarily increase the output and size of the frequency converter. A motor which is too small and which is overdriven in particular during acceleration phases can cause excessive noise (so-called "torque how") In normal elevator operations the motor will be operated intermittently; the typical duty cycle is 40%, and a maximum of 65% which virtually eliminates any possibility of overheating.
- The nominal voltage for the machine should, if possible, be slightly less than that of the network supply to ensure that the frequency converter will have sufficient regulation reserve. In the normal case, with field-oriented control of the asynchronous motor, there should be a 20V difference from the line supply (i.e. where the mains deliver 400V the motor should be wound for a nominal 380V) Using closed-loop regulation (with an encoder at the motor) by no means requires greater differentials and, in fact, would result in an unnecessary rise in the motor's phase currents (current loading at the converter). As a rule, slight field weakening (motor voltage and line voltage both 400V) will not in itself induce serious problems. In synchronous motors, which are being seen ever more frequently, the differential should be 40V (at 400V line supply a suitable synchronous motor would be wound for a nominal 360V). A larger spread is selected here for safety reasons since operating synchronous motors above the limit for "back-e.m.f." can become critical (damaging share of reactive current and/or danger of the motor "stumbling" and going out of synch).
- Field-oriented regulation is suited in principle for "hard-running" machines. These are identified on the basis of their high nominal speed, i.e. low slippage, large rotor time constants and good efficiency. The "very hard" 1ndustrial motors have, however, not proven themselves in elevatorengineering because of their torque noises; as a consequence slightly "underexcited" motors are given preference here.

Design of the frequency converter(field-oriented speed control)

First we introduce the following, time-tested rule of thumb, used to estimate the maximum amount of motor current which will be required. The result is used to select the frequency converter on base of its specifications. The formula is very simple but at the same time amazingly accurate.

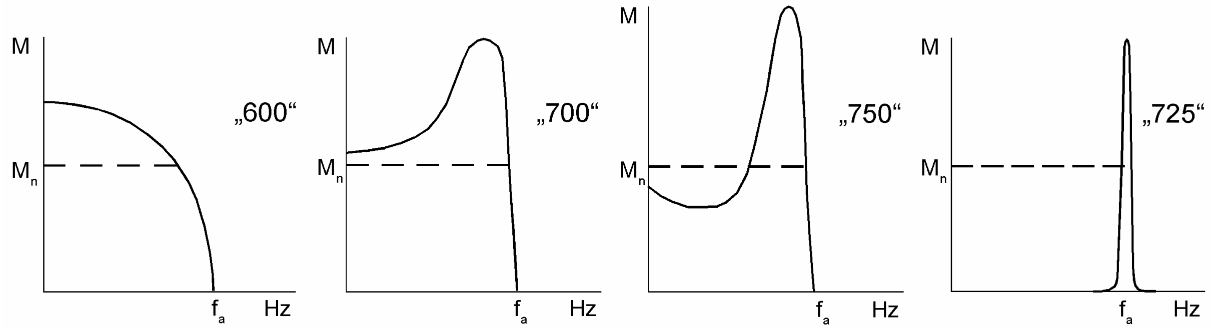
$$I_{max} = \frac{m_n\ [kg] * V_{max}\ [m/s] * 16As}{\eta\ (\text{efficiency for gear and rope sheaves}) * \text{ID No} * 1kgm}$$

Where m_n = 1000 kg, V_{max} = 1,6 m/s, η = 0,7 and ID No. = 700 the result is:

I_{max} = 52,2 A

This means, for example, that a 40 amp frequency converter with a dynamics factor of 1,5 (I_{max} = 60 A) is needed; here I_{max} = 52,2 A at 1m/s² is specified for the acceleration phase. The formula is based upon so-called characterising factors (ID numbers) which will depend upon the motor's design (see Figure 9). Include among the characterising factors are the motor's efficiency and the maximum differential between rated voltage and the line
At present you should note the five most important characterising factors used in the above formula:

ID No.	Type of motor, description
600	Silumin-Motor, also referred to as a high-impedance Motor. In older systems this motor can be stared directly from the line. The cos φ value is usually less than 0,75
700	Elevator motor suitable for frequency-converter drive and gearless, asynchronous operation
750	Industrial, standardised or servo motor. These motors are by nature not optimised for noise generation and thus will rarely be found in passenger elevators.
725	Synchronous elevator motors (with planetary gearing) and synchronous gearless wiches.
800	DC-motors (using brushes without Leonard converter gearless DC.



(Figure 9) Motor characteristic curve

Design of field-oriented speed regulation using torque

The active current in a synchronous or asynchronous motor is proportional to the torque. Since the excitation or field current is negligible near the rated torque, the following formula can be used as a good approximation for the range from 60 to 200% of nominal motor torque.

$$I_{mot} = I_{nmot} * \frac{M_{ges}}{M_n}$$

What this formula means is that to figure the maximum possible motor current we will have to calculate the torque, referenced to the motor shaft, in the least favourable loading situation. Overall torque can, in the interest of simplification, be broken down into several components:

1. Hoisting torque	M_h	(holding the load)
2. Torque loss	M_v	(friction loss, efficiency η)
3. Acceleration torque	M_b	(acceleration of cab and payload)
4. Rotational acceleration torque	M_{rot}	(inertia)

Hoisting torque
$M_h = (m_n + m_{kab} - m_g) * g * D/2$ (the torque at the drive sheave)
$M_h = 1471{,}5$ Nm
$M_{hmot} = M_h / i$ (referenced to motor shaft divided by i)
$M_{hmot} = 51{,}6$ Nm

Torque loss
$M_{vmot} = M_{hmot} * (1/ \eta - 1)$ (torque loss referenced to motor shaft)
$M_{vmot} = 22{,}1$ Nm

Acceleration torque
$M_b = (m_n + m_{kab}) * a * D/2$ (acceleration torque at the drive sheave)
$M_b = 630$ Nm
$M_{bmot} = M_b / i$ (referenced to motor shaft)
$M_{bmot} = 22{,}1$ Nm

Torque for rotational acceleration

$$M_{rotmot} = 2\,\text{л} * J_{ges} * \frac{\Delta n}{t_a}$$

t_a is the acceleration period during which the differential in speed Δn is overcome; J_{ges} is total inertia, referenced to the motor shaft. Disregarding the rounding times (we want to examine only the least favourable situation) and at a speed differential of 0 to 1450 rpm, the result for this example is:

$$t_a = \frac{v}{a}$$

$t_a = 1{,}14$ sec

$$M_{rotmot} = 2\text{л} * 0{,}4\ \text{kgm}^2 * \frac{1450/60\ \text{s}^{-1}}{1{,}14\ \text{s}}$$

$M_{rotmot} = 53{,}3$ Nm (Note [$\text{kgm}^2\ \text{s}^{-2}$] F=m*a, M=m*a*r)

The total torque, referenced to the motor shaft in the least favourable case, will result from the following addition:

$M_{gesmot} = M_{hmot} + M_{bmot} + M_{bmot} + M_{rotmot}$

$M_{gesmot} = 149{,}1$ Nm

Now we can use the formula cited above to ascertain the maximum intermitted motor current:

$$I_{motmax} = I_{nmot} * \frac{M_{gesmot}}{M_{nmot}}$$

$$\mathbf{I_{motmax} = 50{,}2A}$$

By using the system data selected we have naturally verified our tested rule of thumb. There is no doubt that we have chosen a very high acceleration value for our example, one which, however, also shows the influence of motor and gearing inertia. The torque required to overcome inertia here is greater than the hoisting torque. The rule of thumb must, of course, incorporate sufficient reserves so you will not encounter problems during commissioning, resulting from a system which is not powerful enough in its design.

Engineering the braking resistor

Braking resistors with the following data are normally offered together with the above-mentioned frequency converter. Taking our example once again, we will examine the technical design:

Resistance R: 18,8 Ω Rated continuos power P_d: 2,0 kW

High-load resistors such as this can be briefly overload by a factor of 10 to 15. Normally the loading cycle will be specified for a 120-second cycle (e.g. 20kW for 12s and 108 cooling time). Without taking all the various efficiency factors into account, we first estimate whether the overall system - motor, frequency converter and braking resistors - can generate the maximum braking torque at all. The braking resistance is looped into a typical DC-bus circuit at U = 700V. The resulting P_{brmax} is:

$$P_{brmax} = \frac{U^2}{R}$$

$$\mathbf{P_{brmax} = 26\ kW}$$

Based on this power value, one may use the familiar formula to calculate the maximum possible braking torque:

$$P = \frac{M * n}{9550}$$

$$\mathbf{M_{brmax} = 172\ Nm}$$

Since M_{brmax} is greater than M_{gesmot}, we can continue with our sample calculation.

Now, in order to estimate the possible travel cycles, we have to determine braking power in the least favourable case. To do so we recall the hoisting torque M_{hmot} and the loss torque M_{vmot} previously calculated and insert these values into the formula, together with nominal rotation speed taking account of the motor's efficiency:

$$P_{brhub} = \frac{(M_{hmot} - M_{vmot}) * n_n * \eta_{mot}}{9550}$$

$$\mathbf{P_{brhub} = 4{,}0\ kW}$$

In the above calculation we have disregarded acceleration and inertia since the additional braking output is only very brief (t=1,14 sec) in relation to the travel time.

At P_{brhub} = 4,0 kW, a cycle time of 120s and the nominal continuous power of 2,0 kW it is possible to examine many travel cycles more exactly; we want to limit ourselves to the borderline situations.:

- Maximum travel distance 96m (v=1,6 m/s, 60s travel time); after this period the selected braking resistor may not be operated for a period of 60s.
- Trips between floors will be possible without any restrictions, this being due to the door opening and closing times.
- The least favourable case is represented by the following operational states: descending fully loaded and ascending empty.

Summary
Calculating for the mechanical components using the torque results is a very god depiction of the electrical specifications for the drive motor and the frequency converter. Where standardised systems are manufactured in volume it is necessary in each case to verify the electrical specification on site. Our example shows in addition that torque needs can be shaved by way of small sacrifices in acceleration. It was further demonstrated that the dynamic current which a frequency converter must deliver can be readily estimated using the rule of thumb provided above.

Important:
The sample calculation describes the design for genuine field-oriented speed control. It may miss the mark when used for systems with feedback transducer or with converters under pure frequency control (U/f curve with super imposed speed control), since these systems either do not register motor slip at all or do so only by approximation and have no capability for vector separation (via the parameters for rotor flux and for the rotor time constant.