Evaluation of the external moment of inertia to the motor moment of inertia ratio

An aid for specifying limit values for the color coding in SIZER

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Question

How can the external moment of inertia to the motor moment of inertia ratio be evaluated? Which limit values for the colorization should be set in SIZER?

Answer

To fully answer this question, follow the handling instructions and notes listed in this document.

Table of contents

1 Theoretical relationship between motor connection and moment of inertia – representation using a two-mass vibrational system....................4

2 Dynamics definition 6

3 Examples 7

3.1 Variance of the inertia ratio 7
3.2 Variance of the connection rigidity...7
3.3 Comparison between gearbox and complete torque motor.................8

4 Conclusion...9

1 Theoretical relationship between motor connection and moment of inertia – representation using a two-mass vibrational system

The external moment of inertia to the motor moment of inertia ratio is color coded by default in the SIZER motor wizard. The standard limit values can be customized under the SIZER options in the "Rating preassignment" tab. 3 and 7 are the default settings.

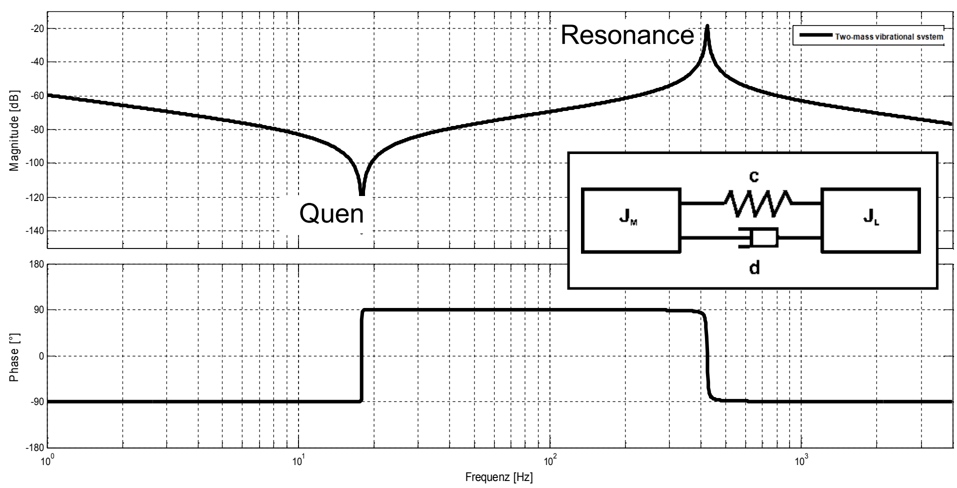
- Moment of inertia ratio < 3 => black coloring
- Moment of inertia ratio 3…7 => yellow coloring
- Moment of inertia ratio > 7 => red coloring

The details of the inertia ratio can, however, be used only to a limited extent for evaluating the suitability for an application. Depending on the rigidity of the motor connection and the demands placed on the dynamic response (load cycle), inertia ratios can be appropriate for certain applications that would not produce the required result for other applications.

The principal relationship between the motor connection and the moment of inertia is shown below using the so-called speed controlled system. The speed controlled section specifies the ratio between motor velocity and motor power. It can be used to make statements concerning the controllability of a machine axis.

The lowest natural frequency - also called quenching frequency - of the mechanical design limits, the motion dynamics and so the bandwidth of the system. It also limits the possible proportional gain factor. A high natural frequency and a high gain factor of the closed-loop control can be achieved with a stiff spring and a light mass. These named factors allow the mass to be brought quickly into the desired position. Movements of the motor with frequencies that lie above the quenching frequency act ever less on the load. The load is decoupled from the motor movement.

Fig. 1-1



The basic equations for calculating the quenching and the resonance frequency are shown below. They show that when the moment of inertia increases, the connection rigidity also increases so that the natural frequency can be kept constant. The larger the moment of inertia ratio between the load and the motor, the more that the two frequencies differ.

$$f_T = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{c}{J_{Last}}} \qquad f_R = \frac{1}{2 \cdot \pi} \cdot \sqrt{c \cdot \left(\frac{1}{J_{Mot}} + \frac{1}{J_{Last}} \right)}$$

Meaning of the symbols:

c = torsion rigidity

J_{Mot} = motor moment of inertia

J_{load} = load moment of inertia

f_T = quenching frequency

f_R = resonance frequency

Note for the speed controlled system:

The further to the right that the first quenching lies on the x-axis and the more negative the overall curve is displaced on the y-axis, the larger is the proportional gain in the speed and position controller and thus the dynamic response.

2 Dynamics definition

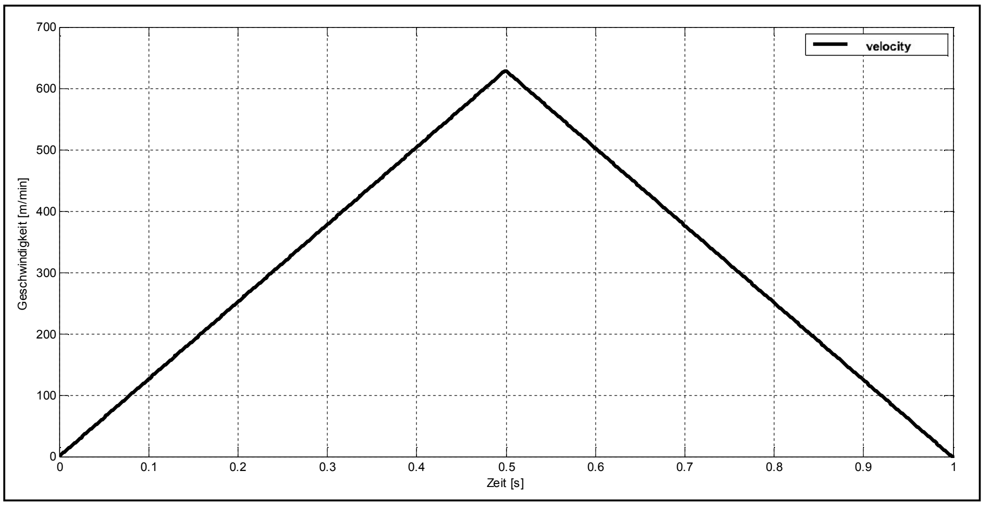
The dynamics defines how fast a fault can be compensated and how fast a position change can be achieved. The latter is also called acceleration capability.

Tip:

The controller bandwidth should be factor 5…10 larger than the cycle clock frequency in order to approach a position with low oscillations.

An example with a certain speed curve follows.

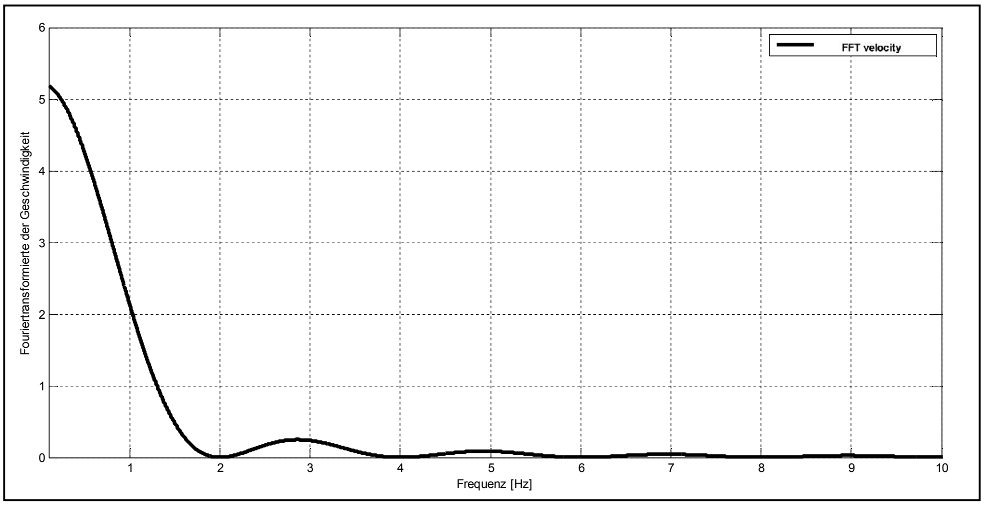
Fig. 2-1



$$f_{Takt} = \frac{1}{t_B}$$ with t_B = acceleration/deceleration time

Fourier transformed speed

Fig. 2-2



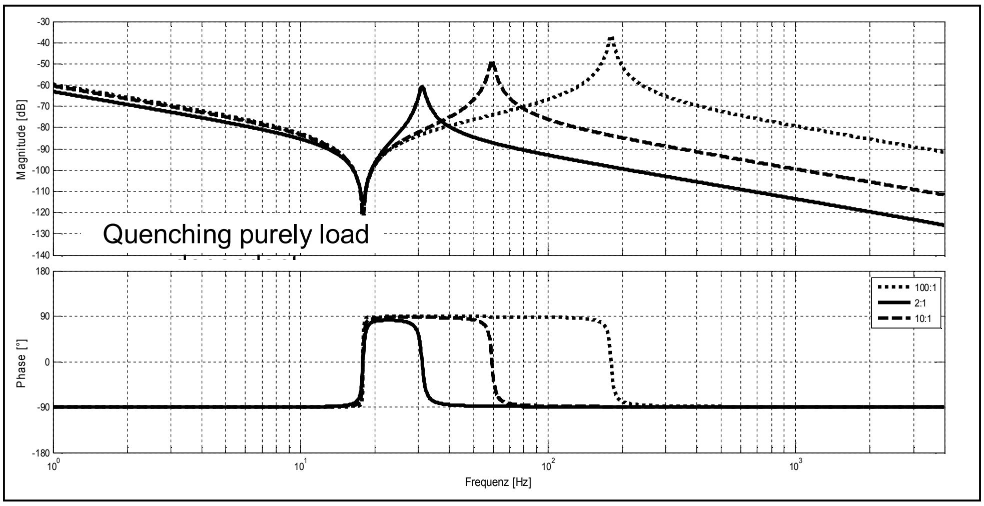
The speed curve contains primarily frequencies up to the clock frequency, in the example 2 Hz. This would require a controller bandwidth of at least 10…20 Hz in order to provide a good representation of the curve.

3 Examples

3.1 Variance of the inertia ratio

Figure 3-1 shows various load inertia ratios. The load inertia remains constant and the rotor inertia varies. Increasing the inertia ratio moves the resonance to higher frequencies. The quenching frequency depends only on the load and remains unchanged. The amplitude instance between quenching and resonance rises with increasing inertia ratio.

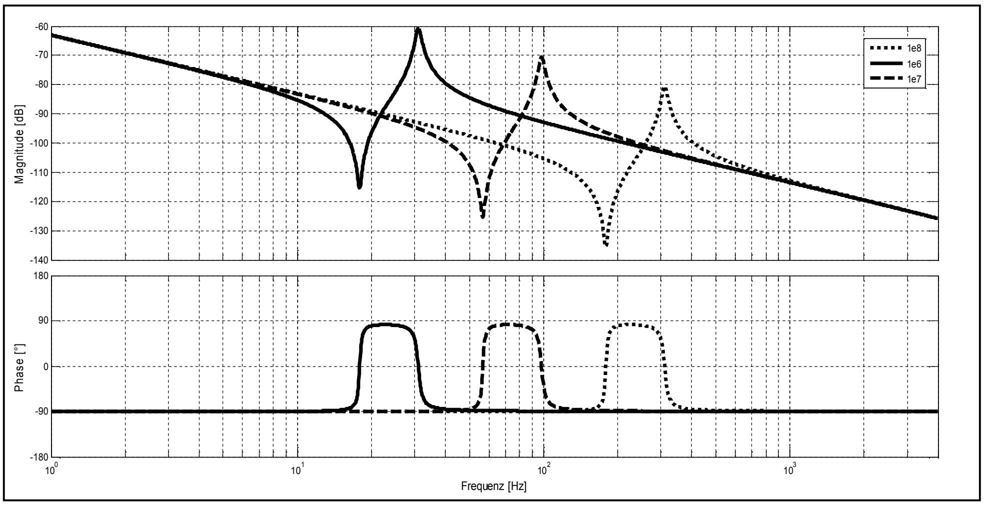
Fig. 3-1



3.2 Variance of the connection rigidity

Figure 3-2 shows the effect of the connection rigidity variation. Increasing the shaft rigidity causes the quenching and resonance to move to higher frequencies. The frequency response characteristic curve does not change. The size of the separation between quenching and resonance based on the logarithmic scale remains unchanged. The adaptation of the shaft rigidity does not affect the amplitude instance – quenching and resonance each move linearly.

Fig. 3-2

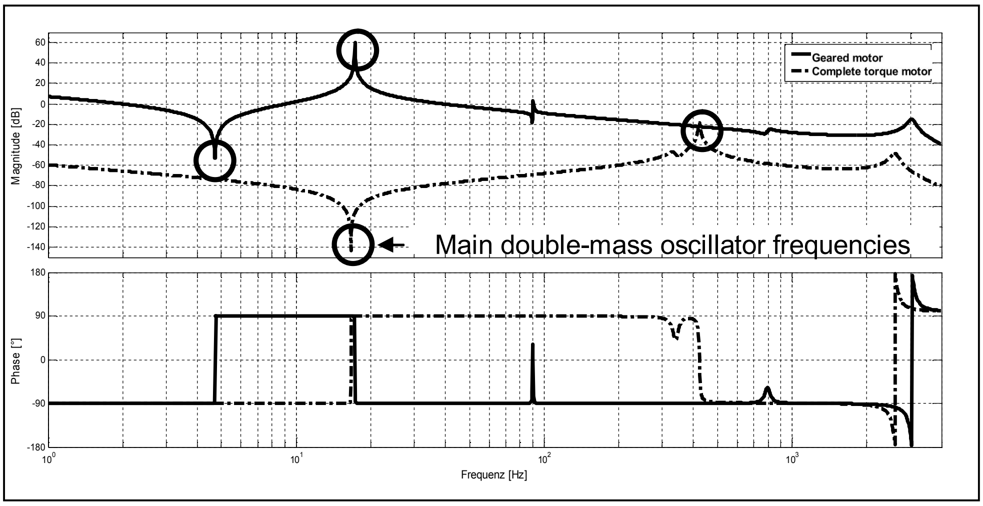


3.3 Comparison between gearbox and complete torque motor

Two drive systems are compared with regard to their speed controlled systems below.

1. Geared motor
   - AH80 geared motor with a planetary transmission, transmission ratio 50, and a metal bellows coupling
   - Moment of inertia ratio 13
2. Complete torque motor
   - Complete torque motor in the AH200. Rotor connected directly to the machine shaft
   - Moment of inertia ratio 555

Fig. 3-3



Despite the inertia ratio of the complete torque motor higher by the factor 43 compared with the geared motor, a larger control bandwidth and so better dynamic response can be achieved with the direct motor. This is caused by the much more rigid connection between the motor and the load shaft. A gearbox and coupling is relatively soft, a very critical factor with regard to the achievable control bandwidth. The torsion rigidity is reduced by the square of the transmission ratio. This limits the achievable dynamic response, in particular for large transmission ratios, even when this allows the inertia ratio to be reduced.

4 Conclusion

It is very difficult to generalize the limit values with regard to the moment of inertia ratio, because depending on the motor connection (rigidity between the rotor and the machine shaft) and the required load cycle (acceleration/deceleration), it must be evaluated for each specific application.
Generally, the limit value can be set to 3, in particular for drives in the machine tool area. The limit can often be increased for drives in the production machine area. The rigid load connection for direct motors allows the limit value to be further increased. Depending on the required load cycle, the moment of inertia ratios can be 50:1, or for less dynamic applications, even 2000:1.