TECHNIQUE TO REDUCE THE SHAFT TORQUE STRESS AT AN INDUCTION MACHINE

METODA DE REDUCERE A SOLICITARILOR DE TORSIUNE IN ARBORELE MASINII ASINCRONE

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1. Introduction

For the active attenuation ot the appearing load stresses in the drive shaft, the control system should receive as input signal the instantaneous shaft torque value. The estimation of detectable and measurable signals represents a sensitive problem in the design and applications area of the drive systems. In this context must be developed an intelligent observer for the shaft torque of mains operated induction machine, which is able to very fast responding by variation of LIF (Load Input Function).

This proposal represents a low-costs and low-losses solution compared with classic methods for locally influencing the dynamic performance of the induction machines.

In order to obtain a practical validation, the simulated regulator has been designed and tested in the Institute of Electrical Engineering in Clausthal/Germany.

2. Developing the mathematical model

In the present paper the drive system with induction machine using known differential equation will be modelled. Figure 1 shows the structure of the controlling system with estimation of the shaft torque value via intelligent observer.

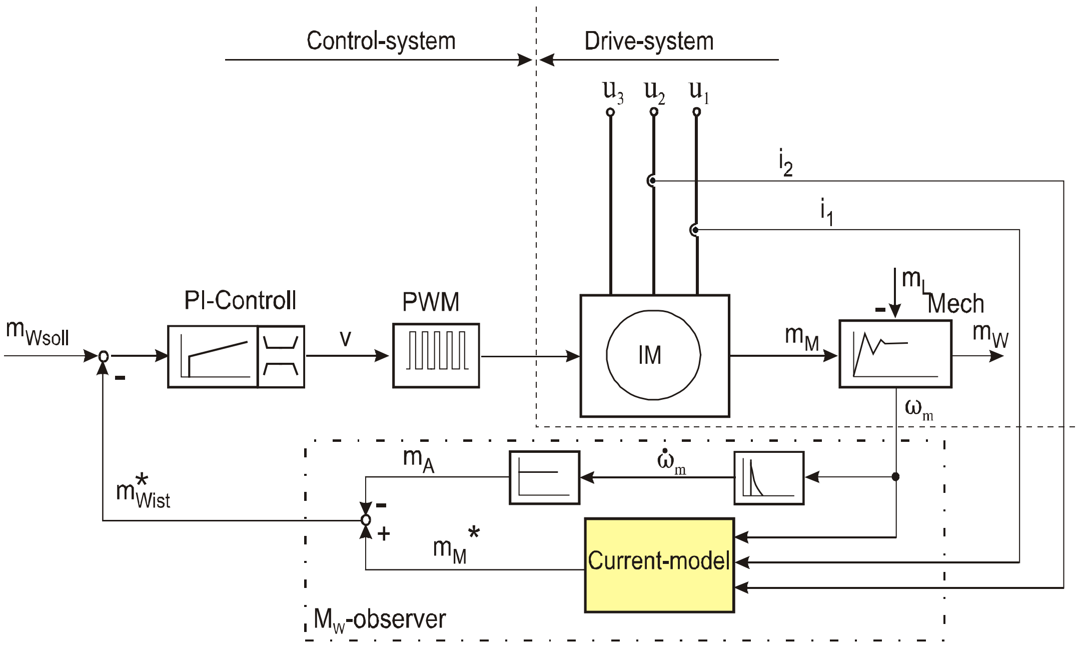

Fig. 1 Structure of control system with estimated shaft torque

Like in the classic PI-control strategy, the input signal of the regulator is the error deviation signal between desired and measured value. The gate trigger voltage for the semiconductors will be generated by the PWM (pulse width modulation)-method. The operating point and by this the internal attenuation capacity of the machine depend on the pulse duration of pwm-signal (duty cycle).

The starting point for developing the mathematical model is the motion equation (1.1.), the total sum of active torques is proportional to the gradient of angular speed [3]. Thereby the internal torque M_i (air-gap torque) can be considered as the sum of motor torque M_M and “loss torque“ M_V, which serves to compensate the rotor-, friction- and fan losses, (rel.1.2).

$$M(t) = M_A(t) = M_M(t) - M_W(t) = J_M \cdot \frac{d\omega_M(t)}{dt} \qquad (1.1)$$

$$M_i(t) = M_M(t) + M_V(t) \qquad (1.2)$$

In order to simplify the mathematical model of the observer, in the first step the ideal case with null losses will be considered.

Basing on the current model [2], [3] from figure 1, without considering speed dependent losses, the normalised mathematical equation of the shaft-torque estimator will result (per-unit relation):

$$m_W(t) = m_M[i_1(t), i_2(t), \omega_m(t)] - T_M \cdot \frac{d\omega_m(t)}{dt} \qquad (1.3)$$

As a general conclusion it has beeen observed that the most simple signal flow diagram is that with current model by rotor flux orientation [4].

From the point of view of control engineering, this method have some advantages. From this reason the adopted algorithm has been applied for simulations, although this strategy is much more sensitive parameter changing, than stator flux orientation. The used model has as inputs the following signals: the phase currents i_1, i_2 and the mechanical speed ω_m and as output generates the air-gap-torque (motor-torque) m_M* of the induction machine. For obtaining the mathematical model the known equations of the IM (induction machine) written in the rotary K-coordinates system are used. In order to get dimensionsless expressions, the presented machine model is normalized. After introducing the rotor time factor τ_2, rotor flux angel θ and splitting in d,q-components defined by the flux angle *($\psi_{2d}=0$)*, the equations can be simplified, rel.(1.4) till (1.7).

$$\tau_2 \cdot \frac{d\psi_{2d}}{dt} + \psi_{2d} = x_h \cdot i_{1d} \qquad (1.4)$$

$$\omega_2 = r_2 \frac{x_h}{x_2} \frac{i_{1q}}{\psi_{2d}} \qquad (1.5)$$

$$\theta = \omega_2 dt + Z_p \omega_m dt \qquad (1.6)$$

$$m_M = 3 Z_p Z_N T_N \frac{x_h}{x_2} \psi_{2d} i_q \qquad (1.7)$$

3. Practical realisation

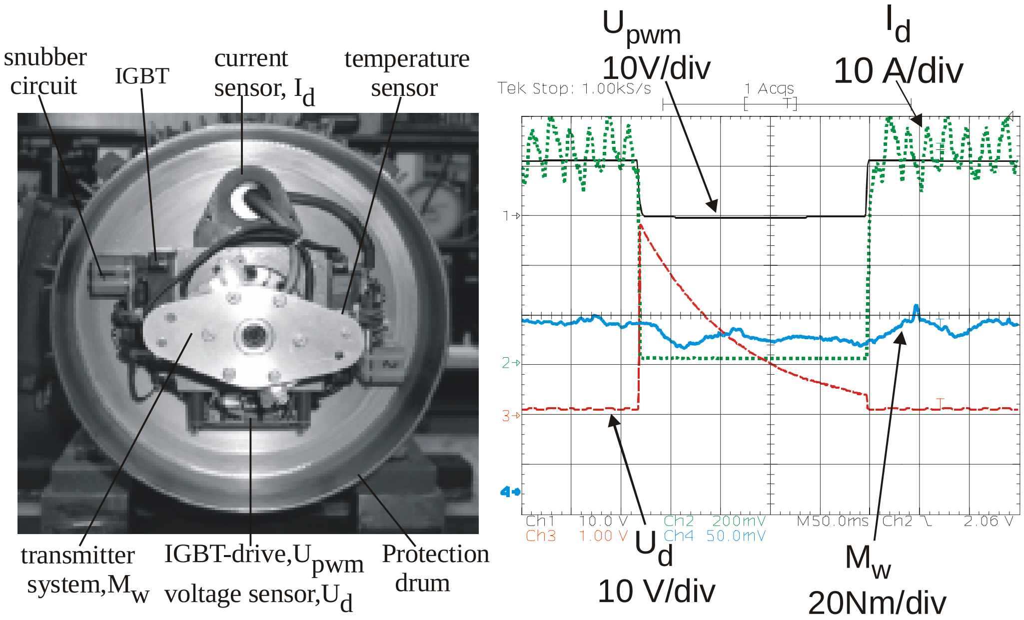

Fig. 2 (Left) Preview of the integrated controlling device and (Right) the measurements made by this

The damping device (fig.2) is composed by a controller unit (dSpace, Fig.3) and an electronical power switch, as a combination of multiphase rectifiers with schottky diodes and IGBT breaker. This device is able to switch the working cage on and off according to the control algorithm in order to minimize the amplitude of the shaft-torque signal.

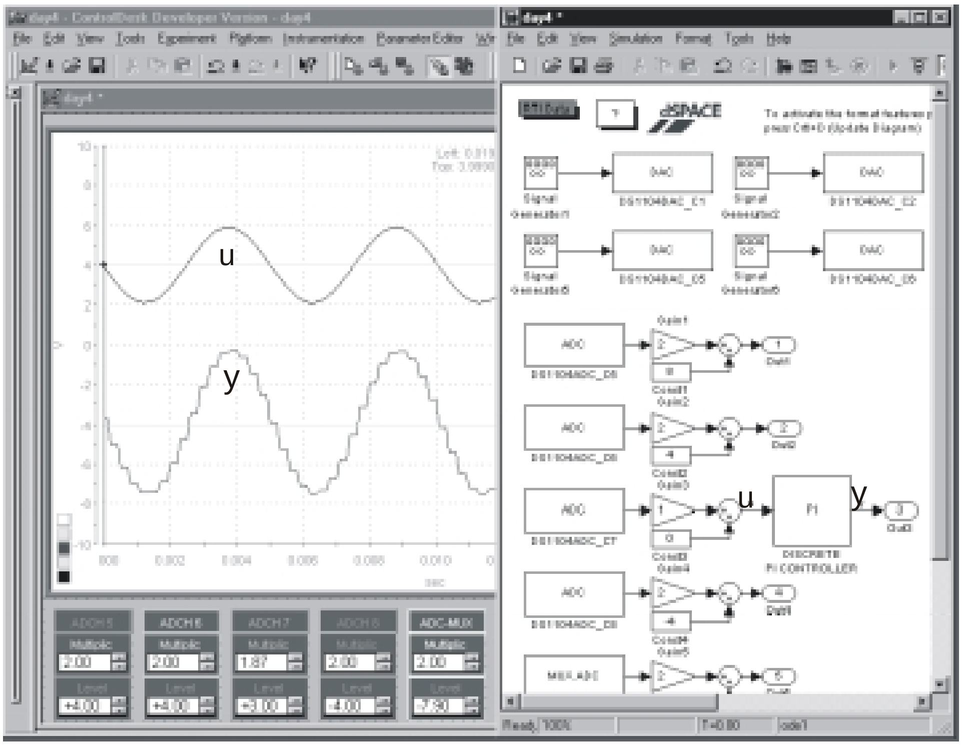

Fig. 3 Design of the PI-Regulator with Rapid-Prototyping-Tool from dSpace

4. Simulations and Measurements

The simulated current- and torque-wave-forms will be compared with the experimental values. For examing the characteristic performance of the induction machine, the simulator softwares MATLAB and NETASIM have been used. For regulator parametrisation and practical experimentation the embedded system dSpace was used.

In order to analyse the new damping concept by using simulations the object orientated model from figure 1 will be applied. For this task the instantaneous values (phase currents i_1, i_2 and angular speed ω_m) can be taken directly from the simulation model.

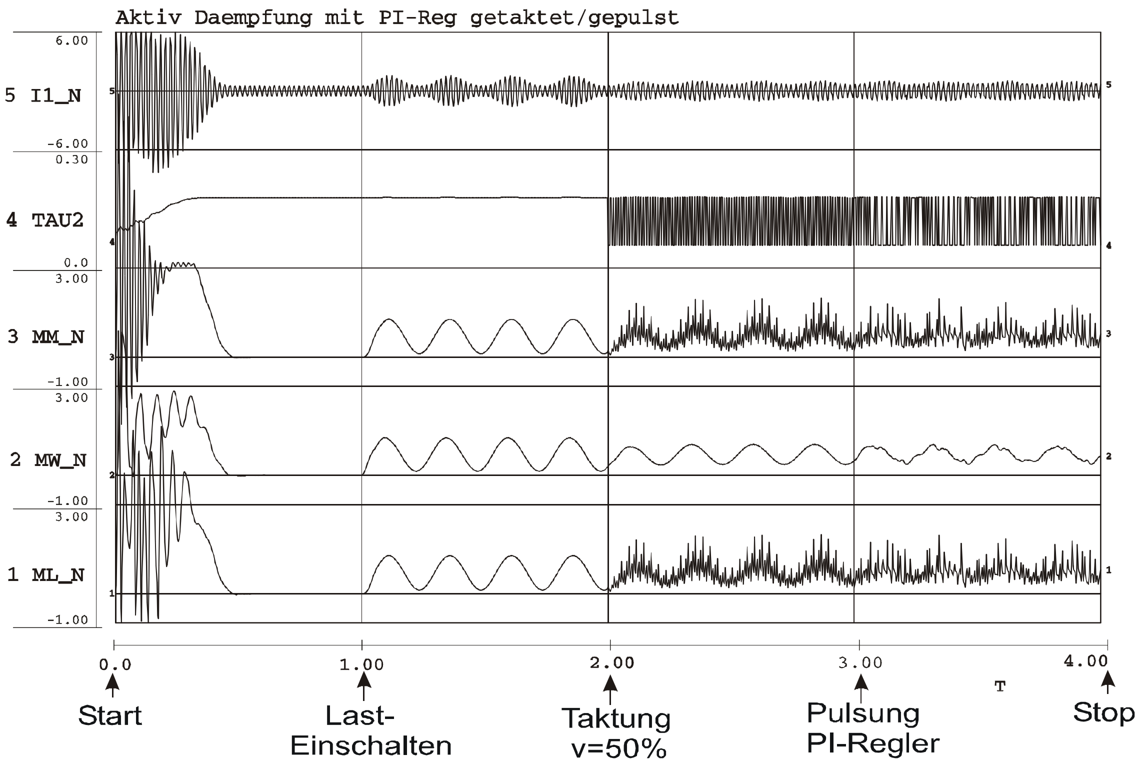

Fig. 4 Simulation of induction machine with pulsed service-cage under load operation

The behaviour of the IM was analysed in the same operations mode for different parameters of PI-regulator. The results from fig.4 show that by using the proposed control strategy with pulsed operating mode, the torsional oscillations in the shaft-torque signal (Ch.2 M_{W_N}) can be better damped.

5. Evaluating the control solutions and conclusions

On the base of the FFT-analysis of the shaft-torque waveforms the effects of different control algorithms are evaluated in comparison to the operation mode without control.

Table 1 offers decision support to select the optimal solution for the oscillations damping. The proposed and tested control circuits have been compared regarding some necessary properties and specific requirements.

Table 1. Assessment of control -loop circuits (+ high, o average, -low)

Requirements **Control circuits**	Flexibi-lity	Parameter sensitivity	Dynamic perfor-mance	Vibration damping	Technical expense	Work intensity
PI-controller Var.1	=	=	=	o (43%)	+	o
PI-controller Var.2	-	+	=	o (40%)	o	+
TP-controller (two-position)	+	-	+	+ (50%)	+	-

High flexibility and robustness are depending on the application case. The simpler the basic control system has been considered, the badder is the robustness related to parameter changing.

Very relevant for the service life of installation is the value of the stress amplitude in the mechanical drive shaft.

Using the damping strategy with PI-controller the oscillations amplitude can be reduced theoretically at about 40%. Applying the damping strategy with a two positions TP-regulator the amplitude at the first resonance frequency ($f_{1e}=4Hz$) can be reduced theoretically with 50% compared with the operation mode without regulation.

Taking into account all system costs, the financial effort to develop the regulator circuit should be at an acceptable level.

References

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