Direct Mean Torque Control with improved flux control

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Abstract

This paper presents an improved direct torque and flux control algorithm for induction machines based on the Direct Mean Torque Control. The new algorithm combines the high dynamic performance of a direct torque control method with a precise flux control.

Summary

Servo drive systems for high dynamic applications need a fast torque and flux control. Several methods to control torque and flux of an induction machine are well known: the field oriented control and the some direct torque control algorithms like the Direct Torque Control (DTC), the Direct Self Control (DSR). Here we use the Direct Mean Torque Control (DMTC). DMTC is a model-based, predictive method, which results in a constant switching frequency and is applicable for all kinds of induction machines, especially for servo drives with a very low leakage inductance. Under some particular conditions, the original DMTC algorithm [1], [2] did not provide the maximum dynamic performance. The maximum dynamic performance is necessary for active damping of mechanical oscillations with high resonance frequencies (up to 1kHz). The original algorithm uses *one* voltage vector and one zero voltage vector for torque and flux control per sampling cycle. At low speed and torque, the duration of active voltage vectors for torque control is too short to avoid a decay of the flux. Then flux supporting voltage vectors have to be chosen which may influence the torque in an adverse way. In the subsequent cycles the adverse effects of the flux supporting voltage vector concerning torque and speed has to be corrected. At the experimental set-up this leads to the excitation of unwanted torque and speed oscillations.
But with the improvements presented in this paper this problems can be solved and it is possible to actively damp mechanical oscillations even with high resonance frequency [3].

1. Direct Mean Torque Control

Hysteresis controllers like the DTC can result in extremely short sampling periods if the control of an induction machine with low leakage inductance is realised by a micro processor [4]. This is especially true at low or high speed. At these operating points, the difference between an active voltage vector applied by the inverter and the EMF is large, consequently the rate of change of the stator currents is high.. To obtain a suitable torque ripple, a sampling period of less than 5 µs would be necessary with DTC at our servo machine. This would end in an unacceptable high computational burden for the controller.
A significant improvement is achieved by the original DMTC, which is a model-based, predictive method, resulting in sampling periods of e.g. 125µs. DMTC calculates two switching events per sampling period. The switching events are calculated such that the torque time area under and over the torque set point value has the same size in steady state operation [1], [2]. See fig. 1:

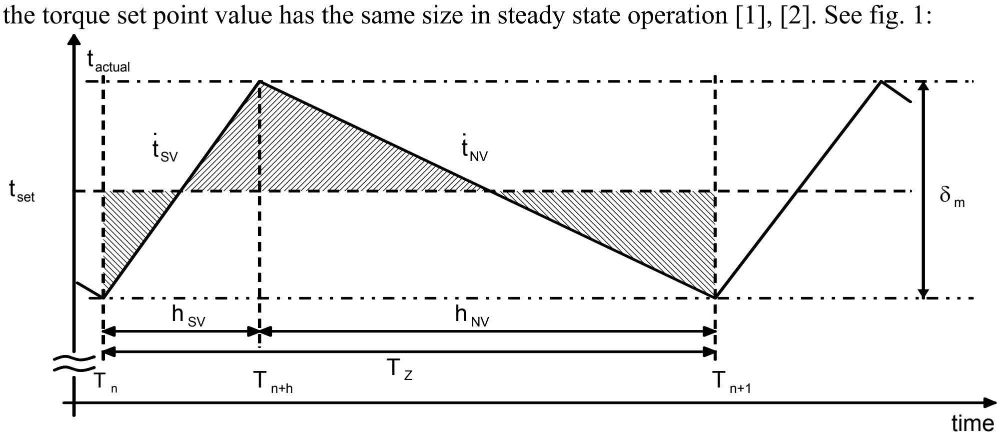

Fig. 1: Torque control cycle with DMTC

The DMTC algorithm checks several voltage vectors and a zero vector for torque control and calculates the adequate switching instants using a machine observer. Finally, the vector producing the best results concerning torque and flux is selected and applied to the machine in the next sampling cycle. If it is not possible to satisfy torque and flux demand simultaneously, priority is given to torque performance. The observer uses the complete model of the induction machine in the stationary $\alpha\beta$ reference frame. The final paper will explain the algorithm and the model in detail.

2. Improved flux control

The original DMTC algorithm uses *one* voltage vector and one zero voltage vector for torque and flux control per sampling cycle. At low speed and torque, the duration of active voltage vectors for torque control is too short to avoid a decay of the flux. Then priority is reversed and DMTC selects flux supporting voltage vectors, but these may violate the torque requirements. To solve this problem, the improved flux control presented here uses ***two*** voltage vectors and one zero voltage vector per sampling cycle in the above mentioned situation. The improved flux control algorithm applies a flux increasing voltage vector for a fixed duration of 5 µs if the flux is lower than a certain level at the beginning of the cycle. This is enough to move the flux in the direction of its set point value. The duration of this voltage vector is fix and should be chosen considering the leakage inductance of the machine. With the remaining two vectors the torque can be set according to the DMTC-algorithm. Such a sampling cycle of the duration T_z and the three sections h_{FS}, h_{SV} and h_{NV} for the flux increasing vector, the active and the zero voltage vector respectively is shown in Fig.2. In all other cases, i.e. flux is not below a certain level, sampling cycles with two sections h_{SV} and h_{NV} are used, see start of Figure 2.

Fig. 2: Twice-shared cycle and three times shared cycle with flux increase

Theoretically it is possible to calculate the switching times for the two voltage vectors and the zero vector with the DMTC algorithm and the machine model that way that torque and flux are set correctly, but this results in very complicated equations which cannot be calculated in a short time with micro processors or controllers. Practically, it is sufficient to use the short but constant time h_{FS}=5µs .This algorithm combines the high dynamic performance of the DMTC-algorithm and relatively moderate calculation times at the used set-up. The control has a cycle time of 125 µs on a PentiumII processor working with 220 MHz [4]. The final paper will explain this algorithm more detailed.

3. Simulations and measured results

The following simulations and measured results prove the performance of the proposed algorithm. The first simulation shows the trajectory of the stator flux in the machine at low speed and low torque and at low torque and high speed:

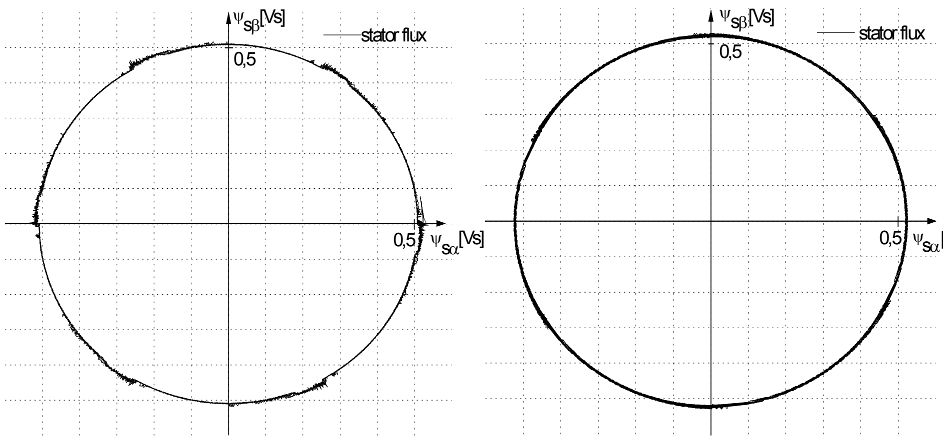

Fig. 3: Simulated stator flux of the induction machine at no load and 10 rpm (left) and 500 rpm (right)

From the above simulations it can be seen that the flux in the machine is kept rather precisely on a circle.
Figure 4 shows a measurement at the experimental setup. A step change of the speed set point value from zero to 100 rpm is applied. A simple PI-speed controller is superimposed to the described improved DMTC algorithm.

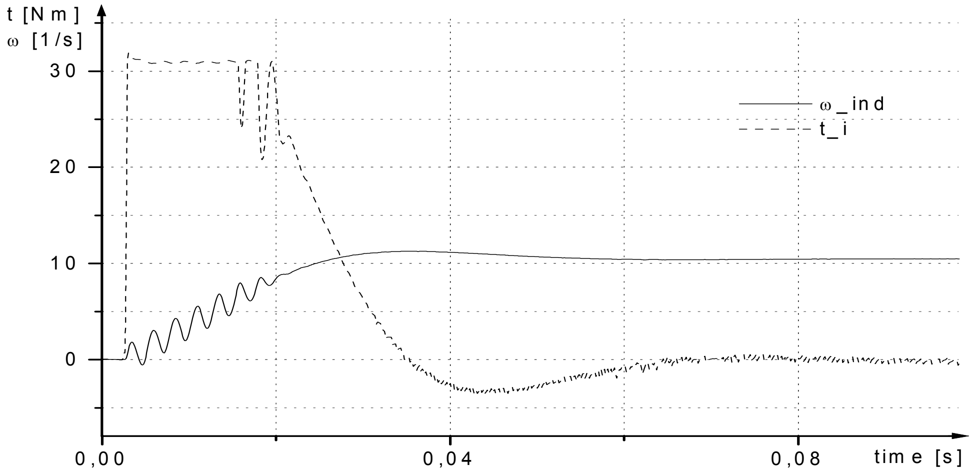

Fig. 4: Measured active damping of high frequency mechanical oscillation with the new torque control algorithm

At the beginning, the torque control is saturates as 33Nm. During saturation of the torque control, no active damping is possible and the speed oscillates with mainly the first mechanical resonance frequency of 400Hz. As soon as some control margin becomes available, which occurs at about 20ms, the mechanical oscillations are damped out quickly, due to the high dynamic performance of the proposed conrtol method.
The final paper will show more simulated and experimental results with the proposed algorithm.

4. Conclusions

The proposed algorithm improves the dynamic behaviour of the DTMC algorithm and reduces the complexity of the control system. This makes also a realisation on a micro processor much easier. The torque and the flux can now be controlled correctly in every cycle. The performance of the algorithm can be demonstrated with the active damping of 400 and 850 Hz mechanical oscillations.

References

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