Benefits and limits of using an acceleration sensor in actively damping high frequency mechanical oscillations

1. Introduction

IGBT inverters with high switching frequency in conjunction with advanced digital control methods enable induction motor drives which can adjust the mechanical torque T in a very short time (high dT/dt). For high torque dynamics, the closed torque- (or current)-control loop is processed in a short cycle time of about 100µs. In many applications, e.g. in machine tools, drives with high accelerations are attractive in order to boost productivity. But unfortunately, a high dT/dt trends to excite mechanical resonance frequencies of the machine. Therefore active damping of the resonant oscillations is essential. A number of papers can be found in the literature, which deal with active damping of mechanical oscillations. But generally, the highest mechanical resonant frequency, which is actively damped by the induction motor is in the range of 100Hz. In stiff machine concepts, which are used in high speed machining, the resonance frequencies begin well above 100Hz. In this work, we investigate a three inertia system, with the dominant resonant frequencies at 400Hz and 850Hz. The experimental set-up is shown in figure 1 and the block-diagram in figure 2.

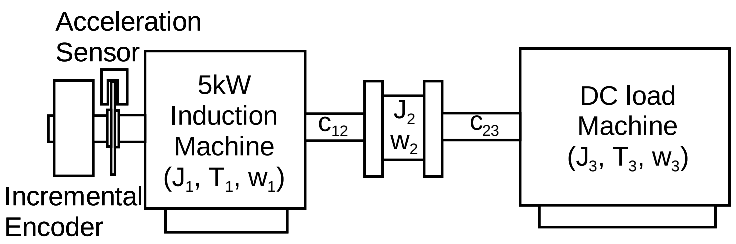

Figure 1: Experimental set-up

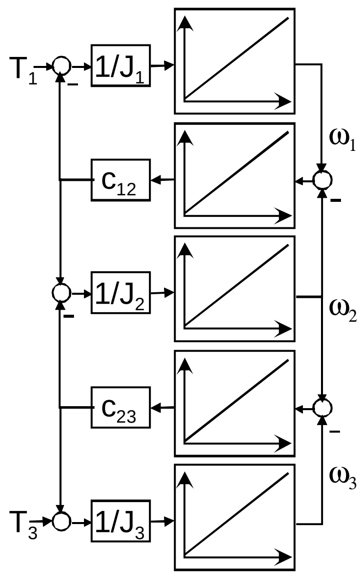

Figure 2: Block diagram of the controlled plant

To control the speed of such a system, of course, a state variable feedback controller complemented by a state observer may be considered. But to get reasonable results, high expenses are required: Firstly, precise parameters of the plant should be supplied to the state observer. But in practice, parameter estimation of a **stiff** system with only a motor-side speed measurement is a tricky task. Secondly, tuning the controller's 5 feedback-parameters by pole-placement or by a Riccati-approach is easier said than done in practice. Thirdly, additional on-line computing power is required to deal with the observer.

Therefore, in this paper we investigate a simple but robust and efficient PI-speed-controller for active damping. If the parameters of the plant are coarsely known it is possible to tune the controller by searching the parameters which place the poles nearest to the desired ones (similar to [1]) within the possible parameter space. An easy way to do this is by matlab [2]. The stability and the performance can be proofed by simulation using a model of the three inertia system without natural damping (Fig. 2). Additionally, the simulation includes a complete induction-machine model and the “Direct Mean Torque Control” [3], [4] with constant switching frequency. Assuming an ***ideal***, motor side *speed measurement*, simulation shows, that the PI-speed-controller performs well in actively damping the investigated plant. The final paper will explain the PI- and also PID-controller design in depth and will show detailed simulation results.

At the real drive, speed is not measured directly, instead the position is measured by an Incremental Encoder with sin / cos -outputs and 5000 lines/rev. Its specified accuracy is 10^{-5} Rev. By evaluating the sin / cos -signals, apparently a much higher resolution is obtained, but the accuracy of course is not increased. To get speed from position, differentiation has to be performed either explicit as a time-discrete differentiation or implicit by an observer structure. In each case, the speed signal calculated from successive position measurements is contaminated with noise. The noise increases as the cycle-time (time between two measurements) and the actual speed decreases. To obtain a reasonable speed-control loop, the speed signal has to be filtered and / or the controller’s gain has to be low. But unfortunately, then active damping of high frequencies is impossible.

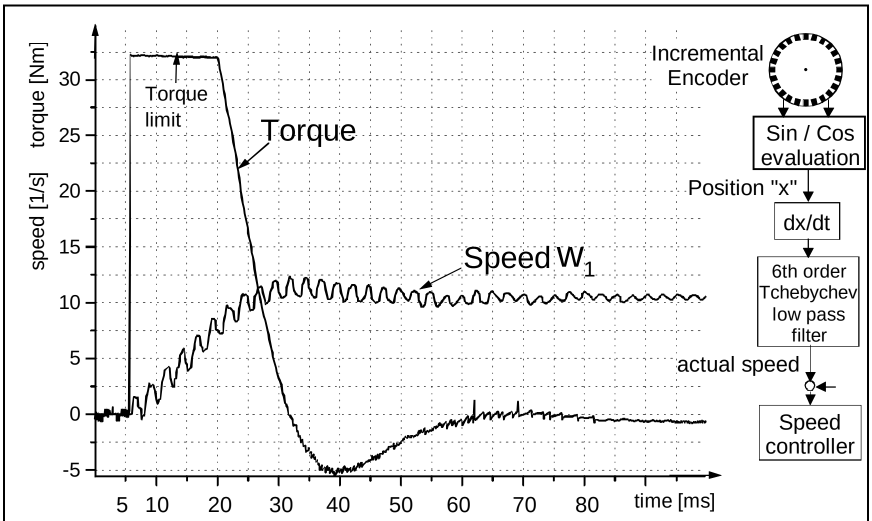

Figure 3: Measured results with low pass filter for speed signal.

Fig. 3 shows the speed ω_1, measured at the experimental set-up and the torque, calculated on-line by the “Direct Torque Controller”. The speed signal is filtered with a 6^{th}. order Tchebychev low-pass with a cut-off frequency of 380 Hz. The controller’s P-gain is 10 and its integration time is 1 ms. Only a very poor damping of the resonant oscillations is achieved in this case.

2. Using an acceleration sensor to produce a high quality speed signal.

Recently, an acceleration sensor for rotating devices based on the Ferraris principle became commercially available [5]. In research labs, Ferraris based acceleration sensors have been used since a long time [6], but now they are commercially available, and it seems possible, to integrate the acceleration sensor in the housing of the incremental encoder.

The acceleration signal of the Ferraris sensor is of rather low noise. To get the speed from the acceleration, an integration has to be performed, which additionally reduces noise. But each analogue device has a drifting offset and a slightly drifting gain. The signal of the Ferraris sensor has also some kind of PT_1-behaviour [7] which is slightly delaying the speed signal in comparison to the differentiated position signal.

On the other hand, the position signal from the incremental encoder has no offset or offset drift and the average value is always correct. But, as previously mentioned, the speed signal derived from the position sensor is contaminated with noise. Both sensors are fixed at the b-side of the induction machine (Fig. 1). This connection causes an additional resonant frequency of about 2 kHz. Combining the signals from the position- and the acceleration sensor produces a high quality speed signal, which enables active damping of resonant oscillations. The combination is done by an observer, shown in the right part of Figure 4.

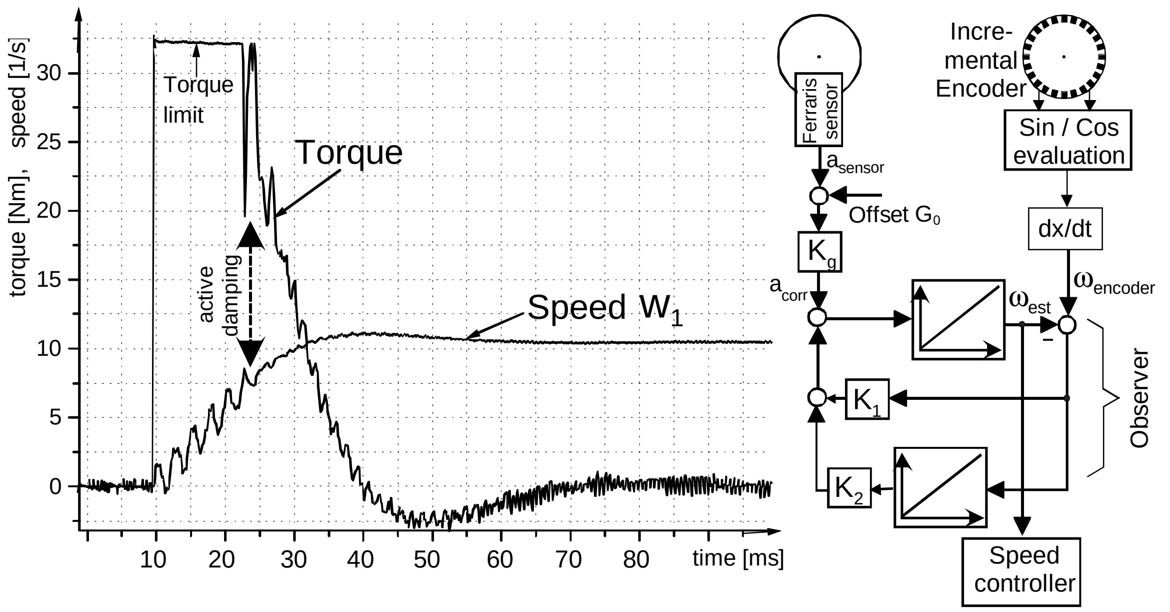

Figure 4: Left: Measured results.
Right: Combination of acceleration and position – signals to produce a high quality speed signal.

The signal a_{sensor} has to be corrected (offset and gain), the correction method is explained in the final paper. The observer is realized in a time discrete way on the controlling processor. The final paper will give detailed information. It can be generally noticed, that this method is filtering the speed signal sufficiently and is generating also a sufficient low phase lag to damp the three inertia system.

The measured speed and the on-line calculated torque is shown in the left part of Fig. 4. As long as the torque control is saturated, no control margin for active damping is left and the resonant oscillations take place. But as soon as the torque is reduced, there is a control margin and the oscillations are damped.

3. Conclusions

It is possible with rather small efforts to synthesize a low noise high dynamic speed signal with the help of the Ferraris sensor. With this signal a robust and easy to design PI-speed controller is proposed to damp the high frequent oscillations of the three inertia system. The disadvantages are the additional sensor, the small additional computational effort and the required torque reserve to damp the oscillations.

References

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