DSpace Platform for Speed Estimation AC Slip-Ring Motor in Crane Mechatronic System

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***Abstract* - This paper describes DSpace microprocessor platform and Matlab/Simulink environment for development of a speed estimation algorithm. The main principle of the estimation algorithm and proposal for algorithm change in sense of the system performances improvement are described. DSpace enables algorithm developing and testing just on a personal computer. Only final testing is made on the laboratory model of the mechatronic crane system.**

I. INTRODUCTION

The tendency of modern software development tools is that through user-orientated interfaces programming becomes much easier using different advanced functions. These features enable user to spend more time on the algorithm development because he doesn't need to work with different, in most cases user unfriendly, implementation tools. DSpace hardware platform is based on digital signal processors (DSP). This platform has two characteristics which discern it from other similar products. First one is that this microprocessor board is mounted in the PCI slot of a personal computer, and the second one is that system uses Matlab/Simulink as a software development tool. Hardware platform consist of two DSPs, which share different application-communication tasks in order to achieve real-time application running.

For the software developing, DSpace system uses Matlab/Simulink. Almost all Simulink features and tools can be used for creating a user algorithm. DSpace software package includes additional Simulink toolboxes which define different hardware characteristics like timers, counters, PWM generators, encoders, etc., L[5]. When the user algorithm is created in Simulink, target DSP code must be generated. Matlab's Real time workshop and the specific builder, installed with DSpace software package, provide that building and downloading of user algorithms are possible directly from Simulink. When the user algorithm is downloaded real time debugging, parameters adjustment and signals observing are realized with the Control Desk software package.

II. AC SLIP RING SPEED ESTIMATION

The speed estimator is developed for the commercial controller ASTAT®, produced by company ABB. This is a digital system for the AC slip ring motor speed control, designed especially for the crane applications. In order to ensure good dynamic control characteristics, speed estimation system must be designed as a real-time system. The estimator is developed and designed using DSP software and hardware development system and introduced in the commercial produce as a part of the ASTAT® control system.

For AC slip ring motor, speed estimation algorithm is based on the rotor voltage frequency measurement. From simple relations

$$
\begin{aligned}
&f_2 = s \cdot f_1 && f_1\text{–}stator\ \ frequency\ \ (50\ or\ 60)\ [Hz] \\
& && f_2\text{–}rotor\ \ frequency\ \ [Hz] \\
&n = (1-s)\cdot n_s && n - rotor\ speed\ [rpm] \\
& && n_s - synchronous\ \ speed\ [rpm]
\end{aligned}
\tag{1}
$$

it can be seen that rotor and stator voltage frequency as well as rotor and synchronous speed are connected through the slip s. Based on relations (1), the main accent of the speed estimation algorithm is on the rotor voltage frequency measurement. Rotor frequency is determined by measuring the time period between two zero crossing of the rotor voltage. Depending on the drive operating point (in the torque-speed characteristic), frequency of the rotor voltage is changed between 0-100 Hz, L[1]. In the case of supersynchronous braking mode this frequency can be grater then 100Hz. Rotor voltage amplitude is dependent on the load torque, voltage amplitude is smaller as the load torque is smaller. In these specific conditions it is difficult to determine a rotor voltage frequency so these conditions enlarge complexity of the speed estimation algorithm. In order to precisely determine rotor voltage frequency, filtering of the measured rotor voltage must remove higher harmonics and interference, while attenuation of the rotor voltage amplitude is negligible. In selection of the filter cut off frequency, filter time compensation must be taken into a consideration, in order to achieve real-time running.

III. DSPACE ALGORITHM MODELING

Because the rotor voltage frequency change between 0-100 Hz, it is difficult to determine just one cut-off frequency to fulfil above mentioned filtering demands. Because appropriate filter selection can have influence on the speed estimation precision, including variable filter in the estimation algorithm is justified. The adaptive filter, based on the specific drive parameters, selects appropriate cut-off frequency. Therefore presented filter is variable just in sense of cut-off frequency change but the filter structure (type and order) remains unchanged. The base structure of the variable filter makes filter cascade with three Butterworth 1st order low pass filters (Fig.1.).

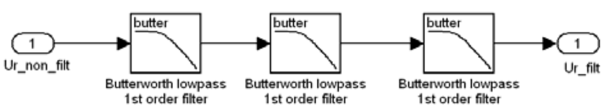

Fig. 1. The base structure of the variable filter

On the Fig.2. the Simulink subsystem block of the rotor voltage variable filter is shown This block has four inputs and one output. On the first input *U_r_non_filt* unfiltered rotor voltage is connected and the output *U_r_filt* gives the filtered rotor voltage. The other inputs represent signals which determine the criterion for filter cut-off frequency selection. On the base of this criterion, there is possibility to select eight different cut-off frequencies. Experimental results are shown that increasing numbers of the filters above eight doesn't improve filter or estimator performance.

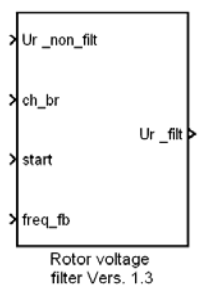

Fig. 2. Simulink subsystem of the variable rotor voltage filter

The main criterion for the selection of an appropriate cut-off frequency is the calculated frequency of the last sample *freq_fb* (Fig.3.). In the specific drive conditions one sample time delay of the frequency feedback *freq_fb* may result in wrong cut-off frequency selection (to low or to high) resulting in wrong information of rotor voltage frequency, i.e. actual speed. To avoid this problem additional signal should be introduced in order to prevent this situation. Algorithm use special program routine for situation where speed estimation is not accurate. That is happening when actual speed is close to synchronous, when load is too small and by step slip change (e.g. plugging). Actual speed is controlled combining the changes of the stator voltage amplitude and value of the connected external rotor resistance, L[2,3,4]. Change of the stator voltage is made by thyristor converter allowing the change of electromagnetic torque direction and on that way four quadrants operation is realized. Digital control system detects direction of the electromagnetic torque by two digital signals. One of these two signals is used in estimation algorithm as a logical signal of the converter state, *ch_br* (Fig.2.). This signal detects the change of electromagnetic torque direction and no-current state during torque direction changing. At the moment of torque direction change, there is almost step change of the rotor voltage frequency. Because the frequency feedback signal of adaptive filter delays one sample, wrong cut-off frequency will be selected and estimation error will occur. To avoid this, it is necessary to detect a moment of torque direction change. From that moment (*ch_br=1*) frequency feedback *freq_fb* is frozen in order to enable the choice of appropriate cut off frequency. Period of the feedback freezing (the several tenths of second) is experimentally determined by measuring the duration of no-current period and transient state of rotor voltage. With high frequency feedback signal (high slip) voltage filter use the high cut-off frequency, ensuring successfully detection of rotor voltage frequency step change. Third input (signal *start*, fig.2.) is logical variable that define the moment of system and filter start up. If *start=0* outputs of the adaptive filter and estimator is set to zero.

Some DSpace system features enable system modelling in Matlab/Simulink environment. For the purpose of the speed estimation algorithm developing, rotor voltages for different electric motor drive operating points are recorded. These voltages substitute the mathematical model of controlled AC slip ring motor. Besides the voltages, the signal for torque direction is also recorded. All needed signals are recorded with DSpace system in Exel format (*.csv) and imported in Matlab.

IV. EXPERIMENTAL RESULTS

The experimental testing was made on laboratory mechatronic crane model. This mechatronic crane model consist off 3-phase AC slip ring motor (18.5 kW, 1460 rpm) controlled with industrial converter ABB-ASTAT. AC machine is loaded with DC machine in torque operating mode (controlled with SIEMENS-SIMOREG). DC machine in this mode can provide approximately 60% of AC machine nominal torque.

Comparison between rotor voltage filtering with variable filter and with three cascade 1st order filters (cut off frequency 110 Hz) is presented on the fig.4. The first harmonic frequency of the tested rotor voltage (blue line on Fig.4.) is near 3 Hz. Rotor voltage is measured in no-load operation condition of the AC slip ring motor. This comparison is chosen because it represents unfavourable operating condition and is suitable for estimation algorithm verification. Presented estimation method is based on the time period measuring between the two zero crossing of the rotor voltage (frequency measurement). From the waveform presented on fig.4 it is clear that proposed estimation method with variable filter is better solution.

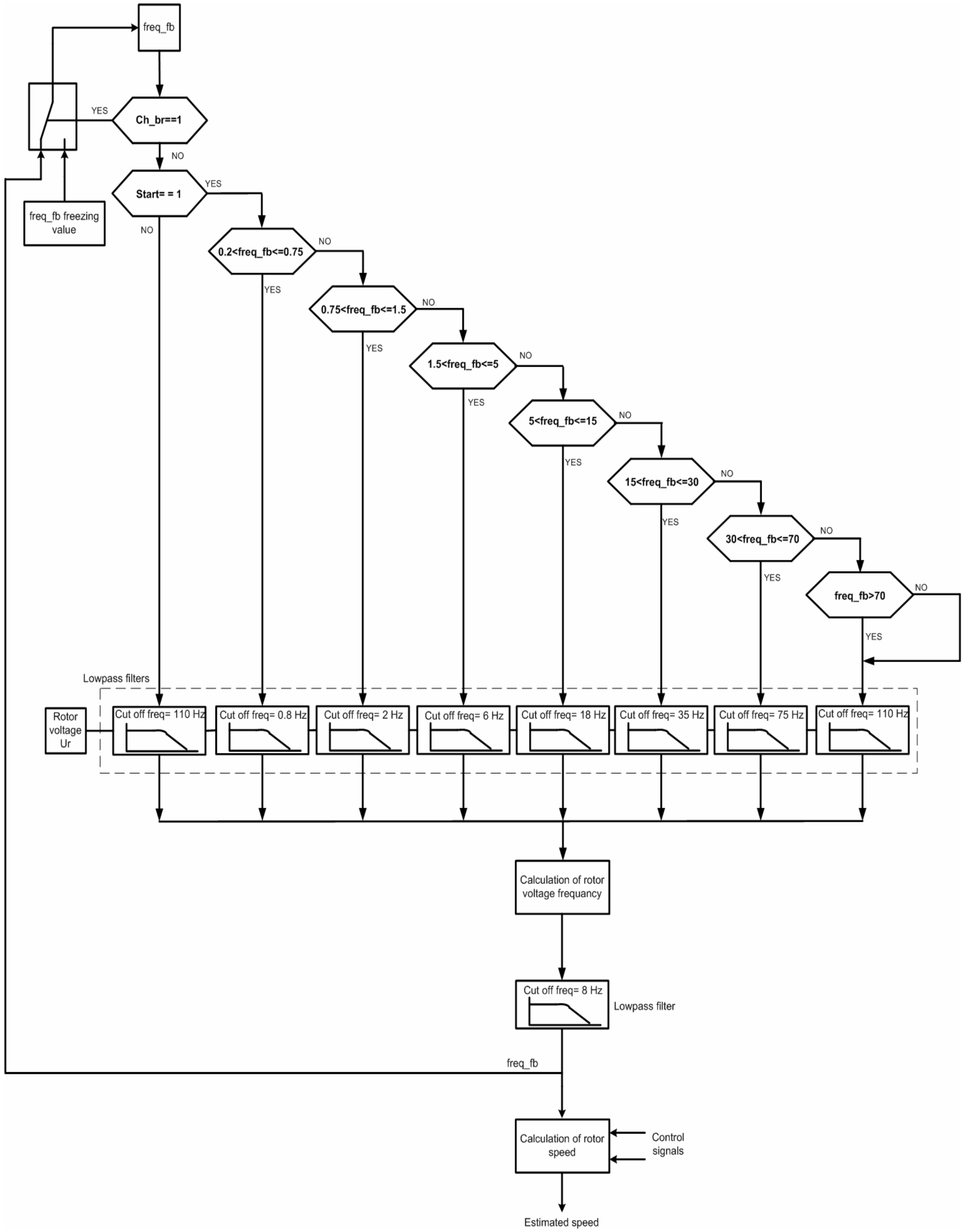

Fig.3. Flow chart of variable filter algorithm

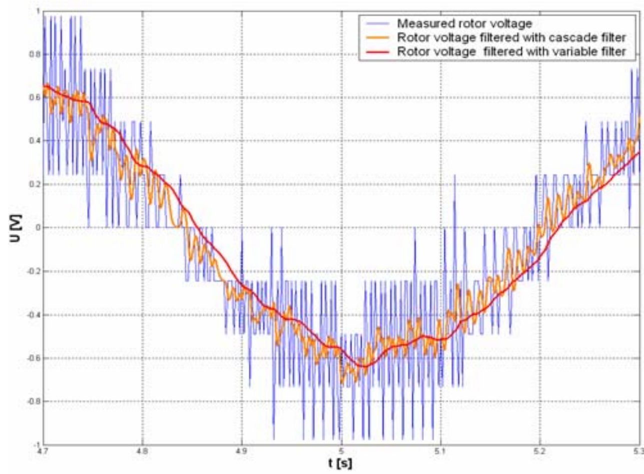

Fig.4. Comparison between filtering results with variable filter and with three cascade 1st order filters (cut off frequency 110 Hz)

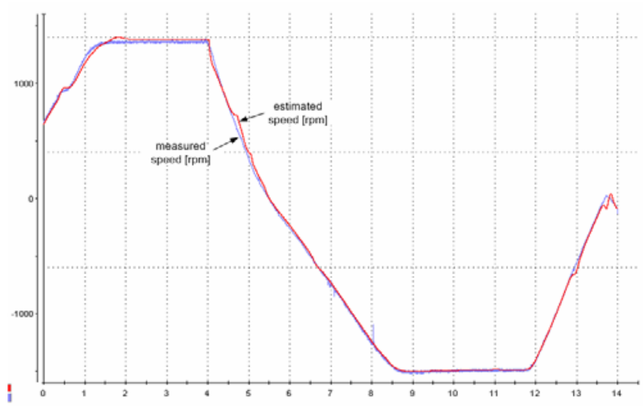

Fig.5. Comparison between estimated (red) and measured (black) motor speed in range of 0–1500–(-1500)–0 rpm with 60% of motor rated torque.

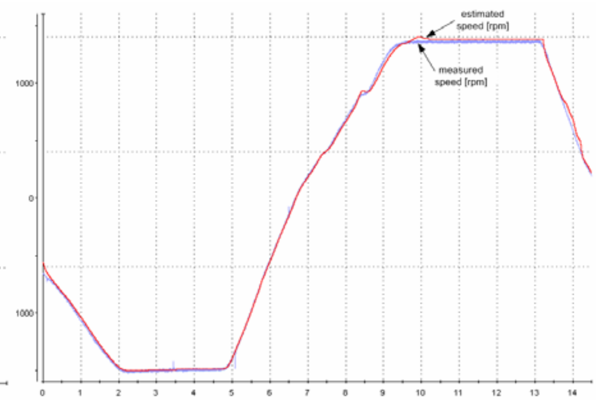

Fig.6. Comparison between estimated (red) and measured (black) motor speed in range of 0–(-1500) –1500–0 rpm with 60% of motor rated torque.

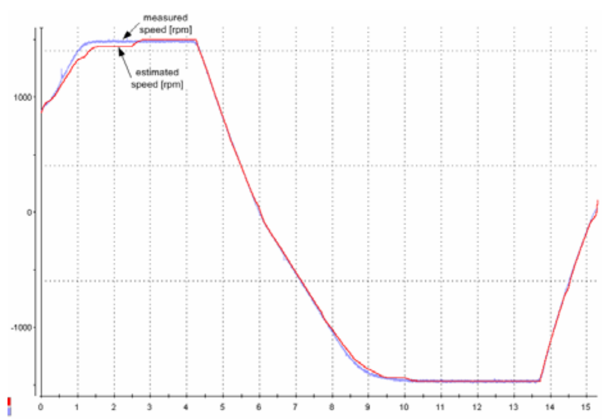

Fig.7. Comparison between estimated (red) and measured (black) motor speed in range of 0–(-1500) –1500–0 rpm with cca 5% of motor rated torque .

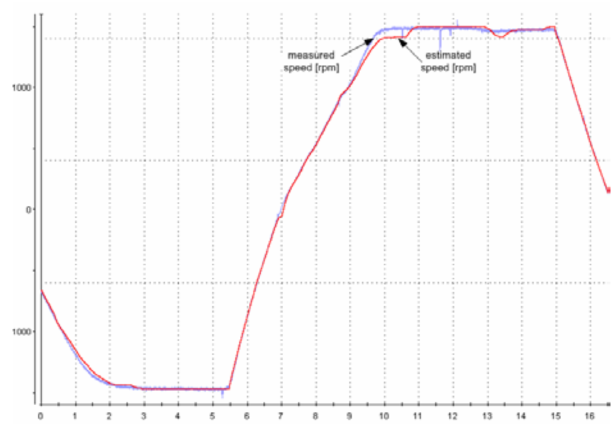

Fig.8. Comparison between estimated (red) and measured (black) motor speed in range of 0–(-1500) –1500–0 rpm with cca 5% of motor rated torque

Fig.5.-8. presented comparison between estimated and measured motor speed in different operating condition. It is clear that this estimation technique gives good dynamics characteristics in all operating conditions except some specific area in no-load operating mode. In continuous nominal speed area of no load condition estimation has error caused with small rotor voltage and low frequency of voltage. Because of that estimator need more time to determine correct speed. The crane systems usually don't work in no-load condition so these speed estimation error is acceptable. The loaded operating conditions (fig5., fig.6.) don't consist these problems.

VI. CONCLUSION

Development of the speed estimation algorithm with DSpace microprocessor platform and Matlab/Simulink environment is simplified. This solution enables estimation algorithm developing and testing using only one personal computer with installed DSpace. Only final testing and parameters adjustment is made on the laboratory mechatronic crane model. Results show that this method is appropriate for algorithm developing because it saves time allowing simple use of an advanced DSpace and Matlab/Simulink functions and tools.

Proposal for algorithm change was made in sense of rotor voltage filtering improvement. The estimation algorithm structure with variable rotor voltage filter enables good dynamics characteristics in all operating conditions. The future work must be focused on the estimation error in unfavourable operating conditions cancellation (no-load, oversynchronous condition, etc.).

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