CONTROL OF MULTI-MASS DRIVE SYSTEM USING NEURAL NETWORK CONTROLLER AND FILTER TUNED TO SEVERAL SYSTEM FREQUENCY RESPONSE

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Abstract - The article presents a compared the dynamic properties of neural adaptive controller for the system with a complex mechanical structure of variable parameters. Two filters were implemented: a simple LPF and fixed filter, taking into account the changing parameters. In the paper was placed a results of laboratory tests with PMSM motor for the multi-mass system of variable parameters.

I. INTRODUCTION

In recent years, a continuous increase of demands for the quality of servodrives is observed and it can be expected, that this process will progress. Many of these controlled devices have complex mechanical structure e.g. industrial robots, machine tools, wind turbines, paper machines or rolling machines [1-3]. The increasing demands on the control dynamics imply, that the phenomenon of mechanical resonances, occurring in drives with elastic coupling between the motor and the driven device, cannot be neglected, because it has an impact on the properties of the drive dynamics [2]. Nowadays progress in the construction of modern mechanisms has led to a reduction of the mass. Also the small moment of inertia of contemporary electric motors (like, for example, Permanent Magnet Synchronous Motor; PMSM) causes the resonance (NTF; Natural Torsional Frequency) and anti-resonance (ARF; Anti-Resonance Frequency) frequencies in the systems of motion control increase significantly. Control systems with active damping of mechanical vibrations described in the most recent publications are designed for resonant frequencies below dozens of hertz [2], but nowadays drive systems achieve NTFs of 100 Hz and more. Additionally the changes of the moment of inertia, cause changes in the mechanical resonance frequencies, which essentially complicates their damping. In such cases, the adaptive controllers, based on artificial neural networks [3], an ANFIS (Adaptive Neuro-Fuzzy Inference System) or predictive control systems, are utilized.

In order to solve this issue was proposed: anti-resonance filter with fixed, properly tuned frequency characteristic, provides a compromise effect of higher frequency torsional vibration damping at changing values of these frequencies (Fig. 3) and adaptive neural controller. This solution was compared with simple the low-pass filter with fixed parameters damping higher frequencies at changing values of these frequencies (Fig. 3) and the same controller. The comparison of these two proposed solutions was performed by experimental research. The investigated system consists of PMSM and the driven mechanism with variable moment of inertia.

II. CHARACTERISTIC OF INVESTIGATED SYSTEM

The structure of the control system consists of a cascade connection of the current controller and speed controller (Fig. 1). Motor shaft position was measured using an incremental sensor. The maximum motor speed is equal to 2.5 rev/s. The sampling time is equal to \( \tau_s = 100 \) µs. The output of the speed controller is the current command in q-axis \( i_{ref} \). The high mechanical resonance frequency components are transmitted by the control system. Use of the anti-resonance filter allows to attenuate the frequency components. As a result the feedback signal is filtered \( \omega_r \), and don’t excite system to vibrate. Two digital filters were applied (Fig. 3)[4]: LPF (low pass filter) and filter tuned according to identified mechanical part (Fig. 2) [5]. Both filter gives good attenuation of mechanical resonance components in measured speed signal. Fixed filter attenuates four NTFs: 88 Hz, 200 Hz, 280 Hz, 400 Hz. LPF Chebyshev II parameters are as follow: pass-band edge 20 Hz, stop-band edge 50 Hz, maximum ripple in the pass-band 3 dB, minimum attenuation in the stop-band 30 dB.

![Fig. 1. Control structure of electric drive](image1)

![Fig. 2. Investigated system frequency response](image2)

![Fig. 3. Filters frequency response](image3)
III. NEURAL ADAPTIVE CONTROLLER

A structure of ANN depends on assumed type of controller. In the paper non-linear controller of PD-2DOF is proposed, which is realised by ANN shown in Fig. 4. The ANN network has one hidden layer with 3 neurons (nonlinear activation functions) and one output neuron (linear activation function). The assumed criterion for ANN training is a square of speed control error:

\[ E(k) = \frac{1}{2} \left( \omega_{ref}(k) - \omega_z(k) \right)^2 = \frac{1}{2} e^2(k) \]  

(1)

For the network learning a simple Resilient Backpropagation (RPROP) algorithm [3] was chosen, in order to simplify the computations processed in real time. The basic advantage of this algorithm is a determination of only sign of the function gradient, instead of its value. The weights of the neural network are modified according to the equation:

\[ \Delta w_{ij}(k) = -\eta_{ij}(k) \cdot \text{sign} \left( \frac{\partial E}{\partial w_{ij}}(k) \right) = -\eta_{ij}(k) \cdot \text{sign}(S_{ij}(k)) \]  

(2)

where \( \eta_{ij}(k) \) is a training coefficient in k-step and \( S_{ij}(k) \) is an error gradient in step k. Specific for RPROP algorithm is that training coefficient \( \eta_{ij}(k) \) in (4) is determined individually for each weight and changed in each step of training in agreement with formulas:

\[
\eta_{ij}(k) = \begin{cases} 
\min(a \cdot \eta_{ij}(k-1), \eta_{ij}^{\max}) & \text{if } S_{ij}(k) \cdot S_{ij}(k-1) > 0 \\
\max(b \cdot \eta_{ij}(k-1), \eta_{ij}^{\min}) & \text{if } S_{ij}(k) \cdot S_{ij}(k-1) < 0 \\
\eta_{ij}(k-1) & \text{in other cases} 
\end{cases}
\]

(3)

In this paper neural network controller with modification was applied, presented in the previous work [3].

IV. EXPERIMENTAL RESULTS

In addition to the mechanical part of the laboratory stand consists of the power circuit (including rectifier and power inverter) and PMSM with encoder speed sensor. The central unit of the controller is digital signal processor (DSP), which is connected with DAC and ADC modules, system contains PWM generator and encoder interface. The study involved comparing the dynamic properties for two different moments of inertia with the LPF and Fixed filter.

Fig. 5. Waveforms of the rotational speed after learning (J_{max}) for LPF and Fixed filter. Step change of load torque was applied at 0.5s.

Fig. 6. Waveforms of the rotational speed after learning (J_{max}) for LPF and Fixed filter. Step change of load torque was applied at 0.5s.

In Tab. I are presented the response times of the step change of speed and load torque. Studies shows that the use of the fixed filter, in terms of the assumed change of the object parameters, has better dynamic properties of system.

V. CONCLUSION

The study compared the dynamic properties of neural adaptive controller for the system with a complex mechanical structure of variable parameters. They were implemented two filters: a simple LPF and fixed filter, taking into account the changing parameters. It has been shown that the use of a LPF filter is insufficient in terms of assumed requirements for the multi-mass system of variable parameters.

REFERENCES


