OPTIMUM SELECTION OF DESIGN FEATURES OF ELECTROMECHANICAL DRIVE SYSTEMS INCORPORATING A CONTROL UNIT

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Summary Problems relating to modelling, sensitivity analysis and optimization of a high-power electromechanical drive system incorporating a control unit have been dealt with in the paper. A spatial model in which couplings between particular subsystems have been taken into account was employed here. The vibration level has been lowered and the energy consumption of the system has been reduced due to the optimization procedure carried out. Evolutionary algorithms have been used to perform the optimization.

INTRODUCTION

Reducing of excessive vibrations of electromechanical drive systems is a complicated problem that, in general, needs carrying out of numerical simulations with the aid of mathematical models of systems under consideration. The effectiveness of a method used to lower the vibration level depends on the proper selection of parameters of the system and is conditioned by exactitude of the employed mathematical models of electromechanical systems. Thus, there is a tendency to develop the applied models when taking more and more factors determinant of phenomena occurring in kinematic pairs of the system, especially in transient states of the operation of a machine, into account. It seems that a method consisting in incorporation of control units into a coupling loop of electromechanical systems allows the level of vibroacoustic signals, generated by a machine, to be lowered in a simpler way. An active or semiactive control of dynamic phenomena occurring in the drive system involves the necessity of supplying of additional energy to the system. Especially, this is a case when short time-constants of functioning of a vibration reducing system are required. When aiming at obtaining of the system characterized by a low level of vibration, high durability and reliability and by a low energy consumption, it is necessary to tune a mechanical subsystem, an electrical subsystem as well as an electronic subsystem which controls the drive system. The selection of dynamic properties must be aided by optimization-oriented procedures to make the selection effective.

The paper presents problems relating to modelling, sensitivity analysis and optimization of a high-power electromechanical drive system with an induction motor, when considered from the mechatronic point of view. The investigations covered the mining machine`s drive system composed of a squirrel-cage motor, a toothed gear and planetary gear to which a vector control unit is applied.

MODEL OF AN ELECTROMECHANICAL DRIVE SYSTEM

An electromechanical system with a control unit is a system of complicated structure and variable parameters. Therefore, it is difficult to describe exactly the dynamic phenomena occurring in the system. The assumed physical model and the mathematical model serve for describing of an electric subsystem and a mechanical subsystem as well as of a control unit. A model of the electrical part has been considered as a monoharmonic model and as a polyharmonic one with one or several harmonics of the field in the motor`s air-gap being taken into account, respectively. The mechanical gear has been modelled by means of the hybrid finite element method and stiff finite element method. Owing to such an approach to the problem, it was possible to develop a spatial model of transverse torsional vibrations of a gear when taking the flexibility of shaft bearings into account. Numerical calculations were made in the MATLAB/SIMULINK environment.

SENSITIVITY ANALYSIS AND OPTIMIZATION

The sensitivity analysis is suitable for aiding the procedure of selecting of design features of the system and allows exactitude of the applied models to be improved. However, solving of the mathematical model of the system, which depends on the selected decision variables, is a prerequisite. A method of direct differentiation has been employed in the paper, because the algorithm used is relatively simple and the method makes it possible to calculate derivatives and to solve the model at the same time. It is possible to carry out the analysis of sensitivity and optimization, among others, for an objective function described in the time domain, e.g. for time courses of dynamic forces

$$\psi = P^2(\boldsymbol{b},t)$$

where: P - calculated value of a dynamic force in the selected kinematic pair of the system, $\boldsymbol{b}$ - set of design variables, t -time

This problem needs solving of differential equations of motion of the system and encounters difficulties involved in the necessary analyzing of a time-varying objective function. Nevertheless, the so formulated problem allows phenomena of energy dissipation, the state of external load and the effect of coupling between the electrical drive and the mechanical part to be taken into consideration during calculations. This method can be applied to minimize vibration amplitudes of electromechanical drive systems in transient states (starting-up, sudden change of load) so that the obtainment of steady state within the minimum time is assured. The objective of investigations has been achieved through minimizing of maximal values of instantaneous dynamic reactions in the selected kinematic pair:

$$Min \;\; \psi_{max}$$

where: ψ - objective function

The discussed optimization problem, described in the time-domain, is of MinMax type and consists in minimizing of the maximal values of the objective function. Evolutionary algorithms served as a tool for finding the optimum parameters of dynamic systems.

RESULTS OF NUMERICAL CALCULATIONS

The performed numerical calculations embraced simulations of functioning of the system when being started and when operated under steady-state conditions. The obtained time courses of generalized coordinates of a model of the electrical and mechanical part were used to determine dynamic forces in kinematic pairs and the power absorbed from the supply network. Sensitivity of the course of dynamic forces in kinematic pairs of the drive with regard to electromagnetic parameters of the motor was investigated with the aid of the model of torsional vibrations of a gear incorporating a monoharmonic model of an induction motor. It has appeared that parameters of the electric motor have a considerable effect on maximal values of dynamic forces in all kinematic pairs of the gear, especially in transient states. Simulations have also been carried out for a spatial model of transverse torsional vibrations and for a polyharmonic model of the induction motor with a vector control unit. The objective of the optimization problem was to minimize maximal values of the electromagnetic moment of a driving motor.

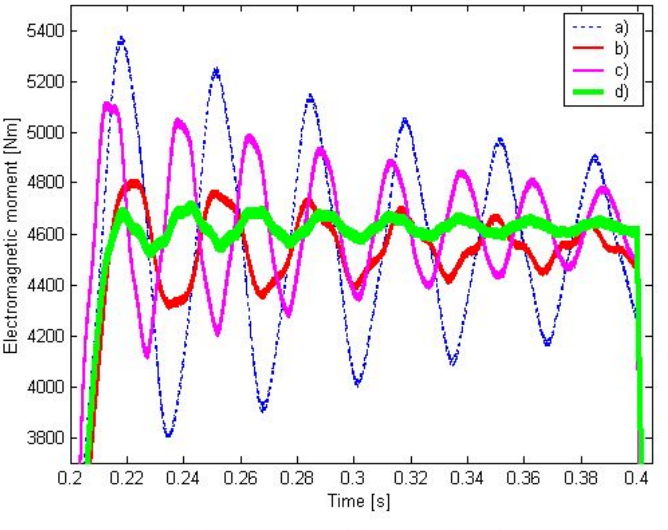

Figure 1. Electromagnetic moment of a driving motor with control unit versus time. Results of calculations for an electromechanical model: a) with preliminary selected settings of a control unit, b) after optimization of settings of a control unit, c) with a control unit before optimization and optimized some parameters of mechanical part, d) optimized control unit and parameters of a mechanical part

According to a variant of calculations, the set of design variables contained separately or jointly parameters describing design features of gear shafts, settings of control units. Numerical simulations have proved that when parameters of the mechanical part and those of the control unit are taken jointly into consideration, the maximal values of dynamic reactions are much lower than the maximal values obtained when a vector control unit of the driving motor is applied (see Figure 1).

CONCLUSIONS

Designing of electromechanical drive systems of machines characterized by the required dynamic properties is a complex problem that needs formulating of developed mathematical models. Results of the performed investigations have indicated that the application of a control unit, that has an active effect on changes of dynamic forces in kinematic pairs of the system, can assure a low level of vibrations. It is evident that when all subsystems are tuned one to another the best results can be obtained in respect of lowering of the vibration level, reducing of energy consumption and improving of durability. However, there is a necessity to aid such investigations by optimization procedures.

References

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