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ANALYSIS AND MODELING OF DYNAMIC PROPERTIES OF INTERACTIVE DRIVE SYSTEM

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The recent drive systems are considered as interactive systems containing a range of subsystems with different physical nature. This contribution deals with the modelling of mechatronic drive systems using numerical package DYNAST. The theoretical general observations are demonstrated on particular experiments on real system.

Key words: drive system, experiment, modelling, DYNAST

Analiza i modeliranje dinamičkih svojstava interaktivnog pogonskog sustava. Moderni pogonski sustavi smatraju se interaktivnim sustavima koji sadržavaju podsustave različitih fizikalnih svojstava. Ovaj document prikazuje modeliranje mehatroničkog pogonskog sustava korištenjem numeričkog paketa DYNAST. Načelna teorijska razmatranja demonstrirana su pomoću konkretnih eksperimenata na realnom sustavu.

Ključne riječi: pogonski sustav, eksperiment, modeliranje, DYNAST

INTRODUCTION

This contribution shows the solution of mentioned problems during the analysis of particular technical systems with tooth wheels and gears. To model and simulate such systems it is necessary: a) to create objective and partially structured model of basic mechanical structure; b) to create at least simplified models of meshing conditions, transfer functions and kinematic excitation for tooth wheels and gears; c) to create model of surrounding environment; d) to formulate the concept of drive system control and e) to propose the way of integration of basic drive structure, surrounding environment and control.

SYSTEM METHODOLOBY AND ITS USE IN DRIVE SYSTEMS MODELLING

The system approach is usually understood in narrower concept than its real content. The most often its reduced only to structural object examination, object-object and object-environment linkage consideration -and target behaviour formulation. Sometimes only the creation of relevant quantities system is considered as system approach. In detail one can find the information about these problems in [1-3], we will consider only simplified limitations. Together with necessary understanding of object structure we recommend at least its intention consideration. That means that during the selection of structures elements, its properties and outputs, linkage and interaction selection its essentiality determination is the most important. Among other attributes of system approach which we recommend to consider is the requirement to examine the objects as open (non-isolated) systems with the linkages and interactions with the environment, as complex and interdisciplinary problems and as hierarchic organized structures. Oriented examination respecting the preservation of substantial relations input-output, cause-consequence, or superior solution - specific solution, time dependent dynamical examination and level balanced examination are considered as inevitable, if we want to work on the current - level of science and technology.

Various types of modelling not just the technical systems itself but its behaviour, dynamic properties and environment effects appear to be the most progressive. The basic step during dynamic tasks solution using arbitrary type of modelling is creation of essential variables set, containing variables describing the structure, states and effects on technical objects and also variables describing the effects, that means its expressions and behaviour.

Methods for mathematical modelling of drive system, interactive in general can use:

– applications of known physical principles for description of phenomenon appearing in drive systems (e.g. II. Newton's law, Kirchhoffs law, etc.), or
– application of mechatronics methods based on artificial intelligence algorithms (e.g. genetic algorithms, neural networks, etc).

Its clear that modelling of particular technical system must respect general recommendations mentioned

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above and at the same time it has to consider the particularities coming from the given system requirements definitions and its purpose. In drive system we have to consider that the systems primary purpose is to work as the drive for working machines. We can see that the drive as independent structural subsystem is connected with certain other subsystems, which must be considered in corresponding model.

That means that our aim is to create certain submodels of: electrical (hydraulical) parts of the motor, mechanical parts (motor, gearings, clutches), working environment model, technological requirements model.

That means that we must build: a) equations of motion of particular subsystems of the drive according to its physical principle, that means for mechanical part, electrical part, control, etc.; b) for gearing subsystems create at least models of gearing conditions and kinematic excitation; c) model of surrounding environment effects; d) model of algoritmized requirements of technology and control and integrate those into control submodel; e) formulate and model driving, parasitic and malfunction effects and finally f) model subsystem of information elements.

PROCEDURE FOR DESIGN AND CONTROL OF SYSTEM

The design procedure for designing a control system is an orderly sequence of steps. Good engineering design is interdisciplinary and requires that the engineer first thoroughly understand the requirements of customers, the defined control system specifications, the environment that the control system will operate in, the available power, the schedule that it must be built in, and the available budget.

Due to the availability of a large number of techniques to solve the great variety of control system problems present, the element of experience is very important to the approach used for the solution of a specific problem.

1. Obtain a complete understanding of the job requirements with respect to: a) general description of the problem; overall control-system performance and accuracy with respect to the steady-state and transient phases; b) identification of the transfer function of the controlled process; c) miscellaneous requirements as to reliability, schedule, cost, maintainability, size, weight, and available power.
2. Consider several alternative solutions, including electric and hydraulic power servo drives, the use of continuous control or digital control, etc.
3. Choose the most desired approach based on the specifications, requirements, and elements fixed by the customer.
4. Interpret these requirements in terms of such closed-loop design characteristics as frequency and transient response.
5. Establish the approximate open-loop characteristics that will satisfy the closed-loop requirements.
6. Design the system and select the sensors, actuators, amplifier, and stabilization required (analog or digital) in order to satisfy step 5.
7. Review, refine, and simplify steps 5 and 6.
8. Simulate the system on a computer, including its linear and nonlinear characteristics, to check the design. Make any necessary changes to the design.
9. Build a prototype, and check the design experimentally. Make any necessary changes to the design.
10. Refine the design in order to optimize performance and minimize cost.

EXAMPLE: REAL DRIVE SYSTEM AND ITS MODELLING

In following text we will analyse the behaviour and dynamic properties of the real electromechanical drive system with controlled DC motor shown in Figure 1.

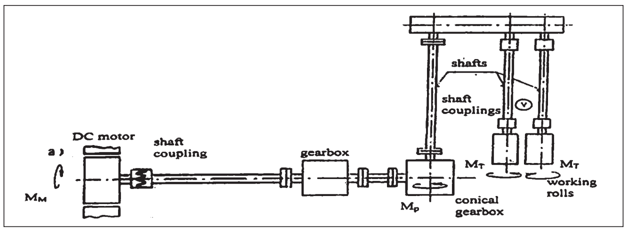

Figure 1. Real drive system

Figure 2 shows idealized drive systems. The system consists of motor subsystem, transimission subsystem and technological subsystems. The model of drive motor control is shown in Figure 2c and model of superior technological regulation is shown in Figure 2b.

The model of mechanical subsystem, discretized with concentrated parameters and non-linear couplings is shown in Figure 2a. Its parameters are as follows: I_1=950 kg·m^2; I_2=55 kg·m^2; I_3=I_4=120 kg·m^2; k_{21}=1.75 N·m/rad; k_{32}=1.97×10^7 N·m/rad, couplings allowance 0,01/0,015 rad. Load levels: impulses 10 % of medium value of driving torque; kinematic load and noise max 25 % and 5 % of medium value of driving torque; impulse duration 0.01 sec, its frequency 1 and 10 [Hz], kinematic load frequency 28.5 Hz.

MATHEMATICAL MODEL

The mathematical model of drive system is formulated using state vector

$$x(t) = [x_M(t), x_R(t)]^T,$$

where vector x_M defines the quality of mechanical subsystem and vector x_R defines parameters of the motor and control circuits. Vector x_M is defined by means of

$$\mathrm{x(t)} = [\varphi(\mathrm{t}), \dot{\varphi}(\mathrm{t})]^{\mathrm{T}},$$

where $\varphi(t)$ represents the relative angular replacements of mechanical parts of reduced model. The state equation and output equation are expressed in the following form:

$$\dot{\mathrm{x}}(\mathrm{t}) = \mathrm{h(x(t),\ u(t),\ t)}$$

$$\mathrm{y(t)} = \mathrm{g(x(t),\ u(t),\ t)}$$

where u(t) is the vector of the input quantities.

PARASITIC EXCITATION AND ITS MODELS

We can divide the parasitic excitations of drive system into two groups:

– first group represents the kinematics excitation (so called stress kinematics excitation). These matters were discussed in our articles [4, 5].
– second group represents balanced signal of motors feedback circuit.

DRIVING KINEMATIC EXCITATION

DC motor produces periodic torque, which acts onto motor's rotor. The cause of rising of this moment could be a periodic fluctuant signal on the output of motor feedback angular velocity sensor. The frequency of periodic driving moment is given by angular velocity ofsensor's shaft.

Modeling function must involve real shape from practical measuring and this function must have a definite mathematical definiction. In our case, the modelling function is $\sin^2\varphi$, so parasite stress moments are described by expression:

$$\mathrm{M(t)} = M_0 + \mathrm{M}\sin^2\varphi\left[\frac{\pi}{\alpha}\varphi(\mathrm{t}) - \varphi_0\right]$$

$$2k\pi \le \varphi(t) \le \alpha + 2k\pi,\ k = 0, 1, \ldots$$

where $\varphi(t) = \int\limits_0 \omega(t)\mathrm{d}t$ is angular defection and $\omega(t)$ is spot angular velocity of rotating parts.

NUMERICAL RESULTS

The courses of directive torques depending on time in particular couplings of the drive model structure are shown in Figure 3. We can found the states in which the peak load torques appear and its characteristic courses and conditions under which the "disconnection" of the particular couplings appear.

The representation of transient responses in phase plane enables the detail study of transient phenomena. As the example we show the phase diagram in places 2 and 3 in which one can see the limit cycles (characterizing parasitic vibration on "free space borders" and transient trajectories) shown in Figure 4 a, b.

The size and the range of limit cycles characterize the level of parasitic phenomena which complicates the control of angular speed. It can be limited to the certain level by suitable selection of control parameters. At the same time the courses of transient trajectories can be influenced mainly by eliminating the uncontinuousness and rapid changes. This operation is called qualitative analysis of dynamic properties.

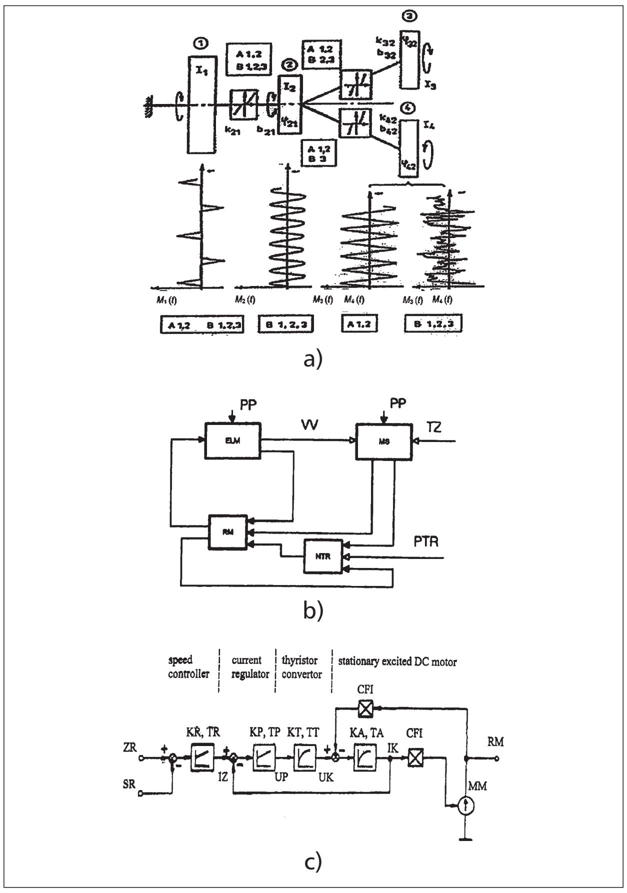

Figure 2. Model of complex drive system (ELM - electric motor, MS – mechanical subsystem (transmissions and working machines), VV - power coupling, RM - motor control, PTR – requirements of technological regulation, PP - failures, noise, TZ – techhnological load)

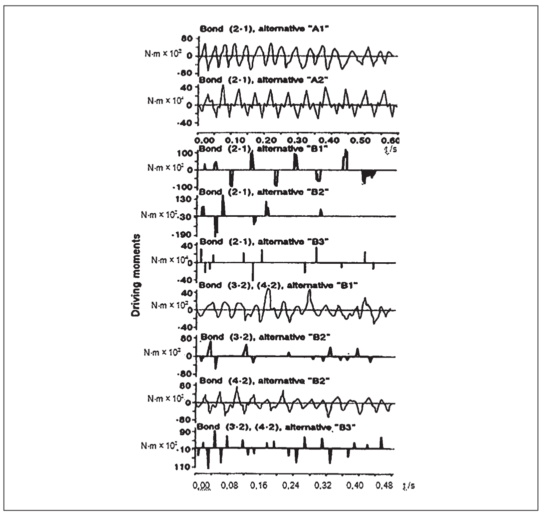

Figure 3. Time dependending of directive torques

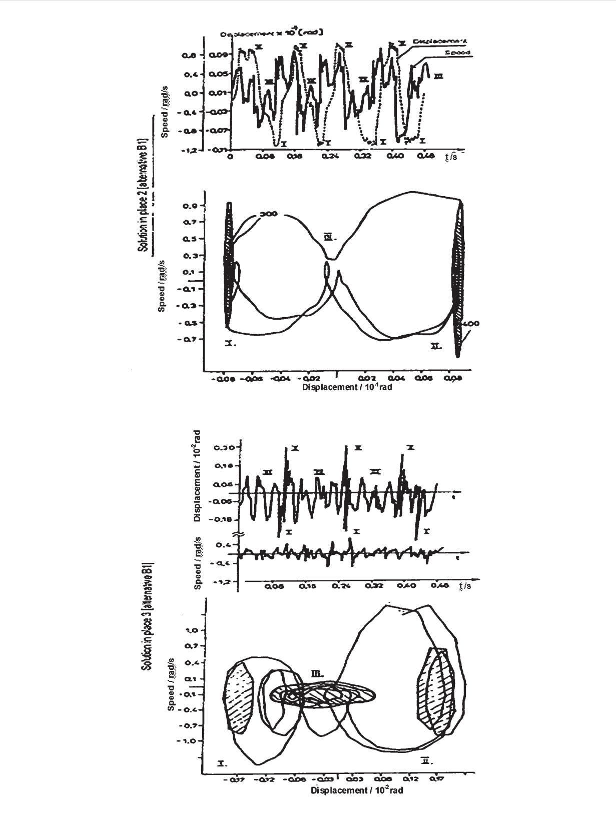

Figure 4. Transient responses of system

CONCLUSION

In this contribution we described general requirments for the analysis of dynamical properties of real drive system using numerical simulations of their models. The numerical package DYNAST was used.

Problems of design of dynamic drive system with toothed gearings and simulation of its dynamical properties is extremely broad and complex. Today's drives represent interactive systems with elements or subsystems of various physical principles. Therefore we limited the contribution onto selected problems including basic thoughts connected with creation of the model, its function and control.

Let us finaly summarize:

– The pass from real technical system towards model system is possible after selection and formulation of those properties of real system, which are characteristic for required functions satisfaction and therefore must be performed by the model system.
– Only model system which is essentially simpler than real system Is worth, and mainly the system which enables creation of computational and computer models.

More and more often one can see the design and modelling "in variants", based on sequential creation of models or different complexity which are then used for performing simulation experiments with the aim to select the model as simple as possible, but keeping given requirements.

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