The Simulation of Electromechanical Drive with DC Motor

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Abstract: The presented paper is outgoing form the mechatronic conception of structure of the electromechanical drive (EMD). A goal is the identification and modelling of electromechanical drive with separately excited DC-motor, identification of the driving part, controlled part and of mechanical part of real electromechanical gear is realized. A system of differential equations formulating mathematical model is put into the Laplacean transformation and a new mathematical computing model in the MATLAB-SIMULINK environment is created. Simulating experiments including the analyses of influence of the moment of inertia changes of motor on the transient curve ω_m of EMD.

Key words: electro-mechanic drive, modelling, identification, simulation experiment.

1 Introduction

The present-day electro-mechanic drives (EMD) are presenting complicated technical systems with a very closed linkage between the electrotechnical, microelectronic, mechanical and technological part. A quicker response to intervention of control, precise positioning and cutting-off, steady and stabilized run, energy-saving and operational effectiveness are required from modern (EMD) electro-mechanic drives.

However, increasing of the EMD dynamics at the mechanical parts is calling into necessity of resolving problems coupled with the increased "vibrating". Spontaneous mechanical vibrating increases noisiness and failure rate, especially then of bearings, clutches and gear boxes, or cause sparking on the bursts of direct current engines and is giving rise to a higher probability of processed material damage in the mutually coupled EMD (for example in the textile industry, metallurgy or in the paper mills).

Technical and economical requirements posed on the EMD are possible to be preferably met, when a mechatronical conception considered acording to Fig.1.

The Fig.1 shows the concrete mechatronical context between an optimal controlled transformation of primary energy and information in the required technological effect.

1.1 Previous work

This work follows up a project of parts textile maschine parameters optimalization. The purpose of the work is to optimize construction of these electrical and mechanical machines parts.The optimalization is executed on computers models with using mechatronical access for model formulation. Concrete recommendations for constructional changes flow from simulation experiments. For example a drive of shuttle was optimized this way. The following text shows the principle of the textile coiling EDP model formulation and presents ilustration of the simulation experiment.

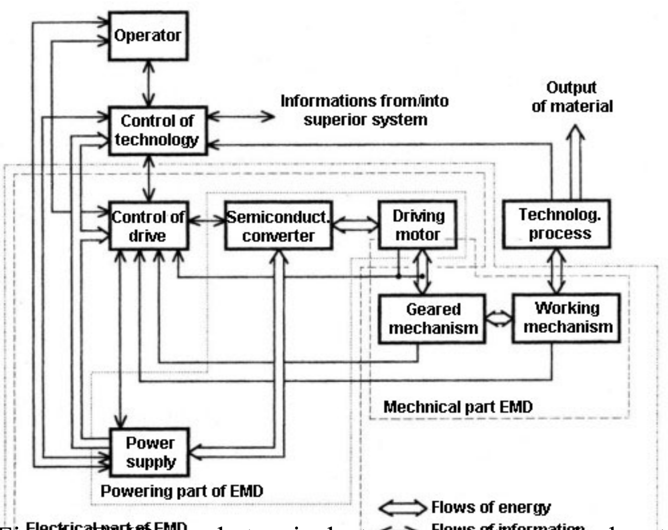

Fig. 1. EMD mechatronical structure with marked out the flows of energy and information (the feedbacks included).

2 Problem Formulation

2.1 The System EDP

In order to analyse a real object, the system of following structure is to be defined:

Controlling part - is presenting a subsystem of angular velocity control of DC-motor and of field and armature currents. The measuring subsystem includes the angular velocity measuring of motor, measuring of field current and armature voltage of the DC-motor. The controlling part is realized in analogue, however a digital version is possible to be considered, too.

Powering part:

a) Power supply – two three phase transformers with two windings and smoothing choke

b) Semiconductor converters - 6-pulse-2-quadrant-drived armature circuit rectifier and 6-pulse and 2-quadrant driven rectifying excitation circuit

c) Driving motor – separate excitation DC-motor ŠKODA 33 ASY 5452F/8. The parameters of driving motor are determined by measurement and obtained from the manufacturer and stated in the Table 1.

Pm = 1100kW	ωmax = 94,25 s^{-1}
Uan = 750V	Ra = 0,373 Ω
Ian = 1600A	C.Fi = 19,43Wb
ωnm = 30,37 s^{-1}	Jm = 975kg.m^2
Overload 2720A/15s max.	

Table 1. Technical parameters of ASY motor

Working mechanism - Three mass torsion system, elastic couplings without backlash, the working mechanism is not connected with other mechanical parts of neighbouring EMD be means of any material (see Fig.3).

2.2 Mathematical Model of Motor

The identification of required parameters for a mathematical model reflecting all electromagnetic contexts should require extended and complicated measurements. It is possible to state on the base of experiences that advanced costs for creation of models have not been for the most part proportional to increased precision of the models. This is a reason why these facts, if the technical practice of creating the models to DC-motors considered, have been vanished. They are:

- Leakage flux of exciting winding
- Influence of reaction of armature (ASY motor is a compensated engine)
- Mutual transformational incidence of individual windings
- Influence of eddy currents in the magnetic circuit
- Voltage drop on the collector mechanism of the motor

When formulating the model, we consider the DC-armature circuit, exciting circuit and mechanical circuit each separately. Forasmuch as the control of motor is to be an object of our interest, the appropriated differential equations will be put into the Laplacean transformation an the resulting model DC will make a block diagram ac-cording to the fig. Nr. 2 where the individual transmission functions are of following purpose:

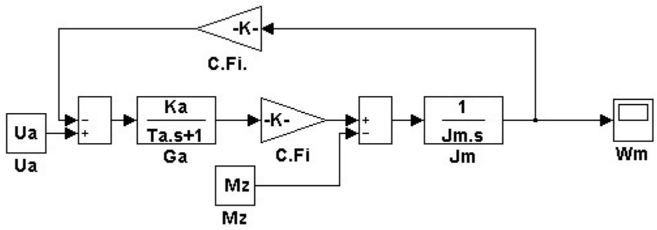

Fig. 2. A bloc diagram of the DC-motor with separate excitation

2.2.1 Mathematical model of controlled rectifier

No exact substitute model of controlled rectifier with thyristors, which would make possible an analytic solution of controlling circuit , is known at the present time. It has been given by discreetness and imperfect controllability of used thyristors. For our needs, we meet both ends meet with the linear dynamic approximation in the form of transfer:

$$G_t(s) = \frac{U_{si}(s)}{U_r(s)} = \frac{K_t}{T_t s + 1} \qquad (1)$$

Where U_{si} (s) [V] is the mean value of controlled rectifier measured voltage (in Laplace-transformation)

U_r (s) [V] is the controlled rectifier control voltage

2.2.1 Identification of EMD control parts

PI angular velocity controller is realized by means of an operation amplifier with the following transfer function

$$G_{R\omega}(s) = \frac{I_a(s)}{E_{R\omega}(s)} = \frac{K_{R\omega}(T_{R\omega} s + 1)}{T_{R\omega} s} \qquad (2)$$

Where Erω(s) is the Laplace image of angular velocity controlling deviation.

The total transfer of serial wired P controller of control variable deviation of the armature current and the PI armature current controller are:

$$G_{RI}(s) = \frac{U_r(s)}{E_{Ia}(s)} = \frac{K_{RI}(T_{RI}s + 1)}{T_{RI}s} \qquad (3)$$

Where $E_{ia}(s)$ is deviation of the armature current.

2.2.3 Angular velocity sensing device

Measuring of angular velocity ω_m of motor is to be realized by means of impulse sensor where its frequency output is transformed on the analogue value ω_{ms}. The system for angular velocity measuring is modelled as an inertial block of first order with the transfer:

$$G_{\omega m}(s) = \frac{\omega_{ms}(s)}{\omega_m(s)} = \frac{K_{\omega m}}{T_{\omega m}s + 1} \qquad (4)$$

2.2.4 Measuring system of armature current

The appropriated transfer will be considered in form:

$$G_{mIa}(s) = \frac{I_{as}(s)}{I_a(s)} = \frac{K_{\mathrm{Im}}}{T_{\mathrm{Im}}s + 1} \qquad (5)$$

Where Ia(s) is Laplace – image of measiring armature current.

2.2.5 Identification of flexible coupling of motor with a working mechanism

We consider a system "motor - working mechanism" with three degrees of freedom, where a rotor disc and two discs of working mechanism are included, and the elastic coupling will be without play – see the Fig.3.

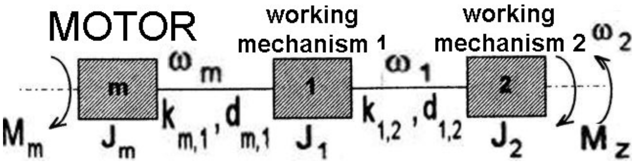

Fig.3. Elastic coupling

The following equations of motion are true for this mechanical system:

$$J_m.\frac{d\omega_m(t)}{dt} = M_m(t) - M_{m,1}(t) \qquad (6)$$

$$M_{m,1}(t) = k_{m,1}.\int_0^t [\omega_m(\tau) - \omega_1(\tau)].d\tau + d_{m,1}.[\omega_m(\tau) - \omega_1(\tau)] \qquad (7)$$

$$J_1.\frac{d\omega_1(t)}{dt} = M_{m,1}(t) - M_{1,2}(t) \qquad (8)$$

$$M_{1,2}(t) = k_{1,2}.\int_0^t [\omega_1(\tau) - \omega_2(\tau)].d\tau + d_{1,2}.[\omega_1(\tau) - \omega_2(\tau)] \qquad (10)$$

$$J_2.\frac{d\omega_2(t)}{dt} = M_{1,2}(t) - M_z(t) \qquad (11)$$

3 Problem Solution

A bloc diagram of the complete model in the MATLAB-SIMULINK environment is presented on the Fig. 4.

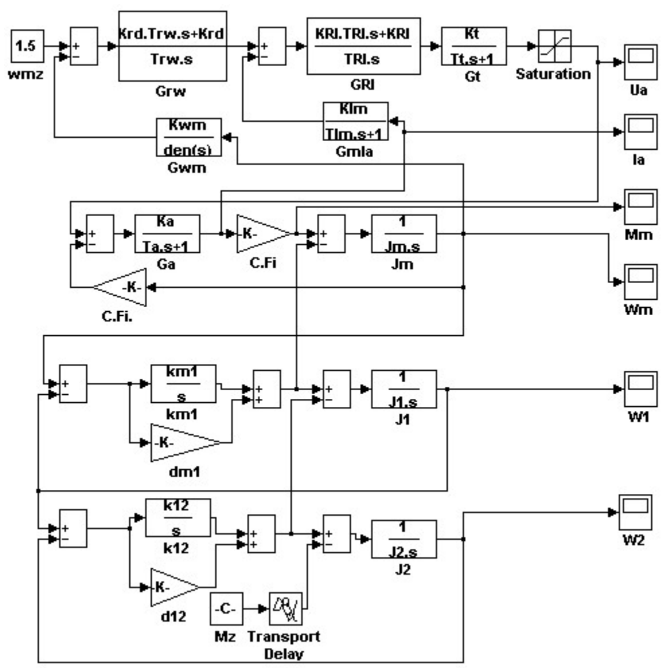

Fig. 4. A bloc diagram of the complete model

Calculating of constants for a mathematical model of elastic coupling of motor with the working mechanism (see in Table 2).

$G_{R\omega}$	$K_{R\omega} = 17{,}9$
	$T_{R\omega} = 0{,}18$ s
G_{RI}	$K_{RI} = 2$
	$T_{RI} = 1{,}9$ s
Gt	Kt = 101,2
	Tt = 0,00167 s
G_{mIa}	$K_{mIa} = 0{,}0037037$
	$T_{mIa} = 0{,}003$ s
$G_{\omega m}$	$K_{\omega m} = 0{,}106103$
	$T_{\omega m} = 0{,}018$ s
Ga	$Ka = 2{,}28\ \Omega^{-1}$
	Ta = 0,152 s
$J_1 = 182{,}2$ kg.m^2	
$J_2 = 4{,}5$ kg.m^2	
$J_m = 975$ kg.m^2	
$d_{m1} = 17{,}67.10^3$ Nms.rad^{-1}	
$d_{12} = 0{,}326.10^3$ Nms.rad^{-1}	
$k_{m1} = 17{,}67.10^6$ Nm.rad^{-1}	
$k_{12} = 0{,}326.10^6$ Nm.rad^{-1}	
Mz = 10000 Nm	

Table 2 Constants for a mathematical model

A simulation experiment has been realized for the entered parameters (see Table 2). The input of the model was supplied with a step change of the required angular velocity and a transient curves of output angular velocity and of the motor current at diverse torque moments J_m have been monitored. For J_m = 100 kgm^2, the out put voltage behaviour of controlled rectifier Ua. In the course of simulation at the time t = 7s, the load of M_z = 10^4 Nm has been added to the motor. The appropriated transient curves are represented on the following figures.

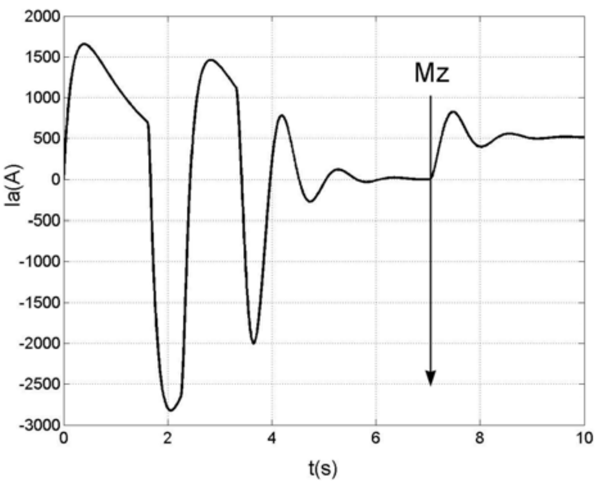

Fig.5 Transient response of motor current for Jm = 1200kg.m^2

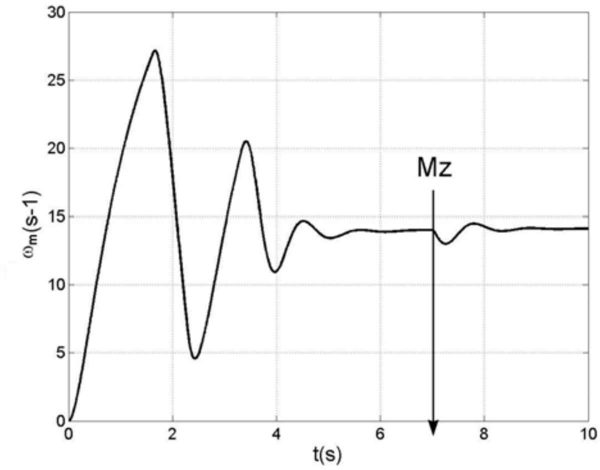

Fig.6 Transient response of angular velocity for Jm = 1200kg.m^2

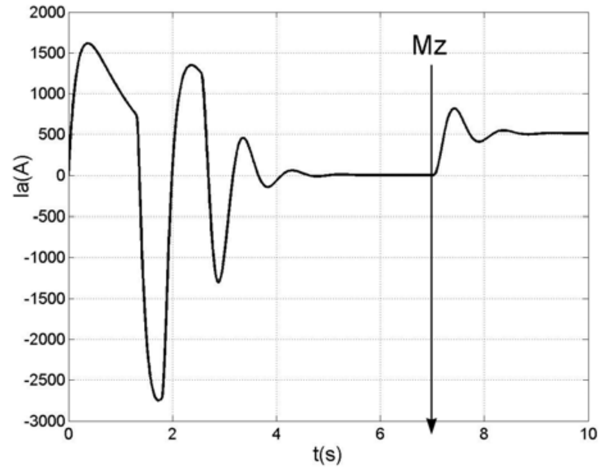

Fig.7 Transient response of motor current for Jm = 975kg.m^2

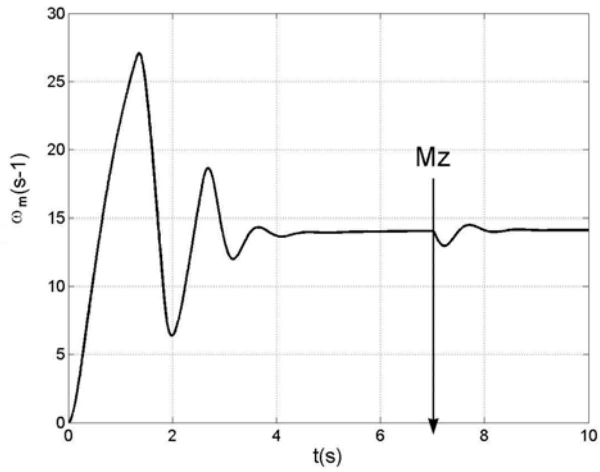

Fig.8 Transient response of angular velocity for Jm = 975kg.m^2

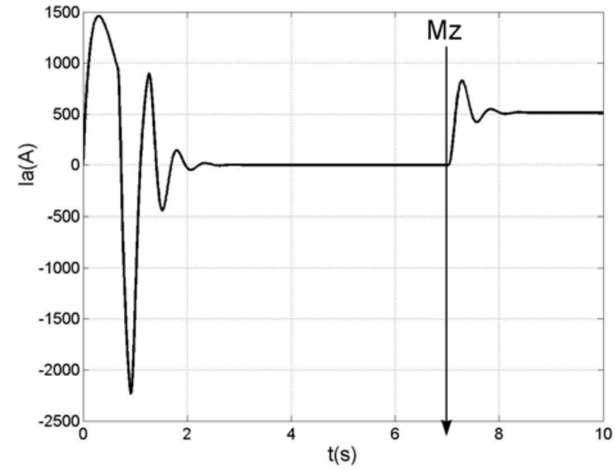

Fig.9 Transient response of motor current for Jm = 400kg.m^2

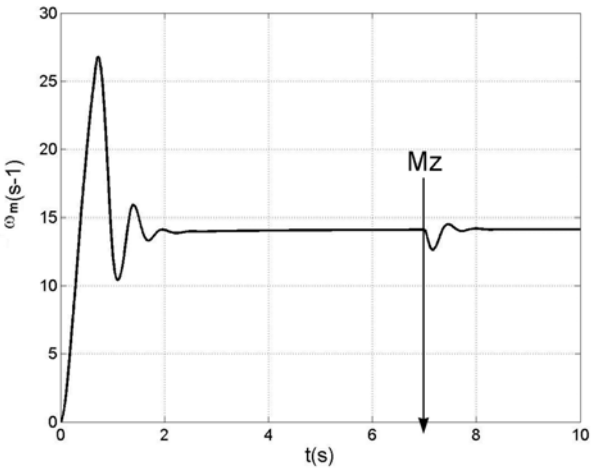

Fig.10 Transient response of angular velocity for Jm = 400kg.m^2

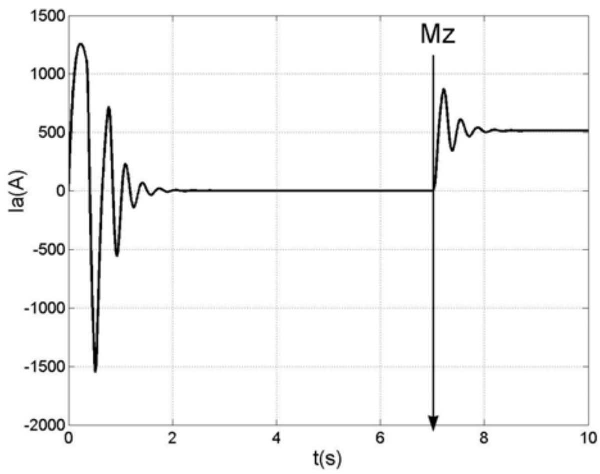

Fig.11 Transient response of motor current for Jm = 100kg.m^2

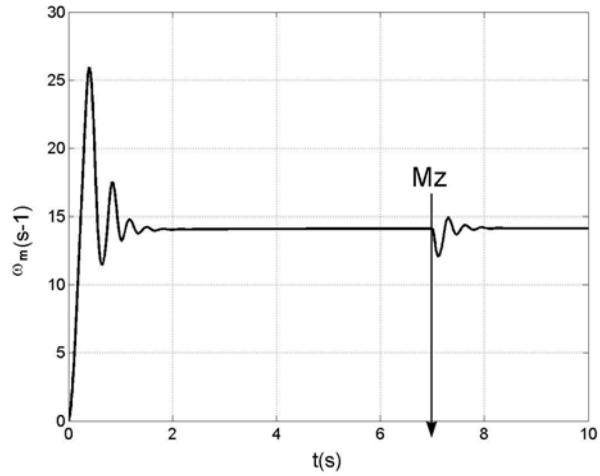

Fig.12 Transient response of angular velocity for Jm = 100kg.m^2

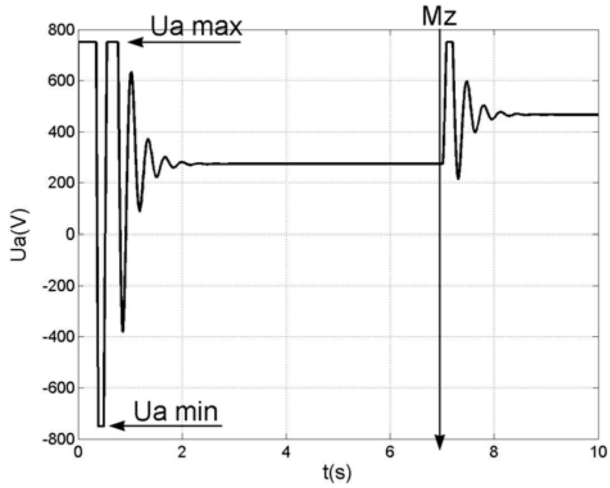

Fig.13 The voltage distribution of the controlled rectifier for Jm = 100kg.m^2

It is shown that the transient response for J_m = 400 kgm^2 has at least oscillating course.

Maximum overshoot values and the control time t_r have been read from the course of velocity response $\omega_m(t)$. Integral criterion of control deviation was counted, too (see Fig.14).

Better parameters of controling will be achieved by decreasing Jm of EDP as flows from curves in the picture (Fig.14). From the point of view of the transient response characteristic oscillation is the most optimal Jm about 400kgm^2. It is possible to recomend mechanical adjusting of the drive. It is also possible to improve the parameters of controling for example by the appropriate choice of different type of the control unit. This possibility is economicly preferable for achieving the same parameters, but this solution is beyond the frame of this article.

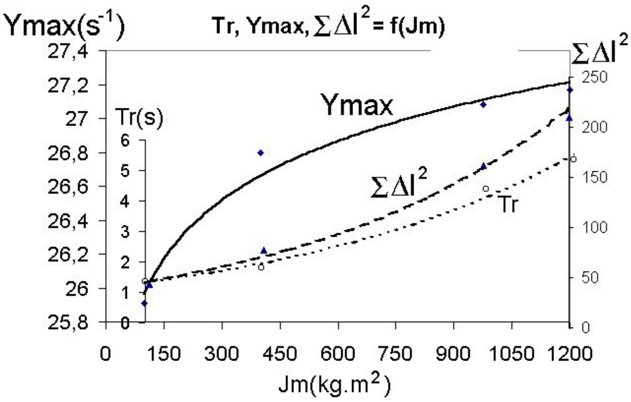

Fig.14 Courses of the duration of control, maximum value of angular velocity, integral criterion for various Jm.

4 Conclusion

It was created a linear model of DC-drive with the PI-control of rotational speed and the armature current of an ASY motor and realized a simulation at the concrete values of model parameters in the MATLAB-SIMULINK environment. The model is possible to be used for setting up the optimum voltage parameters of controller as well as that of current. The analysis of transient responses shows Jm reduction is necessary for beter controlling of electromechnical drive tensil force of the textile slasher sizing machine.

In a case of more precise simulation, it would be necessary to get considered a non-linear model of the motor exciting circuit.

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