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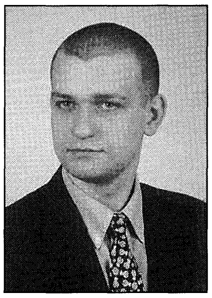
Facility for Induction Motor Velocity Control with a Magnetorheological Brake



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Jest doktorantem w Katedrze Automatyzacji Procesów na Wydziale Inżynierii Mechanicznej i Robotyki Akademii Górniczo-Hutniczej w Krakowie. Jego zainteresowania koncentrują się wokół sterowania układami mechanicznymi. Aktualnie prowadzone prace badawcze dotyczą wykorzystania hamulców magnetoreologicznych w układach regulacji automatycznej oraz wykorzystania logiki rozmytej do celów sterowania i diagnostyki. Jest autorem projektów wdrożonych w przemyśle oraz kilku zgłoszeń patentowych.

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Streszczenie

W artykule przedstawiono stanowisko badawcze do testowania możliwości wykorzystania hamulca magnetoreologicznego (MR) w układzie regulacji prędkości obrotowej silnika indukcyjnego. Silnik indukcyjny sterowany jest za pośrednictwem przetwornicy częstotliwości. Do pomiaru położenia wału zastosowano enkoder przyrostowy. Układ regulacji składa się z komputera PC wyposażonego w kartę pomiarowo-sterującą RT-DAC. Sterowanie układem zrealizowano w środowisku programu Matlab/Simulink. W artykule opisano parametry i charakterystyki hamulca MR oraz budowę i działanie stanowiska badawczego. Pokazano również przykładowe wyniki badań eksperymentalnych.

Abstract

The paper presents the facility which was developed for testing velocity control system with induction motor and magnetorheological (MR) brake. The induction motor was equipped with frequency inverter. An incremental encoder was used to measure rotation velocity. The control system consisted of PC with multi I/O board of RT-DAC type, operating in Matlab/Simulink environment. The paper describes parameters and characteristics of MR brake, construction and operation of the experimental setup and exemplary results of control system tests.

Key words: MR brake, velocity control, facility, induction motor

1. Introduction

Investigations under MR devices like brakes and linear dampers, tests of usage them as an auxiliary part of control systems [1, 2, 3] and in mechanical vibration damping systems [5] shows, that these devices, in spite of nonlinear characteristics and expensiveness, can be successfully applied in automatic control systems. Experiments are also conducted in Department of Process Control* in the field of mathematical modeling, structure and control [4, 5, 6]. Advantages of MR brakes, clutches and dampers are: fast acting, reflexivity of MR fluid transformation, low static friction coefficient, low power consumption and fluent torque or force control [12].

Viscosity of MR fluid depends on magnetic field strength. Moving parts of MR devices (rotor and stator in brake or piston and cylinder in linear damper) are mechanically connected with each other with the help of MR fluid. Resistance caused by fluid depends on it's viscosity. Viscosity changes with the current flowing through the coil.

Because of high inertia of rotor (for example in comparison to DC motor of same power), braking and acceleration time of induction motor is longer that for other kind of drives. Due to this, dynamic properties of drives, that uses induction motors are impaired. On the other hand, usage of induction motor is explained by low price and long durability

Induction motor coupled with MR brake allows to control rotation velocity not only by use of frequency inverter but also by change of resistance torque. The main goal of facility creation is to test control algorithms obtained in simulation tests.

During the design of experimental setup two assumptions were made: motor torque must be lower than MR brake torque and rotation speed of motor can be changed from zero to maximum rotation speed of brake (1000 rpm).

2. Structure and operation of MR brake

Structure of MR rotary brake was shown in Fig. 1. Structure of brake with MR fluid (8) and coil (2) enables the gap (7) to be in magnetic field H. Rotor (3) is fixed to the shaft (6), which is placed in bearings (5) and can rotate in relation to housing (4). Wires (1) allow supplying electric current to the coil.

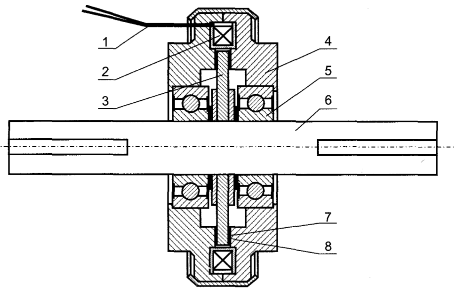

Fig. 1. Structure of MR rotary brake.

MR fluid is suspension of magnetic particles in the carrier liquid (water, oil or some other kind of liquid). Magnetic particles are dissipated in the liquid when field strength is equal to zero ($H = 0$) (Fig. 2.) but when the field strength is greater than zero ($H \neq 0$) then particles are magnetized, gather in chains and make liquid flow through them to be more difficult. Direction of chains is parallel to magnetic field lines.

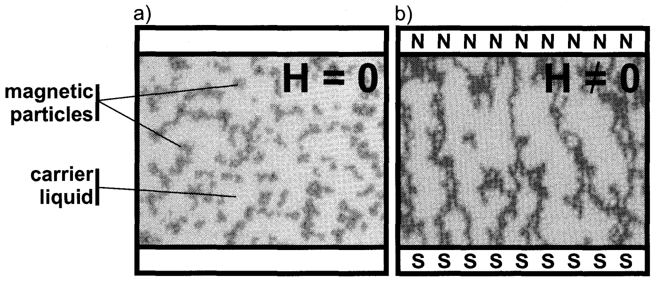

Fig. 2. Behaviour of MR fluid a) $H = 0$, b) $H \neq 0$

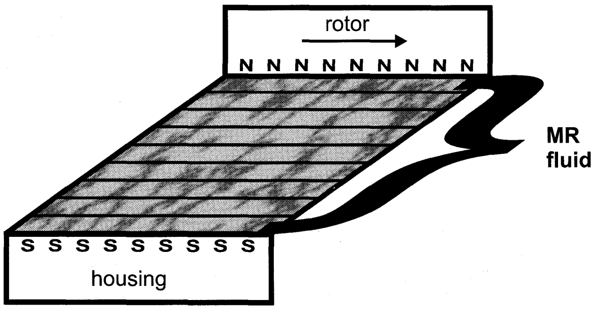

Fig. 3. Direct-sheer mode of MR fluid.

Operation of MR brake is based on so called 'MR effect' [2, 3]. MR fluid being in the gap changes viscosity very fast when magnetic field is applied. Fig. 3. shows MR fluid in the gap during working in clutch (direct-sheer) mode, when there is magnetic field applied ($H \neq 0$). Fluid is between two surfaces moving in the different directions. In the brake these are surfaces of housing and rotor. Current in the coil creates magnetic field in the gap. Value of the current can be set from 0 to 1 A. Fluid viscosity depend on the current in the coil. Viscosity of the fluid influence torque that brakes the rotor.

Fig. 4. shows the ideal static characteristic (dependence between torque M and current I) of MR brake. When the current in the coil is equal to zero, then there is no magnetic field ($I = 0 \Rightarrow H = 0$) and torque is equal to minimum M_{min}. This value is equal to the torque caused by bearings, seals and viscosity of carrier liquid. When current $I = 1$A then $H \neq 0$ and brake has highest possible value of the torque ($M_{max} \approx 5{,}65$ Nm), that is limited by maximum current in the coil I_{max} and construction of brake. Maximum electric power consumption is 12W. Maximum mechanical power dissipation ($\omega = 1000$ rpm, $M_h = 5.65$ Nm) is 600W.

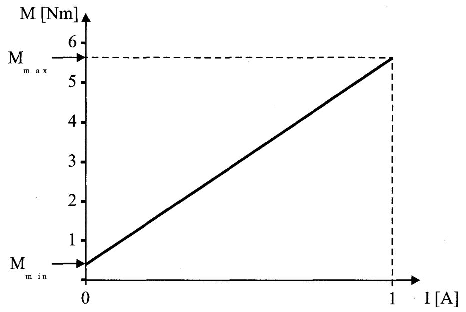

Fig. 4. Current I in the coil vs. torque M.

3. Experimental setup

The experimental setup is shown schematically in Fig. 5. and 7. It consists of hardware (mechanical and electrical subsystems) and software. Photo of mechanical subsystem was shown in Fig. 6.

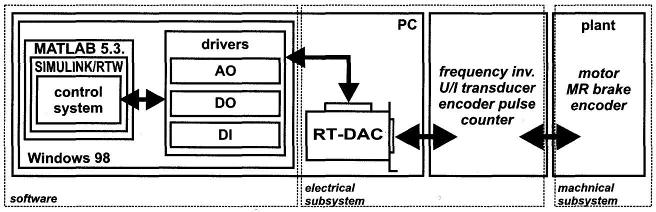

Fig. 5. Block diagram of experimental setup.

3.1. Mechanical subsystem

Induction motor (5) (rated torque: $M_n = 1.7$Nm, power: $P = 0{,}12$kW) was chosen as an actuator. Motor's shaft is coupled with brake's (3) shaft with the help of rigid or elastic coupling (4). Additional inertia load (1) is connected to the shaft of brake. Incremental encoder (6) with 360 pulses per rotation is position measuring device. Motor and brake are fixed to aluminium housing (2).

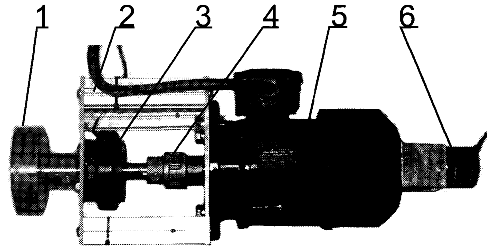

Fig. 6. Mechanical part of experimental setup. 1 - inertia load, 2 - housing, 3 - MR brake, 4 - coupling, 5 - motor, 6 - encoder

3.2. Electrical subsystem

The control system is based on PC equipped in multi I/O board of RT-DAC-2 type. Board being an interface, that connects plant with PC is universal type, that is why it was necessary to design electronic device, that counts pulses from encoder and passes number of them as 16-bit value to board though digital inputs. To obtain possibility of induction motor velocity control frequency inverter (MITSUBISHI, FR-E520S-0,75K) was used. The board is equipped in two 12-bits analog outputs. One of them is used to control frequency of electric current, that supplies motor. Second analog output is connected with current amplifier ((0 ÷ 5) V → (0 ÷ 1) A), that supplies coil of MR brake.

3.3. Software

Control system designed in MATLAB/Simulink [9] with Real-Time Workshop (RTW) environment enables to run application in real time [8] and makes possible to store measurement data.

4. Control system

The facility configuration made possible to test different kind of rotation velocity control algorithms. Diagram of control system and connection of it with plant is shown in Fig. 7.

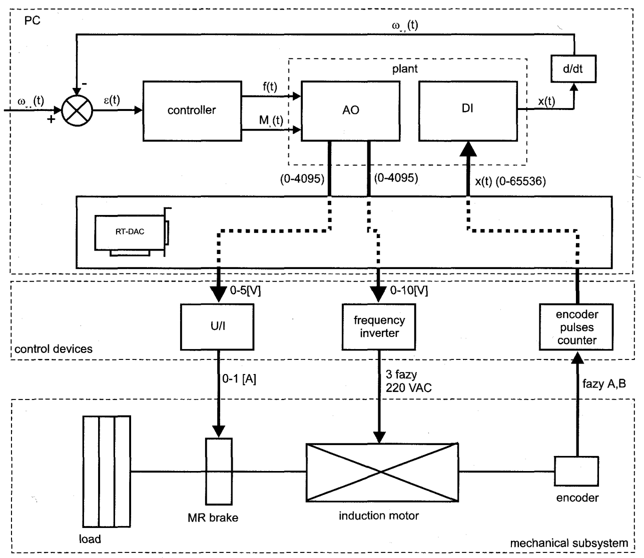

Fig. 7. Induction motor velocity control system with MR brake.

Velocity signal in calculated as a slope of a straight line, that is linear regression (calculated in real time) of four samples of position signal from encoder.

5. Exemplary results of experimental tests

Experimental tests conducted with the help of facility allowed to verify the mathematical model of induction motor [11]. Synthesis

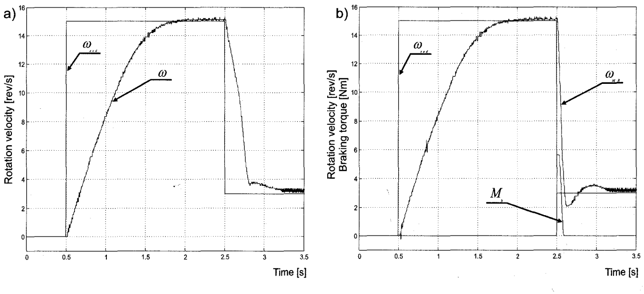

Fig. 8. Step response of velocity control systems a) without MR brake w, b) with MR brake ω_{MR}. ω_{zad} - velocity set value, M_h - braking torque.

and simulation of control system was done. Results of simulation test was verified with the help of facility.

The comparison of two control systems (without and with MR brake) was done. Time responses of two control systems to step and sin wave were shown in Fig. 8. and 9.

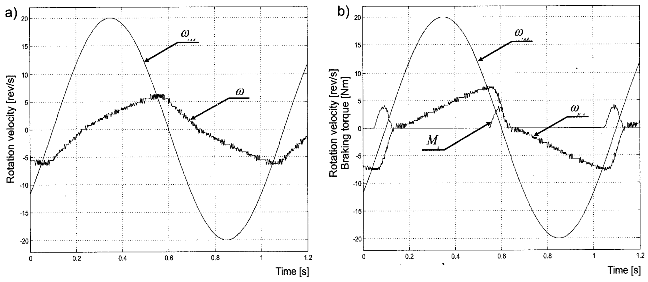

Fig. 9. Time patterns of velocity for sine excitation ω_{zad} with frequency 1 Hz for control systems a) without MR brake ω, b) with MR brake ω_{MR}. M_h - braking torque.

6. Conclusions

Experimental tests show, that preliminary assumptions taken during design process were satisfied. Facility enables to make studies over control system and is also usable for didactics.

MR brake connected to induction motor reduces setting time during rotation velocity decreasing as it is shown in Fig. 8. and 9.

Improvement of control algorithm and determining of accurate static and dynamic characteristics of brake are being planed.

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Artykuł recenzowany