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MEASUREMENT OF ELECTROSPINDLE ROTOR DISPLACEMENT

K. Gniotek and J. Zieba
Department of Clothing Technology and Measuring Systems
Lodz Technical University, 90-924 Lodz, Poland

Abstract: In the paper an induction converter for measuring the linear displacement of the individual motor-driven spindle rotor of a ring spinning frame. The motor-driven spindle rotor is drawn into the asynchronous motor stator on connecting the asynchronous motor to the supply voltage source. The rotor displacement is caused by the force acting along its rotation axis formed by the electrodynamic action of the electromagnetic field.
Keywords: individual motor-driven spindle, axial displacement measurement

1 INTRODUCTION

When the asynchronous motor of the motor-driven spindle is connected to the supply voltage source, the rotor starts rotating and is displaced along the rotation axis [3]. The spindle motor rotor displacement is brought about by an electromagnetic axial force and is caused by the skew grooves of the motor rotor, the eccentricity of the rotor position in relation to the stator and the magnetic asymmetry of the motor. The yarn being wound can cause additional unbalancing and promote the wear of the spindle bearing. This phenomenon leads to the deterioration of the yarn packing quality, an increase in the power consumption and further damage of the spindle. The problem arises from the fact that as many as 400 to 1200 spindles can be mounted on a single spinning machine and each spindle has its own three-phase asynchronous motor (Individual Motor Drive System). The spindle motor rotor can move along the axis since it suspended on the thrust bearing mounted on an elastic damper with a lubricating film, (fig. 1) [7]. The damper is used to reduce or eliminate the damper vibrations caused by an unbalanced yarn packing.

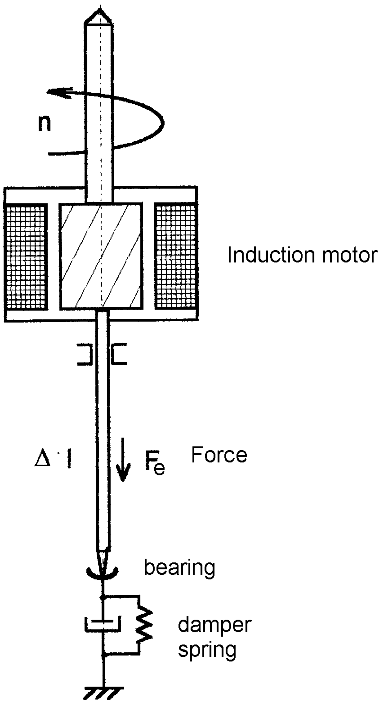

Figure 1. A schematic diagram of the measuring system.

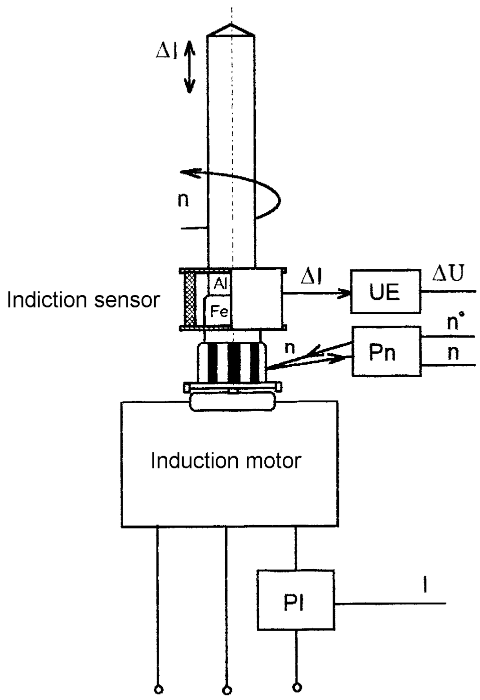

Figure 2. A schematic diagram of the motor-driven spindle.

For measuring the linear displacement along the spindle rotation axis an induction sensor, (fig. 2), was made, whose transformer is placed inside the steel seat Fe, (fig. 2), of the spindle [6].

2 ELECTROMAGNETIC AXIAL FORCE

The spinning IMDS (individual motor-driven system) spindle is driven by a three-phase asynchronous motor whose rotor has skew grooves. The skew arrangement of the winding in relation to the rotor generatrix causes the formation of electromagnetic forces acting along the rotor rotation axis. The use of skew grooves in the rotor causes a reduction in the harmonics (in the flow), a reduction in the formation of parasitic moments causing the rotor swing and a reduction in the electromagnetic noise. When the supply voltage is turned off, the magnetic axial tension decays and the spring pushes the spindle rotor out of the stator to the rest point.

The electromagnetic axial force (1) draws the motor rotor into the magnetic field; it depends on the electromagnetic moment of the asynchronous motor and is expressed by the formula:

$$F_e \cong k_w \cdot T_e \tag{1}$$

where: k_w-is the proportionality coefficient dependant on the geometrical dimensions of the motor rotor.

The drive torque T_e of the induction motor, on the other hand, is described by the relationship:

$$T_e = \frac{3}{2} p \frac{L_m}{L_r} \mathrm{Im}(\underline{Ø^*{}_r I_r}) \tag{2}$$

where: p - the number of pairs of poles, L_m - the reciprocal inductance between the winding of the stator and that of the rotor reduced to the circumference of the stator, L_r- the total effective inductance of one phase of the winding of the rotor, $Ø^*{}_r$ – magnetic flux, I_r – rotor current.

The mechanical equation:

$$T_e - T_m = J \frac{d\grave{u}}{dt} \tag{3}$$

where: J_s – the moment of inertia, ω - angular velocity.

The resistance torque T_m of the spindle results from the electrodynamic resistance and friction in the bearing. It is determined by the relationship:

$$T_m = k_w \cdot n^2 \tag{4}$$

where: k_w - is the coefficient referring to the yarn packing and the bearing parameters, n - is the rotational speed.

The axial force F_e causes the axial displacement of the spindle motor and is balanced by the spring force:

$$F_e = m \frac{d^2 l}{dt^2} + ç \frac{dl}{dt} + k_s l \tag{5}$$

where: m - is the motor-driven spindle mass, l - is the axial displacement of the spindle rotor, η - is the damping coefficient, k_s - is the spring elasticity coefficient.

3 SIMULATION INVESTIGATIONS

The simulation investigations were carried out on a mathematical model whose block diagram is shown in (fig. 3). The machine model consists of the model M of an asynchronous squirrel-cage supplied with three-phase voltage from the block NZ. The motor was supplied with the voltage of a frequency of 50 Hz. The resistance torque T_m of the spindle is supplied to the motor model. To demonstrate that the rotor is displaced axially, the simulation of the motor start-up was performed. The simulation was carried out by means of the Matlab-Simulink packet [4]. The investigation results are illustrated by the curves of the torque – (fig. 4), the angular velocity – (fig. 5), the magnetic axial force - (fig. 6), and the axial displacement of the spindle motor – (fig. 7).

4 ASSESEMENT OF THE DISPLACEMENT MEASUREMENT UNCERTAINTY

The verification of the simulation results was based on the measurement of the motor-driven spindle displacement. The measuring system, shown in (fig. 1), was examined by means of standard gap-gauge plates of a nominal thickness of 0.1 mm, made in accuracy class I. The static characteristics of the system is shown in Table 1.

The characteristics show non-linearity; as a result, a need arises to make an approximation using a second-order polynomial. The maximum error of approximation is 0.025 mm; hence algebraic corrections must be used to restrict systematic effects.

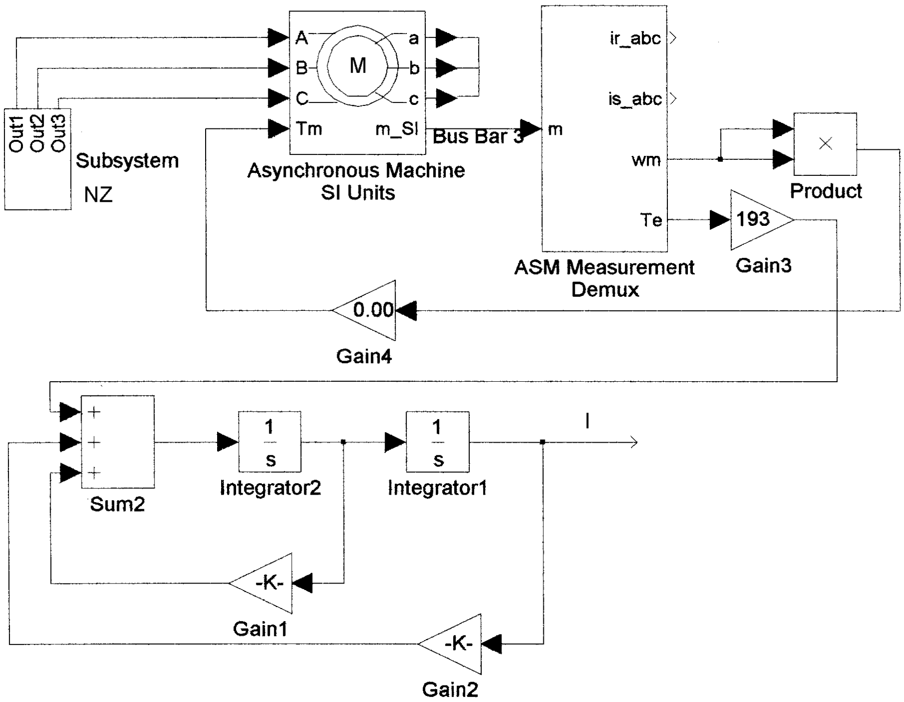

Figure 3. A machine diagram of the motor-driven spindle model.

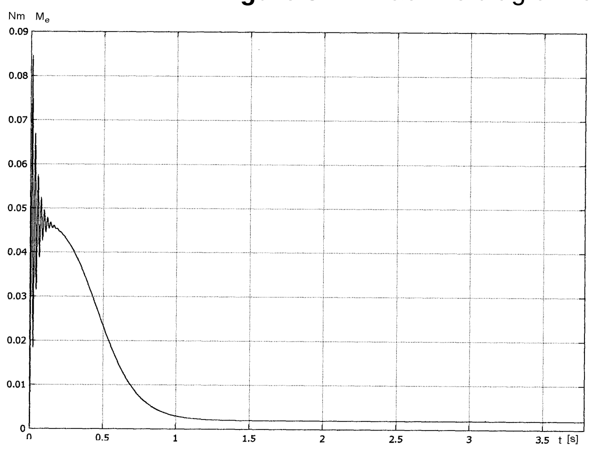

Figure 4. The motor torque.

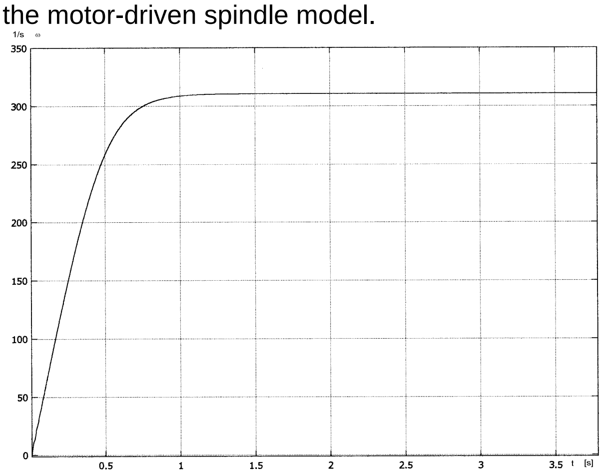

Figure 5. The motor velocity.

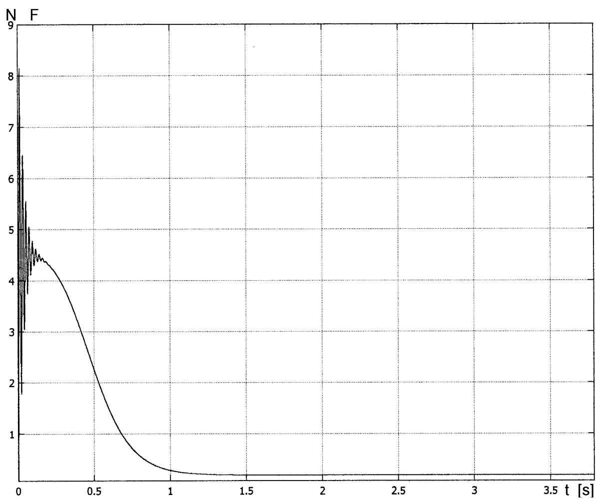

Figure 6. The axial force of the rotor.

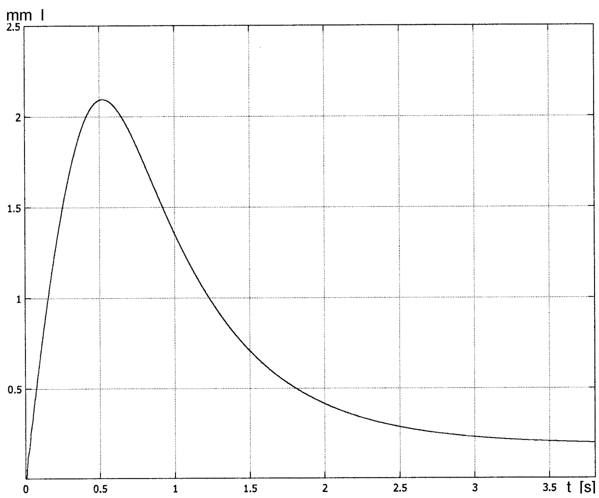

Figure 7. The axial displacement.

Table 1. The static characteristics of the displacement measuring system

x_w	mm	0,0	0,1	1,2	0,3	0,4
U	V	0,00	0,43	0,72	1,03	1,66

The type A uncertainty [9] calculated from 10 repeated measurements for the standard value x_w=0.3 mm was $u_A(x)$=0,00042 mm; thus, it should be assumed that the repeatability of the measuring system is satisfying. In the calculations of the type B uncertainty following were taken into consideration: the resolution of a digital voltmeter (0.01 V), the resulting mean displacement measurement resolution (0.002 mm), and the metrological quality of the standard plates defined by the permissible deviation for class I (6 µm). On the assumption that the distribution was uniform in both cases, the result obtained was $u_B(x)$=0,00115 mm. Since the analysis was made using the significance level α=0.005, the expanded uncertainty value is U(x)=0.00236 mm, while the expanded relative uncertainty $U_{re}(x)$=0.59% for the measuring range of 0.4 mm.

The steady value of the displacement obtained from the simulation is 0.198 mm; the value obtained from the measurement was very close to it and amounted to 0.200 mm.

5 COMMENTS AND CONCLUSIONS

The investigations were carried out for a spindle loaded with a yarn packing, which means that the relative coefficient of the motor-driven spindle inertia was J_w/J_s=1. When the motor is supplied with supply voltage, the motor-driven spindle rotor is drawn into the motor stator by axial forces. In the transient state, during the motor start-up there occur electromagnetic processes which are characterised by the motor moment values exceeding the nominal values; in addition, great magnetic axial forces are formed. These forces cause the displacement of the motor rotor to as much as 2.2 mm (fig. 7). When the motor-driven spindle start-up terminates, the motor moment, and consequently the axial force diminishes. In the steady state, this force shifts the rotor from the rest state by 0.198 mm, which is 0.78% when referred to the rotor generatrix length of 25.3 mm. The experimental investigations show that the motor rotor is displaced from its rest state into the stator by 0.2 mm.

The expanded relative uncertainty of the rotor displacement measurement is 0.59%, which testifies to a good quality of the measurements made.

REFERENCES

[1] A. Jordan, W Jodkowski, Analysis of Operation of the Inductive Transducer Considering the Dissipation Flux, *Archiwum Elektrotechniki.* **Vol. XXVIII**, book 104-2 (1978).
[2] K. Kluszczynski, R. Miksiewicz, B. Drak, J. Kudla, The Influence of Width of Additional Ring in Rotor of Squirrel-Cage Motor Upon its Effectiveness in Suppressing Parasitic Torques, *Scientific Bulletin of Lodz Technical University , Electricity*, book **92**, (789), (1998) 103-110.
[3] W. Paszek, *Nonstationary States of AC Current Electrical Machines*, WNT, Warszawa 1986, 595 p.
[4] Y.C. Pao, *Engineering Analysis-Interactive Methods and Programs with Fortran, QiuckBasic, Matlab, and Mathematica, CRC*, Boca Raton New York Washington, D.C. 1999, 360 p.
[5] A. Rusek, A. Roman, K. Jagiela, M. Lis, J. Flasza, K. Slosarczyk, J. Wawrzeszkiewicz Electrodynamic forces acting on the rotor bars of induction rollway motors. Electrical Engineering Review Vol. **73**, 9 (1997) 232-234.
[6] J. Ziê ba, 1ST Measurement of Linear Displacement of the Individual Motor-Driven Spindle (IMDS), Scientific Conference of the Textile Faculty 1998, Materials of the 1st Scientific Conference of the Textile '98, Lodz Technical University, 6-7 March 1998, Lodz, p. 29-30.
[7] J. Ziê ba, Individual Drive of Spindles (IMDS) of the Ring Spinning, Scientific Bulletin of Lodz Technical University, Textiles, book **52**, (722) (1995) 155-163.
[8] J. Ziê ba Controlling the Individual Drive of the Ring Spinning Frame Spindles (IMDS), Scientific Bulletin of Lodz Technical University, Textiles, book **54**, (760) (1996) 77-85.
[9] Guide to the Expression of Uncertainty in Measurement. International Organization for Standardization, 1992.

AUTHORS: Prof. Krzysztof GNIOTEK, PhD, DSc; Dr Janusz ZÊ BA, PhD; Department of Clothing Technology and Measuring Systems, TU Lodz, ¯wirki 36, 90-924 Lodz, Poland, Phone Int. +48 42 6313311, E-mail: kgniotek@ck-sg.p.lodz.pl and jzieba@ck-sg.p.lodz.pl