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An investigation of the dynamic electromechanical coupling effects in machine drive systems driven by asynchronous motors

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ABSTRACT

In the paper dynamic electromechanical interaction between the rotating machine drive system and the electric driving motor is considered. The investigations are performed by means of the circuit model of the asynchronous motor as well as using an advanced structural hybrid model of the drive system. Using the analytical solutions applied for the electrical and the mechanical systems the electromagnetic stiffness and coefficient of damping, both generated by the electric motor rotationally interacting with the mechanical system of the given dynamic properties, were determined. By means of experimentally validated computational responses obtained for torsional harmonic excitation induced by the driven machine working tool, a modification of dynamic properties of the mechanical system by the electromagnetic flux between the stator and the rotor has been studied.

1. Introduction

Torsional vibrations of drive systems usually result in a significant fluctuation of the rotational speed of the rotor of the driving electric motor. Such oscillations of the angular speed superimposed on the average rotor rotational speed cause more or less severe perturbation of the electromagnetic flux and thus additional oscillations of the electric currents in the motor windings. Then, the generated electromagnetic torque is also characterized by additional variable in time components which induce torsional vibrations of the drive system. According to the above, mechanical vibrations of the drive system become coupled with the electrical vibrations of currents in the motor windings. Such a coupling is often complicated in character and thus computationally troublesome. Because of this reason, till now majority of authors simplify the matter regarding mechanical vibrations of drive systems and electric current vibrations in the motor windings as mutually uncoupled. Then, the mechanical engineers applied the electromagnetic torques generated by the electric motors as '*a priori*' assumed excitation functions of time or the rotor-to-stator slip, e.g. in [1–3], usually based on numerous experimental measurements carried out for the given electric motor dynamic behaviors. For this purpose, by means of measurement results, proper approximate formulas have been developed, which describe respective electromagnetic external excitations produced by the electric motor [2]. However, the electricians thoroughly modeled electric current flows

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in the electric motor windings, but they usually reduced the mechanical drive system to one or seldom to at most a few rotating rigid bodies, as e.g. in [4]. In many cases, such simplifications yield sufficiently useful results for engineering applications, but very often they can lead to remarkable inaccuracies, since many qualitative dynamic properties of the mechanical systems, e.g. their mass distribution, torsional flexibility and damping effects, are being neglected. Thus, an influence of drive system vibratory behavior on the electric machine rotor angular speed fluctuation, and in this way on the electric current oscillations in the rotor and stator windings, cannot be investigated with a satisfactory precision.

Currently fast development of machinery driven by electric motors is observed which requires bigger and bigger knowledge about dynamic interaction between the mechanical and electrical parts of the entire system. An importance of the electro-mechanical coupling effects taken into consideration is particularly significant when possibly exact results are required for investigation of extremely responsible drive systems or for analyses of their sufficiently precise and stable motions as well as in order to elaborate proper active vibration control algorithms. This problem has been already studied for many years and by many authors, but in majority of cases sufficiently accurate electromechanical models are not usually used, e.g. because of the above mentioned far-reaching simplifications of the mechanical system. For example, in [5] an influence of '*a priori*' assumed rotor angular speed oscillation on the electromagnetic torque fluctuations was investigated by means of the circuit model of the asynchronous motors. In [6] rotor-shaft transient torsional vibrations in the turbogenerator sets caused by network disturbances were considered as coupled with the electric current vibrations in the generator windings. Coupling effects between the geared drive system torsional vibrations and the electric current oscillations in the synchronous motor windings were investigated in [7], where the current flows in the electric machine windings were modeled using Park's equations. In the case of synchronous machines the complex torque coefficients method is commonly applied in order to determine the torsional vibration frequency dependent electromagnetic stiffness and damping coefficient, where negative value zones of the latter indicate a probability of dynamic instabilities. Advantages and drawbacks of this approach are described in [8]. A practical application of the complex torque coefficients method has been demonstrated in [9] for the coupled electromechanical vibration analysis of the multi-generator drive system. In [10,11] the dynamic interaction between the asynchronous or synchronous motors and the drive system was studied, where the motor electromagnetic flux was modeled using two-dimensional finite elements and the drive train was substituted by means of the simple spring-mass model. In these papers the above mentioned electromagnetic stiffness and damping coefficient have also been determined for the synchronous and various asynchronous motors, where the torsional perturbations were excited by the use of '*a priori*' assumed test impulses of the motor rotor angular speed.

Nowadays, a severity of the electromechanical interaction is commonly observed in the case of so called 'variable speed drives' (VSD) of large rotating machines driven by synchronous or asynchronous motors controlled by the load commutated inverters. In transient and steady-state operating conditions these devices are responsible for generating additional fluctuating driving torque components which can be a source of unexpected dangerous resonance effects of torsional vibrations. Some results of theoretical and experimental investigations in this field have been reported e.g. in [12,13]. Coupled electromechanical interactions were also studied in [14] using the circuit model of the stepping motor driving a precise mechanism modeled by means of the advanced hybrid torsional train consisting of torsionally deformable continuous structural macro-elements and discrete dynamic oscillators.

As it follows from numerous observations, drive systems of several machines driven by the asynchronous motors commonly indicate diverse sensitivity to resonance effects following from their mechanical eigenvibration properties. It is suspected that for almost complete attenuation of resonance effects at resonant frequencies of excitation induced by the driven machine retarding torque as well as for unexpected severe amplification of torsional vibration amplitudes forced by a non-resonant excitation the above mentioned additional torsional elasticity and viscosity introduced into the mechanical system by the electromagnetic flux generated in the electric motor are responsible. In order to explain such dynamic behavior better, in this paper a qualitative analysis of the electromechanical coupling effects for several rotating machine drive systems driven by various asynchronous motors during their steady-state operation are performed. The investigations are carried out by means of the circuit model of the electric motor and using the advanced structural hybrid model of the rotating machine drive system. Some theoretical results have been confirmed by measurements performed on the real objects.

2. Modeling of the mechanical system

In order to investigate a character of the electromechanical coupling, the possibly realistic and reliable mechanical model of the drive system is applied. In this paper, similarly as e.g. in [14–16], dynamic investigations of the entire drive system are performed by means of the one-dimensional hybrid structural model consisting of finite continuous visco-elastic macro-elements and rigid bodies. In this model by the torsionally deformable cylindrical macro-elements of continuously distributed inertial-visco-elastic properties the successive cylindrical segments of the stepped shafts and coupling disks are substituted, as shown in Fig. 1. In order to obtain a sufficiently accurate representation of the real object, the visco-elastic macro-elements in the hybrid model are characterized by the geometric cross-sectional polar moments of inertia J_{Ei} responsible for their elastic and inertial properties as well as by the separate layers of the polar moments of inertia J_{Ii} responsible for their inertial properties only, $i=1, 2, \ldots, n$, where n is the total number of macro-elements in the considered hybrid model. The inertias of gear-wheels and driven machine working tools are represented by rigid bodies attached to the appropriate macro-element cross-sections.