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An influence of the stepping motor control and friction models on precise positioning of the complex mechanical system

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ABSTRACT

This paper aims to investigate, both experimentally and theoretically, the electro-mechanical dynamic interaction between a driving stepping motor and a driven laboratory belt-transporter system. A test-rig imitates the operation of a robotic device in the form of a working tool-carrier under translational motion. The object under consideration is equipped with measurement systems, which enable the registration of electrical and mechanical quantities. Analytical considerations are performed by means of a circuit model of the electric motor and a discrete, non-linear model of the mechanical system. Various scenarios of the working tool-carrier motion and positioning by the belt-transporter are measured and simulated; in all cases the electric current control of the driving motor has been applied. The main goal of this study is to investigate the influence of the stepping motor control parameters along with various mechanical friction models on the precise positioning of a laboratory robotic device.

1. Introduction

The current rapid development of precise auxiliary drives of machines, vehicles and aircrafts, as well as that of robotic devices and several manufacturing systems usually driven by electric motors requires deeper and deeper knowledge about their transient and steady-state operation properties. Apart from the realization of possible precise motions, factors such as the short duration of positioning times, electric power consumption and the dynamic loadings imposed on the system's moving elements are usually the most important factors from an engineering point of view. The interdependence of the above-mentioned factors with the processes is a result of the dynamic properties of the driven mechanical system as well as the output characteristics and control of the driving electric motor. Recent papers addressing the problem of machinery positioning, e.g. [1–10], point to the following factors. These are:

- electrical properties and control strategies of the driving electric motor,
- dynamic inertial-visco-elastic properties of the driven mechanical system and
- the character of retarding the mainly frictional forces associated with these motions.

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It is worth emphasizing that in the majority of positioned electromechanical devices the mechanical part was reduced to only one rigid body, usually affected by small displacements in comparison with the geometrical dimensions of the system as a whole. Moreover, simple DC or voice coil motors equipped with the necessary control devices were used as sources of power. As regards these driving motors the drive force or the drive torque was assumed to be proportional to the input supply current, as e.g. in [1–3]. For such simple electromechanical systems in [1–7] attention was focused on the design of appropriate control strategies for the possible effects of exact positioning. In [8–10] the influence of frictional forces was investigated and ways of their modelling on courses of the final motions before stopping.

Stepping motors are the commonly known sources of power usually employed for a possible exact positioning of the selected elements of driven precise mechanical systems. As mentioned above, in such systems an accuracy of positioning depends not only on electrical properties and proper control of the driving motor, but also upon the flexibility and dynamic properties of the driven object. Thus, because the flexible mechanical systems usually have a natural ability to vibrate, causing a fluctuation of the angular velocity of the stepping motor rotor, the flow of electric current in the motor windings is affected by these mechanical oscillations. This results in additional variable components of the driving electromagnetic torque, generated by the stepping motor. Consequently, the electrical current oscillations are coupled with the mechanical vibrations of the driven object. In order to ensure accurate positioning of the elements of the mechanical systems driven by the stepping motors, the electromechanical interaction between the mechanical and electrical parts should be thoroughly investigated both theoretically and experimentally.

The problem of dynamic interaction between several mechanical systems cooperating with a variety of electric machines has been the subject of much research, [5–7,11–16]. But usually these focused on modelling of the electric machine, e.g. the asynchronous and synchronous motor or generator as well as the DC and the stepping motor. The majority of research in this field, carried out using more or less advanced electromechanical models, has been related to steady-state operating conditions, e.g. in [11–15]. In the case of synchronous machines the complex torque coefficients method is commonly applied in order to determine the torsional vibration frequency dependent rotor-to-stator electromagnetic stiffness and the damping coefficient. Advantages and drawbacks of this approach are described in [11]. A practical application of the complex torque coefficients method is demonstrated in [12] for the coupled electromechanical vibration analysis of the multi-generator drive system. Rotor-to-stator electromagnetic stiffness and the damping coefficient was determined in [13] as a result dynamic interaction between the asynchronous or synchronous motors and the drive systems. In that paper the motor electromagnetic flux was modelled using two-dimensional finite elements and the drive train was substituted by means of a simple spring-mass model. The analogous stiffness and damping coefficient resulting from the dynamic interaction between several types of asynchronous motors and driven mechanisms were determined in [14].

Circuit models enable us to describe the stepping motors, e.g. in [5–7,15–17]. However, the driven mechanical systems were usually reduced to only one rigid body, where its mass moment of inertia was added to that of the motor rotor. The fundamentals of the electrical modelling of the stepping motors can be found in [15]. The aim of the research in [5–7] was to control the stepping motor operation in order to maintain precise angular positioning of the rotor. For this purpose, in [5] the influence of the electrical parameters of the motor and its controller is scrutinized. In [6,7] various stepping motor controllers were developed, whereas in [7] higher harmonic components of the motor electromagnetic torque are taken into consideration to analyze possible resonance excitation. Attempts to investigate the dynamic interaction between the driving stepping motor and the driven mechanical system can be found in [16] and [17]. In these papers, apart from the circuit models of the electric unit, the inertial-visco-elastic properties of the mechanical system have also been taken into consideration, in the form of a structural discrete-continuous and discrete model respectively. In [16] one of the first approaches to a more qualitative analysis of the circuit model of the stepping motor's interaction with the torsionally vibrating structural model of the geared drive system is examined. In this mechanical model all necessary geometrical and material parameters were taken into consideration. Additionally, to simulation examples of transient and steady-state operating conditions, a qualitative spectral analysis of the electrical-to-mechanical response is also performed. In [17], as in [16], a voltage–frequency control of the stepping motor was applied.

This paper studies the dynamic interaction between a typical two-phase hybrid stepping motor and the existent mechanical laboratory belt-transporter system. This system represents a robotic device, characterized by a moving inertial working tool-carrier under translational motion. The main goal of this work is to investigate the influence of the stepping motor current control parameters as well as the various mechanical friction models on the precise positioning of the robotic device. It is also hoped to determine an effective scenario for the positioning of the tool-carrier.

2. Description of the considered object and measurement systems

The above mentioned laboratory belt-transporter system, imitating a robotic device characterized by the moving inertial working tool-carrier under translational motion, constitutes the focus of our investigations, as illustrated in Fig. 1. The translational motion of the tool-carrier is realized by the toothed belt spanned on two rollers of the radii 0.1 m. The axes of these rollers are separated by 4.375 m. The tool carrier trolley moves directly along the guideway, comprising a single Hepco construction beam with a nominal length of 3980 mm and a cross section area of 317 mm^2. This entire structure is suspended from an aluminium truss frame, which can be reinforced by the rigid plate elements in order to maintain horizontal movement of the working tool-carrier, i.e. without any noticeable vertical deflections during testing. This mechanism is