MODELLING FRICTION PHENOMENA IN THE DYNAMICS ANALYSIS OF FOREST CRANES

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Cranes, modeled according to the proposed method of dynamics analysis, can be built from any number (n_l) of links, however, only (n_{dr}) links have their own drive which is considered to be in the flexible form. It was assumed that the cranes were supported on the ground by any number (n_s) of flexible supports modeled as spring-damping elements. Joint coordinates and homogeneous transformation matrices, taken from robotics [2], were used to describe the geometry of the cranes. Equations of motion were derived on the basis of the formalism of Lagrange equations by using algorithms based on those presented in monograph [3]. Joint forces and torques used to calculate friction torque in the revolute joint and friction force in the prismatic joint were determined, in each integrating step of equations of motion, by using the recursive Newton-Euler algorithm [2]. Models of revolute and prismatic joints were worked out for the requirements of the method. The LuGre friction model [1], which is summarized by two first-order nonlinear differential equations, was used to take into account the joint friction. This model, based on the bristles' interpretation of friction, can take into account pre-sliding displacements in phases of static friction and the Stribeck effect in phases of gross-sliding. Moreover, the phenomenon of friction lag can also be taken into account.

The dynamics analysis of a forest crane built of eight links, of which only five have their own drive with driving torque/force $\mathbf{t}_{dr}^{(p)}\Big|_{p=2,3,4,5,8}$, is presented in Fig. 1.

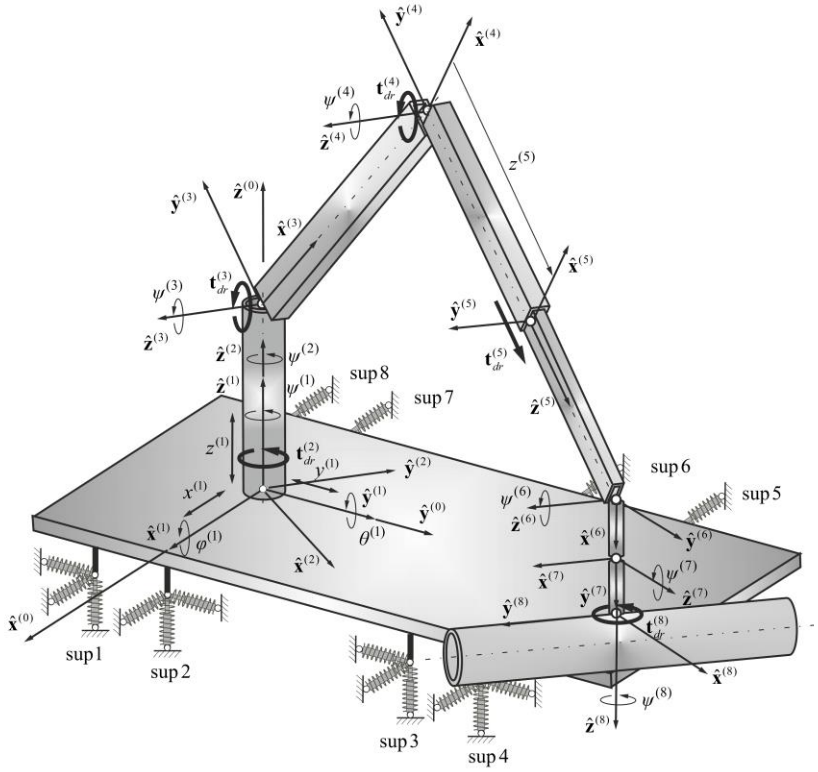

Fig. 1. Crane model

The crane's motion was described by the vector of generalized (joint) coordinates:

$$\mathbf{q} = \left(q_j^{(p)}\right)_{\substack{p=1,\dots,n_l \\ j=1,\dots,n_{dof}^{(p)}}} = \begin{bmatrix} \mathbf{q}^{(p-1)^T} & \tilde{\mathbf{q}}^{(p)^T} \end{bmatrix}^T = \begin{bmatrix} \tilde{\mathbf{q}}^{(1)^T} & \tilde{\mathbf{q}}^{(2)^T} & \tilde{\mathbf{q}}^{(3)^T} & \tilde{\mathbf{q}}^{(4)^T} & \tilde{\mathbf{q}}^{(5)^T} & \tilde{\mathbf{q}}^{(6)^T} & \tilde{\mathbf{q}}^{(7)^T} & \tilde{\mathbf{q}}^{(8)^T} \end{bmatrix}^T,$$

where: $\tilde{\mathbf{q}}^{(1)} = \begin{bmatrix} x^{(1)} & y^{(1)} & z^{(1)} & \psi^{(1)} & \theta^{(1)} & \varphi^{(1)} \end{bmatrix}^T$, $\tilde{\mathbf{q}}^{(2)} = \begin{bmatrix} \psi^{(2)} \end{bmatrix}$, $\tilde{\mathbf{q}}^{(3)} = \begin{bmatrix} \psi^{(3)} \end{bmatrix}$,

$\tilde{\mathbf{q}}^{(4)} = \begin{bmatrix} \psi^{(4)} \end{bmatrix}$, $\tilde{\mathbf{q}}^{(5)} = \begin{bmatrix} z^{(5)} \end{bmatrix}$, $\tilde{\mathbf{q}}^{(6)} = \begin{bmatrix} \psi^{(6)} \end{bmatrix}$, $\tilde{\mathbf{q}}^{(7)} = \begin{bmatrix} \psi^{(7)} \end{bmatrix}$, $\tilde{\mathbf{q}}^{(8)} = \begin{bmatrix} \psi^{(8)} \end{bmatrix}$.

A set of numerical tests was performed which confirmed the correctness of the proposed method of dynamics analysis. The initial and final configuration of the crane modeled here, which is taken into account in the presented sample of calculations, is presented in Fig. 2. The courses, presented in Fig. 3, illustrate the influence of joint friction on the motion trajectories of selected points of the transferred load in $\mathbf{x}^{(0)}\mathbf{y}^{(0)}$ plane. As can be observed, friction plays a positive role here by essentially reducing load oscillations.

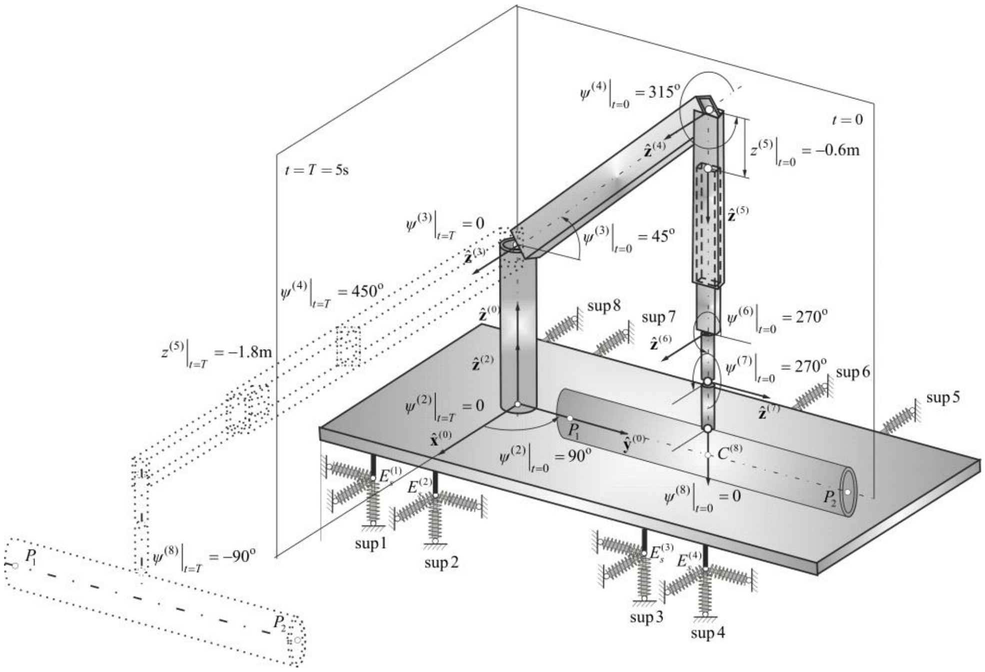

Fig. 2. Initial and final configuration of the crane model

The model of forest cranes worked out here, which takes into account the presence of friction in joints as well as flexibility of their support system and drives, can – as a virtual prototype – essentially aid in their design process, mainly in the range of drive selection and strength calculations. This model allows to reflect the many essential features of real systems. The authors believe that taking into account the LuGre friction model, which has primarily been applied in the dynamics analysis of such systems as robot manipulators and linkages, can been treated as a special achievement of the method presented here.

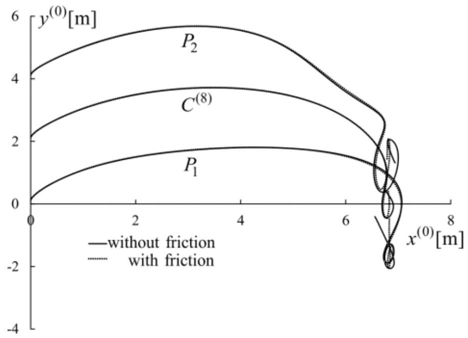

Fig. 3. Motion trajectories of selected points of the load

References

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