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CONTACT PROBLEMS IN ROLLER CHAIN DRIVE SYSTEMS

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Summary A model of a roller chain drive is developed and applied to the simulation and analysis of roller chain drives of large marine diesel engines. The model includes the impact with guide-bars that are the motion delimiter components on the chain strands between the sprockets. The main components of the model of the roller chain drive include the sprockets with different sizes and the chain made of rollers and links, which are represented by rigid bodies, mass particles and spring-damper assemblies respectively. The guide-bars are modeled as rigid bodies and their contact with the rollers are represented by a continuous force. The models proposed effectively represent the polygonal effect, always present in this type of drives, and therefore, all vibration dynamics associated to it.

INTRODUCTION

The presented work is a further development of the methods used in [1]. The dynamics of the roller chain drives are characterized by a complex behavior with impacts between the chain links and sprockets and by discontinuities in the system components velocities giving raise to transversal and longitudinal vibrations of the spans of the chain. These events are the responsible factors for part of the noise presented by mechanical devices that use roller chains and ultimately by the wear of the roller chain drives. Though roller chains have been used for a long time as a reliable mechanical component to transmit power and to handle materials mechanically, only in the last decades their dynamical behavior started to be studied [2]. The main reason for this situation is that their dynamics is very complex, making it impossible to find general analytical procedures able to describe thoroughly the problem. With the development of fast computers some recent efforts have been put forward in order to better understand different aspects of these mechanical components [3]. In a review of the state-of-art Wang and Liu [2] identify many of the investigations that have been carried out and state that integrated models describing the full dynamics of the system are necessary.
In this study an integrated model describing the complex dynamics of the roller chain drive including chain guides and moving sprockets is proposed. The roller chain drive model, based on a multibody dynamics formulation, has one driving sprocket and one or more driven sprockets. The complete chain is modeled by lumped masses connected by spring-damper uniaxial elements. The methodology proposed for the roller-sprocket contacts is penalty forces, which use the continuous force model proposed by Lankarani and Nikravesh [4]. Through the application of this, it is shown that the full dynamics of the roller-chain drive is captured and the contact problem is fully characterized.

THE MODEL OF THE ROLLER CHAIN DRIVE

A typical roller-chain drive is composed of one chain that wraps around two or more sprockets. The roller chain is made of alternating inner and outer links assembled in pivots by bearing pins and bushes. For the purposes of the study presented here, the mass of the chain is assumed to be lumped at the roller locations. Springs and dampers with constant stiffness and damping coefficients model the links. In this model the clearances between pin and bushing are neglected as well as the rotational inertia of the rollers about their center of gravity.
Even if the velocity of the driving sprocket is constant the driven sprocket velocity will fluctuate. This is known as the polygonal effect and it is the responsible for the transverse and longitudinal vibrations that develop in the chain. The excitation resulting from the impact of the roller when it seats on the sprocket and the polygonal effect are the responsible parts for the noise and vibration of the roller-chain drive. In order to have a correct model of the vibration behavior of the chain and the tension fluctuation special attention must be paid to the correct engagement and disengagement description. In the model that is developed here both the driving side and the slack side of the chain are represented. No assumption is made that limits the number of sprockets in the drive, the minimum number of teeth engaged at a certain time or the variance of the angular velocity of the driving sprocket. Moreover the location of the center of the sprockets can be fixed or be time dependent. This allows the introduction of active tensioners in the roller-chain drive. Let the roller-chain be modeled as a system of particles connected by translational springs and dampers. The rollers that are not seated in the sprockets constitute a particle system free in space. The equations of motion of the rollers are

$$m_r \mathbf{I} \ddot{\mathbf{q}}_r = \mathbf{f}_r \tag{1}$$

where $\mathbf{I}$ is the identity matrix, m_r is the mass of a link and $\ddot{\mathbf{q}}_r$ is the translational accelerations of the rollers. The right hand side $\mathbf{f}_r$ is the vector with the forces acting on the individual chain links due to the flexibility of the links. For the rollers in contact with a sprocket or a guide-bar it also includes the contact force between the rollers and either the sprockets or guide-bars. For a sprocket having an external applied force $\mathbf{f}_s$ made up from the forces with which the chain affect the sprocket and from optional directly applied forces the equations of motions are

$$\mathbf{M}_s \ddot{\mathbf{q}}_s = \mathbf{f}_s \tag{2}$$

where matrix $\mathbf{M}_s$ contains the mass and mass moment of inertia of the sprocket, the vector $\ddot{\mathbf{q}}_s$ contains the acceleration of the sprocket in the x- and y-direction and the angular acceleration, thus rotational inertia for the sprocket is taken into account.

THE CONTACT MODELS

A procedure to describe the capture of the roller by a sprocket is to use a non-linear force contact model that can take into account the impact that occurs during engagement.

Based on the Hertzian contact theory [5] several models have been proposed which take into account the energy dissipation due to heat, noise, vibrations or localized deformations. Lankarani and Nikravesh [4] proposed an impact-contact model that besides providing an accurate description of the physical phenomena is numerically stable, leading to an efficient computer performance. The contact model proposed here to describe the roller-sprocket engagement is based on the model by Lankarani and Nikravesh and it takes into account the specifics of the roller-chain dynamics. The contact force is given by

$$\mathbf{f}_c = K_g \delta^n \left[1 + \frac{3(1-e^2)v}{4v^{(-)}} \right] \mathbf{n} \tag{3}$$

where K_g is the generalized coefficient of stiffness, δ is the indentation, the power n is 1.5 for metallic surfaces, e is the coefficient of restitution, v is the relative velocity and $\mathbf{n}$ is the normal vector to the contact surface. The contact model is

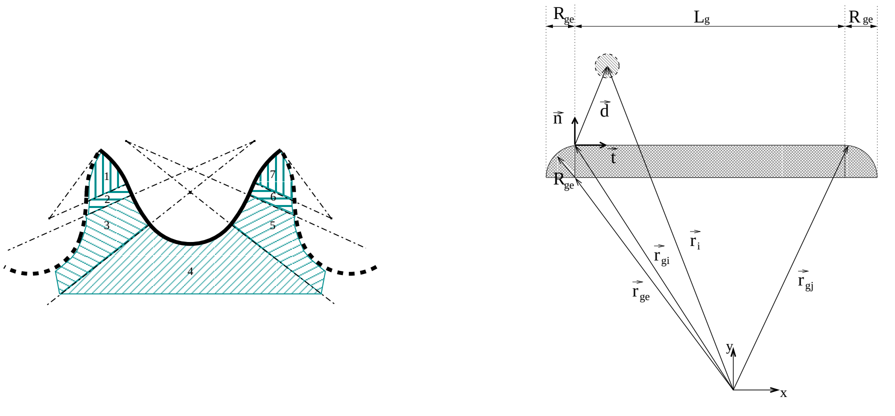

Figure 1. The tooth profile and the shape of a guide-bar

applied to contact between the roller and the surface of the real profile of the teeth, as an extension to earlier work [1], where a circular profile was used. Figure 1 shows the shape of the real tooth profile and the shape of the guide-bars.

NUMERICAL EXAMPLE

The methodology is applied to the simulation of a two stroke diesel marine engine roller-chain drive. The drive is standard in the engines that have between 4 and 12 cylinders for a power range of 1760 to 78000 KW. The roller-chain drive, composed by four sprockets and a chain made of 122 links. The sprocket in the top of the chain drive is part of the pretensioning system and it is located 0.372 m to the right of the crankshaft and 3.127 m above it during normal operating conditions. Each link of the chain, with a pitch of 0.0889 m and a mass of 3.01 Kg, is modeled as a flexible element with a stiffness of 815 MN/m, according to the experimental data obtained from the manufacturer.

The application to the roller-chain drive of a large marine engine demonstrates the level of modeling that is possible to achieve with the purposed formulation.

References

[1] Pedersen, S. L., Hansen, J. M. and Ambrósio, J. A. C.: A Roller Chain Drive Model Including Contact with Guide-bars. *Multibody Dynamics 2003 - ECCOMAS Conference*:16 pages on cd,2003

[2] Wang, K. W., and Liu, S. P.: On the Noise and Vibration of Chain Drive Systems. *The Shock and Vibration Digest*, **23(4)**: 8–13, 1991

[3] Veikos, N., and Freudenstein, F.: On the Dynamic Analysis of Roller Chain Drivers, Part I - Theory. *Mechanical Design and Synthesis, ASME*,**DE-Vol.46**: 431–439, 1992

[4] Lankarani, H. M., and Nikravesh, P. E.: Continuous Contact Force Models for Impact Analysis in Multibody Systems. *Nonlinear Dynamics*, **5**: 193–207, 1994

[5] Hertz, H.: Gesammelte Werke Vol.1. *Leipzig, Germany*, 1895