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Parametric instability of a multi-degree-of-freedom spur gear system with friction

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ABSTRACT

The instability due to parametric excitation from variable mesh stiffness in a gear pair system has been studied with the help of a six-degree-of-freedom translational–rotational model to consider the contribution of tooth sliding friction. A new harmonic balanced method based analytical technique has been developed to find instability boundaries for mesh frequency at different resonance conditions. Results are compared with a numerical method based on Floquet theory and show good agreement for mesh frequency equals to natural frequency and twice the natural frequency of the gear pair system. The effects of friction coefficients, modal damping and tooth profile modification on the stability boundaries are investigated.

1. Introduction

Dynamic excitation from the changing stiffness of the meshing teeth is known to be the primary source of gear vibration and noise. The mesh stiffness associated with elastic tooth bending, Hertzian contact deformation, and gear body rotation varies as the number of teeth in contact changes. The parametric excitation due to the time-varying mesh stiffness may cause instability and severe vibration under certain operating conditions. Experiments by Benton and Seireg [1] and Kahraman et al. [2] have demonstrated the large amplitude vibration induced by parametric instability where the gear mesh frequency equals twice the natural frequency (primary instability) or the natural frequency (secondary instability). Therefore, determination of operating conditions of parametric instability and identification of design parameters that minimize their occurrence are crucial to the design of gear.

In majority of the gear models, friction forces are neglected in comparison with the normal forces that act along common normal of the contacting gear teeth. However, recent researches indicate that the effect of tooth friction should be considered in the gear dynamic model to account for noise in gear system. The possibility of gear noise excitation by tooth friction was quantitatively discussed by Borner et al. [3], who found that it can be a crucial parameter for structure-borne vibration. Velex et al. [4] described an iterative procedure to evaluate the effect of sliding friction, the tooth shape variations and time-varying mesh stiffness in spur and helical gears and compared with measurements. He et al. [5] considered a multi-degree-of-freedom model incorporating time-varying sliding friction and realistic mesh stiffness with tip relief of gears. Rebbechi et al. [6] measured dynamic friction forces to find the coefficient of friction. During gear meshing, the gear and pinion undergo a rolling and sliding action, except at the pitch point, where pure rolling takes place. Since, rolling

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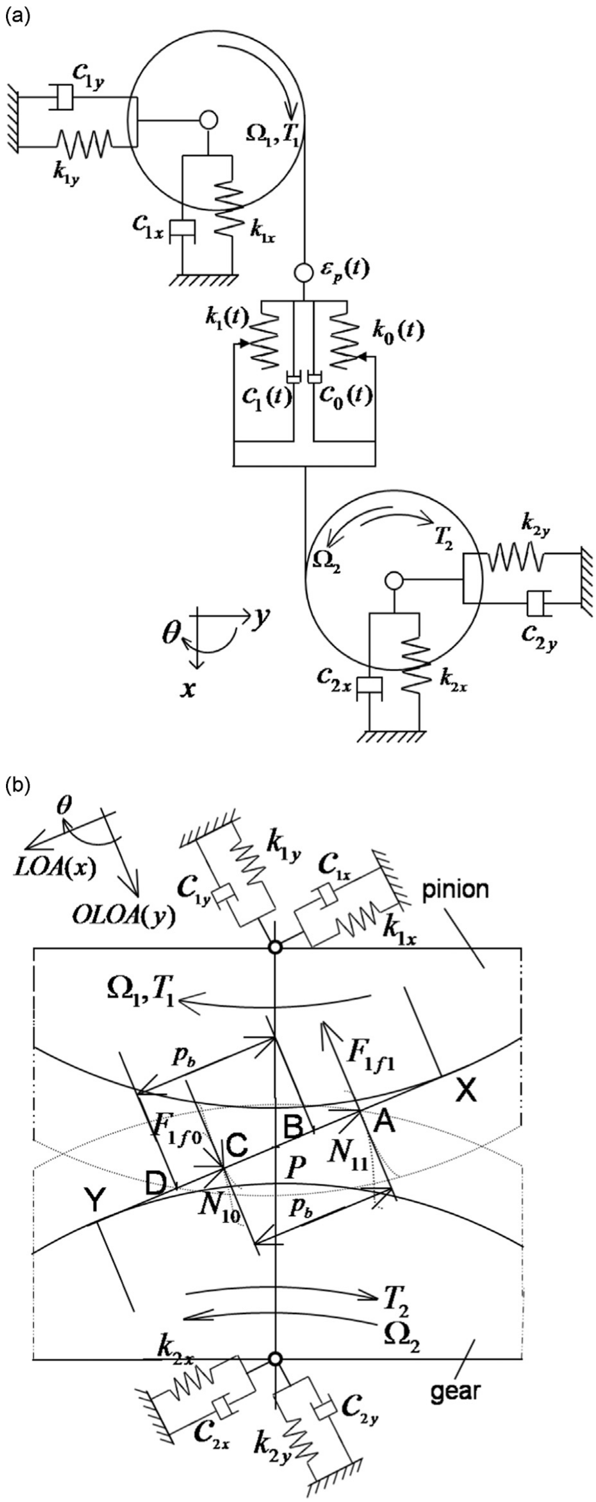

Fig. 1. (a) Six DOF spur gear system and (b) forces on gear teeth at $t=0$.

resistance is considerably smaller than sliding resistance, its contribution to the total tooth friction is usually ignored. The effects of rolling resistance are insignificant in gear dynamics although rolling resistance has important contribution in efficiency and power loss of the gear system [7].