Mechanism and Machine Theory 46 (2011) 986–997

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmt

Effects of eccentricity defect on the nonlinear dynamic behavior of the mechanism clutch-helical two stage gear

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ARTICLE INFO

Article history:
Received 18 August 2010
Received in revised form 3 February 2011
Accepted 6 February 2011
Available online 29 March 2011

Keywords:
Clutch
Helical two-stage gear
Dry friction
Clearance nonlinearity
Mesh stiffness

ABSTRACT

This paper investigates the nonlinear dynamic behavior of an automotive clutch coupled with a helical two stage gear system. The nonlinear dynamic model is simulated by twenty seven degrees of freedom and including three types of nonlinearity: dry friction path, double stage stiffness and spline clearance. The utility of the proposed nonlinear model is illustrated by the industrial need to clearly identify the dynamic behavior of mechanical elements (shafts, bearings, gears, flywheel, pressure plate, hub of the clutch…) and reduce vibration. The governing nonlinear time varying motion equation formulated is resolved by the analytic Runge Kutta method.

Then the modeling of the eccentricity defect located on the gear and the flywheel of the clutch is done. The effect of this defect on the nonlinear dynamic behavior of the system is investigated.

1. Introduction

The modeling and analysis of the coupled clutch and the gear system has been the subject of numerous investigations. Gaillard et al. [1] propose five models of an automotive clutch with dry friction path and study the energy dissipation per cycle for each model. However, they neglect the effect of clearance nonlinearities on the dynamic behavior of these models. Many other investigations model clutches [1–3] and neglect the effect of the clearance nonlinearity, while some investigations [4–6] have treated this type of nonlinearity. Kim T.C. et al. [7] studied the effect of smoothening the nonlinear functions on the frequency response of an oscillator with a clearance nonlinearity. They treated four types of smoothening functions and show the advantages and limitations of each smoothing function. Driss Y. et al. [8] have treated a model of a clutch that contains eleven degrees of freedom which contains three types of nonlinearity. From another side, Joël Perret-Liaudet [9] introduced some flexible shafts in his one stage gear model.

To solve the dynamics response of the system, he used an iterative spectral method that permits to reduce the time of the calculation. The works of research [10,11] included the different types of defects that may be affecting the gearings.

Indeed, the researchers are interested on the gear defects to be able to analyze the dynamic behavior of the transmission in presence of these defects. Parker G. et al. [12] treated a plane problem of two-stage gear systems constituted by three toothed wheels without introducing neither the flexibility of the bearing or that of shaft. They were interested in the problem of instabilities in these systems. Walha L. et al. [13] treated a model of helical two stage gear system affected by manufacturing defects.

All previous investigations do not have to study a coupled system that contains a clutch with three types of nonlinearity: dry friction path, multi-stage stiffness and spline clearance and the two stage gear system. In this article, we propose a new model of clutch-helical two stage gear system that contains twenty seven degrees of freedom. The differential governing equations are

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doi:10.1016/j.mechmachtheory.2011.02.002

numerically solved from a standard Runge Kutta integration scheme. Finally, we investigate the effects of the eccentricity defect on the dynamic behavior of the system.

2. Dynamic model of the mechanism clutch-helical two stage gear

The model of the clutch–helical two stage gear system is represented by a twenty seven degrees of freedom system with dry friction path and two clearance nonlinear functions that described the clearance nonlinearity stiffness and the spline clearance nonlinearity (Fig. 1).

The system is composed of four blocks. The first block contains the flywheel, the cover and the pressure plate, while the second block is composed by the friction shoes, the hub of the clutch and the gear-12. The third block is composed by a shaft and two gears. The fourth block contains a shaft, the gear-31 and the wheel-32.

I_1 represents the torsional inertia of flywheel and the cover. I_2 is the inertia of the pressure plate. I_3 and I_4 are the inertia of the friction shoe and the inertia of the hub of the clutch respectively [14]. I_{12},I_{21},I_{22},I_{31} are respectively the inertia of gear-12, 21, 22 and 31. I_D represents the inertia of the rest of the driveline system.

K_i^θ is the torsional stiffness of the shaft i following the direction θ. Moreover, We suppose that the shafts are of negligible mass and are subjected to torsion. The first block is supported by a flexible bearing modeled by the traction–compression stiffness k_{xm}, k_{ym}, k_{zm}. The other blocks (j) are supported by flexible bearing with k_{xj}, k_{yj}, k_{zj}, $k_{\phi i}$ and $k_{\psi i}$ are the bending and the traction–compression stiffness.

$T_e(t)$is the engine torque (including mean and dynamic terms) and T_D is the drag load as experienced by driveline. The generalized co-ordinates vector of the nonlinear dynamic model includes 27 degrees of freedom and can be defined by:

$$\{q\} = \{x_m, y_m, z_m, x_1, y_1, z_1, x_2, y_2, z_2, x_3, y_3, z_3, \phi_1, \psi_1, \phi_2, \psi_2, \phi_3, \psi_3, \theta_1, \theta_2, \theta_3, \theta_4, \theta_{12}, \theta_{21}, \theta_{22}, \theta_{31}, \theta_{32}\} \tag{1}$$

x, y and z are the bearing displacements. ϕ and ψ are the angular displacements of the bearing following X and Y respectively. θ is the angular displacement of the wheel and gears following the directions Z.

3. Modeling of the time varying gear mesh contact

Each gear mesh contact is modeled by linear time varying stiffness $k_i(t)$ and a teeth deflection $\delta_i(t)$ following the line of action. Referring to bibliographical works [12,13], the helical time varying stiffness can be modeled by a periodic trapezoidal shape along the time. The gear mesh frequency of this form is proportional to the rotation frequency and number of teeth on each gear. In the case of this study, the helical two stage gear system contains two mesh frequencies f_{e1} and f_{e2} already defined in previous papers [13,15].

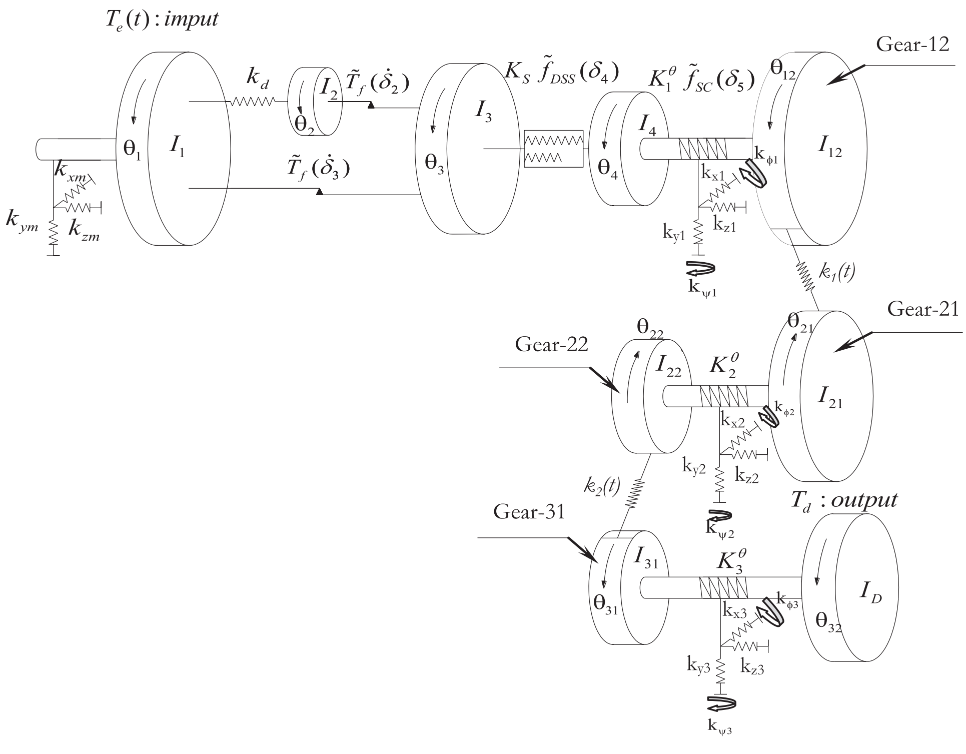

Fig. 1. 3D dynamic model of the mechanism clutch–helical two stage gear.