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ANALYTICAL PREDICTION OF SPEED CAPTURE REGIONS IN MOTOR-DRIVEN GEARED TRANSMISSION SYSTEMS

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ABSTRACT

This paper presents a direct analytical method for estimating torsional instability regions in geared transmission systems driven by DC motors with flexible rotor shafts. These zones represent operating speeds where the rotor shafts carrying spur gears may experience pronounced torsional oscillations, leading to Sommerfeld effect type responses such as speed capture and sudden escape jumps. Unlike earlier works that rely on instability maps derived from monodromy matrices, the present paper introduces an alternative mathematical framework, employing the Mathieu equation to directly predict instability regions. The approach serves as a supplementary tool for design engineers to anticipate critical speed ranges susceptible to speed-locking and jump phenomena effects; such sysmptoms are acknowledged in the literature as 'Sommerfeld effect of the second kind'.

Keywords: *Torsional instability, Speed capture, Jump phenomena, Gear dynamics, Sommerfeld effect*

1. INTRODUCTION

Torsional vibrations are a major source of noise, dynamic excitation, and reduced service life in geared systems. They arise primarily from parametric excitation caused by the time-varying mesh stiffness of gear teeth, which under low damping conditions can trigger torsional instabilities. Early studies [1] emphasized the influence of mesh damping and contact ratio, while later work [2] incorporated effects such as extended tooth contact. More recently, researchers have broadened the scope to multi-DoF formulations and to other gear types beyond simple spur gears [3], [4].

However, most of these investigations assume ideal drive conditions with constant torque and speed, neglecting the feedback of torsional instabilities on the driving source. In practice, when such systems are powered by non-ideal drives, torsional load fluctuations can strongly affect motor power output, leading to speed capture and jump phenomena near instability zones - even in the absence of rotor unbalance. This gap highlights the need to examine nonlinear gear dynamics under realistic drive conditions.

One such problem has already been investigated in detail by the authors in [6], where the analysis was restricted to torsional vibration. The present study may be viewed as a continuation of that work, providing an alternative means of locating torsional instability zones through the classical Mathieu equation framework. Readers are therefore referred to [6] for supporting data, including tables, figures, and related details.

In brief, the system under study is a DC motor–driven gear–shaft driveline (Fig. 1 of [6]), in which the motor applies torque to shaft 1. Power is transmitted through a spur gear pair to shaft 2, which carries the mating gear at one end and a balanced rotor disc at the other. The external load is modeled as a viscous resistance R_L. Both shafts are circular, slender, and torsionally elastic, with flexural motions suppressed by ideal rigid bearings. A list of system parameters and corresponding nomenclature can be found in Table 1 of [6].

2. TORSIONAL DYNAMICS OF THE ASSOCIATED GEAR MESH MODEL

As shown in Fig. 2 of [6], the pure torsional model of the isolated spur gear is illustrated. Fig. 2(b) of [6] shows the schematic representation of the mesh configuration for the involute spur gear pair with two pairs of meshing teeth (Pair #0 and Pair #1). O_P and O_G are the centers of the base circle of pinion and gear, respectively, and XY represents the line of action during meshing action (contact between teeth pairs always occur along the line of action). Let T_p be the applied torque from shaft I on the pinion, while T_g is the load torque acting on gear from shaft II. Since we have considered ideal drive conditions, constant speed input is assumed for the pinion; ω_p and ω_g are the pinion and gear speeds for rigid body rotations in rad/s with G_r as their gear ratio. The corresponding torsional vibratory displacements are represented by θ_p and θ_g. The adjacent Fig. 2(c) of [6] shows the external loads acting on the pinion teeth. Normal forces N_0 and N_1 act along the line of action (LOA), whereas the friction forces F_{p0} and

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