講演番号	221

文献番号	20225221

Nonlinear Vibration Analysis of Vehicle Drivetrain using Return Map

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KEY WORDS: Vibration, Drivetrain, Torsional damper, Bouncing-ball dynamics, Chaotic behavior [B3]

Wide-angle torsional dampers with arc springs or series springs are increasingly applicable to vehicle drivetrains to reduce torsional vibration caused by engine torque fluctuations. However, these dampers have complex restoring force characteristics that depends on speed and amplitude. They are also known for their possibility of occurrence of nonlinear vibration due to dynamic backlash, especially under certain operating historical conditions such as high rotation speed and heavy load. Vibration behavior caused by dynamic backlash is a potential source of disturbance in engine control systems, for instance, and may trigger misjudgment of engine failures. Therefore, it is necessary to clarify the mechanism of dynamic backlash and to develop a practical signal analysis method to detect its vibration behavior.

In this paper, the first return map method proposed by Poincaré (hereinafter called "return map") is used to clarify the mechanism of nonlinear vibration caused by the dynamic backlash characteristics of a dual mass flywheel (DMF), which is one of the wide-angle torsional dampers in the vehicle drivetrain.

First, a return map signal analysis of both the numerical analysis based on a Vehicle drivetrain 1D model with detailed DMF (Fig.1) and the experimental results on a actual vehicle has revealed that the unstable vibration caused by dynamic backlash is a chaotic behavior (Fig.4(a)). Concurrently, the return map has proved its effectiveness as a practical signal analysis method for detecting these vibration behaviors. In addition, all periodic motions appeared in this dynamical system. This means that, in a certain average engine torque range, the oscillations are converged to 1/nth-order sub-harmonic vibrations in natural number n. As the average engine torque increases, the number n decreases, and finally the periodic vibration is associated with the excitation period. Moreover, the identification of two different return map shapes at the occurrence of chaotic behavior indicates that two mechanisms interact in the system.

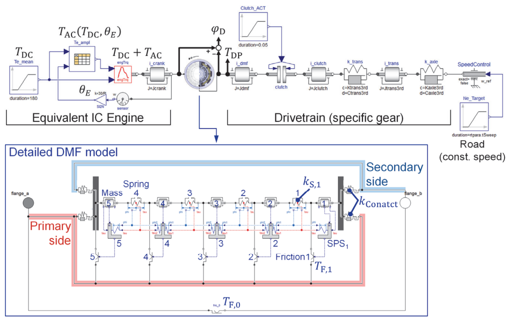

Fig.1 Vehicle drivetrain 1D model with detailed DMF

Next, the two mechanisms, bouncing with friction and elastic sliding behavior, that are three-stage piecewise linear characteristic were obtained from actual operating torsional characteristics (Fig.2). Then, obtained mechanism 3-DOF model focusing on the four dominant parameters was developed (Fig.3), and its return map (Fig.4(b)) was validated by confirming the possibility of chaotic behavior as well as the vehicle drivetrain 1D model.

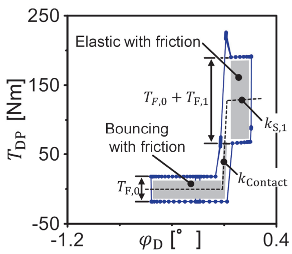

Fig.2 Obtained mechanisms and 4-dominant parameters

Finally, it was confirmed that the similar chaotic behavior occurs in the 2-DOF model, in which dominant parameters other than contact stiffness are removed from the 3-DOF model. Therefore, it was clarified that the essence of this phenomenon is a physical phenomenon classified as a piecewise linear system, namely, a bouncing-ball system. However, the dominant parameters other than contact stiffness, such as friction and elastic effect of the bouncing element itself, have an influence on the conditions for the occurrence of these nonlinear vibrations.

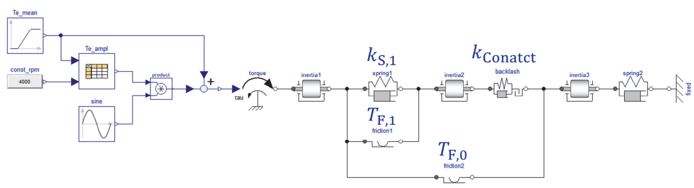

Fig.3 Obtained mechanism 3-DOF model

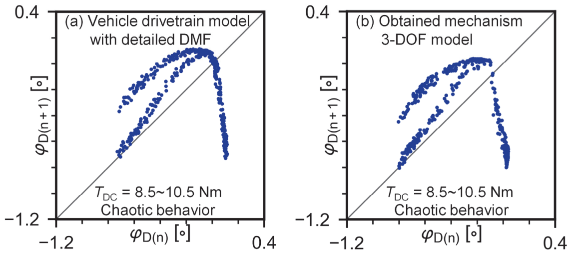

Fig.4 Return map comparison during chaotic behavior occurs

2022 JSAE Annual Congress (Spring) - Summarized Paper
Issued on May 20, 2022