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Crank Shaft Torsional Vibration Analysis on the perspective of Improving the Crank Angle Measurement Accuracy for Closed-loop Combustion Control in ICES

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Abstract

Crank shaft torsional vibration has impact on the crank angle measurement accuracy in large-bore Internal Combustion Engines (ICE). In large bore engine, the torsional vibration angular displacement can be up to 1 degree, which in turn can cause a fault of 2 bar in Indicated Mean Effective Pressure (IMEP) and a fault of 0.6 degrees in the Crank Angle of 50% burned (CA50). IMEP and CA50 are critical feedback parameters for closed-loop combustion control, therefore to compensate torsional vibration effect in real-time engine control system can not only provide higher accuracy crank angle data but especially improve the combustion analysis and closed-loop control accuracy. Thus, in this work, a torsional vibration dynamic model is established to improve the accuracy of the crank angle measurement. A lumped parameter model of torsional vibration is established for a Wärtsilä engine, the numerical computing method is determined, harmonic analysis is applied, the Transfer Matrix Method (TMM) result is verified with flexible Multibody Simulation (MBS) calculation and the accuracy of the torsional vibration model is estimated. For the trial of online crank angle correcting, the computation time of this model was found to be around 300 to 400 times heavier as IMEP calculation. A direct IMEP correcting model based on a linear dependence of cylinder number with an accuracy of ±0.1 bar compared with the reference was proposed.

Based on all those results, it is concluded that the TMM method can calculate the angular displacement from torsional vibration with high accuracy and correct the crank angle measurement from cylinder-wise and crank angle wise, and the torsional vibration calculation resolution needs to be considered based on performance and calculation capacity.

Introduction

For a dynamic running engine, torsional vibration is one of the greatest threats for crankshaft over loading [1, 2, 3, 4]. Research about the torsional vibration have been developed since the 1950s [1, 4]. The applications of using torsional response for engine combustion diagnosis have been mostly relying on the flywheel speed measurement for engine misfiring detection [5, 6, 7, 8], cylinder pressure reconstruction [9, 10], engine roughness criteria development [11], and IMEP and HRR estimation [12]. Additional work have been published about the torsional vibration analysis, for example: practical methods to reduce torsional vibration [13, 14, 15], system nonlinear dynamics [16], model simplifications [17, 18] and coupled torsional, longitudinal and bending vibrations [19, 20, 21], and transient torsional vibration response [22]. However, regarding online crank angle correction, so far according to the author's knowledge, there is not much work done. Therefore in this work a preliminary study of the online crank angle correction is done.

Torsional vibration is caused by the periodic and uneven excitation torque in each crank pin, and it leads to different angular velocities or displacements from this oscillating torque in the shaft. Out of many excitation torques acting on the crank-rod system, the tangential component of the piston force is the excitation force for crankshaft torsional vibration [1, 16, 23]. Moreover, torsional vibration is the most significant error contributor for crank angle measurement system [24]: torsional vibration of a 10 cylinder V-engine can have up to 0.4 degrees error in crank angle measurement. Therefore, a further research about the torsional vibration phenomena and its feasibility of correcting the crank angle measurement error online is carried out in this work.

Crankshaft modelling is the base of crankshaft torsional vibration analysis. Practically, there are three most basic shaft models used for torsional vibration analyses: simple mass-