Active Damping of Torsional Vibrations of Internal Combustion Engines

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Introduction
For large medium-speed engines – used in power plants and marine propulsion applications – stricter demands on emission control and performance are addressed by new computer-controlled techniques, such as common-rail fuel injection, dual fuel techniques, etc.

Electronically controlled fuel-injection techniques provide today essential means for optimizing the performance and emissions of fuel-combustion process of internal combustion engines. Due to varying dynamics and ageing of components of the fuel-injection systems, there may be a significant dispersion of the injected cylinder-wise fuel amounts. As the resulting discrepancy between the cylinder-wise torque contributions increases torsional vibrations of the crankshaft, it is important to continuously monitor and calibrate the fuel injections.

Problem Formulation
The objectives of the project are to:
- Reconstruct the superposed oscillating gas torque applied on the flywheel from measurements of angular speed of the crankshaft
- Retrieve information of the relative cylinder-wise torque profile from the reconstructed gas torque
- Adjust the cylinder-wise fuel injections in such a way that the torsional vibrations of the crankshaft are minimized.

Reconstruction of superposed torque
The behavior of the flywheel is mainly dependent on the cylinder-wise torque excitations, how the crankshaft dynamics filters these excitations and the dynamics of the flexible coupling, cf. Fig. 3.

Fig. 1. Common-rail fuel injection system.

Fig. 2. Cylinder balancing device.

Fig. 3. Fuel combustion excitations of a six cylinder engine

By assuming that the crankshaft is rigid, the engine-generator set can be represented by a two-mass lumped model, cf. Fig. 4.

Fig. 4. Engine-generator model.

The oscillating gas torque \( M \) can be calculated from measurements of the angular speeds from both sides of the flexible coupling as:

\[
\begin{align*}
J_1 \ddot{\phi}_1 &= \frac{1}{2} \frac{dA}{dt} \omega_1 + D_1 \dot{\phi}_1 + C_1 (\phi_2 - \phi_1) + K_1 (\theta_2 - \theta_1) - M \\
J_2 \ddot{\phi}_2 &= D_2 \dot{\phi}_2 + C_2 \phi_2 + K_2 (\phi_2 - \phi_1) + K_I (\theta_2 - \theta_1) + M
\end{align*}
\]

By using the engine-specific phase-angle diagrams which relate each excited order to the consecutive cylinder fringes, the lowest torque frequencies can be analyzed in order to retrieve the cylinder-wise torque contributions of the engine.

Conclusions
In comparison with automotive engines, cylinder balancing of large medium-speed engines requires different approaches in order to successfully minimize torsional vibrations. By, moreover, using adaptive approaches the convergence rate improves significantly.

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Publications


Fig. 5. Phase-angle diagram for frequency order 1/2 of a six cylinder engine.

Fig. 6. Block diagram of the cylinder balancing method.

Fig. 8. Tests on 20% engine load