PUBLICATIONS
MEASUREMENT AND ANALYSIS OF VALVETRAIN DYNAMICS AND DUAL-MASS FLYWHEEL CHARACTERISTICS

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Abstract
Over the last decade the automotive industry has achieved significant progress in improving both fuel economy and driving comfort. In order to make accurate assessments of engine and transmission capabilities state-of-the-art testing equipment in the development phases needs to be used. This paper presents experimental investigations involving two areas of current interest: valvetrains and dual-mass flywheels. Instrumentation used, test configurations, test parameters and analysis software are discussed.

Higher valvetrain efficiency is a key factor in reducing fuel consumption and emissions. Methods for measuring valve motion are outlined. The increasing complexity of valvetrain systems demands application-specific test and analysis software. Valve lift, valve velocity and valve acceleration curves versus camshaft speed and angle are presented. Measured data are compared with kinematic curves and the dynamics of valve opening, closing and seating are discussed.

The dual mass flywheel or DMF is increasingly used in vehicles fitted with manual transmissions in order to optimise driving comfort by reducing noise and vibration in the driveline. The DMF eliminates excessive gearbox rattle and reduces gear change/shift effort. Measurement data are used to describe the pros and cons of single and dual mass flywheel systems. Typical analyses include DMF wind-up angles and the comparison of torsional vibration amplitudes on the engine and transmission sides.
1. EQUIPMENT AND METHODS FOR MEASUREMENT AND ANALYSIS

The data acquisition and analysis equipment used in the applications described here is developed, manufactured and marketed by Vispiron ROTEC GmbH [1, 2, 3]. The company’s core products are pc-based signal acquisition and analysis systems which are fitted with both digital and analogue input channels. Rotational speed signals are acquired using 10GHz digital counter channels which record the time intervals between TTL pulses. Analogue channels facilitate conditioning and capture of a variety of signals with sampling rates up to 400kHz. The analysis software, working primarily in the angle domain, provides comprehensive analyses in the time and spectral domain (FFT order and frequency analysis). Near real-time capability with display and analysis of all channels allows for adjustment of test parameters during the measurement. A distinctive feature of ROTEC systems is the phase-matched acquisition of all signals: speed signal acquisition with variable discretisation of time (angle-equidistant sampling) and acquisition of analogue signals – displacement, velocity, acceleration, force, pressure, torque, etc. – at constant time intervals (time-equidistant sampling). The main purpose of this paper is to give an overview of the test and analysis possibilities offered by ROTEC equipment. For further details on sensors, test setups and interpretation of results the reader should refer to the technical reference works cited by the author.

2. DYNAMIC VALVETRAIN TESTING AND ANALYSIS

2.1 VALVETRAINS IN INTERNAL COMBUSTION ENGINES

The valvetrain controls the gas exchange process, i.e. the intake of fuel mixture and the discharge of exhaust gases [4]. To allow the maximum amount of mixture to be drawn into the cylinders, the inlet valves should open as quickly as possible and remain open for as long as possible followed by rapid closing. There is generally a conflict between fast valve opening and closing, which means large valve accelerations, and the requirement of limiting loads, which means small accelerations. Development tasks include ensuring that valvetrain components satisfy strength and durability requirements and that they operate to a high degree of accuracy.

Development requirements include dynamic valvetrain testing on both running engines and motored test rigs either for speed ramps or steady state speeds. The sensors required must measure the valve lift (and valve velocity if possible). Camshaft speed and angular position are ideally measured using a rotary encoder attached to the camshaft [5]. In addition, quantities such as shaft torques and spring forces are also measured. Comprehensive valvetrain testing requires data acquisition equipment which enables fast, synchronous acquisition of all test data. The testing equipment must enable the behaviour of valve trains of different cylinders in the same engine to be quickly compared and also confirm the repeatability of successive tests for the same valve train. Prerequisites for the equipment include high resolution, sufficiently large memory (particularly for speed ramp data which are acquired at high sampling rates) and application-specific valvetrain motion software.
2.2 VALVETRAIN DATA COLLECTION

Figure 1 shows the minimum signal requirements for valvetrain testing.

1. Reference pulse for triggering the measurements
2. Camshaft speed signal
3. Valve lift signal

Modern instrumentation and testing equipment enables measurements to be performed on both single and multiple valves. Depending on the type of valvetrain testing performed – component test stand, motored cylinder head test bench, fired engine test cell, etc – the following additional data may be collected and analysed:

- Valve velocity (when using laser vibrometers)
- Torque
- Displacement (e.g. spring displacement)
- Forces (e.g. using strain gauges)
- Torsional vibration
- CAN signals (pressure, temperature, etc).
2.3 VALVETRAIN ANALYSIS SOFTWARE

Software features available in the ROTEC valvetrain analysis include:

- Online display of valve lift, valve velocity and valve acceleration versus angular position, time or speed.
- Automatic measurement and analysis of speed sweeps and speed steps.
- 3D plots of lift, velocity and acceleration (z-axis) versus angular position (x-axis) and speed (y-axis).
- Quick calculation of seating velocities, closing angles, lift-off angle, lift loss, curve max. / min. values, etc.
- Comparison of measured and theoretical lift, velocity and acceleration profiles.

2.3.1 MOTORED CYLINDER HEAD TEST BENCH

Test benches powered by electric motors are widely used for validating valvetrain capability and dynamics [6, 7]. In comparison to fired engine test cells, their main advantages are that instrumentation is easy to install and comprehensive measurement and analysis of valvetrain dynamics is possible. The valve motion results presented below were obtained using Polytec’s High Speed Laser Vibrometer (HSV) which can measure valve lift and also valve velocity up to 30m/s [8]. Its high bandwidths combined with the high resolution of the ROTEC equipment enhance valve acceleration calculations. Figure 2 shows typical waterfall plots of valve lift, velocity and acceleration from 500 to 3000rpm. The camshaft speed and angular position was measured with a 3600 line rotary encoder. The valve lift and velocity signals were acquired at 400kHz sampling frequency. Valve velocity is calculated in m/rad and acceleration in m/rad2.
Figure 2: 3D waterfall plots of valve lift, valve velocity and valve acceleration