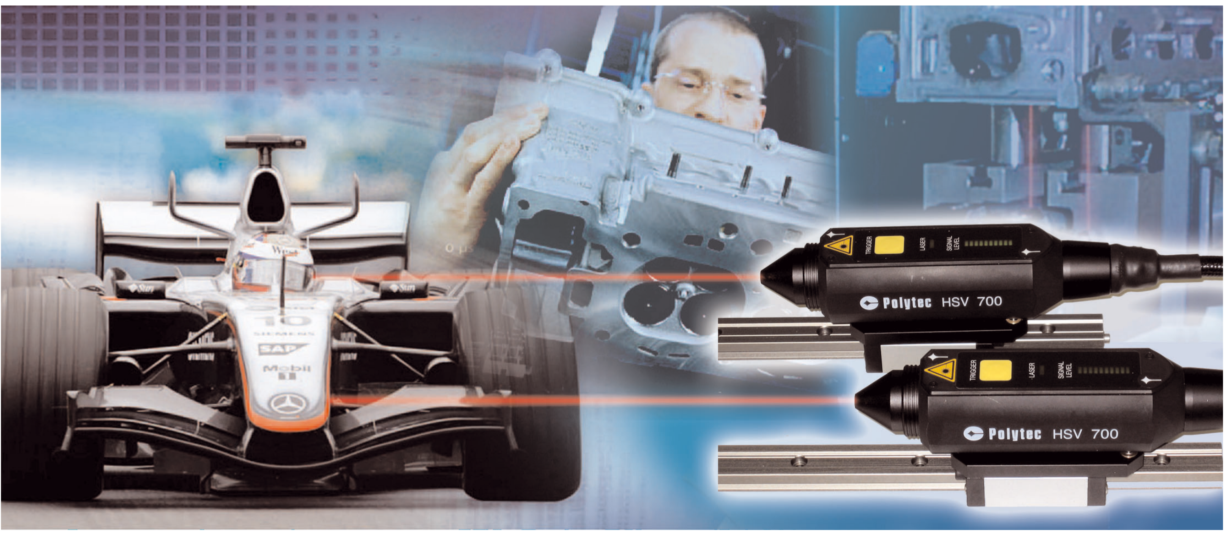
Application Note *VIB-C-03*



FIELD OF APPLICATION

- A Aerospace
- B Audio & Acoustics
- C **Automotive**
- D Data Storage
- G General Vibrometry
- M Microstructure Testing
- P Production Testing
- S Scientific & Medical
- T Structural Testing
- U Ultrasonics

Measuring Valve Train Dynamics Using the HSV-2002 High Speed Laser Vibrometer

Designed to measure the valve train motion of modern, high-performance engines at operating levels up to those found in racing engines, the HSV High Speed Vibrometer can make precision, differential displacement and velocity measurements by simply positioning a reference and a probe laser spot on the corresponding cylinder head and valve assembly.

Introduction

The optimization of the dynamics of mechanically or electromagnetically controlled valve gears is an important factor in optimizing engine performance. Because of their direct influence on motor dynamics, power, pollutant emission, durability and noise level, any small deviation from the predicted valve response can affect the engine performance adversely. The numerical modeling of valve gears is complex and requires very accurate experimental measurements for verification of the calculated values.

At the request of several leading automobile and engine manufacturers who needed high velocity capability for their motor sports divisions, Polytec developed the HSV-2002 high-speed differential vibrometer system. The HSV-2002 system is ideally suited for the task of fast and accurate measurement of the most important parameters, such as valve lift and speed.

When compared to Polytec's differential fiber vibrometers, the HSV-2002 measures to higher velocities (± 30 m/s at 50 kHz bandwidth), features easier setup and operation, is more rugged and has much better optical sensitivity. For these reasons the HSV-2002 is also popular for valve train dynamics testing on lower speed engines (<10 m/s) built for consumers.

The HSV system was designed for optimal signal quality, even under the toughest environmental conditions. For this reason, Polytec chose a configuration with two independent interferometer systems and separate RF signal conditioning for the measurement and reference channel. This configuration maximizes optical sensitivity and significantly reduces signal drop-outs, resulting in excellent data quality.

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Laser Measurement Systems
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HSV-2002 System Setup

The two-channel version allows simultaneous recording of three velocity signals:

- Velocity A
- Velocity B
- Differential velocity, A -B

There are also two displacement outputs available:

- Displacement A
- Differential displacement, A - B

As in other Polytec vibrometer systems, the velocity and displacement values are independent of each other, and are achieved using completely different demodulation techniques.

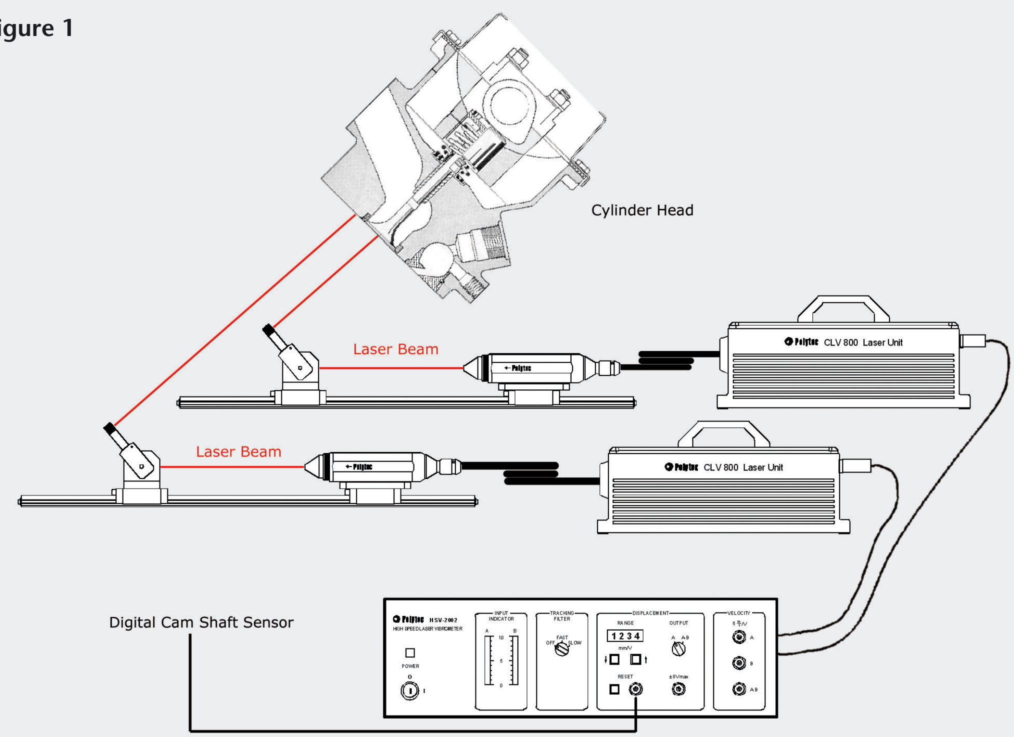
The differential velocity signal, A - B, is generated within the system using a precision differential amplifier on the signal output board. The differential displacement signal is generated using channel B as a reference signal for the quadrature demodulator, which is part of the displacement decoder.

The **velocity demodulator** has excellent linearity and accuracy. The single range (5 m/s/V) velocity demodulator features a very low noise floor and provides good resolution for measuring very low vibration velocities. When viewing the velocity signal in the time domain (e.g. on an oscilloscope), vibrations with levels < 25 mm/s can be detected, equivalent to a dynamic range of >60 dB. In the frequency domain (FFT analyzer), the dynamic range can exceed 100 dB with a vibration resolution to as low as 15 µm/s (rms).

The **displacement demodulator** utilizes a specifically developped 14-bit fringe counter. Each counted interference fringe corresponds to a defined displacement increment. The content of the fringe counter (number of counts and sign) is converted into an analog voltage by a DAC (digital-to-analog-converter). In the highest sensitivity range (320 µm/V) each fringe counter increment is equal to an object displacement of $\lambda/2$ or 0.3164 µm. With a 14-bit (2^{14}) counter, this results in a total measurement range of 5.12 mm peak-to-peak.

For valve train studies, the laser beam for channel A is directed on to the valve, and the reference channel B is directed on to the cylinder head (see Figure 1). Since the main displacement component is always in the same direction (shut to open to shut), an asymmetrical output configuration preferable.

Figure 1



Example

To characterize a valve opening from zero to an 8 mm gap, the best symmetric displacement range setting would be 1.280 µm/V, which gives a maximum displacement of ±10.24 mm. But, by having an asymmetrical output and using the next lower range (640 µm/V) setting, a displacement of -1.24 mm to +9 mm, with a higher resolution of 0.64 µm can be achieved.

In Figure 2, a typical test installation is shown where the free cylinder head of a 16-valve engine has been has been suspended, vibration isolated, and attached to an electric motor via a toothed belt driven camshaft. Camshaft speed, oil pressure and temperature are controlled to simulate various normal operating conditions.

In this test, two HSV-700 Sensor Heads with HSV-AK-800 Beam Steering Units have been mounted on the test rig.

Sensor A is aligned to the exhaust valve, in line with direction of motion, and measures the valve movement. Sensor B is aligned to the cylinder head and provides a background reference.

The signal processing electronics of the HSV-2002 generate the difference of the A and B channels. The analog velocity and displacement output signals are available via BNC connectors on the controller front panel.

Figure 2: Test installation

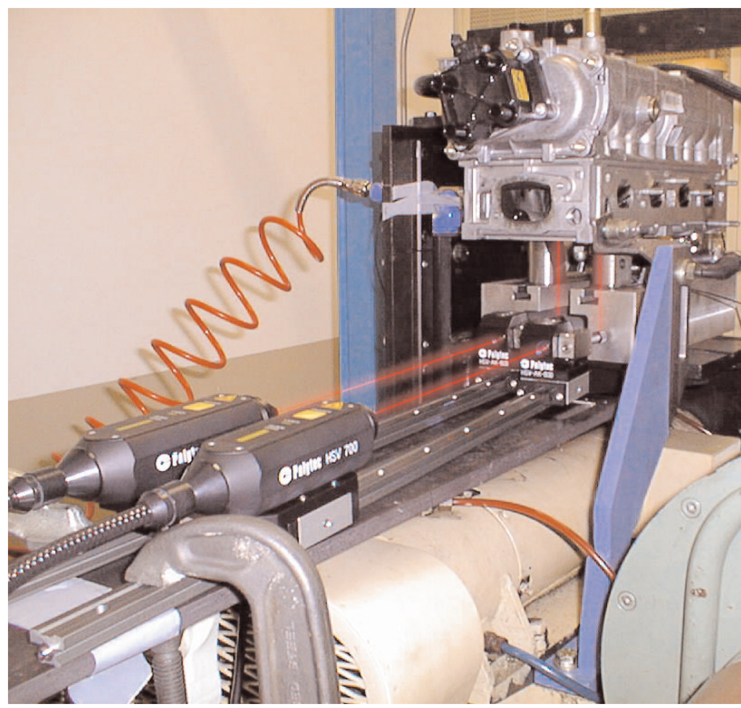
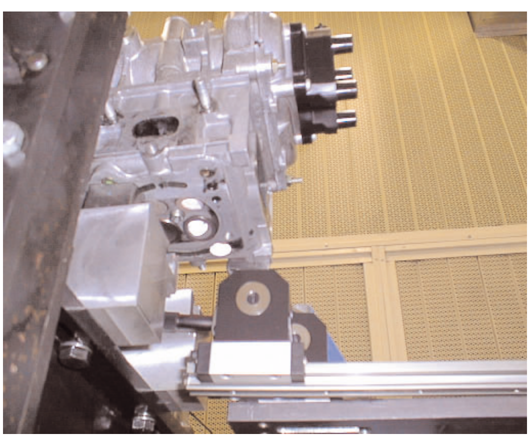


Figure 3: A closer look onto the cylinder head and the beam steering units.



Measurements on High Speed Engines

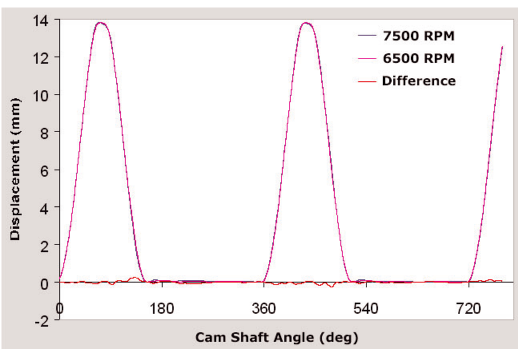
Typical parameters for motor sports engines are camshaft speeds up to 10,000 RPM with valve lifts to 15 mm, generating peak velocities well in excess of 20 m/s. The measurements shown on the next page were taken on an inlet valve of an engine running at camshaft speeds up to 7500 RPM with a maximum valve lift of 13.8 mm (Figures 4 to 7 on the next page).

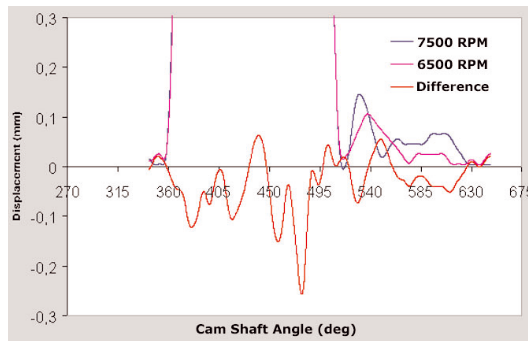
A slow run-up test was performed where the camshaft speed is increased in steps of 50 RPM every 10 seconds resulting in a total measurement time of about 6 minutes. An additional RPM sensor generating a TTL compatible, once-per-camshaft-revolution pulse is connected to the reset input of the HSV system. This signal resets the fringe counter periodically every valve cycle avoiding potential drift effects. The optimal reset point is at the end of a valve cycle.

In this engine, the RPM sensor was adjusted to a point on the camshaft circumference so that the output pulse occurred at 320 degrees. The frequency of the oscillation (Figure 7) at closure is about 12 kHz and is evidence of a longitudinal vibration of the valve shaft. This vibration has a high velocity, a calculated displacement of only 8 µm (peak-to-peak) in the first period of oscillation, and decays rapidly. This displacement is probably too small to be of great importance but demonstrates the resolution of the system. The 12 kHz vibration feature corresponds to the resonance frequency of the valve system.

Summary

With its high velocity and displacement capability, the HSV-2002 High Speed Vibrometer has proven itself to have significant advantages over traditional inductive and triangulation measurement methods for characterizing valve train dynamics. The HSV-2002 is a very powerful tool that has become the gold standard for the development of high performance motor sport and Formula 1 engines, but is equally applicable to diesel and gasoline engines for consumer, commercial and agricultural vehicles.





Figures 4 (left) and 5 (right): Two overlaid time traces taken at 6500 RPM and 7500 RPM. The red trace shows the calculated displacement difference of the two curves.

Note that the two curves do not coincide at maximum valve lift due to an overshoot of about 250 µm. Bouncing at valve closure is 150 µm and is dampened to nearly zero value within two cycles of bouncing.

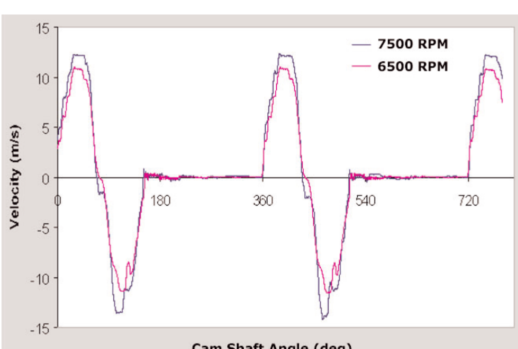


Figure 6: The corresponding valve velocity. Fast velocity variations during one valve cycle, overshoot before valve closure, high frequency oscillation, plus bounce at closure features are all clearly resolved.

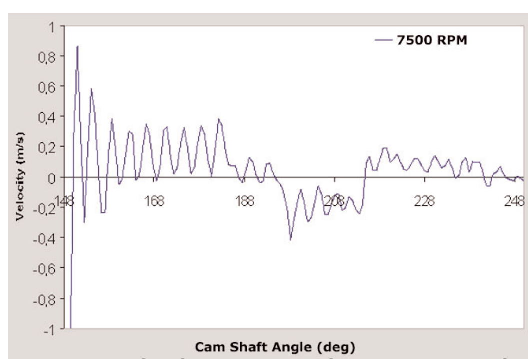


Figure 7: Valve bouncing with superimposed oscillation at closure. The oscillation frequency of 12 kHz can be derived when transforming the angular displacement scale into the time domain.

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www.polytec.com/usa/highspeed

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