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# Algorithm for signal drop-out recognition in IC engine valve kinematics signal measured by laser Doppler vibrometer

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ABSTRACT

We present an algorithm for the recognition of signal drop-out developed particularly for measurements of valvetrain kinematics. This algorithm is needed in order to save data that are not affected by a drop-out phenomenon. Such an algorithm will increase the throughput of the engine test stand and decrease the time needed for the evaluation of the valvetrains of combustion engines. The work shows the most commonly encountered drop-outs and their characteristics and locations. It presents an automatic separation algorithm for the measured signal so that the drop-out recognition tests can be aimed at specific data intervals (valve opening, valve closing, etc.) with specifically set parameters of the algorithm.



## 1. Introduction

The combustion engine has been evolving for almost one and half centuries. Nevertheless, the keystones remain the same. Cams and valves are still used while the research focused on replacing those parts with electromagnetical elements is in progress.

In the electromagnetic actuation concept, the opening and closing of the valve is obtained by alternatively energizing upper and lower magnets with an armature connected to the valve. This actuating principle offers maximum flexibility and dynamic response in valve control, but despite a decade of significant development efforts, the main drawbacks of the concept (it being not fail-safe and its high energy absorption) have not been fully overcome [1]. Thus those elements remain electromechanical [2] or hydraulically-actuated [3] as in case of new MultiAir Technology from Fiat [4].

Testing is an important part of the process of design of the individual component. First, it enables checking of the correct functionality while at the same time monitoring of the critical values that might negatively influence the lifetime of the final product. The mechatronical system we designed and constructed falls within this process. It helps to significantly reduce the time needed for complete analysis of the valvetrain components, offering prompt feedback for the design engineers.

High speed Laser Doppler Vibrometry (LDV) has become a standard measurement technique for obtaining the kinematics of the valves [5,6]. The main reason is that the technique is non-contact and offers information about both the valve displacement (using the fringe counting technique [7,8]) and the valve velocity (based on the Doppler effect) up to high engine speeds. The LDV technique also has its drawbacks. It is sensitive to dust and oil droplets that might appear during the measurement and demands precise focusing of the lenses. However, the main problems arising during the automation of the measurement are *speckle noise* and *signal drop-outs*.

A speckle pattern is produced when the coherent waves of the incident laser beam are dephased during backscatter from a surface that is rough on the scale of optical wavelength. The scattered yet still coherent waves interfere constructively and destructively, producing a chaotic distribution of light and dark spots [9,10]. For the measurements of the valve kinematics the valve is equipped with a retro-reflective tape to achieve higher intensity of the backscatter light. Unfortunately, the tape itself is optically rough and still produces a speckle pattern [10,11]. The speckle pattern is not of high significance unless it changes dynamically. Then it can translate (i.e. speckles appear to move in space while retaining their size and shape) or boil (i.e. no translation of the speckle but a continuous evolution from one size and shape to another) [12,13]. The speckle noise is produced if the Doppler signal amplitude remains high enough for the demodulator to operate. If the Doppler signal amplitude drops to low levels and the demodulation process fails, signal drop-out occurs. During its motion the valve is designed to rotate in order to keep the valve face and seat clean of carbon deposits. This also has the effect of slightly reducing the wear [14]. Because of the acting forces the valve also experiences tilt especially at high speeds. This altogether contributes to significant speckle noise during the valve kinematics measurement and frequent drop-out noise.

Attempts have been made to define strategies for reducing the signal drop-out noise to a manageable level for industrial diagnostics [15]. Algorithms for automated identification of the

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presence of the signal drop-outs and the selection of an unaffected portion of data were presented for measurements on bearings of electric motors [16]. However, the valve kinematics data are very specific so we decided to develop our own algorithm for signal drop-out recognition. The aim of our work was to create a fully-automated system capable of repeating the measurement in case of recognition of signal drop-out in the measured valve displacement or velocity.

## 2. Designed measurement system

The measurement system we designed and constructed can be called as a new generation of the apparatus commonly used for the valve kinematics measurements [5,6]. The systems described in the referenced papers are rather experimental and have their limitations. On the other hand, our apparatus is aimed at industry. It spans all of the engine's operational speeds and can operate with a full-engine or a partial-engine setup (partial-engine setup utilizes only the head and the head cover and the related valvetrain components). As described later, it also automatically compensates for the slippage of the ribbed belt that is used to transfer the torque between the shaft of the electromotor and the combustion engine. Moreover, it is capable of a truly parallel measurement of the camshaft speed fluctuations, which can help to discover a faulty valvetrain component or to improve the precision of calculations that presume the speed of the shaft to be constant. Most of all, with the algorithm for drop-out noise detection, the system is fully automated. It runs the measurement across predefined engine speeds, repeating if drop-out noise is detected and saving only the representative data for further processing.

The apparatus (Fig. 1) utilizes electromotor and frequency inverter with a communication unit to drive it. The electromotor is used to drive the crankshaft of the combustion engine. The step-up gear is installed between the electromotor and the crankshaft to allow the full range of measurement rpm, typically $rpm_{crank}=0$–6000 rpm. The camshafts (DOHC) are connected to the crankshaft via a timing chain. The incremental encoder (IRC) is placed either at the end of the intake valve camshaft or the exhaust valve camshaft offering the information about the camshaft displacement and subsequently about the camshaft speed fluctuations. The cylinder head cover had to be modified to allow that. If needed, the IRC can also be mounted at the end of the crankshaft.

Apertures were milled into the place where cylinders normally belong. The cylinders were removed and in the created space the laser Doppler probes were installed. No gas forces or combustion forces occur in the measurement system. Excluding those forces, however, does not compromise the validity of the experimental data [17].

The measured valve is always equipped with retro-reflective tape, which is placed at the center of the bottom side of the plate. One fiber optics laser probe is aimed at the tape and monitors the motion of the valve (measurement arm). It works as a transmitter and receiver at the same time. The second probe is aimed at the cylinder head (reference arm) itself, which is also rigged with the tape. The probes are connected to a differential laser Doppler system, which uses Mach–Zehnder interferometer design. The vibrations of the cylinder head, which arise during measurement are subtracted from the motion of the valve. Thus the measurement is more accurate. The connected laser vibrometer controller handles the evaluation of the incoming signals and outputs analog signals representing the displacement and velocity of the monitored valve. Those signals are connected to two synchronous channels of data acquisition (DAQ) card. The pulse signal from the IRC encoder is used as an external sampling source so the data are sampled depending on the actual cam displacement. The standard for this type of measurement is 720 pulses per revolution (ppr). This offers resolution 0.5° of the camshaft, which is fine enough, preserves good readability, shows step changes in acceleration that can discover problematic parts and does not pose a problem of handling huge amount of data. Higher resolutions can be also used (i.e. 1800 and 3600 ppr). Moreover, the IRC signal is used by the controlling software to compensate the slippage of the ribbed belt and to measure the camshaft speed fluctuations (caused mostly by the valve spring forces, the shape of the cams and the resulting driving moment, torsional oscillations of the shafts, the chain vibrations and the resonance of those parts [18]). A ribbed belt is used to transfer the torque between the shaft of the electromotor and the combustion engine. It ensures that in critical situations (such as engine jamming), the belt will be allowed to slip, thereby not causing further damage to the engine. The reference

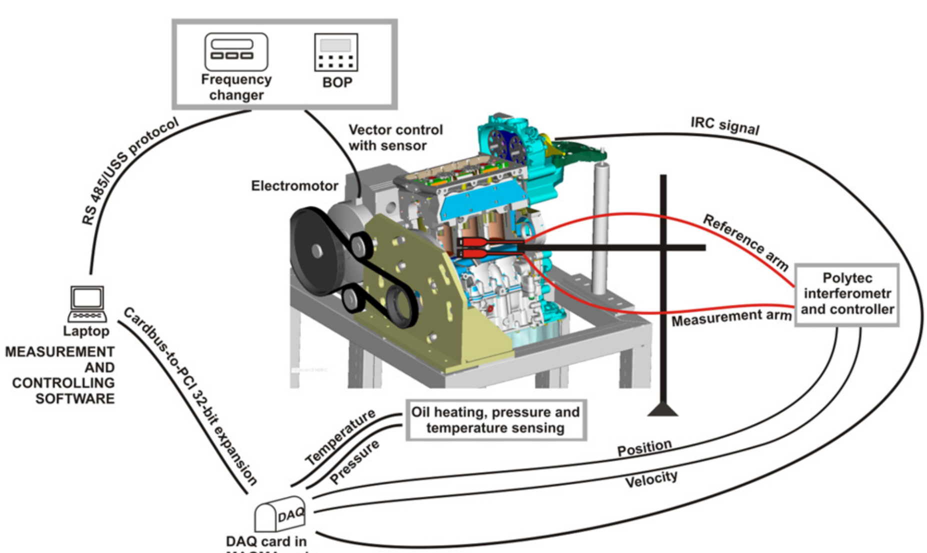


**Fig. 1.** Schema of the apparatus for measurement of the kinematic variables of valvetrains.