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Zebra tape identification for the instantaneous angular speed computation and angular resampling of motorbike valve train measurements

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A B S T R A C T

An experimental test campaign was performed on the valve train of a racing motorbike engine in order to get insight into the dynamic of the system. In particular the valve motion was acquired in cold test conditions by means of a laser vibrometer able to acquire displacement and velocity signals. The valve time-dependent measurements needed to be referred to the camshaft angular position in order to analyse the data in the angular domain, as usually done for rotating machines. To this purpose the camshaft was fitted with a zebra tape whose dark and light stripes were tracked by means of an optical probe. Unfortunately, both manufacturing and mounting imperfections of the employed zebra tape, resulting in stripes with slightly different widths, precluded the possibility to directly obtain the correct relationship between camshaft angular position and time. In order to overcome this problem, the identification of the zebra tape was performed by means of the original and practical procedure that is the focus of the present paper. The method consists of three main steps: namely, an ad-hoc test corresponding to special operating conditions, the computation of the instantaneous angular speed, and the final association of the stripes with the corresponding shaft angular position. The results reported in the paper demonstrate the suitability of the simple procedure for the zebra tape identification performed with the final purpose to implement a computed order tracking technique for the data analysis.

1. Introduction

This paper deals with experimental tests performed on the timing system of a racing motorbike engine. The tests were devoted to get insight into the dynamics of the timing system as well as to validate elastodynamic models of the mechanism [1]. Both the measurements and models can be very useful in order to understand the dynamic behaviour of the valve train, for the engine performance optimisation, and for the diagnostics of the mechanical system. The experiments described in the paper were devoted to the valve motion measurement during cold tests performed on a test bench where four cam-valve mechanisms were actuated. Valve lift and velocity were measured by means of a high speed differential laser vibrometer [1].

As usual for the vibration analysis of rotating machinery, it is preferable referring the actions of moving parts in the valve train system to the camshaft angular positions rather than to time because the inertial loads cause fluctuations of the

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camshaft rotating speed. Indeed, due to the velocity irregularity, the time domain analysis of the mechanism motion could fail to correctly represent the dynamic phenomena occurring in the system. On the contrary, once the vibration data are accessible into the angular domain, a certain event appears approximately at the same camshaft angular position and the measurements are readily available for interpretation and analysis [2]. It is therefore required to synchronise the valve motion to the angular position of the camshaft.

Based on the above mentioned reasons, the well established order tracking method [3] was employed to analyse the valve train vibrations (i.e. the vibrometer signals had to be sampled at constant increments of camshaft angle). No dedicated hardware devices were available, which normally includes a ratio synthesiser and an anti-aliasing tracking filter to sample signals at a rate proportional to the camshaft rotating speed. Thus, it was not possible to apply the conventional order tracking acquisition, which is based on analog hardware. As a consequence, the experiments were performed by means of a computed order tracking method, which is almost fully digital [4]: the valve motion signals were firstly acquired at a fixed sampling frequency by using a conventional multi-channel Analog-to-Digital Converter (ADC board), and then resampled in order to obtain the desired synchronized data, based on a tachometer signal that provides the measurement of the camshaft Instantaneous Angular Speed (IAS).

In this work the tachometer signal was supplied by an optical probe acting close to a zebra tape glued on the camshaft. The sensor tracks the alternating light and dark stripes present on the tape (27 couples of stripes), thus providing an output that has the typical shape of a TTL signal (binary electrical signal based on the Transistor–Transistor Logic standard). Such a system overcomes the drawbacks of other existing solutions that are either expensive or require time-consuming and difficult shaft modifications. On the other hand, the reliability of this simple system strictly depends on both the quality of the stripes over the tape (that must have exactly the same width in order to define evenly distributed sectors) and the accuracy of the tape fitting on the shaft (misalignment at the butt joint of the tape ends are likely to occur [5]). Other sources of error could be possibly present, such as shaft error or installation inaccuracies, but they are not considered in this study. During the tests, the valve motion and the optical probe signal were simultaneously recorded with a fixed sampling frequency, in order to make the data available for the off-line software resampling. Unfortunately, the employed zebra tape was not of high quality (i.e. it presented stripes with slightly different widths), thus leading to pulses that were not uniformly distributed with respect to camshaft angle. This limitation precluded the possibility to directly obtain the correct relationship between camshaft angular position and time, thus making the resampling procedure completely ineffective. Practical reasons (e.g. the tight test programme scheduled by the company) did not permit a rapid retrieval of a better quality tape nor to evaluate other solutions such as using optical encoder. In order to overcome this problem, a simple and practical procedure for the zebra tape identification was developed and implemented. After tape identification the resampling of the valve motion measurements can be properly carried out to transform the data into the angular domain and make them suitable for the analysis, as reported in the literature for different applications [2,6–8]. In particular, a statistical analysis on a number of camshaft cycles was useful to determine for example the average angular position of valve opening or closing, or between openings of different valves, etc.

The emphasis of the paper is on the zebra tape identification method rather than on the theoretical aspects of the digital signal processing techniques. The organisation is as it follows: Section 2 describes the experimental setup; Section 3 deals with the zebra tape identification; Section 4 illustrates the valve motion analysis.

2. Experimental setup

In order to get insight into the valve train dynamic of a racing motorbike engine, the valve motion was deeply inspected by an experimental test campaign. Indeed, it is significant to analyse the valve lift because its actual profile is decisive to guarantee the correct engine fluid dynamics and to assure high performance. In particular, it is very important determining the camshaft angular position of valve opening and closing, as well as the position of the maximum valve lift. In this context, an accurate IAS estimation leads to a reliable determination of the angular position of the valve lift events.

The valve motion measurements were carried out by performing cold tests on a test bench that includes only a portion of the motorbike engine timing system, i.e. it consists of two cylinder heads, two camshafts, and eight cam-valve mechanisms. The apparatus makes it possible to move both the camshafts or just only one, depending on the test aims. The experimental results reported in this study are obtained by driving only one camshaft. Fig. 1(a) shows a schematic of the test bench: it consists of a brushless motor actuating an intermediate shaft by means of a timing belt; the intermediate shaft drives the camshaft by means of an Oldham coupling; the camshaft moves four cam-valve mechanisms, which are numbered as 01,…, 04 starting from the side connected to the driving transmission chain.

The measurement devices present in the test bench are schematically represented in Fig. 2. The valve motion was picked up by means of a high speed laser vibrometer (Polytec High Speed Vibrometer), which permits differential measurements and allows to measure both valve lift and velocity [1]. The optical probe, acting on the zebra tape glued on the camshaft extremity close to the Oldham coupling (Fig. 1(b)), provided the tachometer signal. During the tests only one valve at a time was monitored. Both the valve motion and the tachometer signal were simultaneously acquired by means of a conventional multi-channel ADC board; the signals were sampled at the fixed frequency of 800 kHz (a low-pass filter with a 50 kHz cut-off frequency was applied to the valve motion signals, whilst the tachometer signal was not filtered in order to avoid distortion to the pulse train waveform). The experiments were performed at 13 different camshaft velocities