Low Cost Measurement System for the Precise Monitoring of the Instantaneous Rotational Speed of an Internal Combustion Engine

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***Abstract*— The work presented in this paper concerns the development of a novel low-cost measurement system for monitoring with high accuracy the instantaneous rotational speed of a low power industrial engine. The system has been successfully employed for monitoring the rotational speed of a typical four cylinder engine; a speed recording with a resolution of 0.04 degree of crank angle has been obtained, revealing its suitability for fault diagnosis and engine performance optimization applications. Key features of the proposed measurement configuration are very high monitoring accuracy, low-cost and ability to be installed on-site to an already operating engine with no major modifications; the above suggest numerous potential applications.**

Keywords-measurement system; encoder; instantaneous rotanional speed; 3D printing; fault diagnosis; internal combustion engine.

I. INTRODUCTION

Optimizing the performance of an engine has been the goal of numerous research efforts [1][2], since proper prediction of its main operation parameters (such as torque fluctuation during various loading, etc.) can significantly contribute to efficient fault diagnosis, fuel economy, gas emissions reduction and optimum engine performance in general. The value of the instantaneous rotational speed of the crankshaft is an important parameter employed widely in engine operation analysis and fault diagnosis [3]-[6], since it is relatively easily accessible employing low cost equipment. In general, there are two established methods for measuring the specific parameter: the timer/counter-based technique and the Analog-to-Digital Converter (ADC) based technique [7][8].

The vast majority of modern engine speed monitoring systems are based on the “magnetic pick-up” principle of operation, which is a timer/counter based method. In order to detect the engine’s speed, a given number of dents of appropriate size and geometry are patterned on the surface of the metallic flywheel of the engine, which is attached to the rotating shaft; an inductive sensor is then employed to detect the presence of each dent as the engine is operating (Fig. 1). The rotational speed is deduced from the sensor’s output pulse-train signal.

We should note that the maximum resolution of the above described system (i.e., maximum number of velocity

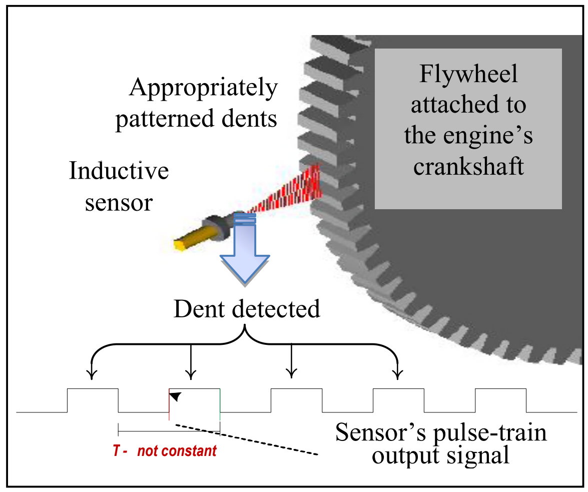

Figure 1. “Magnetic pick-up” principle of operation.

measurements during a single rotation of the crankshaft) is mainly affected by the minimum resolution of the sensor, that is, the minimum size required for each dent in order to be magnetically detected.

In a typical low power industrial engine [9], the above setup provides a maximum resolution of 120 measurements per cycle (i.e., the speed is measured every 3^o of crankshaft rotation). In order to increase that figure, one should increment the number of dents available on the flywheel, resulting in an increase of its overall dimensions; thus, the maximum resolution of such a system is limited by the available space provided for the flywheel –a constrain that cannot be altered easily, especially in the typical case of low/medium power engine.

Although the measuring principle described above is widely adapted regarding engine rotational speed monitoring, other alternative methods have been reported in literature. In more detail, angular speed recording with high accuracy by employing an appropriate optical measurement system has been successfully performed in a low power four stroke, four cylinder industrial engine [10], while the development and installation of a speed monitoring system which is based on a rotary encoder (on a four stroke, six cylinder industrial engine) has also been described [11].

Both of the previously mentioned methods lead to substantial increase of the maximum resolution of speed

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monitoring (i.e. angular speed measurements with a resolution of less than 0.5° are reported) compared to the established "magnetic pick-up" principle of operation. We should note though that an important constraint for employing widely such monitoring systems and rendering them practically useful to typical industrial engines - already operating on-site, focuses on the need of altering the initial engine setup, in order for the measuring system to be installed. With our proposed method, this constraint is practically removed.

The rest of the paper is structured as follows. In Section II, we present the proposed measurement system, while in Section III, the obtained preliminary results after applying the system to a typical industrial engine are discussed. Finally, we conclude the work in Section IV.

II. Description of the Proposed Method

The proposed measurement system overcomes the restriction imposed by the size of the flywheel and the necessity of altering the initial engine setup in general. This is achieved by employing an incremental rotary encoder in order to measure the instantaneous rotational speed which is mounted directly on the engine's crankshaft through a custom-designed coupling, manufactured by a 3D printer.

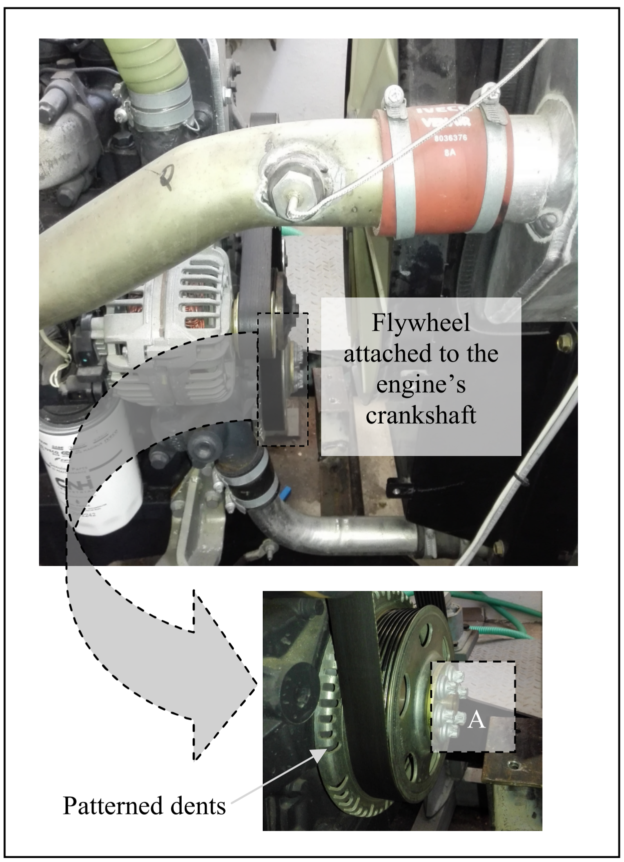

Figure 2. Typical low power engine's flywheel attached to the crankshaft; the incremental encoder is mounted directly on the flywheel (region A) through an appropriate/custom-designed coupling.

In more detail, a low-cost commercially available sensor (IFM electronic, type RVP510) has been employed. The sensor was mounted on the engine's crankshaft (Fig. 2) through an appropriate coupling (Fig. 3) which is designed and then manufactured by a 3D printer, according to the specific engine's crankshaft design. Thus, in the proposed setup, the maximum resolution of the measurement system is not limited by the available space provided for the flywheel as in the case of a typical engine speed measuring system (i.e. the number of dents available to be magnetically detected) but only by the resolution of the employed encoder which is directly coupled to the crankshaft. Typical incremental rotary encoders can easily perform more than 2,000 measurements per revolution [12] while the specific industrial type encoder that was employed has a maximum resolution of 10,000 measurements per cycle.

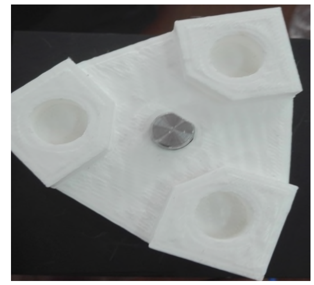

Figure 3. Appropriate coupling-manufactured by 3D printer; the encoder's shaft is visible at the center of the coupling.

Furthermore, the appropriate coupling –manufactured by 3D printer, can be custom-designed in order to fit to the crankshaft of basically any low/medium power already installed and working IC engine that needs to be monitored in a short time, eliminating the need for performing any alteration on the initial engine setup; the only addition necessary is the creation of a mechanical support for the encoder.

III. Results

Angular speed monitoring of 9,000 measurements per crankshaft rotation was successfully obtained employing the developed system on a typical low power four cylinder Diesel Engine, installed in the Department of Naval Architecture at the University of West Attica (Fig. 4). Note that all four cylinders firings are clearly noticeable at speed recording with an angular resolution of 0.04°.

We should point out that the speed profile presented in Fig. 4 is deduced directly from raw experimental data with no filtering applied for noise reduction purposes, making the specific method extremely immune to noise compared to similar results in literature [11], which are presented in Fig. 5. The above characteristic makes the system particularly suitable for fault diagnosis and engine performance optimization applications.

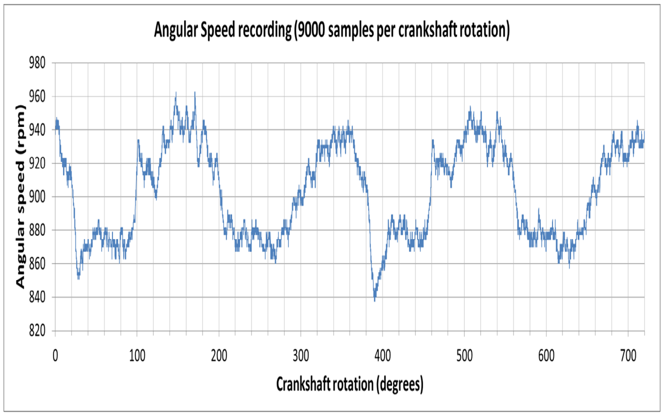

Figure 4. Angular speed monitoring of 9000 measurements per crankshaft rotation performed on a typical low power four cylinder Diesel Engine.

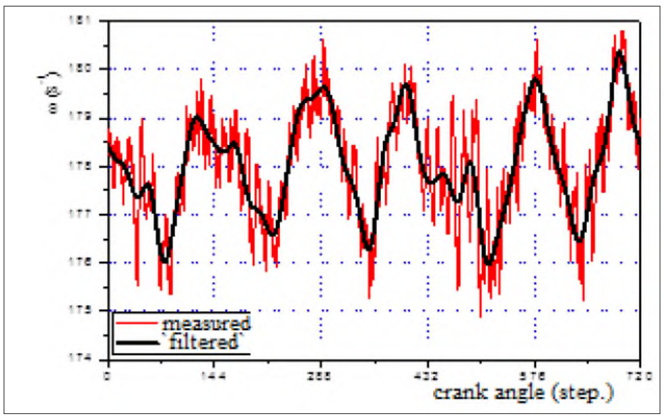

Figure 5. Angular speed monitoring before and after filtering at a four-stroke, six cylinder industrial engine [11].

An initial repeatability investigation has also been performed by recording rotational speed for a specific number of consecutive engine cycles. In more detail, the angular speed of the same engine was recorded for five consecutive engine cycles (i.e. 720° of crankshaft rotation) under the same operating conditions. The corresponding results are presented in Fig. 6; as we can clearly notice, there is a high concurrence between the different runs.

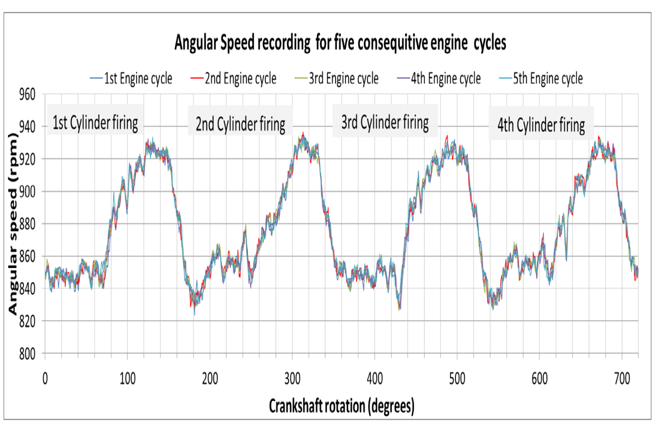

Figure 6. Rotational speed recording for five consecutive engine cycles (720 samples per crankshaft rotation).

IV. CONCLUSIONS

A novel low-cost measurement system for monitoring with high accuracy, the instantaneous rotational speed of an internal combustion engine has been developed. The system has been employed successfully for measuring the rotational speed of a typical industrial four cylinder engine with a resolution of 0.04 degree of crank angle, revealing its suitability for fault diagnosis and engine performance optimization applications.

The key features of the proposed measurement configuration are very high monitoring accuracy, low-cost and ability to be installed on-site, to an already operating engine with no major modifications, suggesting numerous potential applications.

Ongoing studies are focusing on fabricating a metallic coupling for long-term monitoring and also on determining how effectively the developed sensing arrangement can be employed in optimizing an engine's performance and in real-time fault diagnosis monitoring under different engine load conditions.

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