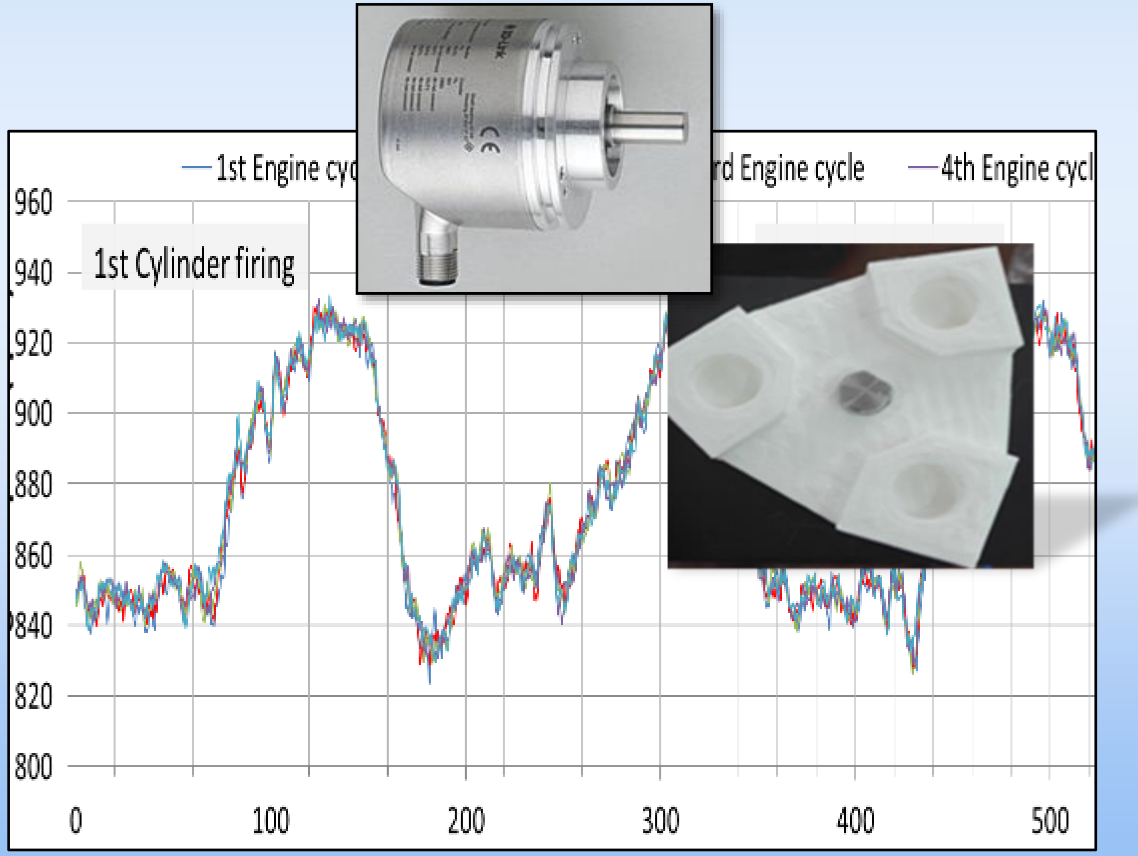
Low Cost Measurement System for the Precise Monitoring of the Instantaneous Rotational Speed of an Internal Combustion Engine

D.- N. Pagonis, S. Peppa and G. Kaltsas,
Dpt. of Naval Architecture, University of West Attica, Athens, Greece
D.N.Pagonis@uniwa.gr, speppa@uniwa.gr, gkaltsas@uniwa.gr



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

Sofia Peppa

Assistant Professor, Department of Naval Architecture

University of West Attica

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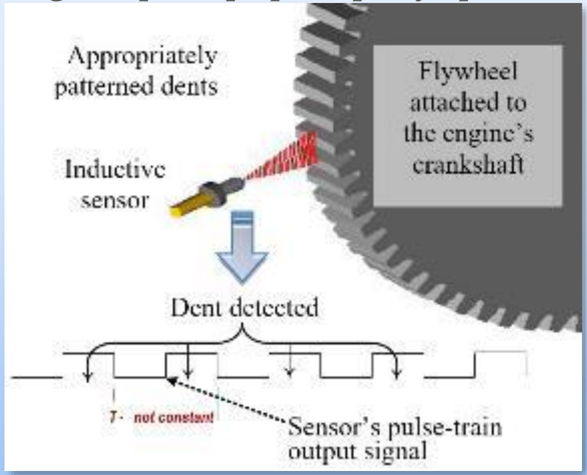
Objectives of the performed work

- This work 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 is mainly based on a commercially available incremental rotary encoder which is mounted directly on the monitoring engine's crankshaft through a custom-designed coupling, manufactured by a 3D printer
- The system has been successfully employed for measuring the rotational speed of a typical industrial four cylinder I.C. engine
- The accuracy of the system is high; a speed recording with a resolution of 0.04 degree of crank angle has been obtained
- The experimental results were compared with previous reported in literature revealing the proper functionality of the system and its suitability for fault diagnosis and engine performance optimization applications
- Key-features of the developed system are accuracy, simplicity and low-cost, suggesting numerous potential applications

The "inductive" principle of operation

- The principle that the majority of the modern engine rotational speed monitoring systems are based on
- Requirement for a metallic wheel carrying a given number of teeth (usually the engine flywheel is used)
- An inductive sensor is triggered accordingly; the rotational speed is deduced from the sensor's output signal
- The maximum resolution of the system i.e. maximum number of velocity measurements during a single rotation of the shaft, is limited by the minimum resolution of the sensor, i.e. the minimum size required for each pattern in order to be magnetically detected

"Magnetic pick-up" principle of operation



Principle of operation of the proposed system (1/2)

- In order to increase the resolution of an inductive system, the number of teeth available on the rotating disc should be incremented, resulting to an increase of its dimensions

- Therefore, the maximum resolution of such a system is limited - especially in the case of low power engines - by the available space provided for the engine flywheel

- In order to overcome this limit, an incremental rotary encoder has been employed

- A custom-designed coupling, manufactured by a 3D printer, is employed in order for the encoder to be mounted directly on the engine's crankshaft

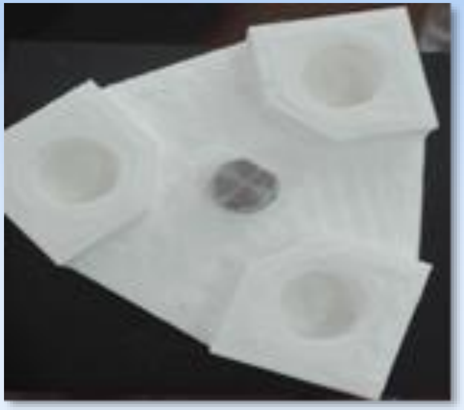
Typical commercial rotary encoder

[ifm electronic gmbh, *type RVP510*]

Principle of operation of the proposed system (2/2)

In more detail….

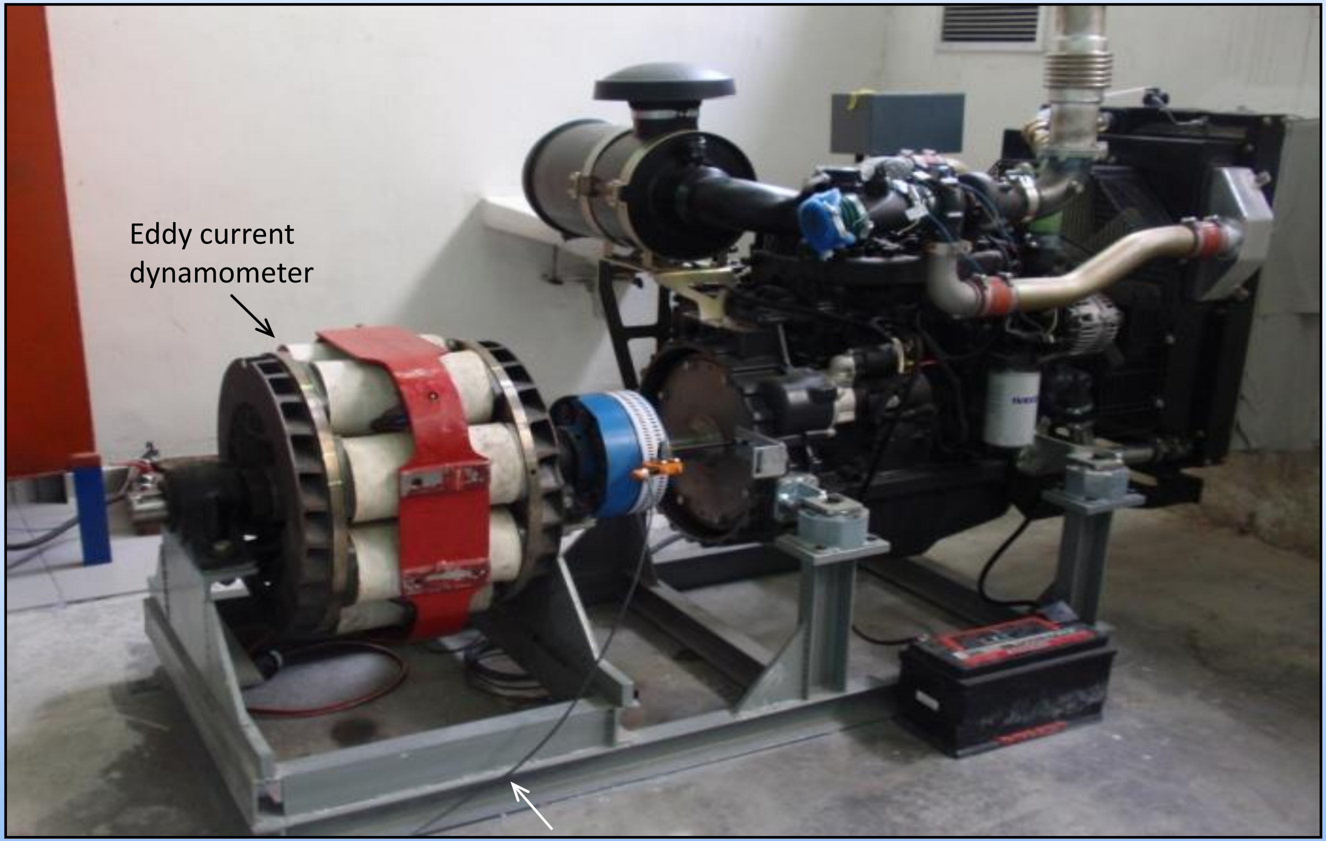
An appropriate coupling has been designed for the specific IC engine that is monitored. A 3D printer has been employed for manufacturing the coupling
(The encoder's shaft is visible at the center of the coupling)



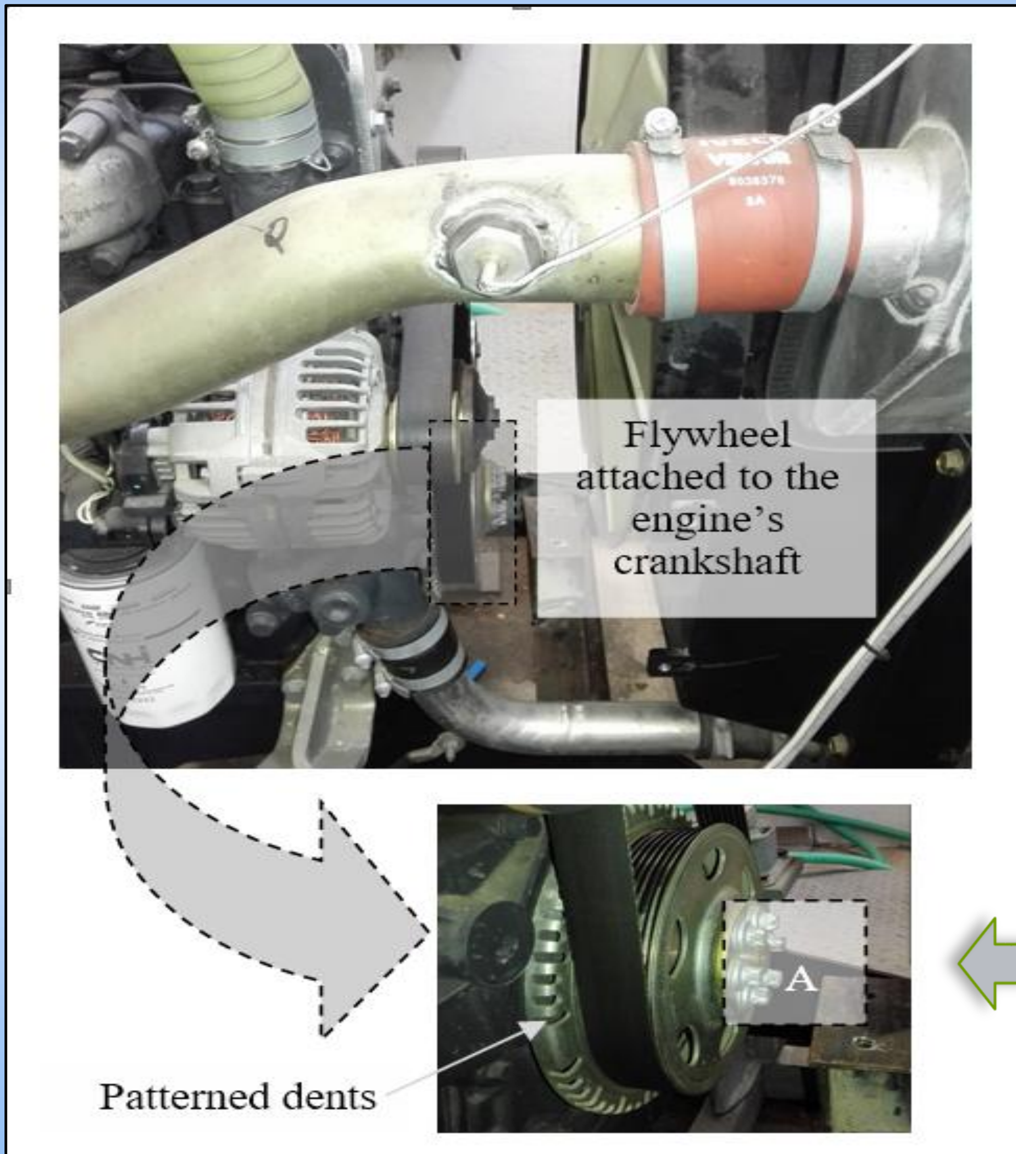
- The maximum resolution of the measurement system is not limited by the available space provided for the flywheel (i.e. the number of dents available to be magnetically detected) but only by the resolution of the employed encoder
- Typical incremental rotary encoders can easily perform more than 2,000 measurements per revolution - the specific industrial type encoder employed has a maximum resolution of 10,000 measurements per cycle
- The appropriate coupling 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
- The measuring setup can be accomplished 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

Experimental set-up layout (1/2)

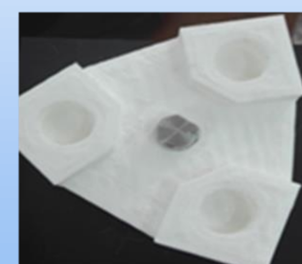
- The engine employed is already installed and running at the Department of Naval Architecture
- It is a typical industrial low power, four-stroke, turbo-charged DIESEL engine
- No major alteration on the engine set-up can be performed



Experimental set-up layout (2/2)

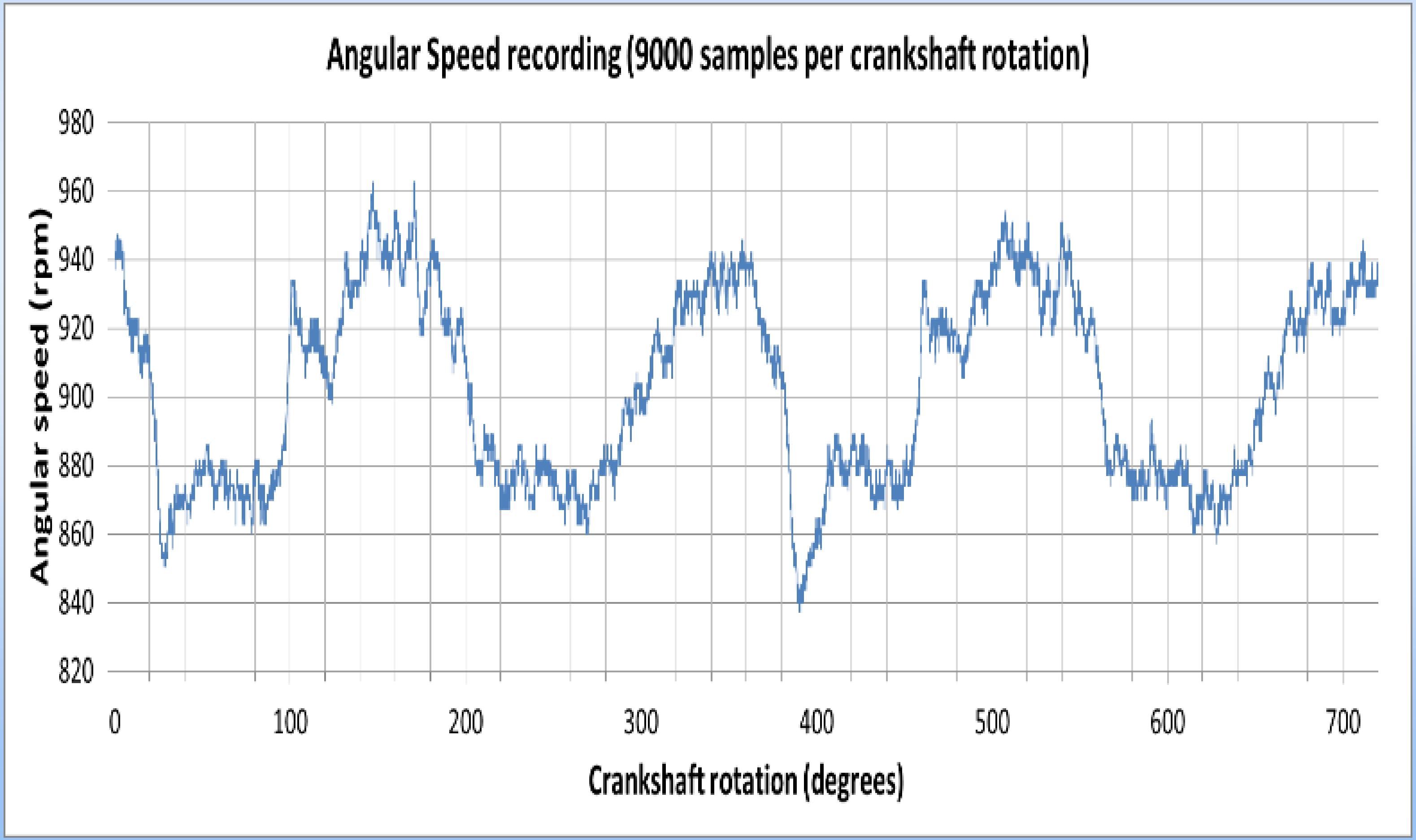


- The specific engine has a rated power of ***93 kW*** (125 HP) at 2200 rpm
- The engine is mechanically coupled with an appropriate Eddy-current dynamometer
- The incremental encoder is mounted directly on the flywheel (region A) through the appropriate/custom-designed coupling



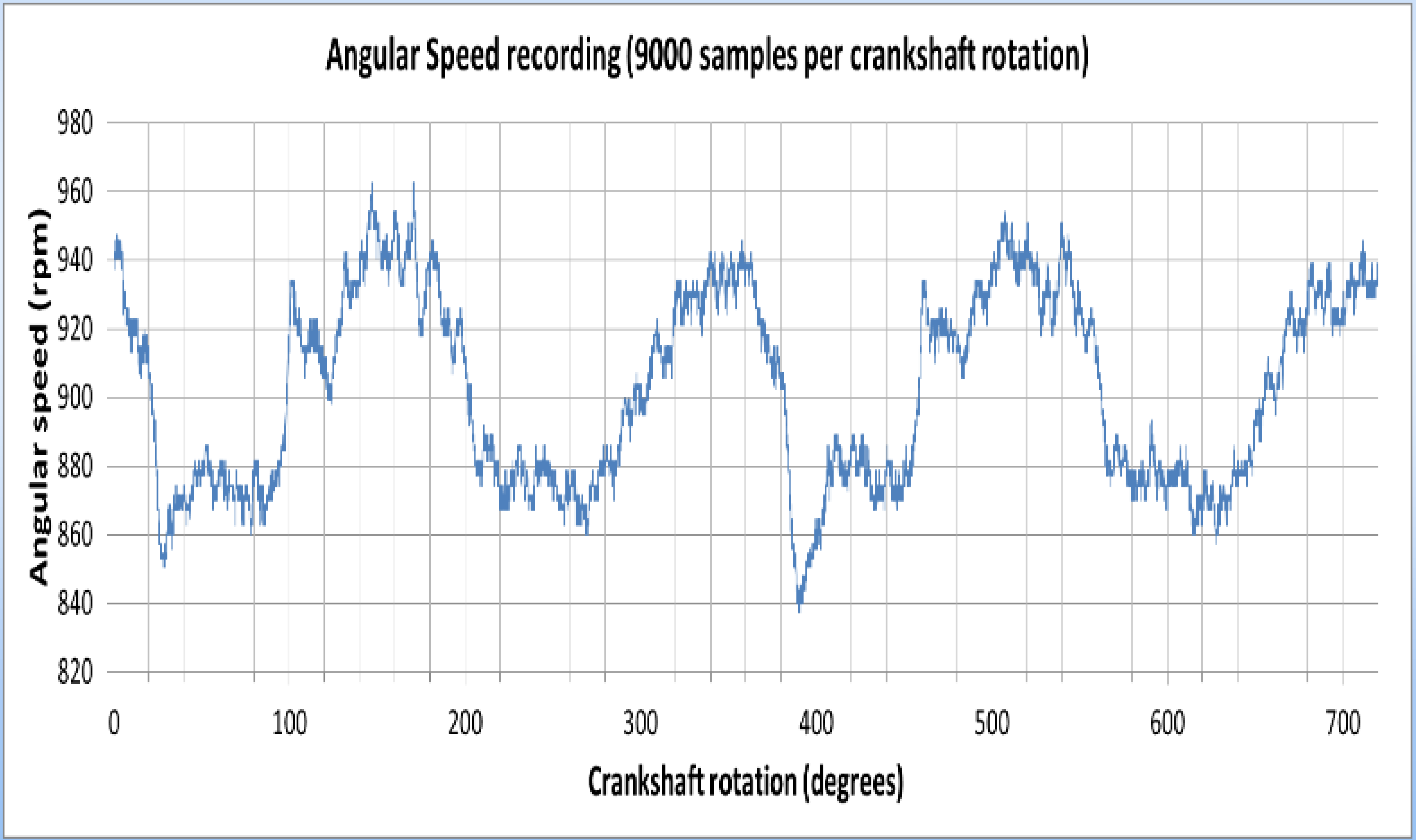
Initial experimental results (1/5)

- As a first approach the engine was set to run at idle speed
- Angular speed monitoring of 9,000 measurements per crankshaft rotation (i.e. an angular resolution of 0.04°) was successfully obtained



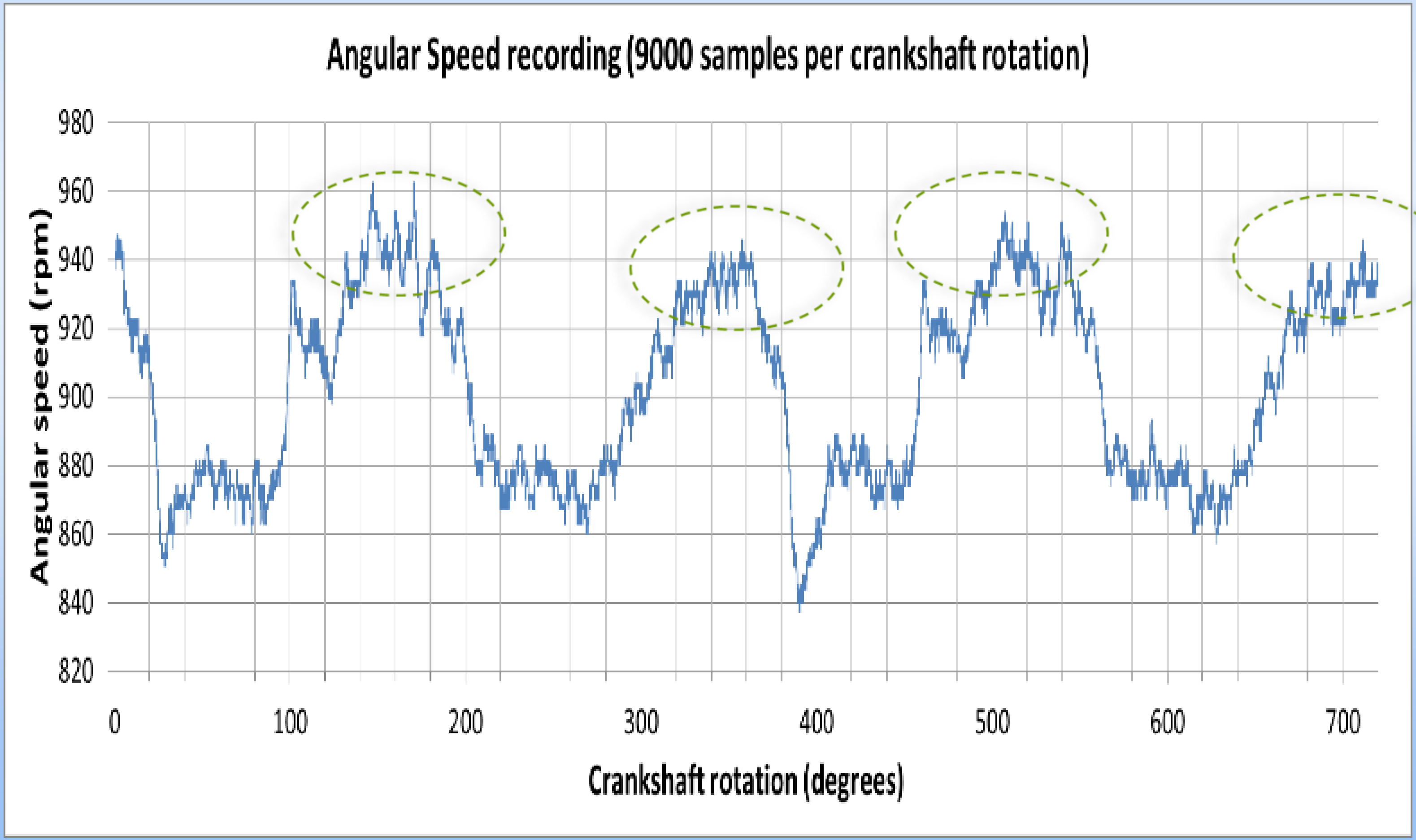
Initial experimental results (2/5)

- The speed profile presented is deduced directly from raw experimental data with no filtering applied for noise reduction purposes; therefore, the specific method seems extremely immune to noise



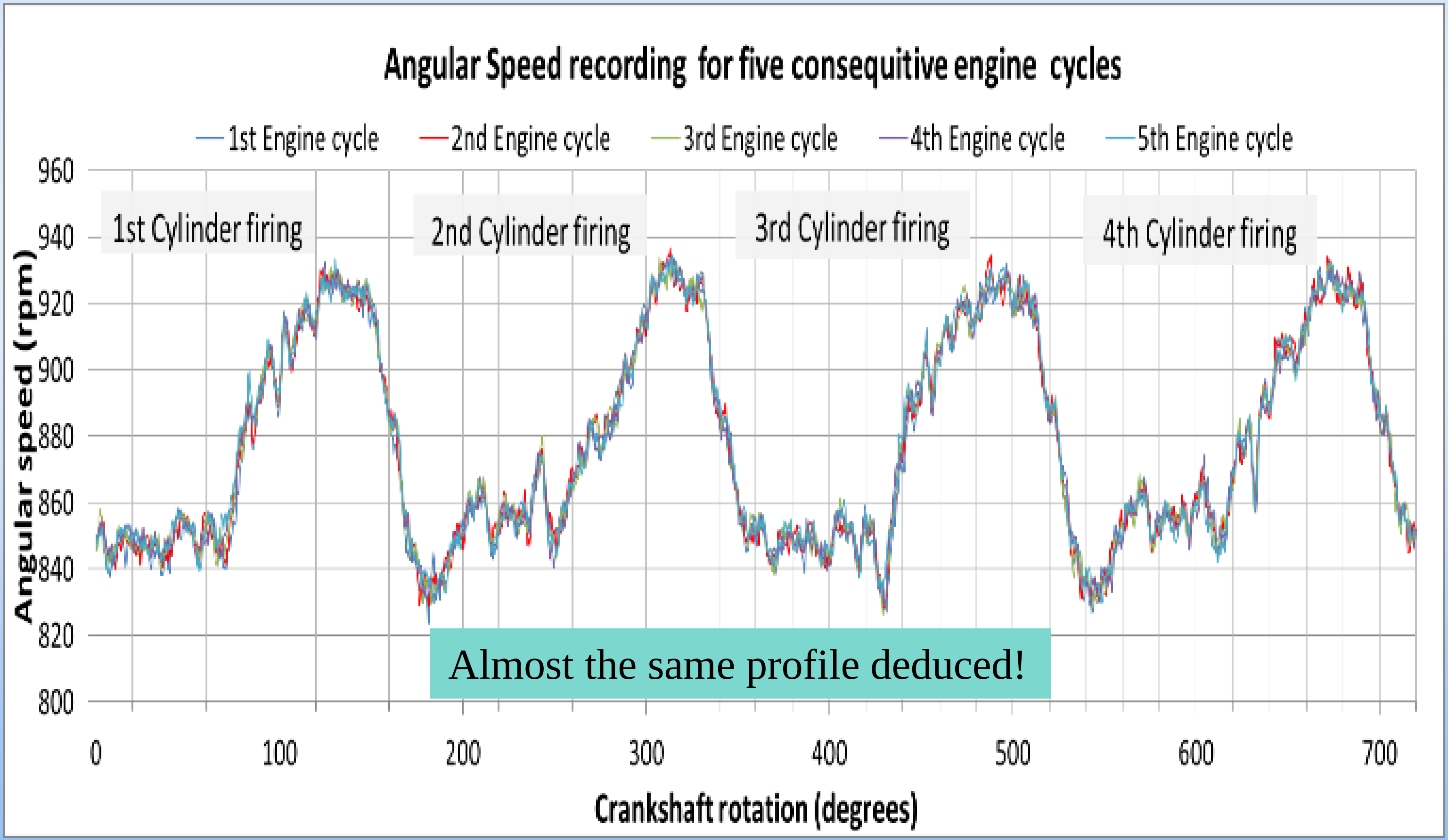
Initial experimental results (3/5)

- All four cylinders firings are clearly noticeable
- The immunity to noise and the high resolution of the system make it particularly suitable for fault diagnosis and engine performance optimization applications



Initial experimental results (4/5)

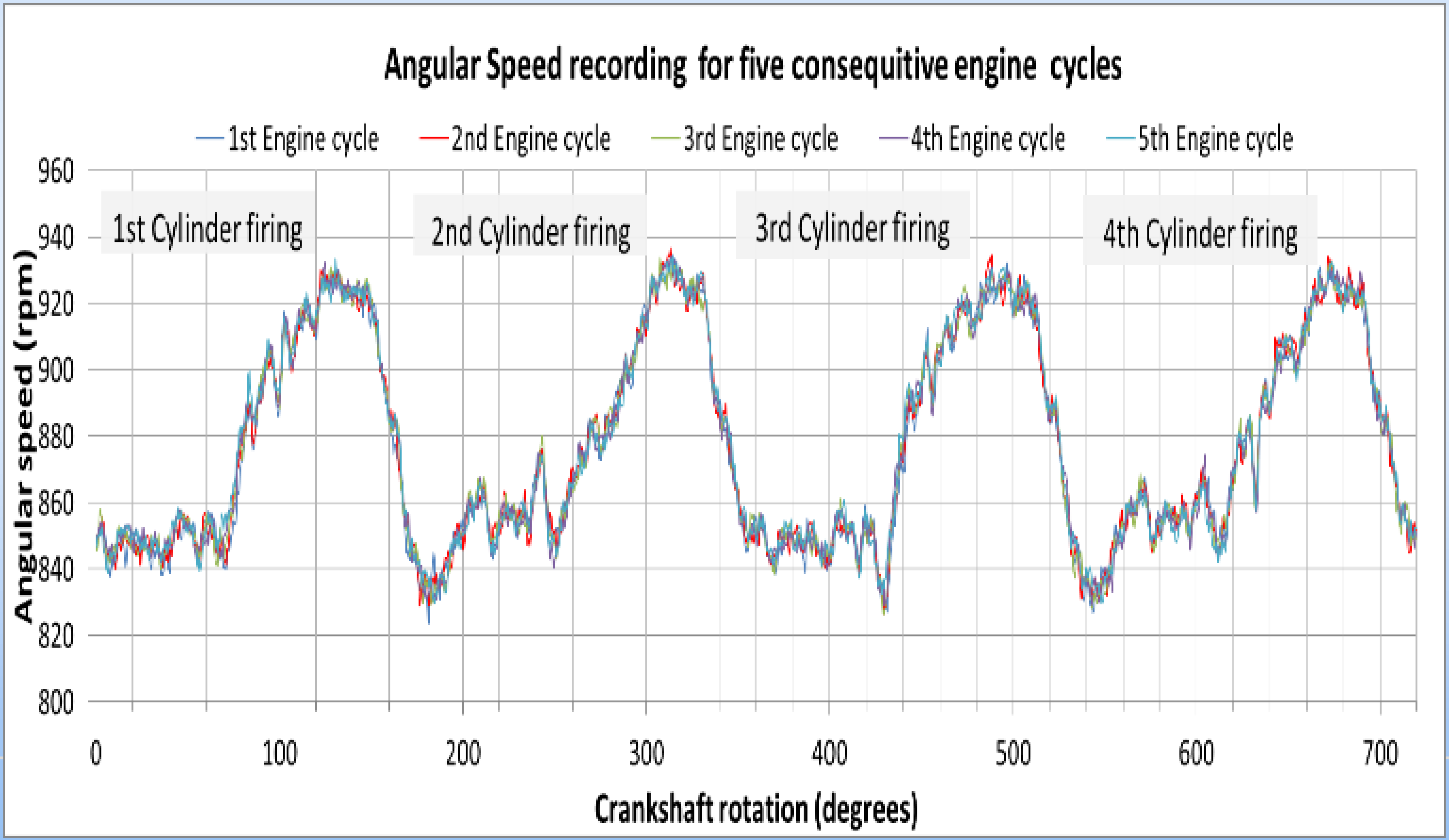
- An initial repeatability investigation has been performed by recording rotational speed for a specific number of consecutive engine cycles
- The angular speed was recorded for five consecutive engine cycles (i.e. 720° of crankshaft rotation) under the same operating conditions



Initial experimental results (4/5)

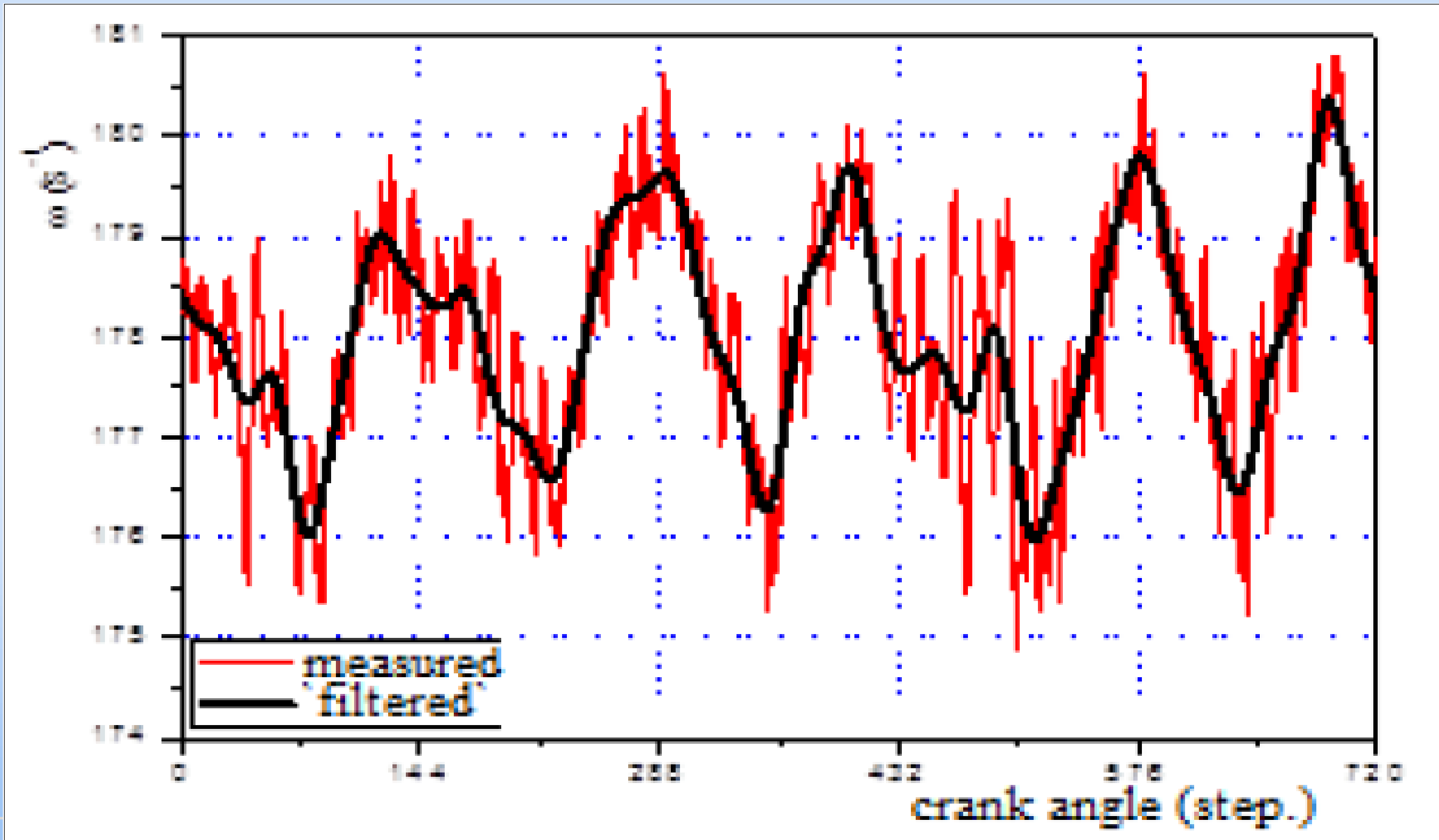
- There is a high concurrence between the five separate engine runs

Similar results in literature?



Initial experimental results (5/5)

- Much lower resolution
- Substantial noise is present – appropriate filtering is employed in order to reveal the speed profile signal



[S. Biocanin et al., Serbian Journal of Electrical Engineering, vol.14 (2), pp.257-275, 2017]

Conclusions (1/2)

- 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 is mainly comprised of a ***low-cost commercial rotary encoder*** and appropriate designed coupling manufactured by a 3D printer
- The system was successfully integrated into ***a typical industrial*** low power engine
- The rotational speed of a low power four cylinder engine with a resolution of 0.04 degree of crank angle has been succeeded, revealing its suitability for fault diagnosis and engine performance optimization applications
- An initial repeatability investigation has been also performed by recording rotational speed for a specific number of consecutive engine cycles

Conclusions (2/2)

- 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

Thank you for your attention!