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Wireless Eddy Current Telemetry System for Measuring Axial Piston Ring Movement in a Combustion Engine

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Summary:
This paper presents an approach to measuring axial piston ring movement in a running combustion engine using a wireless telemetry system. The electrical design of the telemetry is discussed as well as steps taken to enable operation under the extreme conditions inside an engine. Emphasis is placed on the embedded system, power supply, signal acquisition, and data post-processing techniques. The paper concludes with an outlook for future applications and measurements with eddy current sensors.

Keywords: wireless telemetry, inductive position measurement, piston ring movement, embedded systems, harsh environment

Background

Ongoing development of sensor technology and electronics is making it possible to solve more and more measurement tasks that were not possible in the past. Modern sensor systems are becoming increasingly popular in the field of combustion engines, the further development of which is essential in the fight against climate change with regard to the use of alternative fuels [1]. Conventional sensor systems are typically not suited for application inside the engine or on the piston, due to the high temperatures, vibration, and size constraints. While measurements of piston temperature and pressure are possible with both wired [2] and wireless [3] methods, until now, the piston ring kinetics could only be calculated with the help of simulation models [3],[4].

In piston engines, the combustion of fuel initiates an oscillating movement of a piston, which is then converted into a rotational movement at the crankshaft. The combustion chamber, between the moving piston and the cylinder in which it moves, is sealed with the aid of piston rings. The kinetics of the ring are crucial regarding the efficiency and reliability of the engine, as this system causes up to 50 percent of internal friction losses [5] and 20 percent of the total mechanical losses of the engine [6].

Methodology

Piston ring movement in the axial direction is measured with a wireless telemetry system developed for application in the crankcase of a combustion engine. The embedded measurement system is based on an ARM cortex-M33 microcontroller with extended operating temperature range to 125 °C. Measurement data is transmitted to a receiver on the testbench via a Bluetooth radio integrated in the microcontroller. Due to the low number and compact size of the auxiliary components and microchips required for the telemetry, the entire signal acquisition system, measuring 3 x 6 cm, can be mounted on the piston.

Power is supplied to the system via inductive coupling. A receiver coil, buffer, and voltage regulator are mounted on the side of the piston. When the piston reaches the bottom of the cylinder, the receiver coil becomes aligned with a transmitter coil mounted inside the engine. A changing magnetic field produced by the transmitter coil charges the receiver during their alignment. The stored energy allows for the telemetry to measure continuously over the complete engine rotation.

The axial ring movement is measured by eddy current sensors installed in the piston ring grooves. A cross-section of the sensor installation is shown in Fig. 1. The top ring position is measured with a sensor installed in the bottom flank of the groove, while the second and third rings are measured with sensors installed in the top flanks of the respective grooves. The sensors feature a sub 5 mm diameter and 2 mm height, allowing them to be installed in a piston with 19 cm bore without modifying the piston and potentially influencing its performance. Signal acquisition of the eddy current sensors is performed with Texas Instruments LDC1101 inductance to digital converter integrated circuits.

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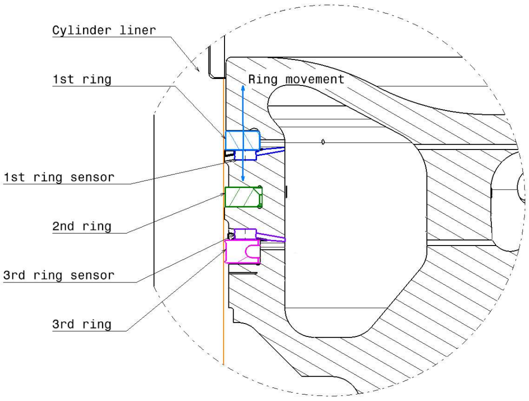

Fig. 1: Cross section of eddy current sensors in piston ring groove flanks

The LDC feature an internal sensor driver which brings inductive sensors into oscillation. Each sensor is paired with a parallel capacitor to set the resonant frequency around 2.5 MHz. Capacitors with C0G dielectric are used due to their low temperature coefficient of capacitance, as temperature on the telemetry PCB readily exceeds 100 °C during full engine load.

In most applications, the distance of a conductive target to an eddy current sensor is measured by the change in power input to the sensing coil as it induces eddy currents and dissipative power in the target. Due to the low Q factor of the small eddy current sensors required for installation in the piston ring, this parameter is out of the measurable range for the LDC1101. Instead, the position of the ring is acquired by measuring the change in inductance of the eddy current sensor. As the ring approaches the sensor, the sensor's inductance decreases and resonation frequency increases. This frequency is digitized by the LDC with an internal register and reference clock generated by the telemetry microcontroller.

The digitized frequency is polled at a sample rate of 10 kHz. For an engine operating at 1500 rpm, this corresponds to approximately 400 samples per revolution which is sufficient to capture transient motion during combustion. While the M33 microcontroller features a core clock speed of 38.4 MHz, there is insufficient time to simultaneously sample and transmit data from all sensors in real time at this rate. Therefore, a buffer solution using magneto-resistive random-access memory is employed to store data over an 8 second sample period. The high storage density, extended temperature range, and lack of write delays are essential for successful implementation of the telemetry. Time synchronization with other sensors on the testbench is achieved with a reference signal transmitted once per revolution via an infrared diode to a photodiode receptor on the telemetry. When a sampling period is complete, measurements are wirelessly transferred to the testbench.

Results

An example of the eddy current sensor output of the 2nd piston ring's axial movement is plotted in Fig. 2. As the measurements were performed on a 4-stroke engine, the x-axis covers 720 degrees of revolution, starting at 90 degrees before combustion and continuing to the compression stroke of the next cycle at 630 degrees. The measurement consists of 150 combustion cycles overlaid on the same plot in gray. For each crank angle, the most common result is displayed in navy and the average result in orange. This post processing strategy is required as the incremental resolution of the sensor is low, with approximately 10 increments of 12 µm corresponding to a maximal ring movement of 120 µm.

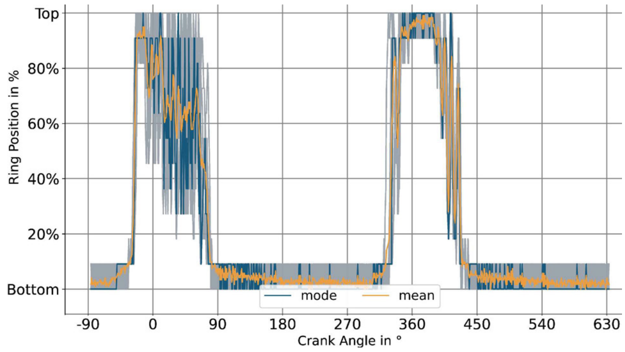

Fig. 2: Eddy current sensor measurement results

It can be seen that for some portions of the cycle, 45° before combustion for example, the mode and mean values agree with each other, indicating minimal variation between cycles. However, during combustion, from 0° to 80°, the mode and mean diverge, indicating larger variations between cycles due to irregularities in the combustion process.

Conclusion

The development and successful testing of the measurement system confirms that this technique is suitable for applications in combustion engines. The sensors and signal acquisition circuitry proved to hold up to the extreme conditions in the engine, although improvements are required to robustness of the first ring's sensor, as it failed during the first combustion cycles.

Future research will focus on broadening the application of wireless eddy current sensor telemetry systems. Current topics include measurement of cylinder liner distortion and oil film thickness, as well as improvements to sensor robustness and measurement quality in the second generation of the telemetry.

References

[1] C. Kendlbacher, K. Schrattbauer und R. Schimon, Alternative fuels and their applications on large engines,*18th Symposium "Sustainable Mobility, Transport and Power Generation", Graz, Austria* (2021)

[2] D. E. Richardson, Comparison of Measured and Theoretical Inter-Ring Gas Pressure on a Diesel Engine, *SAE Transactions,* Vol. 105, 1910-1923 (1996); doi: 10.4271/961909

[3] A. Higgs, B. Rossegger, A. Tilz, M. Vareka, M. Engelmayer, & A. Wimmer, The Development and Application of Advanced Sensor Solutions for Gaining New Insights Into Large Engines, *ASME 2023 ICE Forward Conference, (2023); doi:* 10.1115/ICEF2023-110623

[4] D. Weiß, S. Posch, M. Engelmayer und A. Wimmer, Development, Calibration and Validation of a Tribological Simulation Model for the Piston Ring Pack of a Large Gas Engine, *SAE International Journal of Advances and Current Practices in Mobility*, Vol 5, 642-651 (2022); doi: 10.4271/2022-01-0323

[5] A. Götze und D. Jaitner, Combined experimental and simulative approach for friction loss optimization of DLC coated piston rings, *Automotive and Engine Technology*, Vol 7-3, 283-293 (2022); doi: 10.1007/s41104-022-00115-7

[6] K. G. Mahmoud, O. Knaus, T. Parikyan, G. Offner und S. Sklepic, An integrated model for the performance of piston ring pack in internal combustion engines, *Proceedings of the Institution of Mechanical Engineers*, *Part K: Journal of Multi-body Dynamics*, Vol. 232-3, 371-384 (2018); doi: 10.1177/1464419317736676