COMPARISON OF TWO PEDALING SENSORS, ICRANKSET AND SRM, AGAINST A STANDARD REFERENCE SENSOR

Julien Bernard, Arnaud Decatoire and Patrick Lacouture
Institute Pprime, CNRS & University of Poitiers, Poitiers, France

Our aim was *i)* to validate the I-Crankset sensor (I-CS) with a reference torque sensor (RTSL) for the calculation of crankset torque, power and work outputs and *ii)* to compare I-CS with the SRM sensor, a popular device. SRM and I-CS sensors were mounted simultaneously on a test bench instrumented with the RTSL used to validate I-CS. The protocol included multiple sets of 30 pedaling cycles in three conditions to explore various solicitations. Torque magnitudes, angular velocity and power output were compared using the coefficient of multiple correlation inter-protocol. The results showed a good validity of both the I-CS and SRM for all the conditions in comparison to RTSL for torque's measurements and power's calculations, even if an average angular velocity is used by SRM. But this one showed its limitations when calculating the work output.

KEY WORDS: powermeter, SRM sensor, I-Crankset sensor, validation, cycling.

INTRODUCTION: In the last decade, several measurement systems have been designed to evaluate the crankset torque and power output during pedaling. These tools are used by cyclists and coaches both during training and competition sessions. SRM (Schöberer Rad Meβtechnik, Julich, Germany) and I-CS (SENSIX Society, Poitiers, France) are two interesting systems that cyclists can install on their own bike on the road or during laboratory testing. Many authors proposed validation studies of cycling powermeters [eg PolarS710 (Millet, 2003), PowerTap (Bertucci, 2005), SRM (Paton, 2001). But no study has validated the I-CS. This newer mobile cycling powermeter measures the forces and torques produced at the right and left pedals together with pedals' orientation and then calculates the resultant torque and power output at the crankset. To our knowledge, no study has compared torque obtained with powermeter to reference torque sensor's measurements. The aim of this study was to assess the validity of the I-CS with a RTSL [Eaton Corporation, Troy Michigan, USA] and to compare it to the SRM.

METHODS: Subject One subject took part in this study since the aim of this work was to validate a measurement chain. The validation should be independent of the subject, of his level of practice and of his technique. Before the tests, the cyclist was verbally informed of the objectives of the study. He gave written his consent. The test bench was composed of several elements (Figure 1).

Instrumentation: The chainring (A) was used to connect the ergocycle to the bench through a chain. The RTSL (C) was installed on the axis (B), and finally a flywheel (D) used to modify the resistive load through a mechanical braking device (E) compound tray to put additional masses. The cyclist had to produce a pedaling torque to overcome that resistive load. The SRM uses a technology based on strain gauges to measure the torque and calculates an average angular velocity for each revolution of the chainring. The I-CS calculates torque and instantaneous angular velocity from measurements of instrumented pedals (six load components and optical encoders positioned on the crankset axis). After calibration procedure, precision of the RTSL was 1 Nm. All the signals are acquired at 200 Hz. We recorded a synchronization signal from the acquisition system of the I-CS in order to synchronize all the measuring devices. Thus, for each cycle and for each acquisition system, we had the same number of acquisitions.

Protocols The rider adjusted the cycle ergometer (saddle and handlebar positions) according to his personal preference. The validation protocol was implemented to realize multiple pedaling conditions included in three conditions presented in table 1. Verbal instructions were given to the cyclist and feedback of mechanical power and cadence were displayed on the "Power Control" SRM bicycle computer.

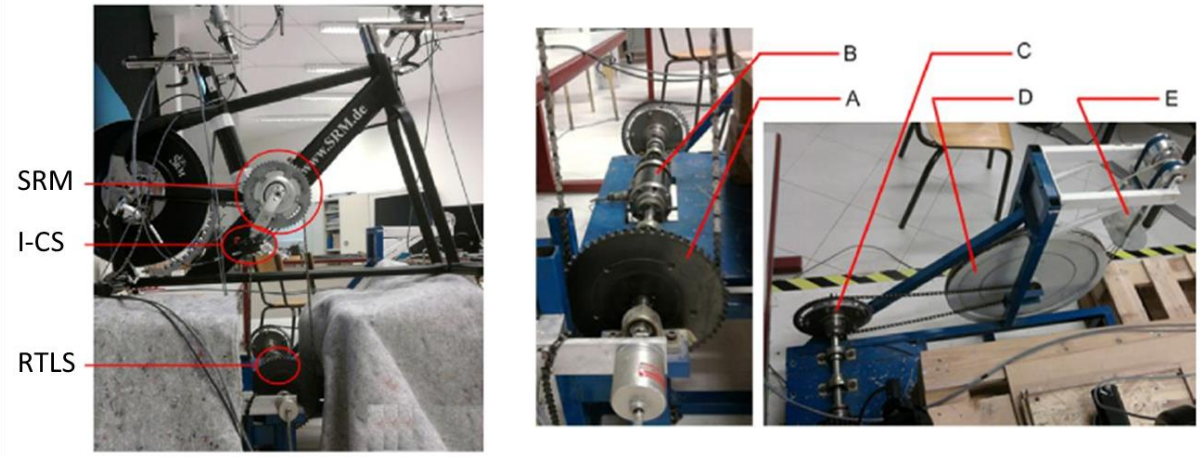

Figure 1: Test bench description: SRM sensor, instrumented pedals by I-CS sensor, RTSL (B), chainrings (A,C), flywheel (D) and mechanical braking device (E).

Table 1: The pedaling conditions. The C1 was obtained with both fixed pedaling cadence and resistive load; C2 with a fixed pedaling cadence and an increasing resistive load and C3 with a fixed resistive load and an increasing pedaling cadence.

Conditions	C1	C2	C3
Resistive load	26 Nm	18 to 30 Nm	42 Nm
Pedaling cadence	80 rpm	80 rpm	56 to 90 rpm

Statistical analysis: For each condition, the same analysis was performed on torque, angular velocity and power output obtained from the different systems. The pedaling cycles, once normalized were compared using a coefficient of multiple correlation inter-protocol (CMC_{ip}) proposed by Ferrari (2010). The CMC_{ip} is designed to appreciate the similarity of the measures given by various sensors in a single acquisition of the same parameter. In our case, the CMC_{ip} compared two by two the values obtained for the three parameters for each cycle. A CMC_{ip} close to 1, indicates that values obtained by two devices are significantly identical while a value less than 0.95 indicates no possible conclusion on significant similarity of the measured values.

RESULTS: Torque comparison: The signals are compared pairwise; the torque produced by the RTSL is compared with those given by I-CS and SRM. Then the data from the I-CS and SRM are also compared (Figure 2). Table 2 reports the average values of the CMC_{ip}^{Torque} obtained for the comparison of the torque measured for the three systems and for the three conditions. All the values are very close to 1.
Angular velocity comparison: Similarly to the torque, we calculated $CMC_{ip}^{Velocity}$ for the angular velocities measured by SRM and I-CS. By the way it is design, the SRM determines a constant value of angular velocity averaged over the cycle (see dashed line of second graph of figure 2). By calibration, RTSL and I-CS give the same instantaneous cranks' angular velocity thus resulting to $CMC_{ip}^{Velocity}$ equal to 1. In contrast, there is no similarity for the angular velocity between I-CS and SRM sensors; result confirmed by the complex values of $CMC_{ip}^{Velocity}$ (not reported here).

Mechanical power output comparison: Table 2 also shows the values of CMC_{ip}^{Power} for the mechanical power output. Whatever the systems used and whatever the conditions, CMC_{ip}^{Power} values averaged over all cycles are greater than 0.95.

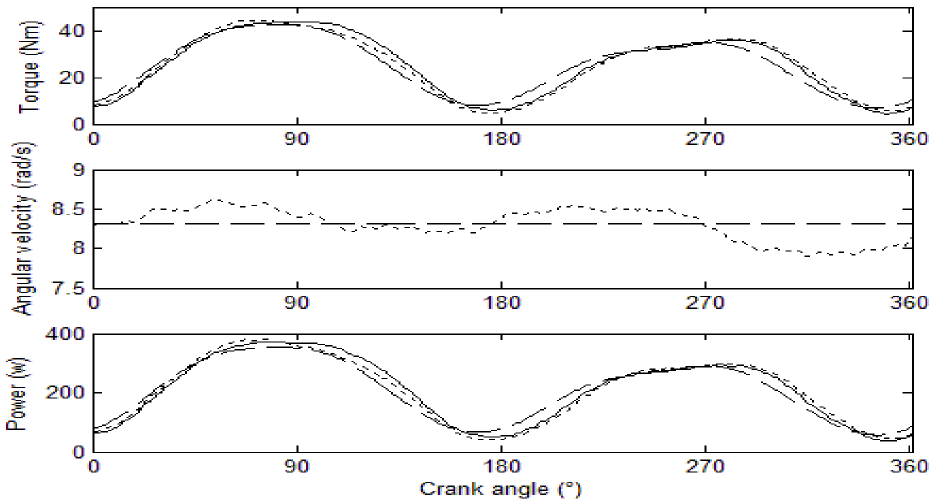

Figure 2: Representation of one cycle for the torque, angular velocity and power obtained with RTSL (solid line), I-CS (dotted line) and SRM (dashed line). The cycle starts at 0° with the left pedal in the top dead center.

Table 2: Average values of the CMC_{ip}^{Torque} and the CMC_{ip}^{Power} obtained for all cycles measured by the different sensors and the different pedaling conditions.

	C1		C2		C3	
	Torque	*Power*	Torque	*Power*	Torque	*Power*
I-CS versus RTSL	0.99	*0.99*	0.99	*0.99*	0.99	*0.99*
SRM versus RTSL	0.98	*0.98*	0.98	*0.98*	0.98	*0.98*

Mechanical work output comparison: Table 3 shows the difference of cumulative output work over thirty cycles between I-CS versus RTSL and SRM versus RTSL. The differences are also expressed as the percentage of the total cumulated work. To analyze the influence of the angular velocity, we integrated power output over time to calculate the work output in using *i)* the torque and angular velocity measured by SRM and *ii)* the SRM's torque multiplied by I-CS's angular velocity. These results are presented at the last lines of table 3.

Table 3: Total difference of cumulative work output over thirty cycles between I-CS and RTSL sensors and SRM and RTSL sensors. * Work calculated with $W = \int [\tau_{SRM} \bullet \bar{\omega}_{SRM}]dt$ and calculated with ** $W = \int [\tau_{SRM} \bullet \omega_{I-CS}]dt$ with τ_{SRM} is torque measured by SRM, $\bar{\omega}_{SRM}$ is average angular velocity measured by SRM and ω_{I-CS} instantaneous angular velocity measured by I-CS.

	C1		C2		C3	
	Work (J)	*(%)*	Work (J)	*(%)*	Work (J)	*(%)*
I-CS versus RTSL	1.63	*0.03*	74.27	*1.88*	117.44	*1.56*
SRM versus RTSL*	46.25	*0.98*	45.72	*1.16*	396.77	*5.26*
SRM versus RTSL**	38.42	*0.81*	39.37	*1.00*	108.28	*1.44*

DISCUSSION: In this study, the parameters analyzed were torque, angular velocity, power and work outputs generated at the crankset. In figure 2, we note that the variations of the torque and power output given by the three sensors are similar but not for the angular velocity. This result is confirmed by the CMC_{ip} values (table 2). Consequently, I-CS and SRM sensors were validated with the RTSL for the measures of torque and power output whatever the conditions. Thus, the powers calculated by I-CS and SRM were similar although the angular velocities were not. Apparently, changes in angular velocity do not seem to have much influence on the power's calculation. However, table 3 shows that considering average angular velocity affects work's calculation, especially for C3. The error in percent was 5.26% for the SRM sensor against 1.2% for I-CS. Also, for this condition (C3), SRM sensor was less accurate than I-CS compared to the reference sensor. For the other conditions (C1, C2) calculated precisions were included in those announced par the manufacturers (>1% for I-CS and 1% for SRM). Thus, when pedaling with variable angular velocity, the power output measured by SRM was not enough accurate to calculate work output. The integration of power over time accumulated small differences between the powers measured by SRM and I-CS. If these differences measured at each instant were not significant ($CMC_{ip} > 0.95$), it was necessary to take into account when calculating the work as part of an energy study of the pedaling motion.
However, the error in % was reduced to 1.44% when the torque measured by SRM was multiplied by the instantaneous angular velocity measured by I-CS. For the C1 and C2 conditions, the results were also better. Also, for C3 condition, SRM sensor was less accurate than I-CS compared to the reference sensor.

CONCLUSION: Our study demonstrated that I-CS is a valid powermeter and compared well with a standard reference sensor and the SRM irrespective the pedaling cadence and the resistive load. It can be used as a valid torque/power/work evaluation system with the advantage of being able to differentiate the right and left legs contributions in the overall torque and power output at the crankset. These differentiated measures are necessary input data to initiate the inverse dynamics procedure, in order to proceed to energetic analysis of the cyclist. Finally, if some studies have shown a good accuracy of the SRM, these authors were limited to the comparison of powers calculated while the assessment of energy expenditure required to compute the work. In this case, we showed that the SRM sensor is not suitable; pedaling velocity measured by the SRM is not enough accurate especially when it varies significantly.

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