WKO4 Pedaling Metrics

Rationale and Derivation

by Andrew R. Coggan, PhD

WKO4 PEDALING METRICS

RATIONALE AND DERIVATION

by Andrew R. Coggan, PhD

Contents

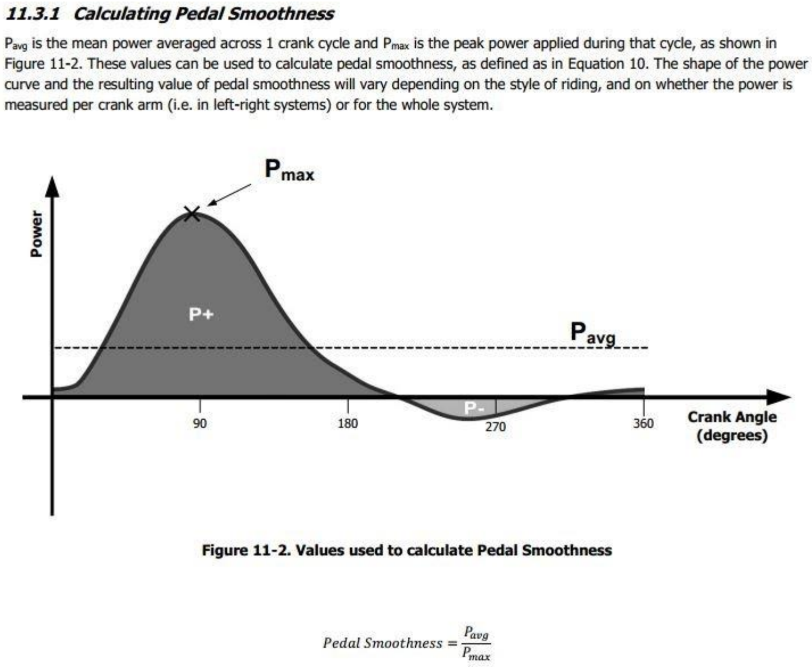
Introduction

The recent proliferation of power meter brands has led various manufacturers (starting with Rotor) to try to differentiate themselves in the marketplace by offering products that not only measure power, but also at least attempt to provide insight into the pattern of force application while pedaling (see Appendix). In some cases this requires use of proprietary software and/or hardware, but in many cases pedaling action data are summarized and transmitted using the ANT+ metrics **pedal balance**, **pedal smoothness**, and **torque effectiveness**.

Unfortunately, these ANT+ metrics seem to be largely based on the misconception that a rounder (less peaky) pedal stroke is somehow more efficient and/or less fatiguing. Fortunately, however, it is possible to use pedal smoothness and torque effectiveness (along with L/R balance) to calculate other parameters that I believe to be more relevant. Specifically, by “undoing” the summarization involved in calculating pedal smoothness and torque effectiveness, it is possible to calculate a) the **maximum effective pedal force (MEPF)**, b) the **gross power released (GPR)**, and c) the **gross power absorbed (GPA)** during each pedal revolution. The purpose of this document is to describe some of the rationale for this approach and to document how these metrics are derived.

MEPF

As indicated above, power meters utilizing the ANT+ protocol can report pedal smoothness, the mathematical basis for which is illustrated in Figure 11.3.1 below:



11.3.1 Calculating Pedal Smoothness

P_{avg} is the mean power averaged across 1 crank cycle and P_{max} is the peak power applied during that cycle, as shown in Figure 11-2. These values can be used to calculate pedal smoothness, as defined as in Equation 10. The shape of the power curve and the resulting value of pedal smoothness will vary depending on the style of riding, and on whether the power is measured per crank arm (i.e. in left-right systems) or for the whole system.

Figure 11-2. Values used to calculate Pedal Smoothness

$$Pedal\ Smoothness = \frac{P_{avg}}{P_{max}}$$

It is important to note that while the figure indicates that pedal smoothness is calculated using maximum and average *power*, in this context power and torque can be used interchangeably, since 1) all power meters presently on the market assume that crank angular velocity is constant throughout a single pedal revolution, and 2) actual variations in crank angular velocity (e.g., due to use of non-round chain rings) are generally small. Similarly, torque and force can also be used interchangeably in this context, since crank length does not change within a single training session or race (file).

With the above in mind, recall the equation for calculating **average effective pedal force (AEPF)**:

$$AEPF\ (N) = \frac{power\ (W) * 60}{cadence\ (rpm) * 2 * \pi * crank\ length\ (m)}$$

Since pedal smoothness (as a percentage) is the ratio of average power (or torque, or force) to maximum power multiplied by 100 for either the left (L) or right (R) legs, it therefore follows that:

$$MEPF\ (L\ or\ R)(N) = \frac{AEPF * 100}{pedal\ smoothness\ (L\ or\ R)\ (\%)}$$

Alternatively:

$$MEPF\ (N) = \frac{power\ (L\ or\ R)\ (W) * 60 * 100}{cadence\ (rpm) * 2 * \pi * crank\ length\ (m) * pedal\ smoothness\ (L\ or\ R)\ (\%)}$$

Power for either the left or right leg can be calculated from the total power and pedal balance (which is expressed as the percentage of total power generated by the left leg):

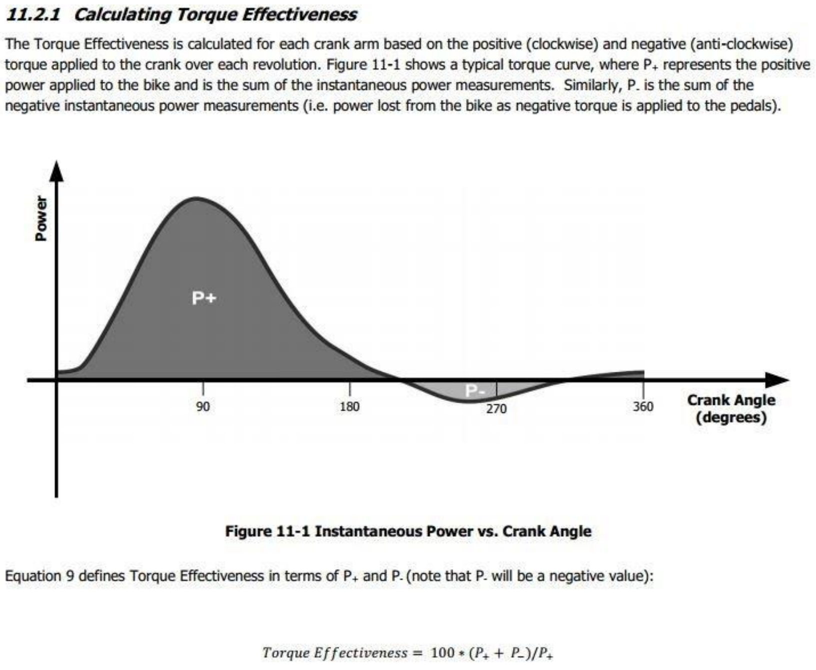
$$Power\ (L)\ (W) = total\ power\ (W) * pedal\ balance\ (\%)/100$$

$$Power\ (R)\ (W) = total\ power\ (W) * (100 - pedal\ balance\ (\%))/100$$

In verbal terms, MEPF is the *maximum* force applied tangentially to the crank at any point in the pedal cycle. As such, it should provide a better indicator of, for example, motor unit recruitment than AEPF when plotted against circumferential pedal velocity in a **bilateral quadrant analysis (bilateral QA)**. As well, calculation of MEPF can reveal discrepancies between legs that are partially or even largely concealed when examining only the summary metrics balance, pedal smoothness, and torque effectiveness. Finally, plotting of MEPF along with slope and cadence against distance (or plotting MEPF vs. slope itself) may provide insight into when the contractile properties of a cyclist's leg(s) tend to become a limiting factor while climbing (in other words, the point at which they feel they must stand). Indeed, standing on the pedals can almost always be identified by comparing MEPF to the cyclist's body mass, as at least at normal cadences, it is difficult to generate forces approaching or exceeding the downward pull of gravity due to muscular actions alone.

GPR and GPA

The other parameter provided by power meters utilizing the ANT+ protocol is torque effectiveness. The mathematical basis for its calculation is shown in Figure 11.2.1 below:



11.2.1 Calculating Torque Effectiveness

The Torque Effectiveness is calculated for each crank arm based on the positive (clockwise) and negative (anti-clockwise) torque applied to the crank over each revolution. Figure 11-1 shows a typical torque curve, where P_+ represents the positive power applied to the bike and is the sum of the instantaneous power measurements. Similarly, P_- is the sum of the negative instantaneous power measurements (i.e. power lost from the bike as negative torque is applied to the pedals).

Figure 11-1 Instantaneous Power vs. Crank Angle

Equation 9 defines Torque Effectiveness in terms of P_+ and P_- (note that P_- will be a negative value):

$$Torque\ Effectiveness = 100 * (P_+ + P_-)/P_+$$

Again, this calculation seems to be based on the mistaken belief that negative power/force/torque (these terms can be used interchangeably in this context, for the reasons already described) represents “wasted” energy and hence should be minimized. What this perspective overlooks, however, is that power/force/torque as measured at the pedal or crank represents the *sum* of muscular, gravitational, and inertial components. These can only be differentiated by knowing (estimating) the mass of the limbs and their position in space throughout the pedal cycle, which allows calculation of their separate magnitudes (an approach referred to by biomechanists as inverse dynamics). Doing so reveals that, except at very high cadences, the muscular component is rarely negative even in non-cyclists; that is, few cyclists *actively* resist the pedal as it rises from 180 to 360 degrees of the pedal stroke. Instead, the transiently-negative power/force/torque that often occurs during this portion of the pedal cycle is due to the gravitational and inertial components, *which are balanced by changes in the potential and kinetic energy of the opposing leg*. In other words, energy is not being wasted, but is simply being transferred (with coupled cranks) from one side to the other via the bottom bracket spindle. The negative power/force/torque therefore simply means that the cyclist is not pulling their foot up rapidly enough to get it completely out of the way of the rising pedal.

Moreover, while it is tempting to suggest that even this implies that a rider’s pedaling might be improved, studies have demonstrated that 1) elite (i.e., more powerful, national class) cyclists actually pull up slightly *less* than non-elite (i.e., less powerful, state class) cyclists (Coyle et al., *Med Sci Sports Exerc* 1991; 23:93-107), 2) metabolic efficiency is *negatively* correlated with the minimum power/torque/force generated during the pedal cycle, i.e., across cyclists those who pulled up *more* were *less* efficient (Edwards et al*., J Sports Sci* 2009; 15:319-325), and most importantly 3) deliberately modifying the pattern of force application during pedaling to emphasize pulling up *reduces* metabolic efficiency (Korff et al., *Med Sci Sports Exerc* 2007; 39:991-995).

Although based on the above the ANT+ measurement of torque effectiveness would seem to have relatively limited utility, it may be possible to obtain useful insight into a cyclist's pattern of force application while pedaling by breaking it down into its two parts, P+ and P-, which can also be termed GPR and GPA (net power being the total power reported by the power meter; i.e., GPR + GPA). Potential uses for these metrics would be to assess changes in fit/positioning that impact power (e.g., road vs. TT bike), to identify causes and/or consequences of acute or chronic injuries, etc.

GPR can be derived from torque effectiveness (as a percentage) as follows:

$$GPR\ (L\ or\ R)\ (W) = \frac{total\ power\ (L\ or\ R)\ (W) * 100}{torque\ effectivenes\ (L\ or\ R)\ (\%)}$$

GPA can then be calculated from GPA and total power:

$$GPA\ (L\ or\ R)\ (W) = GPR\ (L\ or\ R)\ (W) - total\ power\ (L\ or\ R)\ (W)$$

Caveats and limitations

Although the above-derived metrics of MEPF, GPR, and GPA bring things one step closer to a full biomechanical analysis of a cyclist's pedaling "style," they still do not account for the not-insignificant contributions of gravity and inertia to the final measured values. At least at the present time, however, only one biomechanics lab in the world appears capable of performing inverse dynamic calculations in real time for a cyclist pedaling an ergometer. It will therefore take significant advances in power meter technology before such measurements are available to cyclists in the field.

Appendix

Capabilities of presently-marketed power meters with respect to pedaling metrics

Unless indicated otherwise, entries in the table apply to all models of power meter offered by a particular manufacturer. The listings in red are those that provide ANT+ metrics and hence will show GPR, etc. in WKO4.

Power meter	**Sensor location**	**L/R Balance**	**ANT+ pedaling metrics**		**WKO4 pedaling metrics**			**High resolution mode**	**Proprietary pedaling metrics**
			Smoothness	**Effectiveness**	**Gross power released (GRP)**	**Gross power absorbed (GAP)**	**MEPF**		
iBike (Powerstroke, Powerstroke TT)	Handle-bars	N	N	N	N	N	N	Y (16 Hz)	Y
PowerTap (all models)	Hub	N	N	N	N	N	N	N	N
SRM (all models)	Spider	N	N	N	N	N	N	N	N
Quarq (CinQo, CinQo Saturn, Riken)	Spider	N	N	N	N	N	N	N	N
Quarq (Elsa or Red)	Spider	Y*	N	N	N	N	N	N	N
Power2Max	Spider	Y*	N	N	N	N	N	N	N
Stages	L crank	N	L only	L only	L only	L only	L only	Y (64 Hz)	N
Rotor (LT)	L crank	N	L only	L only	L only	L only	L only	N	N
Rotor	L & R cranks	Y	Y	Y	Y	Y	Y	N	N
Verve	L & R cranks	Y	Y	Y	Y	Y	Y	N	N
Factor	L & R cranks	Y	Y	Y	Y	Y	Y	Y (192 Hz)	Y
Pioneer	L & R cranks	Y	Y	Y	Y	Y	Y	Y (? Hz)	Y
Garmin	L & R pedals	Y	Y	Y	Y	Y	Y	N	N
Look	L & R pedals	Y	N	N	N	N	N	N	N

*Pseudo-balance (i.e., R downstroke + L upstroke vs. L downstroke + R upstroke)