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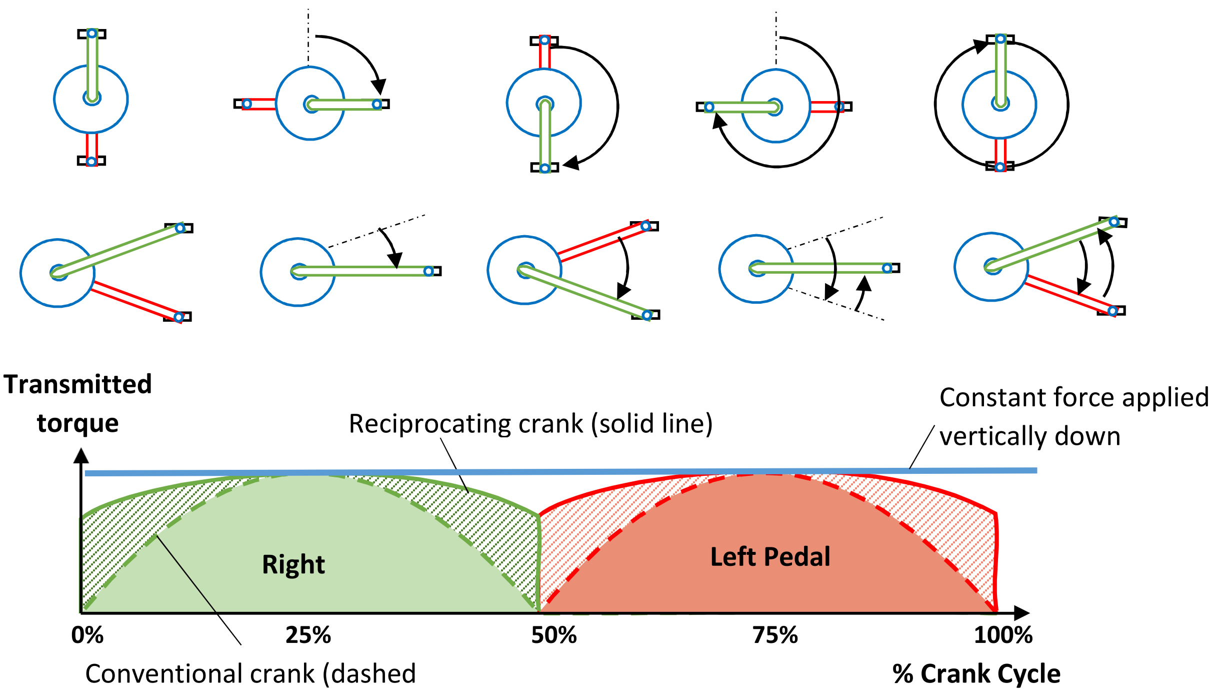
Why a reciprocating crank-bike allows a person to cycle using less energy.

The increased efficiency is the combination of three related factors:

1. A conventional, rotating crank is about 50% less efficient at converting linear, reciprocating motion into rotary motion then a reciprocating crank.
2. Applying power in pulses is less efficient than applying power continuously by a factor that depends inversely on the ratio of the time the pulse is applied to the time available.
3. Human muscle is made up of a combination of powerful, but energy expensing fast twitch muscle fibers and less powerful, but very much more energy efficient slow twitch muscle fibers. A typical person's leg muscle has 50% fast twitch and 50% slow twitch fibers. For endurance performance, it is optimal to use only the slow twitch fibers.

Explanation of how these factors apply to cycling.

1. A conventional, rotating crank is about 50% less efficient at converting linear, reciprocating motion into rotary motion then a reciprocating crank.

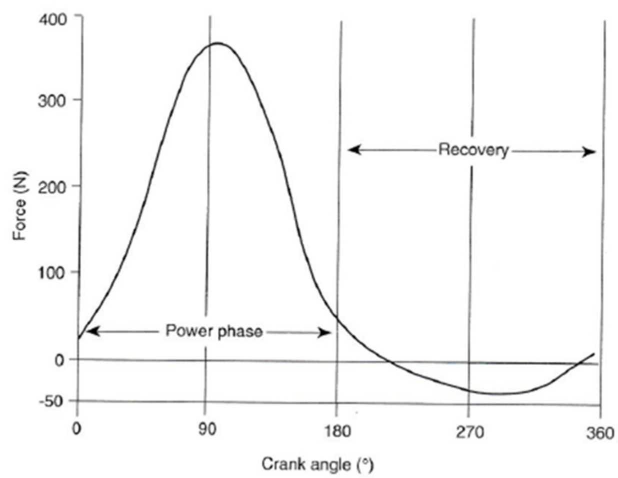


One Pedal Cycle (Simplified - assumes constant force applied vertically down)

The images and graph above are schematic representations of the transmission of power by a cyclist to the bicycle crank ring, comparing a conventional crank transmission system to a reciprocating action drive (RAD). The diagrams above are simplifications and assume that the cyclist applies a constant force vertically downwards. With that simplification, it can be shown that the reciprocating crank converts 50% more of the applied force into usable torque transmitted to the crank ring, and hence the bicycles driving wheel. Transmission of power from the crank ring to the driving wheel via the chain is typically greater than 95% efficient.

Cyclists mitigate the inefficiency of the conventional crank, primarily by only applying force in pulses at times corresponding to the more efficient parts of the crank cycle, and less importantly by use of their ankles, and by attempting to apply uplift via toe clips.

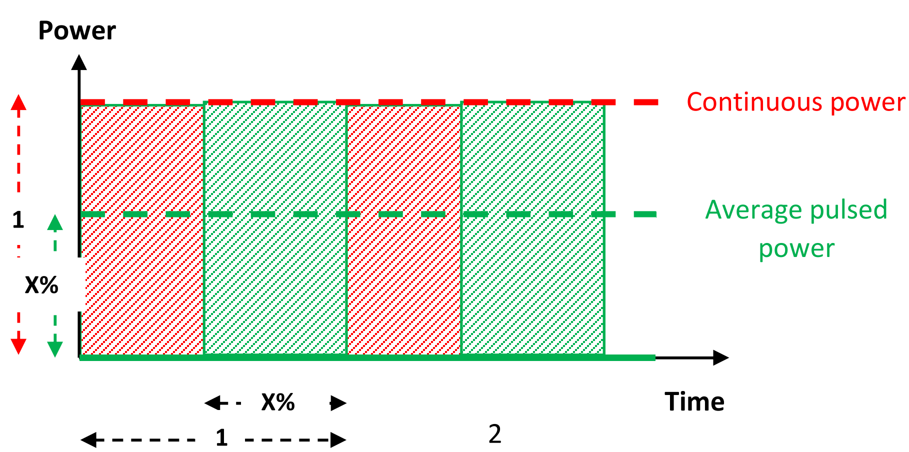
As a consequence, cyclists a typically apply power to the pedals in pulses. This is shown below in a graph of applied force verses crank angle in a conventional crank power bicycle. The graph plots the actual data of a US national team cyclist pedaling a stationary bicycle at 90 revs/min producing 350 W of power.



Applying the force in periodic bursts brings in the second factor.

2. Applying power in pulses is less efficient than applying power continuously by a factor that depends inversely on the ratio of the time the pulse is applied to the time available.

This is illustrated in the graphs below



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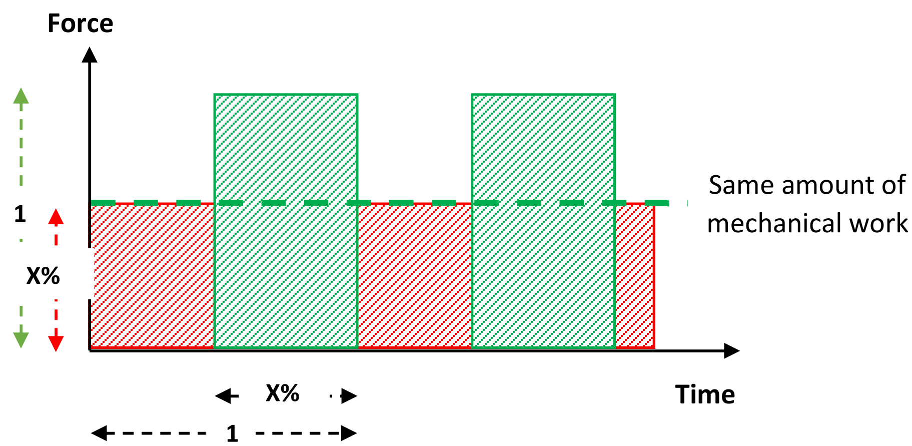
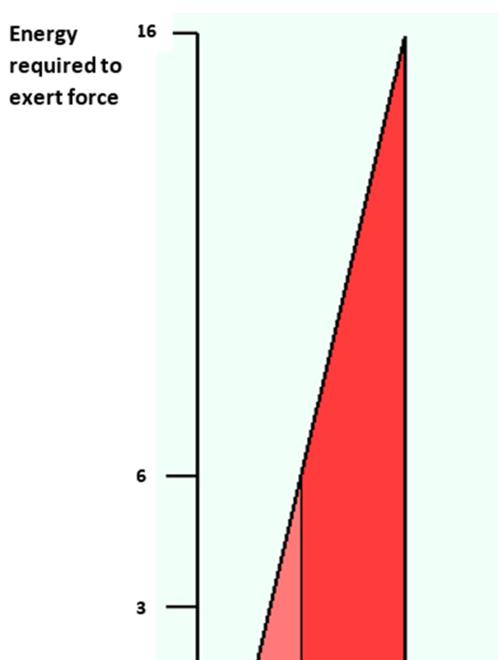
The graph above shows that the average power supplied by a pulsed force applied for only x% of a time period, is only x% of the power that would be produced if the same force had been applied continuously.

If the power source is purely mechanical, this disadvantage can be overcome by simply applying a larger force for the shorter pulsed time so that the average pulsed power is the same as the continuous power, and the same amount of mechanical work is accomplished.



However, in cycling the force is supplied by human muscles, which brings in the third factor.

3. Human muscle is made up of powerful, but energy expensing fast twitch muscle fibers and less powerful, but very much more energy efficient slow twitch muscle fibers. For endurance performance, it is optimal to use only slow twitch fibers.



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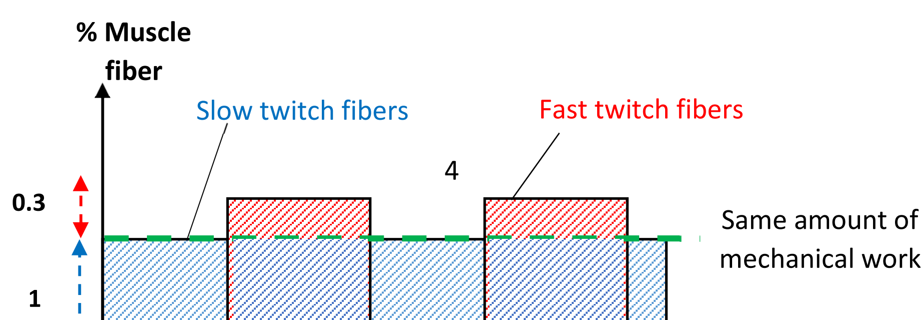
Human muscle has two components – fast twitch and slow twitch muscle fibers. Fast twitch fibers can generate three times as much force as a slow twitch fiber, but use fifteen times as much energy. By only using only the slow twitch fibers, which make up 50% of an average person's muscle, that muscle can generate only 25% of the maximum force the entire muscle can – but only uses 1/16 of the amount of energy.

In endurance events, i.e., anything longer than a few minutes, optimal performance from human muscle is obtained by limiting the forces to those that can be generated by the slow twitch muscles. This is borne out by the performance of elite cyclists. While capable of working at close to 3 HP for short, five second bursts, in a one-hour time trial the same cyclist will work at an average of only 0.65 HP, i.e., only 22% of their maximum capability. This is because, in the time trial, they rely almost exclusively on their slow twitch muscle fibers, avoiding exhausting themselves before the end of the course.

The consequence of the biomechanics of human muscle is that, for human powered machines, attempting to match the work rate that can be achieved by a continuous application of the force available from all the slow twitch muscles by the pulsed application of a greater force in which fast twitch muscles are recruited, costs a great deal of additional energy.

The cost of producing a given amount of work by using human muscles in a pulsed manner rather than in a continuous manner can be quantified by imaging a slightly simplified case. Consider a cyclist using a rotating crank, supplying power in pulsed bursts, attempting to achieve the same power output, or work rate, achieved by another cyclist using a reciprocating action drive (RAD) that allows them to apply a constant force, continuously. Assume that the RAD cyclist uses all their available slow twitch fibers, all the time, while the conventional crank cyclist generates twice the force, but for only half the time. The conventional crank cyclist needs to recruit fast twitch fiber to produce the additional force. Because fast twice fibers are three times as powerful as slow twitch fibers, only a third of their available fast twitch fibers need to be recruited, as illustrated in the graph below.



	# of slow twitch units	# of fast twitch units	Total Energy units
Continuous	2	0	**2**
50% pulse	1	0.33	**6.28**
Pulsed as % of Continuous			**314%**

However, activating a fast twitch fiber requires 16 times more energy than activating a slow twitch muscle, because of the significantly less efficient process that fast twitch muscles use to convert glucose into muscle activating ATP molecules.

The continuously applied force of the reciprocating crank cyclist uses 1 unit of muscle fiber (all the slow twitch fiber) for two units of time, cost 2 units of energy.

The pulsed force to the conventional, rotating crank uses 1 unit of slow twitch fiber for 1 unit of time, and then to generate the extra force, and because fast twitch fibers are 3 times more powerful than slow twitch muscles, 0.33 units of fast twitch muscle for the same 1 unit of time. However, because the fast twitch fibers cost 16 times as much energy to activate as the slow twitch, the total energy cost for the conventional crank is 6.28 units of energy. This is **314% more energy than the reciprocating crank**.

This is not going to be sustainable over any significant period of time. The conventional crank cyclist will soon settle back to generating just the maximum force that can be obtained using only slow twitch fibers. As this will be applied for 50% of the time, conventional crank cyclist will now be 50% as effective as the reciprocating crank cyclist who is suppling that force 100% of the time.

Muscle energy requirement for same work from 50% pulse as continuous

This example is a simplification, but does illustrate that the RAD cyclist will be significantly more efficient – with the conventional crank cyclist using up to 3 times as much energy to do the same amount of work under certain circumstances.