Power meters have been accompanying competitive bicycling since the late 1980’s when the first prototype strain gauge model was tested by Power Pacer and Greg LeMond. The device became first commercially available in 1989. Since then, many power meter configurations were suggested. Some are mounted on the bottom bracket, some on the rear freehub, and some on the crankset. Some devices rely on estimating the opposing forces such as wind resistance, rolling resistance and gravity to calculate approximate power output.¹

Power meters help cyclists keep track of how much power they put into pushing the crank and when compared to the distance their speed, can provide them with relative efficiency of their pedaling. Effectively, the apparatus can help athletes find the pedaling technique that would provide the best power or efficiency depending on their needs.

The problem with the power meter on the market right now, however, is that they are extremely expensive. The price comes from the difficult manufacturing process, difficult installation process, and extra hardware that has to come with the power meter. Power meters that utilize strain gauges and can reach uncertainty of 2% are about $2,000. The low-end power meters that utilize opposing forces and can get 10% accuracy over long distances are about $600. Furthermore, all power meter devices come pre-mounted on specific crank systems thus significantly lowering the spectrum of usable cranks and pedals.²

Design overview:

The traditional design of a bicycle power meter has been simplified to use only 4 strain gauges and the necessity to use any specially manufactured bicycle part has been eliminated. Thus, the production and installation costs of each unit were decreased, while still maintaining adequate accuracy of the measurements.

Each crank would have 2 strain gauges - one on top of a crank and one on the bottom - in a Wheatstone half-bridge configuration. In this configuration, only the bending strain would be accounted for, while the twisting strain would theoretically be canceled out. Thus, the signal coming from the half-bridge would be proportional to torque as it would only read the perpendicular component to the crank. By multiplying torque by the angular velocity, which could be attained from the sinusoidal signal, the useful power that the cyclist puts into the bicycle can be attained.¹

The final apparatus would only consist of 2 strain gauges and a circuit box per pedal. The signal from the strain gauges would be sent to the circuit box and then be transmitted via Bluetooth to a Smartphone for tracking the data in real time, or to a computer for later analysis. The circuit box would be placed on the inside of the crank to prevent possible damage and reduce wear. The strain gauges would be placed on the top and bottom edges of the crank as shown in figure 1 below.

The fact that strain vs. angle is not perfectly sinusoidal can be explained by the geometry of the crank. Bicycle cranks, however, are not uniform blocks of metal and have different shapes. In addition, force is not always going to be applied perpendicularly to the crank as the crank will be spinning. Thus, a few hypotheses were made which had to be tested:

1. As the crank rotates, the relation between torque and the angle is sinusoidal.
2. Even as the angle of the force applied changes, the half-bridge configuration would still ignore the twisting strain.

Proven Concept

Under ideal conditions (rectangular metal rod and perpendicular force), half-bridge configuration is able to completely neglect the twisting strain and only indicate the bending strain. Bicycle cranks, however, are not uniform blocks of metal and have different shapes. In addition, force is not always going to be applied perpendicularly to the crank as the crank will be spinning. Thus, a few hypotheses were made which had to be tested:

1. As the crank rotates, the relation between torque and the angle is sinusoidal.
2. Even as the angle of the force applied changes, the half-bridge configuration would still ignore the twisting strain.

The first series of experiments was performed with an 8-cm-long rectangular bar with strain gauges in half-bridge attached to it viced to a table, which allowed the angle relative to the ground to be changed. Then a mass was attached to the end of the bar and the bar was rotated in the vice. Then strain was measured for angles between -75 to 75 relative to the ground with increments of 15. Then, the experiment was repeated, but the mass was attached to the rod via an 8-cm-long pivot to a side, so that it twisted the rod. Results are illustrated in figure 2 below. The data suggests that as the crank rotates the relation between strain (and torque) and the angle is indeed sinusoidal.

The second series of experiments was performed on an actual bike mounted to a table and with a fixed crank. The force was applied by a car jack and the magnitude of the force was measured by a bathroom scale. The force was increased from 0 to 352 N with increments of 44 N. The experiment was repeated for the crank at 0, 35, and 90 degrees to the ground. The setup is illustrated in figure 4 below.

Figures 5 and 6 show strain as a function of angle for a constant force. Figure 5 shows the force being applied directly to the crank thus causing only bending strain and no twisting strain, while Figure 6 shows the force being applied at the end of the pedal thus causing bending and twisting strains. The data is fitted by sine curves and it is obvious that while the data supports hypothesis 2, it does not closely match the sine fit.

Figures 7 and 8 show strain as a function of force for constant angles and compares force applied directly to the crank to the force applied to the pedal. It can be seen that until 200 N data there is no difference between pivoted and direct force. After 200 N, little discrepancies can be seen, but they can be described by the structure of the apparatus. At 90 degrees, the net strain is 0, because the force applied is parallel to the crank. Thus, this data also supports hypothesis 2.

Conclusion

The data suggests that the concept of a power meter with 2 strain gauges per crank is valid. The half-bridge configuration successfully cancels out twisting strain at all angles. The fact that strain vs. angle is not perfectly sinusoidal can be explained by the geometry of the crank - it is not a rectangular rod, so its axis of rotation is not exactly at the center. Once calibrated for a specific crank, however, it can be predicted how the strain would behave and the power input can be measured accurately.

References