vantages compared to other drive types. Foremost among them is wear. Maybe you won't use your pedal-powered blender or electrical generator long enough to find out, but the very friction that the drive depends upon to transfer torque will also, in time, deteriorate the wheel. One manufacturer of friction-drive motors for bicycles predicts that users will have to replace their bicycle tire after 500 to 1,000 hours of contact with the motor's spindle. Such a lifespan is much shorter than the life of a chain drive, gear drive, or pulley drive.

Flywheels

So far, most examples of pedal-powered drives in this chapter have assumed that your design will use a bicycle wheel — that is, a spoked wheel. However, for sustained efforts that require a steady amount of power, and especially when significant power is needed, it's better to use a heavy flywheel. A flywheel is a disc that relies on its mass and rotational speed to continue generating power after it's been brought up to speed. Flywheels operate on the principle of Newton's 1st law, which explains that a body at rest tends to stay at rest and a body in motion tends to stay in motion. Once you get a flywheel spinning, it wants to keep spinning. Furthermore, as a flywheel spins faster it accumulates more energy. As it slows down, it releases that energy. Flywheels store kinetic (in this case, rotational) energy and then return it to the system. Some people call them mechanical batteries. The heavier and larger the flywheel, the more energy it can store — but also, the more energy it requires to get it spinning.

The advantage to using a flywheel is that it evens out normally jerky torque inputs. Pedaling, treadling, and hand-cranking, especially one-armed cranking, issue force periodically, mainly on the downstroke. The graph in Figure 2.18 depicts how power output varies while pedaling a bicycle, as measured by crank-arm angle. When one leg is partially extended and the crank arm is at about 90 degrees past an upright position (in other words, pointing forward and parallel to the ground), the power output for that leg peaks. The other leg's power output peaks in the same relative position, when the crank arm angle is at 270 degrees. Adding a flywheel to a pedal-powered drive would smooth out the periodic curve in Figure 2.18 to a nearly straight line, representing a nearly constant application of power.

Force applied to a treadle sewing machine varies in a similar manner. Without a flywheel connected to the treadle, the machine

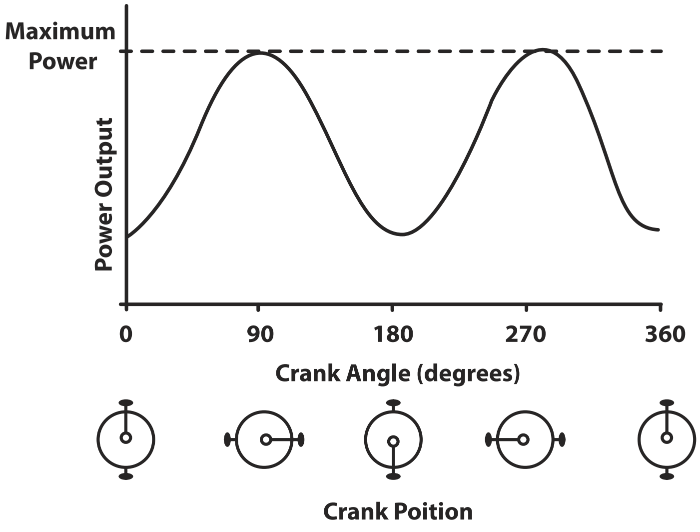

Figure 2.18 Pedal-Power Output at Varying Crank Angles[50]

Figure 2.19 Potter's Kick Wheel With Concrete Flywheel

would make a few stitches each time your foot pressed the treadle and then pause until you pressed the treadle again. The flywheel evens out your foot pressure, storing it, then releasing it when you aren't pushing on the treadle, so that stitching continues uninterrupted. It will spin until it spends all of its stored energy or until you apply pressure to stop it.

(Technically speaking, a spoked wheel, like a bicycle wheel, is a flywheel, because it does have mass and velocity when spinning, and therefore, it stores and releases energy you put into it. But because it's so lightweight it isn't considered a powerful flywheel.)

Some human-powered potter's wheels, like the one shown in Figure 2.19, use heavy flywheels in direct drives to spin the wheelhead on which a pot is shaped. In this instance, a potter kicks the wheel to start it and continues to rotate it with her foot. This type of wheel is called a kick wheel. Another type of human-powered pottery wheel uses treadles to keep the flywheel spinning.

The 2-inch-thick flywheel shown in Figure 2.19 is made of cast concrete and weighs 140 pounds. Potter Scott Cooper, who prefers a human-powered pottery wheel says, "I've never used an electric wheel for any extended period of time. I find them to be loud, abrupt, too fast, and prone to being out of control. I enjoy the quiet hum of the concrete flywheel as it spins by beneath my feet; the direct physical connection between the energy I expend into the wheel and the speed of the wheelhead (and thus the available energy for making pots)."[51]

What if flywheels, as mechanical batteries, could effectively enable one human to triple or quadruple his output by storing human power for some period of time, then releasing it suddenly? This question led J. P. Modak, professor and mechanical engineer, to design what he calls the Human Powered Flywheel Motor (HPFM). The machine, refined over the last 30 years, combines a bicycle's chain drive with a gear drive to deliver power to an 80-cm-diameter flywheel. The flywheel, with the aid of another gear drive, delivers power to a device that would otherwise require fossil fuels or electricity. It has successfully powered brickmaking machines, water pumps, algae processing machines, wood laminate cutters, drop forge hammers, and winnowers. In the case of the brickmaking machine, Modak and his students determined that the motor works best when the operator pedals for 60 to 90 seconds at approximately 40 rpm, after which the

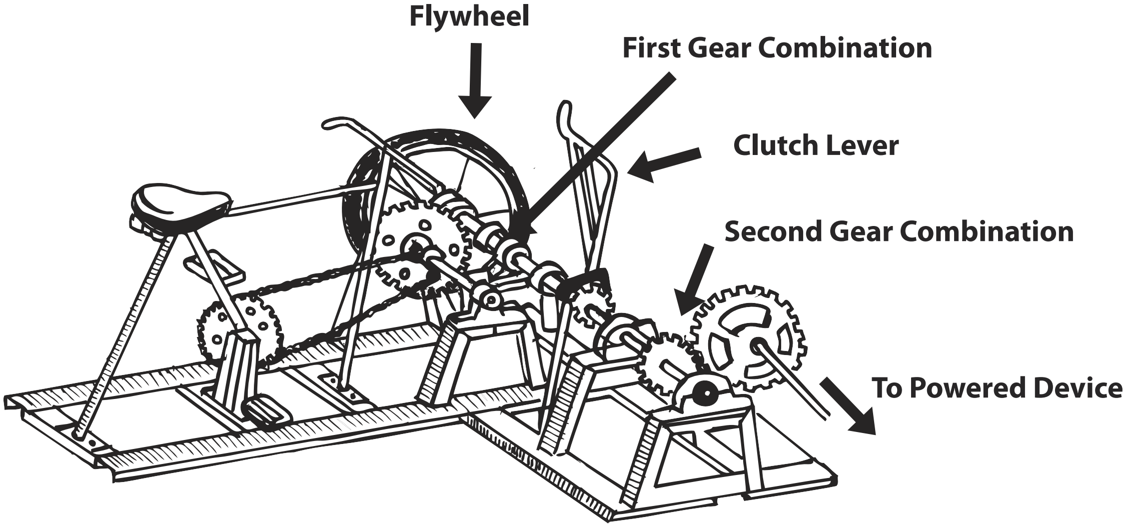

Figure 2.20 J. P. Modak's Human-Powered Flywheel Motor

flywheel spins at about 240 rpm with an accumulated force of approximately 1,490 newtons. Then a clutch is engaged to release the gearing from the bicycle drive and rapidly redirect the flywheel's stored power to an auger, which compresses a lime-flyash-sand mixture into a long brick. Modak estimates the Human Powered Flywheel Motor could generate up to 6 hp from the efforts of one person![52]

The diagram in Figure 2.20 offers a simplified schematic of Dr. Modak's invention. The chain drive between the bike's chainring and the first shaft has a gear ratio of 3:1. The gears between the first shaft connected to the chain drive and the shaft connected to the flywheel also have a gear ratio of 3:1. Thus, the total increase in rotational speed between the pedals and the flywheel is 6:1. The gears on the other side of the clutch, which transfer the flywheel's rotation to the device it's powering, have a ratio of 1:4, thereby multiplying the force delivered to the device.[53]

While considering whether to incorporate a flywheel in your design, you might wonder about its optimal characteristics. The desired mass of a machine's flywheel depends on the device and its purpose. One designer whose machines power tool grinders and electrical generators says he aims for flywheels that weigh from 25 to 35 pounds. By contrast, as mentioned above, the flywheel for a commercially made potter's kick wheel weighs 140 pounds.

Some stationary bikes and spinning machines (found mostly at fitness centers) have heavy, cast metal flywheels as their front wheel. If you don't have this type of exercise bike, or if you're making a machine from a used bicycle, you can replace the spoked wheel with a homemade flywheel. Figure 2.21 shows a pedal-powered macadamia nut sheller (bicimacadamia) built by Maya Pedal, which uses a large, custom flywheel.

Custom flywheels can be crafted from wood, concrete, or metal or adapted from parts found at junkyards or flea markets. The flywheels pictured in Figures 2.19 and 2.21 are made from concrete, a common substance for flywheels because it's weighty, widely available, and can be molded. In addition, if extra friction is desirable along the faces or edges of the flywheel, as in the case of a kick wheel, one can use a broom to lightly score the cement before it's dried. To make a cement flywheel, you need a form that's perfectly symmetrical, so that the wheel will be true, and you also need reinforcing material to embed in the cement. The reinforcing material could be wire mesh, rebar (steel reinforcing bar), or even an old cast-iron gear. Carlos Marroquin Machàn, chief mechanic for Maya Pedal, made the flywheel pictured in Figure 2.21. He began with a bicycle wheel as the frame, then used disk wheels — the lens-shaped plastic wheel covers that bike racers attach to their rims to reduce drag — to create the mold around the frame before pouring in the concrete.

Figure 2.21 Maya Pedal's Bicimacadamia (Macadamia Nut Sheller)

A flywheel could also be made from rebar wound around a tire rim four or five times, then cinched or welded in place. Others have built flywheels from plywood, for example, by simply cutting the wood in a circle. For a heavier flywheel, glue, or bolt several of these circles together. If you're a metalworker or know one, you could also cast a flywheel from iron or aluminum. A simple solution is one recommended by human-powered machine inventor David Butcher: use a round table top for a flywheel.

When constructing a flywheel, no matter what the material, it's vital to make the wheel as true, or balanced, as possible. Ideally, it should be symmetrical in thickness and width from the center hole to the edge.

Also note that the weight of the flywheel is more effective when it's located toward the outer edges of the circle. In other words, a tire rim with rebar wound is actually more advantageous than the flying-saucer shaped flywheel pictured in Figure 2.21. (However, Maya Pedal's customers preferred the looks of this flywheel to others.) On ChocoSol's pedal-powered cacao bean grinder, featured