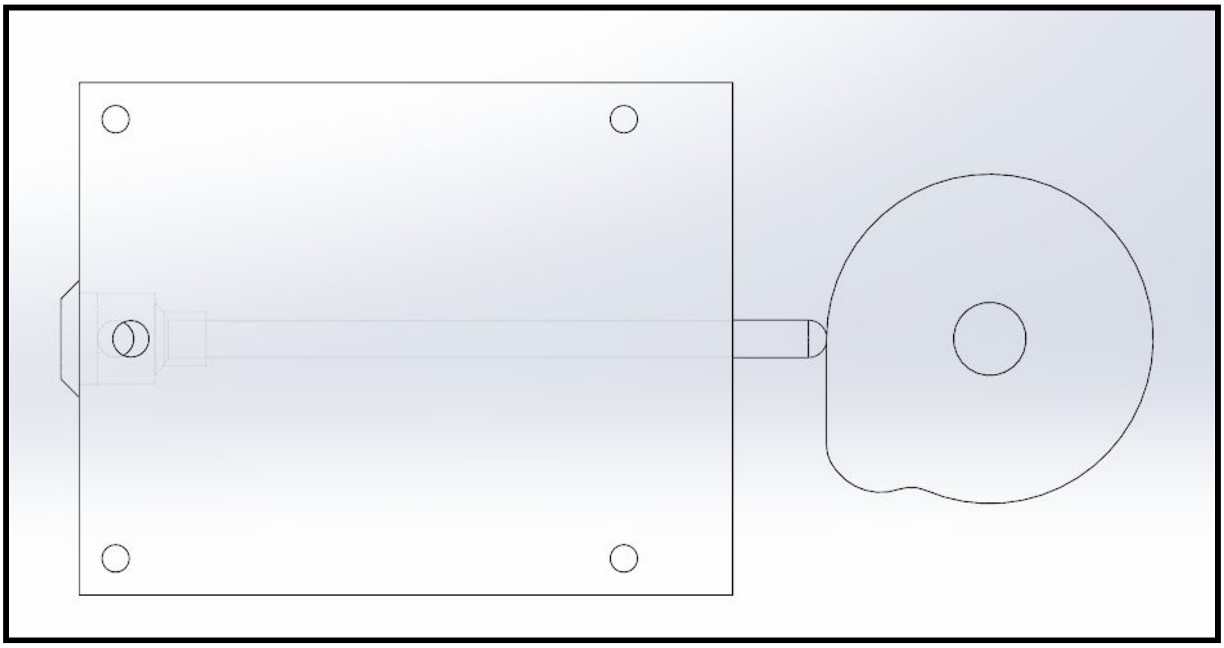
Greensteam Report: Valve Actuation Systems & Further Research

Tae Rugh, Summer 2020

Valve Actuation Systems

Greensteam aims to design a modern steam engine that maximizes simplicity and frugality while maintaining high energy efficiency. The valve actuation mechanism presents one of the most important design challenges in achieving this objective. A number of potential options have been designed, each with its advantages and drawbacks.

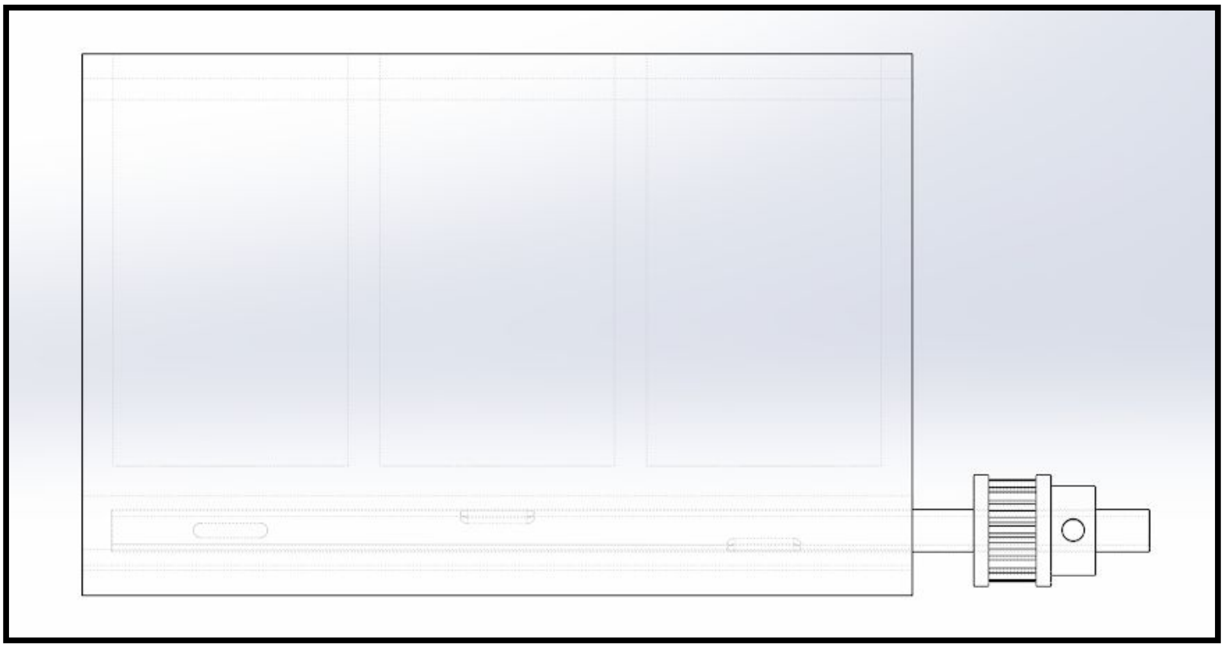
Cam/Poppet



The classic option--a staple for internal combustion engines--is the cam/poppet valve system. Unlike internal combustion engines which typically have a separate belt-driven camshaft, we can simply attach the cam to the crankshaft to reduce complexity. As the crankshaft rotates, the cam's asymmetric shape pushes the cam follower rod up which opens a poppet valve to allow inlet steam to enter the cylinder. This system has superior sealing qualities and reliability. The drawbacks are that it can be complex to manufacture (high precision is required for the poppet head, poppet seat, and cam), it requires a heavy spring to maintain contact between the follower and cam (which reduces efficiency), and a separate poppet valve is necessary for each cylinder (meaning more moving parts).

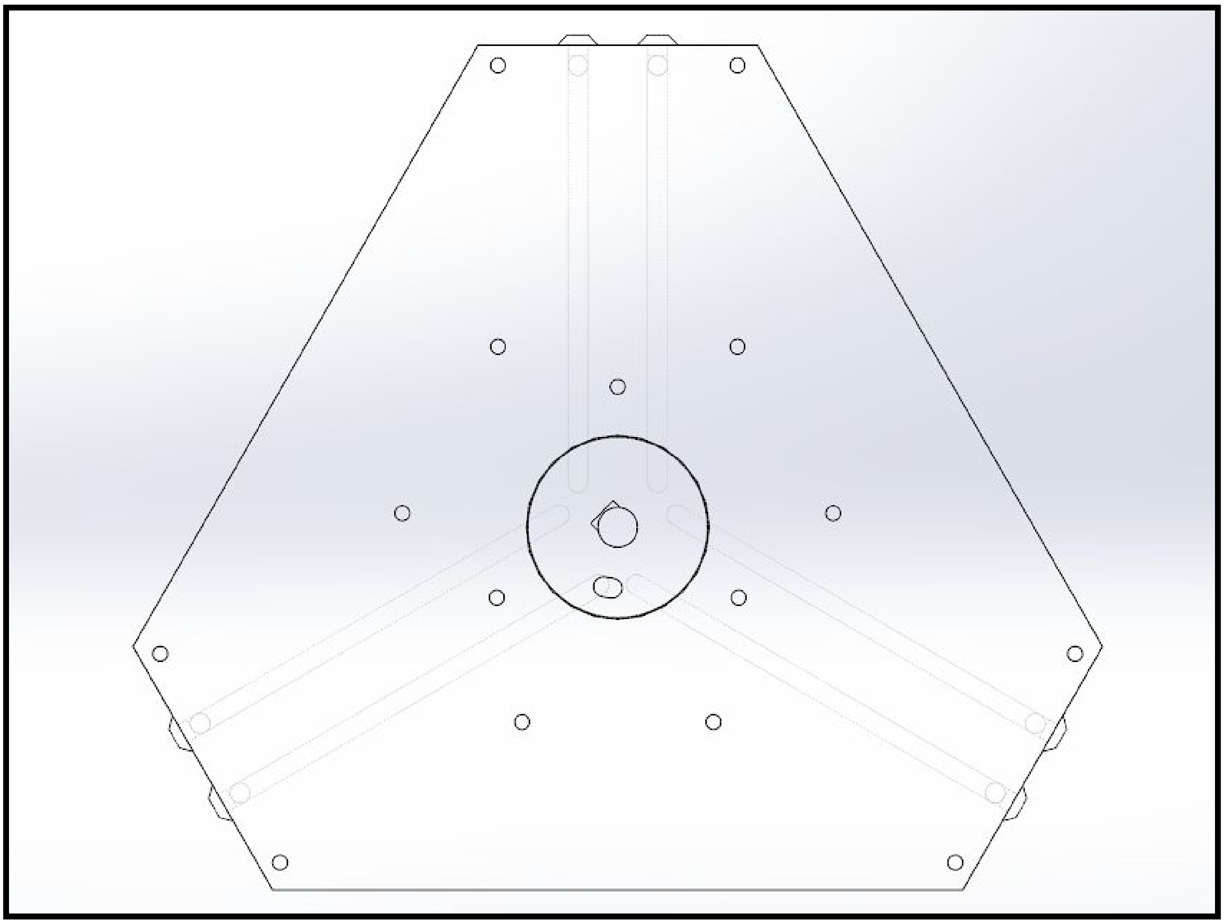
The cam shape determines the engine's timing, but it is constrained by a number of variables. The first constraint is cutoff (cutoff is the percentage of the powerstroke duration in which steam is allowed to enter). For a 20% cutoff, the incline and decline must occur within 38° of the cam's rotation. The second constraint is that the height offset must be sufficient for the desired inlet flow rate. Additionally, the ascent must be a straight tangent to minimize resistive forces. Finally, the time at full height should be maximized so that the steam flow rate is maximized.

Rotating Tube



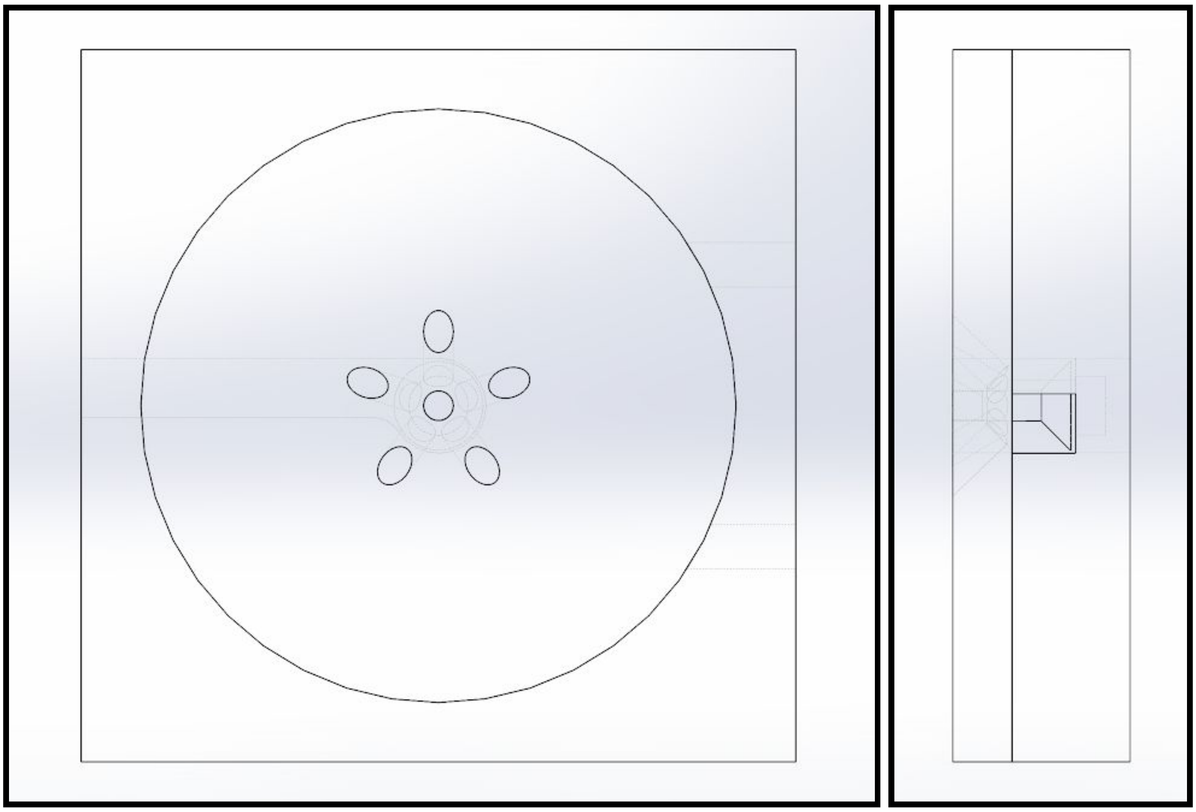
The rotating tube valve has a hollow center with inlet steam flowing through it and slots on the edges that line up with inlet manifolds so that steam enters the cylinder upon rotation. The rotating tube design can also be used for exhaust, in which the hollow center directs exhaust gas out to the atmosphere or wherever it is needed. The benefit of the rotating tube valve is that a single tube can be used to feed multiple cylinders, which reduces the number of moving parts needed. For this reason, an inline engine layout with tubes running below the cylinder heads is ideal for this valve type. There are concerns for sealing, lubrication, and thermal expansion. Thermal expansion should not be a huge issue though, since the engine is meant for power generation purposes, so it will be running for long periods of time at a constant rate and constant temperature. Because of this, the tube and corresponding bore diameters can simply be toleranced for an expected operating temperature. The engine will leak heavily at start up before it has reached its running temperature, but after this it will run smoothly for the rest of its operation period. Cross-cylinder sealing can easily be accomplished by o-ring seals, stuffing boxes, or a similar alternative, but sealing for cutoff is much more difficult. There is potential for labyrinth seal grooves here, though apart from this, ensuring precision tolerancing is the best that can be done. This solution will never seal as well as a poppet valve, but it may still be preferred due to its simplicity.

Rotating Disk



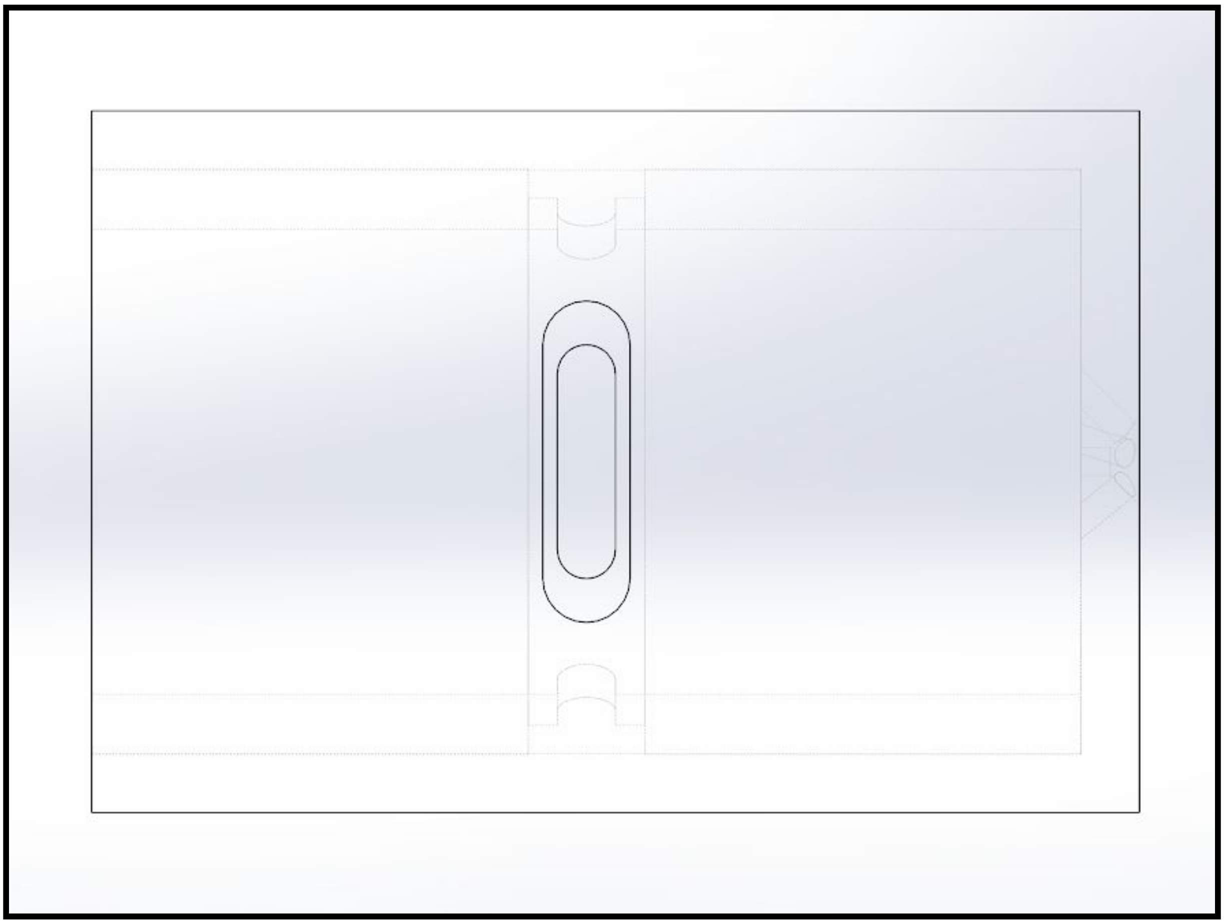
The rotating disk valve is attached to the crankshaft and lies against a manifold plate. The disk has a slot--the shape of which determines timing and flow rate--which allows inlet steam to enter the cylinders through corresponding passages on the manifold plate. The disk is attached to the shaft in such a way that it rotates along with the shaft but is not fixed for translational movement. In this way, steam on the open side of the disk pushes the disk against the manifold plate, creating a pressure seal (similar to the once common sliding D valve). While the pressure addresses sealing, it also creates a large amount of friction, so the disk and manifold plate must be heavily lubricated or plated with a low-friction material such as teflon. A separate rotating disk, or a separate track on the same disk, can be used for exhaust as well. The rotating disk valve is ideal for a triradial cylinder layout since in this case, the disk could feed 3 equally spaced manifold holes for each cylinder. The main advantage of the rotating disk valve is that it can replace the need for multiple complex valves with only a single moving piece, attached directly to the crankshaft. The main drawback is with the friction that the pressure seal causes, which tarnishes the efficiency of the engine, raises concerns for overheating, and must be heavily lubricated.

Bash



The bash valve is built into the cylinder head and actuated by the piston itself. As the piston approaches top dead center, it pushes on a rod which opens a poppet valve and releases inlet steam. Then as it leaves top dead center, the valve is pushed back down via spring. Since the bash valve uses a poppet-shaped head, it has superior sealing and wear qualities. Due to mechanical constraints, however, the bash valve is severely limited in controlling cutoff since it must be open before top dead center for the same amount of time as it stays open after top dead center. The bash valve is a simpler, but less accurate alternative to the cam/poppet system since both require a separate valve system for each cylinder, but the bash valve does not need to be actuated from a mechanism on the crankshaft as it is instead actuated from the piston itself. The bash valve only accounts for inlet, so it is commonly paired with uniflow exhaust.

Uniflow



The uniflow port is a valveless alternative for exhaust. One or more ports are located just before bottom dead center, so that for the last portion of the piston's power stroke and the first portion of its return stroke, exhaust steam is free to exit the cylinder. Since the port is not open for the entire return stroke, a significant amount of exhaust remains in the cylinder, but this turns out to be beneficial in some ways since the remaining exhaust cushions the piston's return as it compresses and minimizes cooling of the cylinder. Uniflow exhaust was invented as a simpler alternative to the compound engine, and while it does not quite compete with the efficiency of the compound, it can be far smaller with far fewer components.

Areas for Further Research

Compound Engines

The compound engine is a highly efficient type of steam engine which was widely used for power generation applications at the height of the industrial revolution. It is multi-stage, meaning that steam first goes through a small bore, high pressure cylinder and then--rather than exhausting to the atmosphere where the remaining heat energy is lost--it exhausts to a larger bore, lower pressure cylinder for a second stage of expansion. In this way, more heat energy is utilized resulting in a highly efficient engine with the drawback of being highly complex.

Condensers

Condensers provide an alternative solution to harvesting the remaining energy in exhaust steam by preheating the boiler feed water. They work by condensing the exhaust steam back into water using the cold feed water as the heat sink. Condensers typically require a pump of some sort which is usually driven by the engine which it services. Some potential condensers to consider include percolating condensers, jet condensers, and surface condensers.