

Adventures with the Atkinson Differential Engine

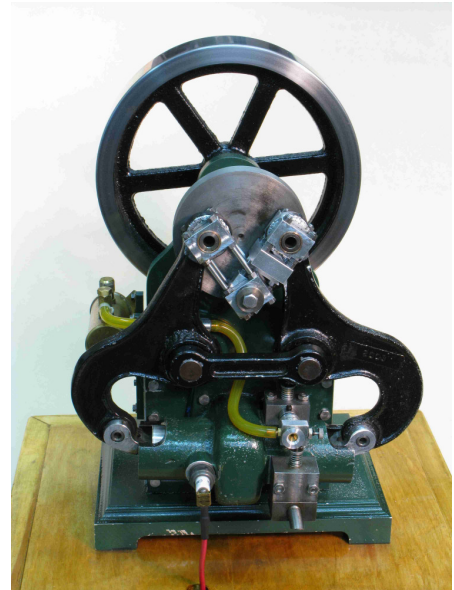
I read about the Atkinson Differential engine in an encyclopedia when I was a kid in grade school. It's a fascinating idea. Two pistons in one cylinder. No head. No camshaft. Four stroke cycle in one crank revolution. Levers and motion all over the place. Cylinder ports instead of valves. How can you not be excited about something that unique?

Then Ed Irwin's model of the design by Brooks Pendergrast appeared on the cover of the Feb/Mar 1998 edition of *Strictly IC*. Only a few months later, in August of 1998 I saw a working model of that same design at tractor show in Marshalltown, exhibited by Jim Hay of Des Moines, IA.

A somewhat different Vincent Gingery design was available, published in book form in 2000. With that book in hand and some brand new green sand for making aluminum castings, I took the plunge and started work on my own model in November of 2002. I won't bore you with details, but by spring of 2004 I was finally ready to belt it up to my lathe spindle and start the breakin process, as it was described in the Gingery book.

Of course, you know the story. I couldn't get it to run on its own no matter what I did. Nothing seemed to work. I was overcome with anxiety and guilt for having "screwed it up" somehow. It wasn't until the spring of 2005 that I finally made up my mind that this machine was not going to beat me, so I plunged in and tried about everything I could think of, following every lead and every non-derisive suggestion. Progress came in little fragments, but by the NAMES show in 2005, I did get it running. Of course it ran well at home, but quit running at every show I took it to. As with many things, every crisis turned out to be a learning experience, and today the engine has become a steady, if occasionally temperamental, performer.

I am always amazed at how many people approach me at shows saying that they, too, had built the one or the other of the Gingery-designed Atkinsons. Most told me they have no problem with the single-piston "Cycle" engine, but many who built the "Differential" never got it to run and gave up on it. I don't believe the fault lies with the Gingery design. Even the original full size engine was reported to be "fussy" and "impractical" to operate for commercial use. Atkinson himself is said to have sold only a few of the "Differentials" but at least a couple thousand of the "Cycles." But I found that by giving attention to certain areas—some to my workmanship and some to the certain aspects of the design—I was able to make my Gingery Differential model pretty reliable. It now needs only some paint and loving attention to cosmetics to make it into show engine. In the paragraphs that follow, I'll try to relate some details that may be of use to you in getting your model running.



Design-related areas

Ignition energy: High energy ignition was the biggest single factor in making the engine run consistently. The spark plug chamber on this engine is outside the combustion space with only a single 3/16" port into the cylinder. This chamber doesn't really get flushed out with new mixture each revolution, so it takes a hot spark to light what there is to light. When I first got my engine to run a little bit, it would misfire and run very erratically. The mixture setting was super critical, and would seem to change from time to time as the temperature and the fuel level in the tank changed. I eventually found that a full sized automotive coil with a full 12 volt battery helped enormously. I suppose any really high-energy ignition system would give equally good results. It works best with at least 0.035" gap on the plug

(I've used up to 0.050", but it will flash over the outside of the spark plug insulator sometimes on a humid day.) I haven't tried it, but this may be a good application for capacitor discharge ignition.

Carburetor: I never could get the engine to run consistently using the carburetor in the Gingery book. It was probably my fault for not building it right in some way, but in the end I decided to modify the design. It now seems to be much more stable in operation with much finer control over the mixture. This carburetor has a replaceable venturi with minimal bore size so the flow velocity is high, which improves fuel atomization. You can't throttle it up, but you really don't want to run this engine very fast anyway because it's not that well balanced, and you want people to be able to follow the motion of the levers. If you like, you can make two or three venturies and have different venturi sizes to change "throttle settings." You can change venturies without modifying the other parts of the carburetor.

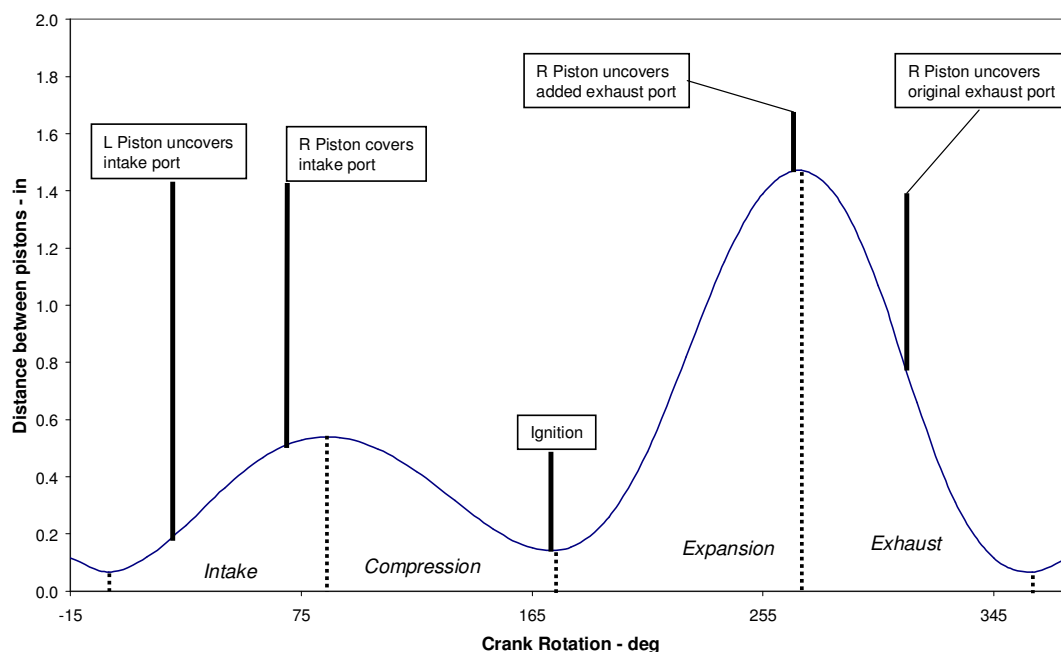


Detailed drawings of the carburetor design are provided in the drawing section. The picture shows the D-reamers I made to shape the inside of the brass venturi tube.



Exhaust port timing: The Engine Timing Chart below will give you a good idea of what the problem is with port timing in the original engine. By the time the exhaust port opens up, the pistons have already partly re-compressed the hot exhaust gas. That takes a lot of power and generates a lot of extra heat. Fixing that problem will make a world of difference in the way your engine runs. The exhaust note will be much quieter. It will run much cooler. Most importantly, it will have a lot more power and will run much more reliably.

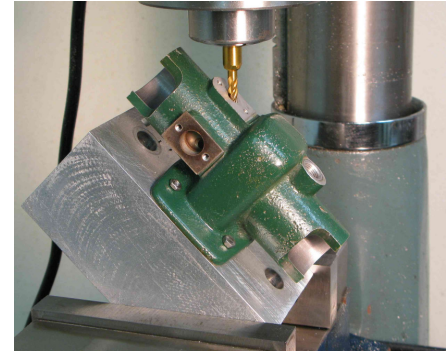
Atkinson Engine Timing Events



Fixing this exhaust timing problem requires that you open up a second exhaust port in the cylinder. The cylinder is set up in the mill inclined 45° as shown. Use a 3/16" end mill starting at the center of the existing exhaust port and plunge through the cylinder wall. De-burr the hole, and you're ready to go. The two ports should look like the photo below when you are finished.

You'll notice on the chart that the intake port timing is not ideal either. The intake port opens too late and closes too early. I didn't try to fix that. It gets enough fuel/air charge to run well as is. If you were going to use this engine to do work, the intake timing might be the first place to start improving it.

If you want, you can make your own engine timing chart for your engine. All it takes is a dial caliper and a degree wheel. The Dwight Giles degree wheel in the July/August *Model Engine Builder* would do nicely, or you can make a paper one and glue it (accurately centered) to the flywheel like I did. Accurate marks every 15 degrees would be good enough. Each 15° of crank rotation you find the distance between the pistons by taking the length of the cylinder minus the length of each piston minus the measured distances from the cylinder ends to each piston skirt. You can use a spread sheet to record all the measurements and do all the subtractions, and even draw the graph if you like to use that sort of thing. Then read the degree wheel indication when intake and exhaust ports open and close, and mark those on your chart.



Big flywheel: I've never been sorry for putting a heavy flywheel on the engine. It's not that you can solve problems with more inertia, but it sure makes it easier to find problems if you can run through a few misfires now and then. I used the 7" PM Research FWC-4CI casting.

Bearings: Expecting that friction would be the enemy, I started out with ball bearings on the main shaft, roller bearing central pivots for the rocker arms, and a ball bearing at each end of all the crank links. However, I had to give up on the crank link ball bearings and go back to sleeves because I couldn't find the right bearings for that application. I don't think it's vital to use anti-friction bearings anywhere if you are careful with fit and alignment of sleeve bearings, but I'm very happy with the main shaft and rocker pivot bearings I'm using.

Valve seating and spring tension: This is the one area where my engine has always been good, but it's an important place to check. Early on, when using regular two-cycle oil for lubricant, I did have some stuck valves due to varnish or sludge residue.

Breakin: This is not a design change, but is a noteworthy change from the breakin procedure in the Gingery book. I have not found it necessary to run the engine with an external motor or even to use a mechanical starter. When I finished my recent overhaul, with new rings and newly-lapped cylinder (see below), I was able to hand start the engine. It took about fifteen minutes of hand flipping and spark plug cleaning to find the right mixture setting and get a good enough compression seal to pull itself, but after the first ten or fifteen minutes of running and warm-up it settled in nicely and ran without intervention.

Self-induce workmanship problems

Scored Cylinder: For the second time I have just repaired a scored cylinder. The scoring caused severe loss of compression. This engine must have good compression. There are twice as many pistons to leak, and the performance of the engine at its best doesn't have a whole lot of margin. I can't prove it yet, but I believe my aluminum pistons were originally fitted too tightly in the cylinder. When they got hot, the clearance went to zero, and scoring was the result. It's also probably true that 6061 aluminum is not the

best choice for piston material, but that's what I have. Gingery recommends 0.002" piston clearance; I'm now using 0.003", and the compression so far just keeps improving as I run the engine. Avoid dust and dirt around the engine as much as possible.

I like the method shown on the *Colorado Model Engineering Society* web site for making the piston rings. They seem to start out with fairly good compression, and they break in quickly.

Too much oil: When it comes to oil in the fuel for lubrication, my original theory was that a little more and a little thicker wouldn't hurt. I ended up with a big mess, and a big pile of fouled spark plugs. Gingery recommends a 50:1 mixture of fuel to oil. I think you could go to 100:1 without a problem. The engine does not scavenge oil out of the cylinder very efficiently, so it tends to accumulate there. Some people like to use *WD-40*. Our local area machinists like *Marvel Mystery Oil*. I've used both, but I've standardized on the latter because it seems to be a better all-around lubricant. Neither one thickens in the combustion chamber like 2-cycle oils seem to do, and both seem to keep carbon in suspension and help a little with carbon fouling of spark plugs.

Dirt in fuel: When I first ran the engine I bought a model airplane fuel syringe to handle the fuel. It worked great for a while, but when the plastic O-ring disintegrated, it filled the fuel tank and all my fuel supply with debris. I've probably had more shutdowns from that stuff clogging the fuel jet than from any other cause. Model airplane fuel filters are not fine enough to trap the stuff, either. It took a year to run enough fuel through to flush everything out.

Venting the fuel cap: Nobody would be dumb enough to try to run an engine with no vent in the fuel filler cap. Right? Well, almost nobody, except maybe for some guy who gets focused on port timing and carburetors and ignition and stuff like that.

Chronic problems

Spark plug fouling: This is an ongoing problem. If you have compressed air the plug can usually be cleaned and re-used. On the road, I carry a can of dust and lint remover from a photo shop to blow out the spark plug, and a stock of *Q-tips* to swab out the spark plug chamber. Because the plug runs so cool in its isolated chamber, it is subject to fouling in three different ways: water fouling, oil fouling, and carbon fouling.

Water fouling comes from burning the hydrogen in the fuel, and occurs sometimes when the engine first starts up from cold. After the engine operates and comes up to temperature, the problem goes away because the water stays vaporized and exits with the exhaust. Remove the plug, blow out the water, and swab out the spark plug chamber.

Oil fouling comes from an accumulation of lubricating oil. It helps to use oil in the fuel very sparingly. I use between 50:1 and 100:1 fuel to oil mix, as I said above. Even so, oil accumulates in the spark plug chamber and will sometimes completely fill the spark plug and submerge the gap. As with water fouling, remove the plug, blow out the oil, and swab out the spark plug chamber. (Incidentally, if your high energy ignition source can arc over and fail when firing into an open circuit, this may be a big problem. You may need a safety gap to keep from blowing out the coil when the plug won't fire.)

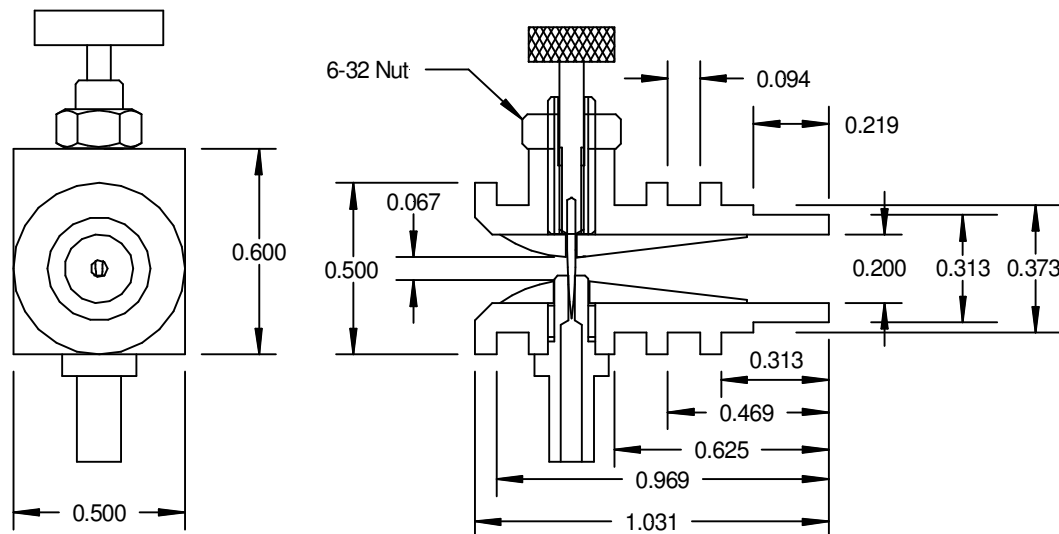
Carbon fouling arises mostly because the fuel mixture must run relatively rich in order to get enough fuel into the spark plug chamber to fire reliably. Oil in the fuel can also burn and contribute to carbon buildup, but that is less of a problem, depending on the type of oil. When the center insulator of the spark plug gets enough carbon to start shorting out some of the spark energy, the engine becomes flaky. This requires a replacement plug, but I reclaim carbon-fouled plugs for a few more cycles by heating them in my heat treat oven to 1100° F for about 15 minutes. (I haven't tried to use my kitchen self-cleaning oven; the process generates strong *eau de burning oil*.) Afterward you should oil the steel spark plug body inside and out to prevent rusting.

Corrosion: During my recent overhaul, I discovered some rust and corrosion pits in the cylinder in the vicinity of the spark plug. To minimize this problem, I try to run the engine long enough to get thoroughly warmed up before I shut it down. While it's still hot, I remove the spark plug and turn it over by hand (no fuel) to pump out any moisture in the cylinder and spark plug chamber. Then I let it cool down with the pistons at left dead center and the spark plug still removed. I don't like to put very much oil in the cylinder before storage because it will surely foul the spark plug when it is re-started the next time.

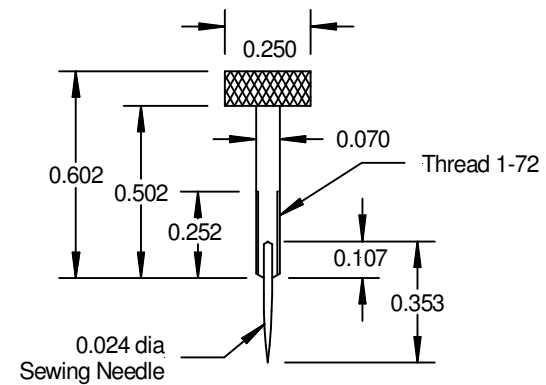
The bottom line

The Gingery version of the Atkinson Differential engine may not be an ideal beginner's project. It will always require a little more than average TLC to get it running and keep it happy, but it certainly is a manageable project. If you have already invested a lot of work in building one in the first place it is worth the trouble to see it through and make it run. The engine never fails to inspire questions and discussions at a show. It can only help the hobby if it encourages new people to dig into the history of IC engines and learn more about them.

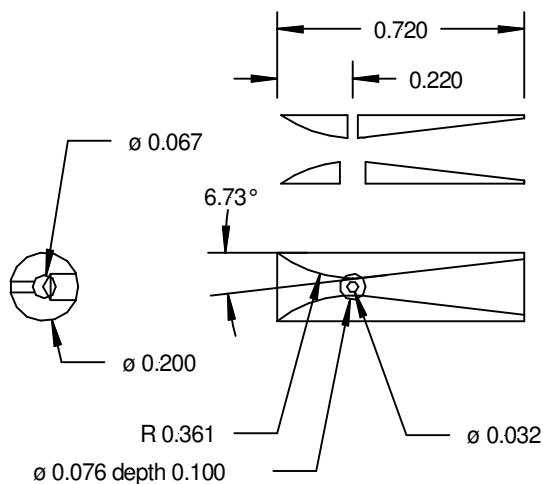
Carburetor Assembly



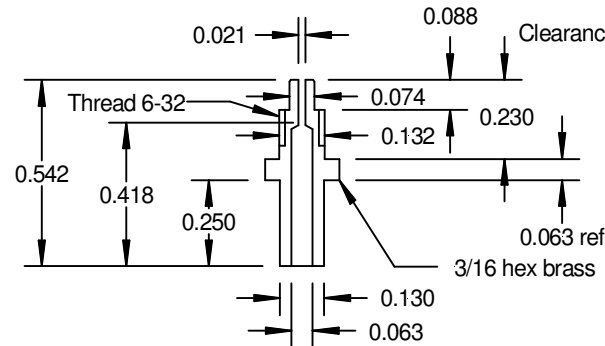
SS Needle Valve



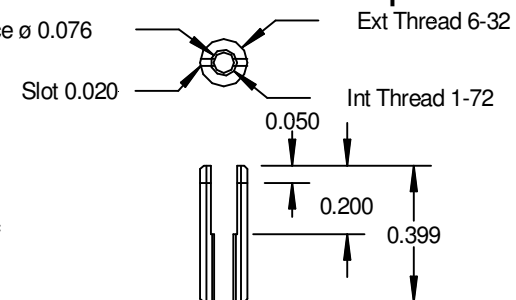
Brass Venturi



Brass Fuel Jet



SS Threaded Adapter



F: New Dwg Page, Chg venturi and jet sizes 11/25/07
 E: Finer Needle Valve 2/10/05
 D: Complete redesign 1/27/05
 C: Redesign to improve venturi 5/2/04
 B: Revised Needle Valve 8/19/03
 A: Original Drawing 8/15/2003

Drawing Number

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Atkinson Engine
 Carburetor

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