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Analysis of the Firing Order and Sound of a John Deere Engine

By Duane Larson

At last month's Two-Cylinder Club meeting several of us got into a discussion of the firing order of John Deere two-cylinder engines. This month's Technical Corner will discuss the firing order and (hopefully) explain the resulting sound. Since all JD's use a "180 degree" crankshaft, the first analysis will be for that crank. Some tractor-pulling enthusiasts modify the crankshaft by cutting and rewelding it so it is a "0 degree" crank, i.e., the pistons move together – both are at top dead center (TDC) and bottom dead center (BDC) at the same time. We will also analyze that crank to see what differences it produces in operation and sound.

First is a review of the fundamentals of a four-cycle engine. The four cycles consist of compression C, power P, exhaust E, and intake I, with the pattern repeated as long as the engine runs. Note that the cycle order CPEI-CPEI-CPEI must be preserved — the engine will not run if the E cycle follows the I cycle, for example. However, one can start anywhere in the cycle, for example, EICP preserves the proper cycles but starts with the exhaust cycle. For a two-cylinder engine this order must be preserved for both pistons, and that limits the allowed firing options to two. Also note that as a piston approaches TDC it will be completing either the C or E stroke, and as it approaches BDC it will be completing either the P or I stroke. Figure 1 assigns the CPEI cycle to the #1 piston. Hence, as #1 approaches TDC on the C stroke (1a), the #2 piston approaches BDC, and must be completing either the P or I stroke. 180 degrees later (1/2 revolution) (1b) #1 is completing the P stroke and #2 must be completing either the E or C stroke. 180 degrees after that (1c) #1 is completing the E stroke and #2 must be completing either the I or P stroke. Finally, after another 180 degrees (1d) #1 is completing the I stroke and #2 must be completing either the C or E stroke. Then we start over again with 1a, and the cycle repeats itself.

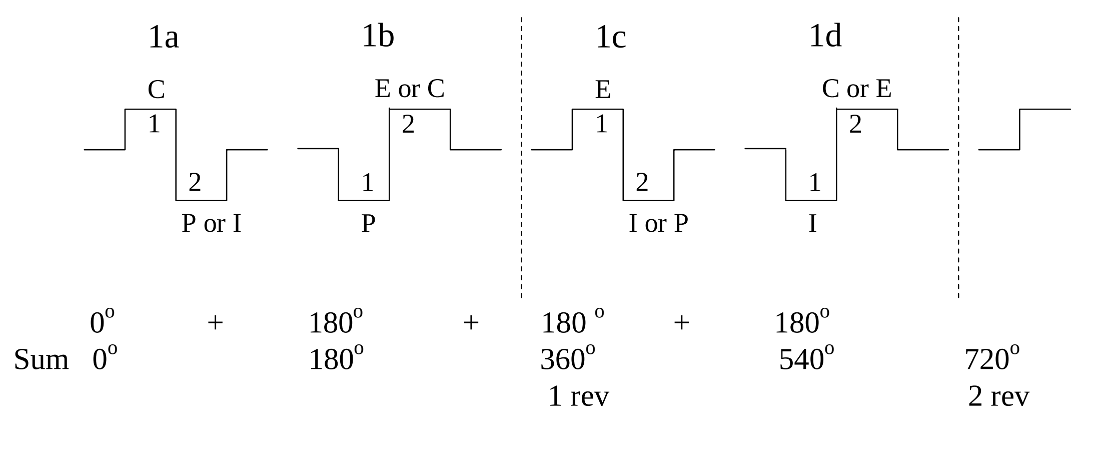

Figure 1

So, we can now write down the possible firing combinations for the two cylinders, starting with 1a. For the first option for piston #2 we find (labeling is: piston #1 piston #2)

CP PE EI IC | CP PE EI IC | etc,
and for the second option for #2 we have
CI PC EP IE | CI PC EP IE | etc.

Vertical bars separate the repeating cycles.

Studying both these options, we observe that both have power strokes separated by 180 degrees (1/2 revolution), ie, CP-PE and PC-EP. So there are two power strokes in one revolution, followed by no power strokes for the next revolution Thus, there is no way to get a power stroke each revolution with a 180 degree crankshaft. There is basically no difference between the two possible options—the second corresponds to the flywheel side piston firing followed by the pulley side piston firing 180 degrees later, and the first option corresponds to the pulley side piston firing first, followed by the flywheel side piston. John Deere two cylinder tractors use the second option.

Why we Hear the Putt-Putt Sound

Now, turning to the “putt-putt” sound we are all familiar with. Thinking about it, we realize that the sound does not result directly from the P (power) stroke itself, but rather from the E (exhaust) stroke—the sound comes out of the muffler, after all. Looking again at the firing combinations, we find that in both options the exhaust strokes are also separated by 180 degrees (logical!). Thus, we should hear a “putt-putt-nothing-nothing-putt-putt-nothing-nothing….”, in other words an aperiodic sound. But as we know, we hear a regularly spaced “putt-putt-putt-putt…..”. How can this be? The answer is found by looking at the exhaust valve operation. From some service information I have we find that for Models A and B tractors, the exhaust valve opens 45 deg before BDC and closes 5 deg after TDC. (It is not important for this discussion, but the intake valve then opens 10 deg after TDC and closes 40 deg after BDC.) So, the exhaust valve is open for 230 degrees (more than 1/2 revolution). Figure 2 shows when the exhaust valves open for each piston. Valve timings are similar for the D, G, and H.

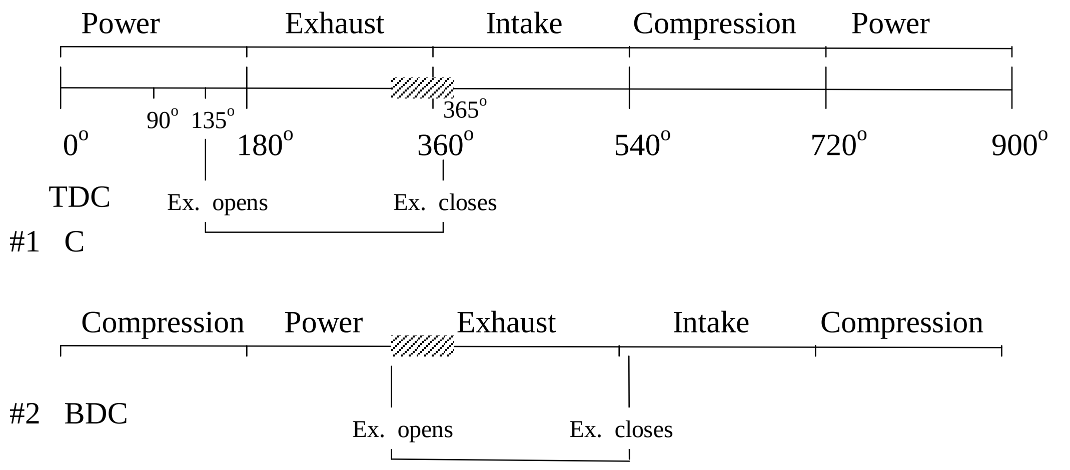

Figure 2

So, we have the answer. The exhaust valve for #1 opens, and before it closes the exhaust valve for #2 opens, and they are both open for 50 deg before #1 valve closes, then finally #2 valve closes. The crosshatched area shows the time the open exhaust valves overlap. Thus, we do not hear a distinct "putt" from the exhaust valve for each cylinder, but rather they merge into a single "putt", and the middle part of the "putt" is twice as loud as the beginning and end of the "putt" since both exhaust valves are contributing to the sound. If we pull one plug wire, we still hear the same number of "putts per second", but only one exhaust valve is contributing so the sound is weaker since there is no overlap with both contributing, and it is also only about 1/2 as long.

This can all be summarized in a table, shown below.

In the following table, "revolutions" counts the flywheel revolutions, and "degrees" is a running total for five revolutions, showing each 180 degrees as that is how the JD crankshaft is designed. P = power stroke, E = exhaust stroke, I = intake stroke and C = compression stroke. The next two lines shows the action of each piston, and each E provides a "putt" as noted in the "exhaust strokes" line. However, due to the exhaust overlap what we actually hear is given in the last line.

Revolutions			1		2		3		4		5
Degrees	0	180	360	540	720	900	1080	1260	1440	1620	1800
#1 cyl	P	E	I	C	P	E	I	C	P	E	I
#2 cyl	C	P	E	I	C	P	E	I	C	P	E
Ex strokes		putt	putt			putt	putt			putt	putt
We hear			putt			putt				putt	

It is possible, when the engine is idling very slowly and not under load, that the individual "putts" can be heard.

Modified Crankshaft Case

Now we turn to the case of the modified crankshaft in which both rod journals are at TDC or BDC at the same time. In this case we again have two options for the second piston, given the action of the #1 piston.

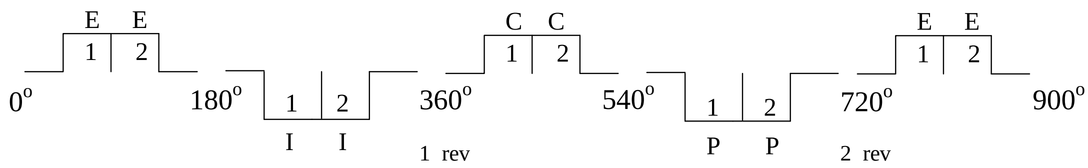

Figure 3

The first option, shown in Figure 3, is obvious – the #2 piston does what #1 does – i.e., EE II CC PP. Not too interesting in that both pistons undergo the power stroke at the same time, and do not fire again until a full revolution later. So, we hear "PUTT" nothing-nothing-nothing "PUTT"….. The "putts" are big because the exhaust stroke contains exhaust from both cylinders and would be loud. The other option, shown in Figure 4, is more interesting. Doing the same analysis as before, one can see that the second option for the #2 piston results in EC IP CE PI, with the cycle repeated. So we see that we have one power stroke during each revolution, and they are equally spaced between revolutions. This gives the most even distribution of power available from two cylinders, but results in balance issues since lots of counterweights must be carefully added to provide dynamic balancing – and the balance will likely be good only near one rpm, so getting to that rpm could be a time of vibration.

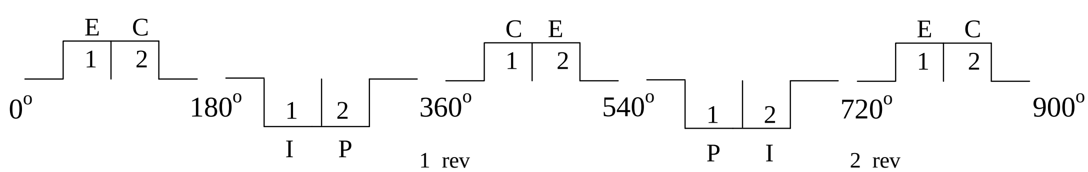

Figure 4