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Polygon oscillating piston engine

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Abstract: *Recent trends in engine design have pushed the state-of-the-art regarding high power-to-weight ratio engines. This paper described the polygon oscillating piston engine invention. The engine configuration presented herein makes it possible to package a large number of power producing pistons in a small volume resulting in a power to weight ratio of approximately 2 hp per pound, which has never before been realized in a production engine. The analysis and design of a lightweight, two-stroke, 6 sided, in-plane, polygon engine is summarized this paper. The engine can be configured to operate as an internal combustion engine that uses diesel fuel, gasoline, Jet-A, or natural gas, or it can be configured as an expansion device to convert high pressure high temperature gas to rotary power. As an expansion engine, the two-stroke engine design modified to function in a supercritical carbon-dioxide (SCO2) Rankine waste-heat recovery renewable energy application.*

Keywords: *polygon engine, expansion device, power-to-weight*

I. INTRODUCTION

A polygon oscillating piston engine having multiple pistons on one of two oscillating disks is described in the US Patent of Cunningham and Stuart [1]. The polygon engine is shown in Fig. 1. The original engine design of [1] takes its genesis from a two-stroke university sponsored research design project sponsored by Butte Industries, Inc. [2,3]. The current evolution of the polygon oscillating piston engine design stems from the works published in [4,5,6,7] for the renewable energy application of using the engine as an expander in a SCO2 Rankine cycle for waste-heat recovery. A key component of the system design is the modeling of chamber pressure as this drives all design modifications. This thermodynamics modeling was centered about a polytropic model which spurred a new methodology for determining the polytropic process index as detailed in [8].

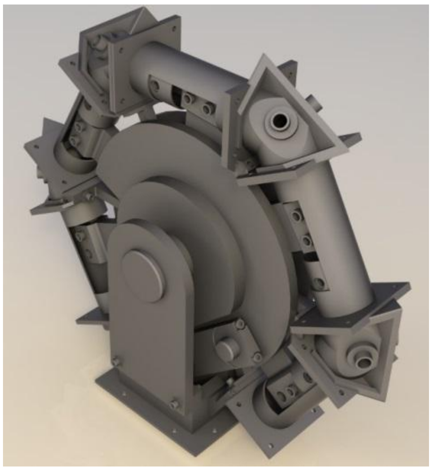
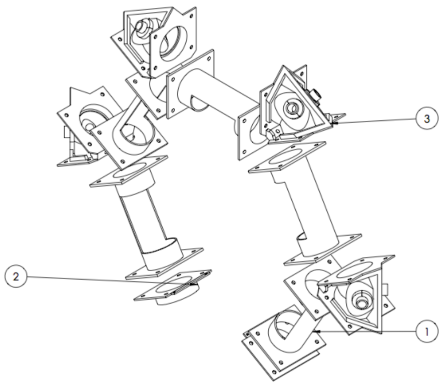


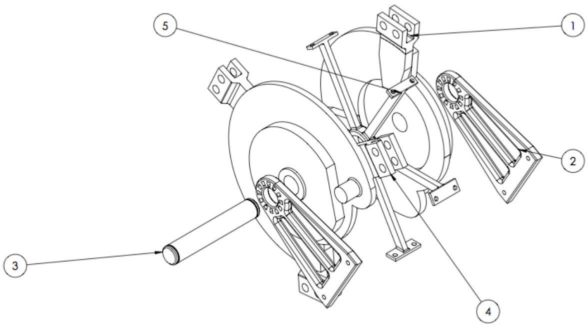
Figure 1: Polygon oscillating piston engine

Many different configurations of internal combustion engines have been introduced historically, with inline and V-configurations having become dominant. Other configurations use opposed pistons where two pistons come together in a single combustion chamber. More recently, configurations where the combustion chamber is a toroid and where multiple pistons move in an oscillating manner have been proposed. One such engine is disclosed in the US patent of March 29, 2011 [9]. The engines of [9] have the advantage of having a high power-to-weight ratio and they offer high torque at low engine speed. The engines of [9] have the disadvantage, however, of being difficult to manufacture and of having unreliable piston seals due to the motion of the piston in an arc. Clearly, an engine design that solves these problems is desirable. The current design described herein and in [1] overcomes the disadvantages of the toroidal engine of [9] while keeping the advantages of [9]. The invention stated herein and in [1] accomplishes this by having the pistons arranged in a polygon with straight sides. Each piston moves in a straight cylinder with conventional piston rings. The combustion chambers lie at the intersection of the sides of the polygon. The pistons in adjacent positions around the polygon move toward and away from each other giving the advantages of the opposed-piston configuration with a common combustion chamber in between. In addition, the drive mechanism that connects the oscillating pistons to the rotating crank shaft has been simplified to lower the part count and subsequent cost of construction. The manufacturing process selection was crucial to obtaining a design that could be produced. Due to the relatively low operating temperatures, various steels were chosen to meet loading requirements and provide thermal expansion uniformities. The design is detailed in Fig. 2 through Fig. 6 which show detailed drawings and bill of materials of the primary components comprising the expansion engine design.



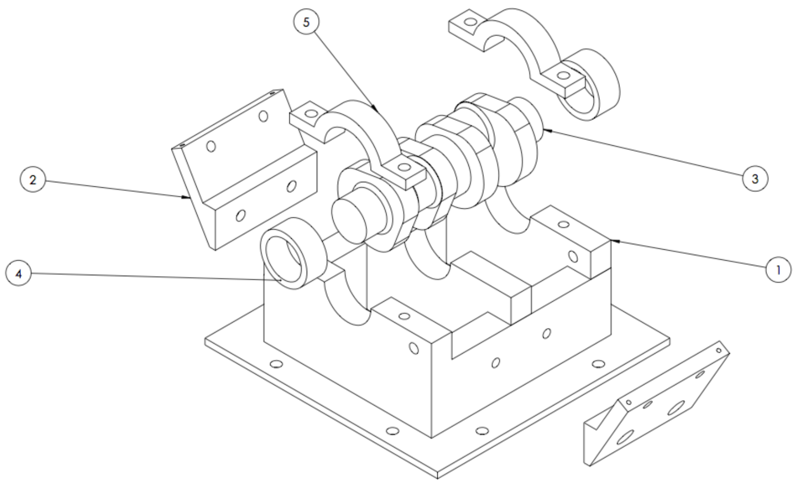
ITEM NO.	PART NUMBER	DESCRIPTION	Material	Finish	QTY.
1	2500-802_B_exhaust-sleeve-standard_V2	EXHAUST_SLEEVE	AISI 1020	SAND CASTED/POST MACHINED	5
2	2500-701_A_end-piece_V2	END_PIECE	AISI 1045 Steel, cold drawn	CNC MACHINED	2
3	2500-206_A_corner-combustion_V2	CORNER_COMBUSTION_CHAMBER	AISI 1020	SAND CASTED/POST MACHINED	4

Figure 2: Detailed drawing and bill of materials for combustion chamber subassembly



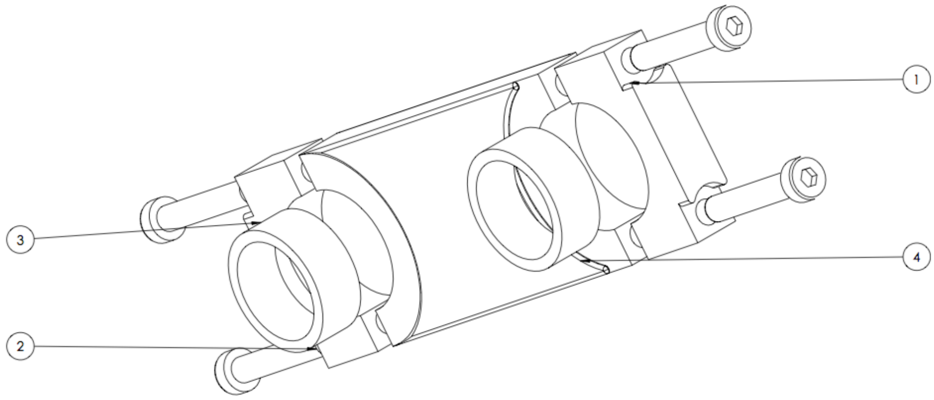
ITEM NO.	PART NUMBER	DESCRIPTION	Material	Finish	QTY.
1	2500-604_A_back-disk	BACK_DISK	AISI 1020	SAND CAST/POST MACHINED	1
2	Main Shaft Support^Full Assembly	MAIN_SHAFT_SUPPORT	AISI 1045 Steel, cold drawn	CNC MACHINED	2
3	-1		AISI 1045 Steel, cold drawn	CNC MACHINED	1
4	2500-603_A_front-disk	FRONT_DISK	AISI 1020	SAND CASTED/POST MACHINED	1
5	-1		AISI 1020	SAND CASTED/POST MACHINED	1

Figure 3: Detailed drawing and bill of materials for disc subassembly



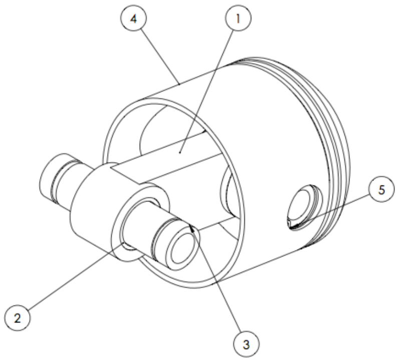
ITEM NO.	PART NUMBER	DESCRIPTION	Material	Finish	QTY.
1	2500-501_B_crank-bearing-support_V2	CRANK_BEARING_SUPPORT	AISI 1045 Steel, cold drawn	SAND CASTED	1
2	2500-601_A_external-case_crank-support_V2	EXTERNAL_CASE_CRANK_SUPPORT	AISI 1045 Steel, cold drawn	CNC MACHINED	2
3	2500-515_A_crank-shaft	CRANK_SHAFT	AISI 1020	SAND CASTED/MACHINED	1
4	-1		AISI 1045 Steel, cold drawn	CNC MACHINED	3
5	2500-505_A_crank-bearing-cover	CRANK_BEARING_COVER	AISI 1045 Steel, cold drawn	CNC MACHINED	2

Figure 4: Detailed drawing and bill of materials for crankshaft subassembly



ITEM NO.	PART NUMBER	DESCRIPTION	Material	Finish	QTY.
1	2500-609_A_push_rod_end	PUSH_ROD_END	AISI 1045 Steel, cold drawn	CNC MACHINED	2
2	2500-608_A_Bolt_.38	BOLT_3/8"	STEEL	COATED	4
3	2500-516_A_neddle_bearing_cam	NEDDLE_BEARING_CAM	AISI 1045 Steel, cold drawn	CNC MACHINED	2
4	2500-610_A_push_rod_center	PUSH_ROD_CENTER	AISI 1045 Steel, cold drawn	CNC MACHINED	1

Figure 5: Detailed drawing and bill of materials for pushrod subassembly



ITEM NO.	PART NUMBER	DESCRIPTION	Material	Finish	QTY.
1	2500-614_A_piston_rod	PISTON_ROD	AISI 1045 Steel, cold drawn	CNC MACHINED	1
2	2500-220_A_piston_bearing	PISTON_BEARING	AISI 1045 Steel, cold drawn	CNC MACHINED	2
3	2500-219_A_piston_rocker_pin	PISTON_ROCKER_PIN	AISI 1045 Steel, cold drawn	CNC MACHINED	2
4	2500-205_A_piston_end-piece-dome	PISTON_END_PIECE_DOME	AISI 1045 Steel, cold drawn	CNC MACHINED	1
5	99142A390	INTERNAL_RETAINING_RING	STEEL	BLACK-FINISH	2

Figure 6: Detailed drawing and bill of materials for piston subassembly

As seen in Fig. 2 through Fig. 6, the pistons are attached to one of two disks, with the even piston numbers on one disk and the odd piston numbers on the other disk. Each disk can pivot on a central drive shaft. Each disk has a set of pegs or bars that extend in the radial direction (one for each piston) and which slides in a sleeve that pivots in the center of each piston. The back and forth oscillating motion of the piston within its cylinder is translated to the angular oscillation of the corresponding disks. The two disks oscillate in opposition to one another. When the pistons on the first disk move in the clockwise direction, the pistons on the second disk move in the counter-clockwise direction, and vice versa. As the pistons approach each other, they compress the fuel-air mixture. At the point of closest approach, combustion occurs and the pistons are pushed apart. Then the pistons on each disk move to the opposite corner of the polygon and the process repeats. In a two cycle engine, every stroke of the two-sided piston is a power stroke. The operation of this engine is very similar to the operation of the toroidal engine describe in the patent of [9]. The fundamental difference between the current invention and that of [9], is that for the engine described herein, the pistons beneficially move in a straight line, whereas the pistons in the cited prior design of [9] move in an arc. Herein, the basic configuration is that of a polygon with an even number of sides. One or more crank shafts for the engine can be provided inside the polygon so that pistons occupy all sides of the polygon, or a crankshaft can be provided that actually occupies one of the sides of the polygon so that the total number of pistons becomes an odd number. With state-of-the art crankshaft designs, the former configuration will function well for lower power applications, whereas the latter configuration works well for high power applications. However, the former design can be made practical for higher power applications where stronger crankshafts are provided than are typically available. A comprehensive stress analysis and machine design procedure has been carried out for this invention as outlined in [7].

II. OPERATION

As shown in Fig. 2. through Fig. 6, each piston moves in a straight line along one of the sides of a polygon within a cylindrical chamber, while the oscillating disks move in an arc about a central shaft. The difference in the straight motion of the piston and angular motion of the oscillating disk is accommodated by a slip sleeve within the piston that slides on a peg or bar mounted to each disk. The engine can be configured to operate as an internal combustion engine that uses diesel fuel [5], gasoline, Jet-A [4], or natural gas, or it can be configured as an expansion device to convert high pressure high temperature gas to rotary power [2,3,6,7,8]. This engines compact design results in a high power-to-weight ratio. This invention relates generally to the field of internal combustion engines. More specifically, this invention relates to the conversion of energy from chemical energy from the combustion of a variety of petroleum products into rotational mechanical energy using an oscillating disk methodology. The rotational mechanical energy can be used to drive a generator to create electricity or drive a transmission in a moving vehicle (e.g., a car, truck, plane, or boat). The modular design shown in Fig. 1 allows the ability to have multiple engines stacked in series as shown in Fig. 7.

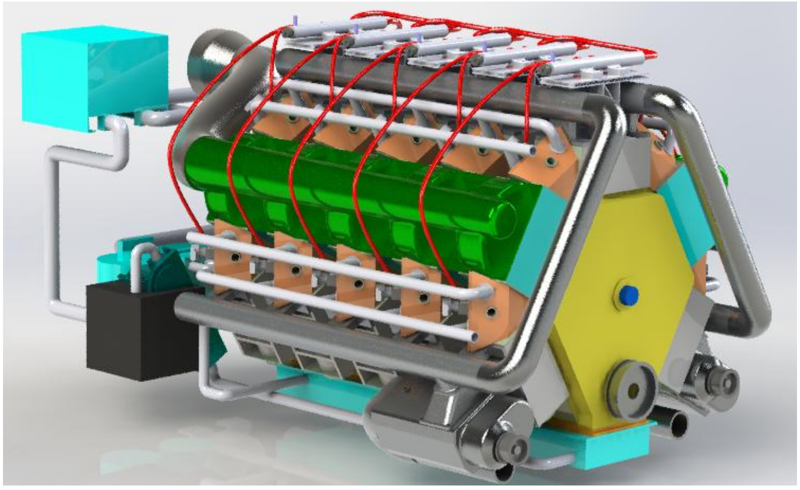


Figure 7: Polygon oscillating piston engine stacked configuration

The power to weight ratio of this engine is very high [5]. This comes about for several reasons. First is the use of opposed pistons. For opposed pistons, the speed of a piston is around half that of a conventional piston engine for the same displacement. This allows the engine to run at about twice the rotational speed and therefore generate about twice the power with about the same displacement as prior art engines. Second is the use of two sided pistons. This was common with steam engines, but is not common with gasoline engines. The improved design uses two sided pistons arranged in a closed polygon. Third is the optional use of a two cycle design rather than the more common four cycle design. These last two items allow every stroke of every piston to be a power stroke. This is in contrast to the conventional automobile engine where every fourth stroke is a power stroke, or the conventional two cycle engine where every second stroke is a power stroke. Finally, the weight is greatly reduced compared to an opposed piston engine in that the invention herein has the same number of power producing combustion chambers as there are pistons, whereas the conventional opposed piston engines have one combustion chamber for two pistons. The engine designs described herein are a piston based engines where the piston chambers are arranged as the sides of a polygon. The polygon can have any even number of sides starting with four. The embodiment shown here has six sides, but engines with eight, ten, or twelve sides are also possible and may be preferred in some applications. There is no limit to the number of sides, but the disclosed designs use an even number of sides.

III. TYPICAL POWER SPECIFICATIONS

The analysis and design of a lightweight two-stroke 6-sided in-plane polygon engine having a geometric compression ratio of 15.0, an actual compression ratio of 8.8, and a piston speed of 3500 ft/min are presented in the study of [5]. Typical results from [5] show that for a hexagonal engine with 2 inch diameter pistons and 1.25 inch stroke running diesel fuel, a single piston displacement is 7.85 cubic in., while the total engine displacement is 47.1 cubic inches. Full power at 12,960 rpm at an air flow rate of 353 cubic feet per minute affords 0.444 cubic ft/min/hp for specific power. For an efficiency of 21%, the blower power is 168 hp. The air-flow analysis of [5] shows that the power of the engine does not depend on the number of pistons, but rather on the volume of the gas-air mixture which passes through the engine. System level engineering of power output, kinematic modeling, air-flow modeling, efficiency, scavenging predictions, crankshaft sizing, and weight estimates are presented in [5].

IV. CONCLUSION

This paper summarizes the invention of the Polygon Oscillating Piston Engine. The invention discussed in this paper is described in US Patent WO 2013158452 A1 Polygon Oscillating Piston Engine. An overview of the supporting engineering analysis and operation of the engine has been provided. This paper documents the current state-of-the-art of this particular invention.

V. ACKNOWLEDGEMENTS

The research discussed herein were sponsored by Buttes Industries, Inc. and the invention is per US Patent WO 2013158452 A1 Polygon Oscillating Piston Engine, by Martin A. Stuart and Stephen L. Cunningham, October 24, 2013.

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