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ABSTRACT

The Parallel Combustion Two-Stroke is an internal combustion engine utilizing a hypocycloid gear mechanism and parallel combustion chambers. The hypocycloid mechanism provides mechanical balance and linear rod motion which eliminates piston sidewall forces and creates two chambers in the working cylinder. These two chambers are connected to combustion chambers external to the working cylinder. The resulting engine operates on a two-stroke cycle with many of the advantages of a four-stroke engine. It operates as an internal combustion engine with many of the advantages of an external combustion engine. And it operates as a reciprocating engine with the dynamic balance of a rotary engine.

INTRODUCTION

The purpose of this paper is to define where we are today in the evolution of engines, to outline the forces at work shaping the future of engines, to review past and present alternative engines, to summarize the likely characteristics and requirements of future alternative engines, and to compare these characteristics and requirements to the attributes of the Parallel Combustion Two-Stroke engine to demonstrate its potential for certain applications.

BACKGROUND

Three engine types dominate the world markets of today and each has found a significant niche. Although all three of these engines use pistons and crankshafts to convert combustion energy to useful mechanical energy, each engine also has distinctive mechanical and operating differences that gives it an advantage for certain applications.

Because of its simplicity, the two-stroke has found widespread use in outboard motors, lawn and garden equipment, snowmobiles, and wherever a small, inexpensive, portable power source is required. The diesel dominates the other end of the spectrum consisting primarily of commercial trucks, locomotives, marine vessels, and industrial applications. And the Otto four-stroke continues to dominate the large middle which includes automobiles, light trucks, and motorcycles.

Although these three engines have dominated for over a century, their future is far from certain. As more and more cities have experienced increasing air pollution in recent decades, the hydrocarbon fuels used in internal combustion engines have been found to be a major cause. The primary product of an efficient hydrocarbon combustion process is carbon dioxide which can only be minimized by reducing the consumption of hydrocarbon fuel through increased fuel efficiency or through conversion to an alternate fuel. But there are also three types of emissions that result from an inefficient hydrocarbon combustion process. First, there are the hydrocarbon emissions that result when unburned fuel escapes directly to the atmosphere. Second, there is the carbon monoxide that results from incomplete combustion when the process fails to reach the second step in the two stage process required to form carbon dioxide. And third, there are the oxides of nitrogen that form when the combustion process is not fully controlled and generates areas of excessive pressure and heat. With an understanding for the need to control these vehicle emissions beginning to gain acceptance in the 1960's, a second factor affecting the future of internal combustion engines also became apparent. The first oil embargo, beginning in late 1973, resulted in long lines at the gas pump and increased our awareness that oil reserves are limited.

As our knowledge of vehicle emissions and fuel supply limitations has grown, the consequence has been twofold. On the one hand, several levels of government have responded with legislation to limit emissions and improve fuel efficiency. On the other hand, industry has embarked on research programs aimed at improved or alternate power sources and fuels, sometimes in partnership with government. Initially, most legislation to control emissions was directed at automobiles but now even small engines are being targeted. In 1990, the California Air Resources Board (CARB) established emission standards (1)[1] for lawn, garden, and industrial engines to be implemented in two phases beginning in

1. Numbers in parenthesis designate references at end of paper.

1994. The U.S. Environmental Protection Agency has also announced that it is developing air-quality standards for small engines (1).

These legislative pressures have resulted in efforts to improve all three engine types which dominate today's markets. These three engines are essentially first generation engines which are largely unchanged in their basic mechanical configurations and operating cycles from when they were invented in the last century. What has changed in recent years are the enhancements for extracting more of the potential to make these engines meet today's requirements. These enhancements include the electronic controls, intake chargers, balance shafts, fuel injectors, multiple valves, catalytic converters, and other add-ons which reduce emissions and improve combustion and performance. Since most of the emphasis has been on the Otto four-stroke, that is where results have been most significant in meeting emissions and efficiency mandates. But it is uncertain whether continued increases in efficiency and emissions-control of sufficient magnitude can be gained from the four-stroke to meet future requirements. Attempts to also gain significant advances from two-stroke and diesel engines to make them viable alternatives to the four-stroke have so far met with limited success.

During this same period that automobile manufacturers were successfully improving the four-stroke engine, they simultaneously spent hundreds of millions of dollars to develop a new generation of engines. Searching for a major leap forward in emissions control, fuel efficiency, and operating performance, General Motors Corporation initially focused on developing the Wankel engine while Ford Motor Company concentrated on the Sterling engine and Chrysler Corporation devoted its research to the turbine engine. At the same time, dozens of other corporations and individuals around the world have worked to develop alternative two-stroke and diesel engines and other engine concepts such as the rotary "V" engine, the cruciform engine, the scotch-yoke engine, the opposed piston engine, the free piston engine, and several variations of orbital and rotary engines. While each of these alternative engine concepts has significant merit, they also present offsetting challenges in emissions-control, fuel efficiency, operating performance, or manufacturing cost that have prevented them from becoming viable alternatives to any of the three types of engines that continue to dominate today's markets.

General Motor's focus on the Wankel rotary engine had the promise of greater power from a smaller, balanced, smoother-running package. But with intake and exhaust characteristics similar to existing two-stroke engines, the Wankel has been unable to attain sufficient emissions-control and fuel efficiency to become a viable alternative. Sealing the rotor has proven troublesome and expensive and the special metals and coatings plus the epitrochoid shaped housing, which requires special machining and grinding equipment, makes the Wankel expensive to manufacture. Consequently, after several years of research and development, General Motors abandoned the Wankel project in 1977 (2).

Ford's concentration on the Sterling engine had the promise of low emissions and high thermal efficiency as a result of its continuous combustion process external to the working cylinders. But to realize these benefits requires a confined working fluid and high operating temperatures that create sealing and lubrication challenges and the need for expensive materials. In addition, the mechanism for converting the thermal energy to rotary output motion has added to the Sterling's complexity and expense. Consequently, after several years of research and development, Ford abandoned further Sterling development in 1978 (3).

Chrysler's research into the gas turbine engine also had the promise of low emissions and high thermal efficiency as a result of its continuous combustion process. But, as with the Sterling, to realize these benefits requires high operating temperatures that necessitate expensive materials. In addition, the turbine fans for converting thermal energy to useful output motion have presented additional challenges toward achieving high operating efficiency, performance, and reliability. Consequently, after several decades of turbine engine research and development, Chrysler is still unable to solve all the problems associated with the turbine engine and announced in 1996 that it was shelving its Patriot program aimed at developing a turbine-powered race car (4).

Another result of the pressures to improve automobile emissions and fuel efficiency has been the new attention two-stroke engines have received from nearly all major automobile manufacturers in recent years. Two-strokes also have the promise of greater power and performance from a smaller, lighter package because they deliver twice as many power strokes per revolution as four-strokes operating at the same speed (RPM). In addition, existing two-stroke engines use ports instead of valves and therefore are simpler and less expensive to manufacture. But they also have several disadvantages compared to four-strokes. They operate at a higher temperature, they require that a lubricant be mixed with the fuel, and, because of intake and exhaust overlap, they lose a portion of their new charge of air and fuel through the exhaust ports while failing to remove a significant portion of their exhaust gasses during each cycle. Consequently, they create more thermal stresses on their moving parts, they produce more emissions, and they are less fuel efficient than four-strokes.

It would appear that allowing the two-stroke more complexity by adding valves, fuel injection, supercharged intake and other enhancements, its inherent advantages in power and weight could be preserved while eliminating its shortcomings. While such improvements have eliminated many of the two-stroke's disadvantages, they have not yielded the results in emissions-control needed to meet proposed U.S. emissions standards. As a result, Chrysler suspended its two-stroke program in 1996 (5).

Of the many other alternative engine concepts published in recent years, none has achieved even limited commercial success. While all have shown significant theoretical advantage in one respect or another, they also have offsetting shortcomings which diminish their potential. Some use ports for intake and exhaust which results in increased emissions and reduced fuel efficiency due to function overlap as in two-strokes and the Wankel. Some use a sliding mechanism for power conversion that introduces lubrication and sealing problems and friction losses. Some use a rotor that also introduces sealing losses and function overlap. And many attain their specific advantage at the expense of complexity and cost. In a time and place without the options available today, each of the alternative engines developed in recent years could likely play a significant role. But given the standards for economy, cost, and performance established by the three types of engines which dominate today's markets, none of these alternative concepts appear to exhibit sufficient overall advantage to command the interest it would take to move to the level of a viable competitor.

For any alternative engine concept to challenge any of the three dominate engines for even a niche in the market place, it must be superior in emissions control and fuel efficiency without significantly increasing manufacturing cost. And it must offer sufficient operating performance to meet the requirements of that specific market niche. To attain these goals, an alternative internal combustion engine for the 21st century would likely require most if not all of the following attributes:

1. The functions of the operating cycle consisting of intake, compression, combustion/expansion, and exhaust are largely separate from each other to avoid significant fuel and power losses.
2. The metering and timing of fuel input is highly controlled.
3. The elements of the combustion process consisting of compression, mixing, ignition, peak temperature, peak pressure, and elapsed combustion time, are sufficiently controlled to attain complete combustion with minimum oxides of nitrogen.
4. A greater amount of the heat generated by combustion is captured and utilized to facilitate the expansion of gasses that drive the mechanism when compared to existing crankshaft engines.
5. The movement of gasses for intake, expansion, and exhaust is efficient and pumping losses are therefore minimized.
6. The mechanism for converting thermal energy to mechanical energy compares favorably to the piston/crankshaft mechanism presently used in the three engine types currently dominating today's markets. Therefore, this mechanism does not introduce significantly greater lubrication obstacles, sealing losses, or sliding friction losses from side forces.
7. Performance meets requirements for specific application.
8. Manufacturing costs are reasonably competitive with current alternatives.

PARALLEL COMBUSTION TWO-STROKE

The Parallel Combustion Two-Stroke (PC2S) is a reciprocating piston engine based on the operating characteristics of the Linear Gear Drive, a dynamically balanced hypocycloid mechanism that efficiently converts linear piston/rod motion to rotary output motion. This mechanism makes it possible to create four chambers for separating the functions of operation thereby creating a new two-stroke operating cycle. This new operating cycle results from these chambers altering the combustion, lubrication, and cooling characteristics of engine operation. In addition, the natural motion and pressure forces of two-stroke operation are utilized to facilitate intake, exhaust, and fuel injection.

Starting with the connecting rod, which is now able to move in a linear path, two independent chambers are created in the operating cylinder as shown in Figure 1. Separated by the piston, these chambers are both connected to a pair of external combustion chambers mounted parallel to the operating cylinder. Working together, these four chambers allow the intake, compression, combustion, expansion, and exhaust functions of the operating cycle to occur during two strokes of the piston (one revolution of the output shaft) but without the function overlap and losses associated with existing two-stroke engines. Therefore, the PC2S operating cycle is two-stroke in its power output but more closely resembles the Otto four-stroke engine in its separation of functions and operating efficiency. It is an internal combustion engine that utilizes external combustion chambers for controlling the parameters and duration of combustion and utilization of heat to capture many of the advantages of external combustion engines such as the Sterling or turbine. And it is a reciprocating piston engine that utilizes a hypocycloid Linear Gear Drive mechanism to achieve the balance and smoothness of a rotary engine such as the Wankel.

TWO-STROKE OPERATING CYCLE – In the three engines that dominate today's markets, a cycle consists of four distinct functions - intake, compression, combustion/expansion, and exhaust. The PC2S cycle consists of five distinct functions - intake, compression, combustion, expansion, and exhaust. This difference results from combustion and expansion occurring as one blended function in the working cylinder in existing crankshaft engines but as two separate functions in separate chambers in the PC2S engine. Therefore, the PC2S engine operates on a new and different operating cycle which includes a true constant volume combustion process, greater time for combustion, and increased potential for heat retention and utilization.

Referring again to Figure 1 and assuming the engine is just being started, the first two-stroke operating cycle begins with the intake stroke as the piston starts upward from the bottom of the cylinder. During this upward stroke, air is drawn in through port-holes located around the entire base of the cylinder. The air then passes through a second set of ports in a reed-plate which allows the air to pass only in one direction, thereby confining it to the lower "intake" chamber below the piston. As the piston reaches the top of its upward stroke, a valve opens at the base of an external combustion chamber providing communication between this adjacent combustion chamber and the intake chamber below the piston. As the piston then travels downward, it compresses the air into the adjacent combustion chamber. During the final one-quarter inch of downward travel, an additional burst of compressed air is created and follows a different path to inject fuel into the combustion chamber. As flywheel momentum carries the piston past its bottom position to begin a new intake cycle, the lower valve in the combustion chamber closes and a spark ignites the mixture inside the combustion chamber. The combustion process then takes place during most of the upward stroke of the piston and therefore simultaneous to the intake stroke for the next cycle.

As the piston again reaches the top during its next stroke, two valves open simultaneously. A valve in the top of the first combustion chamber opens and allows the hot, pressurized gasses to flow from this combustion chamber into the expansion chamber above the piston in the working cylinder. This upper valve remains open during most of the expansion stroke as the hot gasses continue to flow out of the combustion chamber and drive the piston downward. In addition, a valve at the base of the second external combustion chamber also opens providing communication with the intake chamber below the piston. As the piston is driven downward by the hot gasses flowing from the first combustion chamber, the new charge of air below the piston is being compressed into the second combustion chamber.

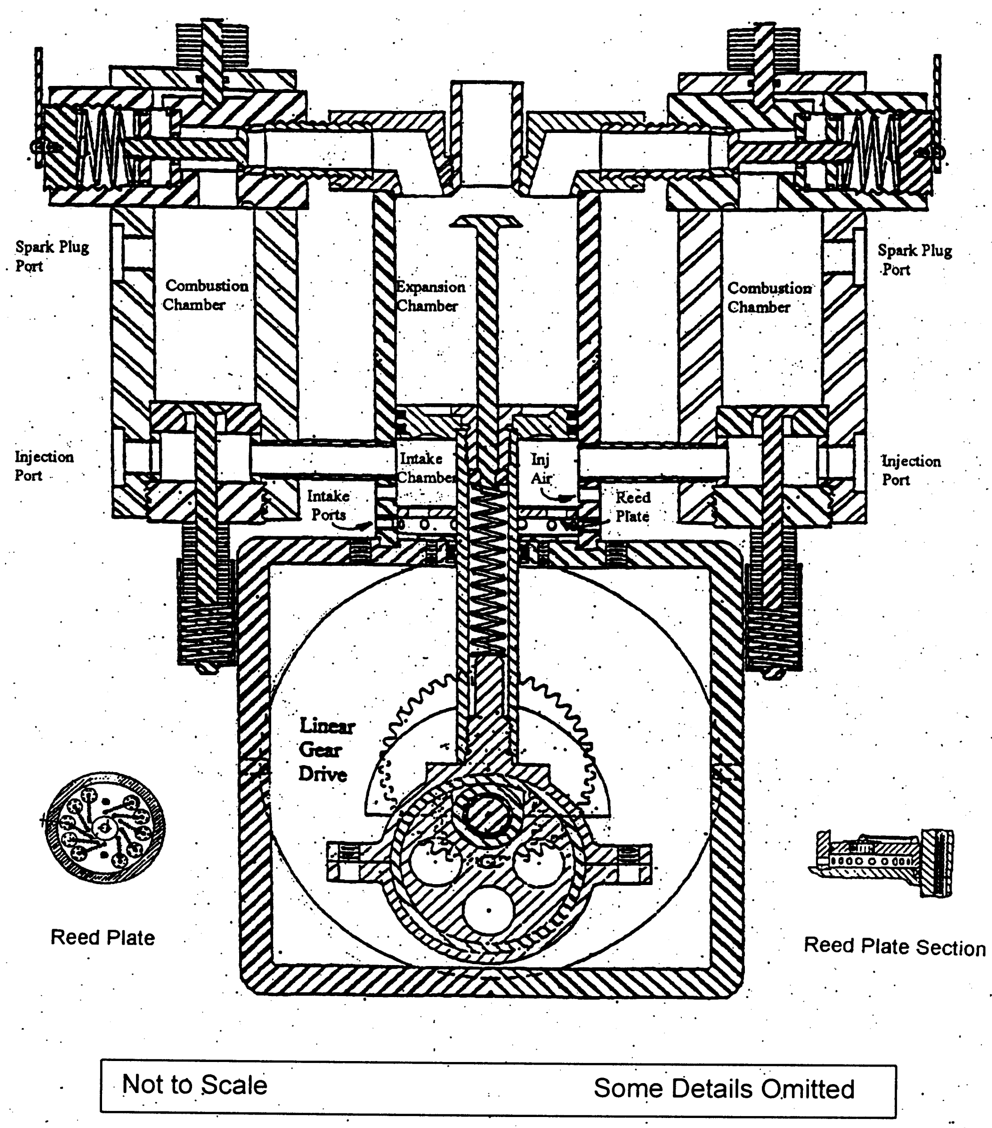


Figure 1. Parallel Combustion Two-Stroke Engine

Table 1. Cycle Overlap

Stroke	Piston Direction	Cycle 1	Cycle 2	Cycle 3	Cycle 4
1	Up	Intake			
2	Down	Compression			
1	Up	Combustion	Intake		
2	Down	Expansion	Compression		
1	Up	Exhaust	Combustion	Intake	
2	Down		Expansion	Compression	
1	Up		Exhaust	Combustion	Intake
2	Down			Expansion	Compression

As the piston approaches the bottom of its stroke, three valves function simultaneously. The upper valve in combustion chamber number one closes while the lower valve in combustion chamber number two also closes. In addition, an exhaust valve in the head of the working cylinder opens. Then, as the piston begins its next upward stroke, the exhaust gasses in the expansion chamber above the piston are forced to flow upward through the open exhaust valve and exit the engine. This exhaust function takes place simultaneous to yet another intake stroke taking place in the lower chamber below the piston and also simultaneous to another combustion process taking place in combustion chamber number two. When the piston reaches the top of its exhaust stroke, the exhaust valve closes and the first cycle is complete. Also, the next cycle is now three-fifths complete (intake, compression, combustion) and a third cycle is one-fifth complete (intake). As shown in Table 1, three functions occur simultaneously during the upward stroke of the piston and two functions occur simultaneously during the downward stroke of the piston.

Because the PC2S engine has separate intake and combustion chambers, the combustion function occurs simultaneous, or parallel, to the intake and exhaust functions and the expansion (power) function occurs simultaneous to the compression function. Each of these five functions are defined by a full stroke of the piston. Since there is one power stroke for each complete revolution of the output shaft, the PC2S engine operates on a two-stroke cycle, and, as with prior two-stroke art, the independent cycles overlap each other. But unlike prior two-stroke art, the functions within each PC2S cycle do not overlap. This eliminates the major sources of combustion inefficiency and hydrocarbon emissions associated with two-stroke engines and therefore significantly increases operating efficiency and emissions-control over existing two-stroke designs.

Also, because the PC2S operates on a two-stroke cycle, it eliminates the two pumping strokes required for intake and compression in the Otto four-stroke engine. Therefore, the pumping and mechanical friction losses associated with these strokes are also eliminated and operating efficiency is further increased compared to existing four-stroke engines.

THE LINEAR GEAR DRIVE MECHANISM (LGD) – The basis for the Parallel Combustion Two-Stroke engine is an elementary gear relationship that produces a linear motion from a rotary motion and vice versa. While this linear motion is significant in itself by the elimination of side forces, there are also several other inherent advantages plus several opportunities. The inherent advantages of the Linear Gear Drive mechanism include dynamic balance, sinusoidal motion, and mechanical efficiency. The opportunities created by these LGD advantages include the utilization of a piston, the creation of a separate intake chamber, the creation of a simple means for fuel injection, the creation of separate combustion chambers, the creation of an exhaust mechanism utilizing piston/rod motion, and the design freedom to create unlimited multi-cylinder configurations.

The linear motion created by this elementary gear relationship is a special case in a family of curves called hypocycloids. A hypocycloid is a curve generated by a point on a circle when that circle is rolled inside a larger circle. When the diameter of the smaller circle is one-half the diameter of the larger circle, the hypocycloid becomes a straight line. In fact, every point on the smaller circle now moves in a straight line. This same linear motion occurs when a small gear (pinion) is rotated inside an internal gear with a pitch diameter twice that of the pinion. Any point on the pitch circle of the pinion moves in a straight line inside the internal gear.

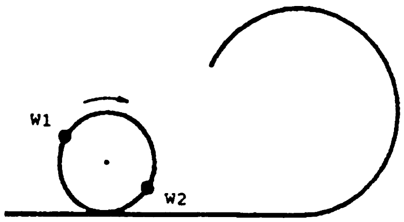


Figure 2. Dynamic Balance

While the hypocycloid linear motion is easily demonstrated, its dynamic balance is less apparent. This aspect can be shown by considering the wheel illustrated in Figure 2. This wheel has two equal, diametrically opposed balance weights located on its perimeter. Traveling down a flat road, as a wheel on a car, dynamic balance is obvious. Now let the road curl up in a circle with a diameter exactly twice the diameter of the wheel. The wheel is still dynamically balanced but now the weights W1 and W2 reciprocate in a linear cross motion as illustrated in Figure 3.

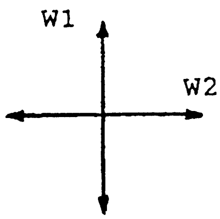


Figure 3. Reciprocating Linear Motion

Figure 4 illustrates this motion and balance in an engine mechanism. The wheel becomes the pinion assembly rotating inside an internal gear. A one-piece piston/rod unit is connected at, and becomes, weight W1. Weight W2 is a counterbalance equal to the weight of the piston/ rod unit. An output shaft whose center is concentric with the center of the larger internal gear converts the motion of the pinion to a useful rotary output motion. It accomplishes this through the use of a common offset (crank throw) which passes through a bushing at the center of the pinion assembly.

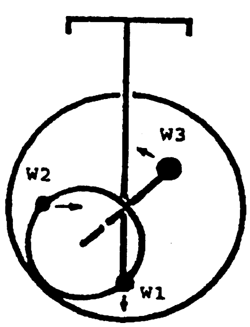


Figure 4. Hypocycloid Mechanism

While the pinion assembly is balanced with respect to its own center of rotation, the overall mechanism is not yet balanced with respect to the center of rotation of the output shaft because the pinion assembly exerts a centrifugal force on the crank throw as it travels inside the internal gear. Therefore, the output shaft must also have a counter-weight offset in the opposite direction from the pinion assembly. This counterweight, designated W3, must be of sufficient weight and distance to balance the crank throw plus the combined weight of the pinion assembly including W1 and W2. At this point, total balance is achieved. Not only is the mechanism perfectly balanced around the center of the output shaft for any position of rest (static balance), but it can be demonstrated empirically and mathematically that all linear and centrifugal forces are perfectly balanced at all positions of rotation and at any speed (dynamic balance).

Dynamic balance can also be demonstrated another way. It can be shown that for any given output speed (RPM), the combined momentum of all moving parts remains constant throughout the entire 360 degree cycle of rotation. This results from the fact that as W1 is momentarily at rest while changing direction at the top and bottom of its stroke, W2 is at the center of its cross-stroke and moving at its maximum velocity and vice versa. In other words, W1 and W2 essentially trade their momentum back and forth as one is slowing and the other is accelerating so that their combined momentum is constant. Therefore, all energy is conserved internally and none is expended as an unbalanced shaking force as in conventional crankshaft engines.

A detailed evaluation of the hypocycloid mechanism was conducted at the University of Wisconsin and published by the Society of Automotive Engineers (SAE) in a 1988 technical paper entitled "A Critical Evaluation of the Geared Hypocycloid Mechanism for Internal Combustion Engine Application" (6). In their summary and conclusions, authors Norman H. Beachley and Martha A. Lenz state:

"The geared hypocycloid engine has been shown to be a promising concept for providing perfect balance and reducing mechanical friction. ...With continuing research, development, and resulting design refinements, it is likely that practical hypocycloid engines will result that are superior to conventional engines for a number of applications."

The inherent advantages of the Linear Gear Drive hypocycloid mechanism and the opportunities it creates are examined in more detail below.

<u>Advantages of linear rod motion</u> – The most obvious advantages of linear rod motion in an internal combustion engine are in the transmission of forces and in the construction of moving parts. Less obvious but more unique is the manner in which linear rod motion can be utilized to change the breathing, burning, lubrication, and cooling characteristics of engine operation by creating the opportunity for multiple chambers to separate the functions of operation.

In a conventional crankshaft engine, the pressure of combustion acts downward on the piston which in turn transmits this force downward through a connecting rod to the crankshaft. As the crankshaft rotates clockwise from its uppermost position, this combustion force must act through an increasingly larger angle as illustrated in Figure 5.

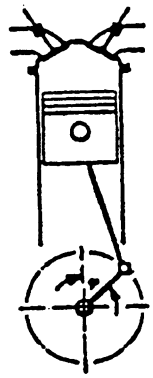


Figure 5. Crankshaft Engine

In order to make the crankshaft turn, the piston and rings must exert a significant counter-force against the cylinder wall. This piston sidewall force reaches its maximum value when the crankshaft has rotated approximately 72 degrees clockwise of top dead center (based on a mechanism with a rod length of three times the crank radius). When combustion pressure is increased while accelerating or overcoming larger loads, this piston sidewall force increases proportionately. While increasing the length of the connecting rod for a given crank radius has the offsetting effect of reducing piston sidewall forces and increasing the crank angle at which these sidewall forces reach their maximum, it also results in a larger and heavier engine. As a result of piston sidewall forces, care must be taken in crankshaft engine design to minimize both rod angle and piston speed and these are major considerations for minimizing piston stroke. Also, care must be taken to provide adequate lubrication to minimize piston, piston ring, and cylinder wear. In addition, the oscillating motion of the connecting rod requires that it and the piston be manufactured as two separate components joined with a movable connection. This requires a piston wrist-pin of high quality material and polished finish, a bushing at the upper end of the connecting rod, and provisions for additional lubrication.

In contrast, the Linear Gear Drive mechanism illustrated in Figure 6 operates with a pure linear motion acting vertically downward along the center of the cylinder, has negligible sidewall forces, and therefore has negligible corresponding wear and friction losses. Cylinder wall lubrication need only be adequate to compensate for piston ring tension. A piston wrist-pin and upper rod bearing are not required because the piston and connecting rod can be made as a unit, eliminating the need for lubrication to this area. In addition, stroke length and piston speed are no longer constrained by friction loss and wear considerations. Interestingly, a crankshaft mechanism with an infinite connecting rod length has no sidewall forces and its motion becomes mathematically equivalent to the linear gear drive mechanism.

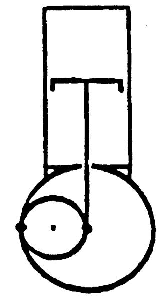


Figure 6. Linear Gear Drive Engine

Advantages of dynamic balance – Because of its total balance, the PC2S engine is dynamically equivalent to the Wankel rotary and to any other balanced engine concept. In fact, even though it incorporates reciprocating piston(s), this engine is dynamically equivalent to an electric motor with its balanced armature smoothly spinning on its axis. The difference is that an electric motor provides nearly continuous power pulses (torque) to the armature as it rotates around its axis whereas the PC2S engine provides intermittent torque whose frequency depends upon the number and arrangement of cylinders. Consequently, as in all internal combustion engines, the PC2S engine requires a properly designed flywheel to minimize speed and torque fluctuations throughout each revolution. But unlike crankshaft engines, the piston, rod, crankshaft, and counterweights in a PC2S engine can all be made heavier to also provide the effect of a flywheel. This is possible because total dynamic balance eliminates rod and piston momentum as design limitations. Also because of dynamic balance, any number of multiple cylinder configurations are possible.

While the PC2S is inherently balanced for any number of cylinders, a single cylinder crankshaft engine can be balanced only by adding complex mechanisms at significant expense. A crankshaft engine has two unbalanced forces - the primary unbalanced force from the reciprocating piston and the secondary unbalanced force from the eccentric motion of the connecting rod. In addition, unbalanced secondary forces can work in concert to introduce additional rocking and shaking couples. In a multi-cylinder crankshaft engine, the primary forces created by the pistons can be completely balanced through combinations of crankshaft throw design, counterweighting, and "V" shaped cylinder alignment. While the secondary forces can be balanced for certain engines such as the six cylinder in-line, they cannot be completely eliminated for most engine configurations without expensive mechanisms such as balance shafts (7).

The advantages of engine balance become more apparent when the disadvantages of imbalance are analyzed. The most obvious consequence of imbalance is vibration and the corresponding energy dissipated in creating this vibration. Consequently, automobile engines require special flexible mountings to insulate the frame from the engine and thereby dampen these vibrations. Another consequence of engine imbalance is the additional strength and weight required of the engine block, the connecting rods and rod bearings, and the crankshaft and crankshaft bearings to compensate for these undesirable, intermittent forces. The addition of balance shafts or other mechanisms to create a balanced effect adds more cost and weight and dissipates additional energy. A third consequence of the imbalance in crankshaft engines is the limitations imposed on design parameters. In order to minimize inertial forces, piston speed must be minimized by keeping stroke length as short as possible with pistons and connecting rods kept as light as possible. Also, the number, size, and arrangement of cylinders are generally limited to those configurations which provide the best balance.

It should be noted that a crankshaft mechanism is inherently unbalanced with regard to both primary and secondary forces and that efforts to create balance only produces a dampening of forces rather than a true balance. These unbalanced forces are either dampened directly as in the case of special engine mountings or they are designed to work in concert to "cancel" each other internally. In this situation, the crankshaft and the engine block are absorbing simultaneous and opposing forces which only give the external feel of balance. This should be contrasted with the true balance of the PC2S engine whereby the energy in all moving parts is conserved and contributes only to the angular momentum of the output shaft and none is lost as a shaking or dampening force. Consequently, the PC2S engine does not require additional strength, weight, or balance mechanisms to compensate for undesirable shaking forces. Nor is it constrained by balance considerations in the design of stroke length, piston and rod weight, piston and rod speed, and the number, size, and arrangement of cylinders. A single linear gear drive mechanism can provide for one, two, or four power cylinders. The simplest and most efficient design is the opposed two-cylinder configuration. One or more drive mechanisms can also be connected in series to create an engine with virtually any number of cylinders.

Advantages of sinusoidal motion – An additional benefit of the Linear Gear Drive mechanism over its crankshaft counterpart stems from its sinusoidal motion. Piston travel in a crankshaft mechanism results from two simultaneous motions as the crank pulls the lower end of the connecting rod to the side as well as down. The mathematical representation of piston travel in relation to crankshaft rotation is a complex trigonometric expression involving several terms as follows:

$$X=(R_c+L)-R_c\text{Cos}(a)-\sqrt{[R_c^2\text{Cos}^2(a)+L^2-R_c^2]} \qquad (1)$$

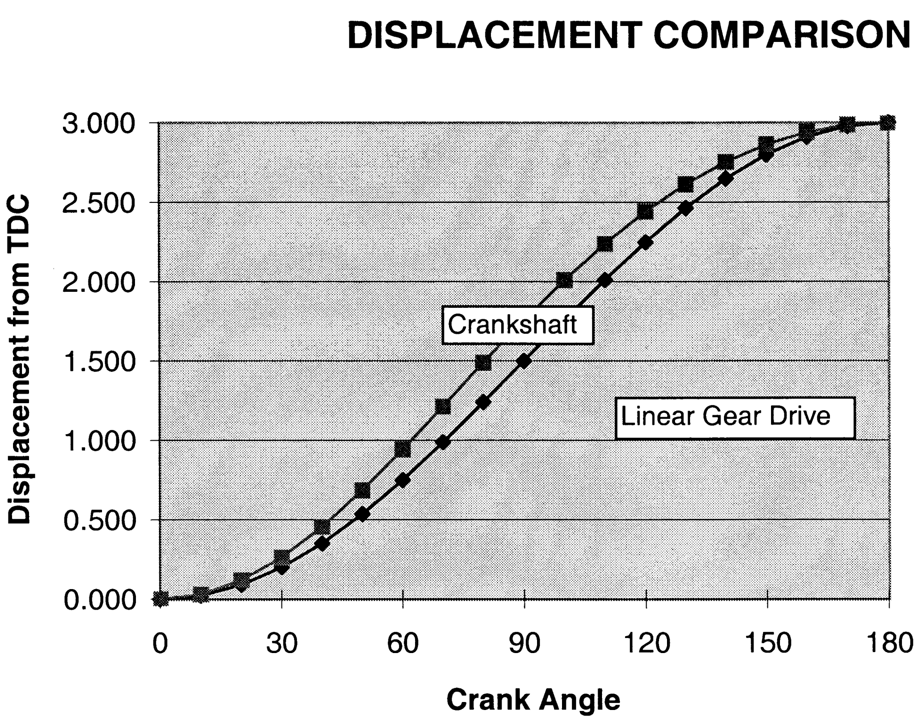
Where X = piston displacement from top

R_c = Crank Radius

L = Rod Length

a = Crankshaft Angle from top

Table 2. Displacement Comparison



Crank Angle	Displacement LGD	Crankshaft
0	.000	.000
10	.023	.030
20	.090	.120
30	.201	.264
40	.351	.455
50	.536	.685
60	.750	.942
70	.987	1.213
80	1.240	1.489
90	1.500	1.757
100	1.760	2.010
110	2.013	2.239
120	2.250	2.442
130	2.464	2.613
140	2.649	2.754
150	2.799	2.862
160	2.910	2.939
170	2.977	2.985
180	3.000	3.000

In contrast, piston travel in a LGD mechanism is a simple harmonic motion which can be represented by the following cosine expression:

$$X = 2R_p(1\text{-}Cos(a)) \quad (2)$$

Where X = piston displacement from top

R_p = Radius of Pinion at Pitch Circle

a = Crankshaft Angle from top

Consequently, the piston in a LGD mechanism travels more slowly during the first part of the expansion stroke.

As shown in Table 2 and illustrated by the associated graph, at 90 degrees of shaft rotation, the LGD piston is approximately one-quarter inch higher in the cylinder than its crankshaft engine counterpart. This slower piston travel away from top facilitates the expansion process by allowing a higher pressure to be achieved and maintained at each comparable point throughout the expansion stroke. This pressure advantage works in conjunction with the greater mechanical efficiency of the LGD mechanism, described below, in more efficiently converting the pressure of combustion to useful rotary motion.

Mechanical efficiency – The Linear Gear Drive mechanism is based on a simple gear relationship utilizing two parallel sets of gears which in turn utilize the involute tooth form for transmitting forces. These involute gears transmit forces primarily through a well lubricated rolling action with only a small sliding component. Therefore, the Linear Gear Drive creates negligible sliding friction and is highly efficient at converting the force of combustion to rotary output motion. In addition, it exhibits an inherent mechanical advantage when compared to crankshaft mechanisms.

As with any mechanism for converting energy from one form to another, both the crankshaft mechanism and the LGD mechanism exhibit a leverage effect, or mechanical advantage. In both mechanisms, the rotational force measured as torque at the output shaft can be expressed as a ratio of the force exerted on the piston as illustrated in Figures 7 and 8. For both mechanisms, this ratio changes as the output shaft is rotated from top dead center. As might be expected, for identical positions of output shaft rotation, the ratios are different between these two mechanisms, assuming a crankshaft rod length of three times the crank radius.

Although the LGD mechanism exhibits less mechanical advantage initially, the two become equal at approximately 70 degrees of shaft rotation and the LGD mechanism has a greater mechanical advantage during the remainder of the expansion stroke. When summed over the entire power stroke, the LGD mechanism exhibits a greater overall net mechanical advantage. In addition, it reaches a higher maximum value of 1.5 at 90 degrees of shaft rotation versus a maximum ratio of 1.42 at 70 degrees of shaft rotation for the crankshaft mechanism. This difference would indicate a greater overall mechanical efficiency by the LGD mechanism in converting combustion pressure to output torque. These differences are shown in Table 3 and illustrated by the associated graph.

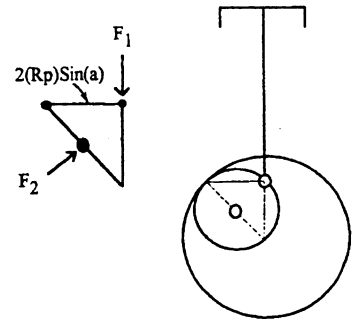


Figure 7. Linear Gear Drive Torque T_g

$$\text{Torque } T_g = F_2R_p = 2F_1R_pSin(a) \quad (3)$$

Where R_p = Pinion Radius

a = angle of pinion rotation

For F_1 = 1 Unit of Force, Stroke = 3”, R_p = ¾”

$$T_g = 1.5*Sin(a) \quad (4)$$

Advantages of a piston – The piston is such a fundamental part of so many engine, pump, and compressor mechanisms that it can be taken for granted and its advantages overlooked. In an engine, the piston is at the forefront of capturing the pressure of combustion and transmitting it to a mechanism for conversion to useful rotary output motion. Possibly nothing is easier to manufacture, seal, and lubricate and is more effective at capturing this pressure of combustion than a round piston operating in a round cylinder.

The advantages of the piston are probably best illustrated by contrasting it with its most familiar alternative, the Wankel rotor. Unlike this complex rotor with its three convex operating faces and two sides, a piston has one operating face and one cylindrical side and can be machined from numerous materials to precision tolerance utilizing the simple set-up and turning process of a lathe. Because of its shape, a piston is easier and less costly to seal. The penalties for ineffective piston sealing are reduced efficiency and increased emissions resulting from the loss of compression pressure, the loss of combustion pressure, and the loss of raw fuel. In a four-stroke crankshaft engine, ineffective piston sealing also results in contamination of the crankcase lubricant from fuel and exhaust escaping past the piston rings. While the Wankel rotor experiences marginal success with its three expensive tip seals and two troublesome sets of side seals, the piston utilizes rings which are inexpensive, relatively long lasting, and proven to be reasonably effective.

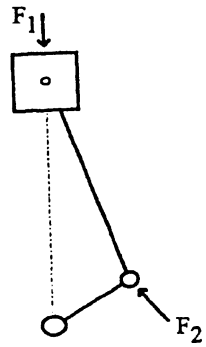


Figure 8. Crankshaft Torque T_c

$$\text{Torque } T_c = F_2 R_c \quad (5)$$

$$= F_1 R_c \left[\sqrt{(1-(Rc/L)^2 \text{Sin}^2(a))}\right] *$$

$$\left[\text{Sin}(a)\sqrt{(1-(R_c/L)^2\text{Sin}^2(a))}+\text{Cos}(a)(R_c/L)\text{Sin}(a)\right]$$

Where R_c = Crankshaft Radius, L = Rod Length

a = angle of crankshaft rotation

For F_1 = 1 Unit of Force, Stroke = 3", R_c = 1.5", L = $3R_c$

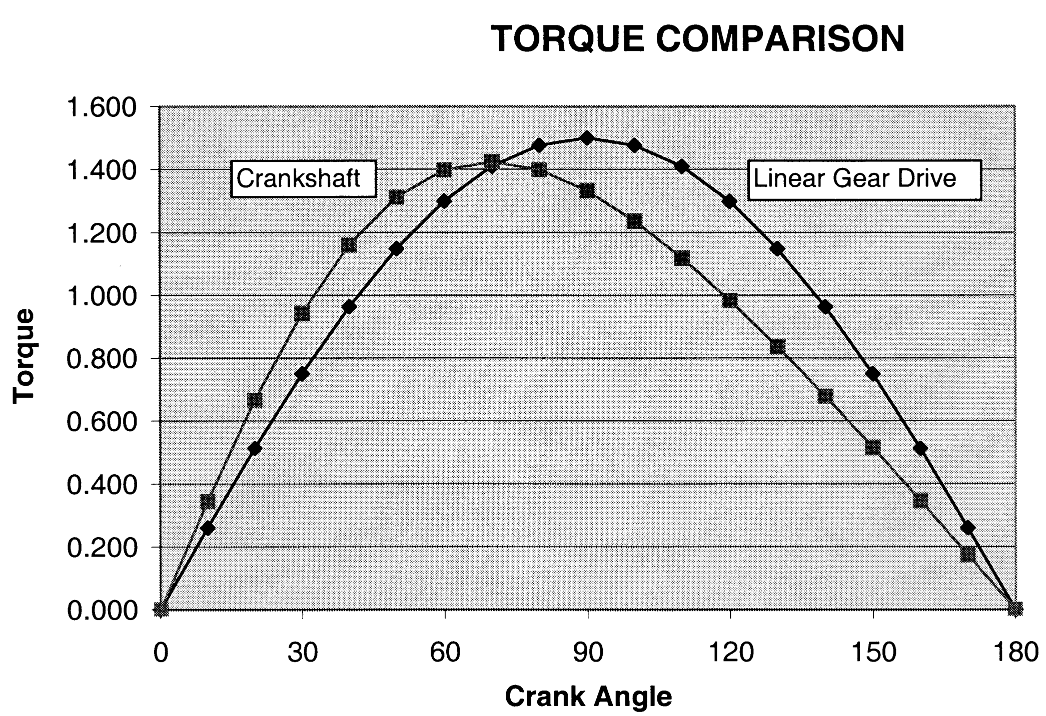
$$T_c = 1.5\left[\sqrt{(1-(1/9)\text{Sin}^2(a))}\right] * \quad (6)$$

$$\left[\text{Sin}(a)\sqrt{(1-(1/9)\text{Sin}^2(a))} + \text{Cos}(a)(1/3)\text{Sin}(a)\right]$$

Also, because of its shape, a round piston operating in a round cylinder is relatively easy to lubricate. In a conventional four-stroke crankshaft engine, the lower of three rings is slotted and allows a minimum amount of lubricant to pass from the underside of the piston onto the cylinder wall. This provides an oil film on the cylinder wall in the area of piston travel without allowing excessive oil into the combustion area above. The result of this oil film is to minimize the energy lost to friction and to minimize piston and ring wear. The Wankel is more difficult to lubricate and resorts to mixing a lubricant with its fuel as do most existing two-stroke crankshaft engines. This has resulted in only limited success as the Wankel also has a history of wear and maintenance problems with its seals.

On the other hand, piston ring and cylinder wall lubrication in the Parallel Combustion Two-Stroke engine is greatly simplified as the result of advancements in lubricating coatings. Construction of the piston and connecting rod as a one-piece unit has eliminated the piston wrist-pin and the need for lubrication to this area. Linear motion has eliminated piston sidewall force and has substantially reduced the need for lubrication to this area. The final step in completely eliminating upper cylinder lubrication centers on the piston rings and this also is now possible. As a result of developments in teflon materials, often abbreviated PTFE, and also in the field of tribology, materials and coatings have evolved that have advanced the temperatures, materials, and operating conditions to where unlubricated piston rings, bearings, and other parts are now commonplace in compressors and internal combustion engines. One of the most severe tests of PTFE piston rings is provided by Mechanical Technology, Inc. in its development of the Mod I Sterling engine where cylinder temperatures

Table 3. Torque Comparison



Crank Angle	Torque LGD	Crankshaft
0	.000	.000
10	.026	.345
20	.513	.666
30	.750	.943
40	.964	1.160
50	1.149	1.312
60	1.299	1.398
70	1.410	1.424
80	1.477	1.399
90	1.500	1.333
100	1.477	1.237
110	1.410	1.119
120	1.299	.983
130	1.149	.836
140	.964	.679
150	.750	.516
160	.513	.347
170	.260	.174
180	.000	.000
Total	16.910	15.871

exceed those found in internal combustion engines (8). While the prospect for long-term operation by PTFE piston rings appears excellent, it should also be noted that the one-piece piston/rod design and corresponding linear motion provides an upper engine simplicity which in turn provides design opportunities for easy maintenance when the rings do need to be replaced.

In addition to its manufacturing, sealing, and lubricating advantages, nothing is more effective at capturing the pressure of combustion than the face of a piston being pushed down a cylinder. An example of the importance of this advantage can be seen by contrasting it with an automotive size turbine engine. While a turbine is more thermodynamically efficient and has better emissions-control because of its continuous combustion process, it is less efficient overall in the automotive horsepower range than an internal combustion engine. This is largely because the turbine fans for capturing and converting the energy of combustion are less efficient than a piston operating in a cylinder. In addition, the constant exposure of these turbine fans to combustion heat without the intermittent cooling inherent in an internal combustion cycle requires that they be made from expensive materials using costly processes.

While the Wankel and the turbine serve as convenient contrasts to emphasize the advantages of the piston, similar manufacturing, sealing, lubrication, emissions, and efficiency problems often result whenever an engine concept depends on a mechanism other than a piston to capture the energy of combustion.

<u>Intake chamber</u> – In existing crankshaft engines, the working cylinder below the piston is open to the crankcase to provide clearance for the oscillating rod motion and to provide lubrication to the piston wrist-pin and cylinder wall. With the elimination of oscillating rod motion, the piston wrist-pin, and upper cylinder lubrication in the PC2S engine, the cylinder below the piston can now be sealed from the gearcase and used for intake and compression.

The first consideration in separating the cylinder from the gearcase is the design of the connecting rod. Being rigidly connected to the underside of the piston, the connecting rod can be designed in the form of a relatively small-diameter tubular shaft. This allows the base of the cylinder below the piston to be enclosed because the connecting rod can now be easily and effectively sealed as it reciprocates through this enclosure. Now, in addition to the expansion chamber above the piston, a second chamber below the piston is created. This lower chamber serves as an intake chamber to receive and then compress each new charge of fresh air while providing cooling to the piston and upper cylinder. It also serves to insulate and protect the linear gear drive mechanism and its lubricant from contamination and heat, and it provides the means to eliminate two of the more undesirable drawbacks of two-stroke engine operation, the need for a lubricant be mixed with the fuel and the loss of unburned fuel through the exhaust ports. In addition, it provides enhanced intake breathing and the means and timing for the injection of fuel.

In existing two-stroke engines, it is the crankcase which serves as the intake chamber. Because of the oscillating rod motion, a separate chamber below the piston is not possible. Therefore, oil must be mixed with the fuel to provide lubrication to the moving parts. Also, during the transfer of air, fuel, and lubricant to the upper cylinder, a portion escapes through the open exhaust ports and this reduces fuel efficiency and increases hydrocarbon emissions. Both these problems are eliminated in the PC2S engine. First, the procedure of adding oil to the fuel is not necessary because upper cylinder lubrication has been eliminated and because the gearcase and its lubricant are isolated and sealed from the rest of the engine. Also, in the PC2S engine the sequence of operation is altered whereas the newest charge of air is not exposed to open exhaust ports but is confined to the lower chamber, compressed, and then transferred to the adjacent combustion chamber where fuel in then injected. These PC2S differences add significantly to both fuel efficiency and emissions control over existing two-stroke engines.

Also because of its location in the lower cylinder below the piston, the intake chamber separates the upper cylinder expansion chamber from the gearcase and thereby protects the gearcase from contamination. One job of the piston and rings is to confine the pressures of compression and combustion to the upper cylinder. This job is impeded by the need to provide for piston sliding clearance, expansion clearance, and, in a crankshaft engine, lubrication clearance. In existing crankshaft engines, a small amount of unburned fuel and exhaust will be blown past the rings into the lower cylinder. This results in significant oil contamination and is a primary factor in internal friction and engine wear as well as the major reason for periodic oil changes. Prior to positive crankcase ventilation (PCV) which vents the hydrocarbons back into the intake manifold, it was also a significant source of hydrocarbon emissions to the atmosphere. In the PC2S engine, piston blowby simply enters the intake chamber in the lower cylinder where it mixes with the next cycle of air. Therefore, it becomes a part of the air that will be used for combustion on the next power cycle and does not enter the gearcase to contaminate the oil. This automatic recycling process not only eliminates another major source of emissions and improves fuel efficiency without the need for positive crankcase ventilation, but it could also greatly reduce the need for oil changes.

Another advantage created by the lower intake chamber is the opportunity it provides for intake breathing. By drawing air into the lower cylinder instead of through the cylinder head as in existing crankshaft engines, intake ports can be placed around the entire perimeter near the base of the cylinder. This creates an intake area approximately double that provided by the intake valve in four-stroke engines. The means for then confining the air inside the lower intake chamber is a circular plate with multiple reed-type valves located around its entire perimeter. This reed plate is positioned in the base of the cylinder above the intake ports to provide ample one-way breathing into the lower intake chamber without the need for a valve mechanism.

Fuel injection – The lower intake chamber also provides the means and timing for direct injection of fuel into the combustion chamber. The transfer port connecting the lower intake chamber to the lower combustion chambers can be located approximately 3/8 inch above the bottom position of the piston. Therefore, when the lower ring of the piston passes the lower portion of the transfer port, the piston still has another 1/4 inch of travel. This creates a final burst of compressed air which can exit only through another, smaller port in the lower cylinder and into a pumping mechanism for propelling fuel directly into the lower combustion chamber just before the valve closes.

External Combustion Chambers – Creating two combustion chambers external and parallel to the working cylinder is made possible by having first created an intake chamber below the piston. Since the intake chamber also serves as the compression chamber, the compressed air can flow from the lower portion of the working cylinder directly into the bottom of the adjacent combustion chamber. After fuel is added and combustion takes place, the hot gasses can then flow from the upper portion of the combustion chamber directly into the upper expansion chamber in the working cylinder where they drive the piston downward. The external combustion chambers create several new opportunities including the preheating of incoming air, the elimination of a cooling system, the reduction of fuel quenching, and increased control of the parameters of combustion including fuel/air mixing, compression ratio, combustion pressure, and combustion temperature.

Preheating of intake air improves both combustion efficiency and thermal efficiency and also contributes to a reduction in fuel quenching. Attempts to improve efficiency by preheating the intake air in a crankshaft engine results in no net gain because the intake system is "open". Heating the air before or after it passes through the carburetor on its way into the cylinder causes it to expand. Therefore, while the air is hotter, it is less dense. Without the aid of a supercharger to pack in more air, volumetric efficiency, and therefore power output, is reduced. The PC2S intake system on the other hand is a "closed" system. After a full charge of air is drawn in cold, it is confined to the lower intake chamber and its volume is fixed as it provides cooling to the working cylinder, piston, and connecting rod. Heat transfer continues, without a corresponding loss in volumetric efficiency, as the air flows from the intake chamber into the external combustion chamber. Because the combustion chamber is external to the operating cylinder, it can operate at a higher temperature without risk to the LGD mechanism or piston rings. And since the combustion chamber is automatically cooled by each cycle of incoming air, other means of engine cooling are unnecessary and heat retention through insulation of the external combustion chamber may actually be promoted. This could significantly increase thermal efficiency compared to existing engines and could be a step closer to adiabatic engine operation.

The higher operating temperature of the combustion chamber and resultant preheating of the incoming air, the reduced time of fuel exposure to the combustion chamber walls prior to combustion, and the reduced combustion chamber surface area all work together in the PC2S engine to reduce fuel quenching and condensation and to promote improved mixing of air and fuel. Efficient combustion requires that the fuel and air be mixed in a certain proportion. Even when the carburetor in a four-stroke engine does its job in creating the correct mixture, other factors can work to alter the ratio. Among the most troublesome factors in efficient engine operation is the quenching effect of the intake manifold and the cylinder wall in promoting rapid fuel condensation. This is also another major source of contamination and hydrocarbon emissions as some of this fuel gets into the crankcase while some escapes with the exhaust. While higher combustion chamber temperatures reduce this quenching effect and promote fuel mixing to further facilitate the combustion process, crankshaft engines must limit heat buildup because oil loses it ability to lubricate at higher temperatures and because the crankcase cannot be protected from combustion chamber heat. These constraints are eliminated in the PC2S engine by the insulating effect of the lower intake chamber and by separating the combustion function from the working cylinder. Also, the PC2S engine exposes fuel to metal surfaces only briefly by injecting it into the combustion chamber just as the compression and transfer function are completed and just as combustion is about to begin. Since the surface area in each PC2S combustion chamber is significantly smaller than the combined manifold and cylinder area of a four-stroke engine, the opportunity for fuel condensation is further reduced.

In addition to the advantages of preheating, the external combustion chambers also increase the opportunity to control carbon monoxide and the oxides of nitrogen by improving fuel/air mixing and by controlling the temperature and pressure of combustion. These parameters can be managed by controlling the compression ratio and the time of combustion. Controlling the elapsed time of combustion is possible because the combustion process can begin as soon as the lower combustion chamber valve closes and can continue during the entire upward stroke of the piston which provides significantly more time than in existing spark ignition engines. Ignition timing can be a variable designed to capture only the portion of available time that is required to optimize fuel/air mixing as well as combustion pressure and temperature before the upper combustion chamber valve opens and the expansion stroke begins. Therefore, these variables offer additional controls over the combustion function and more opportunity to find the optimum parameters for maximizing power, fuel efficiency, and emissions control than are available in existing engines.

The same combustion variables that offer improved fuel efficiency and emissions control also work in conjunction with the simplified fuel injection system to offer increased flexibility in creating an engine that can operate on a variety of alternate fuels, including hydrogen. Hydrogen presents special problems of metal embrittlement that the external combustion chamber could more easily overcome because of its size and isolation from moving parts. Therefore, the costs associated with special metals or coatings to accommodate hydrogen gas would be minimized.

<u>Exhaust Mechanism</u> – Since exhaust must exit the PC2S engine from the upper portion of the working cylinder and since an exhaust stroke occurs on every upward stroke of the piston, it is now feasible to explore the advantages of an exhaust mechanism functioning in conjunction with the piston/rod unit. Such an exhaust mechanism is possible because of the linear rod motion, because of dynamic balance, and because of the natural timing of two-stroke operation.

Linear rod motion creates an opportunity for the valve stem of a poppet type valve to operate from the center cavity of the connecting rod and to seat in the cylinder head. This would not be possible with the oscillating rod motion and piston cross motion of crankshaft engines. Piston cross-motion occurs when the combustion forces in a crankshaft engine act to push the piston against one side of the cylinder while compression acts to push the piston against the other side. Dynamic balance adds to the opportunity to utilize the piston/rod unit for exhaust valve control by rendering the additional weight irrelevant because the added weight can be offset by adjusting the counterweights. Two-stroke operation further adds to this opportunity by providing timing since the valve must open as the piston approaches the bottom of each down-stroke and must close as the piston reaches the top of each up-stroke.

DIFFERENCES AND CHALLENGES – Because the PC2S engine concept introduces differences when compared to crankshaft engines, and because it lacks the development and operating history of crankshaft engines, it inevitably presents certain design and manufacturing challenges. None of these challenges would appear to create a serious obstacle to successful development of this engine concept because it is a relatively simple apparatus utilizing conventional gearing and available materials requiring no exotic processes.

One significant difference is the elimination of upper cylinder lubrication through the use of self-lubricating piston rings. This difference has already been discussed and does not present a significant challenge. Another difference is the requirement to seal the reciprocating connecting rod at the base of the lower cylinder. Again, this does not present a significant challenge since reciprocating seals are readily available and highly reliable. Other differences and challenges include the hypocycloid crankshaft and pinion assembly, combustion chamber valve operation, free movement of gasses, and minimum size limitations.

The crankshaft in the Linear Gear Drive mechanism differs from the crankshaft in a crankshaft engine in two ways. It requires a wider journal at the crank-throw to accommodate the pinion assembly but it does not require as great a crank-throw offset. For example, a crankshaft engine with a four inch piston stroke would require a two inch crank-throw offset while a PC2S engine with the same stroke would require only a one inch offset. The increased journal width would act to decrease the overall strength of the crankshaft while the shorter crank throw would act in the opposite direction. Therefore, these two factors are somewhat offsetting and should not present a design obstacle.

The pinion set consists of two pinion gears, two counterweights, and two bushings which mate with and ride on the crankshaft offset journal. If the pinion set is made as a one-piece unit, then the crankshaft must be made as a two-piece assembly so that the pinion set and crankshaft can be assembled together. Conversely, if the crankshaft is made as a one-piece unit, then the pinion set must be made as a two-piece assembly. Each approach has merit but the split crankshaft design appears superior.

The PC2S engine requires six valves - intake, exhaust, lower combustion chamber #1, upper combustion chamber #1, lower combustion chamber #2, and upper combustion chamber #2. The intake valve consists of a reed-plate utilizing multiple reed-type valves which provide ample intake breathing, are well understood in engine art, and provide no design challenges. While exhaust valve operation provides several design alternatives, the simplest arrangement is a poppet valve operating from the rod cavity. This would provide proper timing, adequate exhaust breathing, and also minimum design challenges.

It is the lower and upper combustion chamber valves that provide the greatest challenge. Both sets of valves must provide adequate breathing, withstand combustion chamber temperatures without distortion, and operate with proper timing. Since the combustion chamber is intermittently cooled, the materials used in crankshaft engine exhaust valves should also prove adequate for the PC2S engine. The final design challenge then is to provide ample breathing without undesirable throttling.

This is the key to operating performance. Significantly restricted flow into and out of the combustion chamber will place limits on the range of operating performance. A restricted range may be adequate for certain applications such as electric generators, air compressors, or industrial lift trucks but would not be adequate for wider transportation applications. To the extent such flows might be restricted, as further development and refinements improve the flows into and out of the combustion chamber, the performance range will increase accordingly and so will the potential applications for this engine.

While the PC2S is not limited as to how large it can be made, it does have practical limits on how small it can be made. The size limitations stem from the mechanics of the Linear Gear Drive mechanism. The pitch diameter of the internal gear defines the stroke length. The pitch diameter of the pinion must be one-half the pitch diameter of the internal gear. In addition, a bore in the pinion must accommodate a bushing plus the crankshaft journal. For example, a small engine with a two inch stroke requires a pinion with a pitch diameter of one inch and within that one inch diameter must be the gear teeth and underlying material plus a bore to accommodate the bushing and crankshaft journal. In addition, the pinion gear teeth must be of sufficient size and strength to transmit the forces generated. While these design constraints do not eliminate the PC2S engine from applications requiring small, hand held engines, its does introduce additional engineering challenges.

MANUFACTURING – The PC2S engine does not present any significant manufacturing challenges. Because of its simplicity, the PC2S utilizes standard materials, standard gearing, and conventional manufacturing processes and involves a relatively small number of moving parts. It is the moving parts which most affect the cost of a mechanism because each moving part requires that a hard metal with quality finish be mated with a softer bearing material with provision for lubrication. To illustrate this simplicity, the following is a comparison of moving parts between the PC2S engine and three other engine concepts in their most basic one-rotor or one-cylinder configurations. Reed type valves have not been included in this comparison because they do not require a control mechanism or lubrication.

Wankel rotary moving parts

1. Rotor Assembly
2. Output Shaft w/two bearings

Conventional two-stroke moving parts

1. Piston w/wrist pin
2. Connecting rod w/two bearings
3. Crankshaft w/two bearings

Otto four-stroke moving parts

1. Piston w/wrist pin
2. Connecting Rod w/two bearings
3. Crankshaft w/timing gear, two bearings
4. Cam Shaft w/timing gear, two bearings
5. Intake valve w/spring, guide, seat
6. Intake tappet w/guide
7. Exhaust valve w/spring, guide, seat
8. Exhaust tappet w/guide

PC2S moving parts

1. Piston/rod assembly w/one bearing
2. Pinion assembly w/two bearings
3. Output shaft w/two bearings
4. #1 lower valve w/spring, guide, seat
5. #1upper valve w/spring, guide, seat
6. #2 lower valve w/spring, guide, seat
7. #2 upper valve w/spring, guide, seat
8. Exhaust valve w/spring, guide, seat

SUMMARY AND CONCLUSIONS

The Parallel Combustion Two-Stroke engine utilizes the Linear Gear Drive mechanism to achieve sinusoidal linear rod motion, total dynamic balance, and increased mechanical advantage. It also utilizes the chamber below the piston for intake to achieve complete isolation of the crankshaft and gear mechanism from heat and contamination. And it utilizes external combustion chambers for increased control over the parameters of combustion and the utilization of heat to create a new constant volume two-stroke operating cycle which approaches adiabatic operation. This new operating cycle consists of five distinct functions, each defined by a full piston stroke without the function overlap common in existing two-stroke engines.

The result is an engine of greater mechanical and thermal efficiency in which the dynamics of the entire operating cycle are improved over existing engines. These improvements include air intake, fuel input, compression, combustion, expansion, exhaust, cooling, and lubrication. The resulting engine captures the most important features of prior engine art and utilizes the natural motion and pressure forces of two-stroke operation to facilitate intake, fuel injection, and exhaust.

Since the Parallel Combustion Two-Stroke engine lacks the development and operating history of crankshaft engines, it inevitably presents some challenges, none of which appear to be major obstacles to successful development. The PC2S engine has all the attributes of a low emission, high efficiency engine that could eliminate the major weaknesses associated with the Otto four-stroke engine, with modern two-stroke engines, and with the Wankel rotary engine. It has the potential to be a rugged, versatile, clean burning, economical powerplant which may prove ideal for compressors, electric generators, or supplemental power in hybrid electric automobiles. Through continued development and testing, the Parallel Combustion Two-Stroke engine may have the potential to evolve into a versatile, high-performance powerplant for more demanding applications.

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