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1972

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A MEANS OF INDUCING VARIABLE SWIRL AND INCREASED ENGINE EFFICIENCY IN THE STRATIFIED CHARGE WANKEL ENGINE

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INTRODUCTION

Recent studies conducted by the Curtiss-Wright Corp. under US Naval contracts have attempted to improve upon the operational characteristics of the stratified-charge, spark ignition Wankel engine. These studies have dealt primarily with the effects of different injector nozzle configurations and rotor pocket shapes. Their results indicated that good mixing of fuel and air while maintaining an adequate local fuel-to-air ratio was the key to fuel economy, to low-speed no-load operation, and to reduced emissions. Further, their studies showed how important rotor pocket shape and complimentary fuel spray patterns were to the accomplishment of these two objectives. (4,5).

High air swirl rates in conjunction with wide, flat sprays proved to be best for high speed operation. This was attributed to the relatively larger quantities of fuel injected under such conditions and the need for greater mixing than at lower speeds. To meet this need, Curtiss-Wright developed and tested their "Beetle" pocket rotor (Figure 1) and an 11 hole nozzle with the spray pattern shown in Figure 2.

For the more difficult low-speed, no-load condition, a more concentrated spray pattern of reduced droplet size and reduced swirl proved to be necessary as the fuel quantity injected is so small that an adequate local fuel-to-air ratio is otherwise impossible to achieve. To solve this problem Curtiss-Wright developed and tested a "deep-pocket" rotor and a 9 hole nozzle with the spray pattern shown in Figures 3 and 4. While it was more effective than the beetle rotor at low-speed, no-load conditions, it was not as effective under any other condition. (5)

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As a final solution, a combination of the two rotors was recommended for development and testing. (See Figure 5.) In response to that recommendation, this paper proposes two alternate engine modifications that the author believes will yield better performance. They combine variable swirl rates, exhaust-gas-recirculation, and more advantages of both the beetle and the deep pocket rotors than the author expects from the Curtiss-Wright combination. One is a new intake system; the other is a new rotor pocket design.

MODIFICATIONS

INTAKE PORT

All current engine intake ports fall into two general categories: (1) side and (2) peripheral porting. In most, no real effort is made to promote air swirl. The primary considerations have been to insure even fuel distribution from the carburetors, good breathing or volumetric efficiency, and an economically feasible design over a variable speed range. In the stratified charge engine two advantages are immediately apparent. First, there is no requirement to design porting for even fuel distribution--only for equal volumetric efficiencies among the various rotors. Second, the presence of hot exhaust gases and the existence of hot spots are insignificant because there is no fuel which might combust. Thus if good intake efficiency can be maintained and the solution is economically feasible, the methods of implementing swirl are open to the designer's imagination.

The design proposed in this paper is graphically portrayed in Figure 6. Its design is based upon the principle of proportional amplificiation as developed within the realm of fluidics. (2) A high pressure jet of exhaust gases tapped during the expansion phase of an earlier cycle is directed perpendicularly against the incoming air stream. The amount of deflection is proportional to the relative momentums of the jet and the air stream. These, in turn, are related to exhaust gas pressure and engine speed respectively. To obtain high swirl rates at high speeds and low swirl rates at low speeds as is desirable, it is only necessary to vary the pressure of the gases from the exhaust chamber. By passing them through an orifice of variable diameter and allowing the gases to expand on the other side, the required pressure drop from chamber pressure can be obtained for each condition. This controlled rate of swirl can be obtained in one or two directions depending on the number of control jets and the original configuration of the rotor housing. It should be noted, however, that maximum deflection in two directions simultaneously will not be as much as can be achieved in either one alone as the allowable concentration of exhaust gases is limited to about 20%. The conservation of angular momentum dictates that the radial mean velocity of the gases will increase as the effective swirl radius decreases and will reach a maximum during the minimum volume of the combustion phase of the cycle. Computer testing has shown that this maximum rate can easily reach 1500 radians per second for one direction. (3)

In addition to the advantage of variable swirl rates, this method offers another significant feature. This is the reduction of engine emissions--especially oxides of nitrogen--achieved through the principle of exhaust-gas-recirculation. The relatively inert exhaust gas molecules act as heat sinks during the combustion process to reduce peak temperatures and to delay the formation of NO_x favored by prolonged exposure time to high temperatures.

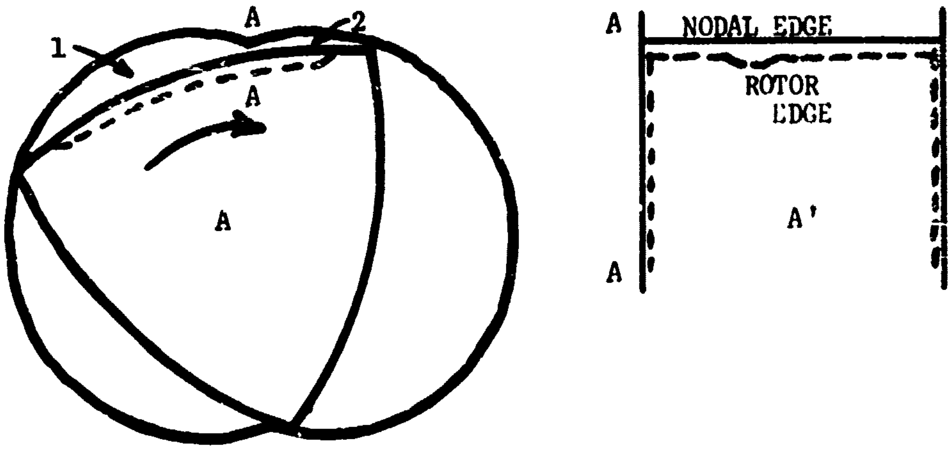
The technique is applicable to either side or peripheral ports. Its production expense is expected to be slightly higher than an alternative such as angled ports, but this may be offset by more efficient engine operation through optimization of air swirl for every operating condition and by the fact that future Federal regulations concerning air pollution may necessitate that exhaust-gas-recirculation be adopted as standard equipment on all engines as one of the few ways to effectively combat the NO_x problem. Testing will be necessary to determine if fouling of the orifice and the jet will be a problem, to determine if a suitable control can be devised to regulate the orifice diameter in accordance with engine operating conditions, and to determine if the long-term savings to the owner will outweigh the higher initial cost.

ROTOR POCKET DESIGN

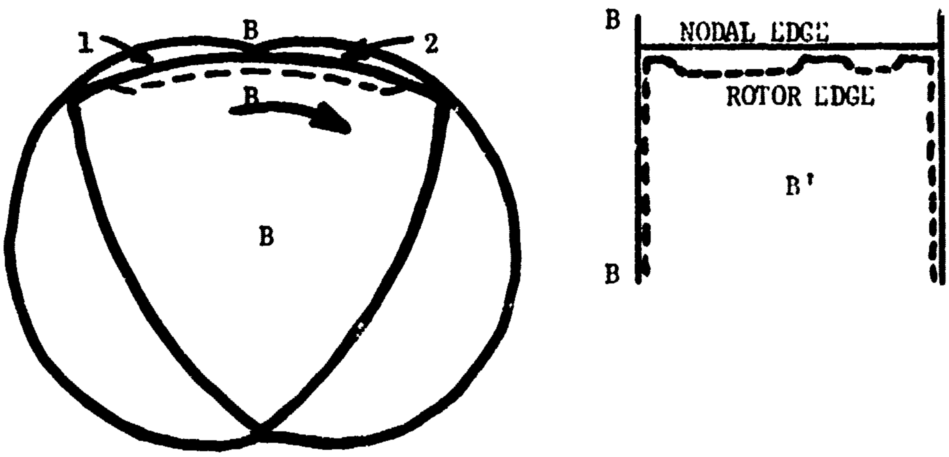
The designs of the rotor pocket and complimentary spray patterns are very important to the creation of optimum local fuel-to-air ratios. A "deep pocket" rotor and a concentrated spray of fine droplets has been shown to produce the most efficient low-speed no-load operation. (5)

A shallower and wider "beetle" rotor and a diffused spray of larger droplets has been shown to produce the most efficient operation with various loads throughout the medium and high speed regimes. (5) To combine the advantages of both rotors for efficient operation throughout the entire speed-load spectrum, this author proposes a T-shaped rotor and two independent fuel injectors. The shape of the pocket and the location of the injectors are portrayed in Figure 7.

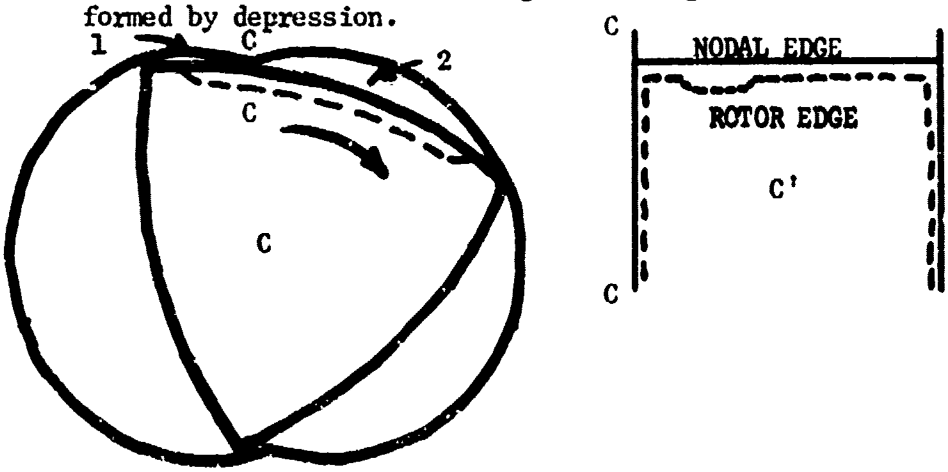
This design incorporates several features of both deep pocket and beetle rotors. The depression on the left (A) is wide and shallow. Dimensionally, the width is about 60% of the rotor width. The depth is about 10% of the rotor width and the length is about 80% of the rotor length. It is offset from the center so as to induce swirl in a manner which is described below. The



A - Volume 1 is large; volume 2 negligible.



B - Volume 1 has compressed while volume 2 has expanded. Pressure differential forces gases through channels formed by depression.



C - All gases in volume 1 have transferred to volume 2.

depression on the right (C) is somewhat narrower, shorter, and deeper. It is about 20% as wide as the rotor width, 30% as long as the rotor length, and the depth is about 30% of the width. This depression is also offset from the center. Note the shallower extensions of the deep pocket on the leading and middle edges. Their purposes will be explained below.

As the rotor passes through the combustion phase, the forward part of the chamber (that part past the node or greatest constriction of the housing) is expanding in volume while the rearward part of the chamber is contracting. The pressure differential created across the node is great enough to cause a rapid flow of gases from the rearward volume part to the forward volume. The depressions in the rotor face act as channels for this flow. By offsetting these depressions the linear momentum imparted to the gases is easily converted to angular momentum and swirl.

The principle of operation is as follows: As the leading edge of the rotor passes the node, the expanding forward volume and contracting rearward volume create a pressure differential. Mass transfer across the node is minimal until the leading edge of depression A reaches the node. At that time a rapid transfer of gases takes place. The velocity of the gases as seen from injector B consists of three components. the velocity induced by the pressure differential; the swirl induced by the intake port; and the velocity of the gases due to the sweeping action of the rotor. (If the hardware necessary for air assisted injection is not deemed too bulky or expensive, its use will add a fourth component to the velocity and greatly affect the mixing and subsequent swirl rates).

If the engine is operating in a medium or high speed mode, the addition of fuel from injector B and combustion would occur at this time. The injection of the fuel and combustion should be 90% complete within 15-20 degrees of rotor rotation. (3) If the engine is operating in a low speed mode the injection of fuel will be delayed until after the leading edge of depression C has crossed the node. The shallow leading edge of depression C is designed to allow some gases to pass through to the leading volume and counteract the previously induced swirl from depression A. The connecting portion between A and C is designed to provide a large effective channel area for gas flow to reduce the transfer velocity for a short period of time. The overall effect should be a period of relative calm in which a small quantity of fuel can be injected from D. The depth of depression C, the concentrated spray of fine droplets, and the reduced swirl rate are expected to produce a condition in which efficient low-speed no-load operation can be achieved. As some swirl will continue throughout the entire combustion phase, any unburned fuel will be thoroughly mixed with the remaining air during the expansion phase and nearly total combustion should occur.

All timing for the engine will be determined by the timing of fuel injection. The spark ignition system is expected to fire machinegun-like bursts from sometime just before injection starts until sometime just after injection ends. The co-location of the injector and the spark plug or the combination of the two into one unit would further reduce the timing and ignition problems and would also reduce the blowby of gases past the apex seals. Each sparking mechanism should fire regardless of whether fuel is being injected from its respective injector. The injectors themselves should be programmed so that injection of fuel during medium and high speed operation occurs primarily from B and so injection during low speed occurs completely from D.

SUMMARY

Two design modifications for the stratified charge, spark ignition wankel engine have been proposed. One is a means for inducing variable swirl at the intake port. The other is a T-shaped rotor pocket with two independent injectors. A computer simulation has indicated that one directional swirl rates on the order of 1500 to 2000 radians per second are possible with the proposed intake system. Independent testing of a beetle rotor and a deep pocket rotor has shown that each works well within a given speed-load range. Testing is necessary to determine whether:

1. fouling of the orifice and the control jet will be major problems.

2. actual swirl rates correlate with the computer prediction.

3. the T-shaped rotor combined with the induced swirl will produce more efficient operation throughout the entire speed-load range to be encountered by the engine than alternative proposals such as the Curtiss-Wright Combination (Fig 5).

4. The benefit gained in more efficient operation and reduced pollution will offset the increased production and maintenance costs of the system.

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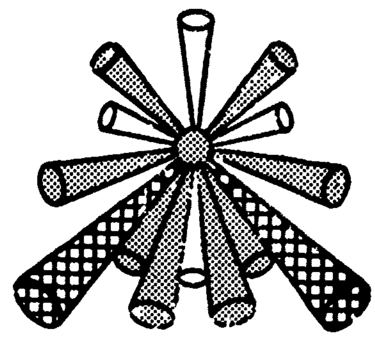
Figure 1



SK10437N5
Total Holes - 11
Total Area - .0003542

Figure 2

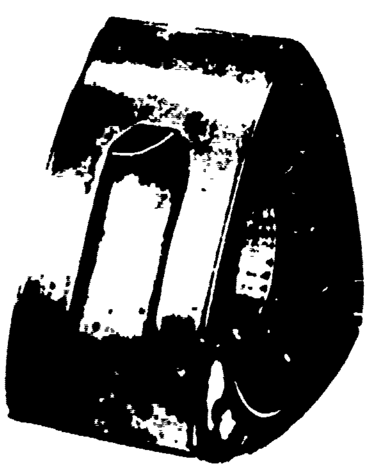
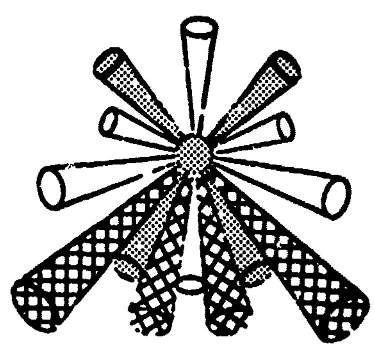


Figure 3

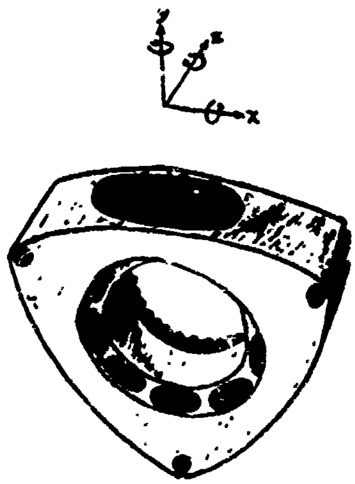


SK10437N7
Total Holes - 9
Total Area - .0003418

Figure 4

Figure 5

Figure 6a - Indicates the directions for x, y, and z planar swirl.



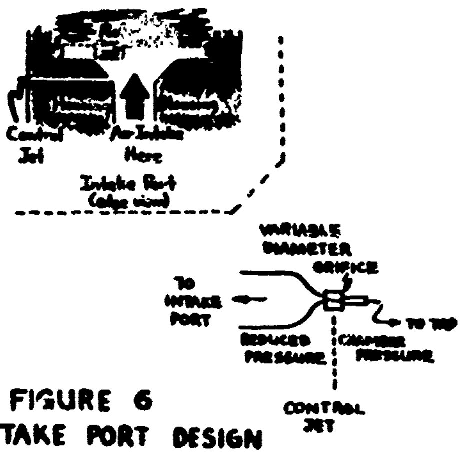


FIGURE 6
INTAKE PORT DESIGN

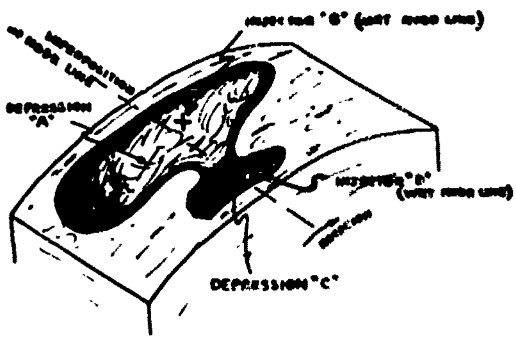


FIGURE 7
T-SHAPED ROTOR POCKET