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Optimization of Two-Stroke Petrol Engine

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***Abstract*— This paper discusses the optimization of two stroke engine with the use of fuel injection system and expansion chamber. This proposed optimization is in the form of lowered emissions following better in-cylinder combustion and enhanced engine performance characteristics. The use of fuel injection system in this engine facilitates proper mixture of fuel and air, giving increased control of combustion and emissions, as a result of which power output and efficiency increases. Fuel injection system is also economical as it provides a correct estimation of the quantity of fuel required at proper time. However, there still exists the problem of fresh charge leaking during scavenging, which decreases the volumetric efficiency. This can be compensated up to a certain extent by the use of an expansion chamber. The introduction of an expansion chamber reduces the emissions while increasing power output due to increased volumetric efficiency.**

***Keywords*— expansion chamber, fuel injection, two stroke engine, engine performance, emissions**

I. Introduction

An internal combustion engine which has a power stroke in each cylinder during each revolution of the crankshaft is classified as a two-stroke engine. The "simple" two-stroke engines use crankcase compression for the induction process, while the controlling of the timing and area of the inlet, transfer and exhaust ports are fulfilled by pistons. Figure 1 shows a schematic layout of such a two-stroke engine.

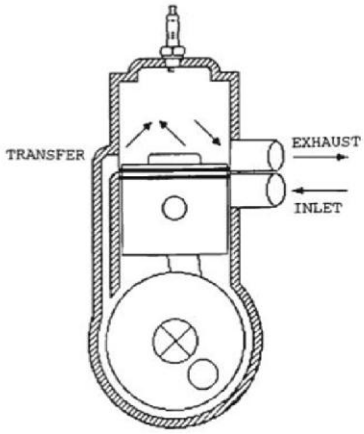

Fig. 1. Simple two stroke engine

The four-stroke engine has four strokes – suction, compression, combustion & expansion. In a two-stroke engine, the processes carried out are the same as the four-stoke but all of it takes place in two strokes. The suction and compression takes place in one stroke and the power and exhaust in the other. This means that for the same number of rotations, the two-stroke engine produces twice has twice the number of power strokes as compared to the four-stroke engine.

During the mid-20th century, the two stroke engines were widely and quite understandably thought of as a “reasonable alternative to four-stroke when weight and manufacturing cost are the main considerations”. Depending on the manner of the introduction of fuel, both compression ignition and spark ignition two stroke engines have been developed in the past. The main advantages of this engine type, compared with its four-stroke engine rival, are its mechanical simplicity, superior power to weight ratio, lower production cost and lower maintenance cost.

Another aspect that played an important role in the popularity of two-stroke engines over four-stroke engines was the ease in implementing modifications. One may think that changing the valve timing in a four-stroke engine may do wonders, but that requires altering a camshaft which is costly. On the other hand, a two-stroke engine’s valve timing may be changed by simply reshaping the holes in its cylinders and its power output can be significantly increases by utilizing the resonant and inertia effects in its intake and exhaust systems. None of these modifications are costly.

As can be inferred from the above discussion, two-stroke engines have many advantages over the four-stroke engines. However, there are also a number of disadvantages. For example, the air-fuel mixture enters the cylinder from the crankcase via the transfer port. While this is advantageous as it reduces the number of moving parts and saves weight, it is also disadvantageous as this arrangement forces the crankcase to be a part of the system and so it can't be used as a sump. This means that the oil has to be premixed with the fuel, according to fuel-oil ratios provided by the engine manufacturer. This oil is burnt alongside fuel during the combustion phase which increases the engine's emissions.

Another disadvantage of the two-stroke engine is the scavenging losses. Scavenging is the process of using the incoming charge to push the burnt exhaust gases out of the cylinder. During this process, some amount of fresh unburnt air-fuel mixture escapes with the exhaust gases. Not only does this decrease the engine output because of decreased volumetric efficiency, but it also increases the emissions since the catalytic converters installed in the exhaust systems are not equipped to filter this escaped charge.

There are a number of other disadvantages too that contribute to the downfall of the two-stroke engines in the last half-century, however, the ones mentioned above are the most generalised and significant ones that can be observed in about every traditional two-stroke engines. This paper proposes a solution to overcome these aforementioned shortcomings.

II. Literature Review

Spark ignition two-stroke engines haven't received much research and technological advancements compared to four-stroke engines. They were very popular in the 20th century in small displacement applications such as chain saws, lawn mowers, scooters. The most relevant areas of development of two stroke engines for automotive applications are supercharging scavenging, dry sump, direct ignition and throttle-less load control.

Shuheng Jiang [1] mentions in their thesis that in conventional two-stroke engines, the fuel and air are mixed in the carburettor and then drawn into the cylinder. Simultaneous opening of the intake and the exhaust ports cause some unburned mixture escape from the exhaust port. Direct injection does not have the carburettor to mix air and fuel. It delivers air only to the crank case while fuel is injected directly into the cylinder. The injection in the engines is precisely timed, so no fuel escapes and reduces emissions. Direct injection models have all the benefits of two-stroke engines and they are still equal to or greater in emission and fuel efficient than many four-stroke engines.

Another advantage, they [1] say, of direct injection two-stroke engines is that they have much lower oil consumption than traditional two-stroke engines since fuel is no longer mixed with oil. Instead, oil is only injected in the crankcase and then it is distributed to the bearing and the other moving components through the scavenging process.

According to Leighton's [2] report, two-stroke direct injection is expected to reduce emissions from 25 to 35 percent inferior than those of four-stroke engine. This system is now applied on marine engines and watercrafts and they surpass the four-stroke standards. Table 1 presents the different type engine combustion gas chemical composition.

				grams/HP/hour
Engine	HC	CO	NO_x	MP
Two-Stroke	111	296	1	2.7
Four-Stroke	8	123	9	0.2
Two-Stroke DI	22	90	3	0.6

Table 1. Combustion gas chemical composition (US Environmental Protection Agency, 2001)

John et al. [3] used four essentials of effective fuel injection, metered quantity of fuel, desired spatial distribution timing of injection, and complete vaporization prior to the start of combustion. Data presented include details of spray formation and engine performance and reported dramatic reduction in fuel consumption and exhaust emissions. The horsepower of the injection engine was nearly the same as that of the carburettor engine while the BSFC was reduced by 25 to 45%and exhaust HC emission was so reduced that it became closer to that of a four-stroke engine at medium to high loads. At low loads, HC emission did not improve due to misfiring.

The Institute of Internal Combustion Engines and Thermodynamics at Fraz University of Technology has developed a direct injection device, a low pressure (5 bar) direct injection (LPDI) combustion system for 50 cm^3 two-stroke engines. The results show that the LPDI technology has the potential to compete with four-stroke engines. The high power to weight ratio, high engine efficiency and the low emissions systems are especially practical in the India market as the urban population is high (Oswald et al. [4]).

Expansion chamber was invented and manufactured by a German engineer, Limbach, in 1938 when Germany was running short of petrol. It had been observed that a two-stroke engine with an expansion chamber installed gave much more power output than one without. However, it was not until later that the expansion chamber was properly recognized when Ernst Degner, an East German motorcycle racer, used this in the 1961 Swedish Grand Prix. In the early 1970s, Gordon Jennings carried out tests on his stock Yamaha DT-1 at Webco dyno facility in order to obtain improved power output by use of expansion chambers. He published his methods and results in the Cycle magazine [5] in the same year. His most successful result resulted from a configuration consisting of an expansion chamber designed by him, a ported cylinder, a shortened piston and a Webco piston head. This configuration yielded a power output of 22.9 bhp @ 6500 rpm when the stock engine gave a meagre 15.86 bhp @ 6000 rpm. This was an increase of 44.5 percent in the power output without exceeding the manufacturer’s redline for this engine, and in fact, by raising the true horsepower peaking speed only 500 rpm. Moreover, there was more power observed with the modified engine over the entire useable power range. The figure below shows a graph of the power output versus engine speed for Jennings’ most successful configuration.

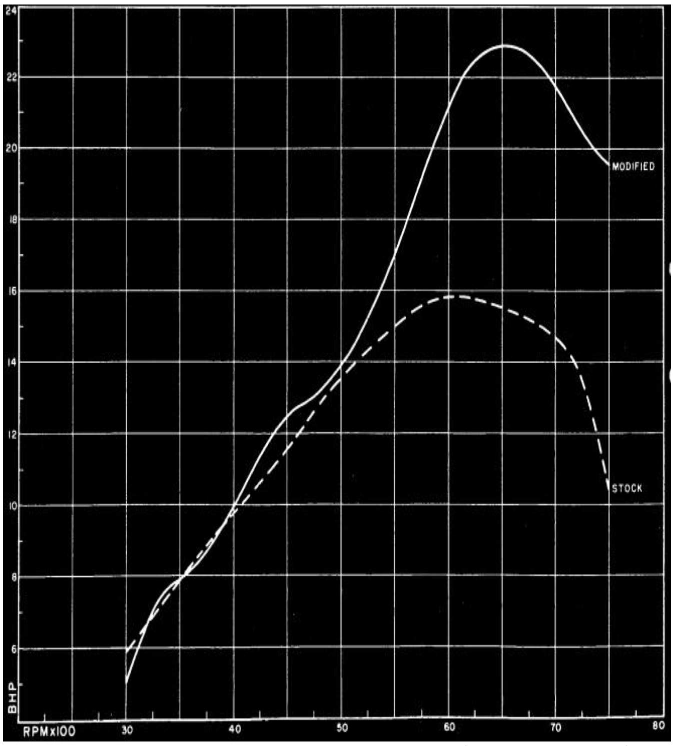

Fig. 3. Power output (bhp) vs engine speed (RPM) for stock and modified engines

The use of expansion chamber might seem to render the muffler useless since one may assume that it may interfere with the backpressure of the expansion chamber outlet. However, Gordon Jennings explains in his book [6] that if properly managed, the addition of a muffler to your expansion chamber will have absolutely no effect on power output, and will increase only slightly the exhaust system's size and weight. Trying to accomplish the same thing with a racing four-stroke engine would be difficult to the point of impossibility, but the two-stroke's expansion chamber must have a restricted outlet in any case, and it cares little whether the restriction is provided by a simple bit of pipe, or by a muffler. He mentions that he had dyno-tested a number of expansion chambers, made as replacements for stock mufflers, that actually showed a gain in power with an add-on muffler.

Tony L. Parrott [7] with the National Aeronautics and Space Administration’s Langley Research centre presented a paper wherein an improved design of an expansion chamber-equipped muffler was introduced for application to an operational helicopter. This method accounted for the effect of mean exhaust gas flow on the acoustics transmission properties of a muffler system. Reduction in noise levels by approximately 11db was observed here with no significant variations in engine performance.

In summary, a lot of research has gone into the development of the two parts individually of the proposed solution and significant advancements have been made. A study of the literature shows that both these systems – fuel injection and expansion chamber – have been widely used individually. However, using both these systems together has not been suggested. This paper suggests the use of the two systems in harmony with each other and the two-stroke engine.

III. WORKING

The proposed solution is simply a traditional two-stroke engine with two modifications – fuel injection system and expansion chamber. The main changes that are expected with these modifications are:

- Reduction in escaped unburnt fuel as a result of scavenging losses
- Inhibiting participation of lubricating oil in the combustion process and thus, promoting effective combustion
- Increasing volumetric efficiency by making more fuel available during the combustion phase

The individual role of both of the modifications will be briefly discussed below.

A. *Fuel Injection*

Fuel injection is the introduction of fuel into the cylinder of an internal combustion engine using an injector. The main components of a fuel injection system are ECU, fuel pump and injector. The injector has a nozzle through which the fuel is injected at high pressure. The high injection pressures are ascertained by the electronic control unit (ECU) according to engine specifications, load and throttle position. The figure below shows a simple fuel injector.

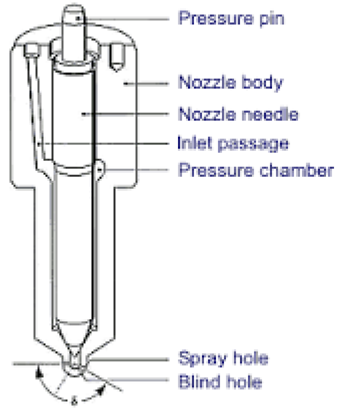

Fig. 2. Fuel Injector

Fuel injection system aids in effective atomization of fuel, provides precise fuel delivery, easier cold starts and better throttle response. All this contributes to increased efficiency and consequently, better performance. Fuel injectors are widely used in the newer four-stroke engines and are mandatory in diesel engines. Two-stroke engines do not usually have fuel injectors as its employment increases the weight of the engine, thereby jeopardizing the main advantages of the two-stroke – its low weight and fewer moving parts. However, the pros of using a fuel injection system outweigh its cons. The advantages of using a fuel injection system in a two-stroke engine are:

- Conservation of fuel due to proper metering by ECU
- Spray angles can be adjusted according to profile of cylinder head and walls which facilitates increased atomization
- Better combustion due to proper mixing of air and atomized fuel
- Since fuel is being injected and only air is being used for scavenging, only air is lost due to scavenging losses and fuel is conserved
- As no unburnt fuel is leaking out with the exhaust gases, emissions are reduced

B. *Expansion Chamber*

Expansion chamber is essentially a tuned exhaust system that increases the power output of a two-stroke engine. This increase is brought about by increasing the volumetric efficiency of the engine. Expansion chamber is usually made up of five parts joined together. These parts – head pipe, diffuser section, dwell section or belly, convergent section or baffle and stinger – can be observed in the figure below.

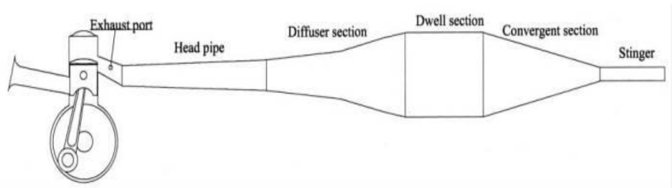

Fig. 3. Expansion chamber

Expansion chambers work on the principle of Kadenacy effect. This principle is named after Michael Kadenacy who obtained patents for an engine employing this in 1933. In Layman's terms, according to the Kadenacy effect, a pressure drop is created due to the momentum of exiting gases that aids in flow of fresh air-fuel mixture into the cylinder. This pressure drop can be utilized in a number of ways by careful tuning.

Expansion chambers are based on a basic principle of wave dynamics which states that when a traveling wavefront, such as the high pressure gases leaving the cylinder, encounter a change in cross-sectional area, it reflects a portion of its wave back in the opposite direction. By carefully timing this backflow of gases, they can be made to reach the exhaust port in the cylinder right when the fresh charge from the next cycle tries to escape with the exhaust gases. This effectively pushes the escaping charge back into the cylinder, thereby increasing the volumetric efficiency of the engine and conserving fuel. However, all this can only happen work if the the expansion chamber has been dimensioned properly. Construction of the expansion chamber plays a very vital role in its working as even the slightest change in, say, the diffuser cone angle can alter the range of engine's power band significantly.

For maximum energy recovery, it is suggested that the diffuser have an 8-degree taper. If the taper is increased beyond 8 degrees, it is possible to get a stronger inverted wave but at the expense of the wave duration. Conversely, the wave duration can be increased by decreasing the taper below 8-degrees but the amplitude of the wave will diminish. A longer wave duration spreads an engine's power band whereas a short wave with higher amplitude gets higher power at peak revs.

Baffle taper angle should generally be taken twice that of the diffuser taper angle. Increasing the taper of the baffle increases the reflection time of the wave thereby broadening the engine power band.

There is no general rule of thumb to define the dimensions of the various parts in an expansion chamber for a given engine. This is so because waves are very fickle and the slightest change in pressure, temperature, profile of boundary walls, etc. can significantly affect the expansion chamber's performance. In other words, every engine is different in construction and specifications, so the configuration that works for one engine might not necessarily work for another. Now while this is somewhat of a shortcoming, it can also be looked at as an advantage. The expansion chamber is entirely customisable and the customisations are not at all costly, so each expansion chamber can be designed to suit a particular engine with specific working requirements.

The way that the employment of an expansion chamber in a two stroke engine will affect its characteristics are:

- It will pull in extra charge up from the crankcase into the cylinder
- It will aid in preventing the intake charge from escaping through the exhaust port
- Will also aid in boosting compression at high RPM for a quicker burn and more power

The way that these systems – fuel injection and expansion chamber – will work with the two-stroke engine in which it is employed is discussed below.

- First, the air enters the crankcase in order to be introduced to the cylinder during induction process
- Meanwhile, the fuel pump ascertains the injection pressures and primes the injector
- When the piston reaches BDC, the air comes into the cylinder due to the action of crank
- This incoming air pushes out the residual gases from the previous stroke. This is known as the scavenging process

- Towards the end of scavenging, the inverted pressure wave reflected from the cones in the expansion chamber reaches the exhaust port, pushing the leaking fresh charge (air, in this case) back into the cylinder
- The piston rises up to TDC and fuel is injected
- The spark plug fires and combustion phase starts
- The piston moves back down towards BDC, exhaust port is uncovered and the exhaust gases are let out
- Leaving gases create a pressure drop inside the cylinder which pulls the fresh charge from the crankcase into cylinder
- Thus, the cycle is complete.

IV. Conclusions

Two-stroke engines provide more power than their four-stroke counterparts but due to factors such as more pollution and fuel consumption, they have become unpopular now.

The solution proposed in this paper offers a chance to revive the two-stroke engines with suitable modifications to overcome the aforementioned factors. The proposed solution has its own disadvantages too, such as more weight and moving parts than the traditional engine, but these come at the expense of increased power output and decreased emissions.

V. Future Scope

With further research and validation, the proposed modifications can be applied to diesel and gasoline engines alike. Also, emissions can be lowered to such an extent that they satisfy the emission norms.

As optimum use of space and minimizing pollution is essential in ships, the two-stroke engines used there can be replaced by the proposed engine with comparatively better performance and lesser emissions.

Two-stroke engines are generally cheaper than the four-stroke ones, this provides an opportunity to make vehicles, mostly two-wheelers, that are cheap and high-performance but also satisfy emission norms.

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