IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 09, Issue 5 (May. 2019), ||S (III) || PP 30-36

Rotory Internal combustion engine- A study

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Abstract: In this paper Wankel and other available rotary internal combustion engine are discussed. The benefit of rotary engine over reciprocating engine are (i)The rotor undergoing a rotary motion,crankshafts onecomplete rotation, completes four stroke cycle, this means that in full rotation of crankshaft one power stroke is delivered. Hence flywheel is not required. (ii) The need of the extra equipment that converts reciprocating motion into rotary motion such as cranks, conventional crankshaftetc will be eliminated. (iii) The internal combustion engine will be much lighter. Also this arrangement will reduce vibration that occur due to reciprocating motion of piston. Towards the culmination some recent trends of using rotary engines in micro electromechanical systems (MEMS) are also discussed.

Keywords-Rotary engine, MEMS, Wankel engine

Date of Submission: 21-05-2019 Date of acceptance: 07-06-2019

I. INTRODUCTION

Rotodynamic internal combustion engine has a biggest advantage of planar design, which makes it easier to use it in vehicles as well as in integrated circuits as a replacement of batteries, if made in micro sizes[1]. Since the development of batteries, the improvement in the energy density provided by batteries has been onlyby afactor of 2. But the requirement of energy density in the recent electronic devices has increased by many factors. Hence researchers are looking for ways to meet these new requirements. One such way is to use a combustions engine designed to work at micro levels, since the energy density of combustion engines are much more than that of batteries [2]. Rotary internal combustion engines are found to be more suitable for these purposes.Engine are the devices which convert one type of energy to another type. Heat engine converts chemical energy of fuel into thermal energy which is further converted to mechanical energy. Heat engine are of two types. Internal combustion engine and external combustion engine. Both of these are further classified as Rotary engine and Reciprocating engine. Rotary IC engine are either Wankel engine or open cycle gas turbine. Reciprocating IC engine are either gasoline engine or Diesel engine. Rotary EC engine are either steam turbine and closed cycle gas turbine. Reciprocating EC engine are either steam engine or Stirling engine. Steam engines are phased out.

Most widelyused internal combustion engine are reciprocatingengine. These have to and fro motion of piston. Converting this motion of piston into rotary motion at output makes it a non-planar designed engine. It undergoes the following four strokes-

1) Suction stroke - The fuel and air is sucked in the cylinder by the downward movement of the piston.
2) Compression stroke –The sucked fuel – air mixture is compressed by the upward movement of piston.
3) Expansion or Working stroke or power stroke -The fuel air mixture after compression expands thereby making the piston move in downward direction.
4) Exhaust stroke- After the power stroke the residual remains of combustion are removed in the exhaust stroke by upward movement of piston.

II. COMPLICATIONS WITH RECIPROCATING PISTON IC ENGINE

The problems associated with reciprocating piston IC engine are

1) The reciprocating motion of the IC engine causes vibrations.
2) Many parts such as crankshaft, cranketc. are required to transmit the reciprocating motion to rotating motion.
3) Since out of four strokes Power is produced only in one stroke so to run the piston for remaining strokes a flywheel is provided. This flywheel absorbs excess energy from the power stroke and releases it in the remaining strokes so that piston keeps moving.

All these makes the reciprocating internal combustion engine unsuitable for general as well as Micro Electro Mechanical Systems (MEMS) purposes.

III. ROTARY INTERNAL COMBUSTION ENGINES

The other internal combustion engines available by default are rotary internal combustion engines. In this paper various available rotary internal combustion engine are discussed. The benefit of rotary internal combustion engines are

1) The piston undergoing a rotary motion will work in all the above four strokes. In this way power from power stroke will be rotating the rotor (piston) and distributing the energy equally. Hence no flywheel is required.
2) The need of the extra equipment such as cranks, conventional crankshaft will be eliminated.
3) The internal combustion engine will be much lighter. Also this arrangement will reduce vibrations that occur due to reciprocating motion of piston.

IV. METHODOLOGY

Besides above benefits, the lack of review literature on the rotary internal combustion engine prompted us to write this paper. Sites such as IEEE, Taylor and Francis online,Elsevier, google scholar and many more were searched for finding the relevant research paper. After reading the research papers on the topic, the following sections were crafted to group the reviewed literature on rotary engine.

4.1 Wankel engine

Most widely studied rotary internal combustion engine is Wankel engine. A lot of research is available on Wankel engine[3].The Wankel engine has triangular rotor as in fig1, which rotates within a trochoidal housing. [4]. The tops of the triangular rotor are continuously in contact with the housing. This results in three separate volumes each of which helpsin a key function.A combustion area is built into each rotor flank which contains about 50% of the total working volume at top-dead-center. Each of the rotor side functions as a sealed working volume, where all the four stroke are accomplished. The inlet port allows air fuel mixture in cavity. As the rotor rotates it compresses this fuel air mixture. A spark plug is provided their which ignites this compressed fuel air mixture. The expansion force from combustion of mixture, acts on the rotor and rotates it further. This movement open the exhaust port thus allowing the residual gases to escape from the chamber as visible in fig1. One crankshaft rotation completes four stroke cycle.The "rotary piston" turns directly on an eccentric shaft.The Wankel's engine crankshaft completes three rotations for every one rotation of the triangular rotor, this means that the full rotation of crankshaft one power stroke is delivered.

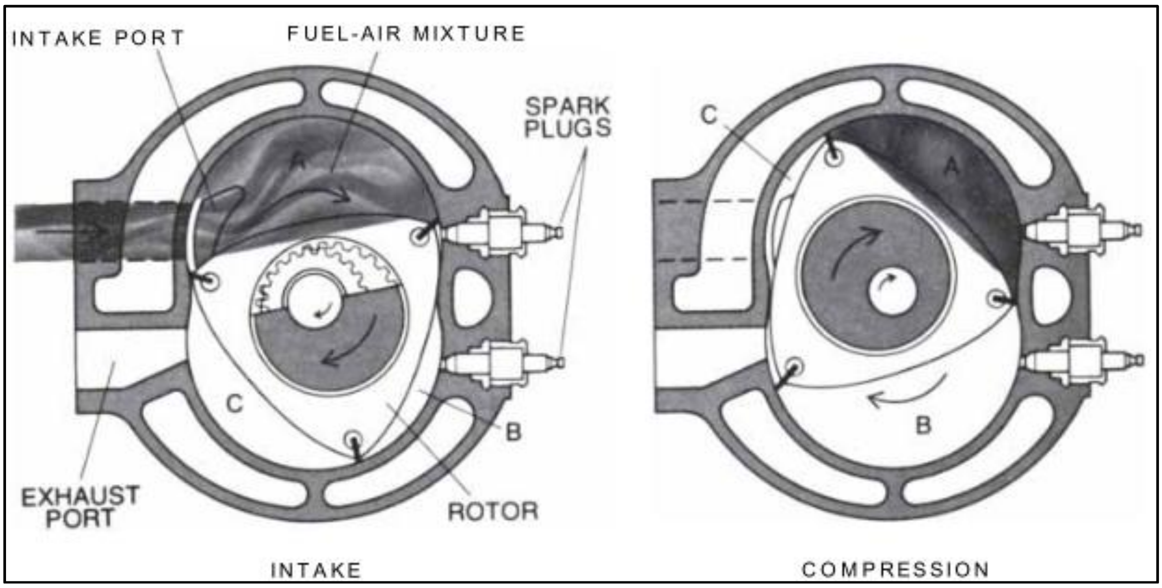

Figure 1 Wankel Engine with variable size chamber undergoing a complete 4 stroke otto cycle in 1 rotor revolution[4].

4.2 Brief history of Wankel engine

The first patent was awarded to Felix Wankel in 1933 for Wankel piston machine, he then collaborated with the German company NSU (currently Audi) in 1954 and filed another patent[5]. Here the inner body was supported within outer body for relative rotation.This invention provided a rotary engine where inner and outer bodiescan rotate in the same direction with the outer body rotating at the higher speeds or vice versa. As a result Wankel engine was used in automobiles, motorcycles, snow mobiles, power generators aircrafts etc. Theywere based on spark-ignited gasoline with intake throttling. By mid-1970's major automobile companies discontinued development programs of Wankel engine as its fuel economy was poor. Some programs at Mazda and Curtiss- Wright Corporation continued, with Mazda achieving success in improving performance and efficiency of the rotary engine.

The Curtiss-Wright Corporation developed multi-fuel-capable rotary engines [6] in mid 1960s.By 1983 NASA became interested in rotary engines for uses in lighter aircraft. Theyprovided a contract to Curtiss-Wright Corporation with a aim to Develop and apply (CFD) methods to rotary engines for better understandingof combustion process, demonstrate multi- fuel capabilities in rotary engines and other objectives[7]. Curtiss-Wright Corporation sold its Wankel engine to John Deere and co in 1984 and thenthey completed the contract. John Deere and co, developed an electronically controlled fuel injection system working on very high pressure, and tested it. They also found that turbocharging improved BSFC as well as the max power of the SCRE.[8]. John Deere under NASA contract in 1986, demonstrated an SCRE with 310 g/kWh (0.51 lb/hp-h) BSFC at 8000 rpm and 160 hp. DEERE and CO. sold its Rotary Engine Division to Rotary Technologies International Inc. of Lincoln, Nebraska in 1991.

Okhubo et al [9] replaced the peripheral exhaust port of previous rotary engine with side exhaust port system in the new rotary engine named renesis. This new engine achieved, improved fuel economy, high performance and clean exhaust gas by allowing an increase in intake port area and exhaust port area.In order to achieve zero emission engine,Hydrogen has been used in a rotary engine combined with a fuel cell, also known as Hydro Wankel Cell, [10].Mazda has been keen on developing the RENESIS hydrogen rotary engine. Companies such as AVL, General Motors, FEV, Lotus Engineering, and Rota power are considering a rotary engine as a power generator for their plug-in hybrid cars.

4.3 Other existingdesigns for Rotary Internal Combustion engines

4.3.1 Rotary piston engine with two lobes

Robert J. Bernstein patented a new design for rotary piston engine in 1972[11]. Ithad a two lobe combustion chamber. A flap pistonwas placedin first lobe, and a rotary piston was placed in another lobe.As the spark plug starts the combustion of fuel, the explosion from combustible fuel expands the gases. These expanding gases drive the flap piston to motion which in turn drives the rotary piston due to cam action.The gases than also drive the rotary piston as in b portion of fig 2. As a resultexhaust gases are also force out from the exhaust chamber formed by rotary piston.The rotary piston then pushes the flap piston back, due to cam action. This compress the new intake of fuel mixture in the first lobe of the combustion chamber. Hencethe cylinder is now prepared for one more cycle. Major efforts were devoted to minimizing the vibration, Smog production and develop more power at low engine speeds.

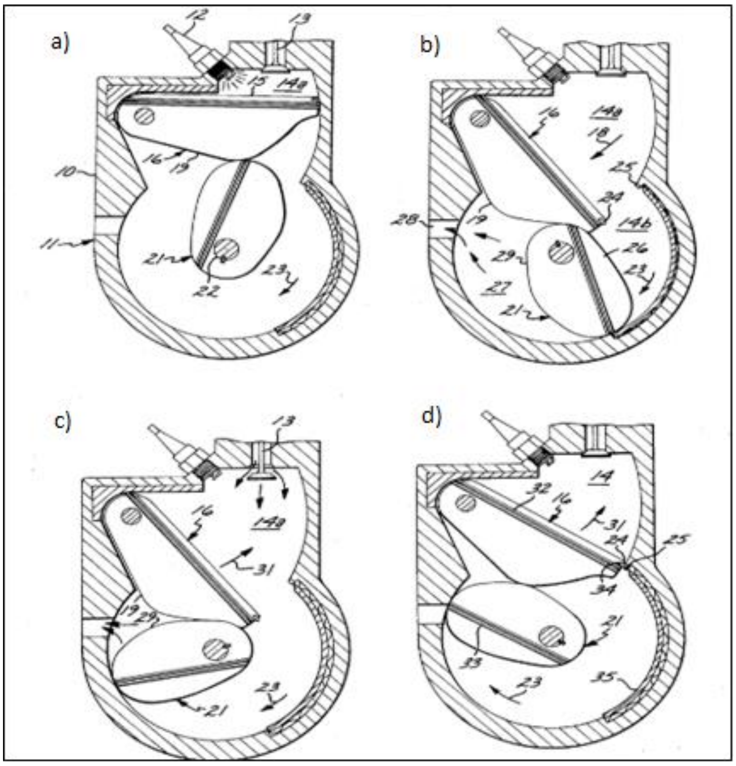

Figure 2 Two lobe internal Combustion engine[11].

4.3.2 Gear type rotary engine

In 1974 Joong Woo Nam patented a gear type rotary engine[12]. This gear-type rotary engine had a partitioned chamber for compression (housing 1) and combustion (housing 2) as visible in b part of fig 3. The gas inlet chambers and ignition chamber were communicable. A set of two gear-like rotors, a concave rotor and a convex rotor are fixed on two different rotor shafts in double O shaped compression and combustion cylinders. The compression cylinder of housing 1 has an intake port for mixture of fuel and air, extending upward. The combustion cylinder of housing 2 has an exhaust port for exhaust of burnt fuel, extending downward. Convex rotor had a pole blade and concave rotor had a pole indentation. The point of their meeting produced compressed gas and an inlet is provided for moving compressed gas from housing 1 to combustion chamber (housing 2).Spark plug (19) in inlet passage ignites the compressed gas such that the expansion force spreads out between the poles of convex and indentation of concave rotor in combustion chamber, thereby making the rotors rotate. The residual gases finds its way out through exhaust port.

Major achievement were separate chambers prevented overheating of engine as found in Wankel engine, high overall efficiency and less vibration.

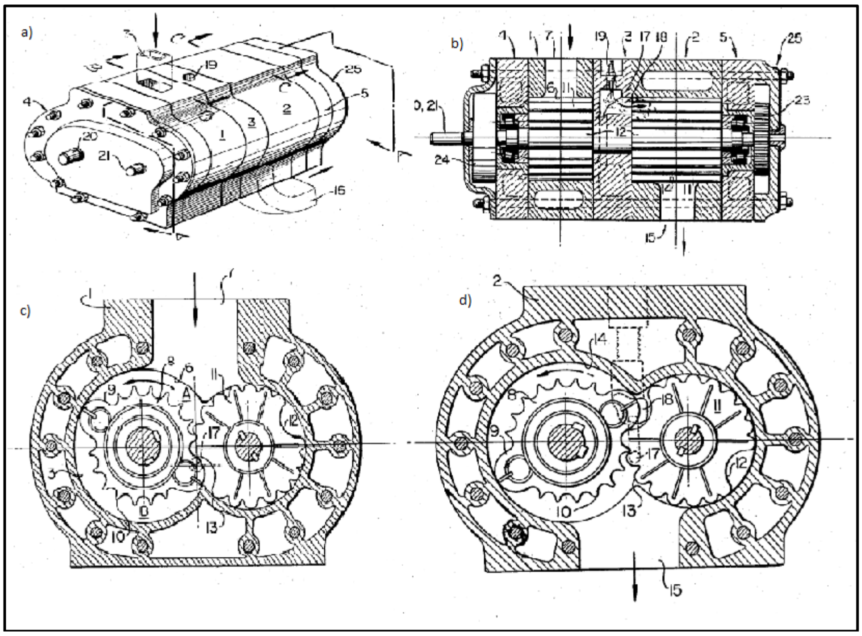

Figure 3 Gear Type Rotary Engine [12]

4.3.3 Rotary engine with tongue and groove cylindrical rotors

In 2001 Robert A. White, patented a rotary engine with tongue and groove cylindrical rotors forming a sealed contact with one another [13]. Similar to gear type rotary engine it also had a compression chamber, a combustion chamber and an expansion chamber. Except for tongue, groove arrangement of rotors everything else remained same as in gear type rotary engine shown in fig 4.

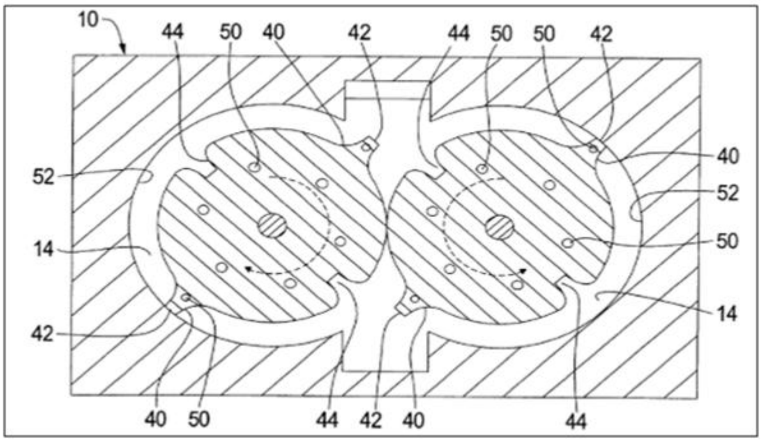

Figure 4 Rotary engine with tongue and groove cylindrical rotors[13]

4.3.4 Quasiturbine Rotary engine

In 2000 Saint-Hilaire et al. patented quasiturbine zero vibration continuous combustion rotary engine, compressor or pump [14]. The working of this engine is similar to Wankel engine except the rotor here is replaced with a variable shaped rotors. Here four pivoting blades and four rocking carriages composes a rotor as in fig 5. The pivoting blades have hook pivot and cylindrical pivot on opposite ends. Each pivot sits on one carriage which is free to rotate in such a way to be in continuous and precise contact contour of housing. Each carriage has a housing seal.Intake ports or exhaust port are either made radial in the housing or axial on the lateral Side covers.Uninterrupted combustion is sustained by an ignition flame transfer Opening. A central Shaft can be attached and moved by the blades, through a coupling. The objective achieved in this engine were low noise, zero vibration, low rpm, fast acceleration, zero dead time engine and use of any energy source such pneumatic, hydraulic , steam or gas fuel mixture for running engine.

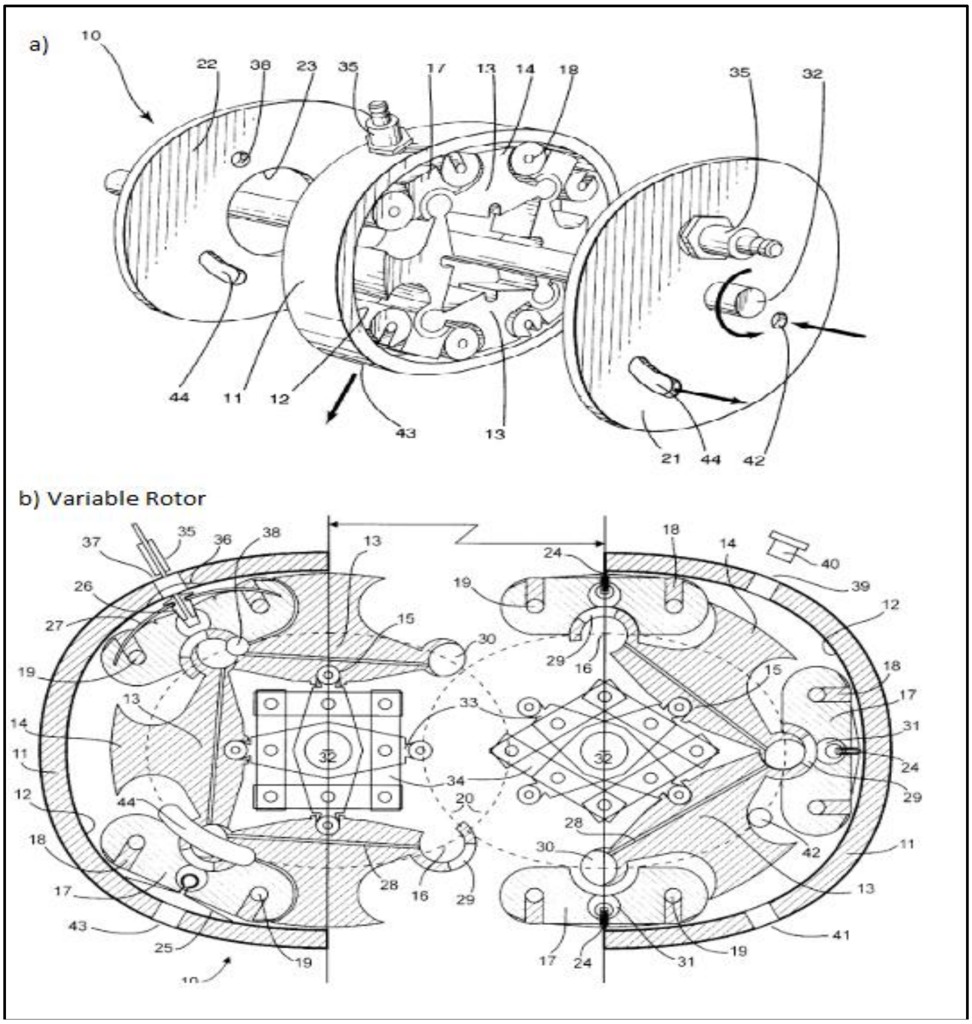

Figure 5 Quasiturbine Rotary engine with variable rotor [14]

4.3.5 Rotary positive displacement control system and apparatus

In 2008 Tien-tung Chung et al. patented a Rotary positive displacement control system and apparatus [15].This system had a transmission assembly with at least one compression assembly, an expansion assembly and a buffer assembly between them. The compression unit containsmany compression rotors with lobes intermeshing witheach other, and the expansion unitcontains many expansionrotors with lobes intermeshing with each other. Similar to gear type rotary engine compression assembly is provided an intake port for fuel air mixture and expansion assembly is provided with an exhaust port. Compressed gases are efficiently transferred from compression assembly to expansion assembly through buffer assembly which can adjust the compression ratio. The residual gases can be removed from the exhaust slots on expansion assembly. The explosion of fuel transmit the power through transmission shafts. Working of compression is same as gear type rotary engine with lobes replacing the poles.The objectives achieved were high pressure air during process of compression, increase operation efficiency and enhanced power output.

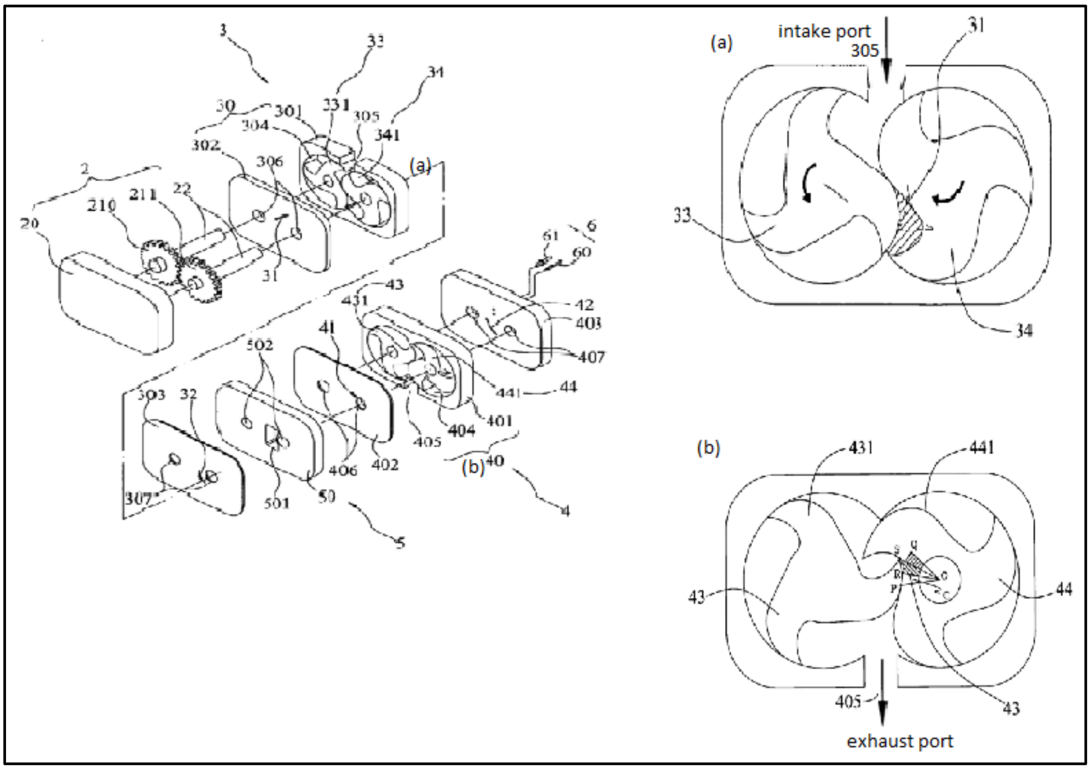

Figure 6 ROTARY POSITIVE DISPLACEMENT CONTROL SYSTEM AND APPARATUS[15]

V. RECENT TRENDS

With the developments of micro electro-mechanical systems (MEMS), recent trends is the miniaturization of rotary internal combustion engine. This trend is gathering momentum as a research effort to develop liquid hydrogen fuelled MEMs type rotary internal combustion micro engine which will replace alkaline or lithium ion based batteries as ahigher energy density source. These micro rotary engine can be easily fabricated with integrated chips due to its planar design. Kelvin Fu et al.[16][1] designed, fabricated and experimented micro rotary engines with housing under $1mm^3$ and swept volume of rotary of $0.008\ m^3$. They obtained a positive power output of up to 2.7 W at around 9,300 RPM from MN125 mini-rotary engine and concluded that the development of the micro-rotary engine is not restricted by any fundamental phenomena. Wang et al.[17]proposed thelower possible limits associated with miniaturization of rotary engines.The leading supporter of a rotary engine for Power MEMS is the University of California at Berkeley.

VI. RESULTS AND CONCLUSION

Rotary engine specifically Wankel engine started to disappear from marketsaround mid-1970's due to its poor fuel economy. But with the advents of electric cars, these engines started to gain market as hybrid engines. Many companies are trying to make hydrogen fuelled rotary hybrid engine. Another major advantage is the planar design which makes it suitable for micro electro mechanical systems. Hence these engines are going to be used heavily in near future and improvement in their design require more scientific research.

FUTURE WORK

Future work could include an improved design for a planar rotary internal combustion engine which could also be used easily as micro engines in integrated circuits.

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IOSR Journal of Engineering (IOSRJEN) is UGC approved Journal with Sl. No. 3240, Journal no. 48995.

Mohammad Arif. "Rotor Internal combustion engine- A study." IOSR Journal of Engineering (IOSRJEN), vol. 09, no. 05, 2019, pp. 30-36.