AN IMPROVED ROTARY MECHANISM ENGINE

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Developments in the field of rotary engines have been reviewed. Potential of scissor action type rotary engine with suitable innovations on linkages and multirotor configuration has been brought out.

Work on rotary piston machines started long before the internal combustion engine had been thought of. Bewildering varieties of rotary piston arrangements have been evolved by inventors at various times. Franz Reuleaux[1] was the first to classify these in 1875 to analyse the factors leading to the failure of most of them. Till the recent past any attempt to evolve a rotary engine did not invite appropriate attention. There are, however, strong points in favour of rotary piston machines, which inspite of repeated failures have been inducing engineers to continue working on them.

Rotary engines eliminate the crank and connecting rod mechanism of reciprocating engines. This results in comparative savings in weight, bulk, number of components and cost. In addition rotary engines have lesser vibrations and smoother operation. Gas turbines also have the advantage of rotary motion, but they are uneconomical for operation on mobile applications and for low and medium power ranges. Optimum performance of gas turbines needs sustained high temperatures, high pressures and high speed. Rotary engines retain the combustion characteristics of reciprocating engines, these are therefore, more suitable for mobile applications requiring low to medium power ranges.

Of the rotary engines developed so far Wankel is the only one which has come into production and limited usage in automobiles. Scissor action engines developed by Kaurtz[2,3] and Virmel had attractive features of more displacement, less bulk and weight, simple fabrication and lesser number of components. These, however, could not make much headway because of frail linkages, greater unbalanced inertia loads and sealing problems. The potential of the proposed mechanism based on Scissor action with innovations on linkages and multirotor configuration to minimise these drawbacks has been discussed in the subsequent paragraphs.

CLASSIFICATION OF ROTARY ENGINES

Before describing the proposed new rotary engine mechanism, it will be worthwhile to glide through some of the developments in this field. Broadly the rotary engines can be grouped[2] into (*a*) Eccentric rotor type, (*b*) Scissor action type with pistons or vanes, (*c*) Revolving Block type. According to Wankel's classification[1] rotary machines are grouped into the following :—

(*i*) Single rotation machines (SIM),

(*ii*) Planetary rotation machines (PLM),

(*iii*) Single rotating piston machines (SROM), and

(*iv*) Rotating piston machines similar to planetary rotation machines (PROM).

Each of the above machines may have any of the following :— (1) Reciprocating engagement, (2) Arctuate engagement, (3) Intermeshing engagement, (4) Slip engagement, (5) Counter engagement.

The classification also indicates whether these machines are of internal axis or external axis type. An indication of the class of the machines is useful and will be given against the engines mentioned below :

Cooley Engine (Internal axis, single rotation machine with intermeshing engagement)

Cooley engine[2] was patented in 1903 for use both as a pump and steam engine. This engine had a two-lobe inner epitrochoid rotor with an outer hypotrochoid to form the working chamber. The geometry of

Cooley engine Fig. 1. is opposite to that of the Wankel engine. The sealing system was primitive and steam consumption was high. Apex seals were provided in the spacer instead of on rotor as done by Wankel. No attempt was made to modify it for operation on the four stroke cycle as an internal combustion engine. Wankel 1945, 1947 and Lind engine can broadly be grouped into this class.

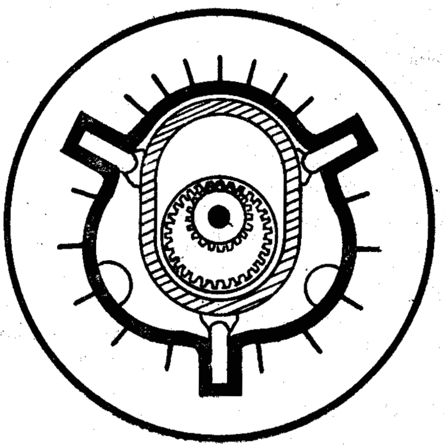

Fig. 1—Cooley Engine.

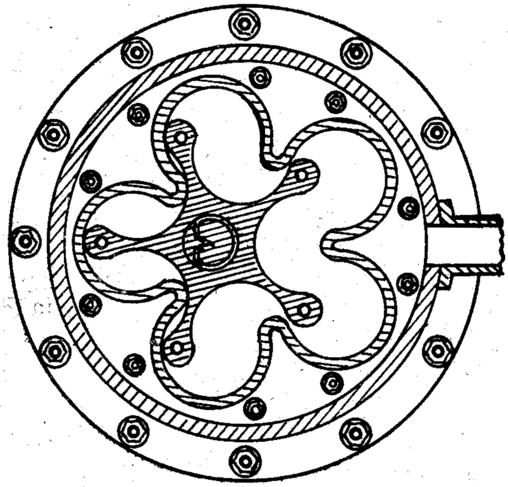

Fig. 2—Galloway Engine.

Galloway Engine (Internal axis, planetery rotation machine)

It was a paracyclic mechanism with a five lobe rotor running in a five lobe housing giving 1:1 ratio of rotational movement[2]. The Galloway engine was run on steam admitted through circular side ports. Although some packing was provided around the ports, no rotor seals were provided to the engine. Therefore, steam consumption was high and efficiency quite low. Fig. 2. It was used as a marine engine and developed only 16 hp at 400-480 rpm. Sauveur and Fiebig engine[1] also come in this category.

Parsons Engine (Planetery rotation machine with reciprocating engagements)

This was invented in the year 1882 and was not a rotary engine in the true sense Fig. 3 (a). It has cylinders and pistons positioned at 90 degrees, in '+' formation. The cyliners revolved on trunnions, and their rotations provided a relative movement between each cylinder and its piston. The Parsons engine was reported to have excellent balance, but it used up steam at the rate of 18 kg per horsepower hour. Not much work has been reported about it. Power Plus, Witty and Andrew engine belong to this type.

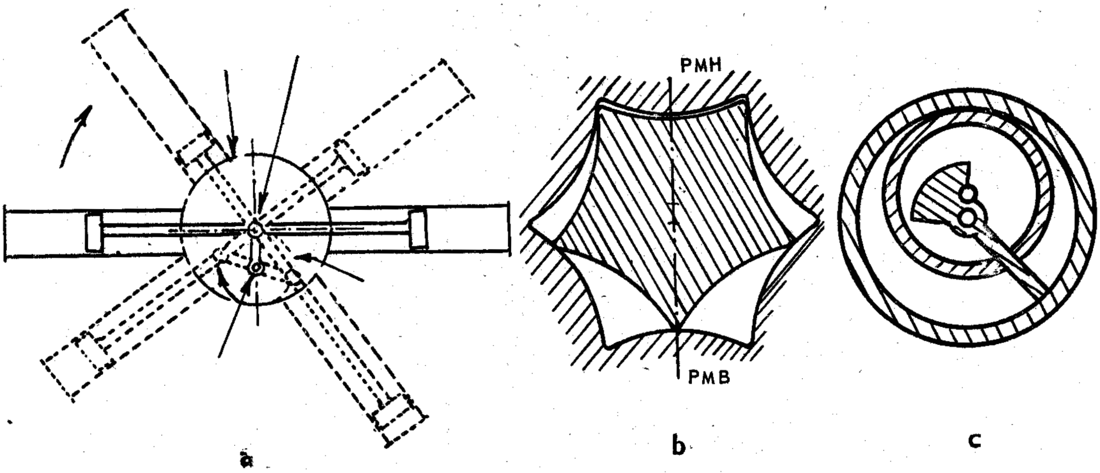

Fig. 3—(a) Parsons Engine; (b) Sensaud De Lavaud Engine; (c) Trotter Engine.

Sensaud De Lavaud Engine (Internal axis, single rotation machine)

The engine consisted of a five lobe outer rotor with the shape of an inner hypocycloid and an inner rotor with six lobes running on a 5 to 6 reduction ratio Fig. 3(b). The relationship between the inner and outer rotors provided a closed chamber between each two apices on the inner rotor. The volume of each chamber changed during rotation. One test engine was built. However, power output never came to the expected figures and this was abandoned in 1941. Fixon was the only one to attempt an engine in this class and used oval, triangular, four and five sided rotors in 1 plus sided housings.

Trotter Engine (Internal axis, single rotation rotating piston machine)

Trotter engine had a cylindrical housing with a concentrically mounted drum Fig. 3(c). It was the first rotary engine to use true eccentric rotation rather than cam shaped rotors to obtain volume variation. None of the machines in this category proved successful. Cochrane, Fletcher[1] also tried similar engagements.

Wankel Engine

Wankel during his long years of work on the rotary engine has tried various configurations[1]. Some of these are indicated in Fig. 4. Wankel engine has a trochoid working chamber like the outline of figure '8' with a fat waist described by the apices of the rotor. The dimensions of the working chamber are decided by rotor

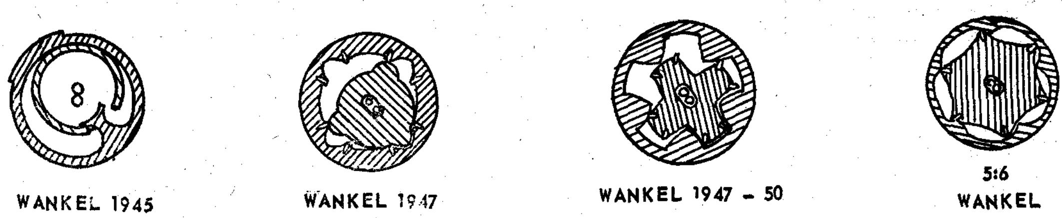

Fig. 4—Various configurations of Wankel Engine.

radius, rotor width and rotor eccentricity. Rotor[2] width has no theoretical limits, but extremely wide and narrow rotors result in slow and incomplete combustion. For efficient operation rotor width is approximately taken as equal to one half of rotor radius. The working chamber is also provided with ports for intake and exhaust and spark plug for ignition of the mixture, sometimes even two spark plugs are provided to achieve complete combustion. Its working[4] is shown in Fig. 5. The cycle used has four strokes i.e. intake compression, expansion and power. All the three working chambers are in continuous action. The pressure of expanding gas acts on one lobe of the rotor to produce rotary motion.

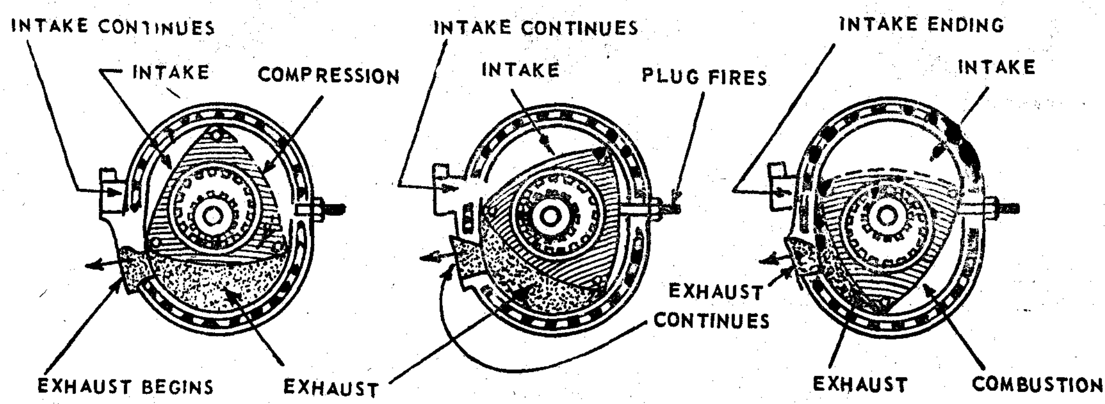

Fig. 5—The four stroke cycle with eccentric rotary motion.

The engine models KM-48 and KM-914 A tried by R&D E (Engrs.), Poona did not come up to the expectations[5]. They could not take their rated loads and in both the models seizure occurred after certain hours of run. The engines could however develop from 60 to 90% of the rated output.

Walker Rotary Engine

Walker rotary engine[6] is a turbine like version of Wankel. It is claimed that 50kg engine with 12 power strokes per revolution develops 205 bhp at 3000 rpm. Further details of this are however not known.

Jernaes and Renault also developed engine similar in principle to Wankel but with a novel type of gearing.

Scissor Action Type Engine With Pistons Or Vanes

Kaurtz, Virmel, Tschudi, Omega engines and the one proposed fall in this category. A brief description of Kaurtz and Virmel is given in the subsequent paragraphs :

Kaurtz Engine (*Central axis rotating piston machine*): This type of machine does not incorporate two axes of rotation, one besides the other, because both shafts are concentric and therefore turn about the same centre line. This is generally called Scissor action engine.

Two sets of vanes rotate on the same axis but continuously change relative angular position. This speeding up and slowing down of one set of vanes changes the volume of gas between the two sets. Changes in gas volume produce the pumping action needed for intake, compression, combustion and exhaust. Correct phasing of the vane motion is achieved by a gear and crank system and is shown in Fig. 6.

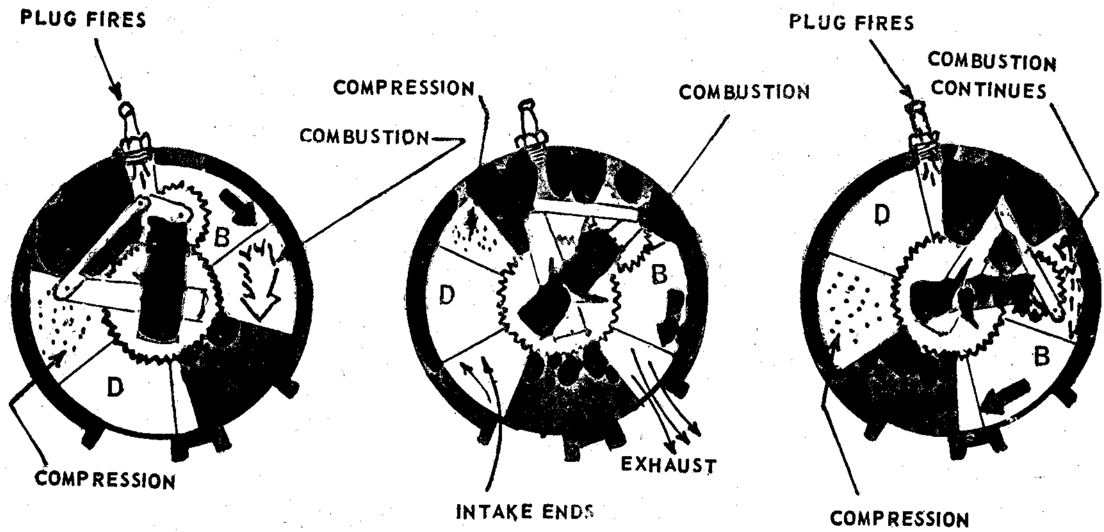

Fig. 6—Working principle of Kaurtz Engine.

A prototype Kaurtz engine had only 22 parts, 7·5 cubic inch displacement and produced 51 horsepower at 4000 rpm as claimed by the inventor.

Virmel Engine : It differs from Kaurtz in several respects, but works on a similar cycle. It has two sets of vane type pistons and a gear-and-crank system that controls piston phasing. In the Kaurtz engine, one set of vanes run at steady speed and the other set at periodically variable speed, while in Virmel Fig. 7 one set of vanes momentarily stops completely twice during each cycle. A prototype is reported to have been tested. It had 50 cu inch displacement and is claimed to have developed 300 hp at 3800 rpm. Work on Scissor action type engine has not proved to be very fruitful due to the drawbacks of heavy inertia loads on the linkages and sealing problems, etc.

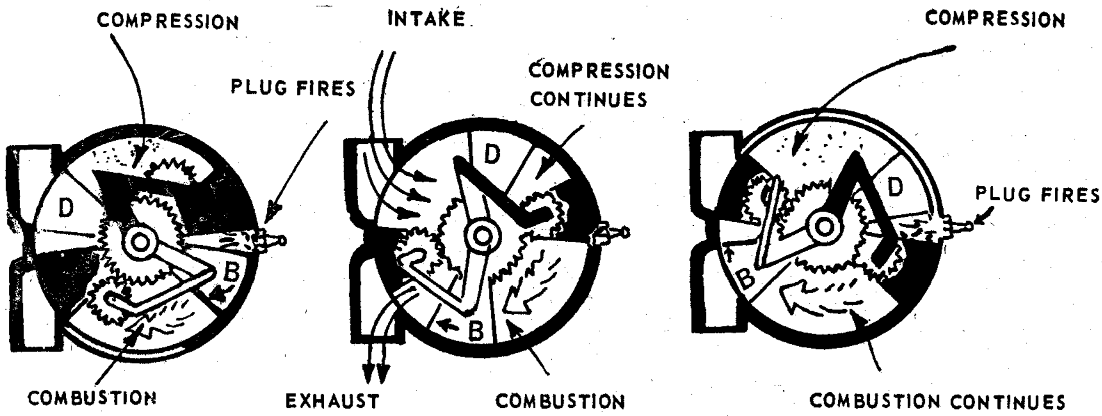

Fig. 7—Working principle of Virmel Engine.

PROPOSED ROTARY MECHANISM ENGINE

This is basically a scissor action type machine with some innovations and improvements incorporated to overcome the drawbacks of similar engines. It combines the two mechanisms :

(1) Scissor action type mechanism for rotating spaces of variable volumes formed by two rotors of continuously varying velocities with respect to each other with multi-vane configuration, and

(2) Guidance mechanism for controlling the velocities of the rotors.

The engine with this mechanism has two co-planer and concentric rotors rotating with continuously varying velocities with respect to each other in a closed cylindrical casing. The enclosed volume between the faces of the adjoining rotors forms spaces of variable volume. One rotor with equal set of vanes is connected, by an ingenious use of end plate which help in simpler sealing, to one of the main links mounted concentrically on the shaft. The shaft is connected to another main link. This main link guide mechanism in turn creates an oscillating movement with the help of first main link, thereby giving the Scissor action of vanes.

The combination of these two mechanisms increases the output in arithmetic progression depending upon the number of vanes. Each rotor may have any number of vanes—one, two or more. More the number of vanes, the higher the output of the machines. The illustrations given below explain the potentiality of the mechanism in a simple mathematical form.

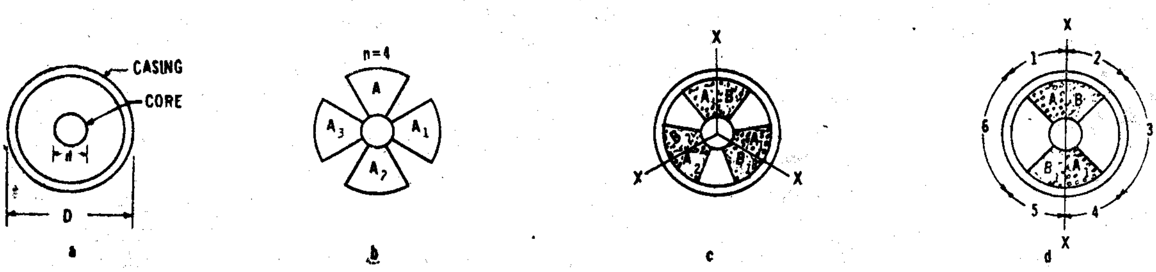

Fig. 8—(a) Cylindrical casing ; (b) Rotor with four vanes; (c) & (d) Typical mechanism.

Cylindrical Casing : If D is the diameter of the casing and d the diameter of core **Fig. 8(a)** then total volume for unit depth is

$$V = \frac{\pi}{4}\,(D^2 - d^2)$$

or=360° angular sweep.

Rotor Properties :

Total angular sweep of a rotor $= 120°$
Number of vanes of each rotor $= n$
Angular width of each vane $= 120°/n$

Number of spaces of variable volumes formed with two rotors $= N_1 = 2n$.

Typical Mechanism Properties :

Volume of casing occupied by two rotors $= 2 \times 120 = 2V/3X$ *Positions :* Where two rotors are adjacent to each other (Fig. 8c), so that half number of spaces have zero volume and remaining half spaces have total volume $V/3$. Adopted number of X positions for highs peed$=n$.

Typical mechanism with two vanes on each rotor i. e. $n=2$ and positively regulated motion of rotor. As rotors with vanes occupying position 1—4 moves through $60° = 2X = 120°/n$, the rotor with vanes occupying position 2—5 moves through $120° = 2 \times 120°/n$ (Fig. 8d). Hence as rotor A—A_1 moves from position 1—4 to 2—5, rotor B—B_1 moves from position 2—5 to 4—1 closing spaces at 3 and 6 (of total 120°) and opening two new spaces on other faces of rotors. Volume swept in this action is 120° or $V/3$. In one complete revolution this action is repeated $2X$ times i.e. $2n$ times.

Volume swept in one revolution$=2Vn/3$. For values of $n=2$, 4, 16, 64, the volume swept is 1.33, 2.67, 10.67, 42.67 respectively. The above reveals that the output of the machine increases in an arithmatic progression with increase in number of vanes. Each face of the vane is undergoing either suction or compression and increases the capacity of the machine $2n$ times in one complete revolution where 'n' is the number of vanes on a rotor. Although apparently the volume available in the chamber remains the same or becomes less irrespective of number of vanes, this volume undergoes the cycle of operation more than once per revolution of the shaft viz., it is admitted and exhausted more than once in a revolution depending upon the number of vanes.

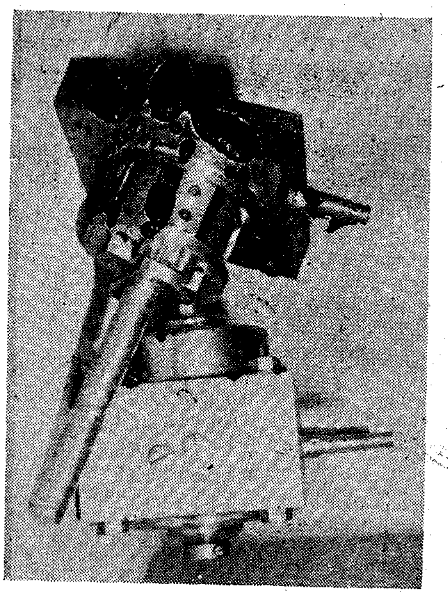

Fig. 9—View showing the arrangement of vanes, end plates, drive mechanism and linkages.

Studies on this mechanism have been undertaken in Defence Science Laboratory. A prototype having two sets of rotors with four segments each, has been fabricated. The rotor diameter is 100 mm and shaft dia 25 mm with hub 50 mm dia. The clearance between the housing and rotor is 0·1 mm. The rotors were initially cut *in-situ* on a milling machine with the help of jigs. This posed finishing problems which have been overcome by machining the segments separately and connecting them to the shaft and plate in correct position.

To start with the rhombic drive was used with straight links and connecting pins. This has been improved by using roller and guide mechanism. The guide plate is so designed that by fixing it on a lathe at four selected points simple machining leads to the desired curvature. The sub-links are also finished on standard machines. The guide plates and sub-links are case hardened and run in an oil filled housing with seals at the ends (Fig. 9).

Potential of the New Rotary Mechanism Engine

The factors to be considered in the evaluation of a rotary engine can be summed up as follows :

(*i*) The weight/power ratio and overall bulk to displacement should be favourable.

(*ii*) Effective sealing should be possible.

(*iii*) Preferably the components should move at uniform velocity—inertia forces should be minimum. The components should be strong enough to accommodate the highest stresses encountered.

(*iv*) The assemblies should be easy to manufacture and should have high reliability and long life between overhauls with simple maintenance.

(*v*) Cost-effectiveness.

(*vi*) The design should be capable of accommodating a favourable thermodynamic cycle and the engine should have maximum efficiency.

(*vii*) Air-pollution should be within acceptable limits, and

(*viii*) Provision for adequate cooling and lubrication.

The success of Wankel engine has been to a great extent due to his practical emphasis on these points. The proposed mechanism will now be discussed considering the above factors. This will also bring out comparative features of the proposed mechanism *vis-a-vis* reciprocating and Wankel engine.

Weight to power ratio and bulk to displacement ratio : Output and displacementwise, a reciprocating four stroke engine gives one power stroke per two revolutions and Wankel engine gives one power stroke per revolution. The power of the proposed engine increases in arithmetic progression, depending upon the number of vanes. The prototype fabricated had theoretical displacement of 785 cc per revolution and its expected theoretical horsepower should be about 40 with a weight of 30 Kg plus the weight of minor fitments. A comparable reciprocating engine for this displacement will be about 3 times bulkier and heavier. The magnitude of this can be visualized from a study made by Curtiss Wright[2] (Fig. 10). Data collected on Wankel engine for weight to power ratio for range of 10 to 100 h.p. compared with a reciprocating engine is given in Table 1.

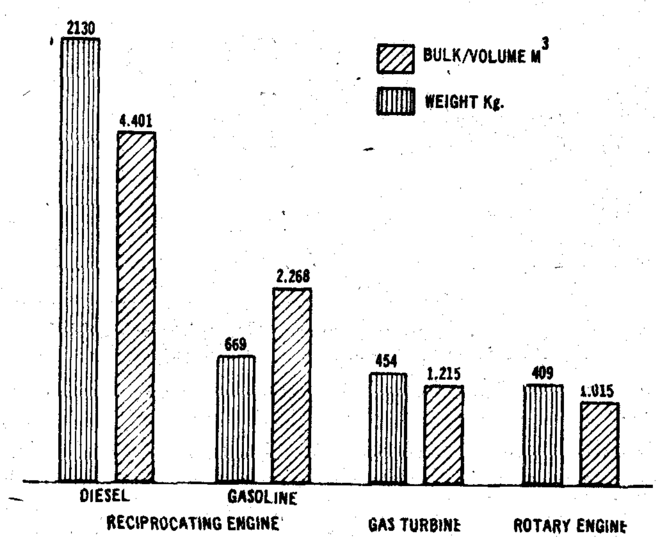

Fig. 10—Comparison of weight to power and bulk to power ratio of different engines for same displacement.

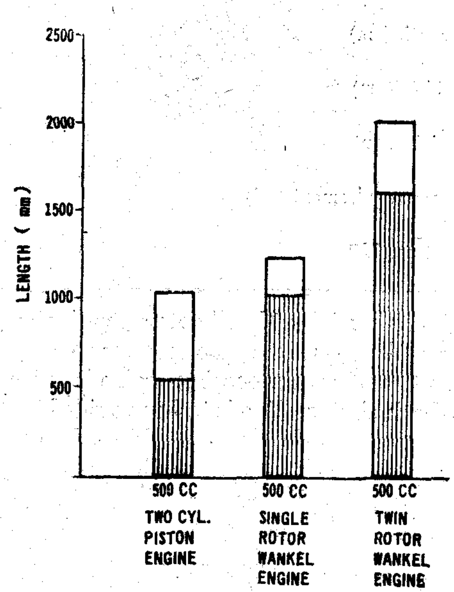

Fig. 11—Comparative study of sealing lines of reciprocating and Wankel Engines.

TABLE 1

WEIGHT/POWER RATIO OF WANKEL ENGINE & RECIPROCATING ENGINE AT VARIOUS HP

Horsepower	Wankel Engine	Piston Engine
10	1.36	5.7
20	1.36	5.6
30	1.36	5
100	0.45—0.80	2—4.3

TABLE 2

COMPARISON OF DIFFERENT FEATURES OF RECIPROCATING ENGINE AND ROTARY ENGINE

CHARACTERISTICS	GM ROTARY	CHEVY 307 V—8
1. Net HP @ rpm	150 @ 6000	130 @ 4000
2. Net torque	125 @ 4000	230 @ 2400
3. HP per kg	1.3	0.61
4. Number of parts	698	1103
5. Moving parts	154	388
6. Weight (kg)	116	212
7. Length (cm)	53	76
8. Width (cm)	56	71
9. Height (cm)	54	78
10. Space requirement (m^3)	0.15	0.70
11. Cost per HP	\$1.80—\$2.20	\$3.00

Sealing : Though all rotary engines suffer from sealing problem, the proposed engine should have less problem as it is much nearer to the reciprocating engine in this respect. Fig. 11 indicates that the sealing line of a reciprocating engine is much shorter than that of Wankel. Wankel engine has rather a greater draw-back since sealing is to be provided on the apices which is responsible for upto 3/4 of the total gas leakage. The apex seals are also subjected to various forces like corriolis component, centrifugal forces, friction forces etc. There is no apex sealing problem in the proposed engine, all the rotor segments are provided with spring loaded sealing strips. The prototype (785 cc displacement) fabricated had a total sealing length of 1800 mm. The rubbing surface of the rotor is kept minimum to avoid loss of power.

Inertia forces : The driving mechanism for the proposed engine is based on rhombic drive invented by Meizer[7] to overcome the penalty of unbalanced inertia forces and to achieve a balanced drive for the elimination of inertia torques. The inertia loads will still exist but the proper proportioning of the components should take care of these to some extent while still keeping weight favourably low.

Ease of manufacture, reliability and cost-effectiveness : The fabrication of the proposed engine is simple. The prototype fabricated in DSL for trials did not involve any special type of machines. All parts like rotors, links, guide plates etc were fabricated on conventional machines like lathes and milling with the help of simple Jigs. In this respect it proves to be simpler than Wankel, which needs special machines for machining trochoidal chamber and other components.

All rotary engines have lesser number of components and the material cost is less. In case of Wankel it is reported that the labour cost is also considerably less. Table 2 gives the comparative idea of various features of reciprocating engine and rotary engine[8].

The cost of the proposed mechanism will therefore be on lower side.

Torque characteristics, thermodynamic Cycle, efficiency and pollution : By its very concept a rotary engine gives a more uniform torque. A comparison of the torque characteristics of a reciprocating engine and rotary engine is given in the Fig. 12. As the proposed engine has more number of thermodynamic cycles repeated in one revolution its torque distribution will be still smoother.

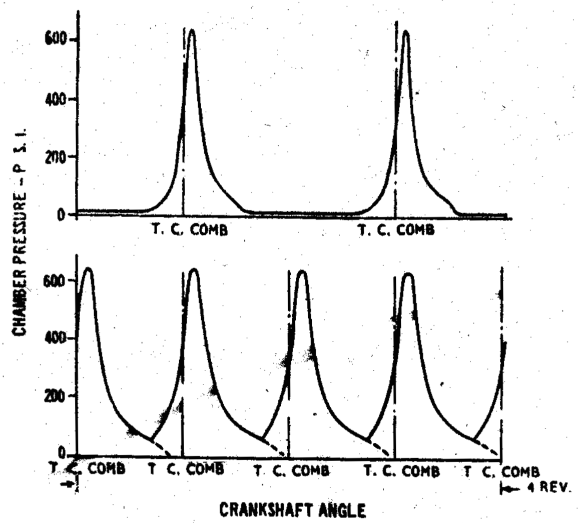

Fig. 12—Comparison of torque characteristics of a single cylinder four-stroke cycle Reciprocating engine (top) and single cylinder rotating Combustion Engine (below)

At this stage of development it is rather premature to comment on efficiency and pollution.

Cooling and lubrication : The provision for these is simpler in Scissor action engine than in eccentric type rotor engines.

CONCLUSION

Rotary engine with multivane rotors and suitable linkages shows good promise for being developed into a light weight, compact, versatile and low cost prime mover. It should prove a very attractive proposition for applications where bulk and weight are of paramount importance.

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