6. Remarks about individual models

Various rotary piston machines are thoroughly examined in this section. They are elaborated with reference to specific inventions which have already become known and the use of the relevant charts is illustrated.

6.1 Reciprocating engagement

Internal axis planetary-rotation machines with reciprocating engagement $\overline{(\mathrm{R})}$ have been shown on chart 8 line I columns 1 to 4 (I/1–4). In each of the machines depicted by I/1 the centre of gravity travels in a circular path at constant angular velocity and the piston rotates about its own centre of gravity, while the cylinder also rotates uniformly about its own stationary centre of gravity. There is only a single piston in this machine suitably extended to incorporate a balance weight which ensures that its c.g. coincides with the centre of the crank-pin. It is, of course, far more advantageous when a pair of pistons is arranged one at either end – as illustrated in several configurations on model sheet PLM I (table 11). A particular model – a steam engine – incorporating two such pistons was, in fact, conceived by Parsons, who is perhaps better known for his work on turbines. Indeed, several of these Parsons engines were installed in ships to drive generators and reports stressed their vibration-free performance. The most notable disadvantage is their large overall size relative to the working chamber volume. Steam inlet and outlet are controlled by a single stationary valve disc, the respective ports being opened and closed as the cylinders revolve and sweep past the openings in the disc. This arrangement probably suffered from considerable steam leakage or friction losses in view of the scant knowledge of sealing rotary disc valves available at that time.

Parsons' machine was preceded by Witty's (1811), whose design is shown in the third line of table 11. A trunnion or block and stationary pin (or, as it is sometimes called Scotch yoke) was used in place of a crank. Andrew's steam-rowing machine (1858) table 11 II/3 also belongs to this category. There is no crank in this design, the correct piston movement being ensured by a trochoidal cam plate which moved at a ratio of 1:2. An internal combustion engine according to this principle is, for example, the Bucherer engine.

An external-axis reciprocating piston machine, designed by the author in 1929, is shown at I/11 of chart 8. In this, both the piston and the cylinder were given a parallel circular motion. The size of this type of machine relative to its stroke volume is more advantageous than for internal-axis machines with reciprocating engagement. However, the continuously shifting radial strain is less desirable than the centrifugal strain in the revolving cylinders of internal-axis machines.

In the patent specification there was a reference to the possible use of this type of fully balanced mechanism for machine tools. Since 1950 it has become known that the high-speed blanking press produced by 'Lempco Products' incorporates a device of this kind.

6.2 Arctuate engagement $\overline{(A)}$

Single- and planetary-rotation machines with arctuate engagement $\overline{(A)}$ are shown in chart 7 II/1–4, 6, 8 and chart 8 II/5–8, 11. Galloway probably invented the first internal-axis planetary-rotation machine in 1846, see model sheet (chart 1) SIM II 2 (table 12), line 3 No. 2. He used it as a marine steam engine but in the absence of sealing elements its performance was unsatisfactory.

A. Lind suggested in 1914 an internal-axis single-rotation four stroke engine with arctuate engagement, see table 12 II SIM 2, line 1.

Machines with constantly shifting contact points between the engaging components may only be sealed by a special grid arrangement in which the sealing elements contact each other, thereby blocking practically every possible leakage path. Machines with arctuate engagement also feature continuously shifting contact points but it is a peculiarity of the arctuate engagement that every point of the engaging parts circles in a parallel path to all other points; thus sealing may be effected by means of relatively few sealing elements. The sealing elements must protrude slightly out of their grooves in order to seal effectively. These elements subdivide the large curved segments of the meshing component into a number of smaller circular segments but the sealing contact shifts from side to side in sequence.

C. H. Varley invented the paracyclic single-rotation pump in 1919 and fitted a sealing system, as described above, during the development stage. However, the author was obliged to rediscover this type of sealing arrangement in 1947 during his work on single-rotation engines with arctuate-engagement features. This exertion was necessitated by the absence of a comprehensive reference and classification system for rotary piston machines, and single-rotation machines in particular.

In position II/11 of chart 8 is shown, as an example, the planetary-rotation external-axis machine invented by Köpke in 1942.

6.3 Cam engagement $\overline{(C)}$

Internal-axis single- and planetary-rotation machines featuring cam engagement $\overline{(C)}$ and incorporating trochoidal curves are shown in position III/1 and 2 of chart 7 and in positions III/5–8 of chart 8. Single-rotation machines with significant trochoidal curves may be realised in two versions, namely as internal- or external-rotor machines in which the curve generating points and sealing elements are part of the respective inner or outer rotor.

In the case of planetary-rotation machines with trochoidal curves, four variants are possible; two with internal- and two with external-rotors. The curve generating points and sealing elements are part of the inner-rotor in one case and in the other they are part of the outer rotor; in the 3rd and 4th cases they are part of the stationary inner- or outer chamber wall respectively.

Single-rotation machines SIM III/1 (chart 7) were invented by Cooley in 1901 in the form of steam engines. Various attempts have been made since to apply this basic principle to planetary-rotation internal combustion engines, for example, by

Umpleby in 1908 and later by the Renault Company. The attraction of this configuration is undoubtedly the way in which the working chambers are formed almost without parasitic displacement. The Japanese ISUZU company produced in 1963 a SIM type four cycle engine with a relative speed ratio of 3 : 2. This engine featured simple inlet and exhaust ports which were accommodated in the inner rotor. E. Höpner who examined such a configuration in 1954 decided not to pursue this design when he found that the inlet and exhaust gases necessarily pass through the shaft. The ISUZU design resembles, to some extent, known $\overline{\text{(SIi)}}$ engine configurations which have a 2 : 3 speed ratio, its inner rotor possesses the characteristic figure eight trochoidal shape. The outer rotor envelopes the inner rotor as well as accommodating the sealing elements, hence there is an unfavourable relationship between engine bulk and the displacement volume. However if the engine is built as a planetary rotation unit (PLM) part of the power must be transmitted by gearing which is not considered an advantageous expedient. Furthermore, the requirements of adequate port sizes and opening periods of PLM engines cannot be easily satisfied by the configuration. For example, it is possible to accommodate the unavoidable ports – as on two-stroke engines – in the end-covers. Unfortunately, it is impossible to dispense with a precompression phase for much the same reasons as in ordinary reciprocating-piston two-stroke engines – that crankcase compression is utilised to ensure efficient exhaust scavenging and charging of the engine. Provision of adequate port areas leaves only relatively short phases available for the compression and expansion of the gases. According to a study pursued by Ernst Höpner in 1957 rotating disc-valves – one on either side – are essential if the four-stroke cycle is to be accommodated. Engine weight is thereby increased and if the planetary-rotation principle is applied considerably higher bearing loads are obtained due to centrifugal forces. The increase in engine bulk is, of course, also undesirable.

Leaving aside poppet valves, the only other possible timing of port opening is by way of rotary valves driven at an appropriate speed. Earlier internal combustion engines of this type failed partly because of these problems, but in particular because of sealing difficulties.

Since parameters of the NSU-Wankel engine and its sealing system have become known, Renault and others have decided to continue development work on Cooley type planetary-rotation internal combustion engines.

Chart 8 – PLM III/7 and sheet 13 of the classification shows that machines based on the same principles and incorporating identical speed ratios may look very different from each other. If in a machine with a speed ratio of 2 : 1 the rotor is of circular section or if the rotor flanks are made of circular arcs, the rotor may move between the parallel walls of a cylindrical tooth gap. This phenomenon is the same as the locus of a point on the pitch circle of a planet pinion which rolls inside a base circle of twice the diameter of the rolling planet, being a straight line. A diagrammatic sketch of this type of machine is shown in line 2, column 1 of table 13. This machine with its circular rotor and arena shaped bore has a resemblence to the configuration shown in the line above it in the table, except that the latter combines a circular rotor with a trochoidal bore. The difference between the two designs is that whereas there are only two curve generating (contact) points in the design with the trochoidal bore, a multiplicity of contacts, on both sides of the bore, occurs in the design incorporating the straight sided arena shaped bore.

A section through the planetary-rotation pump invented by Moineau (French patent No. 400,508), with screw-type engagement, is similar to the machine illustrated in table 13, second line, first column. However, Ludwig Taverdon of Paris obtained a patent for this type of configuration as long ago as 1878.

Retaining the 2:1 speed ratio but introducing two or more circular rotors produces a design similar to the steam engine design patented in 1901 by Franzen and Fahlbeck.

Witte patented a similar diesel engine configuration in 1949. Even if it is possible to master the sealing problems of machines with spherical or rolling cylindrical pistons parallel to the axis of rotation, the resulting machines of this type will not be very desirable. This applies particularly to multi-rotor designs, as unfavourable relationships exist between the displacement volume and the necessary overall bulk of the machine because twice as many cylinders are required as pistons. Only when one double acting piston — first figure table 13 second line — is used is it possible to obtain a favourable displacement/overall bulk ratio.

If, however, this design is converted to a single-rotation machine, for which purpose its piston-rotor will be mounted eccentrically on its shaft while the housing becomes the revolving sealing component, it is possible to re-convert the SIM machine thus obtained, into an easy-to-seal planetary-rotation machine with reciprocating engagement. Accordingly it proved necessary to convert the rotor of the single-rotation machine into an eccentric by mounting on it a planetary-rotation rotor. The resulting configuration is shown in table 11, line 2, column 1.

(To illuminate a little more the multifarious relationships between rotary piston machines in general, it should perhaps be pointed out that this reciprocating-engagement planetary-rotation machine is closely related to the planetary-rotation machine shown in table 19, line 2 column 1 [by Beale]; the power transmitting component of this machine possesses reciprocating-engagement and simultaneously performs the function of a pair of vanes. These vanes revolve in the stationary trochoidal bore with slip-engagement!)

It is possible to derive from the machine shown in table 13, line 2, column 1 a unit with round piston rotors as shown in lines 2 and 3, column 2, which show the rotor in multiple piston form. In addition, it was possible to double the number of generating points and sealing elements, for machines with a speed ratio of 4:3 as shown in table 13 and obtain piston rotors of quite different shapes. For the chosen example it was possible to retain the number of teeth and gaps. It is, however, equally possible to reduce the number of teeth and gaps respectively to six each without having to alter the position of the eight sealing elements.

Wallinder and Skoog proposed a planetary-rotation four-stroke cycle engine with a speed ratio of 6:5, as shown in table 14, in 1923. Sensaud de Lavaud on the other hand experimented in 1938 with a single-rotation engine, see chart 7 (SIM) III/2, table 15. In its basic form there are only small parasitic cylinder volumes (maximum cylinder volume minus stroke volume) in this design and the ports may be opened and closed by rotor movement. Unfortunately, gas flow requirement demand that parts of the inner rotor are scooped out in order to provide adequate port opening areas and periods, which increase the parasitic volume in each cylinder and, in turn, make it practically impossible to realise present day compression ratios.

It is by no means easy to recognise in every instance whether a particular rotary-piston engine proposal is capable in its simplest form of accomodating the four-stroke cycle. Of the $\overline{\text{(Ci)}}$ machines just examined only those with speed ratios of 4:3 and 6:5 etc. may be designed in a form suitable for four-stroke operation. Of the $\overline{\text{(SIi)}}$ machines discussed in section 6 and 4 above only those with speed ratios of 2:3 and 4:5 etc. are capable of accommodating the Otto-cycle. Of all other trochoidal configurations, including $\overline{\text{(Ce)}}$ and $\overline{\text{(SIe)}}$ types, some are quite unsuitable for the application of the four-stroke cycle while others provide additional phases, such as secondary expansion, scavenging or even a supercharging phase, and the engines become special-cycle engines. Only by way of rather complex mechanisms and additional timing devices can these configurations be adapted to the four-stroke cycle.

Various derivations of trochoidal machines are shown on chart 8 (PLM) III/5 (table 14). For example, a trochoidal machine having a 2:1 speed ratio was changed into a single-rotation machine with a piston rolling round the bore. Reference should perhaps be made, in this connection, to the straight line locus traced by a point on the periphery of a rolling circle while rolling inside another circle of twice its diameter. The flanks of the housing 'teeth' are, therefore, straight sided. Beneath the trochoidal machine, with a speed ratio 3:2, is a flat vane rotary piston machine as proposed in the early forties by di Blasi for aircraft superchargers. Machines of an entirely different shape were obtained with speed ratios of 4:3 and 5:4 by altering their eccentricity, that is their crank throws.

The bottom line of the diagrammatic sketches shows machines having speed ratios of 2:1, 3:2 and 5:4, their greatly varying chamber shapes being due to doubling the number of generating points and sealing elements (of the models shown above). It will be noted that on machines with speed ratios of 3:2 and 5:4 the inner rotors penetrate their engaging members almost in the fashion of reciprocating motion between practically parallel flanks, which look like cylinders in the sectional sketches.

In 1950 the author made a design study of a 5:4 speed ratio machine using twice the number of curve generating points and tip-seals. In fact it was the development of these radial tip-seals in conjunction with the interlocking axial sealing plates which formed the last but one step towards the development of the sealing system for the first $\overline{\text{(SIi)}}$ four-stroke engine with a 2:3 speed ratio.

Internal-axis machines, resembling gear type pumps, as used for heavy oil and other fluids, are shown on the model sheet of single-rotation machines, that is in chart 7 in positions III/3, 4 and 8. This arrangement was also intended to perform as an internal combustion engine. Indeed, it has even been patented for this purpose as exemplified by the two-stroke engine evolved by Brown and Bovery in 1924.