7. Remarks about rotating piston machines

It does not follow that every moving part of single or planetary-rotation machines has inherently uniform rotary or circular motion. Consequently, the number of possible configurations is virtually unlimited. Moreover, any single and planetary-rotation unit may be converted into a rotating piston machine by relying upon eccentrically mounted or out-of-round gears which are attached to the shafts of power transmitting and sealing components which mesh with suitably shaped parts. Single and planetary-rotation machines which are thus made less tenable than might otherwise by the case are not, of course, included in this classification. Only those configurations have been added whose functional characteristics are due to variable rotary or circular motion.

Naturally, it is possible to distort any single or planetary-rotation machine by incorporating parts which have variable speed, thereby obtaining further types of rotating piston machines. But they are of no practical significance as far as this analysis is concerned.

While for pure-engagement methods by far the greatest number of different single and planetary-rotation machines are to be found in lines I to V, in the case of rotating piston machines the greater number of variants seem to be found in the lines reserved for mixed-engagement principles.

It may safely be assumed that most inventors of single and planetary-rotation machines have a justifiable aversion to the rather complex mixed-engagement methods. These inventors have probably eschewed components moving at variable velocity and they may, in some cases, have been unaware of the many possible alternative configurations with uniform velocity. Perhaps there are other underlying causes. Whatever, the reasons, they seem to have induced the successors of Ramelli (1588) to devote their inventive talents to single or planetary-rotation machines which relied neither upon the derivations of pure methods of engagement nor upon mixed-engagement principles.

Some inventors seem to be undisturbed by the fact that the uniform motion of the main components of their inventions depend upon the variable velocities of supplementary parts. Others have avoided supplementary parts by giving variable rotation or circulating velocity to the main moving components themselves. Consequently very few rotating-piston machines achieved even briefly performances which equalled or surpassed those of reciprocating piston designs. The vast majority proved decidedly inferior. Often the manufacture of these machines proved more difficult than that of comparable reciprocating piston devices. The shapes of individual parts and their guidance or bearing arrangements failed to permit the achievement of the higher rotational speeds, and they posed rather complex sealing problems.

7.1 Circular outer shape

Planetary-rotation type rotating-piston machines are shown in position XI/5 and 13 of chart 10. These merit attention because clearly they may be divided into internal and external-axis machines. However, they were invariably grouped together in previous classifications because of their actually or apparently round outer shape, while external-axis machines, such as gear type pumps or Roots blowers, were placed in different categories on account of their figure eight type bores. Closer examination of the designs, shown in line XI, reveals that the figure eight type bore is in fact present in column 13, though in rather indistinct form. The second axis of rotation is outside the area swept by the moving rotor and the mode of engagement is similar to a pair of meshing spur gears, though not in the same sophisticated form. It seems essential to resist the temptation to classify these outwardly completely round configurations as internal-axis machines. Due to the presence of a second axis of rotation it is therefore possible to differentiate between internal and external-axis planetary-rotation type rotating-piston machines as shown in lines X and VIII. However, this differentiation is somewhat blurred in the case of the machines of line VI and VII as there is no second axis of rotation; these machines can only be identified by referring to the above mentioned versions.

7.2 Reciprocating engagement

In I/1 of chart 10 of the classification sheet of planetarv-rotation Rotating Piston Machines is a unit designed in 1907 by Seguin as a radial aircraft engine which was, among others, manufactured by Gnôme le Rhône. This rotating engine proved to be the first internal combustion engine to get down to a weight of 2.2 lb/B.H.P.; while its revolving radial cylinders were undoubtedly well cooled, the gyroscopic effects of these rather substantial rotating masses influenced aircraft manoeuvr ability and excessive amounts of oil tended to find their way into the cylinders. Radial engines with stationary cylinders were, therefore, soon preferred although they suffered from the same inertia effects as the reciprocating piston engine.

It is doubtful whether some machines described as 'Rotating Piston' can justify the denomination. An example is provided by the external axis PROM machines shown in I/11 and 12, where the reciprocating cylinders or piston parts are relatively heavy. However, as in all rotating piston (ROM) type machines, the moving components have variable velocity so their size and weight places them outside this consideration.

7.3 Cam engagement

Machines with spherical or transverse cylindrical teeth which engage in suitable round or parallel wall bores (rectangular section) are shown in positions III/1–4, 9, 11, 12, 15 of chart 9 and in positions III/5–8, 11, 15, 16 of chart 10. Because the components containing the bores somewhat resemble Maltese Crosses they turn or move in a circular orbit at variable velocities. Only two configurations are known which facilitate uniform motion, namely:— the internal axis configuration with a speed ratio of 1:2 if the hypocycloidal principle, for the condition base circle radius R = 2 rolling circle radii, is applicable (see part 6.3 and model Chart 8 (PLM) III/7 (table 13), line 2 No. 1 and line 3 No. 1) or, as in the case of external axis machines, the female parts, i. e. the components containing the bores, rotate parallel to the component with the spherical (or cylindrical) mating parts – see classification chart 8 (PLM) III/11. The oval gear principle, as used for certain counting machine mechanisms (for instance, the petrol gauge manufactured by Bopp & Reuther) is shown in SROM III/13 (chart 9). Its conversion into a planetary rotation device is indicated in PROM III/14 (chart 10).

A machine with a speed ratio of 4:3 is shown in PROM III/1 (chart 10), which may at first be classified as a single-rotation unit with uniform speed. On closer examination it will be found, however, that at least one of the meshing components must possess variable velocity because the profiles are not trochoidal. This variable rotary velocity is obtained either by ensuring that the outer member is given an additional rotation – although the inner (3 tooth pinion) is already free to revolve round the crank pin – or by providing another crank pin which must be free to turn about the centre of the first crank pin. The pinion is, of course, free to revolve round the second crank pin. The last design is, of course, a double crank ROM (rotating-piston) machine.

7.4 Slip engagement

Very few arrangements of planetary-rotation type machines with slip-engagement have become known. Among the rare examples is a British design by Huxley (1865) and the Spanish Patent No. 268,765 granted to Martinez Ortega in 1961 as shown in PROM IV/7 and 8 (chart 10). In Huxley's design the correct piston-rotor movement is due to one crank mounted on and orbiting round another crank pin, while in Ortega's configuration the two or three arc rotor engages with a similarly shaped outer member due to the appropriate action of two meshing gears; thereby the rotor is made to move in or round the other two or three arc component. The locus of the centre of gravity of this rotor is no longer similar to a circle although it is in fact a completely closed path with two apexes. This type of machine contains **no** minimum volume at all but this advantage is nullified by the crank-upon-crank arrangement and the problems arising out of the oddly shaped internal tooth gear and by the greatly fluctuating velocity of the power transmitting component.

As only $\overline{(\text{Sle})}$ and $\overline{(\text{Ce})}$ configurations were mentioned in the Ortega patent specification, the related $\overline{(\text{Sli})}$ machines have been added to columns 5 and 6 of the classification chart.

7.5 Reciprocating engagement and engagements similar to slip engagement

Two of the oldest rotary piston machines are shown in chart 9 at VI/11 and in chart 10 at VI/5; both were described in 1588 by Ramelli. Many different versions of these machines have been built in the intervening years; indeed they have even been reinvented, in particular the design indicated in chart 10 (PROM) VI/5. Ramelli probably built his machines with only one sliding vane and it was not until the beginning of the present century that Wittig evolved the multi-vane version which has become widely known in the form of a compressor or blower. The housings of these blowers were equipped with special bearing surfaces capable of dealing with the centrifugal forces due to the vanes. The relative sliding velocity between the vanes and these bearing surfaces is comparatively low but for the faster moving designs minimum running clearances between the vanes and the housing are relied upon rather than high pressure oil-film sealing. The rotating members revolve at full speed and are expected to seal effectively the leakage paths at the ends and between the slot and the vane. Complex sealing elements were, therefore, incorporated in some designs for this express purpose. Although this kind of vane type compressor has been carefully developed by reputable companies, it is meeting increasing competition from single-rotation and Roots type blowers even in the low and medium pressure field. Indeed, in the aircraft field Roots superchargers had virtually replaced the vane type blower before the beginning of the 'twenties'; a process which was repeated in the automotive field. Meanwhile, yet another single-rotation machine, namely the Lysholm-compressor, has become widely used for stationary compressor applications.

Further single and planetary-rotation machines will undoubtedly be designed although the inertia effects due to the near circular path which the c.g. of each vane pursues at variable velocity impose speed limitations. Care, of course, is taken so that the individual vanes of rotating-piston machines are as thin and light as possible. However, the vanes slide considerable distances out of the central drum besides being exposed to working pressure. They must not, therefore, be so thin as to bend under working conditions and so hamper their free sliding motion.

Chart 10 (PROM) VI/5 (table 22) shows a number of designs based on the original Ramelli idea. All suffer from fundamental, and inevitable, disadvantages. These handicaps have been responsible for the failures of various attempts to convert this type of rotating piston machine into an internal combustion engine. Only transitory successes have become known. The first partially successful example recalls the steam engine designed in 1899 by O. W. Hult in Stockholm and manufactured in Germany by the Kieler Maschinenbau A.G., who produced various sizes of engines which developed 35—113 B.H.P. The aggregate power of the engines built amounted to about 6000 B.H.P.

The other Ramelli machine shown in VI/11 (chart 9), in which a sealing element is moved in and out of its slot by the eccentric or cam shaped rotating piston, has been made frequently in the form of pumps besides having been applied to engines. Yule's steam engine of 1836 provides an example. It incorporated only a single reciprocating and sliding sealing element. Two similar sealing components featured on the steam engines designed by Bährens (Germany) in 1847, D. Napier (England) in 1851 and Bompard (Italy, Piemont) in 1867 are thereby divided by two equal working chambers. It was, of course, unavoidable that as soon as the gas engine was invented attempts would follow to apply Ramelli's configuration to internal combustion engines. I. H. A. M. Brunklaus was one aspirant. Indeed, he is referred to as a pioneer in an historical account of German internal combustion engine development published in 1962. The impression is given by this publication that he was the first to make and run a single-rotation gas engine as outlined in his Dutch patent No. 26,198 dated 1929. It is understandable that no references were made to the speed, power output, endurance and fuel consumption of this engine but it is incomprehensible that historical facts which are, after all, so easily verifiable from patent specifications, books and periodicals, have been distorted in this way. Long before Brunklaus or his engine, which incorporated poppet valves, there were quite a number of equally unsuccessful inventors some of whom tried to convert planetary or single rotation machines into internal combustion engines; Fred Umpleby (England) in 1909 produced just such an engine which now reposes at the Keighley museum in Yorkshire.

7.6 Arctuate type of engagement

Some widely known vane type machines are shown diagrammatically in chart 9 (SROM) IX/1—4, 6 and 7. Although this arrangement permits complete balancing of the vane rotor, either the vane-rotor itself or the sealing component must possess variable velocity in accordance with the particular design configuration; only by providing excessive clearances between the vanes and the circular sealing components is it possible to make the machines of chart 9 (SROM) IX/1—4 into true arctuate-engagement machines of table 7 II/1—4 in which all parts rotate at uniform velocity.

Chart 9 (SROM) IX/3 (table 23) shows a variation of these vane type machines which incorporates pins, cylindrical portions and so-called slippers as additional sealing elements which give the vane a certain amount of oscillatory freedom.

This type of configuration has also been tried as a steam or internal combustion engine. Indeed a 100 B.H.P. steam version designed by A. Patschke was in production for a while at the beginning of the present century at the Wilhelmi Company of Mülheim-Ruhr. It did not appear to have the prerequisites of lasting success, however. Its internal details proved rather complex and consequently expensive to produce.

7.7 Central-axis machines

Central-axis rotating-piston machines SROM IX/17—20 (chart 9) belong to a category of SROM machines which exhibit arctuate-like engagement. This type of machine does not incorporate two axes of rotation, one beside the other, because both shafts are concentric and therefore turn about the same centre line.

Variable volume working chambers can only be formed if at least one of the rotating members moves at variable velocity. For this reason it is impossible to convert central-axis rotating-piston machines into single or planetary rotation mechanisms. Central-axis rotating-piston machines with circular-rotation characteristics cannot exist because every crank or other device facilitating this kind of circular movement presupposes two parallel axes while there is only one axis of rotation in a central-axis configuration. Nevertheless, it seems that the importance of deficiencies arising when components move at variable velocity were seriously underestimated by many inventors, scientists, engineers and manufacturers. It can only be assumed that the compactness of these machines relative to their swept volume together with the absence of any kind of valve proved the overriding attraction. Central-axis machines with straight through vanes can displace per revolution a volume which is much greater than the volume of the annular ring chamber of the particular engine. This is due to the fact that the vanes are, of course, double acting and move at variable velocities relative to each other. These features were particularly prominent on the Baradat-Esteve design of 1919 and on the Le Granjaques (1919) and Kraus (1963) configurations which relied upon oval gears to ensure their enormous volumetric throughput; as four-cycle engines they featured four complete thermodynamic cycles per shaft revolution, during which time the vanes are subjected to only two acceleration and two deceleration periods. Furthermore these advantages are also enjoyed by engines devoid of any parts moving at variable angular velocity. The sealing problems of central-axis rotating-piston machines may appear easy to solve to some, who also believe that the broad sealing bands, evident in their designs, are adequate. Despite innumerable failures it seems impossible to shake the widely held belief that good fits and close running clearances constitute a satisfactory means of sealing heat engines and rotary-piston internal combustion engines in particular. In reality differential thermal expansion demands unduly large running clearances which make this type of sealing impracticable. Furthermore, the relative disposition of the rotor and their shapes make it practically impossible to devise mechanical sealing elements which form a complete sealing grid capable of blocking every possible leakage path. Even if the significance of these problems — frequently assumed to be negligible, but actually insoluble — is overlooked, it is surprising that this 'stop-go-stop' rotation (Kauertz in 1960, for example) has found so many protagonists willing to spend considerable effort on its realisation, even among large companies. As soon as the segmental pistons of SROM machines rotate at variable velocity about their respective centres of gravity the particular machine is afflicted with all the disadvantages due to variable inertia forces, as is the reciprocating piston machine. It is, of course, quite immaterial whether stresses or bearing loads are due to linear or angular acceleration and consequential inertia variations. Hence all cross-sections must be so proportioned as to reduce the stresses to acceptable levels and the bearing areas must also be large enough to produce acceptably low bearing pressures and the transmission components must also be able to cope with these additional inertia forces. It is no mere coincidence that inventors incorporate parts which perform essentially the same functions as connecting rods in order to deal with variable inertia effects. The slide connecting rod-crank arrangement has, so far, proved far more capable of dealing with these alternating accelerations and the slowing down of masses, which cause inertia forces, than sliding blocks, rollers, curved guides, cams, oval or elliptical gears.

7.8 Arctuate engagement of oscillating-pistons or sealing components

With regard to the machines of chart 10 (PROM) X) reference is made to chart 10 (PROM) X/11 (table 24) and the machines shown in lines 1/2, 3 and 4 which were developed by Tänzler in 1937. He succeeded in developing the swinging vane type piston into a synchronising coupling link which ensures that the inner and outer ring-rotors move at uniform speed. It is, unfortunately, quite impossible to give uniform velocity to these swinging links as well. Tänzler endeavoured for several years to draw the attention of engineers to the many different types of rotary piston machines by writing papers and lecturing about them.

7.9 Engagements similar to cam engagements and oscillating piston or sealing components

A single-rotation conversion of Geiger's planetary-rotation four-stroke cycle engine of 1960 – see table 26 – is shown in XI/1 (chart 9). While too many inventors, who intend to convert rotating piston machines into engines, follow the well-trodden path of already well-known configurations, or even re-invent them, Geiger suggested an entirely new design principle which was capable of accomodating the four-stroke cycle. Because of the need to provide six apex seals on the three-flank rotor his sealing arrangement is far more complex than those of SIM or PLM $\overline{\text{(SIi)}}$ machines having a speed ratio of 2:3 and depicted in SIM IV/2 and PLM IV/5 (charts 7, 8), despite the similarity of the two machines with their arena shaped bores and their ability to accomodate the four-stroke cycle.

Simpson and Shipton's marine type steam engine of 1848 is shown diagrammatically in chart 9 XI/9 which, according to contemporary report, is said to have worked quite satisfactorily. However, the complexities of the design were such that even today it would be most difficult to devise a satisfactory sealing system. It is not surprising that no more has been heard of this engine.

A rotary-piston machine similar to a James Watt design of 1782, among others, is shown in chart 10 (SROM) XI/11. Watt had been preoccupied with rotary piston machines since 1766. Contemporary reports reveal that in 1768 he endeavoured to seal the internal vane or flap with glazing putty and similar materials but the results were not very satisfactory as the sealing substances formed themselves into little balls which prevented the necessary contact between the flap and the bore or rotor drum. In particular, success eluded James Watt partly on account of the type of mechanism he chose and partly due to the shortcomings of the machine tools of his time. Besides mentioning improvements to reciprocating piston machines in a patent specification of 1874 James Watt referred to 'Steam Wheels', meaning rotary piston machines.

Another Ramelli invention of 1588 is shown in table 26 line I No. 1, the principles of which have reappeared in various designs in the course of time. The figure shown in line I No. 3 on the same model sheet represents a product of the Turboflex Com-