remaining configurations of the same line still feature the parallel sided guide slots but the respective engaging components are not long slab-sided sliding parts. Instead the cylindrical components, which replaced them, perform a rolling motion and have merely a line contact with the sides of the slots; the pure reciprocating engagement has been replaced by an engagement form which is only incidentally similar to it. No kind of sliding engagement is any longer evident because no sealing component is guided linearly or slides along the stationary enveloping casing (bore).
It appears tempting to add a new line headed 'For engagement similar to reciprocating and cam engagement' to charts 7–10 but this is not justifiable for the following reasons:
The above described change over from a PROM-VI design to a needle-roller sealing element and finally to a rolling piston is gradual (as far as the classification is concerned) as indicated in line 2 or table 27. And despite a rolling piston, full reciprocating engagement may still be present.
In particular the parallel sided slots and the bore shapes of the machines shown in line 2 remain the same even when a complete change over to a rolling piston arrangement has been effected. Hence, its derivation from the machines which possess the engagement principles of group VI remains quite apparent.
It may prove far more difficult to place the machines of column 4 in line 2 of table 27, although only the parallel sided guide slots of the power transmitting parts have, in fact, been displaced. In this design the guidance function is no longer performed by the sealing component, as on the other machines of the same line, but has been assigned to a special disc which rotates with the output shaft to which it is attached. The designation of this machine could, therefore, be written VI ± III ± V because the rolling pistons are in counter engagement with the stationary walls of the working chamber housing. However, the designation VI ± II seems adequate for the purposes of correct classification and ease of reference.
It is obvious from the above that the division of rolling-piston machines into more than 12 categories is quite feasible, but this extension should only be resorted to when enforced by, for example, a new and large group of designs.

9. Conclusions

It can be concluded from the above that various mixed mechanisms may be evolved from the 12 different engagement methods elaborated in the classification. Relatively few and only exceptional configurations have, in fact, been analysed, mostly by way of examples which facilitate any particular classification with reference to types and models already described. It is, of course, quite impossible to include in this classification the unlimited differences resulting from detail design, however wide and comprehensive the fundamental classification may be. To some extent these

detail variations may be conveniently shown upon the respective model sheets, on which many more designs may appear in due course.
The number of different design configurations of rotary piston machines is inordinately large, especially since the double group of 'inclined-axis' and 'intersecting-axis' machines ought to be added to the already substantial number of parallel axis machines. Closer study will indicate to the designer that many proposals need not be considered where they have already been superseded by simpler and proved principles and models. When embarking upon the design and development of a rotary piston machine, it is of paramount importance to consider the following:

1. All moving parts should move at uniform velocity — including timing components.
2. A closed circuit sealing system, eliminating as far as possible every leakage path between rotor and housing as well as the shape and size of the unswept volume contained between the rotor and the housing.
3. The design should be capable of accommodating a favourable cycle, besides ensuring adequate valve opening periods and port crossectional areas as required for the higher speed ranges.
4. The ratio of overall bulk/displacement volume (working chamber capacity) and the power to weight ratio (lb/B. H. P.), have to be favourable.
5. The components should be strong enough to accommodate the highest pressures and speeds to which they may be subjected.
6. Feasibility of adequate cooling and lubrication.

It will be found that many rotary piston machines will prove unsatisfactory in one or more of these points and must, therefore, be excluded from the evaluation even if they contain other very attractive features.
This classification of rotary piston machines should not appear without remembering the great dynamist Franz Reuleaux, 1829—1905, who attempted nearly 90 years ago in 1875 to bring order into the chaos of the rotary piston machine field which he described in great detail in his books and writings. His proposed classification was, however, a little too artificial for the purpose of imparting to the designer the characteristics of a multitude of differing machines. Later publications were neither as methodical nor as comprehensive as Reuleaux's effort and confusion prevailed. Reuleaux had apparently read all he could about the unsuccessful rotary piston heat engines which had been proposed during the preceding 150 years not only by inventors but also by otherwise successful technicians and manufacturers.
The invention of the steam-turbine and the electric generator and later the appearance of the motor car gave a new impetus to the desire to replace at least partly the reciprocating piston arrangement, but all efforts proved unsuccessful.
Exaggerated and technically inaccurate announcements sometimes preceded the actual showing of these machines, although they proved hardly capable of performing as well as the more conventional machines they were meant to supersede. An atmosphere of suspicion was thereby created so that any project to do away with reciprocating motions and components had to be pursued in secrecy if it was

not to invite ridicule. The situation was somewhat similar to that which preceded the successful invention of the aeroplane.

Reuleaux behaved in exactly the same way as many engineers did between 1850 and 1950. Lack of success and certain side effects defeated him. Nevertheless, he returned time and again to rotary-piston machines. He had encouraged Otto and Langen in their efforts to develop their atmospheric engines and assisted them right up to the discovery of the four-stroke-cycle. His technical vision is reflected in his books although they also reflected the low standard of knowledge of rotary piston design principles which prevailed. He added, for instance, a footnote pointing out that his book about the theory of dynamics was not intended to be a history of rotary steam engines and pumps. However, his book included so many examples and illustrations that it remained for decades the best known scientific review and collection of this type of machine.

Reuleaux attempted with his book an 'Analytical Geometry' to prove to himself and others the impracticability of rotary steam engines. He thereby became so involved in the terms 'Hemmwerk' and 'Laufwerk' (Braking and Power Transmitting Devices), which he himself had formulated, that he stated that rotating or planetary-rotating machines which incorporated cranks were no more rotary designs than the reciprocating piston engine itself!

In his 'Theory of Dynamics' he devoted considerable attention to the Pappenheim single-rotation machine which possesses uniform velocity; he even advocated its use in the form of gear-pumps for liquids and gases and pointed out that they could be used as engines if actuated by pressurised water or steam, as well as for other applications. He criticised the unsatisfactory sealing arrangements of the very similar steam engine design proposed by Murdock and of the much modified steam engine by Behrens. Today we know that satisfactory linear sealing systems may be devised for these designs but in those days nothing was known about the sealing of rotary-piston internal combustion engines (with the exception of ordinary reciprocating piston engines without rotary valve).

Confusion about the sealing techniques of components which are in sliding contact with each other is perhaps as persistent as lack of knowledge and faulty opinions on the principles of rotary piston machines. This lack of scientific and technical background about sealing of components with relative sliding motion had already retarded, in some respects, the development of the reciprocating internal combustion engine, while in the rotary-piston engine field it militated against proper functioning altogether, since even quite suitable designs presented leakage problems. The development of the rotary-piston machine into a high performance internal combustion engine was facilitated by more than 30 years work on sealing systems and after many different engine configurations had been evalued, developed or invented.

Various design studies assisted in bridging the gaps between different types of rotary combustion engines during this preparatory period. Simultaneously with this, the classification became the instrument which determined more and more precisely the correct relative position of each individual design within the multitudes of rotary-piston machines. A valuable perspective was thereby obtained of these complex designs, facilitating their appraisal, their relative evaluation and exploitation. Many other configurations will probably spring from this work for later classification. Already this classification contains gear-type pumps and rotary blowers and compressors besides single and planetary-rotation four-stroke cycle engines.