THE BERLIN KINEMATIC MODELS.*

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MOST of the models, of which a small number are upon the table before you, are a portion of an educational collection, designed by Professor Reuleaux, the Director of the Royal Polytechnic Academy in Berlin, for use in the classes of that institution, the rest have been sent to the Exhibition by Messrs. Bock and Handrick, of Dresden. They have been designed chiefly to illustrate Reuleaux's Theory of Machines, a theory which differs in some very important respects from any treatment of mechanisms hitherto adopted. Looking at the models by themselves, some of them seem extremely intelligible, and some very much the reverse. I shall endeavour, in the very limited time at my disposal, to point out the leading ideas which run through the whole, and connect these very familiar mechanisms with those more complex ones which, although differing only in degree from the former, appear at first sight so entirely dissimilar.

In the old books upon machinery, such as that of Ramelli for instance (1588), each machine was taken up by itself, and treated as a whole, from beginning to end. One kind of pump after another may be described, but without any recognition of their essential identity, or the use of any single word to express the concept *pump*. Each machine is described separately as an apparatus which raises water from such a place, in such a way, and delivers it at such a place. The complex idea which we cover by the word pump, had not yet found a place in the writer's mind.

Presently it was found, of course, that machines were not all different from beginning to end, but consisted of various combinations and repetitions of similar elements; those elements in time became more distinctly recognised, and were called *mechanisms*. Each machine accordingly was not now described as a whole, but was analysed into the mechanisms of which it consisted, and these received separate treatment. Very much valuable matter has been written upon machinery from this point of view. In our own country, Professor Willis especially gave most valuable contributions to the science of machinery on this basis. Hitherto, however, we have stopped at this point. We have obtained each mechanism "somehow," but have not yet troubled ourselves as to *how* it was invented, or what its elements were. We have, that is, analysed the machine into mechanisms, but we have not yet analysed the mechanisms themselves. We are all familiar with the interesting and valuable work which has been done in the way of analysing the motions of particular pieces or members of a mechanism after it has been presented to us, but it cannot be denied that in all cases the mechanism itself has been in the first place taken as a whole.

Professor Reuleaux has attempted to perform the final analysis to which I have alluded, and to discover of what elements the mechanism consists, and how these elements have been combined. He starts from what appears to be the fundamental principle of every machinal combination or arrangement; that each particular part of the combination must have at each instant only one definite motion relatively to every other part. If, in any machine, there be a piece which at any one instant can move in two directions, there is obviously some defect in the machine. Engineers are familiar with the many devices that have to be employed in connexion with certain mechanisms to carry them across "dead-points," &c. This condition, that it shall be impossible for any point in a machine to move at any instant in any direction other than that intended, is a universal one. The way in which it is satisfied is by giving to certain portions of those pieces which form the machine suitable geometric forms. These forms are arranged in *pairs*, in such a way as to be reciprocally *envelopes* one of the other. The one piece, then, so encloses the other, on account of the form given to both, that each can move only one way relatively to the other at any instant. The motion of such pieces is called *constrained* motion. Let me take a very simple case—a screw and nut. These two pieces are formed in such a way that the nut can move only in one way at any instant relatively to the screw, and the screw in one way relatively to the nut. If the pitch of the screw be made zero, we have simply a pair of solids of revolution, or "revolutes," having such profiles at the end as to prevent any axial motion; and again we have a pair of mutually enveloping forms, whose relative motion is absolutely constrained. If, on the other hand, the pitch be made infinite, we have a pair of prisms, in which the only possible relative motion is axial. In the first case, the constrained relative motion is twisting; in the second, it is turning (twisting without any translation), and in the last case, where the pitch is infinite, it is simply sliding (twisting without any turning). You recognise, in these three pairs of bodies, the geometrical forms which are used in ninety-nine cases out of a hundred to constrain the motions of machinery. Such bodies as these Reuleaux calls *pairs of kinematic elements*, and when they have the peculiarity that one entirely encloses the other, *lower* pairs, or *closed* pairs.

It is not essential, however, that one should enclose the other. There are before you a number of examples of *higher* pairs, the bodies of which mutually constrain each other without complete *enclosure*. I may briefly point out the nature of one of these (Fig. 1.) The one element is an equilateral curve-triangle, which possesses the property that any pair of parallel tangents to it are at the same distance apart. The second element is a square, the side-length of which is equal to this distance. The two elements always touch each other in four points, the normals to these points intersect in one point, and at any instant motion can take place about this point only. The two bodies form a pair of elements in exactly the same sense as before, but with one important difference. In the lower pairs the paths of all points in the moving element are *similar*. Every point in the moving element of the twisting pair, for instance, moves in a helix of the same pitch, all points in that of the turning pair in concentric circles, &c. Here, however, the paths of all the points are different. Some of these paths are very beautiful curves, as you will see if you can follow the motion of the pointer in the model (see Fig 2). These paths are, in this case, combinations of epi- and hypotrochoidal arcs. I cannot here go more fully into their nature. I merely show them to illustrate the fact that en-

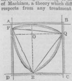

FIG. 1.

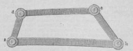

FIG. 3.

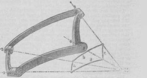

FIG. 4.

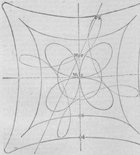

FIG. 2.

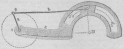

FIG. 5.

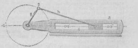

FIG. 6.

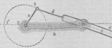

FIG. 7.

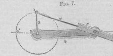

FIG. 8.

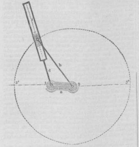

FIG. 9.

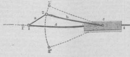

FIG. 10.

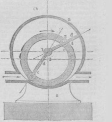

FIG. 11.

* Paper read at the Collection of Scientific Instruments at South Kensington.

closure is not an essential characteristic of pairs of elements having constrained motion.

If two elements be joined together rigidly by a body of any form whatever, we have what is called a *kinematic link*. If I take, for instance, this nut, and fasten it to this open cylinder, I have such a link. This solid cylinder, connected to the screw, gives another link, and so on. By pairing together a number of links I get a combination which Reuleaux has called very happily a *kinematic chain*. In the particular chain which I have here (Fig. 3), there are four links. Each link is a bar rigidly connecting two elements, and these elements belong in each case to a turning (closed) pair of elements. Before me on the table are a number of other chains made up of links, and containing both turning and sliding pairs of elements.

I must now direct your attention to a matter which is of the greatest simplicity, but of equally great importance. If I take any pair of elements in my hands, and move it, you see at once that although the motions of each element, *relatively to the other*, are perfectly determinate, the *absolute* motions are entirely indeterminate. They may move anywhere in space. In the kinematic chain there is just the same peculiarity. It is none the less important that it is almost absurdly obvious. The motions of every link relatively to every other, in other words the relative motions of the links, are absolutely determined; the absolute motion of the whole chain, or, what is the same thing for our purpose, the motion of the links relatively to this table, is left entirely indefinite.

The conversion of the relative motion into absolute motion (in the restricted sense in which we have used this expression) is a very simple matter. In the case of the pair of elements, all that is required is that one element should be *fixed*, that is prevented from moving relatively to any portion of space which is, for our purposes, stationary—it may be to a room (as here), or to a railway carriage, or a ship, &c. The same method applied to the kinematic chain enables us to convert the relative motions of the links into absolute motions. We must, that is to say, fix or make stationary one *link* of the chain.

A combination of kinematic links, therefore, whose absolute motions are unconstrained, is a kinematic chain. The same combination, when one of its links is fixed, forms what is universally known as a *mechanism*. By fixing, for instance, the link *a h* (Fig. 3), we obtain a mechanism similar to the beam and crank of an ordinary beam engine. But the chain has four links, and it is obvious that I may fix any one of them. The combination, that is, the kinematic chain, remains the same, but the nature of the mechanism may be entirely altered. Suppose, for instance, the link *c b* be fixed, we obtain a mechanism which you see at once differs entirely from the last, and which you will recognise as the common drag link coupling.

A mechanism is, therefore, a kinematic chain of which one link is fixed. Two links cannot be fixed simultaneously without making the whole chain immovable. Any one link, however, can be fixed, and thus from any chain we can obtain as many mechanisms as it has links. I shall endeavour to show you, by a few illustrations, what a wonderful insight this gives us into the nature of some familiar mechanisms. I will only mention in passing what may, perhaps, be new to some, that this chain (Fig. 3), with which we are so very familiar, is not movable because the axis of all these pairs is parallel, but because they all intersect in one point. In this particular case that point is at an infinite distance, but the chain moves equally well if the point of intersection be at a finite distance, as is shown in Fig. 4. Upon this mechanism many engines (disc engines, &c.) and other machines have been based. Hooke's universal joint is a familiar illustration of it.

In order to obtain the constrained motion of a closed pair, it is not necessary that both elements should be constructed as fully as in the cases we have hitherto looked at. Grooves might be cut down the sides of a pin, for instance, without affecting its motion in an eye. Professor Reuleaux has made some investigations, which I can only mention here, on the extent to which this process can be carried. Without further proof, I have no doubt you will recognise at once that by the use of the slot and sector of Fig. 5 instead of the pin and eye *g h* (Fig. 3), no change has been made in the chain. The complete cylinder pair has been replaced by a sector and a slot concentric with it, but of totally different diameter; the motions remain absolutely identical. We obtain thus a very convenient method of altering the length of the links of the chain, for the link *f g* has now taken the form of the sector *c* (Fig. 5). To make that link longer, therefore, all we have to do is to give the sector a larger radius. If we make the link infinitely long, the sector becomes a prism, working in a straight slot of which the axis passes through the centre of the pin 1 (Fig. 5), and we obtain this very familiar chain (Fig. 6), the driving mechanism of the common steam engine. It is derived from the former merely by increasing the lengths of two of its links, making them infinitely long. Now, I particularly wish to draw your attention to this chain, because it is very familiar, and because by its inversion, that is by fixing one or another of its links, we get such very notable results. I have already fixed one link (Fig. 6), and you have seen the common steam engine driving train. If I fix another link, say the connecting rod, we have a mechanism which I think you will at once recognise as the driving train of the common oscillating engine (Fig. 7). This appears even more distinctly if we reverse the sliding-pair 4, making the link *d* carry the full prism, and the link *c* the open prism (Fig. 8). The link *c* becomes the steam cylinder, *d* (which was the frame in Fig. 6) the piston and rod, and *b* (the connecting rod in Fig. 6.) the framing of the engine.

This intimate connexion between the driving mechanism of the direct-acting and oscillating engines was never, I think, recognised until Reuleaux pointed it out. They are the *same chain*, the only kinematic difference between them being in the link which is fixed. But we can go further; we can fix, for instance, the crank. We get thus a mechanism doubtless familiar to most of my hearers (Fig. 9), and which has often been described and applied. Sir Joseph Whitworth, for instance, has used it as a quick return motion. If the link *b* revolve with a uniform velocity it gives to *d* the varying velocity which has been so often utilised. The mechanism is obtained from the same chain as before, simply by choice of a different link for the stationary one. In general it is constructively disguised in such a way as not to be only recognisable with difficulty, but when put in this schematic form it can easily be analysed into its kinematic elements.

From the same chain, we may obtain one more mechanism by fixing the block (Fig. 10). This mechanism has been seldom used, but it is occasionally employed. The motion of the link *a* is now characteristic.

We must now proceed to look at a few other leading ideas illustrated by these models. First, we may notice that as long as the *form* of the elements of the pairs remains unchanged, their relative size is a matter of indifference. We have already seen this incidentally in comparing Figs. 3 and 5. By utilising this principle we can obtain a great number of very different-looking forms of one and the same mechanism. Models of many of these are on the table before me; some of them are constantly used by engineers, others have been seldom or never applied. The ordinary eccentric is a familiar illustration of this "expansion of elements." It differs from the train shown in Fig 6 only in the relative size of two of its elements. The turning-pair at 2 (Fig. 6) is made so large as to extend beyond the pair 1; all the motions in the train remain, however, as before.

I cannot here discuss the less familiar-looking mechanisms before you; I can only direct your attention to them. Some of the most extraordinary looking of them have met with frequent application in forms very much disguised constructively. I will only repeat, that although the relative sizes of the elements are altered, their relative motions remain unchanged.

In order to illustrate the way in which the system of kinematic analysis, which I have sketched to you, can be applied to actual machines, Professor Reuleaux has examined analytically an immense number of those unfortunate devices called rotary engines, on which so much ingenuity and excellent brainwork has been wasted. In his "Theoretische Kinematik," he gives illustrations of between sixty and seventy of these machines, analysing every one of them into one or other of the three chains which we have been examining (Figs. 3, 4, and 6). The inventor has generally called his machine "rotary" because of some notion that there were more rotating parts, or more direct rotation, than in the ordinary engine. While there are a few engines in which that is the case, in the vast majority it is entirely a mistake. Here is one (see Fig. 11) which has been invented over and over again. I believe it was invented for the first time in 1805, by a Mr. Trotter; it was re-invented in 1831, 1843, 1863, 1866, 1870, 1872, 1873, and possibly at many other times. One gentleman, whom I see here, told me that he had invented it himself twenty years ago! After all, it is absolutely identical with the chain of Fig. 6. The link fixed is the crank, so that, as a mechanism, it is represented by Fig. 9. I am sorry my time will not allow me to prove this, but by analysing the pairs of elements which it contains it shows itself at once. Many other rotary engines of which there are models on the table are of the same kind. Here is one which was exhibited at the Exhibition of 1851, and which attracted a good deal of notice at the time—Simpson and Shipton's rotary engine. It is really nothing more than the mechanism shown in Fig. 10, although its constructive form so disguises its real character. I might go through a great many more in the same way, but time compels me to leave this part of my subject.

In Reuleaux's work, to which I have alluded, and of which I have just completed the English translation, he uses a method which, while it is by no means original with him, has never been formerly developed to the same extent and in the same way. I must try in a few words to indicate the general nature of this method. If we have any plane figure moving in a plane, its motion, at any instant, may always be considered as a motion about one particular point (it may be at a finite or an infinite distance), and this point is called the *instantaneous centre* for the motion of the figure. The body may continue to move about the same point, in which case the instantaneous centre becomes a *permanent* centre; but in general the motion of the body in successive instants is about *different* points, each being, for the time, the instantaneous centre. The locus of the points which thus become instantaneous centres for the motion of any figure is some curve, and is called by Reuleaux *Polbahn*, for which I propose the use of the word *centroid*. If we have any two figures A and B, the relative motion of which is constrained, and make the relative motion of B to A absolute by fixing A, we can, by moving B, find as many points in the centroid as we wish, so as to construct the curve. This centroid remains, of course, stationary, like the figure A, and is called the centroid of A. By fixing B and moving A relatively to it, we can in the same way obtain the centroid of B. We have then two curves, one connected with each figure, and these possess certain properties which are of great value in the study of mechanism. As the figures move these curves *roll* upon one another, and their point of contact is always the instantaneous centre of motion for the time being. It is, of course, impossible for me to *prove* these or any other properties of these curves here; many gentlemen here must be quite familiar with the proofs. I must content myself with simply showing you these models of mechanisms in which the centroids are constructed in such a way that their rolling can be distinctly seen. By the aid of these centroids we can treat a great number of problems in an extremely simple and beautiful manner, and can treat complicated and simple problems by one general method, instead of using different methods. Centroids have not, so far as I know, been used in English text-books hitherto, but have not unfrequently found more or less extended use in German and French works, principally in static and kinematic problems. Among the more recent books in which I have noticed them, I may mention Dwelshauvers-Dery's "Cinematique," Schell's "Theorie der Bewegung und der Kraft," and Pröll's "Graphische Dynamik."

Considering the constrained motion of *bodies* instead of plane figures only, the instantaneous centre becomes an axis, and the centroidal curve a ruled surface, the locus of all the axes. These surfaces are called *axoids*. For bodies moving parallel to themselves, they are cylinders; for bodies having motion about a fixed point, cones; and for general motion in space, general ruled surfaces, in general non-developable, of which successive generators *twist* upon each other.

I shall only mention one more point in connexion with the subject before us. Professor Reuleaux has devised, for the purpose of aiding his kinematic work, a system of notation founded upon his analysis, which can be used to represent these mechanisms in a perfectly simple manner. Of course, to write down a description of them is a long matter, but hitherto we have not known their real nature analytically, and therefore we could do nothing else. Now that we do know it, we may treat them exactly as we do chemical compounds where, instead of writing down the whole names of everything, we use short symbols for known elements. This kinematic notation I can do no more than mention. It seems to me very original, and I have myself found it very useful in the analysis of really complicated machinery. Mechanisms of great apparent complexity come out, often, in forms of really wonderful simplicity, and one's work is made at the same time much more easy and much more satisfactory.

These models are very beautiful, but they are also necessarily somewhat expensive. I have here a couple of wooden ones, however, which will serve to show that they can be constructed and used in schools without any very extraordinary cost. These two models, and also the stand for carrying them, have been made for me by M. Paul Nolet, of University College.

I must now thank you for the kind attention with which you have listened to my sketch of the nature of this beautiful collection of models, and I should like also to take this opportunity of thanking Herr Kirchner (of Berlin) for the kind way in which he has prepared and arranged them for me.

THE DESILVERISATION OF LEAD.

*On Lead Desilverising, by the Zinc Process, as carried on by Messrs. William Lang and Co., Clyde Lead Works, Glasgow.**

By Mr. J. E. Stoddart.

The treatment of argentiferous leads with zinc, for the purpose of extracting the silver, and refining the lead, is by no means a novel process. About twenty years ago, a metallurgist named Parkes took out patents for desilverising rich leads by means of zinc, and a manufacturing firm adopted his process. They were, however, subsequently obliged to abandon it, in consequence of the difficulty experienced in the separation of the zinc from the concentrated silver, to admit of the cupellation of the latter metal. A German chemist, named Flach, afterwards took up the subject, and by running the alloy of zinc, silver, and lead along with iron slag, through a peculiarly constructed blast furnace, he was enabled to free the concentrated silver-lead from zinc. He also proposed the use of this furnace for the removing of traces of zinc from the desilverised lead, but this was abandoned in favour of the ordinary "improving" or calcining pan. The operation with the blast furnace was found to be very troublesome, and as the greater portion of the zinc was entirely lost it was by no means economical. M. Manes, of Messrs. Guillem and Co., Marseilles, who were the first to work Flach's process, found out and patented a simple means of treating the alloy, and recovering the zinc by distillation. This is the process now in use and known as the Flach-Guillem process, and which is carried on at the Clyde Lead Works in the following manner:

About 18 tons of "rich lead," containing generally from 60 to 70 ounces of silver per ton, are melted in a large cast-iron pot. One per cent. by weight of zinc is added, and the whole well stirred for twenty minutes. The fires are drawn, and the contents allowed to settle and cool until the zinc rises to the surface, and forms a solid ring or crust containing the silver and other foreign metals. This alloy is removed to a small pot at hand, where part of the lead is "sweated" out, and the alloy thoroughly dried.

The large pot, with the lead now partially desilverised, is again heated up and treated in the same way as before, but with the addition of only one-half per cent. of zinc, which when it has risen to the top is removed as before and dried.

A third addition of one-fourth per cent. of zinc is found necessary to take out the remainder of the silver, care being observed, on the cooling of this zincing, that all the crystals are cleanly skimmed off.

The lead in the large pot is assayed and found almost always to contain less than 5 dwts. of silver to the ton of lead; if it should happen to contain more, it is due to carelessness on the part of the workmen.

The pot is now tapped and the lead run down into an "improving" pan, where it is kept at a high heat for nearly eight hours, for the purpose of oxidising or burning off the small percentage of zinc which is left in it from the zincing process. After seven or eight hours' firing in this pan, it should contain no trace of zinc. It is then tapped and run into moulds for market lead, or for the manufacture of lead products.

The old "improving" pans were made of cast iron placed

* Paper read before the Chemical Section of the British Association, Glasgow Meeting.