

CHAPTER X.

ON MECHANICAL NOTATION.

376. IN complex machines of which the parts move according to different laws, and with continually varying relations of velocity and direction, it becomes exceedingly difficult to retain in the mind all the cotemporaneous movements; and a notation is in such cases of almost indispensable service. I have already shewn how in this manner the trains of machines that move with a constant velocity ratio and directional relation may be conveniently represented; and shall now proceed to explain how the more complicated connexions and motions of the last two Chapters may be reduced to notation. The only writer who has endeavoured to form a system for this purpose is Mr. Babbage. His method is not a mere hypothetical device framed to meet an imaginary difficulty; but actually arose from the necessity of the case, during the construction and arrangement of one of the most involved and complicated engines that was ever devised; and having been thus applied to practice, has been found to answer its purpose perfectly. Some parts of this notation belong to mechanical combinations of which we have not yet spoken; I shall therefore, in this place, give an account of the system only so far as it applies to the contrivances hitherto explained*.

377. Every one who has been engaged in the construction and invention of complex machinery, or who attempts

* Vide "A method of expressing by signs the action of machinery," by C. Babbage, Esq., Phil. Tr. 1826, from which paper the following account of the method is derived.

to examine the various motions of an existing machine which is presented to him for the first time, must have experienced great inconvenience from the difficulty of ascertaining from drawings the state of motion or rest of any individual part at any given instant of time; and if it becomes necessary to enquire into the state of several parts at the same moment, the labour is much increased.

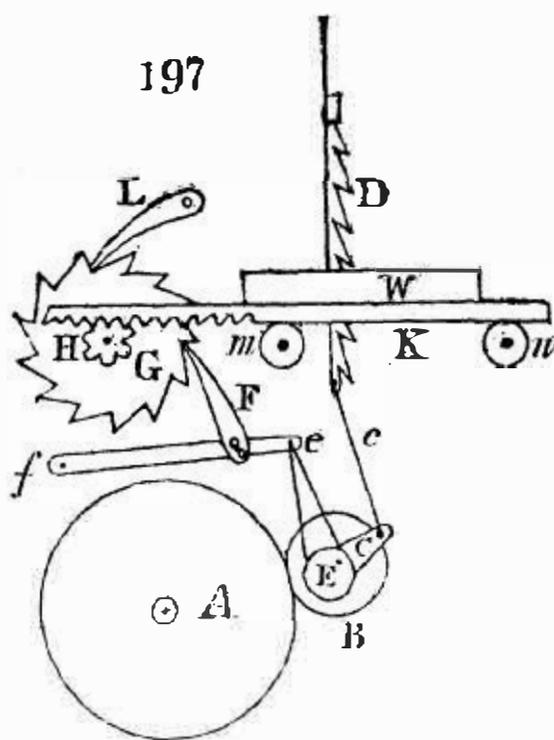
In the description of machinery by means of drawings, it is generally only possible to represent an engine in one particular state of its action. If indeed it is very simple in its operation, a succession of drawings may be made of it in each state of its progress, which will represent its whole course; but this rarely happens, and is attended with the inconvenience and expense of numerous drawings.

The difficulty of retaining in the mind all the contemporaneous and successive movements of a complicated machine, and the still greater difficulty of properly timing movements which had already been provided for, led at length to the investigation of a method by which at a glance the eye might select any particular part, and find at any given time its state of motion or rest, its relation to the motion of any other part of the machine, and, if necessary, trace back the sources of its movement through all its successive stages, to the original moving power. The forms of ordinary language being far too diffuse to be employed in this case, and experience having shewn the vast power which analysis derives from the great condensation of meaning in its notation, the language of signs was resorted to for the present purpose.

378. To make the system more easily intelligible, it will be better to apply it as we go on to some machine. The example taken for this purpose in the original paper is a complete eight-day clock with going and striking parts;

but this machine is so complex as to require a large folio plate for its notation, as well as other plates to explain its construction. I shall therefore take a simpler machine, a common saw-mill. Although this machine is so easily understood as not to require the assistance of a notation, it will answer the purpose of exemplifying the method as well, and perhaps better, than a more complicated arrangement.

Fig. 197 is a diagram to explain the connexion of parts



in the saw-mill, but is not drawn with any attention to the exact proportion or arrangement, which may be found in any encyclopædia or elementary book of machinery. *A* is a toothed wheel which may be supposed to be driven either by a water-wheel, or steam-engine, and its teeth are engaged with those of a second and smaller wheel *B*, on whose axis is fixed a crank *C* and an excentric *E*. The crank is connected by a link *c* with the saw-frame *D*; this is fitted between vertical guides, and therefore when the crank revolves receives a vertical oscillating motion.

The timber *W* which is submitted to the action of the saw is clamped to a carriage which moves upon rollers *m*, *n*, in a horizontal direction. While the saw is in motion as above described, the carriage and timber are made to

advance in the following manner. The excentric E communicates an oscillating motion to a lever ef , whose center of motion is f ; this lever carries a click F , which acts upon the teeth of a ratchet-wheel G , to which an intermittent rotation is thus given. Upon the axis of G is a pinion H , which gearing with a rack fixed to the wood-carriage, causes the latter to advance towards the saw with the same intermittent motion. This intermission is adjusted to the motion of the saw-frame, so that when the saw rises the wood shall advance, and when the saw descends, and therefore cuts, the wood shall remain at rest. The cut is made by the inclined position of the saw, the toothed edge of which is not vertical but slightly inclined forwards, so as to bring the teeth into successive action during the descent of the frame. The detent L serves to hold the ratchet-wheel, and therefore the wood-carriage, firm in its position during the cut. Now all these conditions of motion are very easily represented by the notation which we shall proceed to explain, and which is exhibited in the next page.

| | | SAW-MILL. | | | | | | | | | |
|------------------------------|--|---------------|------------|------------|------------|-------------------------|------------------|----------------|---------|-------------------------|-----------------|
| | | Train to Saw. | | | | Train to Wood-carriage. | | | | | |
| Names. | | Cog-wheel. | Cog-wheel. | Crank. | Saw-frame. | Eccentric. | Lever and Click. | Ratchet-wheel. | Pinion. | Rack and Wood-carriage. | Detent. |
| Signs. | | A | B | C | D | E | F | G | H | I | K |
| Number of Teeth. | | 96 | 22 | ..... | ..... | ..... | ..... | 60 | 20 | ..... | ..... |
| Linear Velocity per minute. |  | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 6 ⁱⁿ | ..... |
| Angular Velocity per minute. | | 11 | 50 | 50 | ..... | 50 | ..... | ..... | ..... | ..... | ..... |
| Comparative Velocity. |  | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Origin of Motion. | | → | + → | + → | → | → | → | + → | → | → | → |
| Comparison of Motion. |  | \| | \| | \| | \| | \| | \| | \| | \| | \| | \| |
| | | | | up down | | | | | | | holds yields |

379. The first thing to be done in reducing any machine to the notation, is to make an accurate enumeration of all the moving parts, and to appropriate, if possible, a name to each; for the multitude of different contrivances in various machinery precludes all idea of substituting signs for these parts. They must therefore be written down in succession, only observing to preserve such an order that those which jointly concur for accomplishing the effect of any separate part of the machine may be found situated near to each other, or in other words, that the succession of parts in each train may be observed as much as possible. Thus in the Saw-mill, against the word "Names" in the first column will be found written in order, first the parts constituting the train from the primary axis to the saw, next those which form the train to the wood-carriage.

Each of these names is attached to a faint line which runs longitudinally down the page, and which may for the sake of reference be called its *indicating line*.

To connect the notation with the drawings of the machine, the letters which in the several drawings refer to the same parts, are placed upon the indicating lines immediately under the names of the things. If there be more drawings than one of the machine, the same letters should always refer to the same parts.

A line immediately succeeding that which contains the references to the drawings, is devoted to the number of teeth on each wheel or sector, or the number of pins or studs on each revolving barrel.

Three lines immediately succeeding this are appropriated to the indication of the velocities of the several parts of the machine. The first must have on the indicating line of all those parts which have a *rectilinear* motion, numbers

expressing the velocity with which those parts move, and if this velocity is variable, two numbers may be written, one expressing the greatest, the other the least velocity of the part. The second line must have numbers expressing the angular velocity of all those parts which revolve; the time of revolution of some one of them may be taken as the unit of the measure of angular velocity; or the same may be expressed in the usual method of the number of turns per minute.

If a wheel communicate an intermitting motion to another, the ratios of their angular velocities and comparative velocities will differ; for example, if the two wheels have the same angular velocity when they both move, but one of them remain at rest during half a revolution of the other. In this case their angular velocities are equal, but their comparative velocities as 1 to 2, for the latter wheel makes two revolutions while the other makes only one. A line is devoted to the numbers which thus arise, and is entitled, "Comparative Angular Velocity." No example, however, of this occurs in our Saw-mill.

380. The next compartment of the notation is appropriated to shewing the origin of motion of each part, that is, the course through which the moving power is transmitted, and the particular modes by which each part derives its movement from that immediately preceding it in the order of action. The sign chosen to indicate this transmission of motion (an arrow) is one very generally employed to denote the direction of motion in mechanical drawings; it will therefore readily suggest the *direction* in which the movement is transmitted. As there are various ways by which the motion is communicated, the arrow is modified so as to exhibit them as far as is necessary. Our author reduces them to the following :

One piece may receive its motion from another by being permanently attached to it, as a pin on a wheel, or a wheel and pinion on the same axis.

This may be indicated by an arrow with a bar at the end.



One piece may be driven by another in such a manner that when the driver moves the other also always moves; as happens when a wheel is driven by a pinion.

An arrow without any bar.



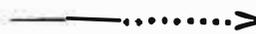
One thing may be attached to another by stiff friction.

An arrow formed of a line interrupted by dots.



One piece may be driven by another, and yet not always move when the latter moves; as is the case when a stud or pin lifts a bolt once in the course of its revolution.

By an arrow the first half of which is a full line, and the second half a dotted one.



One wheel or lever may be connected with another by a ratchet, as the great wheel of a clock is attached to the fusee.

By a dotted arrow with a ratchet tooth at its end.



Each of the vertical indicating lines must now be connected with that representing the part from which it receives its movement, by an arrow of such a kind as the preceding Table indicates. Thus in the Saw-mill Notation, the cog-wheel *A* is connected with the cog-wheel *B* by a plain arrow; the wheel *B*, upon whose axis is fixed the crank *C* and the excentric *E*, is accordingly connected with them both by barred arrows; *F* with *G* by a ratchet-arrow; and *G* with *K* by an interrupted arrow.

381. The last and most essential circumstance to be represented is the succession of the movements which take place in the working of the machine. These movements are generally periodic, for almost all machinery after a certain number of successive operations re-commences the same

course which it had just completed, and the work which it performs usually consists of a multitude of repetitions of the same course of particular motions.

One of the great objects of the notation in question, is to furnish a method by which at any instant of time in this course or *cycle* (Art. 17) of operations of any machine we may know the state of motion or rest of every particular part; to present a picture by which we may on inspection see not only the motion at that moment of time, but the whole history of its movements, as well as that of all the cotemporaneous changes from the beginning of the cycle. In order to accomplish this, the compartment termed *Comparison of Motion* contains adjacent to each of the vertical indicating lines, which represent any part of the machine, other lines drawn in the same direction; these accompanying lines denote the state of motion or rest of the part to which they refer, according to the following rules, and may be called *the motion lines*.

1. Unbroken lines indicate motion.
2. Lines on the right side indicate that the motion is from right to left.
3. Lines on the left side indicate that the direction of the motion is from left to right.
4. If the movements are such as not to admit of this distinction, then when lines are drawn adjacent to an indicating line and on opposite sides of it, they signify motions in opposite directions. (*Thus in the Saw-mill A and B revolve opposite ways, and their motion lines are accordingly drawn on opposite sides of their indicating lines*).
5. Parallel straight lines denote uniform motion.
6. Curved lines denote a variable velocity. It is convenient as far as possible to make the ordinates of the curve proportional to the different velocities (Art. 13). (*The motion of the saw-frame D, and of the lever and click F, are examples of this rule*).

given to the ratchet-wheel by the click does not begin at the instant the change of motion in the click takes place. The click must first move through a small space until it abuts against the tooth of the ratchet-wheel which is ready to receive it. On the other hand, it is evident that the ratchet-wheel and the click will both *cease* their motion in that direction together. When the click moves backwards the ratchet-wheel with the pinion and wood-carriage will remain at rest until the saw begins its cut, when they will be driven slightly backwards until the ratchet-tooth abuts against the end of the detent. All these accidents of motion in the ratchet-wheel and its connected pieces are exhibited by the notation, as will appear by comparing the motion lines of *G* with those of *F*. It is true, that in the actual machine these small motions are reduced exceedingly by giving a great number of teeth to the ratchet-wheel; but I have exaggerated them to shew the susceptibility of the notation, which when applied to complex machinery is of the very greatest service; more especially in assisting in the invention or improvement of machines.

383. The system of motion lines is not intended to exhibit accurately the law of motion of the pieces, as in the graphic representation of Art. 13, although it is founded upon the same principle; but merely its general phases.

When the simultaneous motions are required to be precisely exhibited, their motion curves may be, however, exactly laid down and compared, by placing them side by side; their parallel axes of abscissæ then become the indicating lines of Babbage's system. In this case, however, I am inclined to think the second method (Art. 14) is preferable, in which the ordinates are proportional not to the velocities but to the spaces; of the use of which I have already given an example in Art. 337.

384. I have found some advantages in the amalgamation of the system of Babbage with that of which an explanation has been given in Art. 233.

For in defining trains of mechanism in the present work, I have shewn that they consist of principal pieces moving each according to a given path, and connected one with the other in succession by means of drivers and followers, which are attached to these moving pieces. Now the drivers and followers carried by any one of these pieces must all move according to the same law, since they move as one piece; and a single indicating line with its velocity numbers and motion curves is quite sufficient for every such piece: whereas, as we have seen, in the notation just exhibited every part of the machine has such an indicating line and figure attached to it, and consequently all the parts that are united together merely repeat the same indication as *B*, *C* and *E*; or *G* and *H*, in page 336. In the next page I have shewn the Saw-mill under the form of Notation which I have been in the habit of employing, and which it will be seen at once differs only from that of page 336 by being united with the old clockmakers' form already explained; by which means the *genealogy*, so to speak, of the motion is perhaps more clearly perceived, and the number of indicating lines reduced.

385. To represent a machine in this form, rule as many parallel lines as there are principal moving pieces in the train, writing the name or nature of each in the first column. Upon each line write all the followers and the driver which are carried by the piece to which it belongs; taking care to place every follower vertically under its own driver, if possible. Every follower may be connected with its driver by an arrow formed according to the rules in Art. 380, or by a simple line. The arrow is only

SAW-MILL.

| Names of Places. | Velocity Per minute. | Origin of Motion. | Comparison of Motion. | |
|------------------|----------------------|--|-----------------------|-----------------|
| Main Shaft. | 11 | Spur-wheel A. (96)..... | | |
| Crank Shaft. | 30 |Pinion B. (22) — Crank C. (30) — Eccentric E. (4) | | |
| Saw-frame. | ..... | .....Saw-frame D..... | | up down |
| Lever on Stud. | ..... | .....Click F..... Lever F..... | | up down |
| Spindle | ..... | Ratchet-wheel G. (60) — Pinion H. (20)..... | | |
| Wood-carriage. | 6 | Rack I..... | | |
| Detent on Stud. | ..... | .....Detent K..... | | holds yields |

necessary if the nature of the machine renders it necessary to place some of the followers above their drivers. The connecting lines might also receive additions, by which the nature of the connexion, as by sliding, wrapping, link-work, &c. might be shewn; but the names of the parts are generally sufficient for this purpose; and there is a great mischief in unnecessarily multiplying symbols. Numbers attached to toothed wheels are their numbers of teeth, to pullies their diameters in inches, to cranks and eccentrics their throw in inches, unless otherwise stated. In the column of Velocity the numbers attached to revolving pieces shew their angular velocity in turns per minute, and to sliding pieces their linear velocity in inches per minute, unless otherwise stated in words. In the column of Comparison of Motion, the rules in Art. 381 are followed, but that when two or more pieces move together in a system, one indicating line is made to serve for them all by connecting those to which it applies by a bracket. Thus the variation of motion in the ratchet-wheel spindle and the wood-carriage being the same, one line is used for them both. Columns may be added for the pitch of the wheels, or any other particulars that may be required.

It rarely however happens that the whole notation is necessary. For some machines the table of the origin of motion is required, for others that of the comparison of the motion; and of the system of the latter, and of its utility when properly applied, it is impossible to speak too highly.
