CHAPTER II.

OF THE MOTIONS OF PRIMARY MOVING PIECES IN MACHINES.

SECTION I.—*General Explanations.*

37. **Frame; Moving Pieces, Primary and Secondary.** (*A. M.*, 427.) —The *frame* of a machine is a structure which supports the *moving pieces*, and regulates the path or kind of motion of most of them directly. In considering the movements of machines mathematically, the frame is considered as fixed, and the motions of the moving pieces are referred to it. The frame itself may have (as in the case of a ship or of a locomotive engine) a motion relatively to the earth, and in that case the motions of the moving pieces relatively to the earth are the resultants of their motions relatively to the frame, and of the motion of the frame relatively to the earth; but in all problems of pure mechanism, and in many problems of the dynamics of machinery, the motion of the frame relatively to the earth does not require to be considered.

The *moving pieces* may be distinguished into *primary* and *secondary;* the former being those which are directly carried by the frame, and have their motion wholly guided by their connection with the frame; and the latter, those which are carried by other moving pieces, or which have their motion not wholly guided by their connection with the frame. For example, the crank-shaft and the piston-rod of a steam engine are primary moving pieces; the wheels of a locomotive are primary moving pieces; the connecting-rod of a steam engine is a secondary moving piece

Connectors are those secondary moving pieces, such as links, belts, cords, and chains, which transmit motion from one moving piece to another, when that transmission is not effected by immediate contact.

38. **Bearings** (*A. M.*, 428,) are the surfaces of contact of primary moving pieces with the frame, and of secondary moving pieces with the pieces which carry them. Bearings guide the motions of the pieces which they support, and their figures depend on the nature of those motions. The bearings of a piece which has a motion of translation in a straight line must have plane or cylindrical *

* The word "cylindrical" is here used in the comprehensive sense, which denotes any surface generated by the motion of a straight line parallel to itself.

surfaces, *exactly straight* in the direction of motion. The bearings of rotating pieces must have surfaces accurately turned to *figures of revolution*, such as circular cylinders, spheres, cones, conoids, and flat discs. The bearing of a piece whose motion is helical, must be an exact screw. Those parts of moving pieces which touch the bearings should have surfaces accurately fitting those of the bearings. They may be distinguished into *slides*, for pieces which move in straight lines, *gudgeons*, *journals*, *bushes*, and *pivots*, for those which rotate, and *screws* for those which move helically.

The accurate formation and fitting of bearing surfaces is of primary importance to the correct and efficient working of machines.

39. **The Motions of Primary Moving Pieces** (*A M.*, 429,) **are Limited** by the fact, that in order that different portions of a pair of bearing surfaces may accurately fit each other during their relative motion, those surfaces must be either straight, circular, or helical; from which it follows, that the motions in question can be of three kinds only, viz.:—

I. *Straight translation*, or *shifting*, which is necessarily of limited extent, and which, if the motion of the machine is of indefinite duration, must be *reciprocating;* that is to say, must take place alternately in opposite directions: for example, the piston-rod of a steam engine.

II. *Simple rotation*, or *turning* about a fixed axis, which motion may be either continuous or reciprocating, being called in the latter case *swinging*, *rocking*, or *oscillation*. Continuous rotation is exemplified by the shaft of a steam engine; reciprocating rotation by various beams or levers.

III. *Helical* or *screw-like motion*, compounded of rotation about a fixed axis, and translation along that axis.

SECTION II.—*Straight Motion of Primary Pieces.*

40. **Straight Translation** is the motion of a primary piece sliding along a straight guiding surface. All the particles of the piece move through equal distances in a given time, along parallel straight lines; and the line joining any two particles remains unaltered in length and in direction.

41. **Resolution and Composition of Motions.**—The *resultant* of two or more *component* motions is the motion which results from putting them together. If the component motions are represented by straight lines, their resultant is found geometrically by joining together, end to end, a series of straight lines respectively equal and parallel to the given straight lines, and pointing in the same directions, and then drawing a straight line from the starting point to the further end of the series. For example:—

I. (See fig. 15.) *To find the resultant of two component motions,* A B *and* A C. Let the paper represent the plane of those motions. From B draw B D parallel and equal to A C, and pointing in the same direction; join A D; this will be the required resultant motion; or, in other words, complete the parallelogram, A B, D C; its diagonal, A D, will be the required resultant.

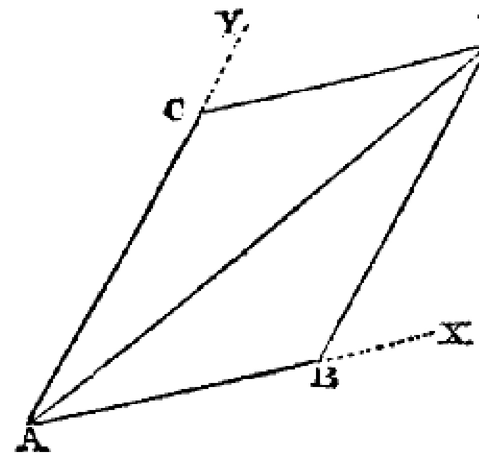

Fig. 15.

A motion may, if required, be *resolved into components.* The following are the cases most useful in mechanism:—

II. (Fig. 15.) *To resolve a given motion,* A D, *into components in two given directions in the same plane,* A X *and* A Y. Through D draw D C parallel to X A, cutting A Y in C, and D B parallel to Y A, cutting A X in B; A B and A C will be the required components.

III. (Fig. 16.) *To resolve a given motion,* A D, *into one component parallel and another component perpendicular to a given direction.* Through A, parallel to the given direction, draw A X, upon which let fall the perpendicular D B; then A B will be the first of the required components, and A C parallel and equal to B D will be the second.

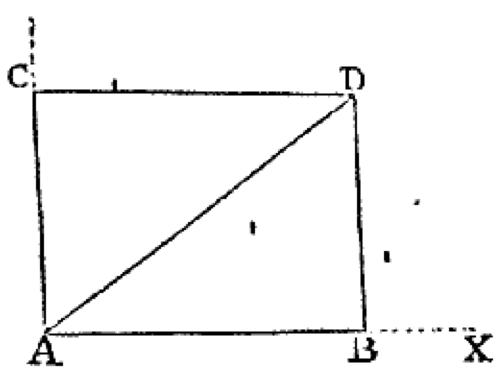

Fig. 16.

IV. *Given, the traces of a plane* (Article 15, page 6) *and the projections of a straight line representing a motion* (Article 11, page 4), *to find the projections of two component motions, one perpendicular and the other parallel to the plane.* By the rule of Article 31, page 13, draw the traces of a second plane paralle. to the given plane, and traversing the point which represents one end of the given motion. Then by the rule of Article 33, page 13, find the projections of the perpendicular let fall on the second plane from the point representing the other end of the given motion. That perpendicular will be one of the required components; and the straight line from the first-mentioned point to the foot of the perpendicular will be the other. The lengths of the lines representing the component motions may be found, if required, by Article 19, page 7.

The component of the motion parallel to the given plane is obviously its projection on that plane. It is sometimes called the *tangential component,* and the component perpendicular to the given plane the *normal component* of the given motion.

V. *Given, a resultant motion and one of two component motions, to find the other component motion.* Combine the given resultant motion with a motion equal and opposite to the given component motion; the resultant of these two will be the required other component motion. For example, in fig. 15, let A D be the given resultant motion, and A B the given component; draw D C equal and parallel to A B, and pointing the opposite way; join A C; this will be the required other component: or otherwise, join B D and draw A C equal and parallel to it.

VI. (Fig. 17.) *Given, the vertical projection,* A B, *and the horizontal projection,* A′ B′, *of a straight line representing a motion, to resolve that motion into three rectangular components parallel and perpendicular to the planes of projection.* Let O X be the axis of projection (Article 9, page 4). Draw the straight lines A A′, B B′,

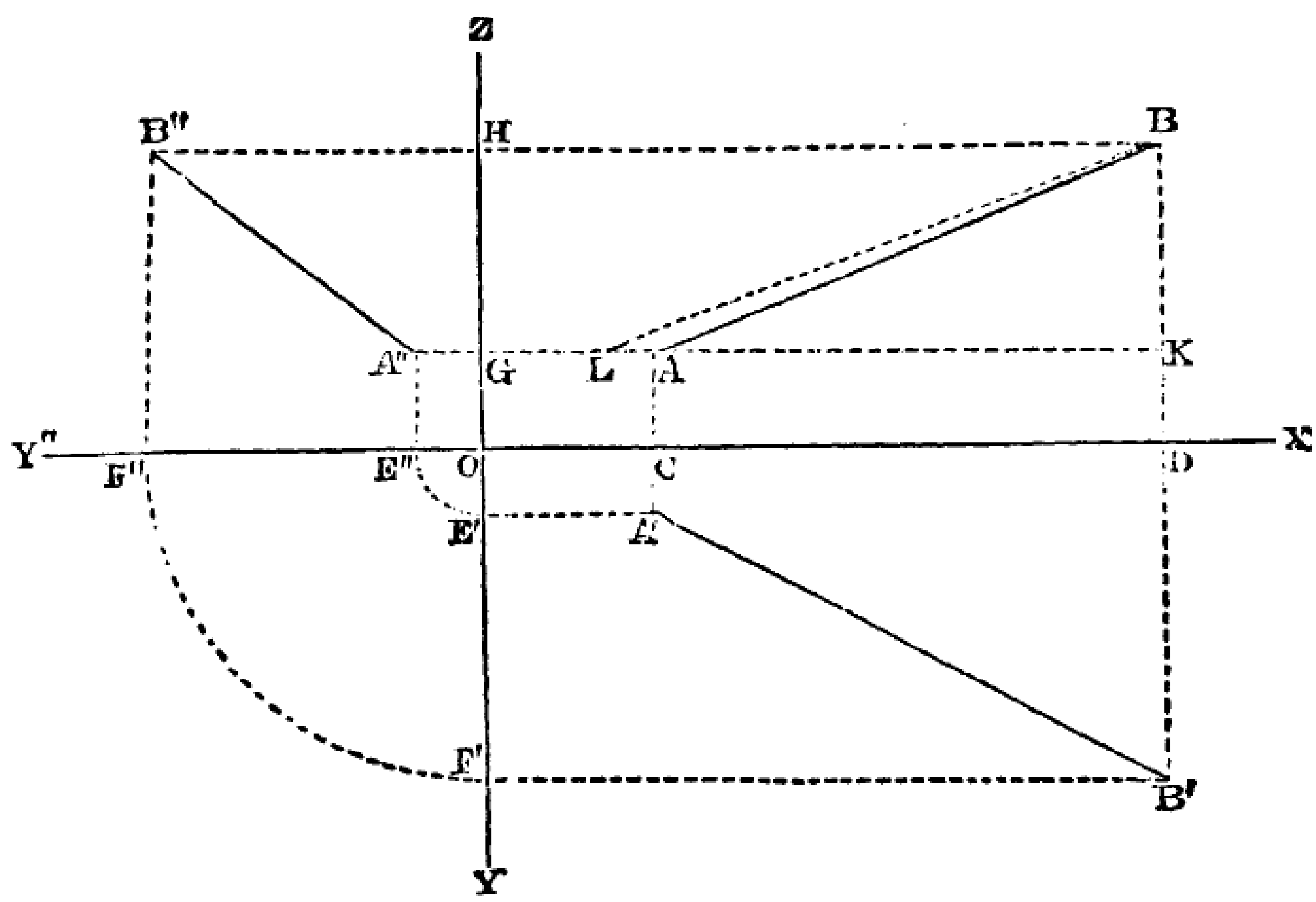

Fig. 17.

cutting the axis of projection (of course at right angles) in C and D. Then through any convenient point, O, in the axis of projection, draw the straight line Z O Y′ at right angles to that axis; and take O Y′ to represent a transverse horizontal axis, and O Z to represent a vertical axis. (The point O is called the *origin.*) Then parallel to X O draw A′ E′ and B′ F′ to meet O Y′, and A G and B H to meet O Z. The three components required will be represented by C D, E′ F′, and G H.

VII. *Given* (in fig. 17), *the vertical projection,* A B, *and the horizontal projection,* A′ B′, *of a straight line representing a motion, to draw a third projection of the same straight line on a vertical transverse plane of projection perpendicular to the first two planes of projection.* Construct fig. 17 as described in the preceding Rule. O Z and O Y′ will be the traces of the third plane of projection. Produce X O towards Y″; then O Y″ will represent the rabatment of O Y′, and Z O Y″ the rabatment of the vertical transverse plane upon the vertical longitudinal plane of projection. In O Y″ take O E″ = O E′, and O F″ = O F′; draw E″ A″ and F″B″ parallel to O Z, to meet A G and B H produced in A″ and B″ respectively; join A″ B″; this will be the projection required.

According to the rule already stated in Article 19, page 7, the motion of which A B and A′ B′ are the projections is to be found by making K L = A′ B′, and joining L B, which line will represent the extent of the resultant motion.

The following are the relations between a resultant motion and its components as expressed by calculation. In fig. 15,—

$$\sin \mathrm{C\,A\,B} : \sin \mathrm{C\,A\,D} : \sin \mathrm{D\,A\,B} :: \mathrm{A\,D} : \mathrm{A\,B} : \mathrm{A\,C};$$

also, $$\mathrm{A\,D}^2 = \mathrm{A\,B}^2 + \mathrm{A\,C}^2 + 2\,\mathrm{A\,B} \cdot \mathrm{A\,C} \cdot \cos \mathrm{C\,A\,B}.$$

In fig. 16,

$$\mathrm{A\,B} = \mathrm{A\,D} \cdot \cos \mathrm{B\,A\,D};\ \mathrm{A\,C} = \mathrm{A\,D} \cdot \sin \mathrm{B\,A\,D};$$

$$\mathrm{A\,D}^2 = \mathrm{A\,B}^2 + \mathrm{A\,C}^2.$$

In fig. 17,

$$\mathrm{L\,B}^2 = \mathrm{C\,D}^2 + \mathrm{E'\,F'}^2 + \mathrm{G\,H}^2.$$

42. **Relative Motion of Two Moving Pieces.**—All motion is relative: that is to say, every conceivable motion consists in a change of the relative position of two or more points. In speaking of the motions of the moving pieces of machines, *motions relatively to the frame* are always to be understood, unless it is otherwise specified. It is often requisite, however, to express the motion of a point in a moving piece relatively to a point in the same or in another moving piece.

In the case considered in the present section, where the relative position of two points in the same moving piece remains unaltered, not only as to distance but as to direction, the relative motion of such a pair of points is *nothing*. The motion of one moving piece relatively to another is determined by the following principle:—Let P, Q, and R denote any three points; then the motion of R relatively to P is the resultant of the motion of R relatively to Q, combined with the motion of Q relatively to P; so that if the motions of Q relatively to P, and of R relatively to P are given, the motion of R relatively to Q is to be found according to Rule V. of the preceding Article, by compounding with the motion of R relatively to P a motion equal and opposite to that of Q relatively to P. For example, let P stand for the frame of a machine, and Q and R for two moving pieces which slide along straight guides;