PART II.

DYNAMICS OF MACHINERY.

CHAPTER I.

SUMMARY OF GENERAL PRINCIPLES.

275. **Nature and Division of the Subject.**—In the present Part of this work, machines are to be considered not merely as modifying motion, but also as modifying force, and transmitting energy from one body to another. The theory of machines consists chiefly in the application of the principles of dynamics to trains of mechanism; and therefore much of the present part of this treatise will consist of references back to Part I.*

There are two fundamentally different ways of considering a machine, each of which must be employed in succession, in order to obtain a complete knowledge of its working.

I. In the first place is considered the action of the machine during a certain period of time, with a view to the determination of its EFFICIENCY; that is, the ratio which the *useful* part of its work bears to the whole expenditure of energy. The motion of every ordinary machine is either uniform or periodical; and therefore the principle of the equality of energy and work is fulfilled, either constantly, or periodically at the end of each period or cycle of changes in the motion of the machine.

II. In the second place is to be considered the action of the machine during intervals of time less than its period or cycle, if its motion is periodic, in order to determine the law of the periodic changes in the motions of the pieces of which the machine consists, and of the periodic or reciprocating forces by which such changes are produced.

The present Chapter contains a summary of the principles of dynamics—that word being taken in the comprehensive sense in which it is used in Thomson and Tait's *Natural Philosophy*, to

* A large portion of the present Part, and especially of the second Chapter, although originally written for this work, has already appeared as an Introduction to *A Manual of the Steam Engine and other Prime Movers;* for that book would have been incomplete without an explanation of the dynamical principles of the action of machines in general.

denote the science of forces, whether employed in balancing each other or in producing motion. The ensuing Chapters will contain the special application of those principles to machines.

276. **Forces—Action and Re-action.**—Every force is an action exerted between a pair of bodies, tending to alter their condition as to relative rest and motion; and it is exerted equally, and in contrary directions, upon each body of the pair.[1] That is to say, if A and B be a pair of bodies acting mechanically on each other, the force exerted by A upon B is equal in magnitude and contrary in direction to the force exerted by B upon A. This principle is sometimes called *the equality of action and re-action.* It is analogous to that of relative motion, explained in Article 42, page 21.

The forces chiefly to be considered in machines are the following:—

I. *Gravity*, exerted between the parts of the machine, fixed and moving, and the whole mass of the earth. The action of the earth on the machine alone requires to be considered in practice; for although the re-action of the machine on the earth is equal and opposite, the enormous mass of the earth, as compared with the machine, causes the effects of that re-action to be inappreciable. This is the only case in which re-action may be disregarded.

II. Forces exerted *between parts of the machine* and *contiguous external bodies*, solid or fluid. Sometimes those bodies support the foundations of the machine: sometimes they drive the machinery; as when the impulse or the pressure of a fluid drives an engine: sometimes they are moved by it; as in the lifting of loads, the overcoming of friction against external bodies, the working of machine tools, &c.

III. Forces exerted *between a moving piece and the frame*, at their bearing surfaces. These forces may be distinguished into pressure and friction. By the pressures exerted by the bearings the moving piece is kept in its proper place and path; by friction its motion is resisted. The equal and opposite re-actions of the moving piece on the frame tend to strain the frame; and the making of the frame so as to be capable of bearing them involves questions of strength, belonging to the Third Part of this treatise.

IV. Forces exerted *between connected moving pieces.* These too may be distinguished into pressure and friction.

When exerted along the line of connection, they serve to transmit motion and motive power; when exerted transversely to it, they produce either a straining effect, or a waste of mechanical work, or both. Here the equality of action and re-action is of great importance. The force which is exerted between a driver and a follower along their line of connection is a *driving force*, otherwise called an *effort*, as regards the motion of the follower, and a *resistance* as regards the motion of the driver.

V. Forces exerted between the *different parts of one piece,* whether fixed or moving. These constitute the *stress,* by which the piece resists the tendency of the forces applied to it externally to overstrain it or to break it; and they belong to the subject of the Third Part.

277. **Forces, how Determined and Expressed.**—A force, as respects one of the two bodies between which it acts, is determined, or made known, when the following three things are known respecting it:—*first,* the *place,* or part of the body to which it is applied; *secondly,* the *direction* of its action; *thirdly,* its *magnitude.*

The PLACE of the application of a force to a body may be the whole of its volume, as in the case of gravity; or the surface at which two bodies touch each other, or the bounding surface between two parts of the same body, as in the case of pressure, tension, shearing stress, and friction.

Thus every force has its action distributed over a certain space, either a volume or a surface; and a force concentrated at a single point has no real existence. Nevertheless, in investigations respecting the action of a distributed force upon the position and movements, as a whole, of a rigid body, or of a body which without error may be treated as rigid, like the solid parts of a machine, fixed or moving, that force may be treated as if it were concentrated at a point or points, determined by suitable processes; and such is the use of those numerous propositions in statics which relate to forces concentrated at points; or *single forces,* as they are called.

The DIRECTION of a force is that of the motion which it tends to produce. A straight line drawn through the point of application of a single force, and along its direction, is the LINE OF ACTION of that force.

The MAGNITUDES of two forces are equal when, being applied to the same body in opposite directions along the same line of action, they balance each other.

The magnitude of a force is expressed arithmetically by stating in numbers its ratio to a certain *unit* or *standard* of force, which for practical purposes is usually the *weight* (or attraction towards the earth), at a certain latitude, and at a certain level, of a known mass of a certain material. Thus the British unit of force is the *standard pound avoirdupois;* which is the weight, in the latitude of London, of a certain piece of platinum kept in a public office. (See the Act 18 and 19 Vict., cap. 72; also a paper by Professor W. H. Miller, in the *Philosophical Transactions* for 1856.)

For the sake of convenience, or of compliance with custom, other units of weight are occasionally employed in Britain, bearing certain ratios to the standard pound; such as—

The grain = $\frac{1}{7000}$ of a pound avoirdupois.
The troy pound = 5,760 grains = $0{\cdot}82\dot{2}85714\dot{4}$ pound avoirdupois.
The hundredweight = 112 pounds avoirdupois.
The ton = 2,240 pounds avoirdupois.

The French standard of weight is the *kilogramme*, which is the weight, in the latitude of Paris, of a certain piece of platinum kept in a public office. It was originally intended to be the weight of a cubic decimètre of pure water, measured at the temperature at which the density of water is greatest—viz., 4°·1 [1] centigrade, or 39°·4 Fahrenheit, and under the pressure which supports a barometric column of 760 millimètres of mercury; but it is in reality a little greater.

A comparison of French and British measures of weight and of size is given in a table at the end of this volume.

A kilogramme is 2·20462125 lbs. avoirdupois.
A pound avoirdupois is 0·4535926525 of a kilogramme.

For scientific purposes, forces are sometimes expressed in *Absolute Units.* The "Absolute Unit of Force" is a term used to denote the force which, acting on an unit of mass for an unit of time, produces an unit of velocity.

The unit of time employed is always a second.

The unit of velocity is in Britain one foot per second; in France one mètre per second.

The unit of mass is the mass of so much matter as weighs one unit of weight near the level of the sea, and in some definite latitude.

In Britain the latitude chosen is that of London; in France, that of Paris.

In Britain the unit of weight chosen is sometimes a grain, sometimes a pound avoirdupois; and it is equal to 32·187 of the corresponding absolute units of force. In France the unit of weight chosen is either a gramme or a kilogramme, and it is equal to 9·8087 of the corresponding absolute units of force. Each of those co-efficients is denoted by the letter g.

A single force may be represented in a drawing by a straight line; the position of the line showing the line of action of the force, and an arrow-head its direction; a point in the line marking the point of application of the force; and the length of the line representing the magnitude of the force.

277 A. **Measures of Force and Mass.**—If by the unit of force is understood the weight of a certain standard, such as the avoirdupois pound, then the mass of that standard is $1 \div g$; and