

CHAPTER XIII.

KINEMATIC CLASSIFICATION OF MECHANISMS.

101. Historical Sketch. — In treating of the theory of Mechanisms, it has been the aim of many writers to devise some method of analysis whereby mechanical contrivances in general might be resolved into their several component parts, capable of being represented, if necessary, by symbols, and capable also of being recombined in such a fashion as to produce new mechanisms. Such a system, if complete and workable, would of course be of great service to the inventor, and would save him from the fate, only too common, of designing with great toil some device which has been known and used for years. In the words of Willis, “there appears no reason why the construction of a machine for a given purpose should not, like any usual problem, be so reduced to the dominion of the mathematician as to enable him to obtain, by direct and certain methods, all the forms and arrangements that are applicable to the desired purpose, from which he may select at pleasure.” It must be confessed that so far no such system of analysis and synthesis has been found of any great practical value; many of the proposals, however, are interesting and suggestive, and a brief account of some of them will not be out of place in this book. Before entering upon it we may glance at the historical development of the subject of the Kinematics of Machines.

A book dating from the eighteenth century* seems to be the first treatise on machines which can be considered at

* Leupold. *Theatrum Machinarum.* 1724.

all systematic. Leupold's predecessors had indeed described sundry machines and devices, but their order of arrangement was always arbitrary, and no attempt was made to study machines by considering the relative motions of their parts. The theory of machines, treated either from the kinematic or dynamic standpoint, did not in fact exist.

Euler* taught that the motions of rigid bodies should be investigated by the methods of geometry, as well as by the aid of dynamics, but it does not appear that he had in view the special application of these principles to the motions of the parts of machines. Monge in 1794 conceived the idea of treating machines as contrivances for changing one kind of motion into another, and was the first to suggest that the essential "elements of machines" should be enumerated and studied. His system formed the basis of the course adopted in the Ecole Polytechnique soon after its foundation—a course laid out by Lanz and Bétancourt,† and classifying the motions of the parts of machines as (1) rectilinear, (2) circular, or (3) curvilinear. Combinations of these motions are considered, while each motion may be continuous or alternate. The work of Lanz and Bétancourt was incomplete, because no attempt was made to calculate these various motions; their scheme underwent many modifications, and has not survived. A system somewhat similar in intention, but differing in detail, was propounded by Borgnis.‡ It has met with the same fate.

It is to the physicist Ampère§ that we owe an important advance. He saw clearly that a mechanism should be studied as "an instrument by the help of which the direction and velocity of a given motion can be altered"; thus going further than Euler, and laying the foundations of that science of Machines to which, in accordance with his suggestion, we apply the name Kinematics.

* Euler. *Theoria Motus Corporum*. 1765.

† Lanz and Bétancourt. *Essai sur la composition des Machines*. 1808.

‡ Borgnis. *Traité complet de Mécanique appliquée aux Arts*. 1818.

§ Ampère. *Essai sur la philosophie des Sciences*. 1834.

Ampère was followed by Willis,* who confined himself to the consideration of what he termed the "Elements of Pure Mechanisms," and did not deal with the "generalities of motion." The "Principles of Mechanism" takes a less abstract view of the science of Kinematics than Ampère seems to have held, and in that book the author endeavors to form a system embracing all the elementary combinations of mechanism, and admitting of an investigation of their modifications of motion. He does not attempt to deal with dynamical questions, but gives practical and useful solutions of many leading problems in applied kinematics. His system of classification will receive some consideration in a later section; we shall see that its groundwork is the mode in which the motion is transmitted, or, as we should now express it, the kind of relative motion existing, in various mechanisms.

In several of his books Rankine † deals with kinematical questions, treated under such titles as the Geometry of Machinery and the Theory of Mechanism. His views were in some few respects erroneous and incomplete, and his nomenclature has not been followed to any large extent, but his system of dealing with the motion of machine parts by the aid of instantaneous centres, and his methods of solving certain special problems, were in many cases far more powerful and effective than any previously employed.

The appearance in collected form of the kinematical writings of Reuleaux ‡ furnished students with the first text-book whose methods have met with really wide acceptance. It is to Reuleaux that we owe the idea of a mechanism regarded as a chain made up of links any one of which may be considered as being fixed. Starting with this con-

* Willis. Principles of Mechanism. 1841. (Second Edition 1870.)

† Rankine. Applied Mechanics. 1858.

Manual of Machinery and Millwork. 1869.

‡ Reuleaux. Theoretische Kinematik. English Translation by Dr. Kennedy. 1876.

ception, and taking account of the relative motion of these links as determined by the pairing of their elements, we are led to a wide and comprehensive view of the whole kinematic theory of mechanisms. The earlier work of Reuleaux has now been supplemented by the publication of a second part of his text-book.*

Burmester's important treatise † is not so well known to English-speaking readers as it should be. Only the first volume, dealing with plane motion, has yet been published. Burmester's method of treatment differs from that of Reuleaux in making a more liberal use of purely mathematical and geometrical principles, but the two authors agree in their fundamental conception of the subject, and, to a large extent, in their nomenclature and definitions. A considerable amount of space is devoted by Burmester to the kinematics of a plane rigid system; he deals with the principles of constraint in plane motion, and passes on to the consideration of plane mechanisms and the relative displacement, velocity, and acceleration of their various parts. The second volume is to treat, after a similar fashion, of non-plane motion.

102. Classification of Willis. Babbage's Notation.—The following sections contain a short account of some of the schemes suggested for classifying and symbolizing the various kinds of mechanisms.

Like almost all his predecessors, Willis contented himself with proposing a scheme of classification without endeavoring to invent any notation, or system of signs, by which a given mechanism could be represented by a formula. Without apparent reason, Willis excludes from his system all hydraulic machines. Some other classes of mechanism, for example those including springs, are also omitted. In fact he considers as "pure mechanisms" only certain types

* Reuleaux. *Die praktischen Beziehungen der Kinematik zu Geometrie und Mechanik.* 1900.

† Burmester. *Lehrbuch der Kinematik.* 1888.

of machines, which seem to have been selected in a somewhat arbitrary fashion. In these machines, according to Willis, motion is transmitted in "elementary combinations" by five methods, namely:

Division.	Method of Transmission.	Example.
A.	By rolling contact.	Toothed gearing of various sorts.
B.	By sliding contact.	Cams, screws, worm- and screw-gearing, escape-ments.
C.	By wrapping connection.	Bands, chains, and other gearing.
D.	By linkwork.	Cranks, eccentrics, and other linkwork. Ratchet-wheels and clicks.
E.	By reduplication.	Tackle of all sorts.

Each of these five main divisions is again separated into three classes, in which the velocity ratio is either (*a*) constant, (*b*) varying, and (*c*) constant or varying; while due regard is had to the question whether the "directional relation" is constant or varying.

This system or classification has not been widely used, and possesses certain manifest imperfections. It was, however, a great advance on that of Lanz and Bétancourt or on that of Borgnis, because it was designed with a view of facilitating calculations regarding the relative motions, or velocity ratios, in mechanisms, rather than with the aim of classifying mechanisms for purely descriptive purposes.

In the "Principles of Mechanism" Willis devotes some space to the exposition of the scheme of notation proposed by Babbage; * a scheme devised by that ingenious inventor primarily for the purpose of clearly representing the relations of the parts of his calculating-machine, and especially

* A Method of Expressing by Signs the Action of Machinery. Phil. Trans., 1826.

