MECHANISMS FOR INTERMITTENT MOTION

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To Anne, David, Peter, and Leila for patiently allowing me the time and privacy required for a project of this magnitude.

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Contents

Glossary

ACCELERATION. The rate-of-change of the velocity of a body as a function of time. A vector quantity.

Angular. The rate-of-change of angular velocity of a body as a function of time.

Linear. The rate-of-change of linear velocity of a body as a function of time.

of gravity. Linear acceleration imparted to a falling body by the earth's gravitation field: equals approximately 32 ft per second^2 in English units.

ASYNCHRONOUS. Running at a variable rate or frequency. For example, a mechanism whose output is produced infrequently, perhaps only on command of the operator, is said to be running asynchronously.

BODY. A piece or portion of a mechanism or machine as distinct from the remainder of the machine.

Elastic. A body whose dimensions change and which typically absorbs and retains and/or releases energy while being used.

Free. A piece or portion of a machine that has been theoretically isolated from the remainder for analysis.

Rigid. A body whose dimensions are assumed not to change in use.

BRAKE. A mechanism or device whose function is to grab and stop a moving body upon command.

CAM. A rotating or sliding machine member whose function is to impart a predetermined motion of some sort to a second part called a cam follower that rolls or slides along a surface of the cam.

CYCLING RATE. The rate or frequency with which output motions are produced by an intermittent motion mechanism. Steps per minute.

CLUTCH. A mechanism or device whose function is to couple one machine member (usually a rotating shaft) to another (usually a second shaft) upon command.

COEFFICIENT OF RESTITUTION. An experimental constant used in the study of impact. It is a measure of the amount of energy lost during a collision between two bodies. A coefficient of 1.0 indicates that no energy is lost. The coefficient of 0 indicates that all energy is lost.

DAMPER. A mechanism or device whose function is to suppress the vibrations induced in a machine or system.

DAMPING CONSTANT. An experimental constant which gives a measure of the degree to which a damper will suppress vibrations in a given machine or system.

Critical. A damper is said to have a critical damping constant if vibrations in the machine or system are suppressed after the first half cycle of displacement.

DIFFERENTIATION. A mathematical or graphical process of determining the rate-of-change of a variable. If we differentiate a curve which represents the velocity of a body as a function of time, for example, we determine the rate-of-change of velocity at various times and hence, the acceleration of that body at those times. The process of differentiation can be performed mathematically, graphically, or experimentally.

DISPLACEMENT. The change in position of a body as a function of time.

Angular. The change in rotational position of a body as a function of time.

Linear. The change in linear position of a body as a function of time.

DWELL. Pause—Rest. An intermittent motion mechanism that is producing no output motion is said to be dwelling.

DWELL-MOTION RATIO. The ratio between the length of time occupied by dwell and the length of time occupied by output motion for an intermittent motion mechanism. The ratio would be very high for a mechanism that produces brief motion after a long rest period. The ratio would be very low for a mechanism that produces a great deal of motion with only short rest periods in-between each motion cycle.

ESCAPEMENT. A mechanism or device that is designed to alternately grab and release a rotating shaft, wheel, slide, etc.

A clock and watch. An escapement designed especially for use in a mechanical or electromechanical timekeeper.

Inverse. A mechanism or device which has geometrical similarity to a true escapement, but which provides the source of power which moves the output shaft rather than just controlling power received from some other source. Not a true escapement.

Machine. An escapement designed to control a rotating shaft, wheel, slide, etc., in a machine instrument or mechanism other than a timekeeper.

FORCE. The phenomenon which causes the acceleration of a body. Forces can be generated by fields (electrical, magnetic, gravitational) or by interactions between bodies.

GEAR. A machine member, generally circular though sometimes having an elliptical or other noncircular shape, whose active surface is provided with teeth that typically engage a similar gear to impart rotation from one shaft to another.

Cycloidal. A special family of gear systems in which one gear essentially rolls along the surface of another, rather than just rotating on fixed centers.

Differential. A special class of cycloidal gearing that is usually used to add or subtract the rotation of one shaft to or from another.

Mutilated. A gear on which some of the teeth have been purposely removed to modify the performance characteristics of a particular system.

GENEVA. A special type of machine or instrument cam that is frequently shaped something like a Maltese cross.

Instrument. Small lightweight Geneva intended for use in instruments and other systems where load requirements are light.

Machine. Heavy-duty Geneva.

GRAPH. A pictorial representation of a mathematical or experimental function. For example, we can draw a graph of the displacement of a body as a function of time.

INDEXING MECHANISM. Generally a mechanism or device that is designed to produce intermittent motion. In machine tool parlance, however, an indexer is usually a mechanism or device used to move an in-process or finished body from one work station to another.

INDEXING PRECISION. The degree of accuracy with which an intermittent motion mechanism or device positions the load.

INERTIA. A measure of the resistance of a body to linear acceleration. A function of the mass of the body.

INPUT. The power input to an intermittent motion mechanism or device. In some cases this will take the form of a rotating shaft driven by an electrical motor (for example in most Geneva, gear, or cam systems). In other cases, the input will be electrical and will be converted to mechanical motion by a solenoid or stepping motor.

INSTANT CENTER. The point about which a body is rotating at one instant in time. For a wheel rotating on a shaft, the instant center is the center of the shaft and does not move. For a wheel rolling along the ground, the instant center is the point of contact between wheel and ground and changes continuously.

INTEGRATION. The process of finding the sum or total of a large number of small values. The act of finding the area under a regular or irregular curve on a graph. Integration can be performed mathematically, graphically, or experimentally.

INTERMITTENT MOTION MECHANISM. Mechanism or device designed to produce intermittent output motion. Input can be either intermittent or continuous.

JERK. The rate of change of the acceleration of a body as a function of time.

LOAD CAPACITY (RELATIVE). The capacity of an intermittent motion mechanism to drive a load. If a body has a high relative load capacity it is able to move and control a very large load.

MASS. A quantity of matter.

MECHANICAL ADVANTAGE. A mechanism or device is said to possess mechanical advantage if a small input force or torque can produce a large output force or torque. A lever can have mechanical advantage, for example.

MOMENT OF INERTIA. A measure of the resistance of a free body to angular acceleration. A function of the mass and geometry of the body.

MOTION CURVES. Graphical representation of the displacement, velocity, and acceleration of a body as a function of time.

OUTPUT. The mechanical output of an intermittent motion mechanism. Consists generally of motion periods followed by dwell periods, followed by motion periods, etc.

PRIM. Programmed Rotary Intermittent Motion mechanism. A name given to a particular type of intermittent motion mechanism by its inventor. (See Figs. 15–25 through 15–27.)

RATCHET. A class of intermittent motion mechanism in which the input device is generally an oscillating tooth or pawl of some type, operating against a gearlike cam called a ratchet wheel.

Cam ratchet. A ratchet in which the basic input to the driver is provided by a rotating cam.

Impulse ratchet. A ratchet mechanism in which the input is provided by electrical pulses to a solenoid or equivalent.

RELIABILITY. A measure of the probability that a mechanism or device will perform its intended function correctly.

SLOPE. The rate-of-rise (or fall) of a mathematical curve. Equals the tangent of the angle between a line drawn tangent to the curve at the point whose slope is to be determined and the horizontal axis (see Fig. 2–10).

SPRING CONSTANT. A measure of the stiffness of a spring. The spring constant is low if it takes little force to extend a spring a considerable distance.

STABILITY. A measure of the degree to which an intermittent motion mechanism or device will continue to produce the desired pattern of output motion over a long period of time. Related to reliability but more a measure of the degree to which an output motion will change, than as to whether or not it will be produced at all.

STAR WHEEL. A particular class of intermittent motion mechanism that has some of the properties of a Geneva and some of a mutilated gear (see Figs. 15–2 through 15–7).

STEPPING MOTOR. An electrical motor designed to produce intermittent rather than continuous output.

SYNCHRONOUS. Fixed rate or frequency. A synchronous motor, for example, will rotate an output shaft at a constant angular velocity in spite of reasonable variations in such things as input voltage, output load, etc. A Geneva mechanism driven by a constant velocity rotating shaft will produce output motions at a fixed frequency and thus could be said to produce a synchronous output.

TORQUE. The product of an applied force and the radius through which it is acting about a center of rotation.

TRANSIENT. Changing, temporary, passing from one state to another.

VECTOR. A mathematical invention used to describe the properties of a quantity when both magnitude and direction are involved. Force, velocity, and acceleration can all be described by vectors.

VELOCITY. The rate-of-change of displacement of a body as a function of time. A vector quantity.

Angular. The rate-of-change of angular displacement of a body as a function of time.

Linear. The rate-of-change of linear displacement of a body as a function of time.

VIBRATION. The periodic motion of a body or portion of a body in alternating and opposite directions from a position of equilibrium.

Preface

Intermittent motion mechanisms play such an important role in modern technology that we might say pacifists would make the world far "safer" by banning intermittent motion than by banning the bomb. Intermittent motion mechanisms are essential elements of such machines as paper tape and card punching equipment, high-speed typewriters, digital servo systems, mechanical and electromechanical counting apparatus, automatic weapons, clocks and watches, and production and assembly machines of all sorts. Nor is the end in sight. Although electronics are certainly going to take over most control and computing functions, man will long have need for "muscle" as well as "brain" and intermittent motion devices will continue to play a significant role.

It is very useful, therefore, for machine and instrument designers to know something about the mechanics and mechanisms of intermittent motion, yet it is rare to find a designer who really understands such devices even if his industry makes use of them. The reason is that intermittent motion is not adequately covered by most engineering texts on mechanics, machine design and the like. Those texts that do cover it are so complicated and mathematical that they are beyond the level of most practicing designers. Furthermore, their authors usually end by inferring that, "exact solutions to these design problems are impossible."

The basic problem is that intermittent motion is a "special case" in several ways:

1. It involves transient mechanics rather than steady-state mechanics.
2. Because impact is often involved, wear characteristics differ somewhat from those found in machines where only sliding contacts are found.
3. Impact and sudden changes in acceleration and velocity lead to force and stress levels that far exceed the apparent (static) force and stress levels that could be produced by the motors, springs, and other power plants the designer has provided.
4. High stress levels, backlash, vibration and resiliency of parts lead to significant control and stability problems that are not found in steady-state machinery.
5. When high stress levels are involved, machine elements and linkages can no longer be considered as rigid bodies, thereby making it impossible for the designer to use much of the mechanics which he was originally taught.

In this text we will try to give the designer insight into some of these things. Like most texts in elastic body and intermittent motion mechanics we will end up by concluding that we cannot obtain rigorous numerical solutions for our design

problems. Unlike most such texts, however, we hope to discuss these problems on a level which will be intelligible to the average designer and thereby give him at least a better understanding of intermittent motion mechanisms and their special problems, so that he can design them to maximize favorable features and minimize unfavorable features.

As a matter of fact, any mechanism or machine with clearance and backlash has some of the problems of an intermittent motion mechanism. Since it is almost impossible to build a machine without clearance or backlash somewhere, one might say that all designers have these problems, usually without realizing it or the implications.

A Text for Designers

This text is not intended for physicists, but for graduate engineers or for non-graduates who have some formal training in basic mechanics. We assume they will know, for example, what a force is, or a mass, and can tell the difference between acceleration and velocity. We will, however, review some of these things, using graphical and pictorial methods instead of mathematics, before getting into a discussion of the complexities of intermittent motion. This is not a complete course in graphical mechanics; only those topics which are pertinent to the purposes of this text will be covered. We hope, however, that by using the graphical approach most readers will gain an insight and understanding into intermittent motion that they would not obtain through the complex mathematical approach.

Like most technical authors, I am indebted to many people for the material which appears in my book. Principal among my own teachers were Francis W. Sears, now at Dartmouth; Dr. Igor Paul, of M.I.T.; Dr. Will Roth of the University of Vermont; and Dr. Karl Maier of Math & Metric, Inc.; all of whom struggled at one time or another to educate me.

I also have to thank, most sincerely, my employers at the Veeder-Root Company in Hartford. Our mutual struggles to make ever better counters (intermittent motion mechanisms) have provided most of the time and resources necessary for my education in this subject.

I must also thank the many individuals, publishers and manufacturing companies who gave me information on, and permission to publish illustrations of their various products and inventions. Special thanks, is due the Penton Publishing Company, publishers of *Machine Design* magazine, for permission to reprint the discussion of impact in Chapter 3. I originally wrote this as an article for their magazine. Penton has also given me permission to reuse many illustrations I drew for articles on several different types of intermittent motion mechanisms; articles which also appeared in *Machine Design*.

The McGraw Hill Publishing Company has also generously allowed me to use a large number of drawings which originally appeared in their *Product Engineering* magazine as illustrations for articles by many different authors.

My colleague, Mr. John Gamble, also deserves much credit for his invaluable assistance on the chapter on stepping motors. Other reviewers to whom I am indebted include: Mr. George Coxeter of Raymond Engineering Company; Mr. John Murray of the Superior Electric Company; Mr. Dennis Klipp of the Commercial Cam and Machine Company; Mr. Martin Zugel of Cyclo-Index Corporation; Mr. Peter Jackson of Jackson Automation; and Mr. H. S. Cummings Jr., of the Lowell Corporation, each of them has reviewed portions of the text and made valuable suggestions.

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