CHAPTER 11

Clock and Watch Escapements

Clock and watch escapements are a special class of intermittent motion mechanism designed for a single task; to measure time. Although they are designed for just one purpose from an historical point of view, they are probably the most important intermittent motion mechanisms ever devised. Mechanical timekeepers made accurate navigation possible and so aided significantly the expansion of Western civilization. The measurement of time was also of pivotal importance to the development of science, and all time measurement until recently was accomplished by mechanical devices (or celestial observations). Timers were considered such an important tool of the scientist, in fact, that some of the greatest scientists of all time, men like Galileo; Huygens; Robert Hooke; and Wheatstone all devoted a portion of their professional lives to the improvement of clock and watch escapements.

We will be considering mechanical escapements primarily (with one or two electro-mechanical escapements thrown in for good measure) since our topic is intermittent motion mechanisms and not clocks and watches. The more recent electronic timers will not be considered at all, even though these are rapidly gaining in popularity and will probably soon replace mechanical devices in a great many situations. The cost of excellent mechanical clocks and watches has been reduced to a point that will be very hard for electronics to beat, however, thus mechanical timers will be with us for a long, long time to come.

Basic Requirements For a Mechanical Timekeeper

The basic requirement for any timekeeper is some phenomenon that can be used as a measure of time or "time base." The earliest clocks used the flow of water or sand through a fixed orifice; or the steady burning of a measured candle was used to track the passage of time. Sundials, of course, were also used. These basically analogue time bases were eventually replaced by systems in which a mechanical oscillator was used to measure the passage of time. Two basic mechanical oscillators quickly gained favor and are still in use today; the pendulum and the rotating-mass-spring oscillator.

A good mechanical oscillator has a cyclical motion which is relatively constant over a long period of time as long as energy lost to friction is replaced. In a clock or watch, the motion of the oscillator is used to regulate the velocity of a gear train which, in turn, drives hands or dials that indicate time. In effect, the clock mechanisms count the beats of the oscillating element (or integrate them) to convert "number of oscillations" to hours, minutes, seconds, etc. The clock or watch escapement is the mechanism that couples the rotating-spring-mass or pendulum to the gear train, and time indicators.

There are some severe restrictions on the escapement if it is to function correctly. It must accurately sense the motion of the mechanical oscillator (mass-spring, or pendulum) and use this information to control the motion of the gear train; which is continuously urged forward either by a large mainspring or falling weights. Since the escapement is generally controlled by the oscillator, it inevitably takes energy from the oscillator in order to function. If it takes out too much energy or takes it out at the wrong time, however, it will disturb the vibration of the oscillator and will affect the accuracy with which the oscillator measures time.

The escapement, furthermore, must also put energy back into the oscillator to keep the oscillator in motion. If this were not done, the oscillations would rapidly die down; thanks to viscous or coulomb friction, as in Figs. 3–16 or 3–18. The amount of energy introduced to the oscillator must be just about equal to that taken out by the escapement and by friction losses in the oscillator, or the oscillations will tend to increase in amplitude. This would destroy the accuracy of the time base (or would destroy the clock!). Thanks to the efforts of generations of superb designers, all of these things are accomplished easily by relatively simple and low-cost clock and watch escapements. We do not have room to go into all of the ramifications of the design of a good timekeeper, or even of a good escapement, but later on we will discuss some of the ways several of these things were accomplished, as we look at examples.

Advantages and Disadvantages of Clock and Watch Escapements

Since this is a special class of mechanism, it would be unfair to consider its advantages and disadvantages relative to the other devices we have been discussing. Needless to say, timer escapements have no peer when the job to be done is to keep time. On the other hand, they have few advantages compared to ratchets, Genevas, clutches, stepping motors, etc., when the job to be done is anything other than keeping time.

This is not to say, however, that they cannot be useful to the designer of intermittent motion mechanisms for machinery. As we will see in a later chapter, there are such things as machine escapements and they bear a strong family resemblance to clock and watch escapements, from which they were, no doubt, derived. Some of the forms and ideas developed for timekeeping might very well find application in heavy-duty machinery.

The first clocks as a matter of fact *were* heavy-duty machines, with escapements only a foot or more in diameter easily controlling weights weighing tons. Some of these designs gave excellent service for centuries, with only routine maintenance. Even small timer escapements are surprisingly rugged devices and should find more application in other instruments than they do at present. Mechanical delayed bomb fuses of World War II, for example, would withstand decelerations of 30,000 times the acceleration of gravity and still go on ticking accurately. Try dropping your high-speed business machine or machine tool with their Genevas, ratchets, stepping motors, etc., out of an airplane sometime and see if the machine will still function! Even though the timer escapement is a very small, lightweight device, its strength-to-weight ratio is very high, and it will stand a remarkable amount of abuse.

Another typical characteristic of good clock and watch escapements is very long life (see Fig. 5–2); almost zero wear in some applications. Disadvantages include the requirement for precision manufacturing techniques and correct lubrication, intolerance of dirt, etc., at least where precision timekeeping is required.

BASIC TYPES OF CLOCK AND WATCH ESCAPEMENTS

There are literally hundreds of different clock and watch escapements. Only a few of the more important ones will be considered in this text, however.

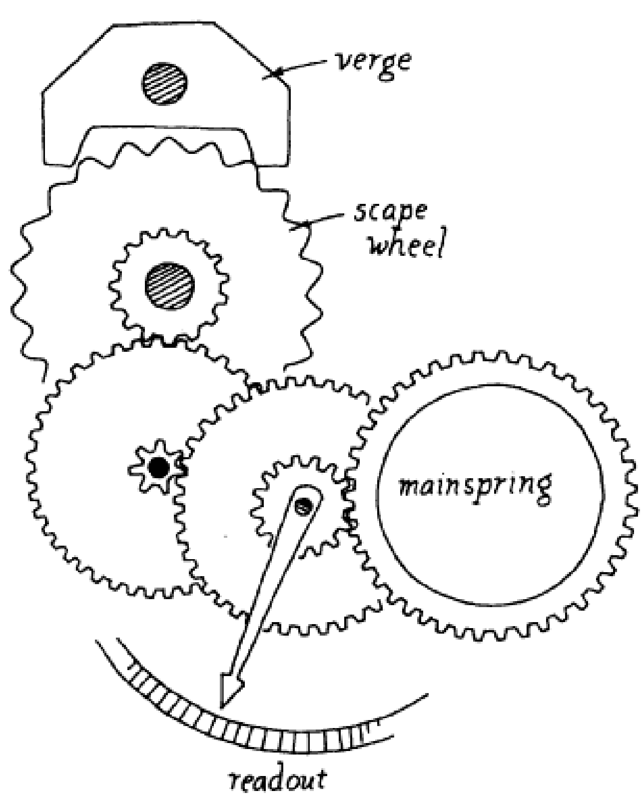

Fig. 11–1. Complete timer mechanism, showing drive spring, gear train and runaway, or verge, escapement.

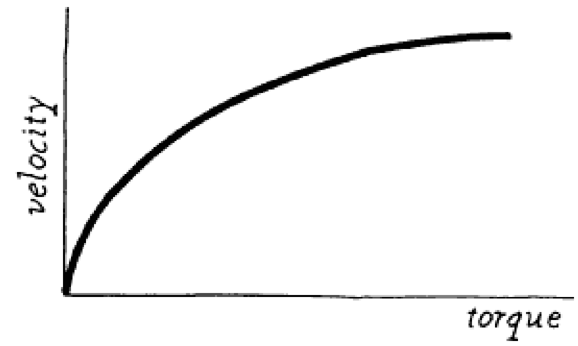

Fig. 11-2. Torque-speed curve for a runaway escapement.

Runaway Escapement

The simplest escapements use a non-resonant oscillating mass rather than an oscillating spring-mass as the basic timekeeper. A modern version of this type of escapement is shown in Fig. 11-1. The verge is the oscillating mass. It interferes with the rotation of the escape wheel as the latter attempts to rotate under the influence of a mainspring-driven gear train. One tooth or pallet of the verge is always positioned to interfere with the motion of the escape wheel or "scape" wheel, as it is sometimes known, so the latter is never allowed to rotate freely.

If the torque applied to the escape wheel is increased, the mass will oscillate more rapidly and the wheel will rotate more rapidly, since the verge is not a true oscillator. Hence the name "runaway" escapement for this type of mechanism. Figure 11-2 shows a typical torque-speed curve for a verge escapement. This type of escapement, incidentally, has a very high "beat rate." It sounds more like a bumblebee than a watch. The runaway finds a great deal of application in such things as portable range timers, parking meters, and in military products such as bomb fuses, rockets, and the like, because it is very rugged and economical. Furthermore, it is a self-starting escapement, which is necessary in many military situations. Also, its characteristics are similar to those of the fluid damper, and the runaway escapement is often used as a mechanical damper for speed control.

Pendulum Clock Escapement

Figure 11-3 shows the clockworks from a typical pendulum clock. The pendulum is hung from a knifeblade by a thin spring or strap, to reduce bearing friction effects. A yoke fastened to the escapement engages the pendulum near the top. As the pendulum oscillates, it moves the scape (escape) lever, which in turn releases the scape wheel. This latter is constantly urged to rotate by the gear train which is driven by the large falling weight. Further gears couple the weight to the output indicator; in this case, a single hour hand. The motion of the pendulum, then, controls the motion of the falling weight; which motion is indicated by the rotation of the hour hand. At some point during each cycle of the pendulum (the maximum velocity, or vertical, position is preferred) the scape wheel pushes on the scape lever which in turn, pushes on the pendulum, replacing any energy lost through bearing supports, air friction and the like. Different types of clock escapement accomplish this transfer of energy in different ways.

Watch Escapement

A typical watch mechanism is shown in Fig. 11-4. The pendulum has now been replaced by an oscillating spring-mass—the mass being called a "balance wheel," and the spring being called the "hairspring." The motion of this oscillator controls an escapement

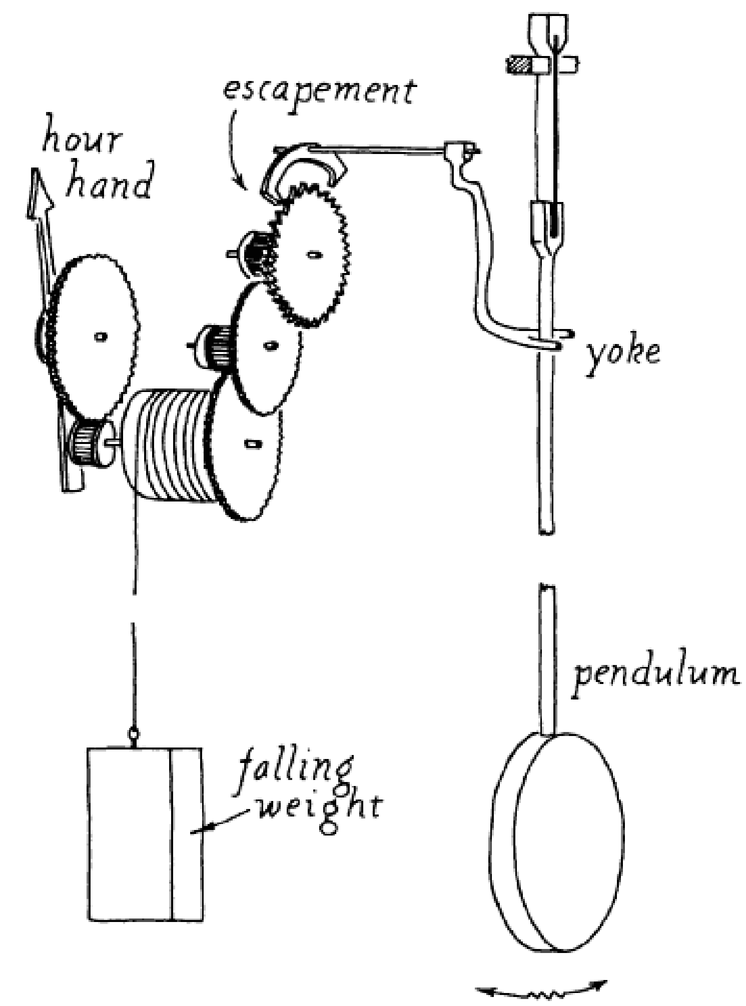

Fig. 11-3. Pendulum clock. Shows the relationship between mechanical oscillator (the pendulum); the clock escapement; the input power source (a falling weight); and the output indicator (hour hand).

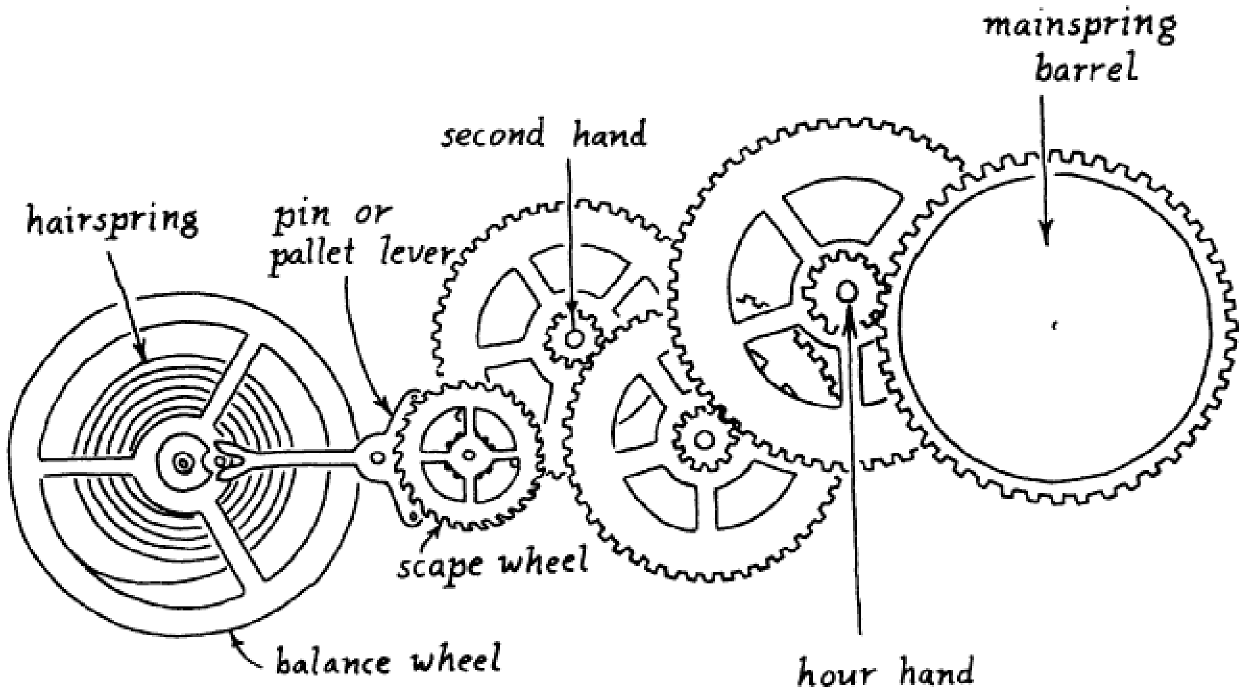

Fig. 11-4. Pocket watch showing the relationship between power source (mainspring), gear train, escapement, mechanical oscillator (balance wheel and hairspring) and indicators (second and hour hands). The minute hand is driven by additional gears (not shown) from the hour-hand spindle.

which in turn regulates the motion of a gear train. In this case, however, the gear train is driven by a large mainspring rather than by a falling weight. Hour and second hands are in turn driven by the gear train, as shown in the illustration. The minute hand would be mounted on the same shaft as the hour hand but would be driven by different gears. I have omitted it for clarity. Again, energy must be delivered from the main power source, the mainspring, to the oscillating balance wheel, by the escapement, at some point during each cycle of oscillation.

And, again, it is best to introduce such energy at the maximum velocity point since an impulse on the balance wheel at this point will have the least effect on the frequency or period of oscillation. Different watch escapements accomplish this energy transfer in different ways. Watch escapements designed for maximum timekeeping accuracy (i.e., minimum interference with the oscillator) inherently tend to be weak in self-starting, but the handling they receive when they are wound is generally sufficient to get them going.

Motion Curves

Figure 11–5 shows typical motion curves; angular acceleration, α; angular velocity, ω; and angular displacement, θ for the scape wheel (and, therefore for any element of the gear train) in a clock or a watch. This picture is also a reasonably correct description of the motion of the gear train in a runaway escapement, although, in this case the velocity ramps would appear "heel to toe" with essentially no sustained dwell periods.

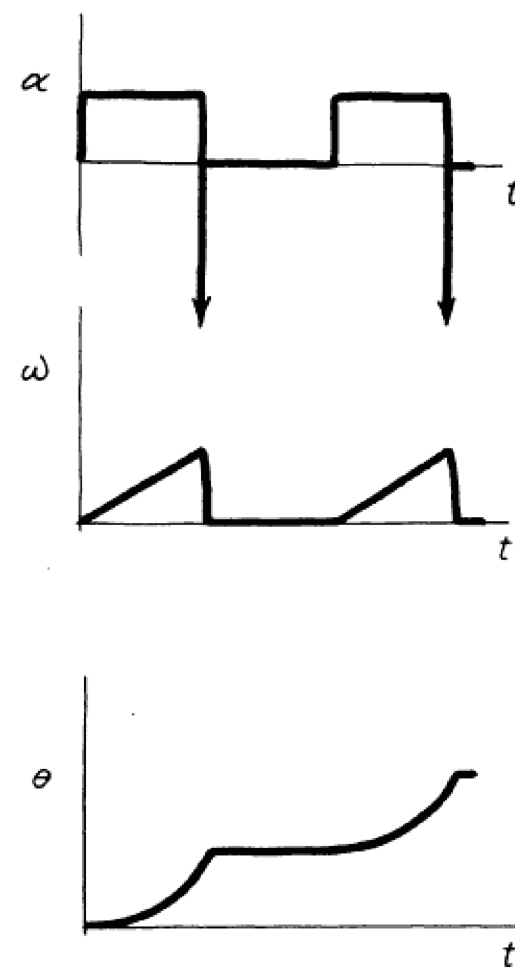

Fig. 11-5. Motion curves for a clock or watch escapement for one complete cycle of a pendulum or balance wheel (a tick and a tock).

As can be seen, a net torque (from the mainspring or falling weight) is suddenly applied to the scape wheel when the latter is released by the scape lever or verge. The wheel then moves until striking the other tooth (or pallet, as it is called) of the escapement; this suddenly stops the entire system. Motion recommences when the escapement permits. Two steps (a tick and a tock) are shown in Fig. 11–5.

Miscellaneous Problems

A mechanical clock or watch can be a superb timekeeper if sufficient attention is paid to design details. In addition to the problems already discussed, great care must be taken to be certain that the bearing friction in the balance wheel, scape wheel and scape lever shafts does not change significantly during the useful life of the device. In the best timepieces, furthermore, provision is made to compensate for temperature effects (which would cause oscillating masses to increase in size, springs to increase in length, etc.). For those clocks and watches subjected to shock, vibration, or moisture, etc., attention must be given to shock-loaded pivot bearings, careful selection of assembly techniques, sealed cases, etc. And, of course, cost is always a factor, with the designer striving for maximum performance at minimum cost. The extent to which cost reduction has been carried in the watch industry is really amazing.

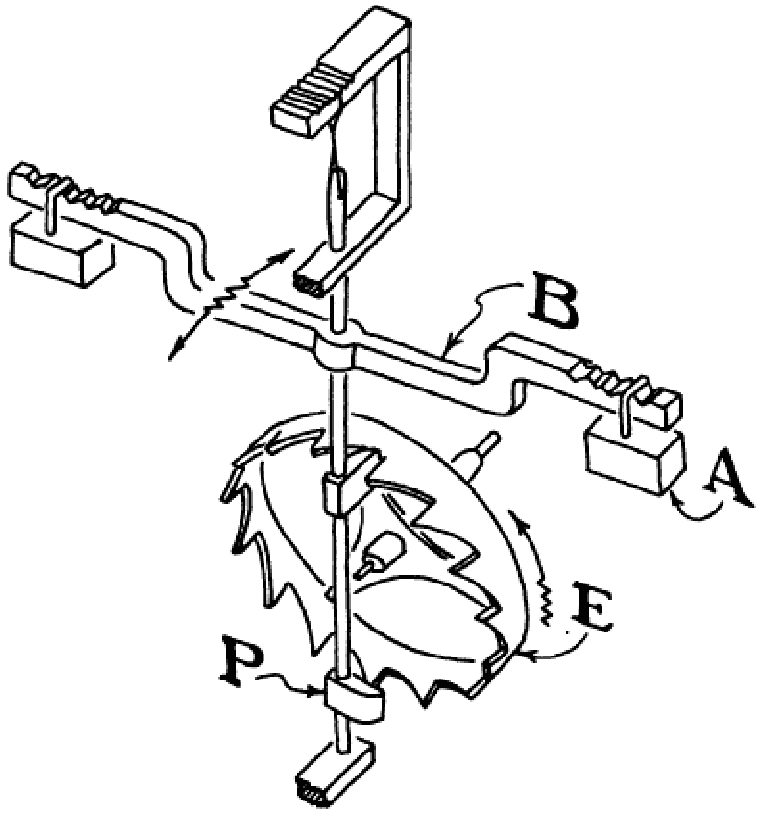

Fig. 11–6. Foliot verge runaway escapement.

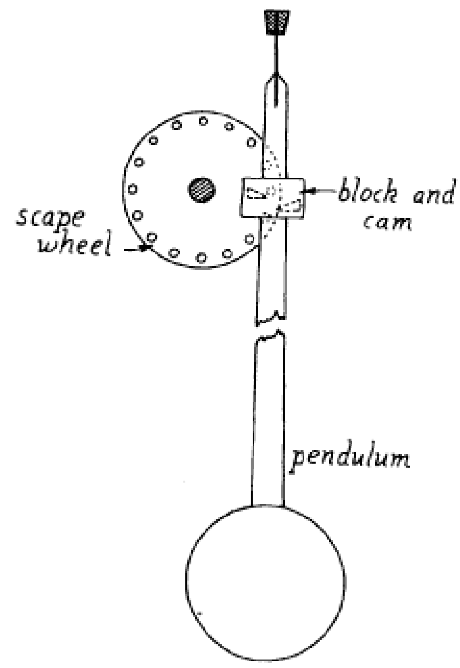

Fig. 11–7. Block and cam runaway escapement.

Varieties of Escapements

Let us look at some escapements. The first, the Foliot verge runaway in Fig. 11–6, is one of the oldest known. Probably the first successful clock escapement, it was widely used in steeple clocks for over three centuries (until the pendulum clock was invented about 1650 AD). This is a runaway escapement, there being only an oscillating mass (the arm *B*, and small weights *A*) to control the motion of the scape wheel (*E*), through the action of the pallets, *P*. There is no oscillating spring-mass combination. This device was, therefore, very torque sensitive; its speed would change if the applied torque changed; a serious problem in steeple clocks which are usually exposed to extremes of weather. Nevertheless, this was a very successful device in its day. The escapement used as a model for this drawing was about two feet high.

Figure 11–7 shows a block and cam runaway escapement, another ancient runaway escapement for a pendulum clock, nearly as old as that in Fig. 11–6, but far less popular. Pins (not teeth) on the scape wheel encounter small wedge cams on the block mounted on the pendulum. These impacts between pins and cams control the speed of the scape wheel, and deliver impulses to the pendulum to keep it swinging.

The small military timers shown in Fig. 11–8, left, are direct descendents of the early devices shown in Figs. 11–6 and 11–7, and use a modern verge escapement such as that shown at the bottom of the drawing at the right. This type of escapement is used in