CHAPTER 12

Machine and Inverse Escapements

MACHINE AND INVERSE ESCAPEMENTS IN GENERAL

In this chapter two more types of mechanisms will be considered—machine escapements and inverse escapements. Neither of these is as popular with machine designers as are ratchets, cams, or Genevas, but both deserve more attention than they get, since they offer the designer significant advantages in many design situations. Both machine and inverse escapements look very much like clock escapements, but neither is designed to run synchronously and both are designed to handle considerably larger loads than the typical clock escapement. Despite the geometrical similarities between these two types of mechanism, they will be discussed separately (machine escapements first) because they differ quite a bit in their operation.

MACHINE ESCAPEMENTS

Description of Machine Escapements

A typical machine escapement is shown in Fig. 12–1. As can be seen from the drawing it looks like a clock escapement except that the scape lever is controlled by the rotation of a snail cam rather than by a pendulum. The scape lever, of course, could also be controlled by a solenoid rather than by an input cam. This would place the length of the dwell period under the control of the operator. In either case, one of the two teeth (pallets) of the scape lever is always in a position to interfere with the motion of the scape wheel which, therefore, can never run away.

As in a clock escapement, the scape wheel in Fig. 12–1 is continuously urged to rotate by the machine to which it is fastened. A spring or weight could be used, as in a clock or watch, but a slip clutch or stallable motor is more commonly used in machine design. Sometimes, both a spring and slip clutch are used, the clutch being used to limit the torque that keeps the spring wound. Spring loaded escapements are usually called "load-and-fire" escapements. Examples of these will be seen later on.

The machine escapement is similar in some ways to certain types of limited motion clutches. In the next chapter a one-turn ratchet clutch will be seen, for example, that might well be mistaken for a machine escapement. The difference is that an escapement controls or releases energy in some other mechanism; a clutch transmits energy from drive to load.

Figure 12–2 shows another machine escapement. It differs from Fig. 12–1 in that the scape lever has only a single pallet. This mechanism will function correctly only if the scape lever moves rapidly enough to catch each tooth of the scape wheel after every motion of the wheel. As mentioned in Fig 12–1 one of the two pallets of that scape lever is always in a position to interfere with the motion of the scape wheel. The mechanism of Fig. 12–2, relying as it does on a race between the scape lever and the scape wheel, is a more risky mechanism; but, never-

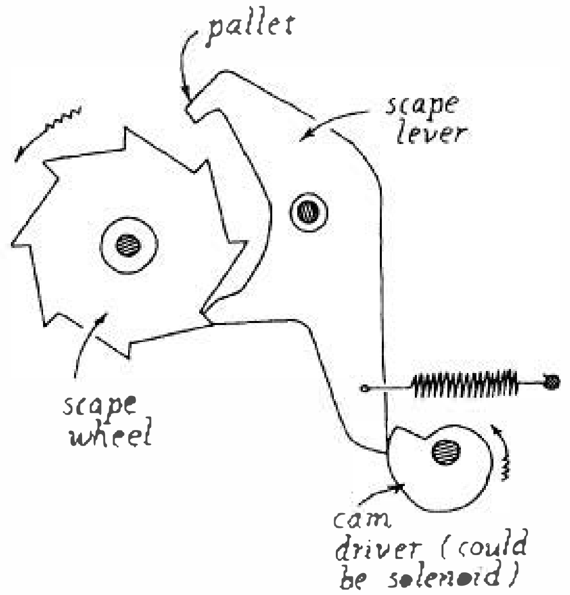

Fig. 12-1. Typical machine escapement.

theless, the single pallet escapement can be made to function correctly with proper design.

One way to help the single-pallet scape lever function correctly is to spring load it in the manner shown in Fig. 12-3A. Every time the pallet escapes a tooth on the wheel the lever, provided with a slot, immediately jumps ahead and downward (Fig. 12-3B). This trick gives the lever more time to re-engage the wheel (or catch the next tooth). The spring also acts to cushion the impacts that occur when the wheel is stopped by the lever.

Advantages and Disadvantages of Machine Escapements

One favorable attribute of the machine escapement is the fact that it has a large mechanical ad-

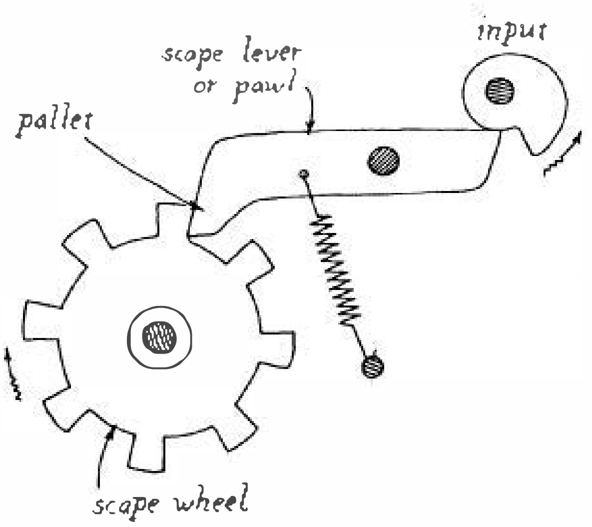

Fig. 12-2. Machine escapement with single-pallet scape lever.

vantage. A small amount of control energy from a low torque rotating shaft or a lightweight solenoid can control (release) a large amount of energy or torque in the scape wheel and remainder of the machine. The only energy which has to be supplied to the control system is that required to extract the scape lever from the scape wheel. The ratio between this energy or torque and that which is controlled, is the same as the ratio between the normal force on the lever and the frictional resistance to its motion. Since the friction force can usually be kept at 10 or 20 percent of the normal force, one unit of energy can easily control ten. With special attention paid to the shape and surface treatment of the scape lever and wheel teeth, with proper balancing of scape lever, etc., the control to output torque ratio can be even greater than this.

This mechanical advantage leads to an additional advantage. The machine escapement can be operated

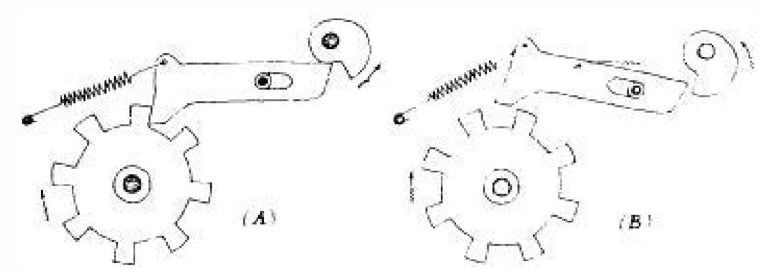

Fig. 12-3. Single-pallet machine escapement. (A) Engaged. (B) Disengaged.

at very high speeds because we do not have to wait for large drive torques to be developed by the system. Such torques are always present (produced by stalled motors, wound springs, slip clutches, etc.) urging the scape wheel forward. The escapement need only produce a small control torque which releases the drive torque. Solenoids, motors, or springs which drive the scape lever, therefore, can be small and the inertia of the escapement parts can be very small. All of this can result in very high speeds (with proper design of the drive circuits, etc.).

A different advantage can be obtained with the "load-and-fire" type of machine escapement. Here, a low-power motor can be used (with suitable gearing) to wind a large spring slowly. A very small control solenoid or equivalent is then used to actuate an escapement to release the energy in this spring. The system produces large output torques with low input energy and torque requirements. Of course, cycle rates have to be slow enough to allow the low-energy motor to wind up the high-torque spring, but this is not a serious disadvantage in many cases.

Another advantage is the machine escapement; it is a very simple device, even simpler than a ratchet. There is no need for such things as a no-back pawl, non-overthrow pawl, pawl springs, etc. Simplicity, in turn, leads generally to lower costs and to improved reliability. Finally, the machine escapement keeps the load under control quite reliably, although there is a period during which the load is free-wheeling between stops. If the escapement is designed properly, the load (scape wheel) cannot get very far before it is stopped (motion control).

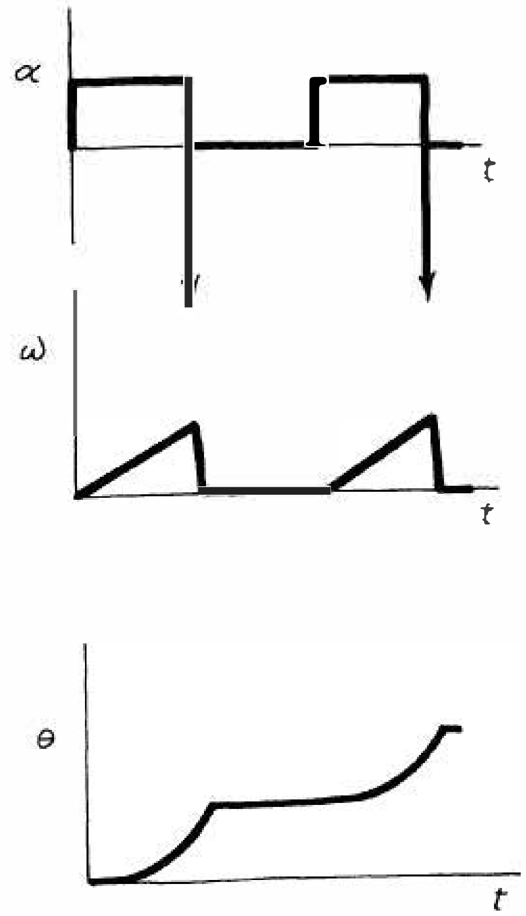

Fig. 12-4. Motion curves of a typical machine escapement. Notice the similarity to the curves of a clock escapement in Fig. 11-5.

There are disadvantages to machine escapements, however. This is an impact mechanism, probably producing more severe impacts than a ratchet, since full drive torque is usually applied to the scape wheel at all times. This means that machine escapements can only be used in relatively light-duty applications and can only take short steps (perhaps one revolution, as a maximum) to reduce impacts. Motion times are always short, therefore, but the dwell period can be placed under the control of the operator, if this is desirable.

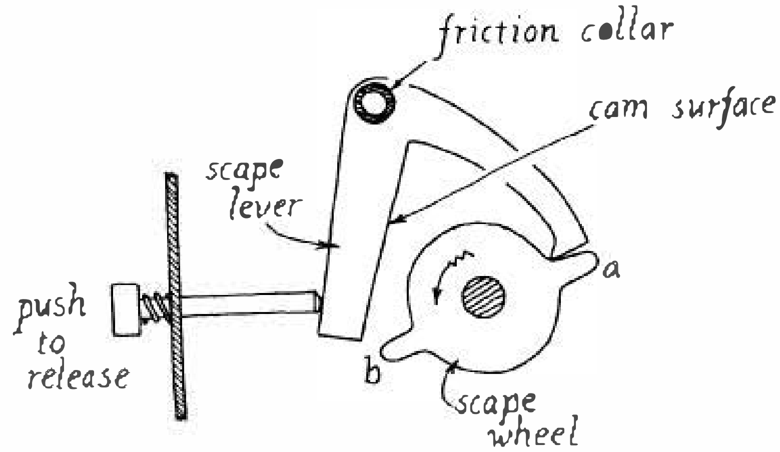

Fig. 12-5. Manually operated escapement in a towel dispenser.

Motion Curves—Machine Escapements

Motion curves for the scape wheel of a typical machine escapement are shown in Fig. 12-4. These are identical to the motion curves for a clock escapement and are characterized by a constant torque period (following release of the scape wheel) followed by a severe impact as the wheel is stopped when it strikes the next pallet of the scape lever.

Examples of Machine Escapements

In this manually operated escapement, from a towel dispenser (Fig. 12-5), the operator pushes the control button which moves the scape lever counterclockwise until it strikes the wheel. He is now free to pull a towel from the dispenser. This act rotates the scape wheel, and tooth *a* of the scape wheel acts on the cam surface of the scape lever to move the scape lever back into the position shown in the illustration. This brings the right-hand pallet of the scape lever into position to interfere with tooth *b* on the scape wheel, and thus prevent the operator from getting more than one towel.

Figure 12-6 illustrates a very simple machine

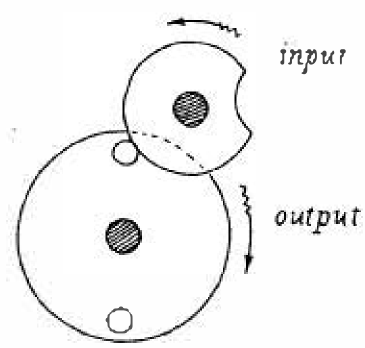

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Fig. 12-6. Simple machine escapement with a rotating input.

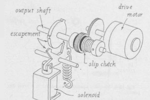

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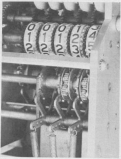
Fig. 12–7. Complete machine escapement system.

escapement with a rotating input. However, to function satisfactorily, the speed of the input must be faster than that of the output.

A complete machine escapement system is shown in Fig. 12–7. A drive motor operating through a slip clutch applies torque continuously to an output



Photograph courtesy of Veeder-Root Company

Fig. 12–8. High-speed industrial counters driven by an escapement system.

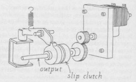


Fig. 12–9. Single-pallet machine escapement.

shaft. This remains at rest, however, until the control solenoid drives the escapement to release the output shaft briefly. This system is shown in Fig. 12–8, incorporated in a high-speed industrial counter. The speed of this counter is much higher than that which could be obtained reliably from a low-cost ratchet, inverse escapement, etc.

In a single-pallet machine escapement (Fig. 12–9), the output shaft will rotate one revolution every time the solenoid is actuated. The scape lever has only a single pallet, therefore the solenoid can only be actuated momentarily if the pallet is to re-engage the scape wheel in time to catch it at the end of the first revolution.

The device shown in Fig. 12–10 is a solenoid actuated escapement used to control the motion of a

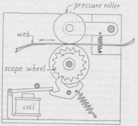
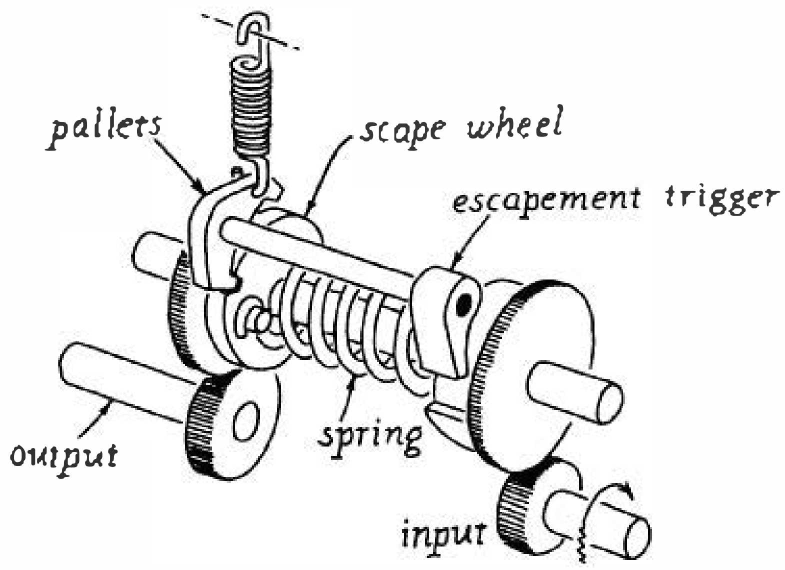


Fig. 12–10. Solenoid actuated escapement for controlling the motion of a web or belt. (U.S. Patent 3,504,558; W. J. Zenner.)



Drawing courtesy of MACHINE DESIGN Magazine; Dec. 23, 1965: p. 121 ff

Fig. 12–11. Load-and-fire escapement.

web or belt. The scape wheel could be powered by a stalled motor (not shown).

The input shaft of this load-and-fire escapement (Fig. 12–11), rotates continuously. The spring is wound until the escapement trigger on the right-hand side is driven outwards by a cam fastened to the large gear on the right. This action moves the scape lever, allowing the scape wheel to be driven by the spring. Both dwell and cycle times are controlled by the mechanism.

Figure 12–12 shows another load-and-fire escapement. In this design, a clock spring is used to increase the amount of energy which can be stored in the system between index cycles. The motor should be a stallable motor in the arrangement shown, or a

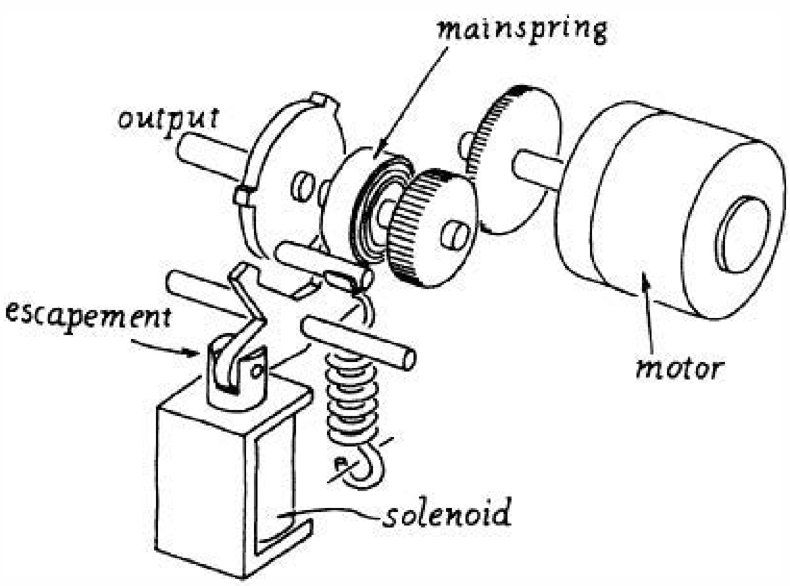


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Fig. 12–12. Load-and-fire escapement with clock spring for storing energy between index cycles.

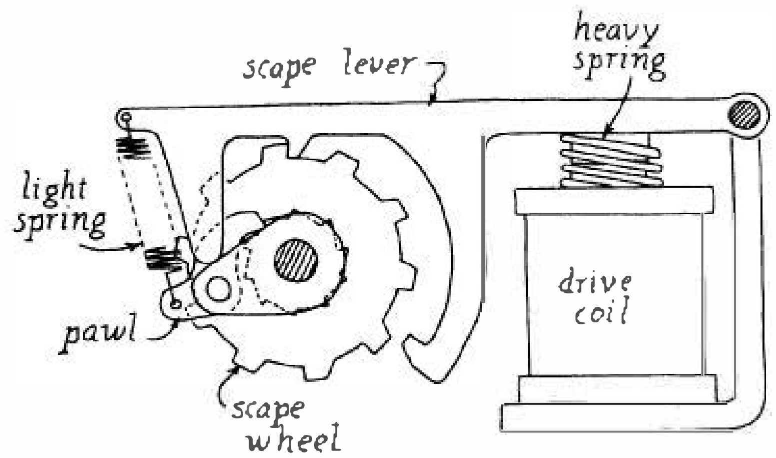


Fig. 12–13 Solenoid powered load-and-fire escapement.

switch of some sort should be provided to fire the escapement prior to the end-of-wind of the main spring.

In the load-and-fire escapement of Fig. 12–13, the input energy is derived from a solenoid which loads a heavy spring. When the coil is de-energized the heavy spring moves the scape lever upward, loading the light spring and then releasing the scape wheel. The heavy spring drives the light spring, which drives the pawl, which drives the scape wheel—until this latter is caught by the lower scape lever pallet. The scape wheel does not rotate further when the drive coil is re-energized. (There should also be a no-back pawl since the input here is through a ratchet mechanism.)

The input of the low-cost load-and-fire escapement in Fig. 12–14 winds the spring of the right-hand shaft until the mutilated cylinder on the left-hand shaft releases the long scape lever (which is mounted on the right-hand shaft for bearing purposes, but which is not fastened to that shaft). This is actually

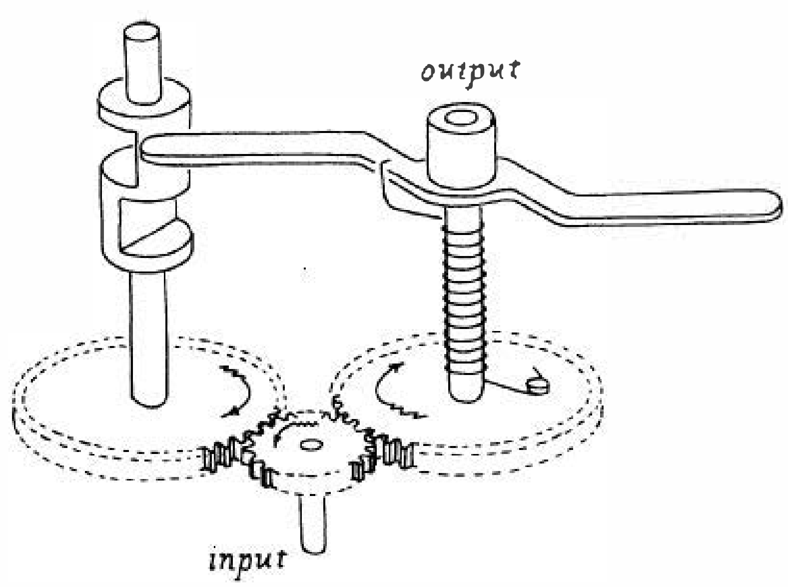
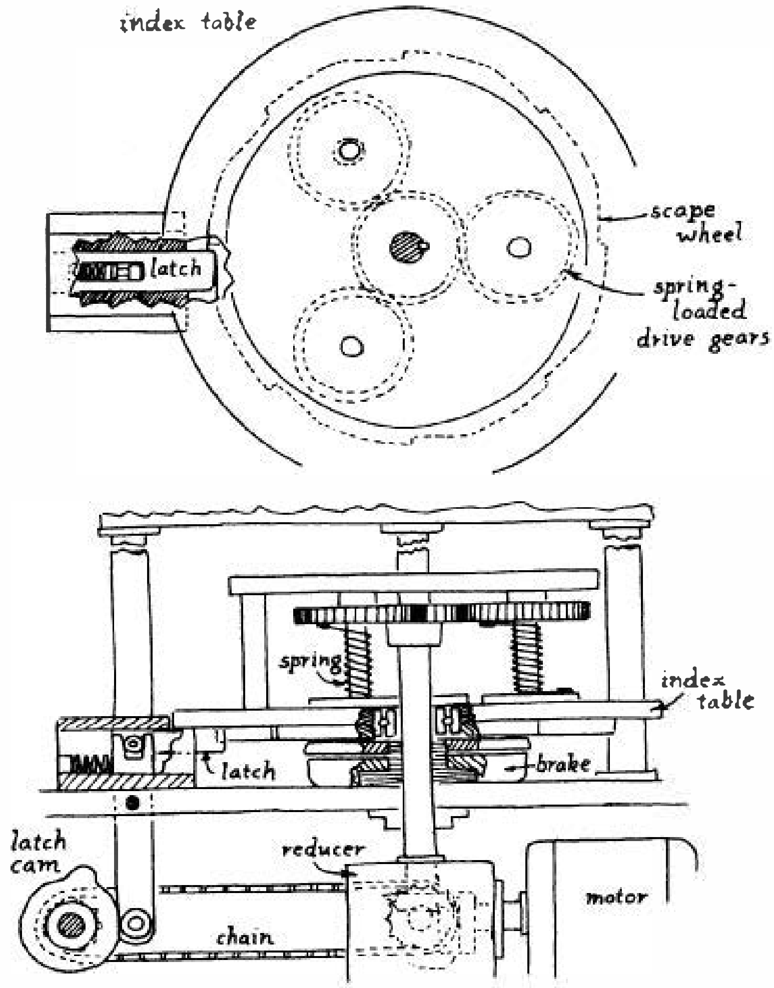


Fig. 12–14. Low-cost load-and-fire escapement.



Developed by J. W. Rieck and A. L. Van Nest; Western Electric Company

Fig. 12–15. Heavy-duty load-and-fire machine escapement for indexing a large machine tool table.

a very simple arrangement in which both dwell and cycle times are controlled by the input.

The heavy-duty load-and-fire machine escapement in Fig. 12-15 is used to index the table of a large machine tool. It is the same type of device as in Fig. 12–14, but with significantly different details. The motor (lower right) winds three large coil springs which are connected to the indexing table through gears. The motor also drives a cam (lower left) which eventually operates a spring-loaded latch releasing the table for one step.

Another load-and-fire mechanism is this escapement (Fig. 12–16A), from a business machine. The "incrementing" wheel (we would have called it a scape wheel) is continuously urged to rotate by a spiral spring (*25*), which is kept wound by a friction drum (*27*). The incrementing wheel, however, is prevented from rotating if solenoid (*70*) is de-energized. A wheel with *flexible teeth* (*50*), serves as the scape "lever." It rotates continuously, periodically escaping the incrementing wheel as long as the solenoid is energized. When the incrementing wheel is held by the solenoid the scape lever wheel (*50*), can still rotate because it has flexible teeth as shown in Fig. 12-16B. Input to this wheel and to the spiral spring, therefore, can be continuous.

A drive roller in the three-piece escapement shown in Fig. 12–17, is frictionally connected to a small cam which contains a wedging tooth. A pair of spring arms constitutes the scape lever (designated as "escapement" in the illustration). When the scape lever is moved toward the left, the drive roller rotates the cam counterclockwise until a resilient wedging tooth contacts the output cam. The wedging tooth and then the drive roller will now drive the output cam until the cutout in the output cam is again positioned opposite the drive roller, as shown in the illustration. At this point motion ceases. The wedging tooth by this time has moved past engagement with the output cam and the tooth carrier has been trapped by the right-hand arm of the scape lever. Moving the scape lever to the right releases the cam to return to the position it had at the beginning of the cycle. This escapement, then, produces one revolution in the output every time the escapement lever is actuated.

Two electrical coils are used to aid permanent magnets in this escapement from a high-speed business machine, Fig. 12–18. An iron scape bar mounted on the end of the spring is captured by the upper or lower permanent magnet until one of the electrical coils is energized; at which point the scape bar will be released by one magnet and captured by the other. Energizing the coils in the proper sequence, therefore, moves the scape bar rapidly up and down, thus releasing the output drum.

The input member of the controlled-output escapement shown in Fig. 12-19 not only drives the scape wheel but releases it as well, and thereby controls output speed, which is rare in an escapement. The scape lever is driven out of engagement with the scape wheel by the rotation of the scape wheel, and is again locked into engagement with the scape wheel during dwell periods by the input cam. This is apparently quite an old design (see Fig. 7–2 for an example).

Figure 12–20 shows a breakaway drawing of a business machine escapement. This highly developed mechanism was designed for the IBM Selectric typesetter. As with the ratchet mechanism of Fig. 7-41,

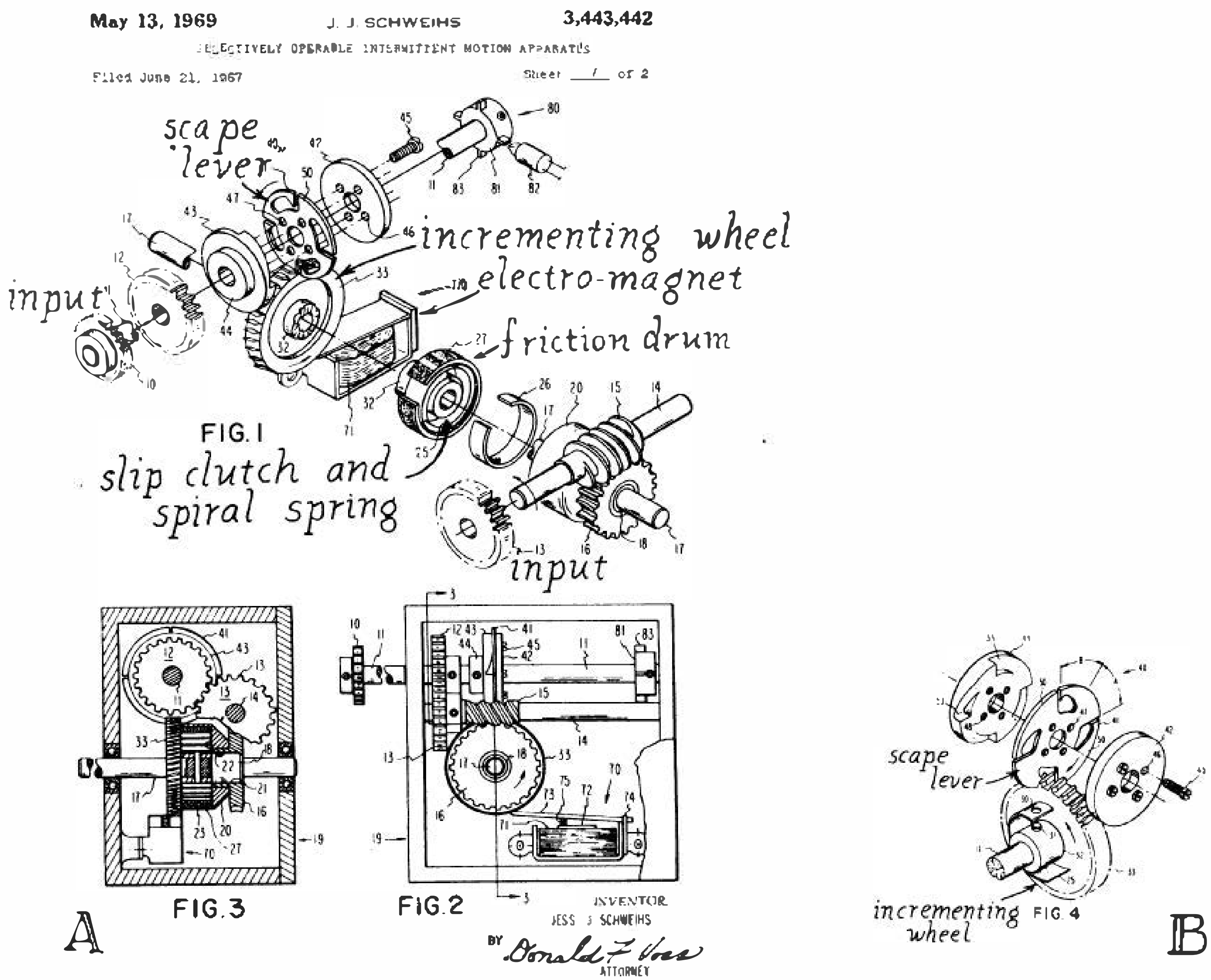


Fig. 12-16. Business machine escapement. Note how in detailed diagram B, at right, portions of scape lever flex to engage teeth in incrementing wheel. (U.S. Patent 3,443,442; J. J. Schweihs.)

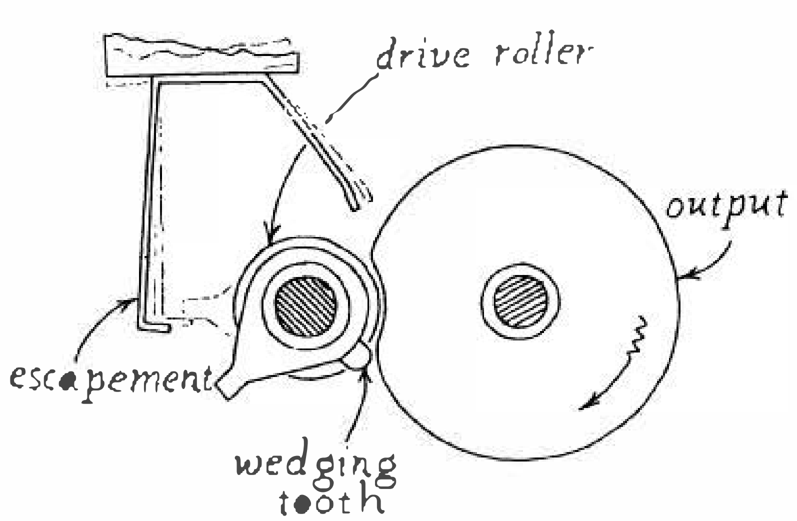


Fig. 12-17. Three-piece escapement with friction drive. (U.S. Patent 3,446,086; J. R. Peltz, et al.)

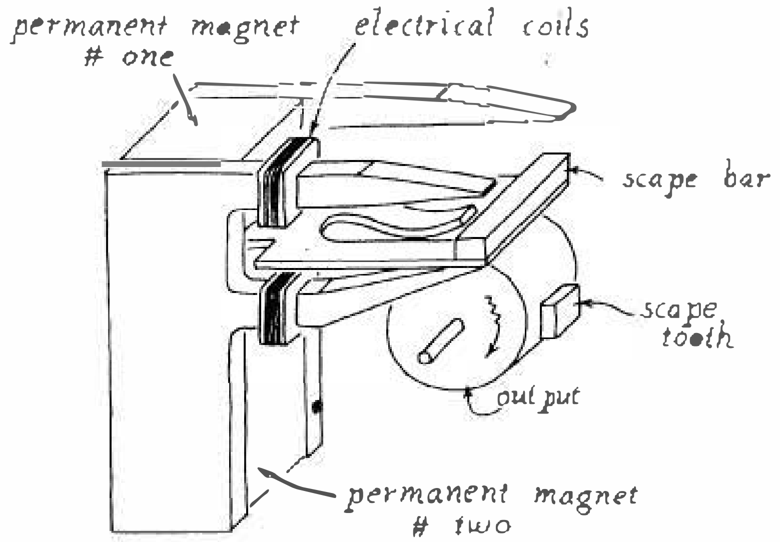
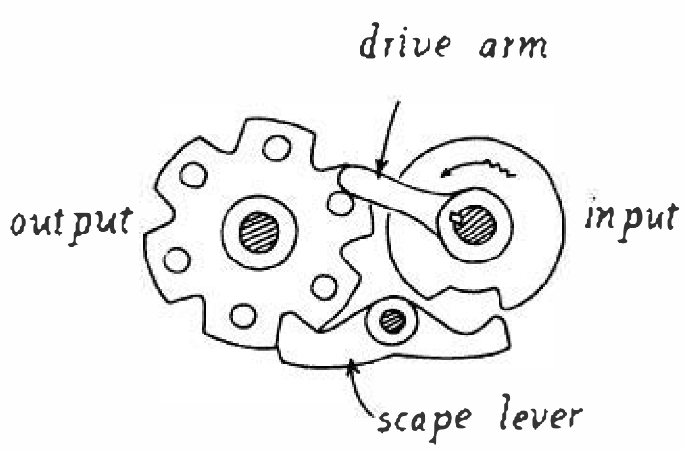


Fig. 12-18. Escapement from a high-speed business machine. (U.S. Patent 3,432,695; J. G. Sims, Jr.)

it was necessary to provide for motion steps of varying lengths. This has been accomplished, in part, by providing change gears to control the ratio between the motion of the carriage lead screw and motion of the escapement. The change gear arrangement, with the sliding collar "clutch" used to couple one of three gears to the gear changer shaft, is best shown in Fig. 12–20. The carriage lead screw can also be seen in this illustration. To provide additional variation in the length of the motion steps, the teeth of the scape wheel were made of sliding pins rather than fixed pins, which can best be seen in Fig. 12–21A. Each pin can be moved laterally out of engagement (or into engagement) with the single-pallet scape lever. The mechanism which controls the pins is shown in Fig. 12-21B; the scape lever is shown in Figs. 12-21A and 12-21C.

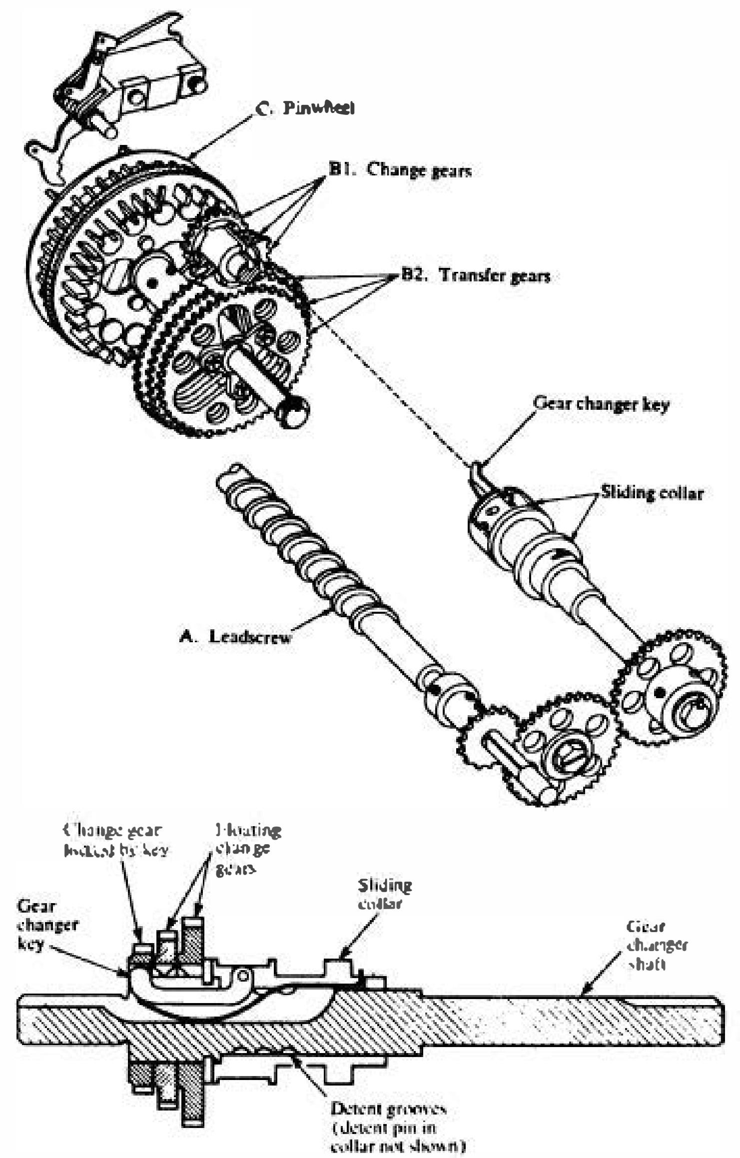
The pin set and clear bars shown in Fig. 12-21B are controlled by logic circuits in the machine, so that different motion steps can be taken for different type fonts and for different characters: a "w" would require a longer step than an "i", for example.

The escape lever in Fig. 12-21C shows the type of refinement that goes into the design of high-speed, high-quality intermittent motion mechanisms. Although only one pallet assembly is provided, there are really two pallets; nearly identical and operating beside each other. One of these is free to jump ahead of the other to catch the next extended pin on the scape wheel, cushioning the impact required to stop the wheel, and improving the reliability of the system by giving the principal pallet more time to re-engage the wheel. See also Fig. 12–3 for a similar, but simpler arrangement.



Drawing courtesy of PRODUCT ENGINEERING Magazine; Dec. 20, 1965: pp. 86-93

Fig. 12–19. Controlled output escapement.



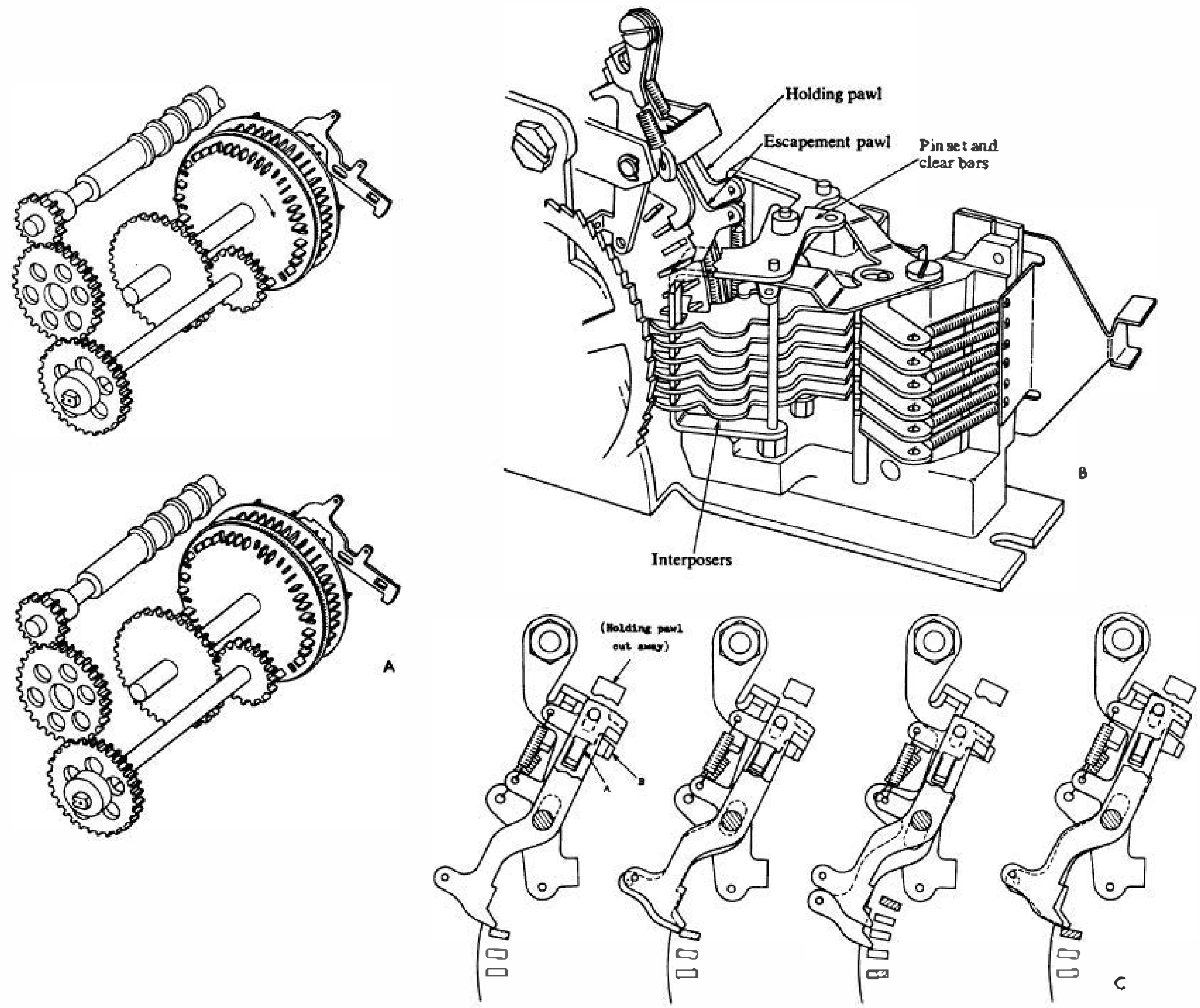
Drawings courtesy of B. W. Miles and C. C. Wilson, IBM Journal of Research and Development; Vol. 12, No. 1, Jan. 1968: pp. 48–59

Fig. 12–20. Business machine escapement.

INVERSE ESCAPEMENTS

Description of Inverse Escapement

Figure 12–22 shows a typical inverse escapement designed for an instrument application; in this case, a high-speed electrical counter. At first glance this looks like a machine escapement with the scape lever being controlled by a solenoid. Notice the size of the solenoid, however. In the inverse escapement the power flow has been altered: the verge arm (or scape lever) drives, rather than releases, the ratchet wheel. All input energy is derived from the drive solenoid and return spring. I have called the "scape wheel" a ratchet wheel, to further emphasize that this system operates more like a ratchet than an escapement.



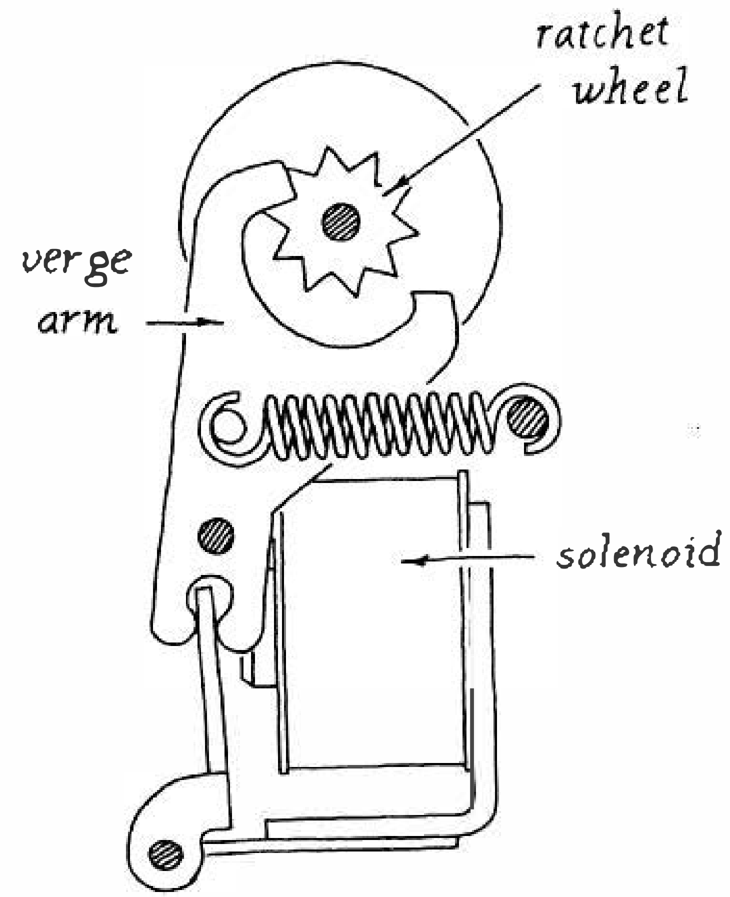
Drawings courtesy of B. W. Miles and C. C. Wilson. IBM Journal of Research and Development; Vol. 12, No. 1, Jan. 1968: pp. 48–59

Fig. 12–21. Details of business machine escapement in Fig. 12–20.

The inverse escapement functions very much like a ratchet but it is simpler than a ratchet. Notice the absence of no-back and non-overthrow pawls, for example, which are required in a ratchet to improve control. In a properly designed inverse escapement, just as in a machine or a clock escapement, one pallet of the verge or scape lever is always in position to interfere with the free rotation of the output wheel which, as a result, can never get ahead of or behind the intended drive position. The inverse escapement, of course, is a cam system in which the "follower" is driving the cam. Like the machine escapement, it is not a very popular device, but it should be more popular than it is. I am sure there are many machine designs now using ratchets that could be improved by the use of an inverse escapement.

Advantages and Disadvantages of Inverse Escapement

The inverse escapement is a very simple device. As a result, its reliability and cost are probably more attractive than those of a ratchet, which is its nearest competitor. It is probably a little better at load control than a good ratchet (by "good" ratchet is



Drawing courtesy of MACHINE DESIGN Magazine; Dec. 22, 1966; p. 121 ff

Fig. 12–22. Typical inverse escapement.

meant one with proper non-overthrow teeth, no-back pawl, etc.); especially at very high speeds. It is possible, however, for the ratchet wheel on the inverse escapement to rebound and back up if it is forced to operate at too high a speed.

Like other escapements, of course, this one produces impact, probably to about the same extent as a ratchet. This means that it is usually used only in relatively light-duty applications, although unlike a machine escapement, the inverse escapement can handle heavy loads at slow speeds as we shall see later in Figs. 12–33 and 12–35. The steps it takes must be fairly short, so the motion times are relatively short and cannot be extended. The necessity to maintain a good cam angle between verge and output wheel (to guarantee adequate drive torque) also limits the number of stops which this device can make per output revolution. (See Fig. 8–3 for further discussion of this point.)

It is doubtful that a successful inverse escapement could be built which would take fewer than two, or three, or more than 100 steps per revolution. However, it is always possible that a clever designer could find a way around any flat statement of that sort! But, at least, such has been my experience.

Motion Curves of Inverse Escapements

The motion curves of inverse escapements are essentially the same as those of impulse ratchets as will be seen later, in Fig. 12–23. When the verge arm strikes the ratchet wheel, the wheel will start to rotate but the arm will rebound. The solenoid brings the arm back under control and moves it back into the wheel for a second blow. After four or five separate impacts of this kind, the arm and wheel will move together to complete the stroke. When the arm has reached the bottom of the wheel tooth, the wheel will come to rest. Since there is some play between wheel and drive teeth, and since the arm will rebound again at the end of the stroke (increasing the backlash a little), the stopping process will also consist of a series of impacts as shown in the curves.

Figure 12-23 depicts motion curves for a typical inverse escapement. Note that these are the same

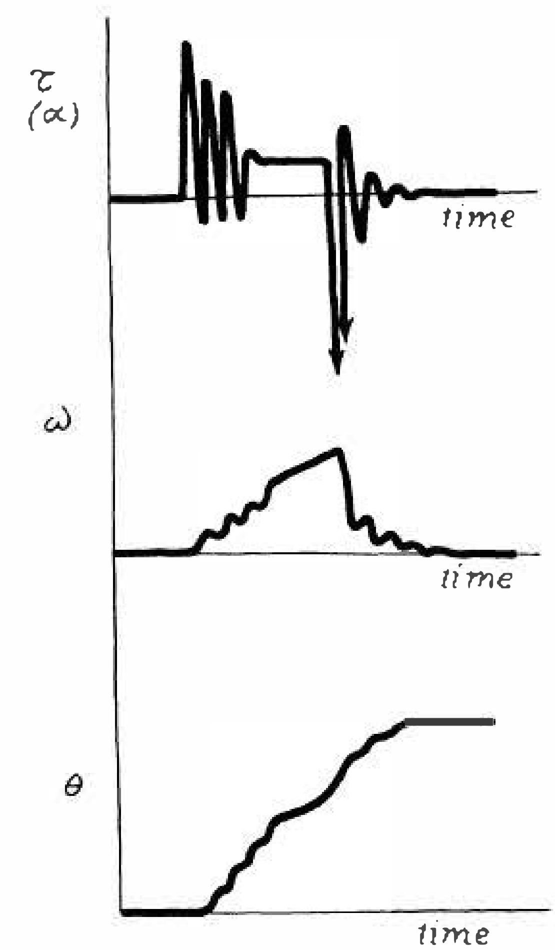
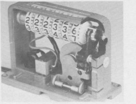


Fig. 12–23. Motion curves for a typical inverse escapement.



Photograph courtesy of the Veeder-Root Company

Fig. 12-24. Electrical counter driven by the inverse escapement of Fig. 12-22.

as the curves for an impulse ratchet as shown in Fig. 7-10.

In Fig. 12-24 the photograph shows an electrical counter driven by the inverse escapement of Fig. 12-22. A portion of the frame of the counter has been removed to reveal the driver more clearly.

In the design of a single-pallet inverse escapement, seen in Fig. 12-25, a continuously rotating input cam operates a single-pallet verge. Note that a detent roller is required to control the output during dwell periods since only a single-pallet is used.

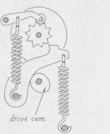


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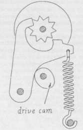
Fig. 12-25. A single-pallet inverse escapement.

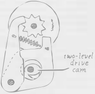


Drawing courtesy of MACHINE DESIGN Magazine; Dec. 23, 1965; p. 121 ff

Fig. 12-26. Inverse escapement with continuously rotating input.

Otherwise the same as Fig. 12-22, the inverse escapement shown in Fig. 12-26 has a continuously rotating input.

There is a period during each drive stroke in an inverse escapement when the wheel is very loosely controlled, although it is not completely free. This can cause troubles which can be avoided, however, if each pallet is separately driven so that the "holding" tooth could be left in engagement with the output wheel until the next "drive" tooth has com-



Drawing courtesy of MACHINE DESIGN Magazine; Dec 23, 1965; p. 121 ff

Fig. 12-27. Inverse escapement with continuously rotating input and separate drive for each pallet pleted its pre-travel and is ready to index the wheel. The two-level cam arrangement shown in Fig. 12–27 would produce this kind of drive sequence; i.e., a continuously rotating input and a separate drive for each pallet.

In a bidirectional inverse escapement (Fig. 12–28), when the clockwise coil is energized it will rotate the output wheel 18 degrees, first driving the spring-loaded lower arm downward to release the output wheel. When the coil is de-energized, the spring loaded arm is released and will engage the wheel to drive it an additional 18 degrees, thereby turning the output wheel a total of 36 degrees for each excitation of the input coil. Energizing the counter clockwise coil will produce the same results but in the other direction. This mechanism is used in a high-speed electrical counter made by the Citizens' Watch Company of Japan.

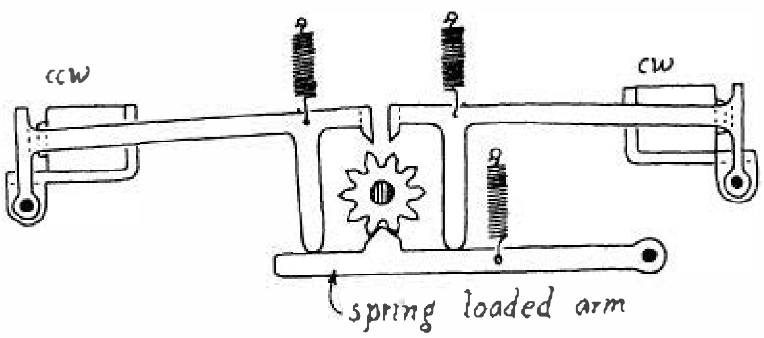


Fig. 12–28. Bidirectional inverse escapement.

A low-cost inverse escapement with magnetic drive for the second half of each stroke is shown in Fig. 12–29. When the input cam pulls down the spring the magnet (which is located behind the wheel) will rotate the iron output wheel a few degrees counterclockwise, since the magnet is nearer to tooth *a* than to tooth *b*. When the cam releases the drive spring it will move upward and cam the wheel into the next position, corresponding to that shown in the illustration, to complete the drive stroke. (U.S. Patent 3,504,306; D. Fritsch.)

The motion of the side-acting inverse escapement device in Fig. 12–30 is basically the same as that of Fig. 12–22, but in this case the action is sideways. To see why these devices are called "escapements" even though they are drivers, compare this drawing with Fig. 11–7.

Figure 12–31 illustrates an axial inverse escapement. The three, toothed members in this illustration are cylinders. The center one is prevented from ro-

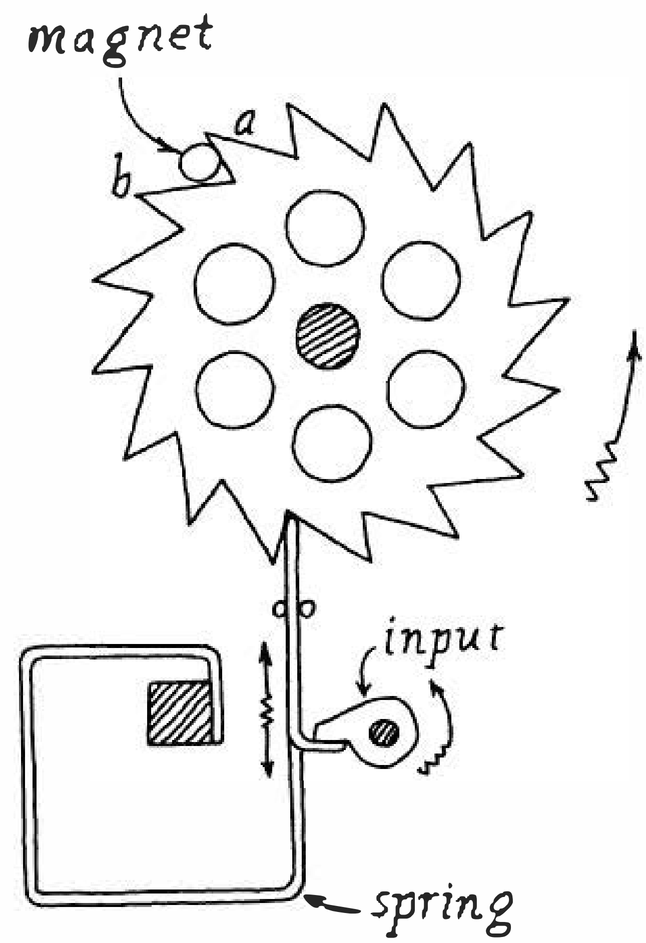
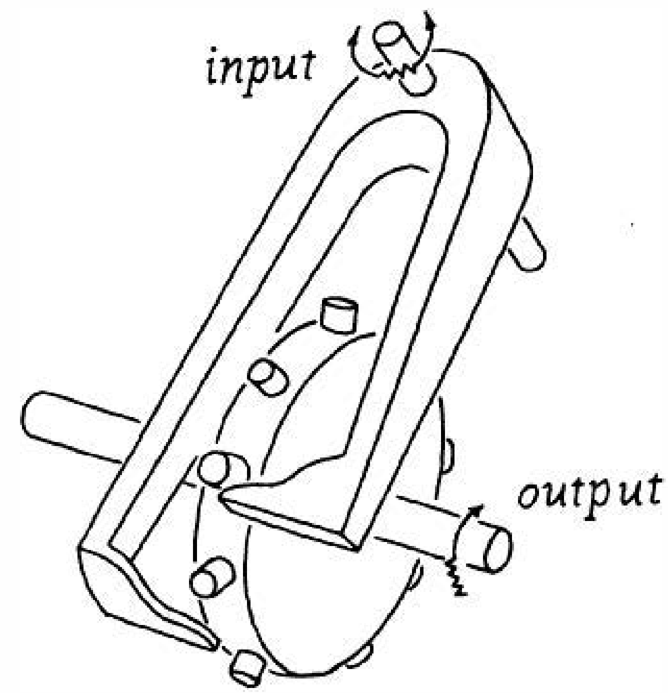


Fig. 12–29. Low-cost inverse escapement with magnetic drive for the second half of each stroke. (U.S. Patent 3,504,306; D. Fritsch.)



Drawing courtesy of MACHINE DESIGN Magazine; Dec. 23, 1966; p. 121 ff

Fig. 12–30. Side-acting inverse escapement.

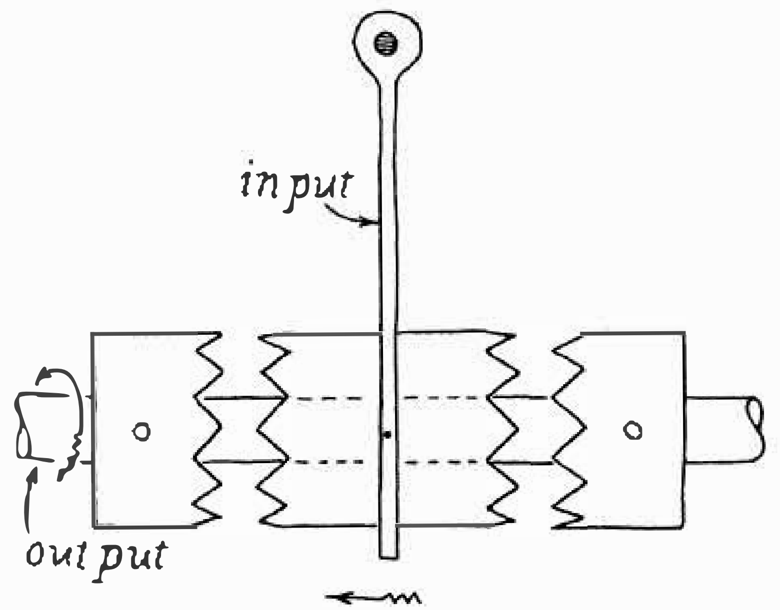


Fig. 12-31. Axial inverse escapement.

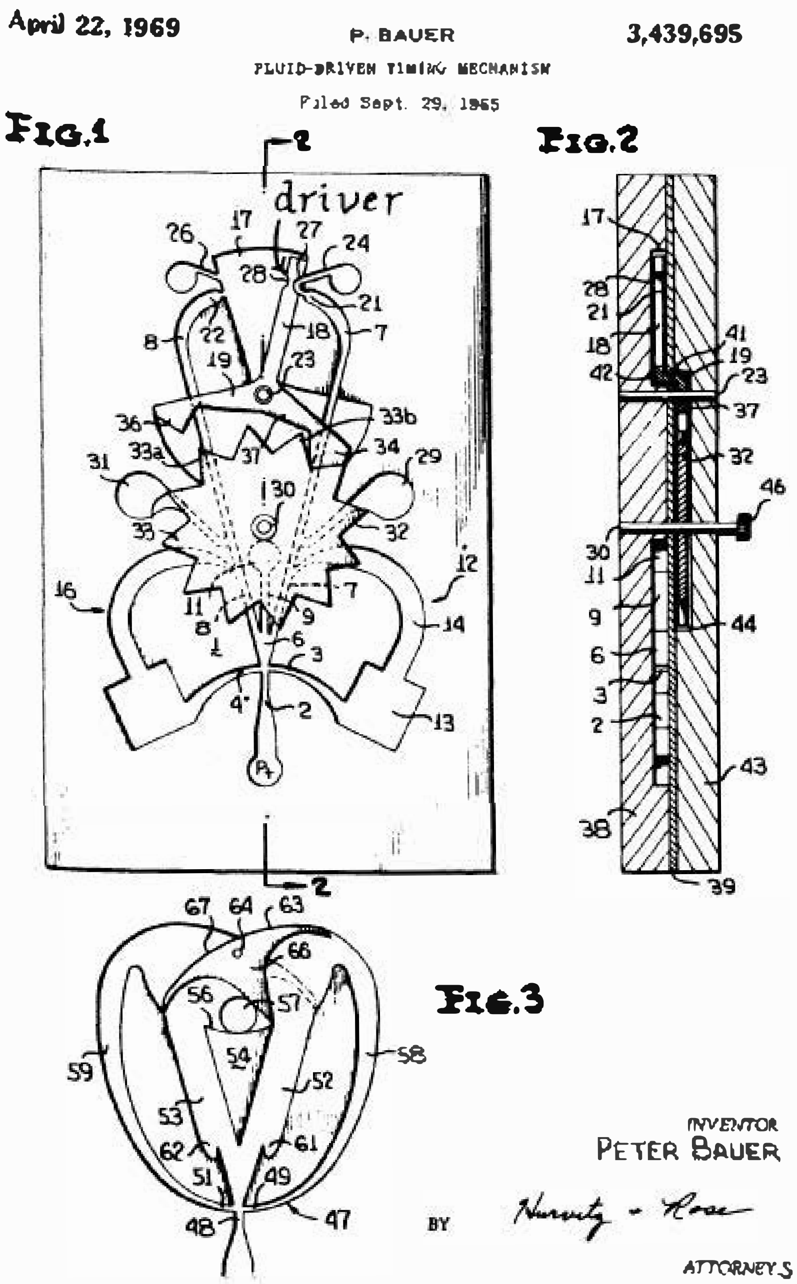


Fig. 12-32. Fluidic inverse escapement. (U.S. Patent 3,439,695; P. Bauer.)

tating, and is moved back and forth, as shown, alternately engaging the cylinders on the left- and right-hand ends of the shaft, both of which are pinned to the shaft. This indexes the shaft.

The principle of the fluidic inverse escapement shown in Fig. 12-32 is the same as that of Fig. 12-22, but here the driver (*28*) is powered by jets of fluid rather than by a solenoid.

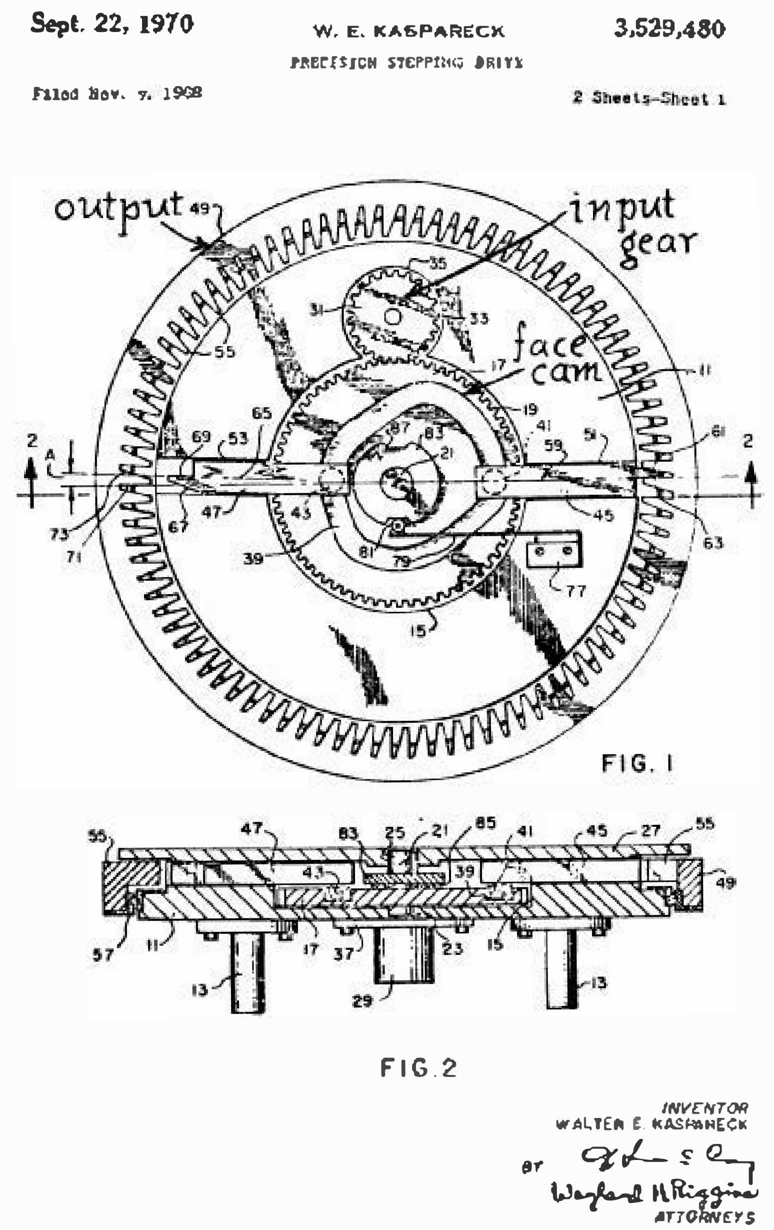


Fig. 12-33. Inverse escapement for an aerospace application. (U.S. Patent 3,529,480; W. E. Kaspareck.)

The design for the inverse escapement for an aerospace application shown in Fig. 12-33 was conceived at the National Aeronautics and Space Agency. Input is through gear (*31*) which rotates face cam (*17*) to move the drive arms in and out of engagement with the teeth of the output member (*49*). NASA says this device produces better torque with greater precision than a conventional gear train. The sequence of operation of the inverse escapement is shown in Fig. 12-34. A design such as this could handle a very heavy load but only at a relatively slow speed.

In the inverse escapement of Fig. 12-35, used on a heavy-duty machine tool, the drive member (*21*) reciprocates rather than rotates, but the principle is still basically the same. Again, this escapement would

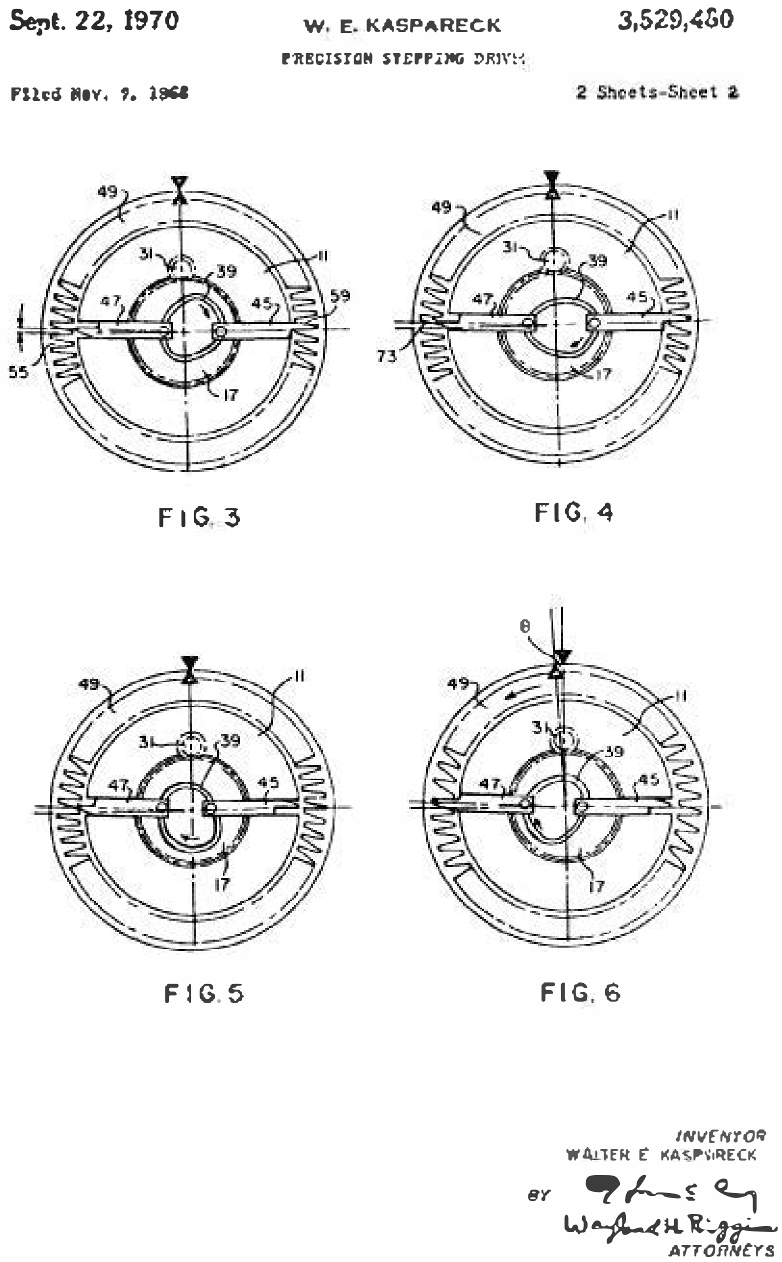


Fig. 12-34. Sequence of operation of stepping drive shown in Fig. 12-33. (U.S. Patent 3,529,480; W. E. Kaspareck.)

be suitable for heavy loads if the speed were low enough.

Among the miscellaneous inverse escapements from high-speed electrical counters in Fig. 12-36, notice the similarity between sketch *D* and Fig. 12-35.

The double-arm inverse escapement in Fig. 12-37 looks less like an escapement and more like a cam

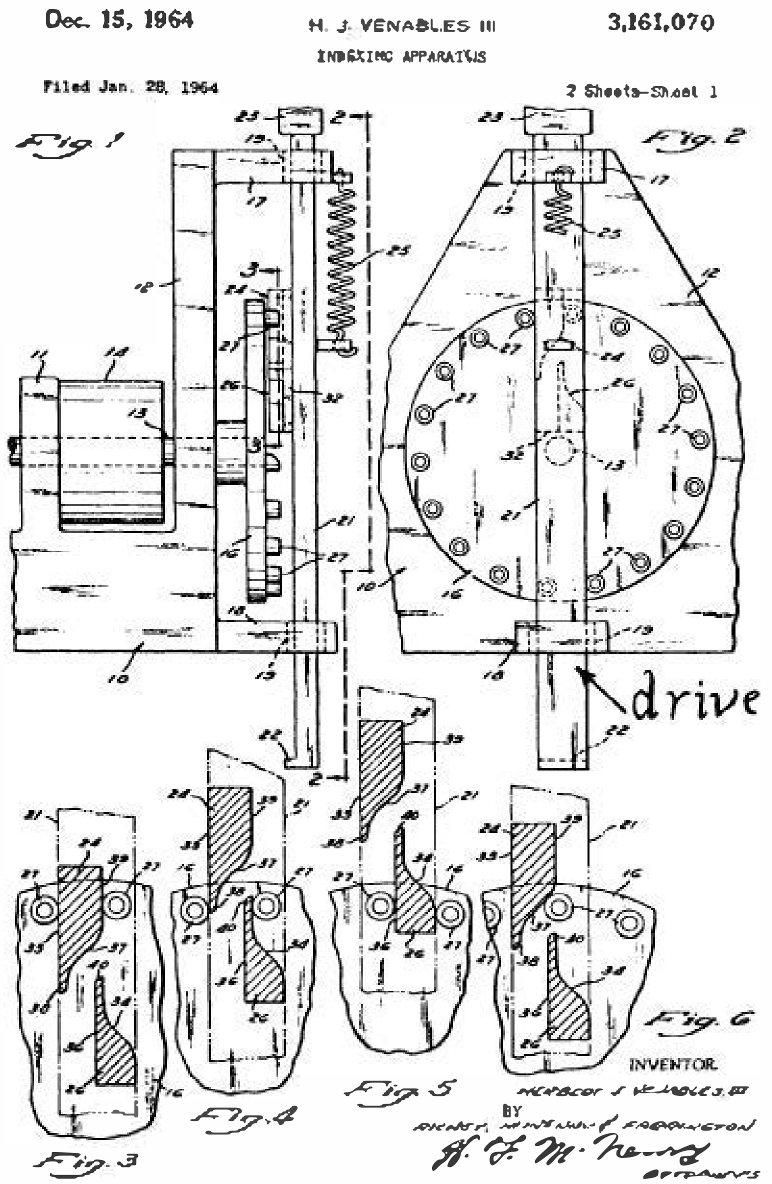
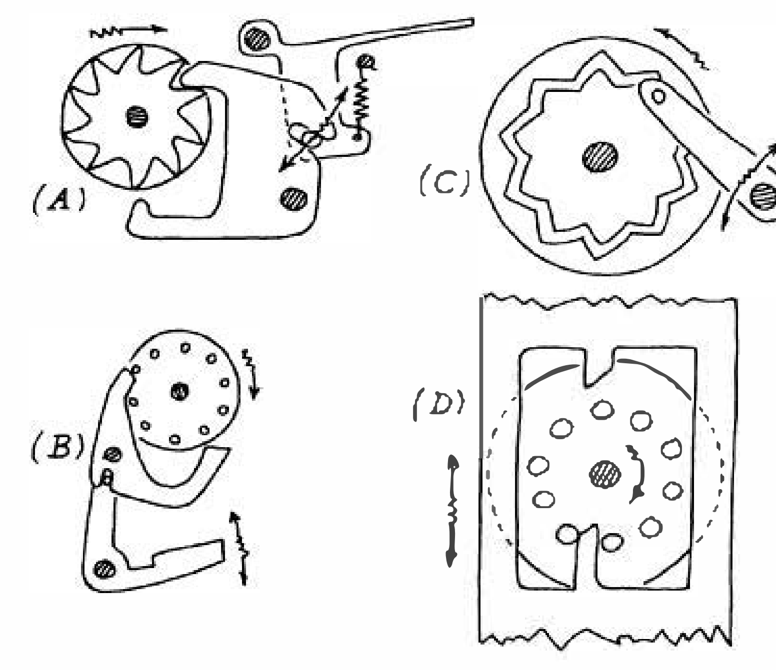


Fig. 12-35. Reciprocating inverse escapement used on heavy-duty machine tool. (U.S. Patent 3,161,070; H. J. Venables, III.)



Drawings courtesy of the Veeder-Root Company

Fig. 12-36. Miscellaneous inverse escapements used in high-speed electrical counters.

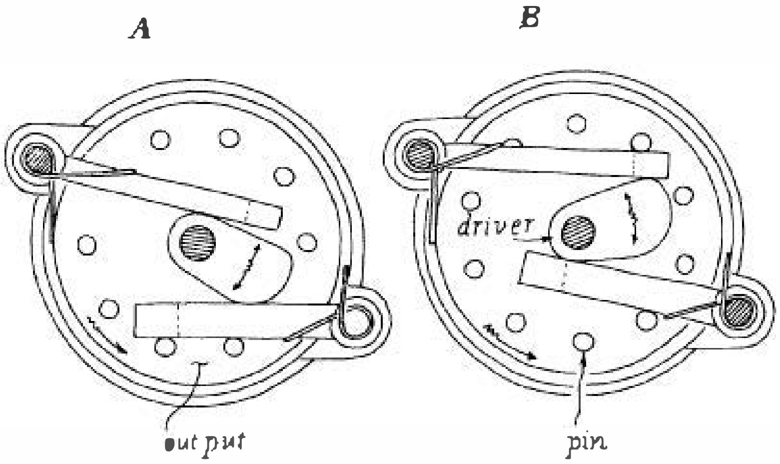


Fig. 12-37. Double-arm inverse escapement. (U.S. Patent 3,444,764; R. Greenwood.)

system than most of the devices in this chapter, but it combines the features of Figs. 12-36D and 12-27. As in 12-36D, for example, the output cam contains a circle of drive pins. These are pushed alternately by two separate drive arms, as was the design of Fig. 12-27. In Fig. 12-37, however, the input cam oscillates, rather than rotates. This motion forces the drive arms outward, alternately, engaging the pins on the output wheel. Note that the drive arms have drive "blocks" at their ends; the pins on the output wheel are able to move under the inner portion of the arms as the wheel turns. The mouse-trap springs force the drive arms to follow the input cam.

Anatomy of an Inverse Escapement

Let us now review the component parts of an inverse escapement device as seen in Fig. 12-38:

A. Output wheel—joined to C; B. Verge or drive arm—serves as drive pawl, non-overthrow pawl, and no-back pawl making this mechanism simpler than a ratchet having the same speed capability; C. "Ratchet" or "star" wheel—teeth must be shaped to provide proper cam angles for the forces received from the verge. It is the principal wear point; D. Drive solenoid—attracts the clapper, which moves the verge, which indexes the wheel. It would take another book to describe all the factors which could be considered in the proper design of a relay movement such as this. Such factors as the coil constant, the time constant, eddy current losses, I^2R losses, form factor, residual magnetic effects, bounce, flux levels, leakage losses, temperature rise, air gap, etc., all influence performance; E. Return spring—with a ratchet we can choose direct drive or spring drive. With an inverse escapement, alternate steps are spring driven and power driven. The spring (which is loaded by the solenoid during the power step) must be strong enough to move the verge, wheel, and clapper fast enough to maintain the desired stepping rate; but the spring must be kept as light as possible to minimize power requirements, impact stress, and wear rates; F. Air gap—usually must be adjusted in production if optimum performance is desired. It affects such things as power consumption, operating speed, impact levels, and ultimately (after wear), whether or not the solenoid driver produces enough motion in the output wheel to put the wheel in the correct position to receive the next blow from the next verge tooth; G. Clapper hinge—must not be in the magnetic circuit since magnetic flux has a way of "gluing" moving parts together; H. Bearings—must be large

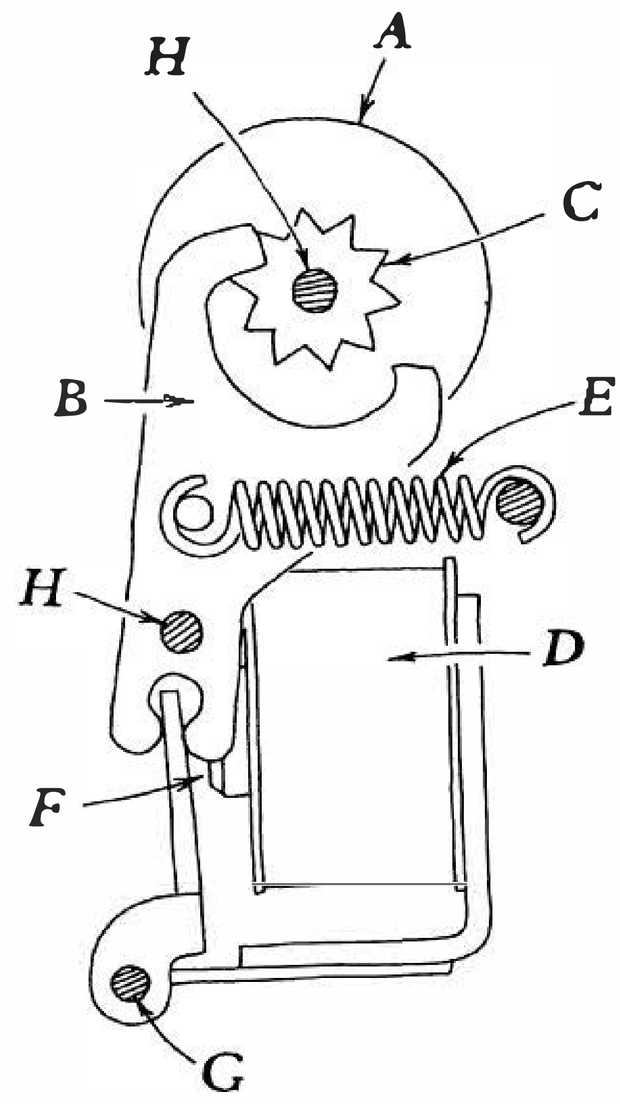
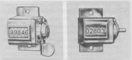


Fig. 12-38. Anatomy of an inverse escapement.

enough in diameter to withstand the repeated impacts to which this system is exposed; yet small enough in diameter to minimize bearing friction torque.



Photograph courtesy of the Veeder-Root Company

Fig. 12-39. (*Left*) Small mechanical counter designed and built by Curtis Veeder in [illegible] of the same counter.

[illegible]

Inverse escapements are widely used today in electro-mechanical counters, having almost replaced ratchets for most applications. Stepping motors are also used in some instances, however, when extreme speed and very long life are required. Mechanical counters generally rely on intermittent gearing of some sort. Figure 12-39 shows a small mechanical counter designed and built by Curtis Veeder in 1895; and also a modern version of the same counter. This latter uses the same mechanisms as its predecessor, but is constructed with the newest materials and techniques. The contemporary version was used in [illegible] ~~flights to the moon. From 1895 to~~ [illegible] pressive "life" for a single design.