CHAPTER 7

Ratchets

General Discussion

The ratchet is one of the oldest of all mechanisms. As such, it was probably the first intermittent motion mechanism, and was certainly the most common during the first century of the industrial revolution. Leonardo Da Vinci's notebooks are full of ratchet applications, and they were probably in use centuries before he came along. Most of these early applications, however, seem to have used the ratchet for mechanical advantage rather than to produce intermittent motion, the latter really being a product or need of the industrial revolution. Leonardo's ratchets, for example, are usually used to control engines of war; a man winds a catapult or crossbow, and the ratchet allows him to do this in short, easy steps, resting (dwell!) between exertions (index!). The drawing of the early machine (Fig. 7–1A), shows ratchets used to convert the continuous, relatively high-speed rotation of windmill sails into the slower, nearly continuous rotation of the rear wheels of a vehicle. I am sure the designer (who was not Leonardo, in this case) would prefer both input and output to be continuous here, but he settled for the wind and the ratchet. Figures 7–1B and 7–2A and B, showing some of the demonstration models built about 1876 by The Science Museum in London, give some indication of the number and variety of ratchets which were known a long time ago. It is interesting to note that such things as Genevas, star wheels, and escapements are also included in these photographs of "ratchet trains."

In any event, the ratchet is a logical place to start a discussion of different types of intermittent motion mechanisms. Another thing that makes it a logical candidate for first place in this discussion is its simplicity. A toothed wheel, a pawl, and a lever are all that is required to make a simple ratchet, as shown in Figs. 7–3 and 7–4. The first of these illustrations, Fig. 7–3, also shows that a ratchet can be built with (A) compression pawls, or (B) tension pawls. Figure 7–4 shows that the input can be through the pawl or through the wheel; and that internal as well as external ratchet wheels are possible.

Simplicity is one of the big advantages of the ratchet. Other related advantages include low cost and reliability. The ratchet is also noted for its ability to carry a large load in relation to its size. It is also a versatile device and is used in an amazing number of applications ranging from moderately heavy-duty machinery to high-speed instruments.

Disadvantages of the ratchet include the fact that it is an impacting mechanism, as seen in Chapter 5. There are ways to reduce the impacts in certain versions, but impact will almost always be present to some extent, and can lead to wear, control, and stability problems unless the rest of the system is properly designed. The basic problem, of course, is that impacts produce forces throughout the mechanism that are well in excess of the subsequent drive forces, as shown in Fig. 7–5, A and B. Impact also results in noise, which is very undesirable in most applications, and "noise pollution" should soon get a lot more attention from machine and instrument

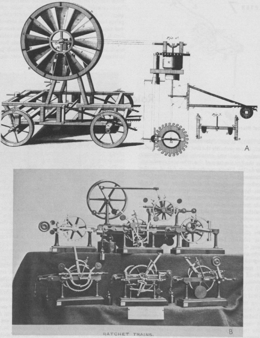


Photo. Science Museum, London

Fig. 7-1. A. Drawing of a ratchet-driven horseless carriage that was built (or proposed) about 1713. B. Display of ratchet trains in The Science Museum, London.

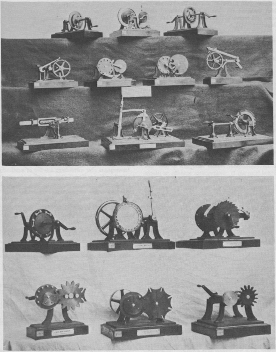


Photo. Science Museum, London

Fig. 7-2. More "ratchet" mechanisms from The Science Museum in London. Note the Genevas, escapements, etc., which are included in this display.

designers than it does at present. The business machine designers are already very concerned about noise, and recent patent literature describes many silent "ratchets."

Ratchet Geometry

Some attention must be given to pawl and wheel-tooth geometries when designing a ratchet. In Chap-

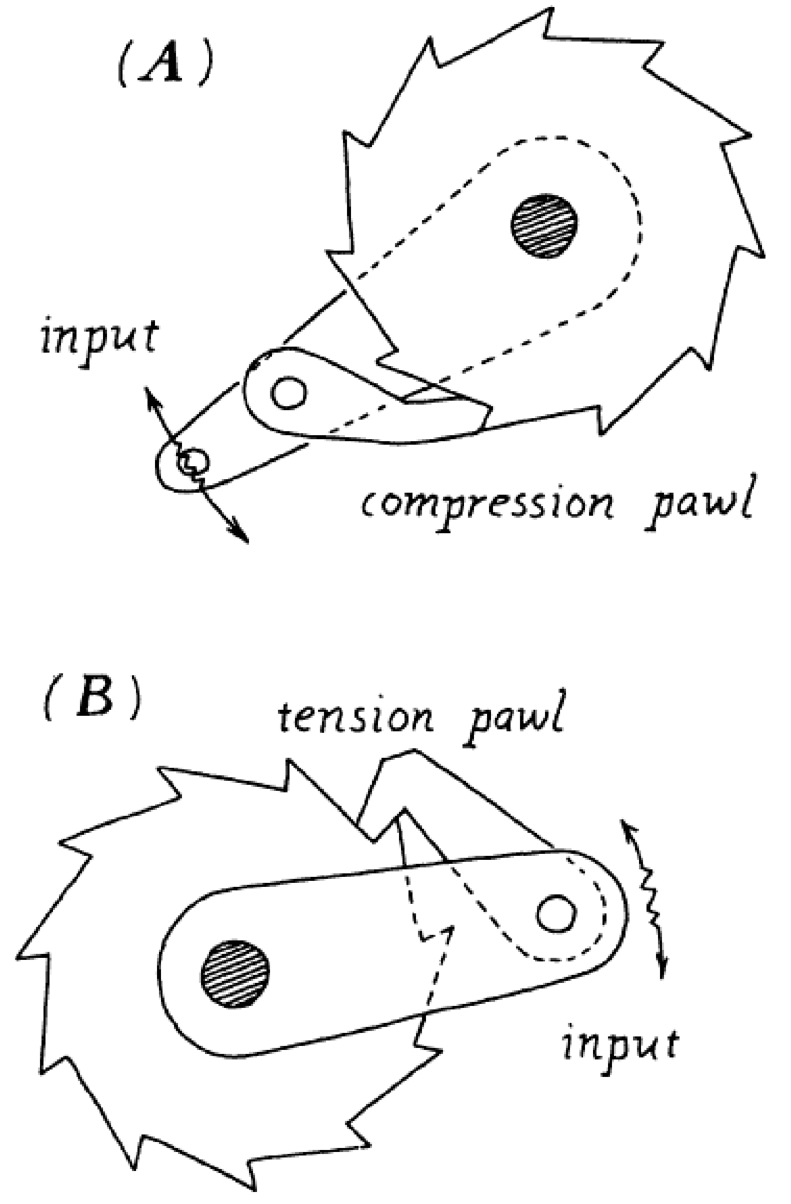


Fig. 7–3. Simple ratchet mechanisms. Example A uses a compression pawl; B uses a tension pawl. Power input is through the pawl in both cases.

ter 5, Fig. 5–11 shows that it is important to shape ratchet wheel and pawl teeth properly, to reduce impact stress and wear. Proper shape also helps the pawl engage and drive the load. In Fig. 7–6, for example, the pawl is trying to pick up the load of the ratchet wheel. The forces on the pawl as it enters the wheel tooth include a normal force and a friction force, as explained in Chapter 1. The friction force

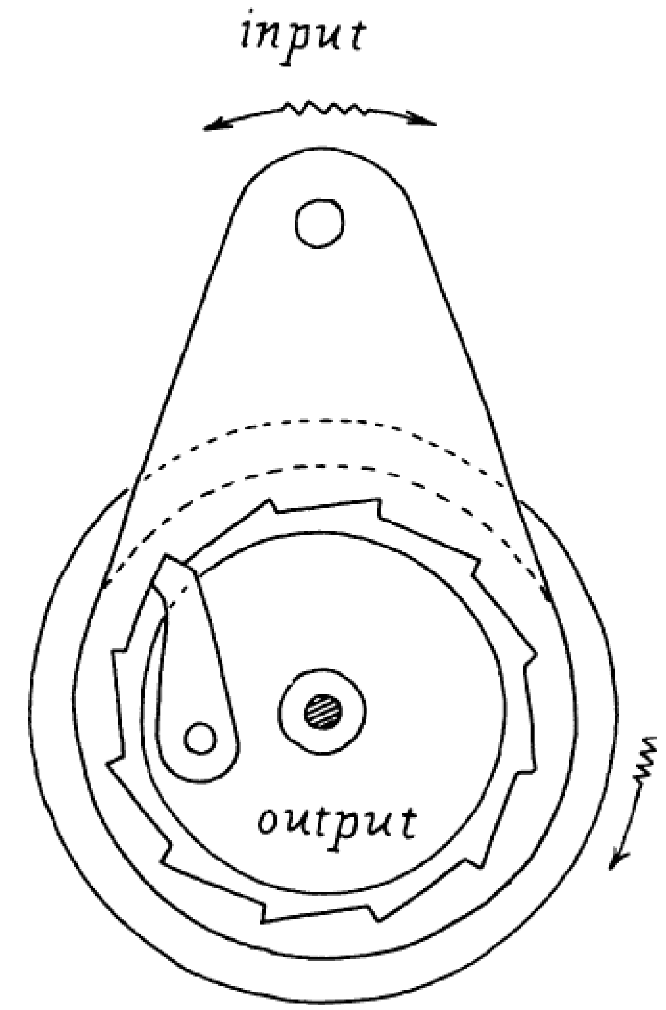


Fig. 7–4. Simple internal ratchet mechanism in which the wheel, rather than the pawl, is the input member.

opposes the *pawl* motion, of course, and so must be drawn in a direction away from the wheel, as shown.

The resultant force on the pawl is in a direction to rotate it clockwise. Yet it must rotate counterclock-

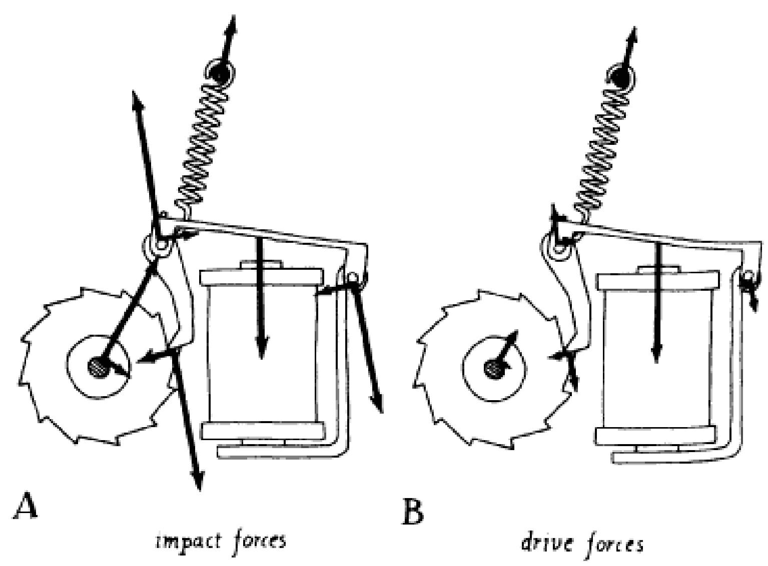


Fig. 7–5. Impact forces (A) on a ratchet mechanism are in the same position and direction as drive forces (B), but are much greater. Forces throughout the entire device are magnified by impact between pawl and ratchet wheel.

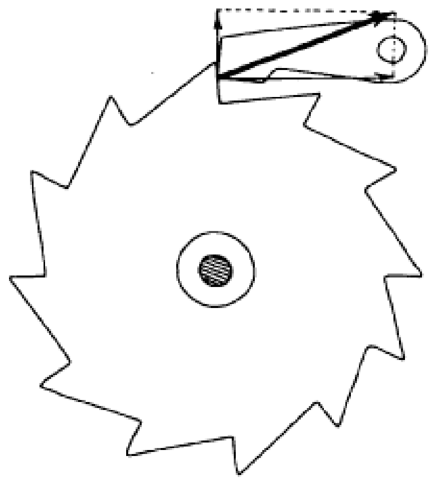


Fig. 7-6. Forces exerted by the ratchet wheel on the pawl as the pawl tries to engage the wheel. The resultant force is in a direction tending toward disengagement.

wise to pick up the wheel tooth. This tendency to disengage must be overcome by providing a spring that urges the pawl against the wheel; or the pawl and wheel teeth must be redesigned to place the resultant pawl force on the correct side of the pawl bearing, as shown in Fig. 7-7. This is usually a better solution to the disengagement problem than a pawl spring, but pawl springs are also required in many applications to get the pawl down into engagement with the wheel more rapidly than it would under its own weight. And, of course, in many designs the ratchet is not oriented in such a way as to engage the drive pawl by weight. Thus, you will see pawl springs even in "correctly" designed ratchets.

Figure 7-8 shows the same ratchet, after full engagement, while driving the load. The forces on the pawl are now those which would be present if the pawl tried to disengage itself from the wheel. Note that the friction force has now reversed, but the normal force remains the same. Note, too, that the counterclockwise torque on the pawl, in this situ-

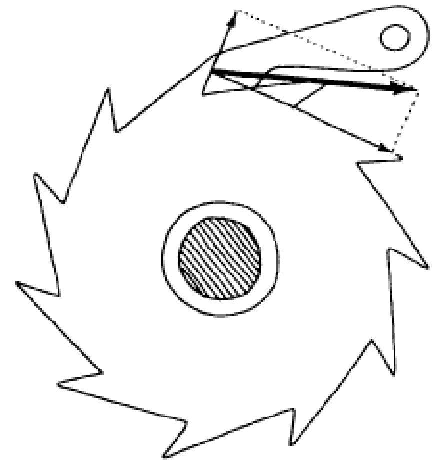


Fig. 7-7. Forces exerted by the ratchet wheel on the pawl as the pawl tries to engage the wheel. With the geometry used in this case, the net force on the pawl is in a direction to encourage engagement.

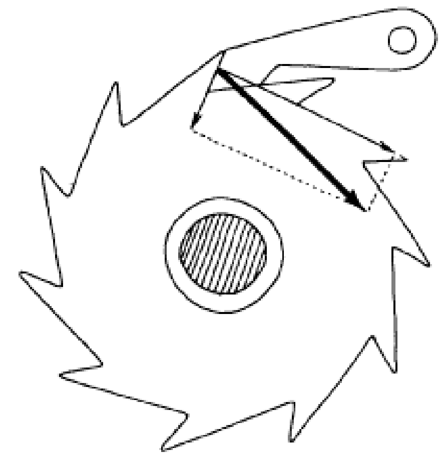


Fig. 7-8. Forces exerted by a ratchet wheel on a fully engaged pawl as the pawl tries to disengage. Note that the friction force has reversed direction from that shown in the previous illustrations.

ation, is even greater than it was during engagement. The geometry selected for proper engagement is more than sufficient for continued engagement even if the load should increase.

The location of the pawl bearing with respect to the wheel's bearing should also be given some attention. If the pawl is positioned as shown in A, Fig. 7-9, it will push almost tangentially on the wheel; an efficient arrangement. If the pawl bearing is located at too great an angle with the tangent, it will have to produce a strong cramping force on the wheel to achieve the same useful, or drive force, as shown in B, Fig. 7-9. Of course, it must be positioned at a large enough angle to result in counterclockwise pawl torque during engagement.

Motion Curves

The motion curves of ratchet mechanisms vary widely, depending upon the means used to power

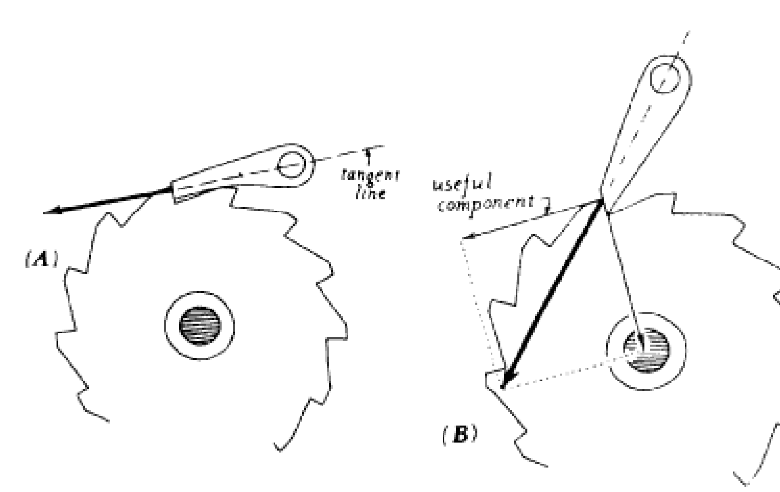


Fig. 7-9. Two pawls that produce the same tangential (useful drive) force. However, the pawl shown in B will tend to cramp the wheel since it is located at too steep an angle to the tangent.

the drive pawl. If a spring, a solenoid, or other pulse driver is used, the torque curve will look like that plotted in Fig. 4-1. If a cam drive is used, however, the motion curves will be those of Fig. 4-8, or similar. The resultant sets of curves for these two cases are shown in Fig. 7-10. Obviously, the designer should strive for the "smoother" curve set. But he may not have the option of providing a continuously rotating cam driver. If he is forced to use the solenoid or spring drive he is stuck with the impact and the "rough" curve set.

Refinements

When ratchet speeds increase, certain additional design refinements are almost always required. One

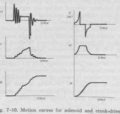
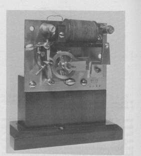


Fig. 7-10. Motion curves for solenoid and crank-driven ratchets.

of these is a no-back pawl; which prevents the spring-loaded drive pawl from dragging the ratchet wheel backwards as the drive pawl retracts to take another bite. Another, is a non-overthrow device of some sort that will prevent the ratchet wheel from moving too far under the influence of a single drive push (prevent the driver from losing control). If electrical (solenoid) drive is used the designer may wish to provide a drive spring which is set by the solenoid, rather than driving the pawl directly, to minimize impact and the effects of voltage variation.

Now let us examine a variety of ratchets: Figures 7-11 through 7-45 give a comprehensive illustrated explanation of ratchet types and the function of their parts.

Both drive and no-back pawls in this solenoid driven ratchet from a large clock mechanism (Fig. 7-11) are urged against the ratchet wheel by weights instead of by springs.



British Crown Copyright, Science Museum, London

Fig. 7-11. Solenoid driven ratchet from a large clock mechanism.

In the variable stroke ratchet shown in Fig. 7-12, the distance that the wheel is indexed will depend upon how far the input lever is pushed. This ratchet was used in a vending machine of German manufacture.

The wheel of the double-action ratchet illustrated in Fig. 7-13 is indexed during both forward and return strokes of the input crank.

The ratchet in Fig. 7-14 produces unidirectional output for bidirectional rotation of the input shaft. Springs on the arms allow the ratchet teeth to disengage from the wheel during the return stroke.

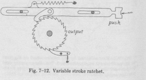


Fig. 7-12. Variable stroke ratchet.

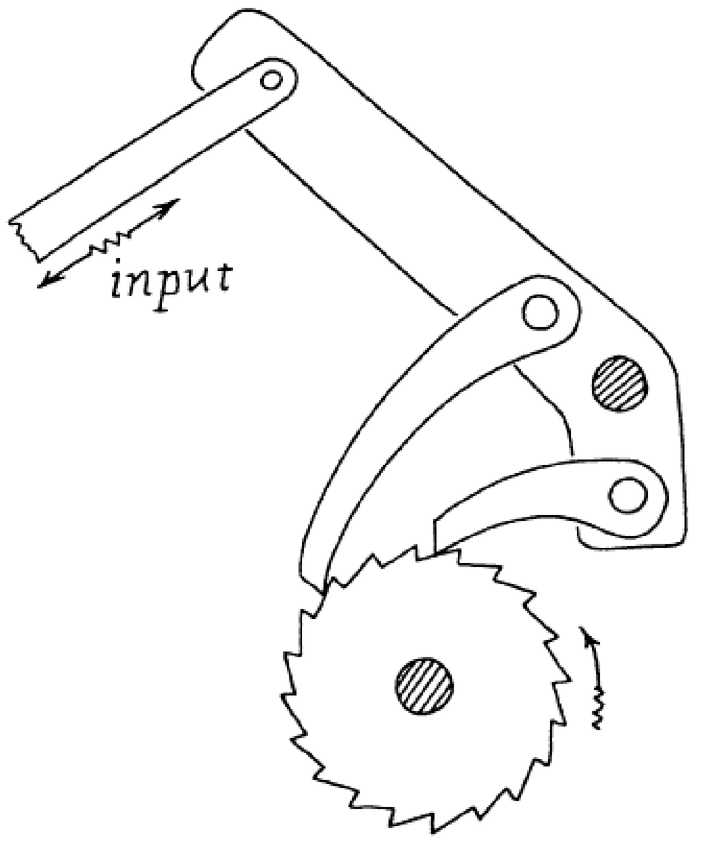


Fig. 7-13. Double action ratchet.

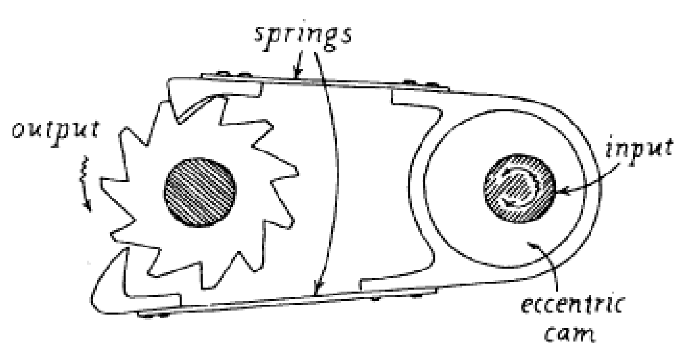


Fig. 7-14. Ratchet producing unidirectional output for bidirectional rotation of the input shaft.

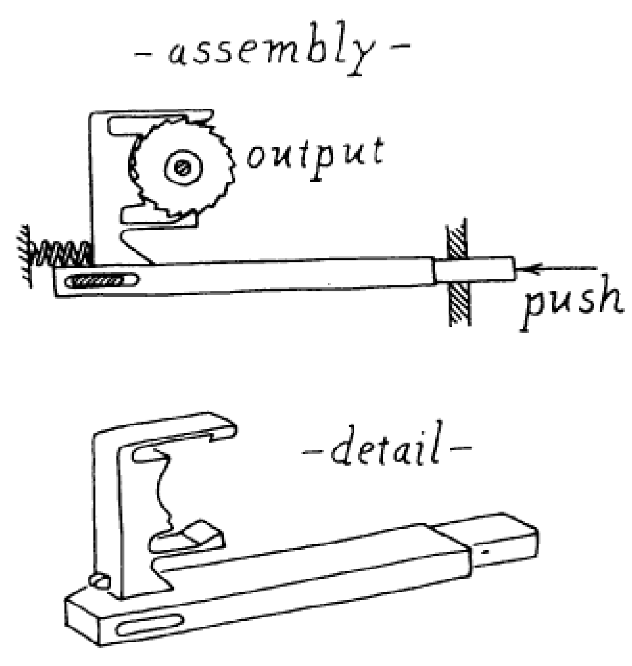


Fig. 7-15. Ratchet with spring-arm drive. (U.S. Patent 3,375,337; Barrett, et al.)

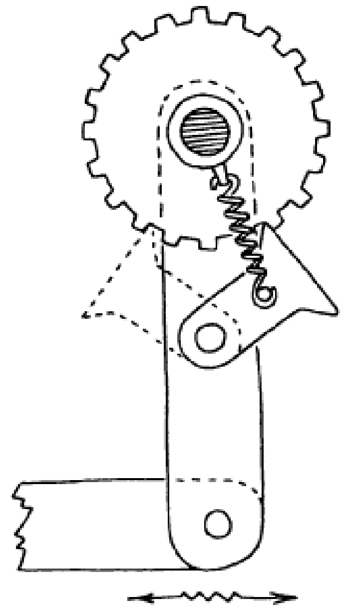


Fig. 7-16. A reversible ratchet.

Note that the top drive tooth operates in compression, while the bottom one operates in tension.

Figure 7-15 shows another ratchet with a spring-arm drive. However, input this time is a push-pull motion rather than continuous rotation.

A reversible ratchet is illustrated in Fig. 7-16. The drive pawl of this mechanism can be flipped from one side to the other to reverse the direction of rotation of the ratchet wheel.

The push-button ratchet mechanism in Fig. 7-17 will produce either clockwise (CW), or counterclockwise (CCW) motion depending upon which way the toggle has been set.

Another toggle-set bidirectional-output ratchet

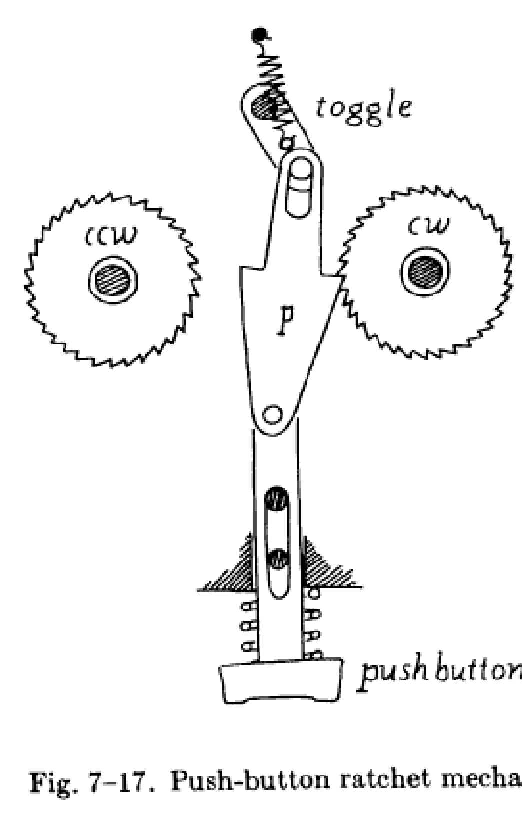


Fig. 7-17. Push-button ratchet mechanism.

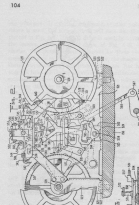


Fig. 7-18. Toggle-set bidirectional-output ratchet mechanism. (U.S. Patent 3,542,183).

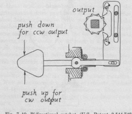


Fig. 7-19. Bidirectional ratchet (U.S. Patent 3,544,748; P. P. Schwab.)

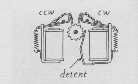


Fig. 7-20. A bidirectional electrical ratchet. (U.S. Patent 3,473,087; K. J. Ylinen.)

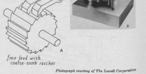
mechanism is shown in Fig. 7-18; this one is used in a contemporary business machine.

The bidirectional ratchet shown in Fig. 7-19, is a mechanism from a manually operated stepping switch.

Figure 7-20 illustrates a bidirectional electrical ratchet.

Multiple-drive pawls mounted on a common shaft can be used to produce fine steps in a coarse-tooth ratchet as shown in Fig. 7-21. The reciprocal motion of the input pawls is less than the pitch of the teeth on the ratchet wheel so that first one pawl engages, and then the others engage, with only one carrying the load at a time. This trick allows us to build fine step ratchets with large, coarse (strong!) pawl and wheel teeth.

Adjustable shields, as shown in Fig. 7-22, can be provided with multiple-pawl ratchets to alter the output stroke. The shield is adjusted to increase or decrease the length of engagement of drive pawls with



Photograph courtesy of The Lowell Corporation

Fig. 7-21. A. Multiple-drive pawls mounted on a common shaft; B. Segmented-pawl ratchet design.

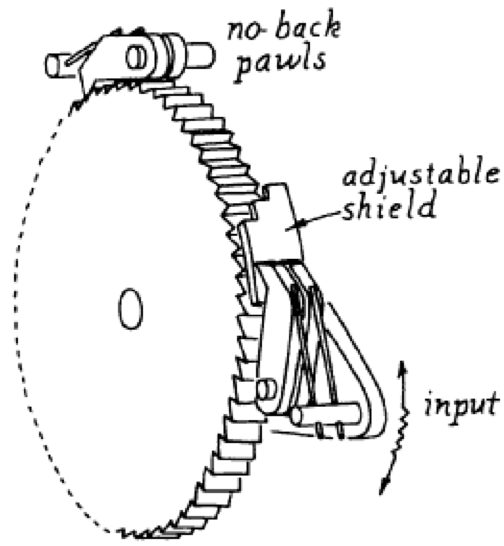


Fig. 7–22. Multiple-pawl ratchets with adjustable shield.

the output wheel. The shield remains stationary during operation of the ratchet, however.

Figure 7–23 illustrates another pawl arrangement designed to obtain fine indexing with coarse teeth. Only one pawl is in full engagement at a time.

In this two-speed ratchet (Fig. 7–24), the two pawls move together on a common input shaft. The right-hand pawl engages the right-hand ratchet wheel with every input stroke, advancing this wheel and driving the "fast" output shaft. The left-hand ratchet wheel has a smaller diameter than the right-hand one, thus the left-hand pawl does not normally engage this second wheel. Twice per revolution of the right-hand wheel, however, the input pawls encounter an extra-deep ratchet tooth *d*. This allows

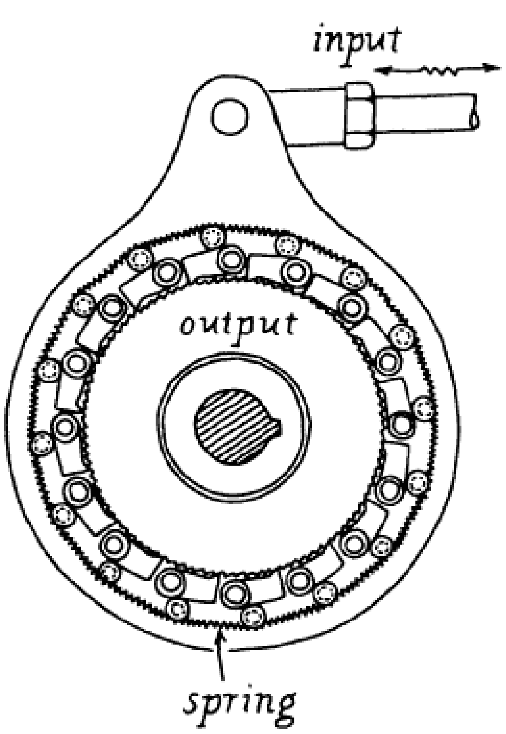


Fig. 7–23. Another multiple pawl design. (U.S. Patent 3,505,890; C. G. Peterson.)

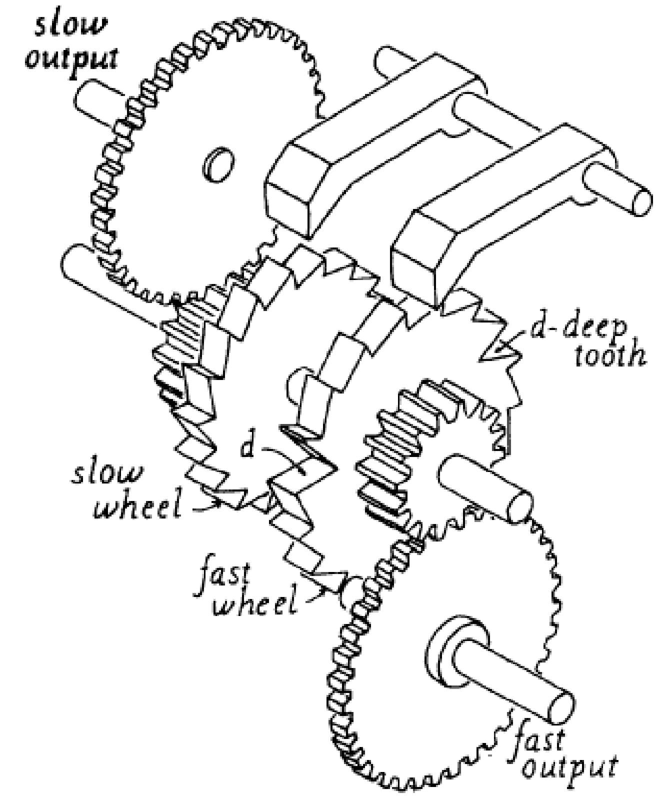


Fig. 7–24. Two-speed ratchet.

the drive pawl to drive down to a smaller diameter and the left-hand pawl engages the left-hand, or slow, ratchet wheel, producing output on the "slow" shaft.

Ratchet wheel teeth need not be saw-tooth shaped. In this hydraulically actuated mechanism of Fig. 7–25, a square block serves as a ratchet wheel. A

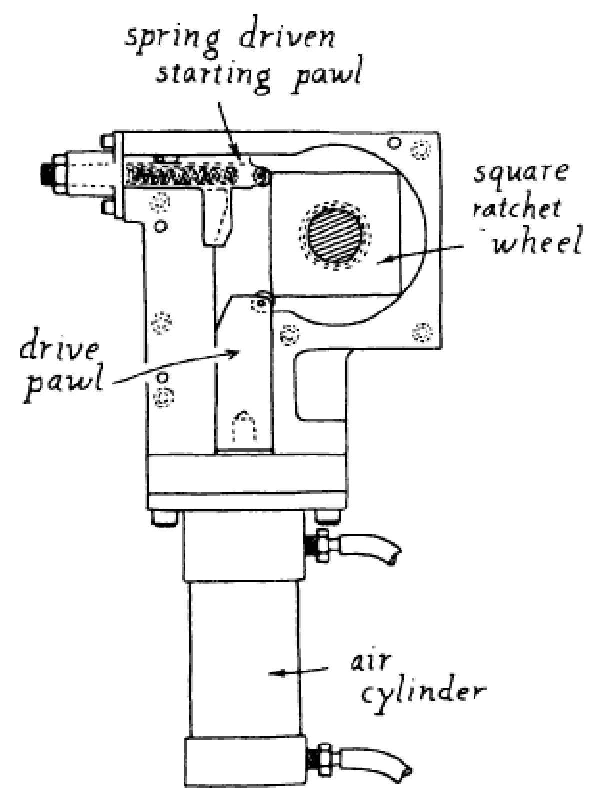


Fig. 7–25. Mechanism with square block ratchet wheel. (U.S. Patent 3,548,684; A. R. Gregersen.)

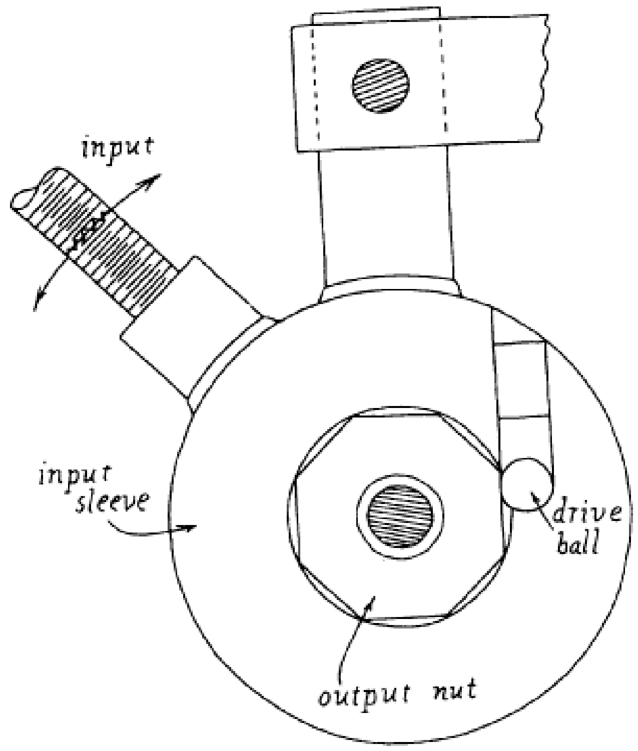
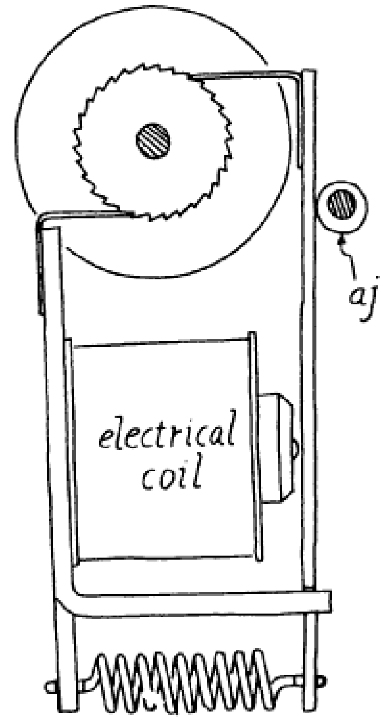


Fig. 7–26. Odd-shaped ratchet wheel. (U.S. Patent 3,323,383; V. A. Parsley.)



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

Fig. 7–28. Another low-cost solenoid ratchet.

spring-loaded pawl serves to start output wheel motion so that the drive ratchet can keep driving a different face of the block with each stroke.

In Fig. 7–26 is another odd-shaped ratchet wheel; really a one-way ball clutch. Here the hexagonal nut is the output wheel. The motion of the input crank in one direction will produce no output motion as the nut merely moves the drive ball out of the way. Motion in the reverse direction, however, will produce output because the ball will jam between the nut and the input sleeve.

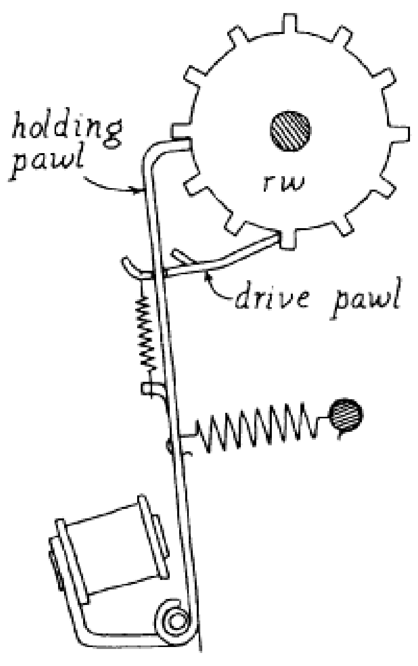


Fig. 7–27. Basic, low-cost solenoid ratchet from a Japanese counting mechanism.

A basic, and low-cost, solenoid actuated ratchet from a Japanese counting mechanism is shown in Fig. 7–27. Drive arms, drive pawl, and holding pawl are all stamped from sheet metal.

Another low-cost electrical ratchet, though not quite as simplified as the first, is seen in Fig. 7–28. Flat springs are used for drive and holding pawls. Note that an eccentric adjustment (*aj*) has been provided to control the starting position of the drive pawl (and, not incidentally, the de-energized air gap of the drive solenoid).

If a ratchet's pawl and drive arm can be made light enough and the teeth on the ratchet wheel can be made very fine, then a ratchet can be operated at very high speeds. The sketch in Fig. 7–29 shows a very-low-cost ratchet motor that is used to power toy racing cars. An electrical coil is energized with 60-cycle AC power. The ratchet armature, and pawl (*B*), are merely pieces of spring steel which are

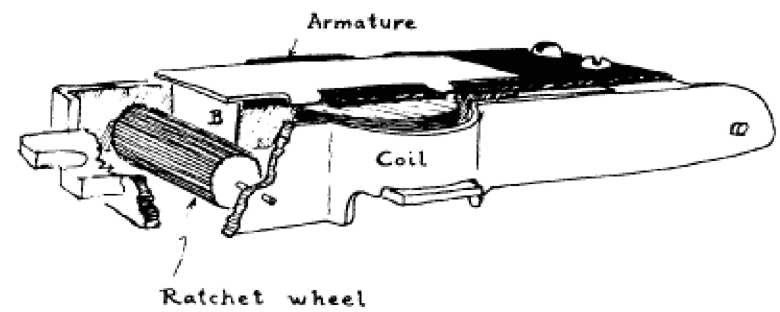


Fig. 7–29. Low-cost ratchet motor used to power toy cars.

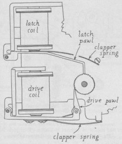


Fig. 7-30. Direct-drive ratchet from a stepping switch.

attracted to the coil every time it is energized and which move away from the coil under their own spring power whenever the current level in the coil nears zero. The armature, therefore, vibrates at a 60-cycle rate. The pawl (*B*), engages the ratchet wheel, driving it (and the racing car) in a forward direction. A no-back pawl (not shown) prevents the ratchet wheel from reversing when the armature moves upwards.

Solenoid operated ratchets have been used for many years in high-performance stepping switches for telephone systems, etc. There are two basic kinds: direct drive and spring drive. The latch coil at the top of the direct-drive model shown here in Fig. 7-30, is energized to remove the latch pawl from

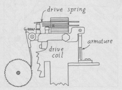
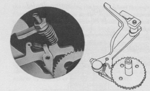


Fig. 7-31. Stepping-switch ratchet employing spring drive.

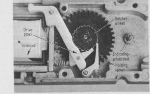


Photograph courtesy of the GTE Automatic Electric Company

Fig. 7-32. Drive arm and ratchet from a high-performance stepping switch.

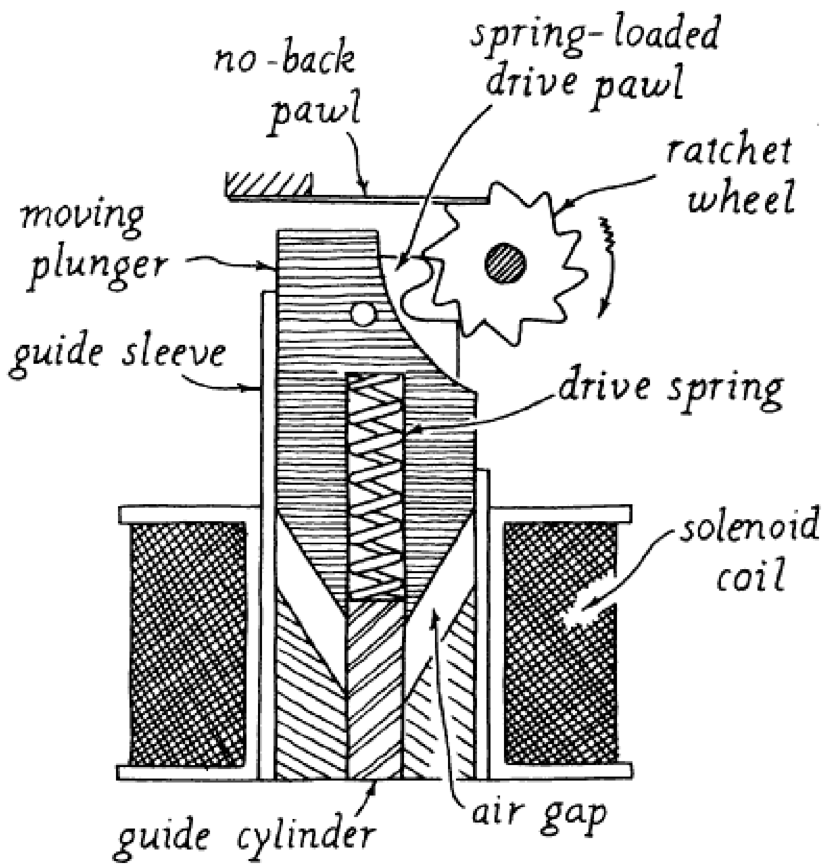
the ratchet wheel teeth. The drive coil is then energized to index the ratchet wheel. Clapper springs return both pawls to their de-energized condition to complete the stroke. (Drawing made from information supplied by C. P. Clare and Company.)

Figure 7-31 illustrates a more popular approach for a telephone stepping-switch ratchet. The drive coil moves the drive pawl upward, loading a flat drive spring. When the coil is de-energized, the drive spring moves the pawl down to the position shown, indexing the output wheel. Drive torque is more uniform than with the system of Fig. 7-30 where voltage variations, magnetic aging, etc., alter the amount of torque delivered to the ratchet wheel. Non-overthrow and no-back control is provided by other elements which are not shown in the illustra-



Photograph courtesy of the Veeder-Root Company and MACHINE DESIGN Magazine; Dec. 23, 1965: p. 121 ff

Fig. 7-33. Ratchet-drive mechanism of high-performance electro-magnetic counter.



Drawing courtesy of The Heinemann Electric Company

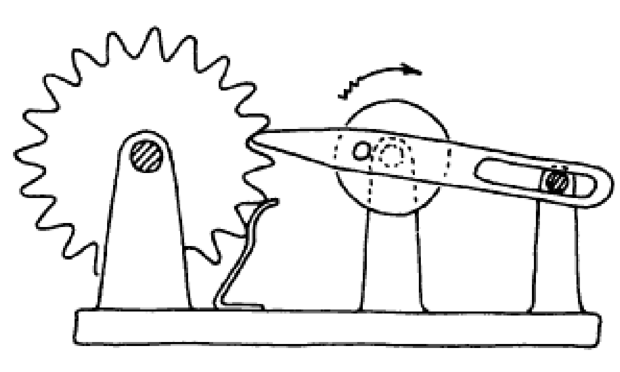
Fig. 7–34. Ratchet mechanism for an electro-mechanical stepping motor.

tion. (Drawing made from information supplied by C. P. Clare and Company.)

The drive arm and ratchet wheel from a high-performance stepping switch is shown in detail and photographed, in Fig. 7–32. These are good illustrations of a stepping-switch drive arm showing a spring-loaded drive pawl and a fixed non-overthrow tooth.

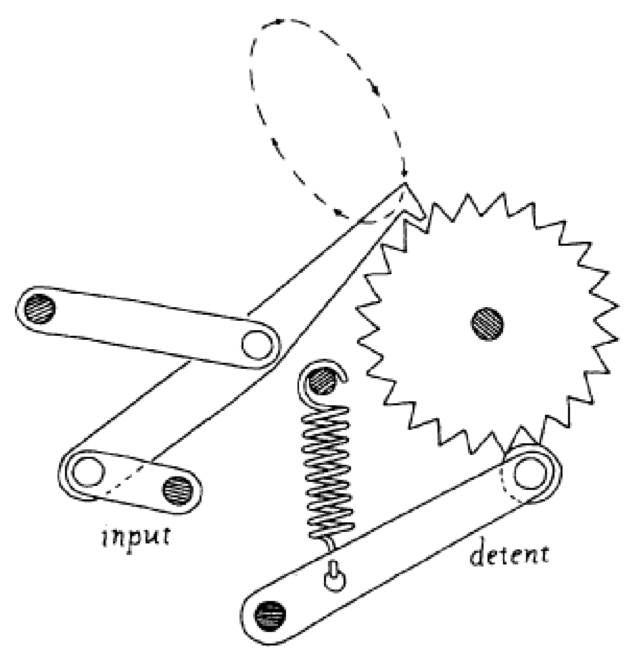
This photograph (Fig. 7–33) of the ratchet drive mechanism for a high-performance electro-magnetic counter shows the drive pawl, ratchet wheel, holding pawl, and drive solenoid.

Figure 7–34 is the ratchet mechanism used in an electro-mechanical stepping motor. The drive pawl also serves as a non-overthrow pawl. (See also Fig. 14–28.)



Drawing courtesy PRODUCT ENGINEERING Magazine; Oct. 26, 1964: pp. 109, 110

Fig. 7–35. Mechanism with drive arm driven by slider crank device.



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

Fig. 7–36. Linkage-driven ratchet mechanism.

A mechanism in which the drive arm is driven by a slider crank device is shown in Fig. 7–35. A linkage-driven ratchet usually exhibits a better acceleration-versus-time curve than does an impulse ratchet.

Another linkage-driven ratchet mechanism can be seen in Fig. 7–36. Note that a spring-loaded detent has been provided to serve the functions of both non-overthrow teeth and no-back pawl. This is only possible at low speeds.

This time, in Fig. 7–37, there is a third linkage-operated ratchet producing two outputs; one in a large wheel and one in a small wheel.

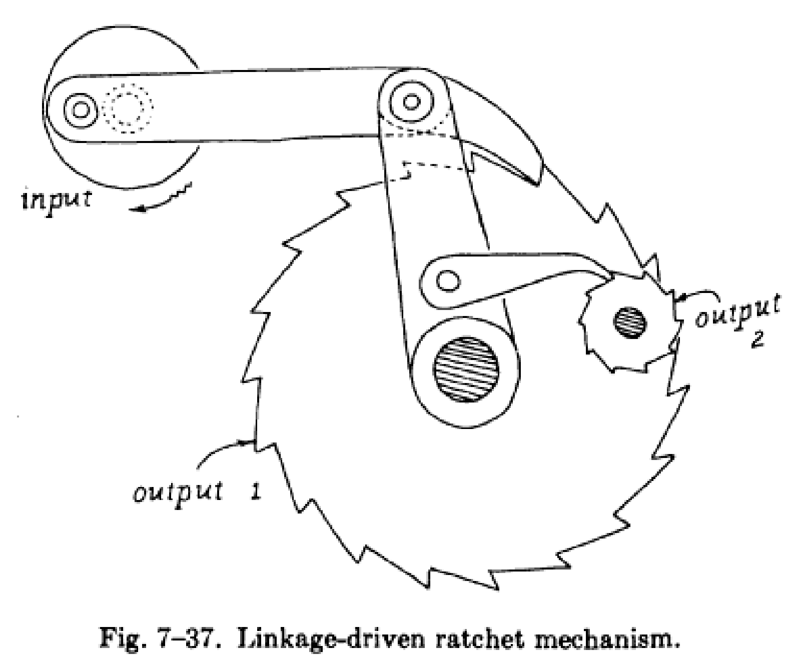


Fig. 7–37. Linkage-driven ratchet mechanism.

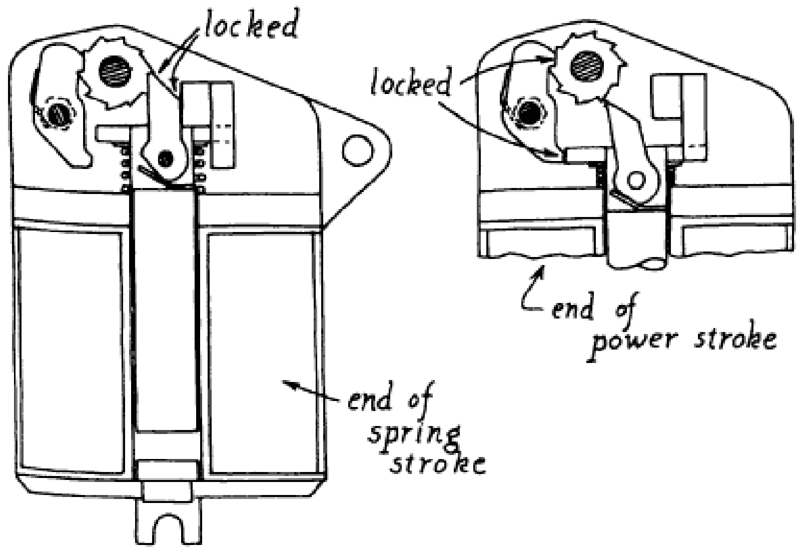


Fig. 7–38. Solenoid ratchet with output wheel locked at end of power and return strokes. (U.S. Patent 3,501,968; G. D. Fredell.)

An electrically actuated ratchet in which the output wheel is locked at the end of both power and return strokes is seen in Fig. 7–38. People are always struggling to improve the stability and control of a ratchet mechanism! But there are still times during which the wheel is virtually on its own.

In Fig. 7–39, is a pneumatically actuated ratchet where air is exhausted from the latch piston cylinder to extract the latch. Air is then introduced to the index cylinder to move the ratchet forward.

With a toothless, or silent ratchet, as in Fig. 7–40, a toggle mechanism jams a drive link down against the output wheel, grabbing the output wheel through friction and indexing it as the input crank moves toward the left. Moving the input crank back toward the right will eliminate the jam between drive links and wheel and allow the arm to retract for another bite. The device depends upon the high forces generated by the toggle mechanism to eliminate slipping. Many versions of this type of device have been built. Rest positions of the output wheel are determined by the length of stroke of the input arm and/or by detents or brakes not shown here.

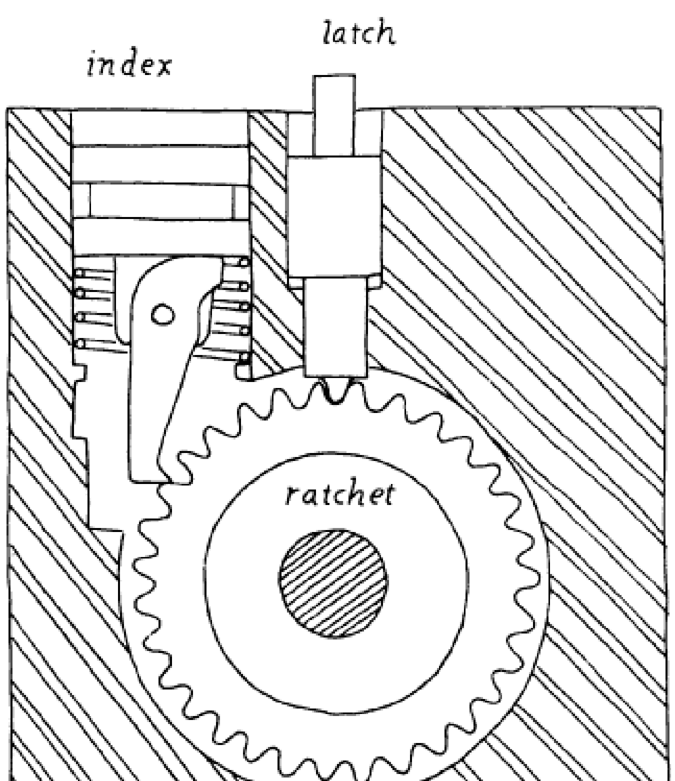
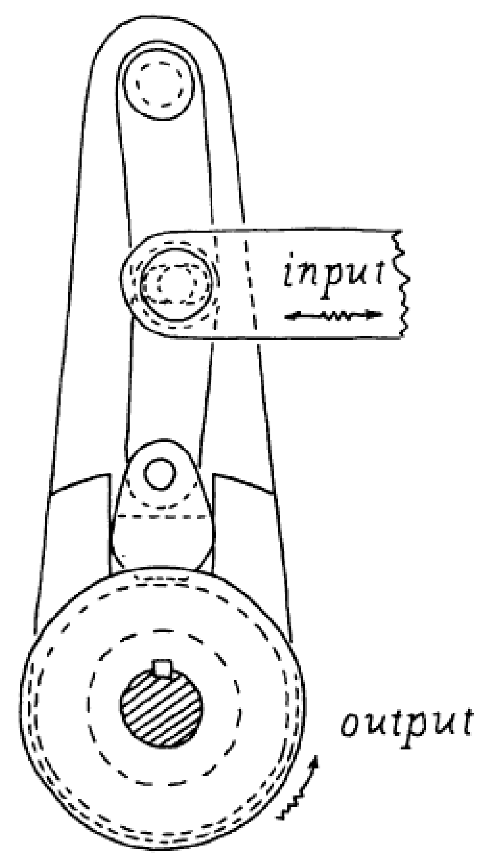


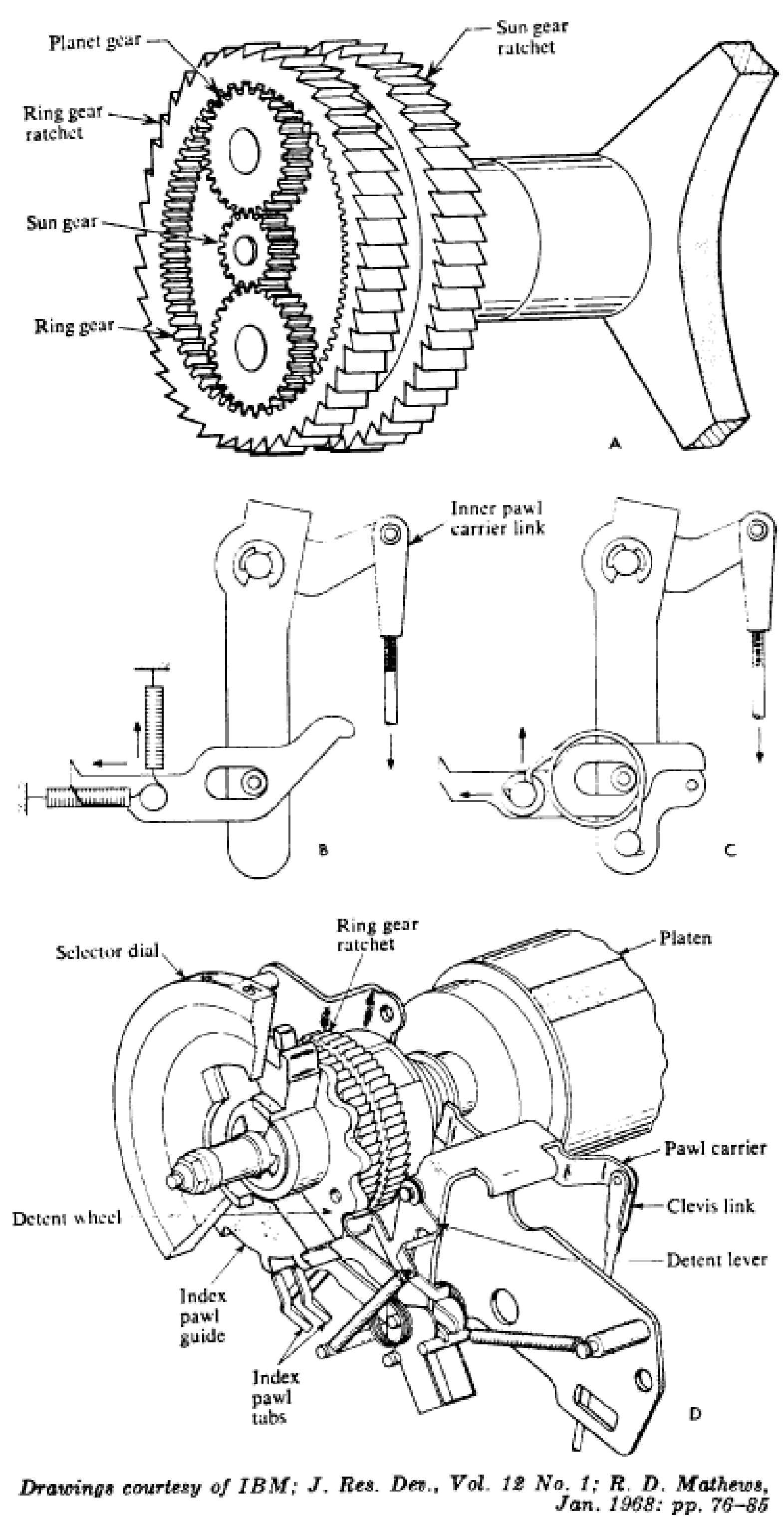
Fig. 7–39. Pneumatically actuated ratchet.



By permission from Douglas Greenwood, PRODUCT ENGINEERING DESIGN MANUAL; New York: Morgan-Grampian Inc., 1959

Fig. 7–40. Toothless, or silent ratchet.

Figure 7–41 shows a multiple step index mechanism that was designed for the IBM Selectric Composer. This machine must handle 15 different sizes of type, ranging from 5 to 20 points. This means that 15 different line spacings have to be provided by the platen indexing mechanism. IBM's answer is this sophisticated ratchet mechanism that can be adjusted to provide 15 different output motions. We cannot go into all the details of this impressive device, but in general it works as follows: two platen indexing ratchets are provided. Their outputs are combined by a differential gear system. Figure 7–41A shows the two ratchet wheels and the gears that are used to add their motions. A cage (not shown) supporting



Drawings courtesy of IBM; J. Res. Dev., Vol. 12 No. 1; R. D. Mathews, Jan. 1968: pp. 76–85

Fig. 7-41. Multiple step index mechanism. A sophisticated ratchet.

the planet gears is connected to and drives the platen.

A differential of this kind will produce three different outputs if the two input ratchets have fixed-length strokes. The length of the output stroke will depend upon whether or not the left ratchet, or the right ratchet, or both are being driven at a given time. Additional variation in output motion is obtained by varying the strokes of the two pawls that drive the ratchet wheels. This is accomplished by providing an adjustable stop, called the "index pawl guide" in Fig. 7-41D. The drive pawls themselves (best seen in Fig. 7-41C, and schematically in Fig. 7-41B) are always moved through the same input motion, but are connected to their input arms by rollers that are free to move in slots. When the tip of a pawl encounters a stop, therefore, the pawl comes to rest and the remainder of the input motion merely loads a spring. By adjusting the stop position IBM engineers were able to provide several different stroke lengths for each drive pawl.

An adjustable stop of this type is one of two basic methods commonly used to vary the stroke of a ratchet. The other technique, an adjustable shield arrangement, is shown in Fig. 7-22. In each case the pawl arm moves through a stroke whose length never varies; the active length of the stroke is varied by an adjustable shield or an adjustable stop.

As a matter of fact, both techniques are used in the ratchet mechanism of Fig. 7-41. Although it is not shown in the illustration IBM also used an adjustable shield to provide a "zero index" (no platen motion) option for the operator.

Figure 7-42 shows another slider-crank ratchet. A simple and low-cost arrangement that minimizes impact forces in the same way as a four-bar linkage. This sketch was made from an all-plastic design.

Depending on the setting of the two control levers the commercially available device shown in Fig. 7-43 will ratchet in a clockwise direction, a counterclockwise direction, or neither. When "neither," the output will either be locked or completely free.

There is no metal-to-metal contact between drive teeth or detent and the output wheel in this magnetic

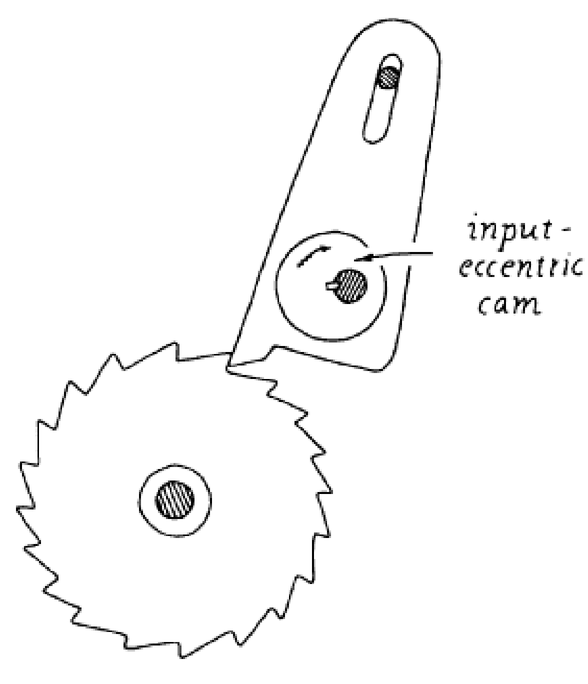
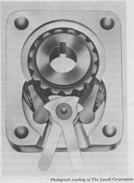


Fig. 7-42. Slider-crank ratchet.

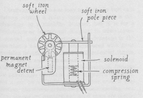


Photograph courtesy of The Lowell Corporation

Fig. 7-43. Reversible or free-running ratchet.

ratchet, Fig. 7-44. Instead, magnetic attraction is used for both drive and detenting.

When one of the coils shown in Fig. 7-45 is energized with 60-cycle power, its armature will oscillate, thanks to a rubber ball "spring" at the bottom of the armature, and the ratchet pawl will also oscillate. The output will step continuously at a 60-cycle rate,



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

Fig. 7-44. Magnetic ratchet.

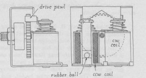
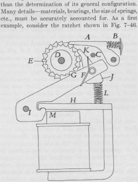


Fig. 7-45. Oscillating ratchet. (U.S. Patent 3,530,346; R. Mariani.)

until the coil is turned off. Clockwise and counterclockwise output is available in this device.

Anatomy of a Ratchet

In this, and the chapters which follow, each discussion of a particular type of intermittent motion mechanism will be summarized by an illustration of a typical example and a point-by-point discussion of its "anatomy." Part of the idea is to show that the design of a successful mechanism involves more than the determination of its general configuration. Many details—materials, bearings, the size of springs, etc., must be accurately accounted for. As a first example, consider the ratchet shown in Fig. 7-46.



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

Fig. 7-46. Anatomy of a ratchet.

The letters indicate various points requiring design attention, as follows:

> A. No-back pawl; B. No-back pawl spring, strong enough to get the no-back pawl down into the wheel teeth soon enough to be effective at the maximum cycle rate, but not so stiff that it produces unnecessary drag (friction load) on the wheel; C. Stop—to prevent drive pawl from getting too far away from the wheel during withdrawal. The pawl is spring loaded, and, just as any spring-mass system, will overrespond to shock inputs (which occur when it is suddenly pulled back over the wheel teeth); D. Ratchet-wheel bearing—small diameter to reduce frictional drag torque, especially during impact load periods, but the diameter is large enough to keep bearing stresses reasonable for long life. This is usually a principal wear point; E. Non-overthrow teeth—engage the tooth on the drive arm (G) to prevent the wheel from turning more than it should in a given drive cycle. These non-overthrow surfaces generally take much abuse; F. Drive-pawl spring—the comments made on the no-back pawl spring (B) apply here also. In addition, this spring must be strong enough to force the drive pawl to engage the ratchet wheel under load if tooth geometry alone will not do this. Sometimes, the drive spring (L) can also serve as the pawl spring; G. Non-overthrow tooth on the drive arm; H. Iron clapper; I. Drive-arm bearing—the comments made for the wheel bearing (D) above, also apply here. It is a good idea to design the magnetic circuit so that the return path for the magnetic flux does not run through this bearing, since flux means force, and this can cause cramping and wear; J. Drive pawl—tooth properly shaped to reduce impact stress levels. Hardened; K. Drive pawl—starts drive stroke about one-half tooth, back of tooth to be driven next. Less backlash would help reduce impact, but would mean tighter production tolerances; L. Drive spring—used instead of solenoid to limit drive torque and make the drive forces more uniform with varying input voltage, etc. Drive torque must be nearly balanced by friction and inertial loads in the ratchet wheel and in related parts of the machine. The inertia ratio between driver and load affects impact levels, bounce of arm, and stability as discussed in Chapter 5; M. "Air gap"—will affect initial magnetic forces on the drive arm and, therefore, the indexing rate.