EXAMPLE.—Let a wheel have 6 arms, and the teeth of a 3 inch pitch, the face being 1 inch. If we make \( h = 2 \) at the centre of the wheel, we have \( a = 2 \), and \( 4 = 5, \) hence we get from the table \( \alpha = 0.35 \) and \( 4 = 4 \times 0.066, \) which gives \( 4 = 0.26, \) which gives \( 4 = 0.26. \) If this is considered too thick, we may make \( h = 0.5 \), which gives \( 4 = 0.08, \) and \( 4 = 1.5. \)

For gears with wooden teeth, and for the iron wheel's gearing with them, the dimensions of the arms may be made 0.8 times that given by the preceding rules. If more accurate dimensions are required, the best plan is to determine the pitch of the equivalent iron teeth, and use this value in the calculations.

\[ \frac{1}{233}. \]

GEAR WHEEL HUBS.

The hub for a gear wheel generally tapers slightly each way from the arms to the end, the length \( L = \frac{1}{2} b \), or somewhat more for wheels of very large diameter, and the thickness of metal at the bore is made \( w = 0.44 + 0.04, \) in which \( b \) is the same as in the preceding section. In cases of much more importance reference should be made to formula (60), \( \frac{1}{2} b. \)

If the wheel is not to be secured by shrinkage the thickness of metal at the ends of the hub may be made \( \frac{1}{2} w \). The key way is cut the entire length of the hub, and for wheels which are subjected to heavy service the metal should be reinforced over the key way. Instead of this, the hub may be strengthened by wrought iron rings, forced on one or both ends. Such rings are usually of rectangular cross section, the thickness being \( \frac{1}{4} w, \) and added grout to the strength of the hub. See Chapter III. \( \frac{1}{2} 151. \) to the end.

\[ \frac{1}{234}. \]

WEIGHT OF GEAR WHEELS.

The approximate weight \( G \) of gear wheels proportioned according to the preceding rules may be obtained from the following:

\[ G = 0.0357 b \frac{1}{2} b \left( \frac{Z}{6} \right) + \frac{0.04}{2} Z \].

The following table will facilitate the application of the formula as it gives the value of \( \frac{1}{2} b \frac{1}{2} b \) for the number of teeth which may be given, and the weight can at once be found by multiplying the value in the table by \( b \).

<table>
<thead>
<tr>
<th>( Z )</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>30</td>
<td>7.9</td>
<td>7.9</td>
<td>7.9</td>
<td>7.9</td>
</tr>
<tr>
<td>40</td>
<td>11.0</td>
<td>11.0</td>
<td>11.0</td>
<td>11.0</td>
</tr>
<tr>
<td>50</td>
<td>14.7</td>
<td>14.7</td>
<td>14.7</td>
<td>14.7</td>
</tr>
<tr>
<td>60</td>
<td>18.5</td>
<td>18.5</td>
<td>18.5</td>
<td>18.5</td>
</tr>
<tr>
<td>70</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
</tr>
<tr>
<td>80</td>
<td>27.0</td>
<td>27.0</td>
<td>27.0</td>
<td>27.0</td>
</tr>
<tr>
<td>90</td>
<td>31.6</td>
<td>31.6</td>
<td>31.6</td>
<td>31.6</td>
</tr>
<tr>
<td>100</td>
<td>36.5</td>
<td>36.5</td>
<td>36.5</td>
<td>36.5</td>
</tr>
<tr>
<td>120</td>
<td>47.4</td>
<td>47.4</td>
<td>47.4</td>
<td>47.4</td>
</tr>
<tr>
<td>140</td>
<td>59.3</td>
<td>59.3</td>
<td>59.3</td>
<td>59.3</td>
</tr>
<tr>
<td>160</td>
<td>72.3</td>
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</tr>
<tr>
<td>180</td>
<td>86.5</td>
<td>86.5</td>
<td>86.5</td>
<td>86.5</td>
</tr>
<tr>
<td>200</td>
<td>101.8</td>
<td>101.8</td>
<td>101.8</td>
<td>101.8</td>
</tr>
<tr>
<td>220</td>
<td>116.3</td>
<td>116.3</td>
<td>116.3</td>
<td>116.3</td>
</tr>
</tbody>
</table>

*Example.*—For a cast iron gear wheel, proportioned according to the foregoing rules, with 30 teeth, \( \frac{1}{2} \) pitch and \( \frac{1}{2} \) face, we have \( b = 2 \), and by the table the multiplier for 30 teeth is 1.114, and the width \( \frac{1}{2} b = 1.114 \times 0.35 = 0.39 \). For a gear of 40 teeth, \( \frac{1}{2} \) pitch and \( \frac{1}{2} \) face, we have \( b = 2 \), which multiplied by 0.39 gives 39.2 pounds.

For bevel gears or for gears with wooden teeth and lighter arms (as given at the end of \( \frac{1}{2} 232. \) the weights will run slightly less than given by the table.

\[ \frac{1}{235}. \]

CHAPTER XVIII.

RATCHET GEARING.

\[ \frac{1}{236}. \]

CLASSIFICATION OF RATCHET GEARING.

Ratchet gearing may be considered as a modification or extension of wheel gearing. The object of ratchets is to check the action of certain portions of a machine or train of mechanism and so modify an otherwise continuous motion into some intermittent form.

Ratchet gearing may be divided into two main divisions according to the nature of the checking action. When the movement of the checked member is impeded in only one direction we have what may be called a Running Ratchet; and when the movement is checked in both directions, a Stationary Ratchet.

The distinction will be understood by reference to the accompanying illustrations, in which Fig. 653 shows a ratchet wheel and pawl \( a, b, c, \) the shape of teeth and pawl permitting motion of the wheel in one direction, and hence forming a Running Ratchet.

If the two members \( b \) and \( c \) are held, \( a \) becomes the intermediate wheel, while if \( a \) be held, \( b, c \) become the intermediate action; as for example, the sustaining pawl and ratchet wheel of a common hoisting winch in the first case, and the reverse lever and quadrant of a locomotive in the second case.

Ratchet gearing is a portion of constructive mechanism which will repay close investigation. For this purpose the following six groups may be considered:

1. Ratchets pure and simple, such as a ratchet wheel and pawl for the mere prevention of rotation. Examples: the ratchet of a windlass, or of a beam of a loom.

2. Releasing Ratchets; those which act to release members which are under stress and which by such release are permitted to perform and determine work. Examples: the pawls which release the drop of a pile driver, the trigger of a gun, or the trip valve gear of some steam engines.

3. Checking Ratchets; those which arrest parts which are already in continuous motion. Examples: the safety check ratchets upon elevators, and upon mine hoists.

4. Continuous Ratchets; those in which a combination of pawls acts to drive a member in a given direction with practically a continuous motion. Examples: a ratchet-driven windlass; some forms of counters. : *5.

5. Locking Ratchets; those which act to detain certain members in a fixed relation against the action of external forces until released. Examples: some forms of car couplings and of releasing shaft couplings, also the mechanism of locks.

6. Escapements; those forms which permit a member under the action of an impelling force to make regular intermittent motion in one direction. Example: the various forms of clock and watch escapements.

By following this classification, the various principal fundamental forms may be briefly examined.

\[ \frac{1}{237}. \]

TOOTHED RUNNING RATCHET GEARS.

In running ratchets, the direction of motion which is not checked by the pawl is called the forward motion, and the reverse, the backward motion. The teeth on the ratchet wheel must therefore be so shaped that when the pawl is in engagement the backward motion only must be impeded. It is also important that the form should be so chosen that the first tendency toward a backward movement should act to produce an engagement of the pawl with the teeth.

In determining the form of teeth, Fig. 655, we observe that the most effective point upon the circumference of the wheel for the action of the pawl is that at which the joining line \( \frac{1}{2} 2 \) of the centre of the wheel, 1, with the point of the pawl 2, is at right angles with the pawl radius \( \frac{1}{2} 2. \) If we describe an arc upon the diameter \( \frac{1}{2} 3, \) or the distance between centres of wheel and pawl, the intersections 2 and \( \frac{1}{2} 2 \) with the pitch circle of the ratchet wheel will give the two most advantageous points of application. If the points be so selected, the attempted reverse movement of the wheel will subject the pawl to compression, while if \( \frac{1}{2} \) be chosen the pawl must be of the hook shape shown, and will be subject to tension. If the teeth of the wheel are to be of straight outline, the flanks should be radial. If a point of
action $a$ or $b$, in front or behind $a$ or $b'$, be chosen, the mechanism will be operative, but less advantageously than when constructed as above, for the lever arm of the force-couple acting upon the wheel will be less, and hence the pressure greater. The angle of the flank, which will cause the direction of the force upon the pawl to pass through the axis $a$, is found by erecting a perpendicular from $a$ or $b$ upon $a_1$, $b_1$, or $a_2$, $b_2$.

It is not necessary to bevel the end of the pawl so that it shall bear in but one point of the tooth, as it is not difficult to shape the tooth profile so that the force $F$ shall pass through the axis $a$, when the pawl engages with the tooth. This is accomplished by making the profile of the flank of the tooth a circular arc struck from $a$ as a centre, as in Fig. 666.

The same result will be attained by giving this curve to the end of the pawl, and making the point of the tooth the bearing, as at $b$, or both pawl and tooth may be formed to the curve, as at $c$. Since the force which acts upon the pawl has no tendency to cause it to lift out of gear, when constructed as thus described we may call this form of tooth the "lead" ratchet tooth. Other forms of teeth will be considered hereafter.

Internally-toothed ratchet wheels may also be made with the teeth adapted to act either in tension or compression, as at $a$ and $b'$, Fig. 667. The axis $a$ may be within the wheel, Fig. 668, in which case the above given conditions for the best position of the point of action cannot be fulfilled.

If the radius of the ratchet wheel be made infinitely great we have a ratchet rack, Fig. 669, in which $a$ is a pawl acting in compression, and $b$ a form-acting in tension.

An important application of the ratchet rack is shown in Fig. 660, which is the upper portion of the lifting frame for a screw propeller. The two ratchet racks $a$, which support the frame as it is gradually lifted, are in the middle plane of the ship, being fast to the walls of the propeller well. In order to insure the engagement of the pawls $b$ and $d$, they are held in gear by the loop springs of rubber. The frame is raised and lowered by a rope tackle, the sheaves of which are shown, the so-called "clutch-coupling" (see § 136), permitting the propeller to be lifted, when its tongue and grooves are in the proper vertical position. The pawls are held out of gear by means of lines, during the operation of lowering. The frame and ratchet racks are both made of bronze.

Ratchet racks are also used extensively in connection with the hoisting machinery in shafts of mines, etc.

* See Fig. 260, § 171, where one of the bearings for the same propeller is shown.
Instead of giving the ratchet wheel an infinitely great radius, the arm $a_3$ of the pawl may be made indefinitely long. This simply means that the motion of the pawl is guided in a straight line, in some form of slide. In Fig. 663 such an arrangement is shown for a ratchet wheel, and in Fig. 662 for a ratchet rack, such forms being not uncommon.

§ 297.

THE THRUST UPON THE PAWL.

The condition that the thrust upon the pawl, in a ratchet gearing, shall pass through the axis of the pawl, is not always fulfilled, and in some cases it is impracticable to attain such a relation of the parts. The mutual action of the pawl and ratchet wheel upon each other must therefore always be considered. If the flank of the tooth of a spur ratchet wheel (or a tangent to the flank of the outline is curved) does not form a right angle with the plane $a_3$ of the pawl, there may exist, under some circumstances, a tendency to force the pawl into the tooth, or in other cases to throw it out of gear.

In Fig. 663 the various cases are examined. If at the point of contact $a$ a normal $N\alpha$ to the plane of the tooth flank is drawn, this normal may be one of three relations to the triangle $a_1 a_2 a_3$. The "thrust-normal" $N\alpha$ may fall without the triangle, or within the triangle, or it may fall upon one of the sides of the triangle.

If it falls upon $a_3$, the thrust is neutral; if it falls upon $a_1$, the thrust is zero; that is, there will be no action of the pawl upon the wheel, or vice versa, barring the action of friction.

The angle $\theta$ between the line $a_2 a_3$ of the pawl and the tangent to $a_3$, which is equal to the angle between the normal $N\alpha$ and the "thrust-normal," is called the angle of thrust. By considering this in connection with the angle of friction, various relations are obtained.

On the one hand, the force applied will act to alter the position of the pawl, either to or from the centre of the ratchet wheel; on the other hand, it will also act to move the ratchet wheel forward and backward.

These relations are classified for various conditions in the following table, in which a force which acts to force the point $a$ from $a_1$ is called an "outward" action, and the reverse, an "inward" action.

### ANGLE OF THRUST $\alpha = 90^\circ$.

<table>
<thead>
<tr>
<th>The Thrust Action is:</th>
<th>The Impelling Force:</th>
<th>Outward Movement:</th>
<th>Inward Movement:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) neutral.</td>
<td>is without effect.</td>
<td>is without effect.</td>
<td>is without effect.</td>
</tr>
<tr>
<td>2) inward.</td>
<td>is without effect.</td>
<td>produces reverse motion.</td>
<td>produces reverse motion.</td>
</tr>
<tr>
<td>3) outward.</td>
<td>is without effect.</td>
<td>produces forward motion.</td>
<td>produces forward motion.</td>
</tr>
<tr>
<td>4) inward.</td>
<td>produces inward movement.</td>
<td>produces reverse motion.</td>
<td>produces by impelling force.</td>
</tr>
<tr>
<td>5) outward.</td>
<td>produces outward movement.</td>
<td>produces reverse motion.</td>
<td>produces by impelling force.</td>
</tr>
<tr>
<td>6) inward.</td>
<td>produces inward movement.</td>
<td>is without effect.</td>
<td>produced by impelling force.</td>
</tr>
<tr>
<td>7) outward.</td>
<td>produces outward movement.</td>
<td>produced by impelling force.</td>
<td>produced by impelling force.</td>
</tr>
<tr>
<td>8) null.</td>
<td>produces inward movement.</td>
<td>produces friction only.</td>
<td>produces friction only.</td>
</tr>
</tbody>
</table>

In this case the wheel is made with pin-teeth. The pawl has a forked end, the inner flank tending to produce an inward movement, the outer flank, outward movement.

In this case, as in the preceding, the wheel must be turned through a small angle before the pawl can be released.
§ 238.

THE SLIDING FLANKS.

We have discussed the action of the flanks of tooth and pawl which work together during the thrust. It is obvious that greater liberty is permitted in the form of the sliding flanks. It is only necessary that the form shall be such that the forward movement of the ratchet wheel will lift the pawls properly out of gear. The forms fall under cases 4 to 7. The usual form is the common zigzag ratchet, but others are also used, as in Figs. 665 and 667; in both of which the teeth are symmetrical.

If it is desired to have the end of the pawl symmetrical, as in Fig. 667, this may be done, and the pawl may be reversed for a reverse movement as shown in the dotted lines. This form is used on the feed motion of some machine tools.

For some purposes it is desirable to form the thrust flank upon which the impelling force acts, in the same manner as the sliding flank, in which case the pawl must be held in gear by some extraneous force capable of resisting the maximum impelling force which it is desired shall act.

§ 239.

SPRING RATCHETS. QUADRANTS.

The form of ratchet last described possesses an especial property, that is, the action of the spring tends to force the pawl into the space as soon as the point is over the middle of the tooth. This causes the pawl to spring into engagement, hence the name spring ratchet, and this action causes an acceleration of the motion either forwards or backwards as the pawl is forced into the space. Applications of this form are found in repeating watches, in which the wheel is star-shaped, and hence called the star, while the pawl is called the star pin or springer.*

A modified form, Fig. 669, is used in Thomas' Calculating Machine. In this case the spring itself acts as the pawl, being attached directly to the arm without joint, forming a plate link. (See § 183.)

* This is shown later among the releasing ratchets.

Instead of using an entire ratchet wheel, a portion only need be made, if the required movement is but small, and in some cases reduced only to a single tooth, as in Fig. 670.

Sometimes the two members may be made of similar form, each working alternately upon the other, Fig. 671. Examples of this are found in the valve gear of some Cornish engines. These belong to the so-called "dead" ratchets, and are called, more or less appropriately, quadrants, or sextants.

§ 240.

METHODS OF SECURING PAWLS. SILENT RATCHETS.

The engagement of the pawl with the ratchet wheel is usually secured by the weight of the pawl, sometimes assisted by additional weights, as in Fig. 672. This may also be accomplished by means of a spring. It is desirable to give such springs but little movement, and small frictional resistance. It should therefore be placed near the axis, and is best placed in the line 1, 3, 5, that is, 4.5, shall line in the same straight line, Fig. 672 a. If this cannot be conveniently done, it may at least be made nearly so, as at b. A weak spring with much movement may be seen below in Fig. 660, yet at the same time the line 3, 4, 5, is only slightly varied from a straight line. In spinning machinery spiral springs of steel are used, and rubber springs have been used in propeller hoisting frames, Fig. 660.

In devices in which the pawls are sometimes above and sometimes below the wheel the springs are sometimes replaced by using several pawls. This is shown in Fig. 673, which is Wilber's ratchet for use in lawn mowers.

Three pawls, with half journal, are here used, and as the axis t, lies in a horizontal position some one of the pawls is always in engagement by its weight. The movement of the teeth under the pawl, and the dropping of the latter into the spaces produces wear upon the parts, and to avoid this action various devices have been made; these being known as silent ratchets. A very useful form of silent ratchet is shown in Fig. 674.

The pawl is made with a projection 5, which is connected to a friction band 6, which is carried upon a hub on the ratchet wheel. When the wheel begins to move forwards, the arm 4, 5 lifts the pawl 6 out of gear. The lift of the pawl is limited by the pins at 5. As the forward motion continues, the band slips upon 4; if reverse movement begins the pawl is at once thrown into gear. This is used in spinning mules, also in Poyser's coupling, Fig. 453, in which two pawls, each with its own device are used. The principle involved in this device is capable of wide and useful application, as will be seen hereafter.

Another form of silent ratchet is shown in Ulbott's coupling, Fig. 454. In this case the pawls 5, lie close against the flanks of the teeth. They are thrown into gear again by auxiliary ratchets, the spring pawls of which are not silent. Then lift the pawls 6, through a small angle when the engagement is
completed by the self-closing action of the tooth flanks, Case 4 or 6, § 237.
Ratchet drills, etc., are often made with silent ratchets. Wilber’s ratchet, Fig. 673, may be used for this purpose. If it is placed so that the axis, 1, is vertical, the friction of the paws against the case will lead them into gear in the forward movement and draw them out on the return movement, the friction in this case taking the place of any operating gear for the ratchets. Various other forms of silent ratchets are in use.

§ 241.

SPECIAL FORMS OF RATCHET WHEELS.

In spur ratchet gears the axes a and c of the wheel and pawl must be inclined to each other. These axes, however, may be placed in the same manner as with gear wheels so that they are inclined or intersect each other. A great variety of forms of ratchet gearing may thus be made. The variations do not at first appear as important as they really are, but this will appear in the further discussion.

A form of ratchet for inclined axes is the crown ratchet, Fig. 675, which is used in capstan gears. The wheel, a, is stationary, and the arm and pawl, b and c, revolve.

The forms shown in Fig. 676 and Fig. 677 are for non-intersecting axes, and use crown wheels also, and hence are called crown ratchets.

By making the wheel, a, in the form of a plane wheel, and substituting a bolt for the pawl, some useful modifications are made. Fig. 678 shows a form of ratchet used in a mule press, in which the bolt can readily be lifted out and placed in the successive holes as the lever arm is moved backward and forward. The ordinary jaw clutch coupling, Fig. 441, is really only a form of crown ratchet with bolt pawl. The portion on the shaft A is the ratchet wheel, and the part fitted to slide on the shaft B corresponds to the bolt &.

§ 242.

MULTIPLE RATCHETS.

It is frequently desired to construct ratchet gearing so that the minimum limit of movement shall be less than the pitch of the teeth on the wheel. This is accomplished by using two or more ratchets acting at corresponding subdivisions of the teeth. Such multiple ratchets exhibit a wide variety of forms and find many useful applications, and in many cases their true nature is not fully understood.

Fig. 679 is a multiple ratchet of common form, with three paws, in which the paws are set a distance from each other

equal to \( \frac{1}{2} \) of the pitch. From this arrangement the wheel can be moved spaces equal to

\( \frac{1}{6}, \frac{1}{3}, 1, 1\frac{1}{2}, 1 \frac{3}{4}, \ldots \),

of the pitch, that is, through \( \frac{1}{2} \) the pitch and any multiples of the same. This is sometimes used in saw mill feed motion, where a fine feed is required with a coarse pitch ratchet.

A double ratchet is used in Weston’s Ratchet Brace, Fig. 682. The paws A and B are placed one above and one below the arm C, and act on the two parts of the double ratchet wheel.

Another ratchet drill, also by Weston, with four paws is shown in Fig. 684. This has an internal ratchet wheel with
five teeth. Double ratchets are also found in Uhlhorn’s coupling, Fig. 454, and Pouyer’s coupling, Fig. 455.

If it is desired, the pitch may be halved, or divided into any two chosen portions, in which case the paws may be made in one piece, Figs. 682, 683.

In each of these there is one pushing and one pulling paw upon the axis 3, the pitch being halved and the paws acting alternately. One form shows a spur wheel, the other an internal wheel. The form of the double paw has caused this to be called an “anchor” ratchet.

If the wheel is a so-called “face” gear, that is, with the teeth projecting from the face of a disc, two similar paws may be used, both pulling or both pushing, and forming the same anchor, Figs. 684, 685.

If the teeth are set alternately in two concentric rings, the two paws may be merged into one, as in Fig. 686. This latter form appears to be new.

§ 243.

STEP RATCHETS.

A very instructive form of multiple ratchet gearing is obtained by combining more than two paws into one piece, and arranging two such paws to work together, and this form is capable of very extended application. In the ratchet combination of Fig. 687, we have such a combination of two multiple paws, with “dead” engagement, released by lifting the paw 6. The part a, which is impelled in the direction of the arrow is thus released, but is arrested again by the shoulder 2. If the flank

\[ z' \] is formed in the arc of a circle from the center 3, a further lifting of 6 will cause, without resistance, a fresh release of a, again arrested at \[ z'' \], and a similar action again for the flank \[ z''' \]; the points 2, \( a, b, y \) all lying on a circle drawn from the center 1. Thus a continuous lifting of 6 will produce three successive advances of a. The angle of each advance of a may be called the angle of advance, and the corresponding angle of lift of 6 the angle of release. In this case the angles of advance are all made equal to each other, as are also the angles of release. When the position in which 2 is arrested by the flank \[ z''' \] is reached, the angle of thrust \( \theta \) becomes so small that further travel cannot well be obtained. If it is required to provide for still further movement it can be done by making additional teeth behind 2, as II, IV, III’, etc., which will engage successively with 6 at \[ z''', \] The construction of “dead” form of teeth is clearly shown in the diagram. As before, the angles of advance and release are made uniform. The mechanism as constructed will give nine successive engagements. The ratchet surfaces on 6 are struck from 2, and the sliding surfaces on a from 1; the flanks on a with a radius \[ 3z'' = 3 \], the flanks on 6 with a radius 1.2.

It is to be noted that the two parts a and 6 are interchangeable in their functions, so that when the extreme notch II of a has been reached, a may be reversed in movement and 6 follow step by step to its former position.

Such step-ratchets are seldom used in practice, but many useful applications are possible.

In Fig. 688 is given a form of step ratchet arranged to give a uniform angle of advance together with uniform drop of the paw. The paw a is actuated by the force indicated by the arrow, and teeth are upon a cam-shaped disc.

\[ \text{Fig. 688.} \]

An arc with radius 1.2 passes through 3, the angles of release on 6 are \[ 3z' \], and the successive angles of drop of a are \[ 3z'' \]. This form of ratchet is used in the striking mechanism of repeating watches. and is known as a “small” movement. The arm \( a \) in this case is frequently made on the form shown in dotted lines at A. The construction of the small is interesting. In order to fulfill the given conditions the points 2, \( z'' \), … must lie on an abscissa of a cycloid; in the given case, where \( z = 1 \), it is the form known as a “homecenter” cycloid. The points of the re-entering angle line on a similar curve. The circles rolling together to describe these curves are shown in the figure 2, rolling about 1, and \( T \) about 3; their radii are inversely as the angles of drop and advance. If the parts b and a move continuously, these circles roll on each other, for the actual movement which take place, the drops of the paw occur as successive ringed points coincide.

* See Reuleaux’s Théorie des Kinematiques, § 24.
In the preceding step ratchet (Fig. 687) the angle of drop and of release were given the ratio 1:2. In this case the points of the teeth were on cycloids, those on a being on a pericycloid, those on $b$ on a hypocycloid. The contact point of the generating circle falls without the figure on $3/4$ prolonged. Since the radii of the circles are as 1:2 with internal contact the hypocycloid becomes an ellipse. A portion of the curve is given in the figure; $3X$ and $3Y$ are the semi-diameters. The simplest form for the line of the teeth will be obtained by making $1/2 = 1/3$, since for this case the ellipse for one diameter of the base circle on $b$ becomes the straight line $3X$.

Fig. 692 and 693 show two modifications of the notched ratchet. The distinction between tension and compression paws disappears, since the pawl is in the same for either action. If the distance between the axes $1$ and $3$ is made infinitely great, the pawl becomes a sliding bolt. Such a form is shown in Fig. 694, which is for non-intersecting axes. The wheel is a crown wheel, and the pawl may have more than one notch.

Another form of notched ratchet with axes 1 and 3 infinitely separated is shown in

If it is desired to combine in the same piece two step paws, Fig. 689, of which one set shall be in tension and the other in compression, an anchor ratchet may be used. In this case a back and forth motion of the anchor permits an intermittent forward motion of the wheel. The anchor has ten steps and the wheel four teeth. This may be considered the general case of which Figs. 682 to 685 were special examples.

Numerous interesting problems may be solved by such devices, such as the conversion of continuous rotation of one piece into intermittent rotation of the second. Applications are found in clock and watch-making.

The various modifications which may be made in the relative positions of the axes 2, 1, and 2, permit a very great variety of step ratchets to be made.

### Stationary Ratchets

A stationary ratchet may be considered as a combination of a pair of running ratchets with the teeth facing in opposite directions. The scheme of such a combination is shown in Fig. 690. From the four possible positions of the parts $2$, $2'$, $II$ and $IV$ we may make the following double combinations:

- $2$ with $II$
- $2'$ with $II'$
- $2'$ with $II$

The first two combinations are practically identical with the stationary ratchet, Fig. 691. The flanks of the two wheels give a notch for the space, while the teeth assume a dovetail shape, and this form of stationary ratchet may be called a notched ratchet. The wheel will be firmly held by the so-called "dead" tooth, or when $(90^\circ - \varphi) < \beta$, $\varphi = 90^\circ$. Many forms of this kind are used in practice.

*This form of ratchet will be recognized as similar to the common jaw coupling. The shaft $a$ carries the crown wheel $a$, the bolt corresponds to the other half of the coupling $a$. The shaft $b$ carries the part $b$, the latter sliding upon a feather.
The cylinder \( \delta \) may be entirely cut through as in Fig. 693, so that the segment shall fall entirely within the surrounding circle. When it is placed opposite the teeth the wheel may be revolved in either direction as far as desired. If this movement is to be limited, as, for example, to a given pitch, it can be accomplished by cutting a corresponding space in the cylinder, such as is shown in Fig. 699 a.

It is not necessary that the spaces in the wheel \( a \) should conform to the circular profile of the cylinder \( \delta \) (see § 237); the thrust is at two points on the right and left of \( \pm \frac{1}{2} \), and it may be formed as at \( \delta \), or pin teeth used as at \( \epsilon \). This last figure shows the modification made in the notch of Fig. 683 to reduce the backlash of the wheel \( a \) through the axis \( 3 \), and the gap in the cylinder is increased proportionally. When the wheel is impelled in the direction of the arrow, the pin \( a \) slips into the space in the cylinder as soon as the opening is turned towards it far enough, but cannot pass out until the cylinder has turned back the same distance in the opposite direction, thus forming an intermittent pitch movement.

This idea is more fully carried out in Fig. 699 c. In this case the inner profile of the space is concentric with the outside of the cylinder, as was also the case with the form shown in Fig. 697. In this case the tension and compression pawls are practically combined in one. When the opening moves into the proper position, the pin \( a \) moves to the point \( z \), and completes the remainder of the pitch movement when the cylinder moves to the left again. This form may be made free from backlash by making the outside of the cylinder fill the space between two teeth as in Fig. 700. If it is required that the intermittent movement should divide the pitch into two equal parts, the arc of the pitch circle of \( \alpha \), which is the measure of the thickness of the teeth, must be equal to the arc cut off by the space in the cylinder. If backlash is permissible, the thickness of tooth may be reduced.

The form shown in Fig. 703 is derived from the globoid gearing of Class III, § 224, the ratchet being a cylindrical notched ring. Fig. 704 shows how a pitch ratchet can be made on this principle.

An examination of the preceding forms of stationary ratchets, in which the pawl consists of a revolving member with a gap cut in it, will show one common property in all of them. This is the fact that an intermittent motion produced by successive release and engagement may be made either by a continuous rotation of the cylinder or by an oscillating movement. If, therefore, we have a continuously revolving shaft to deal with, or a vibrating member, the desired release or intermittent action of the part to be acted upon may be obtained. Both forms are found successfully applied in actual practice.

**RATCHETS OF PRECISION.**

If we imagine the running ratchet of Fig. 682 so modified that upon the release of the pawl \( a \) at a point nearer the tooth than the middle of the pitch, as there shown, the principle will not be changed. If this modification is made to such an extent that the angle \( \alpha \) in both cases becomes zero, i.e., the pawls so made that one enters into engagement at the instant of release of the other, we have the form shown in Fig. 705.

In this case the wheel \( a \), being impelled in the direction of the arrow, can pass the points of both pawls at once. The slightest movement of the member \( \delta \) in either direction, however, will bring either \( 2 \) or \( a \) into engagement and hold the wheel. This form is called a Ratchet of Precision, the especial one given being a running ratchet.

The principle is capable of various applications, and is also suitable for stationary ratchets, two forms of which are shown.

*This form is similar to the running ratchet of Fig. 677.*
in Figs. 706 and 707. In the latter case the pawl assumes the form of a bolt, shown in the illustration with several notches.

The practical applications of ratchets of precision are numerous, and examples will be given hereafter.

General Form of Toothed Ratchets.

We have already seen that several forms of ratchet mechanism which have been described possess numerous points of similarity, and may be reversed and derived from each other, and hence it is not unreasonable to expect that some general form may exist from which the various special modifications can be derived, and in which the distinction between ratchet wheel and pawl, or checked and checking member, shall not exist, but each shall appear in both.

This general form is actually found in the combination of two disc face wheels (§ 241), with their centres carried on the same bar, Fig. 708, in such a manner that the teeth of both shall engage and be engaged by the other. In the illustration is shown such an arrangement made for a stationary notched ratchet. The wheel 2 engages as a pawl with the wheel 3, and if it revolves a space of one-half a pitch, 6 will be released. If so, however, revolves any given odd number of half-pitch angles only, 6 will be checked, and 3 become the pawl. In both cases we have a ratchet of precision of the same type as in Fig. 706.

The pitch ratchet with anchor pawl may also be thus derived; it is true the anchor form cannot so readily be shown as a pair of similar wheels, but it is clearly only another form of the same problem. The zig-zag ratchet, notched ratchet, step ratchet, or their combinations are all reducible to this general form, the only condition being that the direction of the force in the position of engagement of the checking member shall be such that the checked member cannot rotate. The intermediate forms show the "paw lifting" action, § 237. It is evident that in some cases the checked member may have a forward movement, and in others a reverse movement. Since here, as in § 235, we may consider the link 6 as a checked member when the wheel is held fast, we may, from the combination of these parts, obtain four kinds of ratchets, viz.:

1. 6, stationary; a, checked; b, checking.
2. 6, checking; a, checked; b, checked.
3. a, checked; 6, checking; b, checked.
4. 6, checked; a, checked; b, checking.

As a general statement of the fundamental principle we have:

A toothed ratchet consists of a combination of a pair of gear wheels, or of portions of gear wheels, in which the teeth are so made that for certain positions of the wheels the resultant of the pressures on the teeth of one of the wheels either passes through the axis, or differs from such direction by less than the angle of friction.

Running Friction Ratchets.

The mechanical devices which are constructed to modify the relations between two moving bodies by means of friction, may be called by the general term of friction clutches. Such a device, when so arranged that one member opposes a positive frictional resistance or check to the motion of the other in one direction under the action of an impelling force, constitutes a friction ratchet. Such devices may be divided, as before, into running and stationary ratchets, § 235, and the first form will now be considered.

In Fig. 709, is shown a friction ratchet for parallel axes. In this case the friction block b is carried by the friction with the wheel a, when the latter begins to rotate in the direction of the arrow, that the pawl link 6 is crowded against the axis 4. The radii component of the direction 4-3, exerts a pressure upon the brake block bk. We also have the tangential component 5, which we may consider as composed of two forces 5, and 5, acting in the same direction, which hold the friction at 1 and 2 in equilibrium. At 3 we have two opposite forces 5, and 5, which are capable of resisting the friction at 3 and 4 respectively.

The moment M, of the four friction forces is: $M = (S_1 + S_2 - S_3 - S_4)(a + b)$. If we give the angles the symbols shown in the illustration, and make $a + b = a_1 + b_1 = a_2 + b_2$, and call the radii of the several journals $a_3$, $b_3$, and $c_3$, we have:

$S_1 = \frac{Qf}{a + b}$
$S_2 = \frac{Qf}{a + b}$
$S_3 = \frac{Qf}{a + b}$
$S_4 = \frac{Qf}{a + b}$

But we also have $(a + b) \sin \alpha = \sin \gamma$

From this we get:

$S_3 = \frac{Qf}{a + b} \cos \alpha$

$S_4 = \frac{Qf}{a + b} \cos \alpha$

This gives for $M$:

$M = Qf \left( \frac{a_1 + b_1}{a + b} \cos \alpha + \frac{a_2 + b_2}{a + b} \cos \alpha \right)$

The force $P$ which acts at $s_2$ to rotate the wheel in the direction of the arrow, may be considered as a couple. We then have for $M = Pa$:

$P_a = Qf \left( \frac{a_1 + b_1}{a + b} \cos \alpha + \frac{a_2 + b_2}{a + b} \cos \alpha \right)$

*This term only partially expresses the general scope of the German word "Hermelsche," for which there is no exact equivalent in English. — Trans.
But $Q$ is a function of $P$, and in fact we have

$$P' = Q \tan \alpha^*.$$  

This gives:

$$\sin \sigma = \frac{a + a_i}{a + b} = \frac{1}{\cos \sigma} - f \left[ \frac{b}{a + b} \left( \frac{d}{c(a + b)} \cos \sigma + \frac{c_i}{c} \right) \right].$$

and since the angles $a$ and $a_i$ are small, and become smaller under the action of the pressure, a sufficiently close approximation will be obtained by putting:

$$\sin \sigma \approx \frac{1}{\cos \sigma} - f \left[ \frac{b}{a + b} \left( \frac{d}{c(a + b)} + \frac{c_i}{c} \right) \right].$$  \((233)\)

The following conditions must be noted. If an independent force outside of $Q$ exerts a normal pressure $N$ upon the circumference of the wheel, the friction $N/2$ will diminish the force acting to turn the wheel backward. If this is to enter into the resistance which is produced by $Q$, the magnitude of $N$ as given by equation (233) must be modified. If $N$ becomes sufficiently great, $Q$ may become zero; in such a case we obtain a stationary instead of a running ratchet.

The pressure $R$ on the pawl may become very great. We have

$$R = \frac{P}{\cos \sigma}$$

which may be made approximately:

$$R = \frac{P}{(a + b) \sin \sigma}.$$  \((234)\)

Example. Let $a = 15^\circ, a_i = 16^\circ, b = 20^\circ, c = 13^\circ, c_i = 12^\circ$, and $\sigma$ at all points $= 0^\circ$. We have $d = a = a_i = 15^\circ$, approximately, and

$$\sin \sigma \approx 0.66,$$

whence $\sin \sigma \approx 0.66\theta$, which gives $\sigma \approx 4\theta/5$. To be on the safe side we will make $\sigma = 5^\circ$, or $\sigma = 0^\circ$. The actual length of $a$ will be very slightly less than $a = 15^\circ, -15^\circ$.

As will be seen the ratio comes out unfavorably. The method of remedying this will be discussed hereafter.

The pawl $c$ may also extend within the circle of the wheel, as in Fig. 714, in which $c$ is an obtuse angle. The axis of the pawl may be either at $a$ or $a'$, or $a''$ or $a'''$ prolonged; the pawl is in this case a tension pawl. In the event that the pawl having an internal wheel, the combination shown in Fig. 711, the pawl being under compression.

Especially noteworthy are those cases in which one or more of the axes are infinitely distant. In Fig. 712 is shown the case

$$\sin \sigma \approx \frac{1}{\cos \sigma} - f \left[ \frac{(a + a_i)}{(a + b)} - \frac{b}{a + b} \left( \frac{d}{c(a + b)} + \frac{c_i}{c} \right) \right].$$

When $a_i$ is very small, release is difficult, and the arrangement does not appear to be very practical. If the arm $a$ is made infinitely long, so must also $a_i$, and we get the case of Fig. 713. The wheel becomes a sliding bar. The relations

$$\sigma \approx \frac{1}{\cos \sigma} - f \left[ \frac{(a + a_i)}{(a + b)} - \frac{b}{a + b} \left( \frac{d}{c(a + b)} + \frac{c_i}{c} \right) \right].$$

give excellent action.

If with $a$ and $a_i$ we make $c$ infinitely long, we obtain the construction of Fig. 714.

The conditions give:

$$\sin \sigma \approx \frac{1}{(a + b)} - \frac{b}{a + b} \left( \frac{d}{c(a + b)} + \frac{c_i}{c} \right).$$

The joint at $a'$ in Figs. 715, 716, and 717 makes a full bearing for the surfaces at $a$, $a_i$, and $c$. This is also the case with the joint at $a$ in Fig. 715, on which $a_i$, $b$, $c$, and $d$ are infinitely great, while $d$ is the difference between two infinitely long but opposite distances, and hence is finite. We have the relation $\sigma \approx \frac{1}{(a + b)} - \frac{b}{a + b} \left( \frac{d}{c(a + b)} + \frac{c_i}{c} \right).$ By omitting the joint we obtain the simple construction shown in Fig. 716. The friction block is in the form of a key or wedge, as in Fig. 715, and the number of parts reduced to three (see also the following section).

The results as determined by calculation are always practically for the desired ratchet construction, which shows that the selection of the relation between the parts must be made with judgment, and care taken that those pieces which are subject to heavy pressures shall not readily be deformed. As the preceding example indicates, the small size of the angle $\sigma$ renders it an important point for consideration. In this case the actual length of $a$ is only about $d'_{\frac{1}{2}}$ greater than $a + b + c$. The pressures $Q$ and $N/2$ act to lengthen $a$ and shorten $a_i$, $b$, and $c$, and if $P$ too pounds the difference may readily be $\frac{1}{2}b'$, so that with only $\frac{1}{2}b'$ additional wear, $c$ becomes zero, the parts $b$, $c$ pass the centre, and the ratchet action ceases. This will indicate the conditions under which the ratchet becomes a useful device.

The numerical magnitude of the parts $a$, $c$, and $d$ can be chosen so as to render the unavoidable wear least hurtful. This may be done with the sliding ratchet, Fig. 713, by making the length $c$ sufficiently great. It is also important to devise means to prevent the block and pawl from being forced past the centre. A method of accomplishing this is to substitute for the pin joint between the block and pawl, a curve or cam bearing.

In Fig. 717, the block is given a circular profile from the centre $1$, and the pawl an evolute outline developed from a circle about $a$, with radius $d_{\sin \sigma}$, we shall have $e$ nearly constant, notwithstanding the elastic yielding of the parts and unavoidable wear. If the yielding between $1$, $a$ great, the radius of the circle on which the evolute is generated may be made somewhat greater than $d_{\sin \sigma}$. This construction appears to be new. A number of similar modifications may be made, for which see the following section.
It is desirable to examine the value of the coefficient of friction \( f \) in order to increase it at the point 2. This cannot well be done by choice of material, since wood can scarcely be used in many cases, and lubrication of the rubbing surfaces is essential. The application of wedge profiles to wheel and friction block enables greater friction to be obtained, Fig. 718, as in the case of wedge friction wheels, § 196. Instead of the coefficient \( f \), we have the value \( f = \tan \frac{\phi}{2} \), if the wedge angle \( \phi = 60^\circ \), this gives \( f \) for \( \phi = 30^\circ \), nearly \( f \). By combining this with the preceding forms, some very useful devices may be made.

It is desirable to arrange the application of the force \( R \) so as to exert a small disturbing action upon the parts as possible. This may sometimes be done by arranging two or more friction pawls of similar kind to act upon one wheel. Some examples of such devices will be found in the following section. It must not be forgotten that the conditions for \( f \) are not changed by the repetition of parts, since the numerical value of \( F \) does not enter into its determination.

There is yet another form of friction ratchet which is capable of being made very useful. By an examination of formula (223) it will be seen that the influence of the dimension \( a \), is almost as great as that of \( a \) itself. If we increase \( a \) to nearly the same magnitude as \( a \), Fig. 719, we may approach closely the minimum value of \( a \). This carries with it the disadvantage that the frictional resistance to the backward and forward movement at \( t \), is greatly increased, but this effect may be avoided by making a special bearing for the friction block and arranging the parts somewhat as shown in Fig. 720. The attempt of \( c \) to move backward causes the pieces \( b \) and \( d \) to press upon the rim of \( c \) from without and within and grasp it firmly. The angle \( \epsilon \) may now be made twice as great as in the previous forms without danger, all other things remaining the same. A practical form of this device is shown in Fig. 721, as applied to a mill feed motion. Here the screw motion \( M \) is intended to permit of a suitable degree of play for the lever \( c \). If we make \( a \), \( c \), we have the form shown in Fig. 722, which seems quite practical, and when applied to a friction rack we obtain the form in Fig. 724. We shall return to the consideration of these double friction ratchets hereafter.

It must be remembered that these forms of friction ratchets are also applicable to other positions of axes and some resulting devices are in practical use.

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* See Goodacre, Elements of Mechanism, London, 1864, p. 196.

† See Morin, Notions géométriques sur les mouvements, Paris, 1861, p. 208.
by making the curves at 2 and 3 portions of the same circle, and the corresponding curve at 2 so found to produce the required clamping action. The clamping piece \( b \) becomes a cylinder, Fig. 727. If we make the angle \( O = 3 = 4 \) and prolong the radius \( 3 O \) to \( N \), then will \( 3 O N \) be the normal to the curve at the point of contact with \( b \) at 3, since the angle \( a = O = \theta \). The curve for \( c \) is an arc of a circle struck from a centre \( M \), on 3 ON, found by making \( 1 M \) perpendicular to \( 3 O N \). This curve is practically correct for a smaller clamping cylinder as at \( O' 3 \), since the angle of thrust is very nearly the same as at \( O 1 2 \), or in other words the effectiveness of the clamping action is not impaired as the cylinder is reduced by wear.

The pressures at 2 and 3, Fig. 728, are:

\[
T = \frac{Q}{\cos \theta}, \quad R = \frac{T}{\cos \theta}.
\]

whence \( Q = P \left( \frac{a}{\omega + a} \right) \).

A practical application of the preceding form is shown in the checking device for sewing machines, Fig. 729. In this case, a ball of rubber is substituted for the cylinder. Another similar device is the ratchet check used on the old Langen Gas Engine, Fig. 730. In this case, a number of roller checks are used in order to distribute around the wheel \( a \).

The whole forms a sort of continuous ratchet gearing in which the backward and forward movement of \( c \) imparts a continuous forward movement to the wheel \( a \). When \( c \) moves in the direction of the arrow II, \( a \) is clamped and driven, while the parts are released when the motion is reversed. The action of the centrifugal force tends to keep the checking cylinders in contact with the outer ring, and so insure prompt action upon the reversal of motion. The pressure upon those roller checks in the Langen Gas Engine was very great, wrought iron rollers were used rapidly and phosphor bronze was substituted, although even these gradually altered their form under the pressure.

Another ratchet check used by Langen for the same purpose, is shown in Fig. 731. Here again we have a repetition of the parts, and also a return to the friction block, the rollers occupying the place of pads. Comparing this with Fig. 729, the curved bearing surfaces correspond to the journals 3 and 4, and the action is similar to Fig. 727. The block \( b \) is arranged so that full clamping is obtained in a quarter turn. Friction ratchet

cists with double clamps are also used as in Fig. 731 and the same principle appears in Fig. 727, which shows Schede’s “friction pawl.” A similar device is shown in Fig. 733, as applied to a rod movement, and upon inspection the resemblance to the action of the “throttle” pawl will be seen. As long ago as 1793 Hornblower applied this idea to a rotary engine as shown in Fig. 734.

The Release of Friction Pawls.

The release of a friction pawl under pressure requires a certain degree of force, since there is always a friction between the rubbing surfaces which is at least equal to \( F \), which must be overcome if the pawl is to be released under pressure. The release is to be effected under quite different conditions from those which obtain with toothed ratchets in which, for example, with a “dead” engagement, only the “7th” part of \( F \) is exerted at the pawl point. The force required for release may be somewhat reduced by combining the action of two sets of friction surfaces of opposite direction of engagement, Figs. 735 and 736. The motion in the direction of the arrow tends to draw the pawl 2 into closer engagement, and at the same time to release that at 2′. By altering the reliefs of the distances 4-3 and 4-′3, etc., any proportion of the moment may be used to hold the parts in gear. These forms appear to be new, and may be called “throttle ratchets.”

Stationary Friction Ratchets.

A stationary friction ratchet may be defined as one in which the clamping action is not dependent upon the direction of

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See Bulletin von Milius, XII, 186, p. 260, also Schletter's Maschinen.

1. The arrangement will be found to exist in the ring spinning frame. The pawl \( b \) Fig. 724, is made of wire and held at \( a \) by the thread passing through an eye. Since the angle \( a \) is made greater than we have taken it down, a rod or brake is necessary.

2. A similar device is used by Carter, both being found in Wrouth's Scenes of Industry, Plate XV, Fig. 8, and also in Stewart's Alphabet of D. 414.

It may be noted that friction pawl actions are found in nature. Sometimes have such connections to certain bones or spines which they can move and give rise to compressions or depressions. See D. Thiele, Die Sperrenzüge unserer Weise, 4th ed. 1879.
rotation of the wheel. Such a ratchet is shown in Fig. 738. 1 and 4 are parallel axes, the block acts with a radial pressure \( Q \) such that for the circumferential force
\[
F = \frac{a}{g}
\]
the following conditions may exist:
\[
Q \geq \frac{F}{a} \quad (239)
\]

If \( Q \) is less than the right hand expression, \( F \) will only be partially opposed, there will be motion from \( a \) toward \( d \), with slipping at \( c \), or in other words, we have a brake, see § 248. This construction is frequently applied, although it requires a relatively large force at \( Q \), acting through the lever \( d \), giving increased pressure on the axle and which wear on the block. Various forms of lever connection are used to modify the ratio \( Q' \): \( Q \). By clearing the angle which the axes 1 and 4 make with each other, various convenient modifications may be made. The general scheme of such constructions is illustrated in Fig. 738, in which the toggle connection gives a high ratio of \( Q' \) to \( Q \); the block being guided in slides. By making \( a \) an internal wheel, a very practical arrangement is obtained as shown in Poussey's coupling, Fig. 439.

Koechlin's coupling, Fig. 440, is also another form of friction ratchet gearing, the pressure in this case being applied by the means of a rod and a cross screw. The same is true of other forms of friction coupling, and the various methods of applying the pressure and reducing the wear, given in § 248, may also be applied in the design of mechanism for the purpose.

**Example 2—Valve Gear by Wannich, of Berlin.** In this case there are two flat slide valves to be operated by the reciprocating movement of the piece \( e \). It will be seen that this is a form of friction ratchet gearing. The valves are...
A third form is that used in Shank's planing machine, Fig. 744. In this case the lever, with its arm 2, is at right angles to 3, and the latter is provided with a roller. The limit of measurement of 1 is between 2 and 2'.

The forms of tumbling ratchets described in § 239, may be adapted as releasing gears, but it must not be forgotten that in such mechanisms provision must be made for the middle position of the ratchet.

A fourth form of tumbling gear, of which, indeed, there are many varieties, is the so-called "loop" of Hofmann's valve gear, Fig. 745. The loop a is made in the arc of a circle from a centre at 2. A is a heavy roller, with additional weight suspended at 2'. When the loop or curved link is in either of the positions, 3, or 3', the weight acts to continue the motion in the direction in which it started until the limit of travel is reached.

A swinging arm be may be substituted for the slot and roller, Fig. 746, and it will be seen that during the movement from the position 2, 3, to 2', 3', the swinging action of the arm e carries the loop as already stated until the loop will become straight and the two forms will coincide. Hofmann has made the analogy to a ratchet train more complete by placing a ratchet so as to engage with the point 2 in the position 2 and 3; the release being made at the proper time by means of a cam, 4.

In some cases it is desirable to make a gearing which shall be released by the action of a very small force. For this purpose a second releasing gear may be introduced, itself being readily released, and by its action permitting a blow to fall upon the trigger of the main gear. Such a device forms a releasing gear of the second order. Such an example is shown in the firing trigger of a rifle.1

Releasing ratchets of higher orders are also found in textile machinery, as in the Jacquard loom, also in the striking gear of tower clocks and of repeating watches. Another example is found in the relay of the Morse telegraph, besides many other applications which will be considered hereafter.

§ 253.

Checking Ratchets.

Checking ratchets are used in a great variety of machines, but their principal applications are found in machinery for hoisting and lowering heavy loads, as in mine lifts, elevators, and the like, to guard against accidents in case of the breakage of the ropes. In the opinion of the writer these devices have not been as yet regarded as they should be, merely special cases of ratchet construction, and as such capable of utilizing all the various principles heretofore considered. When examined in this light their study will be greatly facilitated.

As a scheme of a general system for checking ratchets a friction ratchet may serve, Fig. 747, in which the rod 1 is held stationary, the inclined member 2 carries the ratchet, and the ratchet e and friction block 3 are held out of

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* Further details of this and the preceding gear will be found in the Austrian report on the exposition of 1873. Section on Steam Engines by A. Knide, Vienna, 1870.


1 Such firing triggers were ingeniously applied to former times upon crossbows.
engagement by the releasing lever, and rod as long as the hoisting connections and are under stress. If the tension is released, the ratchet is thrown into gear and the parts clamped. If a toothed ratchet is used instead of a friction device, the block is omitted. According to the manner in which the various constructive details from to are arranged, we obtain the various systems of checking ratchets which have found practical application.

A collection of such devices was exhibited by the Industrial Association (Verein für Gewerbelehr) in 1879. More than 80 designs were shown, of which only a few can be described. Many of the devices were rather designs for improvements in construction as regards strength and rigidity, rather than examples of mechanical ingenuity.

In most cases the clamping action takes place upon the upright timbers of the shaft; sometimes guide ropes are used.

The greater number of designs shown used friction clamps, those of Fig. 748 being shown, the thumb pawl being roughened, however, or finely toothed. The one which showed the most evidence of careful constructive design in accordance with the principles previously laid down in § 749, was that of Hoppé, shown, as attached to each side of the hoisting car, in Fig. 748.

**Fig. 748.**

The form of friction pawl used is similar to that shown in Fig. 748, there being four paws on each side of the car, or eight in all. The clamping action takes place upon the guide bars, made of iron, as shown. At , the guide rods between and , the double clamp blocks of hardened steel, which are connected at to the coupling rods , . The actuating spring is a torsion spring (see Fig. VII, p. 19); also Fig. VIII, p. 19, secured to the roof of the car at , , and operated by the releasing gear, , and transmitting action from to by the rods , , the connection being made by the links , to the double clamp in such a manner that the arm cannot be drawn too far out of position.

The proper adjustment of the pawl arms is obtained by the keys on the rods , . Hoppé has taken into consideration the fact that the angle , see (233), must not pass beyond certain limits, or too great pressure would be exerted on the frame, , and hence has provided stops in the frame for the travel of the paws , . The parts are so proportioned that a load of double that ever placed upon the car would be supported by the friction clamps before there would be any appreciable elastic yielding of the frame. The adjustments of the rods , provide for the change of relations due to wear. This apparatus does not bring the lowering of the hoisting car to a sudden standstill in case of breakage of the hoisting gear, but the shock is avoided by the gradual action of the friction brakes.

By using the author's device, shown in Fig. 747, at , the value of might be maintained constant, or by proper construction of the guides the wedge friction paws, similar to Fig. 748, may be used; the blocks acting on both sides of the guide. This would reduce the stress upon the frame very materially.

The system of brakes used upon railway trains are really forms of friction checking ratchets. The shocks due to sudden stoppage are also to be avoided, and if the wheels are braked too firmly the sliding action is simply transferred to the rails.

**§ 754.**

**Continuous Running Ratchets.**

Continuous ratchets (§ 248, No. 2) consist of such combinations of pawl mechanism as act to drive a member in a given direction with practically a continuous determinate motion. This may be effected by combining two single running ratchets in such a manner that they both act upon the same wheel, one pawl attached to the arm , which is stationary, the other swinging about the axis , Fig. 749, being this a very common form.

**Fig. 749.**

In this case , is the checking pawl, and , the driving pawl. A movement of the driving pawl, if a little more than one tooth space, moves the wheel one tooth; a little more movement than two spaces moves it two teeth; and a regular back and forth motion gives a forward movement at intervals of a single pitch space.

If this device is made with step ratchets, as in § 243, the pitch may be subdivided into , , or more parts, and for some purposes, such as saw-mill feed motions, this is very desirable.

If the arm which carries the feed pawl swings about an axis removed from , Fig. 749 , there will be a movement between the pawl and the point of application of the wheel; while in the arrangement shown at , the motion of the two is identical, and hence no wear occurs.

The two paws may be connected so that both of them become drivers. If they are arranged so that their movement is alternate, as in Fig. 750 , the wheel will be moved forward for the movement of the lever in each direction, giving a double-acting ratchet motion, the so-called Lagarousse Ratchet. This may also be accomplished in various ways, as in Fig. 750 .

For any movement of the arm which is less than and more than , the pitch, the wheel will be moved pitch for each vibration, and hence for a half vibration a feed of a half tooth may be obtained. Step paws may also be used with these devices to obtain further subdivisions.

If, in Fig. 750 , we hold the lever rigidly, and instead permit the arm to vibrate with the same angle about the axis , the wheel moving with it, we obtain the same relative feed motion. This has been used by Thomson in a telegraph apparatus.
A continuous ratchet gearing may be so arranged that backward movement of the wheel is utilized to compel a uniform division of motion.

This is the case with the feed motion used by Gebrüder Mauser, of Oberndorf, in their revolvers, Fig. 751. In this case a crown wheel is used (see Figs. 677 and 678). The wheel is at \( a \); \( b \) is the feed pawl, jointed at \( 3 \) to the slide \( e \), the whole being carried in the frame \( d \). The zig-zag profile is formed in the rim of the crown wheel, one portion being parallel to the axis, the other spirally inclined, so that the angle of thrust is \( \alpha < 90^\circ - \phi \) and \( > \phi \) (\( \Phi \), cases \( a \) and \( b \)). The movement of the pawl produces a backward movement of the wheel. It should be noted that at \( \alpha' \) and \( \alpha'' \) steps are made in the teeth profiles in order to guide the pawl into the proper path and keep it from reversing.

The anchor ratchet of Fig. 682 may be used for a feed motion, as in Fig. 752, in which there is also the reverse action of the wheel, in accordance with the notation of Fig. 257. Here the wheel is at \( a \) and the anchor at \( b' \), \( b'' \). When the latter is moved into the position shown by the dotted lines, the wheel is moved backward \( \frac{1}{2} \) pitch, and the return vibration completes the pitch movement. In order that the anchor shall enter the teeth properly, the movement should be quick, especially at the entrance of the pawl into the space. This is well obtained by electromagnetic action.

**Continuous Ratchets with Locking Teeth.**

If it is desired to use ratchets according to the method given in Fig. 749, additional parts must be devised to move the pawl in and out of gear. A simple method of accomplishing this result is to use a single tooth wheel for the driver, and operate the pawl in the same manner as in Fig. 743.

Before the single tooth \( s \) begins to drive the wheel \( a \), the arm \( b \) lifts the pawl \( d \) and lowers it into the next space just as the tooth ceases to drive. In this case the usual gear tooth profiles may be used. Still better is the "dead" tooth profile of Fig. 754, in which the entrance and withdrawal of the pin tooth both lock the wheel while the pawl is being lowered.

This form may also be used for rack feed movement, Fig. 755. In this case the profile of the pin tooth is formed in several areas; \( 2' \) \( 2'' \) being struck from \( a \) and \( 2' \) \( 2'' \) and \( 2' \) \( 2'' \) being the paths of the corners of the space (see \( \Phi \)).

By using the cylinder ratchet, as shown in Fig. 696, the number of parts can be reduced, since the driving gear and checking pawl may be combined in the same member. The resulting forms, Figs. 756 to 758, are variously called: Mattle, Cross, Geneva Stop, used in Swiss watches, in which case one of the tooth sections is filled out; or after Redtenbacher we may call them single tooth gears, although this is hardly correct, for the general form of Fig. 758 may have several teeth, and a second tooth is dotted in Fig. 758.

A great number of variations may be made of these cylinder ratchet motions. An interesting form is the intermittent gearing of Binger, Fig. 759.

The pinion \( a \) is the driver, and the wheel \( b \) is driven, and between the passage of each tooth of the pinion the driven gear remains stationary for a short space, about \( \frac{1}{2} \) of the pitch. The points of the teeth of the driven wheel here act as ratchet teeth, in a similar manner to the arc of repose of the single-ratchet gearing of Fig. 756.

The cylinder ratchet gearing of Fig. 760 is similar to that shown in Fig. 706, and is used in the counting mechanism of English gas meters. In Fig. 761 is a modified spiral ratchet of the same general type as Fig. 702, with only a portion of the path of \( b \) in a spiral, and a similar variation of Fig. 704 is shown in Fig. 762.

* Royal German Patent, No. 785, 1871.
§ 256.

LOCKING RATCHETS.

Locking ratchets include all the numerous devices by which the parts of a mechanism are firmly held against the action of external forces, and yet readily and definitely released when desired (see § 235, No. 5); thus the various clutch couplings are included, also car-couplers and similar devices.

Locking ratchets occur frequently in the mechanism of firearms, especially to prevent the danger of premature discharge, etc. The great refinements which have been introduced in such weapons during the last ten years include especially the application of ratchets. The following single instance will serve to illustrate: The mechanism of the well-known Mauser revolver may be divided into two series: one to effect the discharge and the other to release the empty shell from the chamber. The first may be called the discharging mechanism, the second the unloading mechanism. We then have the following details:

A. Discharging Mechanism.

This includes the revolving chamber, barrel, hammer, spring and accompanying smaller parts, giving as combinations:

1. Hammer, spring-rod and trigger = ratchet rack, as Fig. 659.
2. Spring-rod and trigger, acting as locking ratchet for the above, as Fig. 762.
3. Spring-rod, pawl and revolving chamber = continuous ratchet with crown wheel and bolt pawl, as Fig. 751.
4. Securing pawl and revolving chamber = locking ratchet, as Fig. 670.
5. Revolving chamber and pawl, forming a ratchet gearing with limited travel.
6. Tumbling ratchet and securing pawl = ratchet gearing for three positions, Fig. 668.
7. Catch on the axis of hammer = locking ratchet, as Fig. 695.
8. Trigger guard and pin = locking ratchet and stationary pawl.
10. Ruffled barrel and bullet = screw and nut.

B. Unloading Mechanism.

This includes an axial slide which catches under the rim of the empty cartridge shell to withdraw it, actuated by a toothed sector and revolving clamp and axis called the ring clamp. These include the following combinations:

11. Unloading slide and sector = slide with rack and pinion, Fig. 381.
12. Axis of revolving chamber, with pawl to prevent endwise motion = locking ratchet gear, as Fig. 665.
13. Ring clamp, barrel and chamber bearing = locking ratchet gear with stationary pawl, as Fig. 654.
14. Ring clamp axis and axis of securing pawl = locking ratchet, as Fig. 701, forming with (13) a locking ratchet gear of the second order.
15. Ring clamp axis upon the reverse motion of the ring clamp forms, with the axis of the securing pawl, a locking ratchet gear, which combines with (4) to form a similar gear of the second order.
16. Securing pawl acts as a catch for the axis of the ring clamp in the axial direction to form a locking ratchet gear, as Fig. 696, forming also with (4) a similar gear of the second order.
17. Ring clamp hub and axis of securing pawl = locking ratchet, as Fig. 695, and with (4) gives one of the second order.

This analysis shows that in the Mauser revolver there are 17 mechanical combinations; these are composed of 26 pieces. Classified, these are as follows: 1 releasing ratchet, 1 continuous ratchet, a driving ratchet, 3 locking ratchets, of which four are of the second order, 1 screw motion and 1 slide motion. A very important application of locking ratchet mechanism is found in the signal apparatus of Saxby & Farmer for use on railway trains, and many by Henning, Bising and others. This includes many ratchets of higher orders, reaching to the tenth, twelfth, or even higher. When this is used in combination with the electric systems of Siemens & Halske, as in the Black system, we have the further combination of two systems of the higher order with each other.

A branch of locking ratchets which exhibits a great variety of applications is found in the different kinds of locks, such as are used for securing doors, gates, chests, etc. These extend from the most primitive forms, made of wood, to the most refined productions of exact mechanism, and their study possesses an historic and ethnographic interest in addition to their mechanical value.

A door forms itself a ratchet combination; the door being the part  a, the strike the part  e, and the bolt or other piece which keeps it from being opened is the part  d; doors with latch bolts being running ratchets, and doors with dead bolts being stationary ratchets. A simple lift latch and door, as the furnace door shown in Fig. 765, is really a section of a brown ratchet wheel with running ratchet gearing.

A door with sliding dead bolt, as used on common room doors, is a similar section of ratchet gear with stationary ratchet.

In key locks, the key is the releasing member of the ratchet train, and also serves to actuate the bolt after it is released. The key and ratchet mechanism are arranged in most ingenious manners, so that numerous permutations can be made to effect the release.

Some of the most important systems of lock construction are given as examples:

Example 1.—The common so-called French lock, Fig. 764, is similar to the ratchet of Fig. 23. The bolt is a sliding rack, the "tumbler"  b being often as in this case, made in one piece with its spring. The case of the lock corresponds to the frame for the ratchet mechanism, and the key acts as the releasing and actuating member.

Example 2.—The Chubb lock, Fig. 765, which is always made with a dead bolt, forms with the door and door frame a ratchet gearing similar to Fig. 692. The bolt is secured by means of several ratchets of precision, as in Fig. 706, and is moved by a ratchet as Fig. 754. The key, the axis 4, and the various settings of the key form a system of gears. The whole is a ratchet system of the second order with precision gear.

Example 3.—The Bramah lock, Fig. 766 a and Fig. 766 b, is differently constructed. In this case the dead bolt is actuated through the medium of a cylindrical rotating ratchet gear, which does not contain the mechanism of security, the latter being in a distinct portion of the lock, Fig. 766 b. This consists of a number of sliding precision pawls, as Fig. 707, the number being 6 to 12 in the illustration. The number of a of Fig. 727 is here made in the form of a ring with internal teeth, secured to the escutcheon  a by screws. The key is a positive s adjuster of the slides, and the whole in a locking mechanism of the third order with ratchets of precision. The spiral spring around the pin restores the slides to their extreme position when the key is withdrawn.
The most general examples of uniform escapement are found in watches. In these impulses are isochronous, and obtained from the inertia of a vibrating body. The wheel $a$ is called the escape wheel. The vibrating member, or balance wheel, makes its oscillations in nearly equal times for great or small vibrations. If, therefore, in a watch escapement, the time of the fall of the pawl is less than the time of oscillation, the most important requirement is fulfilled, namely, that for uniform periods of time the same number of teeth of the escape wheel shall pass, and the corresponding angle may then be used as a measure of time. A given amount of work may also be abstracted from the motive power and used to produce the impulse. These important points have been fulfilled in the design of escapements, and it has been made possible to measure time with a great degree of accuracy. When the highest accuracy is demanded the greatest care must be given to the construction and execution, and to the reduction of friction and compensation of the balance.

In the case of watches the duty of the impelling force is simply that of overcoming the resistance of the mechanism, the function of the escapement being to provide against any acceleration of the rate motion, and the impulse which is required to operate the escapement may be considered as a portion of the resistance of the mechanism.

A systematic discrimination between the various kinds of watch escapements will show that they vary as to the checking device, the impelling device, the release and the accelerating device. We may have Simple or Compound escapements of the lower or higher orders. Some examples are here given.

### A. Simple Escapements.

#### Uniform Escapements.

If, in ordinary running ratchet, Fig. 768, we have the wheel $a$, impelled by a weight or other force, and suppose the pawl $b$ lifted and dropped quickly, as by the arm $c$, the wheel will move one space, and an escapement will have occurred. In this case the range will be one pitch. If, after a definite time, this operation is again and again repeated, we shall have a uniform escapement. In mechanism the releasing and checking action is produced mechanically and not by hand, the impulse being obtained from the movement of the wheel.

The ancient and modern Egyptian locks, also those of ancient Greeks, Romans and Chinese, contain the principle of running ratchets with flat panels, actuated by a key pushed directly into the lock. The Egyptian lock, with flat precision panels, is quite similar to the Yale lock in principle, although very different in construction. Almost Roman locks, found in Pompeii, are similar in principle. Wooden locks are still in use in China, Persia, Babylon, Russia and Southern States, also in the Faroe Islands and Iceland. At the suggestion of the author, Professor Wagner, of Tokyo, succeeded in inducing some Japanese lockmakers to make a very complete and intelligent collection of motive locks for the kinematic catalog of the Royal Technical High School at Berlin.
THE CONSTRUCTOR.

Example 2—Another method by which the checking and impelling pawls may be combined is shown in the Alto escapement, Fig. 771. This consists of a simple running ratchet a, b, c. The pawl has a plate spring, which is lifted and dropped by the passage of the teeth. The accelleration is given by the deflection of the spring. If the impelling force upon the wheel is great, two teeth will pass, but this can be corrected by the note omitted by the spring, which will then be one octave higher than before.

II. Compound Escapements.

Example 1.—Lamb's escapement. Those escapements which have two escape wheels are properly classed as compound, and in this class belongs Lamb's escapement. This consists of a running ratchet gear, similar to Example 1, and the same form of impelling device, but between those is an

Internal wheel with pitch ratchet gearing, similar to Fig. 690, which is impelled by each direction of a full revolution. Another double-wheel escapement to illustrate, based on Fig. 770, also one devised by the author, like Fig. 696.

Example 2.—Moline's Escapement (also invented by Tiede), Fig. 772. This is a double ratchet gear system, with one pawl in compression and one in

and 17. The pawls are technically known as pallets. The tooth action of the ratchet gear is similar to Fig. 761. The arm 2 is limited in travel by pins at 3 and 3', or as shown here by a fork at 4. Since there is a ratchet 27 and also at 3, this forms a system of the second order.

* A watch escapement of the third order has recently been designed by A. C. Müller of Basle. This is made with a cylinder ratchet, as Fig. 694, between the arm and the escape wheel.
THE CONSTRUCTOR.

Example 2.—Graham's Escapement, Fig. 774. The construction is very similar to the preceding. The connection between the anchor arm $a$ and pendulum $d$, is different, and the arm $b$, does not come to rest, but both it and the pallets $a$ and $z$ slide upon the teeth while the escape wheel is stopped. An earlier form of pallets for this escapement is shown at $P^4$, and $P^5$ (called Clement's Anchors), from Clement, 1666, but described by Dr. Hook in 1682. This form produces a brief reverse movement to the escape wheel at each oscillation.

Example 3.—The form of ratchet of Fig. 663 is used in Laplace's escapement, which was really invented by the watchmaker Casal, afterwards Marquis de Beauchene.

Example 4.—Cylinder Escapement, Fig. 775. This is made from the cylinder ratchet of Fig. 728. The impelling arms being divided between the anchor and the teeth of the escape wheel. The cylinder $b$ is attached to the axis of the balance wheel, and the wide spaces of the teeth of the escape wheel, permit a corresponding wide amplitude of oscillation. If we imagine the pallets of Graham's anchor to be formed between two concentric cylinders (as most watchmakers construct them), the "cylinder" will be seen to be a similar anchor.

Example 5.—Crown Wheel Escapement, Fig. 776. Escapements constructed with crown ratchet wheels (§ 417) are the oldest forms used in ratchets. The form of the pallets causes a reverse movement, and in the old watches using a balance with its centre of gravity in the axis of oscillation, without any assisting spring action, this reverse movement was a necessity, which accounts for the long and extended use of this form of escapement. Toward the end of the sixteenth century the ball spring was introduced by Le Roy in the form of a hog's bristle, and in 1586 Henry II of France made the steel hair spring which made the construction of the modern chronometer possible. The crown escapement is easily modified so as to remove the reverse action, as was done by the author in 1841. We then have a "dead" tooth action, as Fig. 689 shows. The modified escapement is shown in Fig. 778; the pallets are practically horizontally disposed in form.

C. POWER ESCAPEMENTS.

In the case of watch escapements the impelling force is only used to overcome the resistance of the watch mechanism. Escapements can also be used to regulate greater forces, such as are intended to perform useful work, and these may be called power escapements. Alarm and striking clocks are of this class, and there are numerous other forms. The following example will serve to illustrate:

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Example 12.—Power Escapement for a Reciprocating Movement, Fig. 777. At $a$, $d$, and $e$, are ordinary running ratchets and $b$, $c$, and $f$, are auxiliary ratchets and $g$, and $h$, are ordinary running ratchets and $i$, and $j$, are auxiliary ratchets. The escapement is used to control the motion of the swinging arm $a$ by means of the lever $k$, and the descending arm $l$. This is accomplished by a double acting ratchet screw $m$, by means of the slide $n$, driven from $o$ by the arm $p$.

The action is as follows: When the parts are in the position shown in the figure, the motion of the wheel $p$ to the right moves the arm $g$, that pulls the pawl $b$, and until the trigger $k$ trips the pawl $d$, and the engagement at $e$ into the position $f$, as shown in the figure (the small figure to the left). This action, by means of the trigger $k$, throws the pawl $d$, and stops the wheel. At the same time $a$ is thrown out of gear by the connection $o$, $q$, and $r$, and the counterweight $s$, changes the arm $h$ to its original position. This brings the trigger again to the level of $d$, and again shifts the escapement arm. The pawl $b$ falls into gear, and the pawl $d$ is disengaged, leaving the wheel free for another forward movement.

The preceding escapement can be readily converted into a double acting one by introducing a second ratchet wheel toothed in the opposite direction, with proper pawl on $e$, and trigger connections to $f$; the other portions would remain the same. This escapement appears to be new, and many important applications will suggest themselves.

§ 258.

PERIODICAL ESCAPEMENTS.

A great variety of periodical escapements are to be found in the striking mechanism of clocks and repeating watches. The whole period is the revolution of the hour hand, and if the half hours are struck the order will be:

$1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12$.

making in all 90 strokes in the twelve hours. A fan regulator is used to cause the strokes to follow each other uniformly. There are two systems of escapement in use for this purpose, the German and the English, the latter also used for repeaters. An essential piece of the latter is the so-called "snail," has been shown in Fig. 688; its function is to control the number of strokes. Further subdivisions cannot be here discussed, but it must be remembered that the striking arm is itself a ratchet mechanism.*

Important applications of periodical escapements are found in the self-acting winding mule, and both these and the clock striking mechanism are examples of power escapements.

The mechanism in Phillips's mule is here briefly shown. Fig. 778, a and $b$. The shaft 1 is required to make rapid turns through 90° at intervals of different lengths of time. The wheel $a$ is an escape wheel with teeth in four concentric rings, 1, 2, 3, 4 (compare Fig. 686), each ring having one tooth. The other side of the wheel $a$ is shown in Fig. 69, where is the ratchet chain $a$ and $b$. When $a$ is released, the pressure of $d$ at $f$ moves it slightly and brings the running friction wheel $e$ into contact, thus driving $a$ through a quarter revolution, toward the close of which the pawl $d$ again enters into engagement.


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* This has been used since the sixteenth century, having been invented by Bishop Nicholas de Lyra, and afterwards Pope Pius IX, dated 1656, by Heinrich von Wyck about 1700, and applied to a pendulum by Huygens. The oldest fireer clock in New York City, built about 1600, has such an escapement.

In the Kinematic cabinet of the Royal Technical High School there is a schematic model of mode clock and watch escapements.
The recesses in a permit the friction wheel to run freely when the wheel is at rest. This is evidently a form of ratchet in itself. The order of escapements at 2 is as follows:

I II, II III, III IV, IV I.

This is controlled by a second escapement, shown in Fig. 781.

![Fig. 781](image)

The pawl 1 of Fig. 780 is connected by the rod 1 to the beam a, as shown. This mechanism is a step by step, having a further point of interest. The steps are the pawls at, a, b, and the stop on the frame c, giving the positions 1, 2, 3, 4. The action takes place in the four following periods:

1. Drawing and spinning—each at 1.
3. Holding and turning — at 3.

The succession of movements is as follows: At the termination of the first period the projection on the carriage strikes the pawl 1, and after a short time, which is sooner on the left than on the right, moves from position I to position II, in which it is held by the pawl 2. By means of the rod 1, the pawl 3 of Fig. 780 is placed in position 3 II, thus starting the second period.

At the close of the second period the pawl 2 is released, and the lever falls to the position III, shifting the pawl 1 to 1 III, and is held by the pawl 1 at 1 III.

The third period, which is very brief, is terminated by the winder striking 4, releasing the pawl 2, and the lever assumes the position IV, and the rod 1 moves the pawl 1 into the position V, which is the fourth period.

During this period the carriage returns, and just before the end of its motion a roller acts upon the portion 5', bringing the lever back into the first position. This returns the pawl 1 to its original position 1 I, and the action is repeated.

The entire mechanism forms a periodical escapement of the second order, or, when the connections are included, the third order, and when taken together with the ratchet gearing, the fifth order, while a sixth ratchet mechanism is used for the primary control.

### § 289.

**Adjustable Escapements.**

An escapement can be so arranged that the checked member, after the release, will again be checked by the impulse of its fresh start, thus forming what may be called a self-checking escapement. In a mechanism of this kind, the amplitude of the escapement is dependent upon the amount of displacement which is permitted to the releasing member. This may be made greater or less, and hence, such devices may be called adjustable escapements. These devices are likely to play an important part in modern machine design.

A simple form of adjustable escapement is shown in Fig. 782.

![Fig. 782](image)

This apparatus, designed by the author, is based upon that of Fig. 724. The ratchet wheel is stationary, being fastened to the frame a; the pawl is at b, and the link is in the form of a disc c, driven by a force C, and checked by the escapement. At 3, 4 is the guide for the pawl. This can be adjusted by the wheel f, by turning the latter more or less in the direction in which it is impelled. If it is turned so far that the pawl b is lifted out of gear, the force at C will set the disc c in motion. This latter carries with it the axle of the pawl, which, by the action of the guide 5, draws the pawl into engagement again, entering the space 2 and checking the disc. In order to avoid an uncertain or irregular action, a brake may be used as at a'. If the wheel d is moved forward regularly through two, three, or four area, the disc c will be released and checked successively in similar manner.

It will be evident from the foregoing that the ratchet gearings which form the foundation of the various kinds of adjustable escapements are so varied that the different constructions which may be used are very numerous. Among them may be mentioned those in which friction ratchets are used, these possessing the advantage that the arc of motion of the escapement may be varied from the smallest to the greatest without being dependent upon any special pitch.
THE CONSTRUCTOR.

Example.—Fig. 723 shows such an automatic brake device as applied to the passenger bridge at Comiso. At a is a friction cone combined with a spur gear of steel cast in one piece with the shaft, and pivot in the direction to which it is driven by the motion of the drum. The drum is fast to the shaft c, but the cone a is loose on the shaft, being a cone of a different size, the friction cone a being forced into engagement with it, and this engages the spur gear by the difference in sizes of the two, and turns the hand wheel e. The motion of the differential screw enables the required pressure to be obtained, and also causes the motion of c to be in the same direction as a, whereas the wheel a is connected to the shaft e, when the cone a, which slides on a leather, is forced into engagement with it. This enables the brake to be released, thus giving so that a is positively secured to the shaft until e is turned back, when c follows by the motion of c. The brake is operated by pushing upon each other, and the pressure being automatically regulated, and the motion at once checked when c is released.

Other and most important applications of adjustable escapements will be given hereafter. It may, however, be here noted that by means of such mechanism the most powerful combinations may be controlled with the exercise of a minimum effort.

§ 260.

GENERAL REMARKS UPON RATCHET MECHANISM.

Ratchet mechanism, as already discussed, is applicable to a most extensive range of uses; in this respect far exceeding every other form of mechanism. This is plainly due to the fact that ratchets are suited either to produce the effect of relative motion and relative rest. Considered in this light the six preceding classes may be grouped as follows: Common ratchets, checking ratchets, self-locking ratchets and self-locking ratchets which act as brakes, as well as escapements, act to produce definite motion, while releasing and continuous ratchets, as well as escapements, act to produce definite motion. The mechanism produced by ratchets is self-locking; the mechanism produced by ratchets previously considered, such as cranks, friction, or toothed gearing, etc., is continuous. Mechanism for continuous motion may be called "running gear," and produces a net effect. The general principle of ratchets has only been partially covered in the preceding pages, where such forms as may strictly be considered machine elements have been included. An exception must be made as to the allied forms of springs, some of which, indeed, were referred to. There is, however, a large number of machine elements of a different kind, which usually involve the continuous action of the operating forces in one direction; these include tension organs, such as ropes, belts, chains, etc.; compression organs, fluid connections, and many others, all of which are considered in the following chapters. It will be seen that these are to be arranged as to be fairly considered ratchet devices also; as belts or chains may become friction or toothed ratchet gears, and even the valves of fluid connections are really paws.

The pawl mechanism must also be extended to include these classes of machine elements, and their limits thus greatly widened, especially in the case of pressure organs. Examples of this class are: the lifting valves of pump and gas engines, for liquids and gases, which may act as locking or checking ratchets, or in hydraulic motors and steam engines as escapement organs, as well as elements and components of the ratchets combined. Similar comparisons may be made of the ratchet principle with the use of accumulators for hydraulic cranes, presses, riveting machines, and the like, and in the astarct for self-acting steam engines we find a complete analogy to the ratchet. In these cases we have ratchet systems of the higher orders. The history of the development of these machines is really that of their pawl members.

A very interesting example is that of Fig. 779, in which, if we substitute a flow of steam for the ratchet wheel, we have the arrangement of the single acting high pressure steam engine with Fazey's valve gear. The numerous modifications of escapement gear, which are included in the steam engine, have occupied the activity of designers down to the present time. A number of the more recent valve gears have been shown in Fig. 123, and similar devices are used on engines for steam steering gear, called by the French "moteurs assureurs," and such gear also plays an important part in the mechanism of some of the so-called "fish" torpedoes.

In this manner the applications of pawl ratchets may be extended to the eyes and yet the limitations are not reached, and the further researches are carried the broader and more general the scope of operations of this division of mechanism becomes. Not only does it include fluid pressure organs, both liquid and gaseous in a strictly mechanical sense, as in the case of pumps, etc., but also when the mechanism is looked at in a physical sense, it is regarded as being typical of any branch of mechanical engineering. This gives a branch which may be called "physical" ratchet trains, of which the steam boiler is the most important example. In this, when taken in connection with a pipe full of steam, and suitable valves for full opening and closing, forming what has been termed a steam column, we have undoubtedly a physical ratchet train in which the particles of vapor are considered as a physical aggregate, which from the higher temperature, are under higher stress. Further examples of a physical ratchet trains may be obtained for operation by liquid carbonic acid which has been recently used. Electrical accumulators are also instances of physical ratchet trains, as well as some applications of galvanic batteries, the actuating limb by the make and break of electrical contact. The dynamo-electric machine also becomes a physical running ratchet and the electric motor a physical escapement, the whole forming a physical running ratchet train.

Again we may consider a "chemical" ratchet train, such as coal or any fuel, which, during combustion, releases the energy which is stored in it. This may be utilized in numerous ways, but the present considerations, mainly in the production of motion. Chemical action is also included in hot-air engines, and in the operation of telegraph apparatus in a similar sense. We may consider the principal factors in a steam motor plant as portions of a ratchet chain, somewhat as follows: Chemical ratchet = combustion of fuel, Physical " = steam generator, etc., Mechanical escacement = steam cylinder and attachments, Mechanical running gear = crank shaft and wheel, these four uniting to convert the released energy into mechanical motion. If we consider a locomotive engine, we have added to the further running gear in the shape of flanging of the wheels and rails, while the train and wheels and journal bearings unite to form a combination of the sixth order.

Another chemical train is produced by the use of explosion which is released either mechanically, as by percussion or friction, or chemically, by combustion of some auxiliary material. Again, we may have releasing gear of the first, second, or higher orders.

In the case of most firearms the release is of the second order, since the mechanism of the lock acts upon a fulminate by percussion, and the heat of the latter releases the charge. If we examine and classify all mechanism of transmission in the above manner, it will be apparent that all forms are included in one or the other of the following classes, viz.: mechanical, hydraulic, or chemical; these also entering into combinations of the higher orders with each other.

The steam engine itself, as we have already seen, consists of a driving train of the fourth order. Trains of still higher orders are frequent occurrence.

In the recording telegraph, with relay, we have a physical ratchet train of the second order, releasing a mechanical running train and operating a recording train, both physical trains actuated by chemical trains, the whole forming a combination of the fifth order. The ordinary signal mechanism of a railway station, when mechanically operated, is a system of the fourth order.

The Westinghouse automatic brake, not considering the boiler, is a train of the fifth order, consisting of an escapement (steam cylinder), driving ratchet (steam cylinder), escapement (piston and valve connections), friction checking ratchet (brake gear). If we include furnace and boiler, this becomes a train of the seventh order, and may be still further extended.

A still more noteworthy example is found in the application of compressed air for the purpose of operating pumping machinery at the bottom of deep mine shafts. In this case we have:

1. Furnace = chemical ratchet train.
2. Boiler = physical ratchet train.
3. Steam engine = mechanical escapement train.
4. Shafting and transmission to running.
5. Air compressor, " " running.
6. Air chamber, " "
7. Air cylinder in mine, " "
8. Water cylinder in mine, " "
9. Air ratchet, " "

The preceding discussion and illustrations of the relationship existing between mechanical, physical and chemical trains shows the necessity of combining mechanical and technical research, and a complete mechanical training therefore includes these three branches, and also the later science of electro-mechanics. Methods of invention require research into all of these lines of science, and the constantly widening field of mechanical engineering is thus extending its work, while at the same time gathering into still wider form the many branches of applied mechanical science.

*See Theoretical Kinematics, p. 466, in which this classification was originally made.
1 See Theoretical Kinematics, p. 456 et seq.