hot-water pipes, so that the paint may dry quickly. Platforms or trestles should be erected alongside the cars, so as to render the upper portions easily accessible.

71. Winding Shop.—The winding shop must also be enclosed from the overhaul and blacksmith shops. It should contain the repair stands for the armatures, a banding machine, and a coil-winding machine, with formers for the various coils used, also a stove for drying out the armature and field coils. All defective armatures, field coils, and commutators are repaired in this shop; also the various cables used on the cars are repaired in it.

72. Machine Shop.—The machine shop contains the usual engineers' tools, drilling machines, planing and boring machines, a metal saw, and lathes for turning bearings, steel-tired wheels, and commutators. The emery grinder and wheel press are usually placed in an annexe where the wheels can be easily handled.

BRAKES AND BRAKE RIGGING

TRAMWAY BRAKES

MECHANICAL BRAKES

GENERAL PRINCIPLES OF BRAKING

1. If a tramcar is running on the level and the driving power is switched off, the car will continue to run for some time by virtue of the kinetic energy stored in it, but it will eventually come to rest owing to the friction of the wheels, axles, etc., and the resistance of the air. If it is desired to stop the car in a shorter distance or in less time, a retarding force must be applied by means of brakes. When the retarding force depends on the friction of brake blocks applied to the wheels of the car or to the track rails, the braking is purely mechanical. Alternatively the braking may be purely electrical, and then depends on the method of coupling the driving motors to the power-supply circuit or to resistances; sometimes mechanical and electrical braking effects are combined. In the case of mechanical brakes, the maximum retarding force which can be applied to stop a car depends on the friction exerted between the brake blocks and the car wheels or the track, and on the adhesive force between the wheels and the rail.

2. Friction of Surfaces.—If a horizontal force F, Fig. 1, is gradually applied to a block a resting on a plane surface until the block a moves, the applied horizontal force will be equal to the force due to the friction between the surfaces.

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Let F = force required to produce motion, in pounds ;
W = reaction between surfaces, in pounds ;
μ (mu) = coefficient of static friction.

Then, $$\mu = \frac{F}{W} \text{ or } F = \mu W$$

The quotient which results from dividing the force required to produce motion by the reaction between the surfaces, both being expressed in the same units, is known as the **coefficient of static friction**, or the **coefficient of adhesion**. Once movement has been started, however, the retarding force due to friction, and therefore the force required to maintain motion, are less than the force which was at first necessary to produce motion.

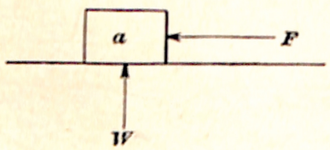


FIG. 1

Let F' = force required to maintain motion, in pounds ;
P = reaction between surfaces or pressure on brake block, in pounds ;
μ' = coefficient of sliding friction.

Then, $$\mu' = \frac{F'}{P} \text{ or } F' = \mu' P$$

The **coefficient of sliding friction** is thus less than the coefficient of static friction. This has an important bearing on braking problems, since a greater braking force can be applied to the car wheels while they revolve at fairly high speeds than can be used at low speeds without causing the wheels to slide on the rails. If the coefficient of friction is referred to, without a specific statement as to whether static or sliding friction is meant, the coefficient of sliding friction is to be understood.

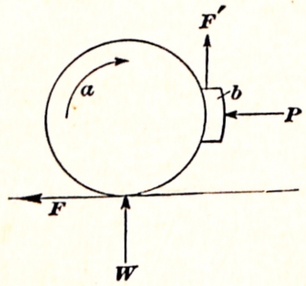


FIG. 2

3. Simple Wheel Brake.—If a wheel braked mechanically by means of a brake block b pressed against the wheel tire by a force P, as shown diagrammatically in Fig. 2, is rolling in the direction indicated by the arrow a, the other arrows will represent the forces acting on the wheel. As the retarding force on the wheel is transferred to the rail head, the retarding force F' or $\mu' P$ at the wheel tire must not be greater than the total adhesion F, or μW of the wheel on the rail due to the reaction W. Unless the retarding force F' is less than F, slipping of the wheel on the rail will take place, and flat spots will be worn in the wheel tread. The coefficient of adhesion for a tram wheel on a clean wet rail is about ·25, but this figure may be reduced to ·1 if the rail is dirty or greasy.

EXAMPLE.—A four-wheeled tramcar weighing 10 tons is to be braked by means of one brake block on each wheel. If the coefficient of friction between the brake blocks and wheels is taken as ·2, and the coefficient of adhesion between the wheels and rails is ·25, with what pressure on the brake blocks will the wheels begin to slide on the rails ?

SOLUTION.—The weight supported on each wheel is $\frac{10 \times 2{,}240}{4} = 5{,}600$ lb. The adhesive force on the rail per wheel is therefore $F = ·25 \times 5{,}600 = 1{,}400$ lb. The wheels will begin to skid when the retarding force on the wheel tire due to the brake is equal to the adhesion of the wheels on the rails. Then, the retarding force $F' = 1{,}400$ lb., $\mu = ·2$, $P = 1{,}400$ lb. Therefore, the maximum permissible pressure on each brake block is

$$P = \frac{1{,}400}{·2} = 7{,}000 \text{ lb. Ans.}$$

4. Negative Acceleration or Retardation.—If the adhesion between the car wheels and rails in any given case is known, the maximum rate at which a car can be stopped can be determined as follows :

Let W = weight of car, or reaction between wheels and rails, in pounds ;
F = retarding force tending to stop the car, in pounds ;
a = retardation of car, in feet per second per second ;
g = acceleration due to gravity.

Then, $$F = \frac{W a}{g}$$

But $\frac{F}{W}$ is equal to the coefficient of adhesion of the car wheels on the rails ; therefore, $\frac{F}{W} = \mu = \frac{a}{g}$, or $a = \mu g$. If the

coefficient of adhesion is taken at ·25, and since g = 32·2 feet per second per second, the maximum theoretical rate of retardation of the car that can be obtained without skidding must be a = ·25 × 32·2 = 8·05 feet per second per second.

5. As the maximum retardation that can be obtained depends on the coefficient of adhesion between the car wheels and rails, it is evident that any given car can be much more easily and more rapidly stopped when the rails are clean and in good condition, when the adhesion is high, than when the rails are dirty or greasy and the adhesive force is low. For the comfort of passengers, it is not usual to make an ordinary or service tramcar stop with a greater retardation than 3 feet per second per second; for emergency stops, however, the retardation must be as great as it is possible to obtain.

In the case of collisions, it is often necessary to be able to state the distance within which a car would stop after cutting off the power and applying the brakes. The distance which would be travelled can be calculated if the original speed of the car and the rate of retardation are known.

Let V = original velocity of car, in feet per second;
a = retardation of car, in feet per second per second;
S = distance travelled, in feet.

Then,
$$S = \frac{V^2}{2a}$$

EXAMPLE.—If a car is travelling at the rate of 10 miles per hour and a brake is applied which produces a retardation of 4 feet per second per second, in what distance can the car be stopped?

SOLUTION.— $a = 4$; V = 10 mi. per hr. = $\frac{10 \times 5{,}280}{60 \times 60}$ = 14·66 ft. per sec. Then,

$$S = \frac{14{\cdot}66^2}{2 \times 4} = 26{\cdot}9 \text{ ft., nearly.} \quad \text{Ans.}$$

HAND-APPLIED WHEEL BRAKES

6. Brake Blocks and Rigging.—The brake blocks commonly used in practice for braking on the car wheels are of chilled cast iron, although many different metals and combinations of metals have been tried in order to combine the best braking effect with

the least wear on wheels and blocks. The blocks may be forced against the wheels, through a system of levers, either by hand pressure or by power. A hand-operated brake is usually fitted to tramcars; the power-operated brake is always used on railways. The levers, rods, and gear generally that are intermediate between the operating handle and the brake blocks are called the **brake rigging.**

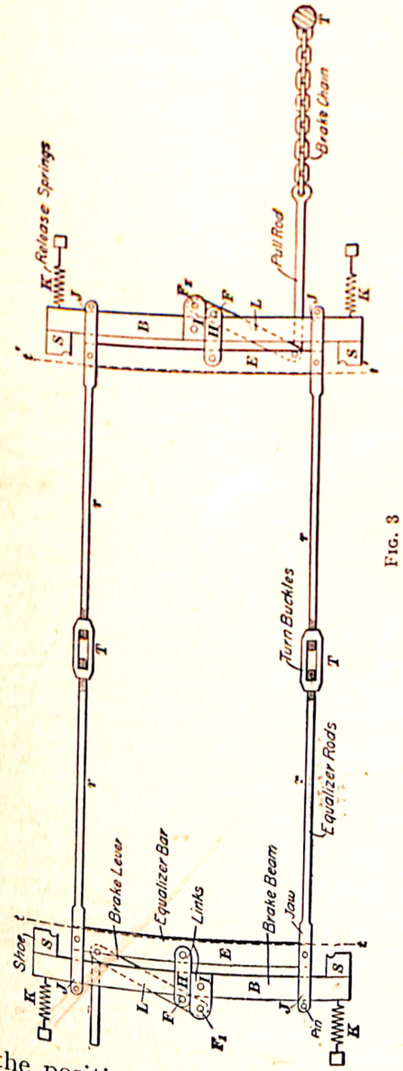


FIG. 3

7. Single-Truck Hand-Brake Rigging.—A common form of single-truck brake rigging is shown in Fig. 3, where several of the parts are named. The brake beams B are supported at the ends, where they slide in cast-iron guides, called the *slide* or *brake-beam castings*, bolted to the side-frames of the truck. The equalizer rods r end in jaws J, to which the equalizer bars E are rigidly connected, but in which the brake beams can slide freely. The levers L transmit any pull on the pull rods or brake chains so as to draw the brake beams toward each other and apply the brake shoes S to the wheels. The dotted lines t, t' indicate the position of the wheel tires. The links H are connected to the brake levers L and equalizer bars by means of pins. Links I connect the brake levers and brake beams; F is a pin round

which lever L and link H can move, and F_1 is a pin common to the lever L and brake beam B. In the illustration, the brakes are off and the shoes have been pulled away from the wheels by the release springs K. One end of each spring is fixed to the car truck and the other end to the brake beam. Turnbuckles T are provided in order to take up the slack as the brake blocks wear.

8. Brake Leverage of Single-Truck Rigging.—A fault of the usual arrangement of single-truck brake rigging is that the lever construction tends to apply the brakes harder on the rear wheels than on the forward wheels. The leverage at one end of the truck rigging is shown diagrammatically in Fig. 4, where the brake lever, represented between P and W, is 36 inches long. The force S_1 acts on the front brake beam, and the force S_2 acts on the equalizer bar which pulls on the rear brake beam ; the force P acts on the brake pull rod. The pin joints for the respective beams are at F and W. If the rear brake shoes are against the rear wheels, the brake lever will pivot about F as a fixed point, and a pull of 2,000 pounds at P, in the direction of the arrow, will force the forward brake blocks against the forward wheels with a total pressure of $S_1 = \frac{30}{6} \times 2{,}000 = 10{,}000$ pounds. If, however, the shoes are against the forward wheels, the lever will pivot about W as a fixed point, and a pull of 2,000 pounds at P will pull the rear brake blocks to the rear wheels with a force of $S_2 = \frac{36}{6} \times 2{,}000 = 12{,}000$ pounds, a difference of 2,000 pounds when compared with the pressure of the forward brake blocks. This occurs because the forward beam is moved by a lever of which the fulcrum is between the points of application of the applied force and the load, whereas the rear beam is operated by a lever of which the point of application of the load is between the fulcrum and the applied force.

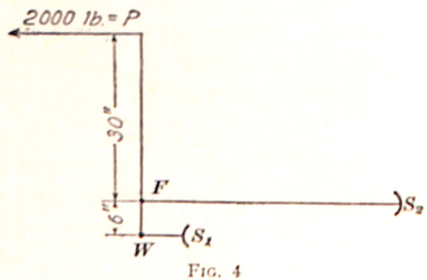


Fig. 4

9. Double-Truck Brake Rigging.—In Fig. 5 is shown a type of **double-, or bogie-, truck rigging** much used. The tendency

to apply the rear brakes harder than the forward ones is overcome by the use of an extra equalizing lever that cannot easily be applied to single-truck riggings. In this rigging, the pull on pull rod No. 1 or No. 2 is transmitted through the brake levers and tension rods to arch bars b, one on either truck. The shape of the arch bars, and the arrangement of wheels W on the tension rods, running on the arch bars, enable the brakes to be applied whatever the relative positions of the swivelling trucks. Turnbuckles T, T_1, T_2 serve to take up slack in the various bars. Both the fulcrum F of the long brake lever and the fulcrum F_3 of one of the equalizing levers are fixed to the car body. The other equalizing lever is connected by a link to a point a on the long brake lever. Levers P_2 and P_3 are supported by a slide rest that permits horizontal sliding motion, and they are connected by a

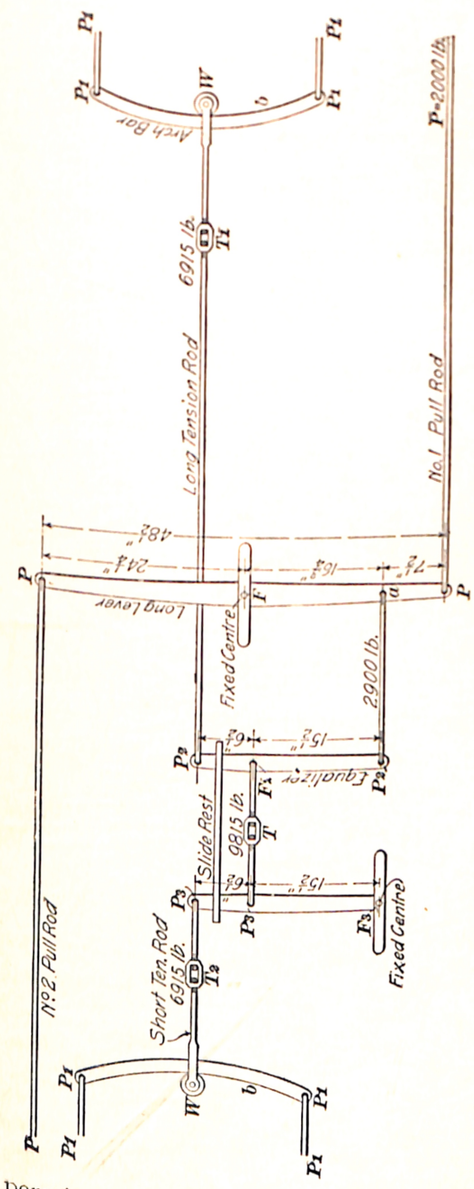


Fig. 5

turnbuckle rod attached to them at the points F_2 and P_3. The rigging is indicated in the position of best leverage, the brake blocks being on the wheels.

10. Brake Leverage of Double-Truck Rigging.—A pull of 2,000 pounds exerted on pull rod No. 1, causes the lower end of lever $P\,F\,P$ to move to the right and thereby exert a pull on rod $a\,P_2$. As the length of the long arm $P\,F$ is $24\frac{1}{4}$ inches and of the short arm $16\frac{3}{4}$ inches, the pull on $a\,P_2$ is $\frac{24\frac{1}{4}}{16\frac{3}{4}} \times 2{,}000$ = 2,900 pounds, nearly. As rod $a\,P_2$ is connected to the equalizing lever P_2, this pull is applied to the lever P_2, of which the long arm is $15\frac{1}{2}$ inches and the short arm $6\frac{1}{2}$ inches, the fulcrum being at F_2. As the power is applied to the long arm, the pull on the long tension rod is $\frac{15{\cdot}5}{6{\cdot}5} \times 2{,}900 = 6{,}915$ pounds. The pull on the turnbuckle rod $F_2\,P_3$ is 6,915 + 2,900 = 9,815 pounds, which, if applied directly to the short tension rod leading to the arch bar of the rear truck, would apply excessive braking pressure. To avoid this inequality, a second equalizing lever, pivoted at F_3, is introduced, the effect of which is to make the pull on the short tension rod 6,915 pounds, thereby ensuring that the braking pressure on both trucks shall be the same.

11. Arrangement of Truck Rigging.—Rods P_1, Fig. 5, at the extremities of the arch bars b, are the truck pull rods that apply

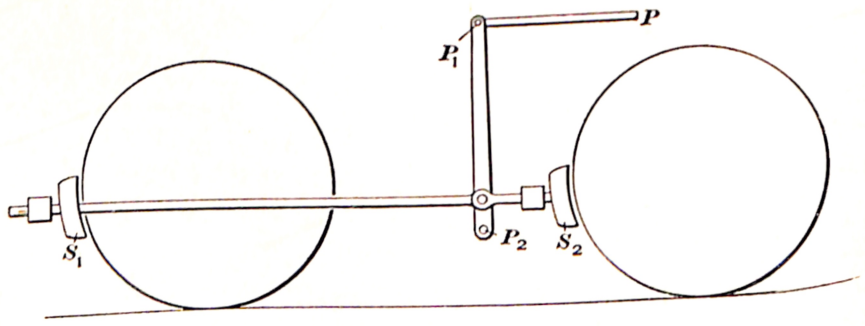


Fig. 6

the braking pressure to the truck levers. Fig. 6 shows the truck rigging on one side of the truck. A pull to the right on rod $P\,P_1$

forces the brake shoes S_1, S_2 against their respective wheels, P_2 being a fixed point on the car truck.

12. Maximum-Traction Brake Rigging.—The brake rigging attached to the car body is the same for maximum-traction trucks as for ordinary double trucks, but the truck rigging must be modified so that the greater braking pressure is applied to the large wheels, the axle of which supports more than two-thirds of the weight carried by the truck. Fig. 7 shows the truck rigging used on one side of the Peckham maximum-traction truck. The truck pull rod is connected to the upper end of a bent lever A, while the lower end of the lever is attached to a push rod that operates the shoe S of the large wheel. Lever A has no stationary fulcrum, but is pivoted at y to lever B, and the latter has a stationary fulcrum at x. The lower end of lever B operates a push rod that applies the brake shoe s to the small wheel. A pull to the left on the pull rod turns lever A in a counter-clockwise direction on y as a centre, thereby applying the shoe S to the large wheel; z then becomes a centre round which lever A continues to turn, thereby moving pivot y to the left and causing lever B to turn in a clockwise direction on fixed centre x, the lower end of B forcing shoe s against the small wheel. The movements of the large and small shoes, in practice, take place simultaneously.

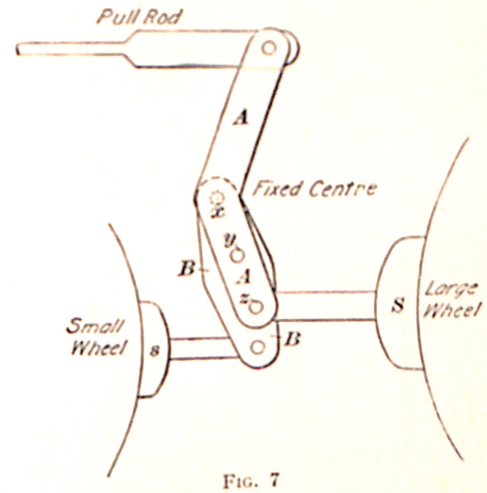


Fig. 7

13. Hand-Brake Spindle.—The usual method of exerting a force on the pull rod of a hand-brake rigging is by means of a handle on a vertical spindle that winds up a chain attached to the brake pull rod. The vertical spindle is carried by brackets attached to the dash of the car; when the spindle is turned by the handle the chain is wound up on it and pulls on the brake

rod. In the Peacock brake spindle, shown in Fig. 8, the chain *a* is not wound directly on the spindle *b*, but is wound on a spiral cam *c*. The cam is suitably grooved to take the chain, and is geared to the spindle, the larger toothed wheel being shown at *d*. The cam is shaped so that when the handle *e* is first turned the slack of the chain is rapidly taken up on a large radius; but when the brake blocks reach the wheels and a greater leverage is required, the radius of the cam is much smaller. A ratchet is provided in the handle at *f*, so that the spindle can be turned with the brake handle *e* always in the most convenient position, and where the pressure on the handle can be most effectively applied. The brake is kept in the full-on position or at any intermediate point when the car is stopped or is descending long hills by means of the dog *g*, which engages with a ratchet wheel *h*.

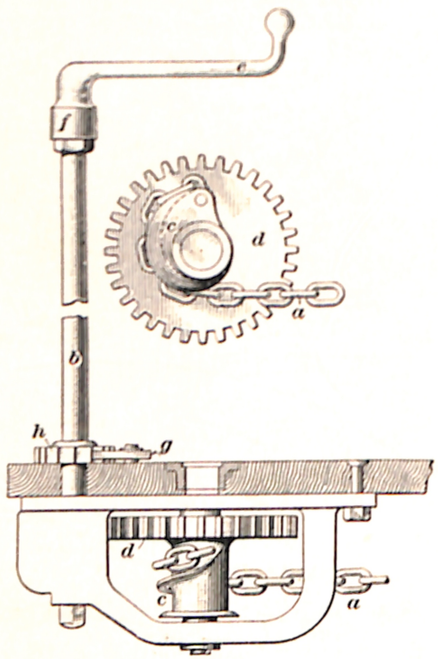


FIG. 8

TRACK BRAKES

14. Instead of utilizing the friction of brake blocks on the car wheels in order to retard a car, the braking may be effected by the mechanical application of brake blocks, or **slippers,** bearing directly on the track rails. A brake depending on this principle is known as a **track brake,** and the pressure of the brake blocks on the rails may be applied either by hand or by air pressure. When the gradients on the line exceed 1 in 15 over any considerable distance, the regulations of the Board of Trade require the provision of a slipper brake or other track brake on every car.

The slipper is made of oak, beech, or other hard wood, and as it picks up grit from the road surface the rubbing surfaces between the slipper and rail have a coefficient of friction much greater than that of an iron brake shoe rubbing on a wheel.

15. Use of Track Brakes.—Track brakes are very useful on routes over long hills. When descending hills, the brake slippers are screwed down on to the rail head with a pressure suitable to the gradient; the speed can thus be regulated very well, and the danger of the car running away is practically eliminated. As a further safety precaution, it is usual to arrange one or more compulsory stops on long and dangerous hills, in order to prevent the car getting beyond control. Stops are effected by means of the ordinary hand-operated wheel brakes. The pressure of the slipper brake on the rails must not be so great as to take the weight of the car off the wheels, and the leverage is generally arranged so that not more than about 40 per cent. of the weight can be taken on the slippers. There is then sufficient weight left on the wheels to obtain some further braking effect by means of wheel brakes, but in any case the reduction of weight on the wheels is a disadvantage in all mechanical track brakes, as the adhesion of the wheels is decreased when the track brakes are applied, and the wheels are therefore more readily locked by the application of the wheel brakes.

16. Combined Wheel and Track-Brake Spindle.—The Peacock combination spindle for hand-applied wheel and track brakes is shown in Fig. 9 (*a*) and (*b*). The wheel brake is applied by the handle *a*, Fig. 9 (*a*), spiral cam *b*, and chain *c*, as already described. The track brake is applied by rotating the hand wheel *d*. This wheel is mounted on a sleeve which passes over the wheel brake spindle. The sleeve drives a pinion *e* and a pair of bevel wheels *f*. The rotation of the screw *g*, view (*b*), moves a nut *h*, to which the pull rod of the track brake is attached, and applies the brake slippers to the surface of the rail with the amount of pressure required.

17. Pneumatic Track Brake.—Instead of using hand power to apply the track brakes to the rail surface, compressed air may

be used, and a better braking effect obtained with less effort on the part of the driver. In the Hewitt & Rhodes track brake, each slipper is applied to the rail by means of a compressed-air cylinder and piston, two- or four-brake cylinders being fitted to a single-truck car, according to its size and the gradients of the line. Four cylinders, one on each side of each bogie, are applied

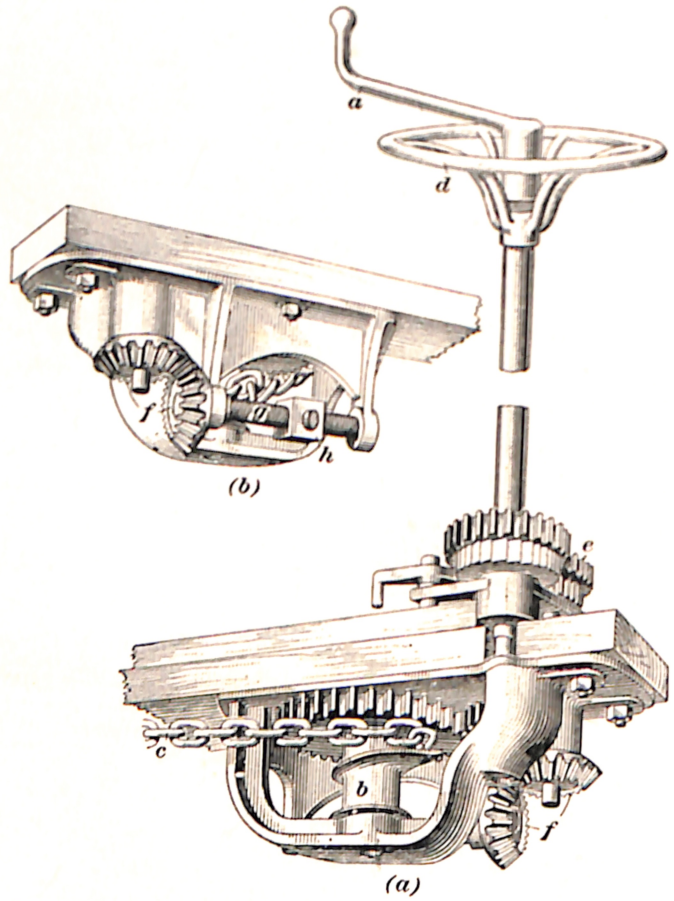


FIG. 9

to a double-truck car. An air compressor is carried on each car and is driven from the car axle by means of a chain gearing, or, in the case of maximum-traction trucks, the compressor may be mounted directly on the pony-wheel axle.

18. Pneumatic-Brake Cylinder.—Each brake cylinder is self-contained, and in the event of failure of one brake the others

are still available. A cross-sectional view of a pneumatic track brake is shown in Fig. 10. The air cylinder *a* is carried on a base *c*, which is bolted to the truck. The piston *d* of the cylinder is connected by a plunger *e* to the toggle-levers *f*, which are pivoted to a bracket carried down from the base by steel pins *g*. The levers carry the cast-steel holder *h*, in which is held the brake block *b* of oak, elm, or other hard wood. When compressed air is admitted to the top of the cylinder, through the air inlet *i*, the piston is driven down against the pressure of the spring *j*, and, acting through the toggle-levers *f*, presses the brake block on to the rail *k*. A pneumatic track brake, unlike a hand-operated brake, causes very little stress on the car body, since the air in the cylinder acts as a cushion to prevent shock as the brake block passes over inequalities in the track.

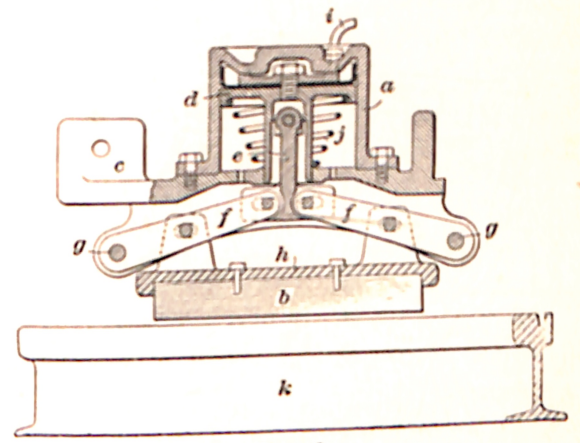


FIG. 10

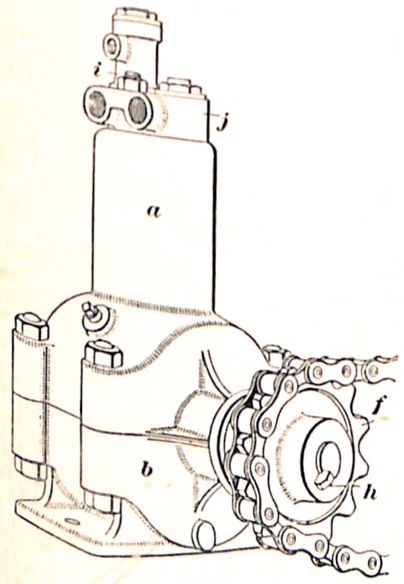


FIG. 11

19. Compressors for Pneumatic Brake.—The general appearance of the air compressor for the Hewitt & Rhodes brake is shown in Fig. 11. Sectional views are shown in Fig. 12, corresponding parts being given the same reference letters in the two illustrations. The body of the compressor consists of two castings *a*, *b*, bolted together, the former being the cylinder and the latter

serving to enclose the crank and form an oil chamber. The crank *c*, Fig. 12, and the crank end of the connecting-rod *d*

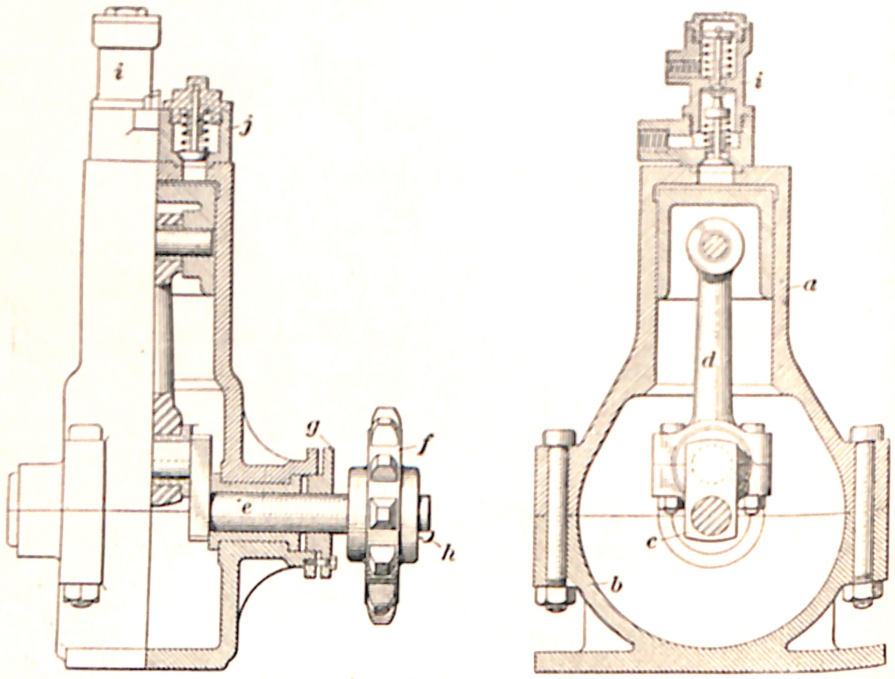


FIG. 12

normally work in an oil bath. The crank-shaft bearing *e*, next the chain wheel *f*, is provided with a stuffingbox *g* to prevent

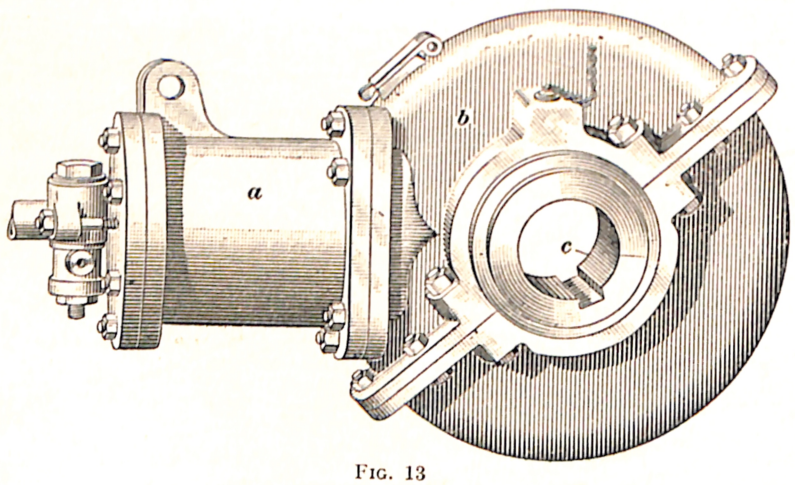


FIG. 13

the exit of oil or the entrance of dirt. The chain wheel is keyed to the shaft by means of a key *h*. The inlet and exhaust

valves *i* and *j*, respectively, are fixed to the top of the cylinder. In order to economize the driving power, and to prevent unnecessarily heating the cylinder when the maximum pressure is attained in the storage reservoir carried on the car, the inlet valve is lifted on the compression stroke and the compressor does no work on the air. In the direct-driven air compressor shown in Fig. 13 the cylinder *a* is placed horizontally to economize headroom, and the crank-case *b* is split diagonally and bolted together. Instead of being driven from a crank, the piston is driven from an eccentric bored out at *c* to fit the car axle to which it is keyed.

20. Arrangement of Pneumatic-Brake Equipment. — The method of connecting up the various parts of a pneumatic-brake equipment is shown in Fig. 14. The compressor *a* delivers air at the required pressure to the reservoir *b*, both compressor and reservoir being carried beneath the car floor. From the reservoir the air passes into the reservoir pipe *c*, which is maintained

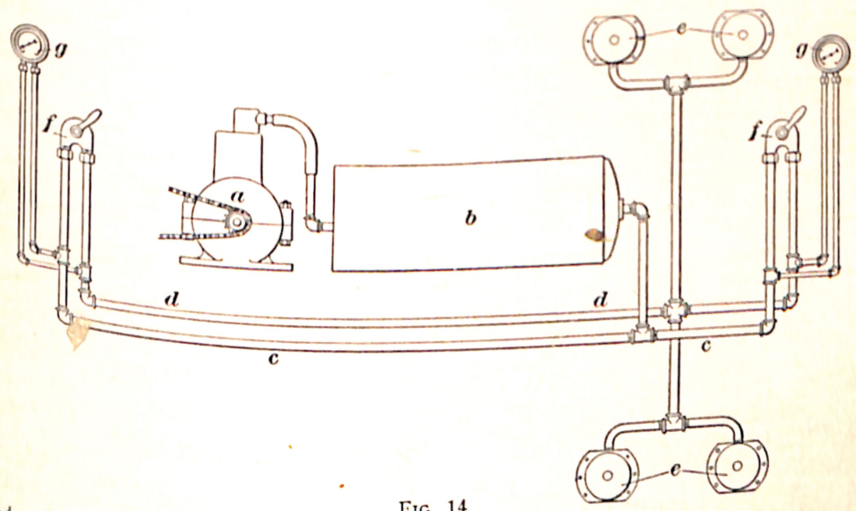


FIG. 14

at reservoir pressure. Air can be admitted from the pipe *c* to the brake pipe *d*, and thence to the brake cylinders *e*, by means of either of the driver's valves *f*, one of which is mounted on each platform of the car, together with a duplex pressure gauge *g* to indicate to the driver the available braking pressure in the reservoir and also the pressure in the brake cylinders.

ELECTRIC BRAKES

21. Rheostatic Brake.—In addition to providing mechanical brakes on a tramcar, it is the general practice to arrange some means of braking the car electrically also. The most common method is to connect the car motors, after disconnecting them from the supply, so that they will act as generators and send current through the whole or a part of the car-starting resistance. The controller which is normally used to operate the car motors is arranged, in this case, so that one movement of the handle will both cut off the power from the motors and connect the motors in such a way to the starting resistance that a braking effect is exerted to stop the car. This arrangement is known as a **rheostatic brake.**

22. Connections for Rheostatic Brake.—The back E.M.F. of a motor opposes the flow of current through the armature from the line, and if the motor is simply disconnected from the line, but is kept revolving in the same direction as before, the back E.M.F. will tend to set up a current in the opposite direction to the original motor current. In the case of a series motor, the residual magnetism of the field will still set up a small E.M.F., which will tend to send a current through the field in the opposite direction to the original exciting current; if the field circuit is closed through the motor armature and a resistance, the motor field will not build up as a generator, but will be demagnetized entirely. In order to make the series motor act as a generator, either the field or the armature connections must be reversed; in practice, it is usual to reverse the armature connections. The ordinary connections for rheostatic braking with two motors are shown in Fig. 15. The two motors are

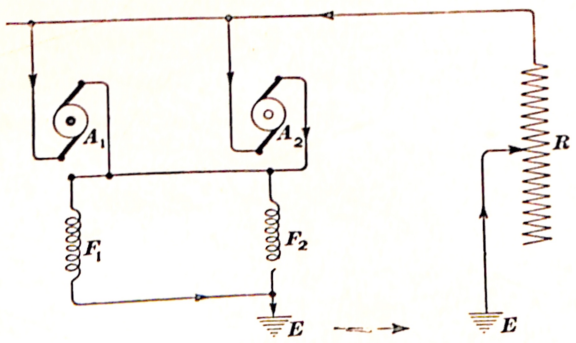


FIG. 15

connected in parallel with each other, with the connections to the armatures A_1, A_2 reversed, and in series with the car-starting resistance R, through the earth wire E of the car. An equalizing wire is connected across the terminals of the field windings F_1, F_2, next to the armatures, in order to ensure, as far as possible, that the field strengths and currents of the two machines are equal.

23. Another method of electrical braking which is sometimes used in making an emergency stop is to change the connections by means of the controller, so that the motors will endeavour to drive the car backwards. The connection of a motor with armature A and field F when driving the car forwards is shown in Fig. 16 (*a*), and when reversed for an emergency stop in Fig. 16 (*b*). The motor does not act as a generator to return current to the line T when connected as in (*b*), but the armature E.M.F. assists the flow of current from the line to the earth E, and the current, and therefore the motor torque exerted to stop the car, are both greater than normal. As this method puts very severe stresses on the equipment, it is resorted to only to avoid collisions when running at fairly low speeds with the two motors of the car in series. If the speed of the car is high enough, the automatic switch on the car will probably open owing to the excessive current. If when this happens the circuit-breaker is not replaced, but the controller handle is moved to a parallel position, the motors being still connected for the reverse direction, a third method of braking is obtained, due to the motors being coupled together in parallel but without any equalizing connection across the field-coil terminals. Under these circumstances, as no two series motors generate exactly equal back E.M.F.'s, the motor generating the higher voltage will force a current through the lower-voltage motor and will reverse it. The motors will then be coupled in series through one another, one acting as a generator to drive the other as a motor in the opposite direction to that in which it has been

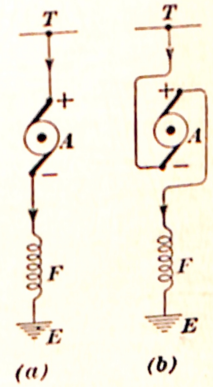


FIG. 16

running. As in the case of the reversal of the motors, this method is a severe one, and should be used only in a case of emergency. A car cannot be brought to a standstill by means of the rheostatic brake alone, because the current supplied by the generative action of the motors, and consequently the braking force, depends on, and decreases with, the speed. In some instances, the generative action of the motors is used to supply current to special magnetic brakes, thus giving double braking action while the car is in motion.

24. Regenerative Braking.—If, instead of connecting a resistance across the terminals of a series motor which is connected to act as a generator, the motor is shunt-wound, and the terminals are connected to the supply circuit, current may be delivered to the mains providing the speed and field flux of the generating machine are adjusted so that the back E.M.F. generated is slightly above the line P.D. The retarding action on the armature of the generating machine is the same as though a rheostat were used, but the power, instead of being wasted, may be used in other parts of the system. Such a system of braking is known as a **regenerative, or recuperative, system.**

Regenerative control and regenerative braking are used in tramway work in connection with direct-current shunt motors, and in electric-railway traction on the three-phase alternating-current system. Regenerative or rheostatic systems of braking are open to the objections that extra work is thrown on the motors, and unless the motors used are larger than would otherwise be required this may result in overheating them. Moreover, the connections and controllers are more complicated than if electric braking is not used.

COMBINED ELECTRICAL AND MECHANICAL BRAKES

25. British Thomson-Houston Magnetic Track Brake.—Very effective braking is obtained by combining the ordinary rheostatic-brake connection with a track brake which is applied to the rails magnetically. A track brake of special form is drawn down on the rails with considerable force by magnetic attraction, when current is passed through its exciting coil, the coil being

connected in the ordinary braking circuit, in series with the motors and the starting resistance of the car. The mechanical braking effect due to the magnetic brake is increased as the controller is advanced notch by notch, increasing the current by cutting out the series resistance.

In Fig. 17 is shown the magnetic track brake of the British Thomson-Houston Company. This brake consists of a cast-steel shoe *a* suspended by means of links *b* from a bracket *c* attached to the side of the truck, and is held close to, but clear of, the track by means of the springs *d*. The magnet coil is placed in a recess in the casting *e*, and a steel core extends through

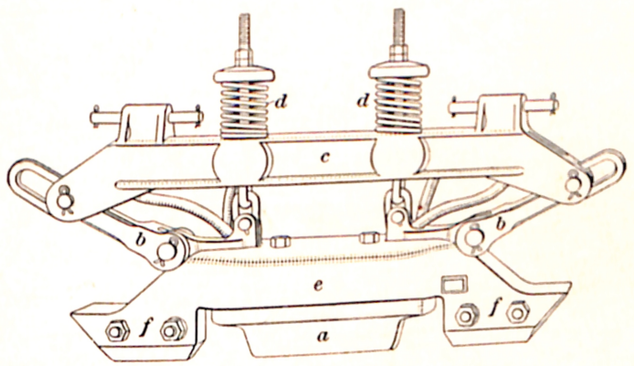


FIG. 17

the coil, providing two magnetic circuits, each of which is completed through the small extensions and shoes *f*, and the section of rail immediately under the shoe. The magnetic attraction exerted between the shoes of each brake and the rail is about 1 ton. The compression of the springs *d*, owing to the lowering of the brake shoes to the track, slightly increases the weight on the wheels instead of reducing it, as is the case with mechanical track brakes. Compared with the rheostatic brake alone, less current is required for the magnetic brake for the same braking effect, consequently there is a reduction in the heating of the motors.

26. Westinghouse Electromagnetic Track Brake.—The efficacy of the magnetic track brake may be greatly increased by utilizing the attraction between the magnetic brake and the rail to

actuate a mechanical brake, applied either to the wheels or to the rails. The former method is used in the Westinghouse brake, and the latter in the Maley brake. The arrangement of the Westinghouse electromagnetic brake is shown in Fig. 18, in which the brake on one side of a car truck is shown as viewed from the opposite side, under the car. The brake gear is placed inside the frame of the car truck. The shoes *a* of the magnetic track brake are drawn down on the rail when the exciting coil *b* is energized by current from the car motors acting as generators. The track shoes and electromagnet are normally held clear of the rail by two springs *c*. The wheel-brake shoes *d*, *d'* are hung

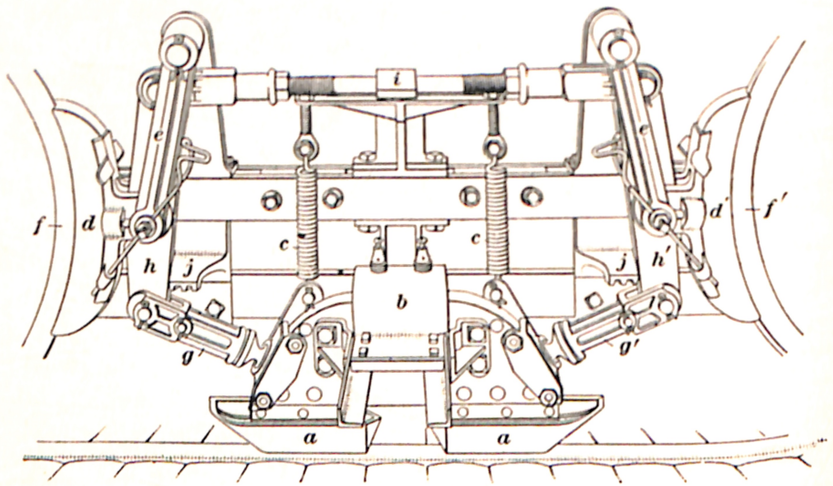


FIG. 18

on links *e*, both the springs *c* and links *e* being hung from brackets fixed to the truck frame. The wheel and track-brake shoes are connected by a link framework so arranged that the act of applying the magnetic brake to the rails also causes, when the car is in motion, the wheel blocks to press against the wheel tires.

27. If the wheels *f*, *f'*, Fig. 18, are rolling from left to right, the track brake, when applied to the rail, drags toward the rear wheel *f*, putting link *g* in compression, and pressing brake block *d* against the wheel *f* through lever *h*, which at first pivots on the joint with rod *i*. Lever *h* now turns about the pivot of brake block *d*, thus putting rod *i* into compression, and moving the

upper end of lever *h'* toward the forward wheel *f'*. Without special provision to the contrary, the brake block *d'* would be drawn away from wheel *f'* when link *g'* is put in tension by the track brakes dragging, but the links *g* and *g'* are actually extensible, being fitted with springs, and the fixed stops *j* attached to the truck frame prevent any considerable movement of either wheel-brake block away from the wheel tire. Thus, when rod *i* is in compression, lever *h'* pivots first about the brake block *d'* and then about the fixed stop *j*, thus braking the forward wheel *f'* firmly.

28. Maley Electro-Mechanical Track Brake.—When making a quick emergency stop with any wheel brake, whether mechanically or electrically operated, the risk always exists that the wheels may be skidded, due to the too great pressure between the wheels and brake blocks. If the wheels of a car are locked, the retarding effect of the wheels sliding along the rails is less than that obtained when the wheels are running with the brakes applied to them with a force just under that which would cause slipping. Of course, the wheels will skid much more readily if any part of the weight of the car is taken off them due to the application of a mechanical track brake. In order to meet this difficulty, the Maley electro-mechanical brake has been developed, consisting of a magnetic track brake combined with mechanically applied track-brake shoes. The magnetic attraction of the brake increases the adhesion of the wheels on the rails and a threefold braking effect is obtained, due to the generative action of the car motors in supplying current to the magnetic brake, the friction between the magnetic brakes and the track and between the mechanical brakes and the track.

29. The arrangement of the Maley brake, as applied to the bogie of a double-truck car, is shown in Fig. 19. The excitation of the magnetic-brake shoe *a*, and therefore its attraction on the rail, and the consequent braking effect obtained, are normally controlled from the car controller, though, in the event of a fault developing in the controller, the track magnet can be excited directly from the trolley wire. The brake rigging is supported on the truck frame at *b*, and when the magnetic-brake shoe is

applied to the rail, it drags, and tilts the stem which acts as the guide for the shoe *a*. The additional brake shoes *c* and *d* are applied to the rail by means of the levers *e*, which are forced

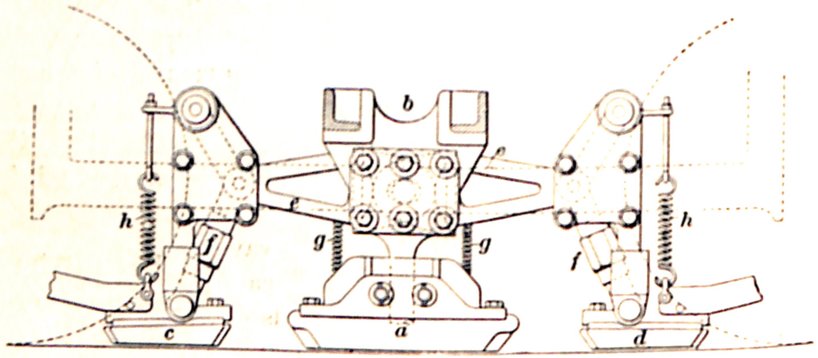


FIG. 19

outwards by the cam between them and thus press downwards on the levers *f*. The springs *g*, *h* serve to hold the brake shoes away from the rail when the brakes are released.

BRAKES FOR ELECTRIC RAILWAYS

ARRANGEMENT OF RIGGING

30. Variations From Tramway and Steam Practice.—Railway braking is confined almost entirely to the use of power-applied wheel brakes. The rails are invariably clean and the adhesion of the wheels good, so that track brakes are not required. Electric brakes have a certain limited use. On single trucks having a rigid wheel base, brake blocks are usually provided on each side of each wheel. On motor trucks, however, there is very often insufficient room for two blocks on each wheel. Brakes hung outside the wheels at both ends of the truck or bogie are the more easily accessible, but in action they tend to tilt the bogie by depressing the front and raising the rear end. On the other hand, brakes hung between the wheels are impossible with some types of motor suspension, on account of lack of space. The general practice in steam-railway work is to connect the

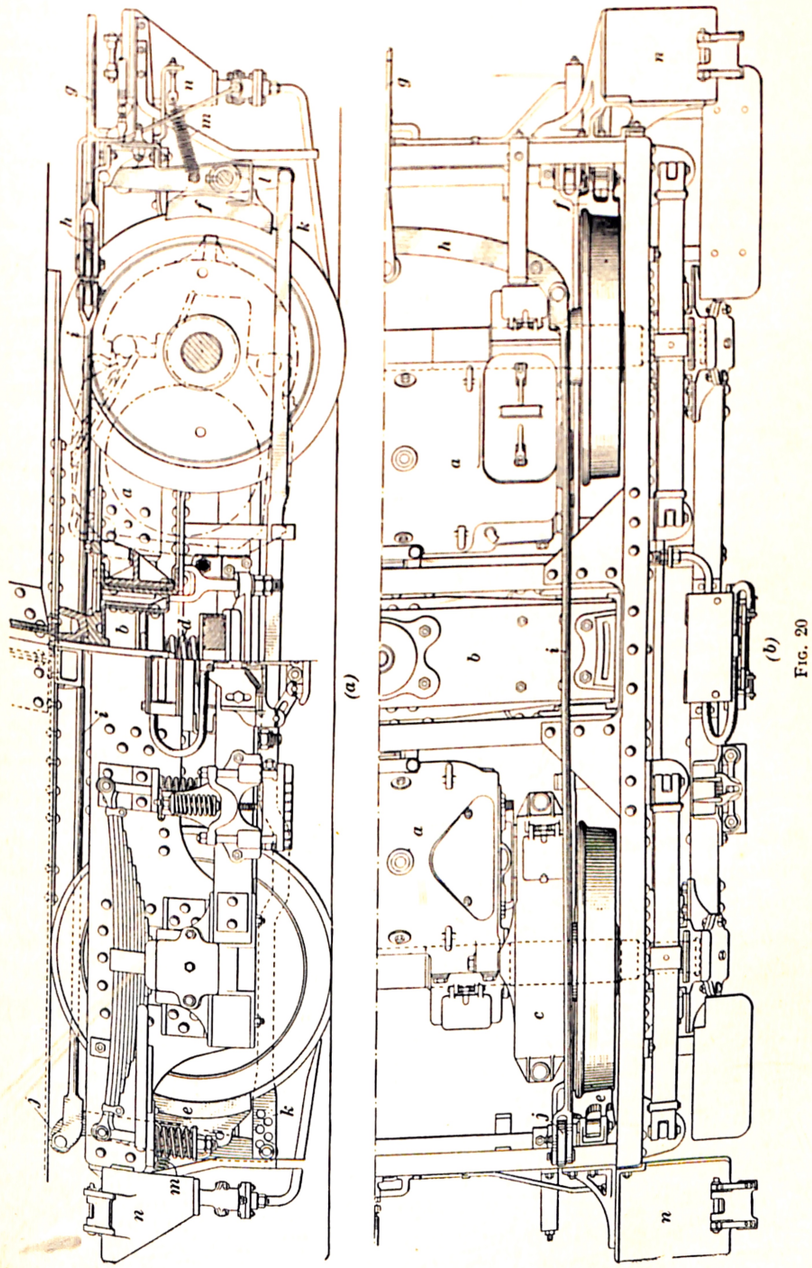


FIG. 20

forward pair of brake blocks directly to one transverse beam, and the rear pair directly to another, the beams being joined through rods and cranks, and operated together by a central lever. As on motor-driven trucks there is no room for such transverse beams in the usual positions, the rigging must be kept at the sides and ends of the trucks, out of the way of the motors.

31. Brake Rigging With One Brake Block Per Wheel.—A brake rigging for a motor bogie with one brake block per wheel, as constructed for the North-Eastern Railway, is shown in Fig. 20 (*a*) and (*b*), which are side-elevation and half-plan views, respectively. The motors *a* are suspended from the axles and the truck bolster *b*, and drive by single reduction gears, one gear-box being shown in plan at *c*. A part of the weight of the motors is supported by the bolster springs *d*. In this case, brake blocks are not provided between the pairs of wheels on each side, but only on the outer sides of the wheels at *e* and *f*. When a pull is applied on rod *g*, it is transmitted by the curved transverse beam *h* to two rods *i*, one on each side, and which extend along the top of the truck to the levers *j*. One lever *j* is pivoted on the brake block *e* and also at the lower end on a tension rod *k*, view (*a*), which connects with the lower end of lever *l*. The lever *l* carries the brake block *f* and is pivoted at its upper end to the truck frame. As soon as the brake block *e* comes in contact with one wheel, rod *k* draws block *f* in contact with the other wheel. Spiral springs *m* are used to draw the brake blocks away from the wheels when the pull on rod *g* is released. Sanding boxes *n* are placed at each end of the bogie frame.

32. Brake Rigging for Brush Bogie.—An arrangement of brake rigging specially adapted to leave the necessary space for two motors, and at the same time to provide every wheel with two brake blocks, is shown in Fig. 21 (*a*) and (*b*), which are elevation and plan views, respectively, of an electric-locomotive truck made by the Brush Electrical Engineering Company for the North-Eastern Railway. The main truck frame is supported on springs *a*. The two motors *b* are carried between

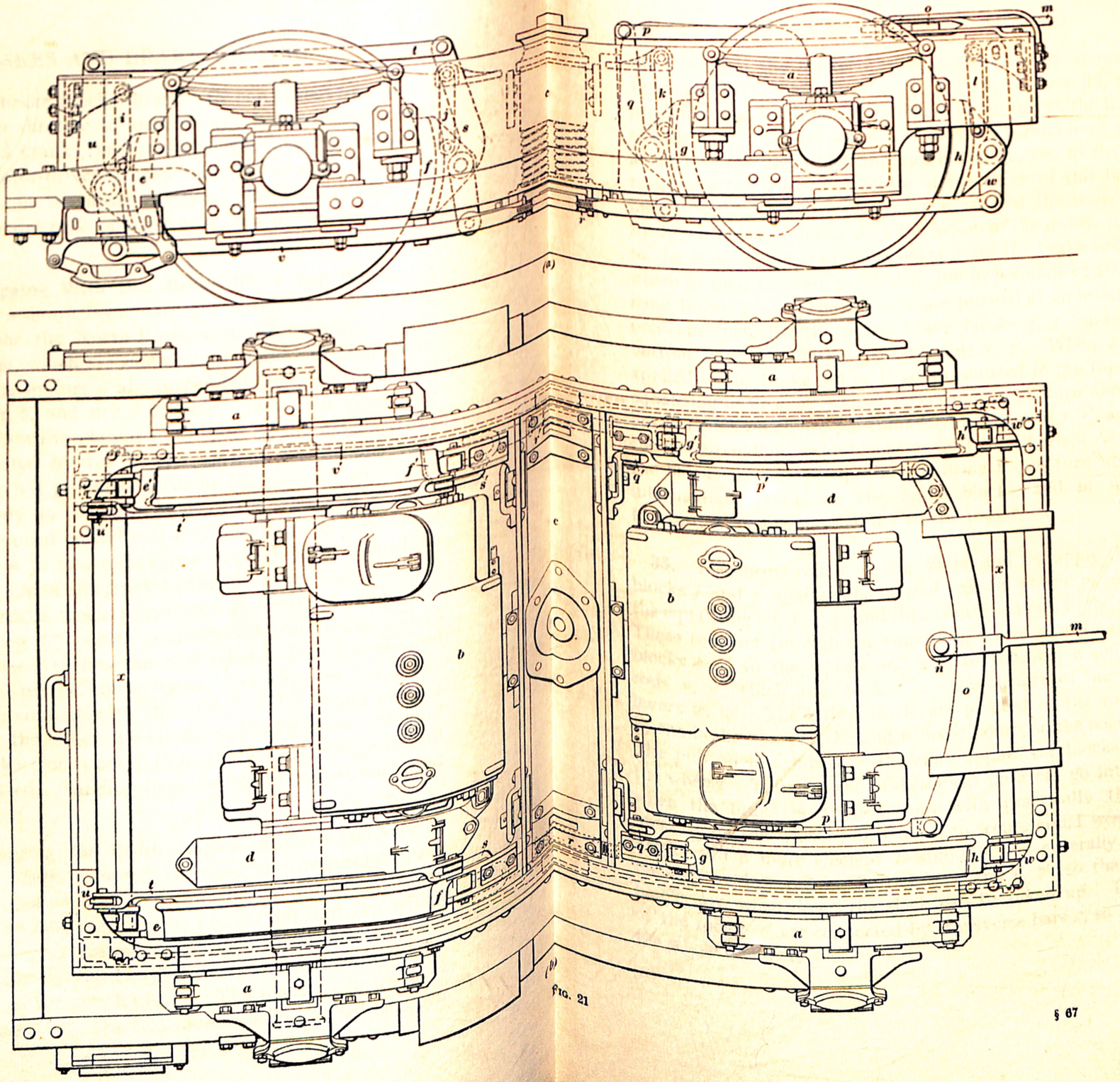


FIG. 21

the axles and the bolster c; the gear-boxes are shown at d. The eight brake blocks e, e', f, f', g, g', h, h', view (b), are suspended from the frame of the bogie by means of the links i, j, k, l, view (a). The tension rod m ends in a forked head carrying a roller n, through which the pull is transmitted to the curved transverse beam o. The centre of the curve of this beam coincides with the centre of the bogie, so that the bogie swivels freely without interfering with the action of the rod m. Pivoted to the ends of the transverse beam o are the brake rods p, p', which in their turn are pivoted to the upper ends of the equalizing levers q, q'. These levers are pivoted at an intermediate point in their length to the brake blocks g, g', and at their bottom ends to another pair of rods r, r'. When a pull is applied to the brake rod m, it is transmitted to the top of each equalizing lever q, q'. These levers first of all turn about their bottom ends which are pin-connected to the rods r, r', and press the corresponding brake blocks against the wheels. As soon as the blocks are pressed up, the equalizing levers turn about the intermediate pivots on the brake blocks, and in so doing transmit a longitudinal thrust to the rods r, r'.

33. The thrust rods r, r', Fig. 21 (a) and (b), apply the brake blocks f and f' against the second pair of wheels by means of the equalizing levers s, s', and then transmit a pull to the rods t, t'. These rods act through the equalizing levers u, u' to apply the blocks e, e' to the wheels and also to transmit a pull to the rods v, v' which run back the whole length of the bogie to levers w, w'. The latter are levers pivoted to the rods v, v', to the brake blocks h, h', and to fixed points on the bogie frame. The pull on the rods v, v' therefore applies the blocks h, h' to the wheels. Thus, all the brake blocks on a car go into action when the brake is applied, and with practically the same pressure on the wheels; this tends to secure equal wear in the blocks and a more efficient breaking action generally. Turnbuckles are inserted in the rods r, r' and v, v', so that as the blocks are worn down the slack can be taken up. The ends of the rods v, v' are connected by transverse bars x, so as to tie the whole together.

BRAKING SYSTEMS

COMPRESSED-AIR BRAKES

34. Systems of Air Supply.—There are in general use two systems of air brakes, namely, the *compressed-air system* and the *vacuum system*. In the **compressed-air system** the brakes are operated by means of pistons worked by compressed air, while in the **vacuum system** the brakes are applied by withdrawing air from one side of the brake piston and allowing atmospheric pressure to act on the other side. In order to get sufficient braking force by this means, either the piston area must be large or the piston must act at the end of a long lever arm. In the compressed-air system, the pressure used is usually 60 to 80 pounds per square inch; this pressure is given by a storage reservoir on the train, a compressor driven by the axle, or a compressor driven by a small electric motor.

35. Storage System.—If air for braking is supplied from a storage reservoir on the train, the reservoir must be large enough to supply the brake cylinders during the entire run between recharging stations, and there should be ample reserve capacity in the reservoirs to allow for emergencies. The pressure in the storage reservoir is usually much higher than the pressure applied to the brake cylinders, a reducing valve being used to keep the braking pressure at the proper value. The system has the advantage of the braking equipment on the train being very simple. The pumping or compressor plant at the recharging stations also works under most favourable conditions, being always under full load and having no restrictions as to space available for equipment. The disadvantages are that each application of the brakes reduces the pressure of the air in the reservoir, for this, together with leakage, may render the brakes inoperative.

36. Axle-Driven Compressor System.—When the axle speed of a train is not greater than 150 revolutions per minute, compressed air may be obtained by means of a compressor driven directly from the car axle. This method of operating the compressor is open to the objections that the compressor is running whenever the train is in motion and thus does unnecessary work when the reservoir is charged, while if the stops are frequent and the grades heavy the compressor may not be able to supply the amount of air necessary to operate the brakes efficiently. If a train has been standing for some time, the air stored in the reservoirs may have leaked away and the brakes will be inoperative until the train has travelled some distance and the compressors have again recharged the storage tanks.

37. Motor-Driven Compressor System.—The system of supplying the compressed air by separate motor-driven compressors is the one most commonly used. The reservoir pressure is maintained within the desired limits by an automatic controller, which starts the motor whenever the pressure falls below a certain limit, and stops the motor when the pressure reaches a given maximum. This system offers all the advantages of the axle-driven compressor system by making the air supply for each coach independent of the others. The compressor runs only when necessary, and will charge the reservoirs whether the train is running or standing so long as there is a supply of electrical energy. The disadvantages are that the equipment is somewhat complicated due to the motor connections and automatic controller.

38. Train Pipes.—The pneumatic-brake equipment of electric railways differs little from that used on steam railways. The brakes on each coach are operated by air from an auxiliary reservoir which the coach carries. The brakes are controlled by means of special balanced valves, called *triple valves*, which may be operated by the motorman's or driver's valve by reducing the pressure in a pipe running the full length of the train and called a **train pipe**. Where a train includes more than one motor coach, each coach necessarily contains a complete brake equipment, and means must be provided whereby, in case of necessity, the compressor on one motor coach can supply compressed air to the reservoirs of the other motor coaches. For this purpose an additional pipe, called a **reservoir pipe**, is provided, which connects the main reservoirs on the motor cars, so that, in the

event of one compressor breaking down, its reservoir is supplied from the other compressors through this second pipe.

39. Typical Equipment.—A complete air-brake equipment for a single coach is represented in Fig. 22. At the bottom of the illustration is the main reservoir *R m*, which is connected through the reservoir pipe to the reservoirs on the other motor coaches. The main reservoir is supplied with compressed air through the check-valve *28*, which is an ordinary flap valve, from the compressor, which is driven by the pump motor. Current for driving the pump or compressor motor passes from the positive main through the pump switch and fuse and pump-governor switch to the armature *A* and fields *F* of the motor and then to ground or earth. The function of the pump governor is to cut off current from the compressor motor when the reservoir pressure has reached a desired amount, and to start the motor again when the pressure falls. This regulation is effected by the governor piston *30*, which works in a cylinder *29* against a spring *31*. At the end of the piston rod is pivoted a lever, which moves about a fixed pivot *33*, its other arm consisting of an insulated switch arm *32* by means of which connection can be made between the contacts *34* and *35*. When the reservoir pressure reaches the normal value, the governor piston *30* is moved against the action of the spring *31* and opens the switch *32*, *34*, *35*; when the pressure falls, the piston is moved inwards by the spring and closes the switch, thus starting the compressor motor. Insulating couplings are provided in the pipe connections between the main reservoir and the pump governor and the compressor, respectively. These couplings insulate the electrical apparatus from the earthed portions of the brake equipment, and they reduce the P.D. between the windings and the body of the apparatus, thus reducing the liability of breakdown in the insulation.

40. Control Valves.—At the top of Fig. 22 is shown the train pipe, which is connected to the chamber *L'* of the triple valve, chamber *R* of which is connected with the auxiliary reservoir *R a*, while chamber *B* is connected with the brake cylinder. The piston of the brake cylinder is connected with the brake rigging, and when the piston moves out the brakes are applied

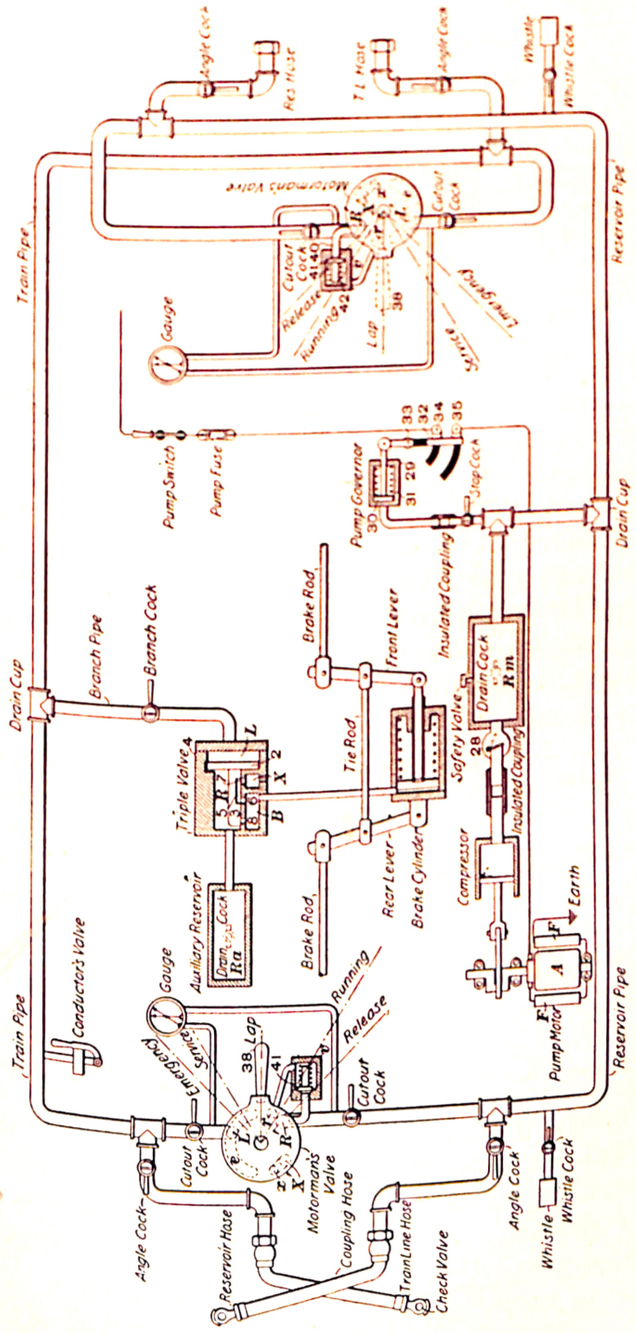


FIG. 22

in the usual way by means of the brake rods. The supply of air to the train pipe is governed by the motorman's valves, which are shown at the right and left of the illustration. In the motorman's valve, exhaust ports X, x in the valve seat connect together and open directly to the atmosphere; ports R', r do not connect to each other except through feed-valve *39*, which makes connection between the train pipe and reservoir pipe under certain conditions. Port R' opens to the reservoir pipe and L' to the train pipe. By means of the curved cavity c in the rotary part of the valve, any desired connection between the ports can be established.

41. Lap Position of Valve.—In Fig. 22, the handle *38* of the motorman's valve is shown in the **lap position**, in which there is no connection between the various valve ports. This is the only position in which the handle can be put on or removed. Lap position is used when it is desired to hold temporarily to the condition which has been established in the braking system. For example, if it is desired to hold the train stationary on a gradient, the train is stopped and the valve handle moved to lap position, in which no motion of air through the braking system is possible.

42. Service Position of Valve.—When the handle *38*, Fig. 22, of the motorman's valve is moved to the **service position**, cavity c connects the train pipe to atmosphere through port x. The pressure in the auxiliary reservoir moves the piston *2* and slide valve *3* of the triple valve to the right, thus establishing connection between the brake cylinder and the auxiliary reservoir through port *8* and closing the port *6*, which normally connects to the exhaust chamber X through cavity *5* and port *7*. By this means, the brake piston is moved out against the spring and operates the brakes in the usual way. In the emergency position, the train pipe is connected to the atmosphere through both ports x and X, and therefore the brakes are operated more rapidly than in the service position. A valve c' is fitted to the train pipe and placed where it can be easily operated by the conductor in case of emergency. Any accidental injury to the train pipe applies the brakes by connecting the train pipe to the atmosphere.

43. Running Position of Valve.—When the motorman's valve is in the running position, cavity c, Fig. 22, is connected to port r. If the difference of pressure between the reservoir pipe and train pipe exceeds 20 pounds per square inch, the feed-valve piston *41* will be lifted against the action of spring *42* and air will pass from reservoir pipe to train pipe through valve *39* until the difference of pressure falls and the combined action of train-pipe pressure and the pressure of spring *42* closes the feed-valve. On steam trains, the governor maintains the pressure in the main reservoir at 90 pounds per square inch, and the feed-valves are set to keep the pressure in the train line at 70 pounds per square inch. On electric trains using electric governors that do not operate until a certain minimum or maximum pressure is attained, the excess pressure, that is, the excess of the pressure in the reservoir pipe over that in the train pipe, is necessarily variable.

44. Release Position of Valve.—In the **release position** of the motorman's valve, cavity c, Fig. 22, covers ports R', r, and L', thus admitting high-pressure air from the main reservoir to the train pipe. In this way, the pressure in chamber L of the triple valve is raised above that in the auxiliary reservoir $R\,a$ by an amount equal to the excess pressure, and therefore the triple-valve piston *2* moves to the left, closing port *8*, and connecting the brake cylinder with the atmosphere through the ports *6* and *7* and exhaust chamber X. The brake piston moves to the left under the action of the spring and releases the brakes. In this position of the triple valve, the auxiliary reservoir is supplied with air from the train pipe through the feed-groove *4*.

VACUUM BRAKES

45. Arrangement of Exhausters.—On steam railways which use vacuum brakes, the locomotive is generally provided with two steam-actuated air exhausters, termed **ejectors**; a small one, which is working continuously, to maintain the vacuum against leakage, and a large one to restore the vacuum in the train pipe and brake cylinders for the release of the brakes.

The restoration of the vacuum which releases the brakes must take place quickly, and therefore the large ejector must have considerable capacity. As an equivalent of this equipment on electric railways there are various alternatives. Where all the cars are fitted up on the same system, two train pipes may be used, one for applying the brakes, and the other for releasing them by equalizing the pressure above and below the brake piston. In some cases, however, trains may contain coaches provided with only one train pipe; two motor exhausters may then be provided on each motor car, one being driven at half-speed to maintain the vacuum. For releasing the brakes, both exhausters are run at full speed, and the vacuum is restored in a very short time.

A single exhauster running normally at quarter-speed, but at full speed when releasing the brakes, may be used instead of the arrangement previously described. This has the advantage of simplicity, but in the case of a single car there is no provision against the breakdown of the exhauster or motor. By duplicating the exhausters, the brakes can always be operated, even though only one exhauster can be run, although it will take longer to release the brakes after application.

46. Equipment of an Electric Locomotive.—A diagram of the arrangement of the exhauster, brake cylinder, and piping, suitable for an electric locomotive, is given in Fig. 23. The exhauster motor *a* drives the exhauster *b*, through a flexible coupling, and is controlled by the switch *c*. According to the position of the switch handle on the contacts *1*, *2*, *3*, the motor is at rest, or driving the exhauster at one-quarter speed, or full speed, as the case may be. The low speed is secured by connecting a resistance *d* in series with the motor armature when the switch *c* is on the middle contact *2*. The exhauster can be put into connection with a vacuum chamber *e* carried on the locomotive and with the train pipe *f* by means of the driver's valve *g*, which is mounted in the cab conveniently near the electrical controller. The air withdrawn by the exhauster is returned to the atmosphere through the exhaust pipe *h*, which is taken below the floor of the cab.

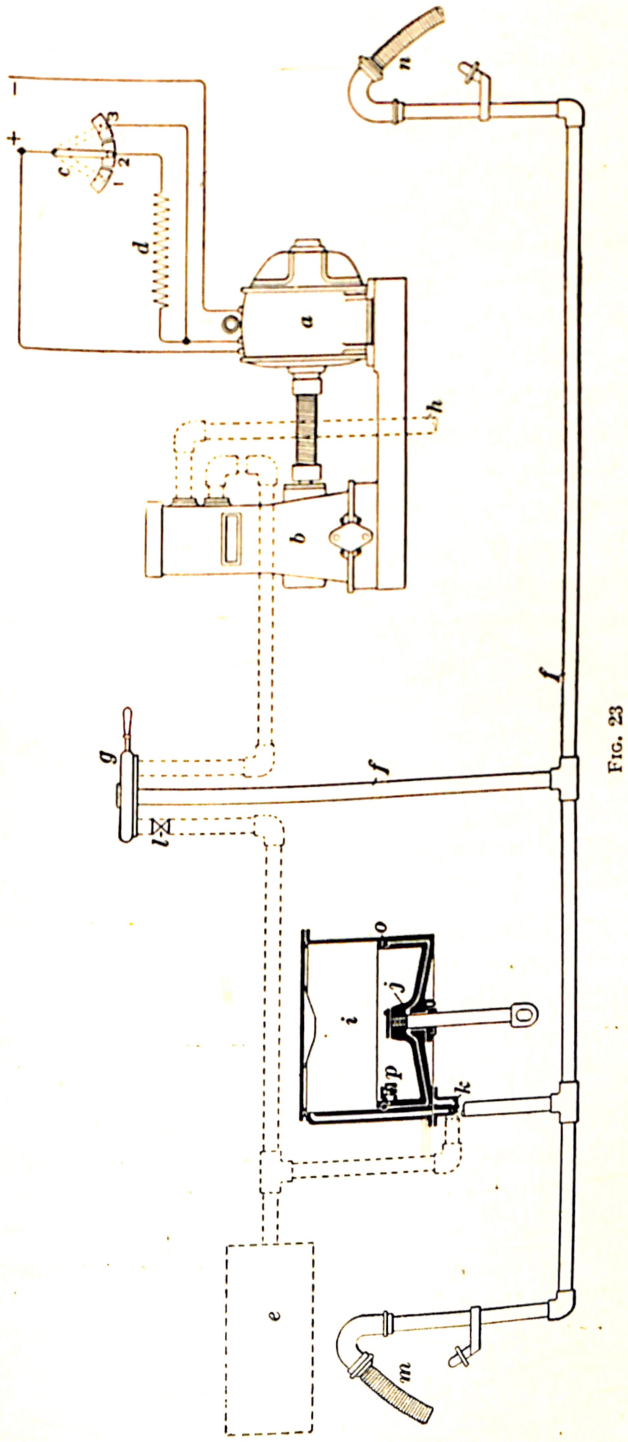


FIG. 23

47. Under ordinary running conditions the exhauster is driven at low speed and maintains a vacuum both in the vacuum chamber *e* and the train pipe *f*, with both of which it is connected through the driver's valve. The vacuum chamber *e* is in communication with the space *i* in the brake cylinder above the piston *j*, and the train pipe is in communication with the port *k* leading to the lower side of the piston. The piston therefore remains in equilibrium, with the brakes off. To apply the brakes, air is admitted to the train pipe through the driver's valve, but the vacuum is maintained in the chamber *e* and above the piston *j*. The air pressure in the train pipe then lifts the piston *j* and applies the brakes. To release the brakes before starting the train, the exhauster is run up to full speed and is put into communication with the train pipe through the driver's valve. As the vacuum is attained in the space below the brake piston *j*, and the pressure above and below the piston is equalized, the piston falls and the brakes are released from the wheels by gravity. When the locomotive is uncoupled from the train and there is air in the train pipe, air may be admitted to the vacuum chamber *e* and the pressure above and below the brake piston equalized by means of the release valve *l*. Couplings are provided at *m* and *n* for connecting the pipe *f* to the train pipe which runs through the coaches of the train.

48. The piston *j* of the brake cylinder is packed with a rubber ring *o*, known as a **rolling ring**, because it rolls up and down the cylinder wall with the movement of the piston ; this ring effectually prevents any appreciable leakage from one side of the piston to the other. The ball valve *p* is provided on the piston so that both the top and bottom ends of the cylinder may be exhausted through the train pipe to the same degree of exhaustion when the brakes are released and the piston is in the lowest position, independently of the existing connection from the brake cylinder to the vacuum chamber *e*. When air is admitted into the train pipe to apply the brake, it holds the ball valve firmly on its seat, so that air cannot pass into the upper part of the cylinder ; this preserves above the piston the vacuum which is necessary in order that the brake may act.

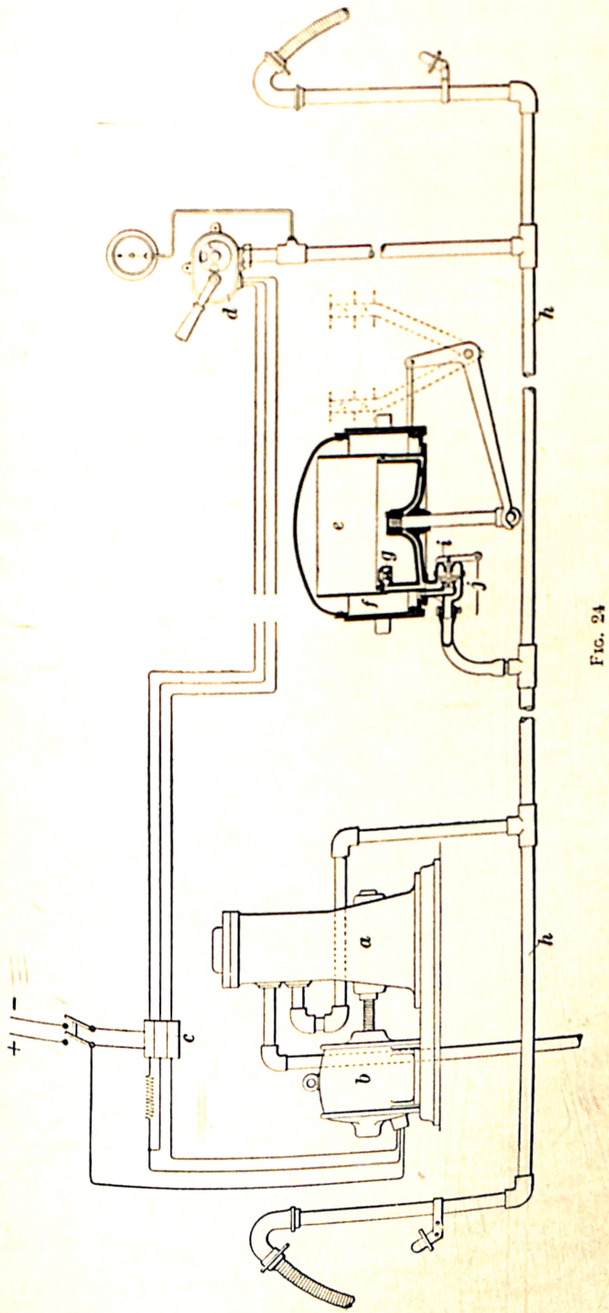


FIG. 24

49. Arrangement of Vacuum Brake on Midland Railway. The brake equipment of the coaches on the electrified Heysham line of the Midland Railway has some special features. The general arrangement of the brake control is shown diagrammatically in Fig. 24. The exhauster *a* is driven by a motor *b*, which is controlled by a contactor group *c* actuated from the driver's combined air valve and switch *d*. No separate vacuum chamber is provided; the brake cylinder *e* combines the functions of the vacuum chamber and the separate brake cylinder shown in Fig. 23. The brake cylinder proper, Fig. 24, is enclosed in an outer vacuum chamber *f*, in which a vacuum is continuously maintained, the degree of exhaustion being kept up by the withdrawal of air through the ball valve *g*, when the train pipe *h* is exhausted and the brakes are released. Release of the brakes when the exhauster is at rest is obtained when the valve *i* is opened by pulling the release cord *j*, thus admitting air to both sides of the brake piston.

50. Combined Driver's Valve and Switch. — The general arrangement of the combined driver's brake valve is shown in Fig. 25 (*a*) and (*b*). The train pipe is connected by means of a union nut to the chamber *a*, view (*b*), through the opening *b*, view (*a*). The front of this chamber is a flat surface *c*, containing openings or ports; the front of the cover, or valve *d*, is perforated to correspond to the openings in the face of the chamber *a*. The valve is so arranged that the latter openings are normally covered. If the valve is turned about its centre, the ports are uncovered to a certain extent depending on the movement of the valve. Air is admitted through the perforations and the ports to the train pipe, and the brakes are applied. The movement of the valve is effected by means of the driver's brake-valve handle *e*, on the switch *f*. This switch consists of a disc *g*, carrying a pair of carbon blocks *h* by means of which connection is made between the two contact segments *j* and *k* or between segment *j* and the block *l*. The disc is geared with the valve *d* by means of the roller *m* working in slot *n*.

51. Positions of Control Valve.—There are three positions of the combined driver's valve. In the first position, the air

ports are closed and segments *j* and *k*, Fig. 25, are connected. This is the normal **running position**, vacuum being maintained in the train pipe by the vacuum pump running slowly, thus keeping the brakes released. In the **release, or off, position**, the air ports are closed and segments *j* and *l* are connected, so that the contactor governing the full speed of the pump motor is excited. The valve is put into this position for restoring the

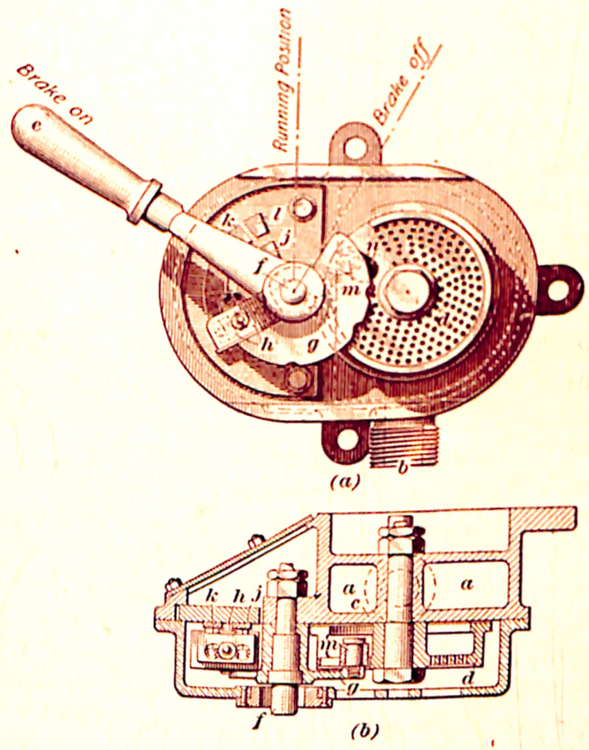


FIG. 25

vacuum, that is, for releasing the brakes. In the **on-position**, the ports are open and segments *j* and *k* are connected. In this position the pump is running at low speed and air is admitted, as desired, to the train pipe, thus causing the brakes to be applied.

52. Quick-Release Vacuum Brakes.—A quick-schedule train speed cannot be maintained unless the brakes are released

within a few seconds after the train comes to rest in the station. Therefore, trains which have to make short quick runs between stations must have provision for the quick release of the brakes. On the Liverpool-Southport line, all the carriages have special vacuum reservoirs and release valves, so that the pressures above and below the brake piston can be quickly equalized. The special release valves connect the train line with the vacuum reservoir, thus at once reducing the pressure sufficiently to release the brakes and allow the train to start.