13. In addition to the steam pipes or ports which carry the steam to the steam chest or valve chamber, and the exhaust passage which takes care of the exhaust steam after it has been used in the cylinder, it is necessary to have passages between the face of the valve and each end of the cylinder. This is so that the valve can admit steam first to one and then to the other end of the

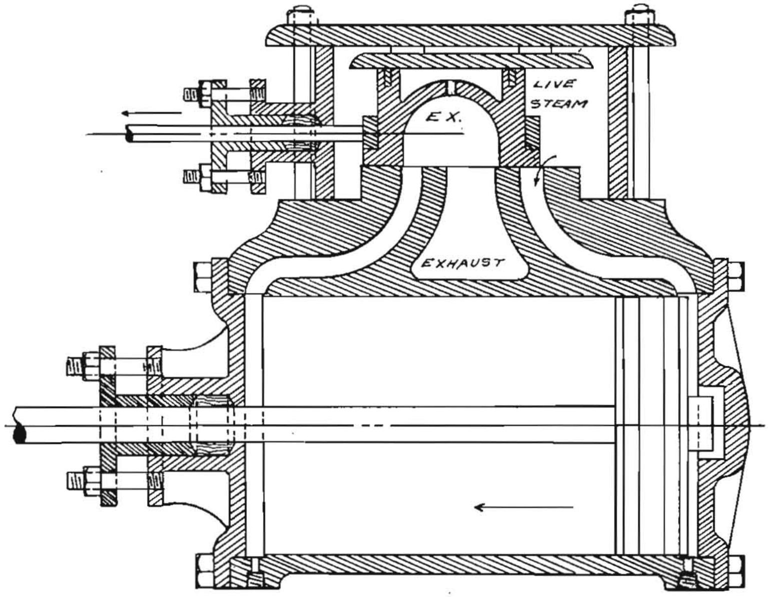

Fig. 5

cylinder, and later allow it to pass from the cylinder to the exhaust. Fig. 5 shows the arrangement of ports between the valve chamber and cylinder of a slide-valve engine. The proper movement of the valve back and forth on its seat covers and uncovers these ports and thus allows steam to enter first one and then the other end of the cylinder. The opposite end of the cylinder in each case is connected properly with the exhaust passage.

14. The slide valve has been superseded by the piston valve in modern locomotive practice. However, there are many old slide-valve locomotives still in service. Slide

valves always are of the outside-admission type, live steam being admitted at the ends of the valve, as shown in Fig. 5. The general arrangement of the piston valve and its valve-chamber, bushings, and ports is illustrated in Fig. 6. Practically all piston valves are of the inside-

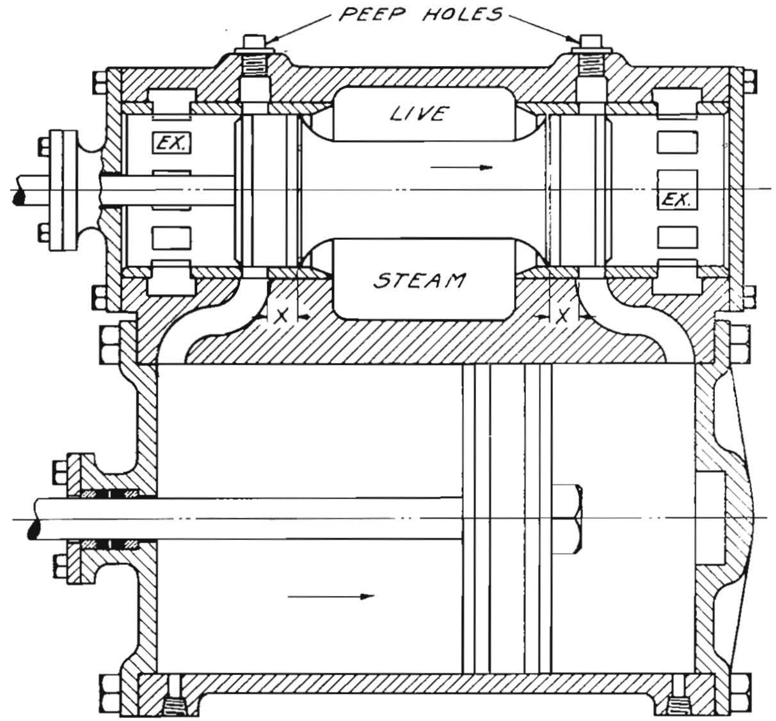

Fig. 6

admission type, the live steam being admitted at the center of the valve chamber.

SLIDE VALVES

15. Locomotive slide valves are almost without exception of the "D" type. Fig. 5 illustrates the reason for the adoption of this name, as a section through the valve is very similar in form to the letter D.

16. Slide valves of high-pressure locomotives always are balanced. A BALANCED slide valve is one that is arranged so that the boiler pressure does not act on the entire top area. The slide valve shown in Fig. 7 is 11½ inches long and 20 inches wide. If a boiler pressure of 200 pounds acted on this entire top area, the valve would be held against the valve seat with a pressure of 46,000 pounds (23 tons). The unsupported area of a slide valve is large; consequently, this pressure would act on the comparatively small bearing surface of the face of the

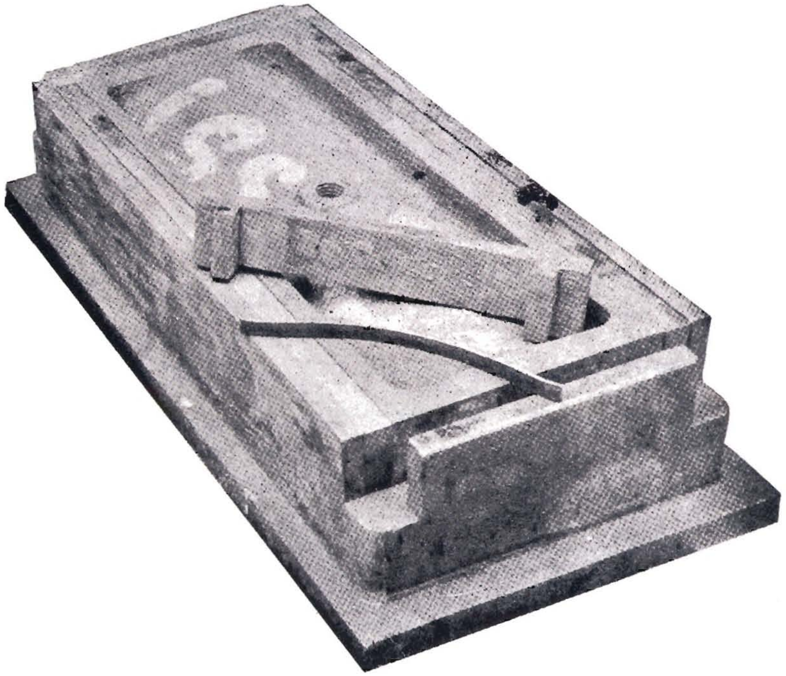

Fig. 7

valve. The bearing surface of the face of the valve shown in Fig. 7 is only 119.5 square inches, and not all of this area bears on the valve seat because some of it always is over a port opening. Even with the best of lubrication, there would be excessive friction and wear between the valve and its seat and a corresponding waste of power. Consequently, a slide valve is balanced sufficiently to reduce the pressure between the valve and its seat to a reasonable amount.

17. The two principal methods of balancing slide valves which still are in use are the Richardson balance shown in Fig. 7, and the American balance shown in Fig. 8. In the first case, the valve is built up so that a certain percentage of the area of the top can be enclosed by balance strips. These balance strips are of cast iron located in slots or grooves in the shape of a rectangle. They are fitted in the grooves, with springs under them, to form a

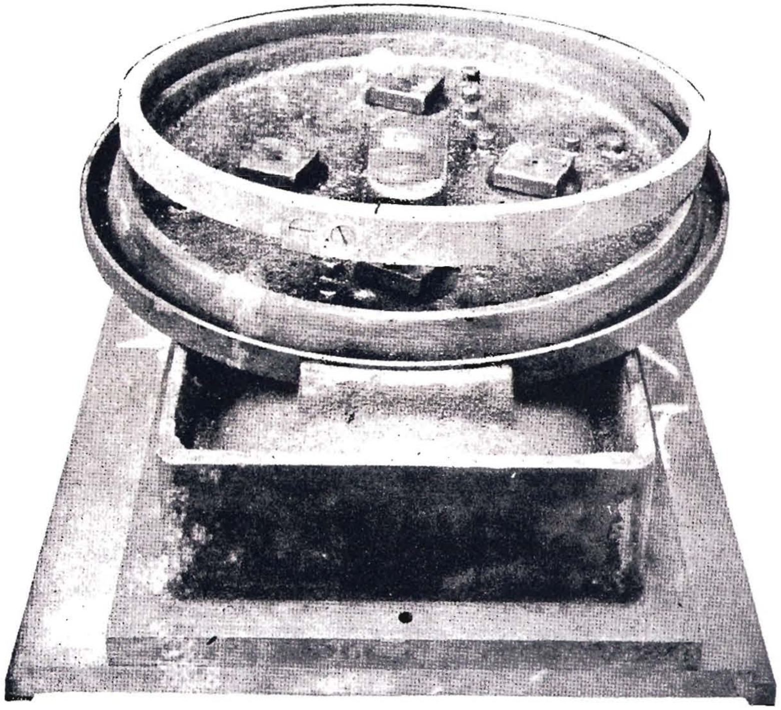

Fig. 8

steamtight joint against a balance plate above them, as shown in Fig. 5. Thus, live steam pressure is prevented from acting on a certain amount of the area of the top of the valve. A hole drilled through the top of the valve allows any steam that leaks past the strips to escape to the exhaust cavity.

18. The American balance is built on the same principle except that it makes use of a removable disc to which a cone-shaped ring is fitted. Sometimes two discs are used. There have been many variations of slide-valve design and balancing methods.

PISTON VALVES

19. The piston valve, which has superseded the slide valve, may be considered for practical purposes a perfectly balanced valve. This feature naturally reduces the difficulty of its lubrication to a minimum. The valve is not of excessive weight, even for the largest power.

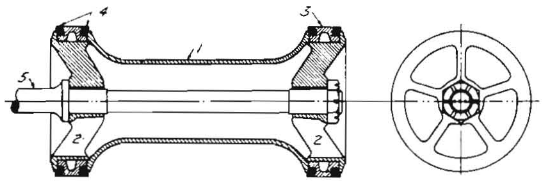

Fig. 9

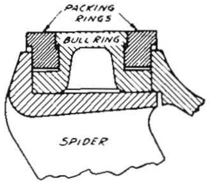

Fig. 10

1 Valve body, or spool
2 Va.ve spider
3 Clamp ring, or bull ring
4 Packing rings
5 Valve stem

20. It can be seen by reference to Fig. 6 that live steam acts equally in all directions on the middle portion of the valve, so that a perfect balance is maintained at all times. Since the valve is hollow from end to end, there is equal pressure on the two outer ends of the valve at all times. Where the valve is of the inside-admission type, the valve-stem packing and the valve-chamber heads are subject to exhaust pressure only, thus reducing the likelihood of steam leaks. The piston valve may be made as long as desired, thus permitting short steam passages between the valve chamber and the cylinder. The cylindrical form of the valve chamber permits the design of steam ports of large area.

21. Figure 9 is a sectional view, showing the construction of the piston valve and the names of its principal parts. Fig. 10 shows an enlarged cross section of the left end of the valve shown in Fig. 9.

22. The nut on the end of the valve stem serves as a clamp to draw the two spiders together against the bull rings and the valve body. The bull rings rest against the ends of the valve body. The recesses on each side of the bull ring form grooves into which the packing rings fit. The two packing rings are shown in place in Fig. 10. A slight offset in the bull ring fits a similar offset in the packing ring. This offset on the ring permits the face of the packing ring to extend slightly beyond the face of the bull ring, so as to insure a snug fit in the valve bushing, but the ring cannot escape from its groove after the valve is clamped together. If a ring becomes broken in service, the offset acts as a retainer to prevent pieces of the ring from dropping into the steam ports and causing serious damage. Fig. 11 shows a valve spider, bull ring, and packing rings disassembled.

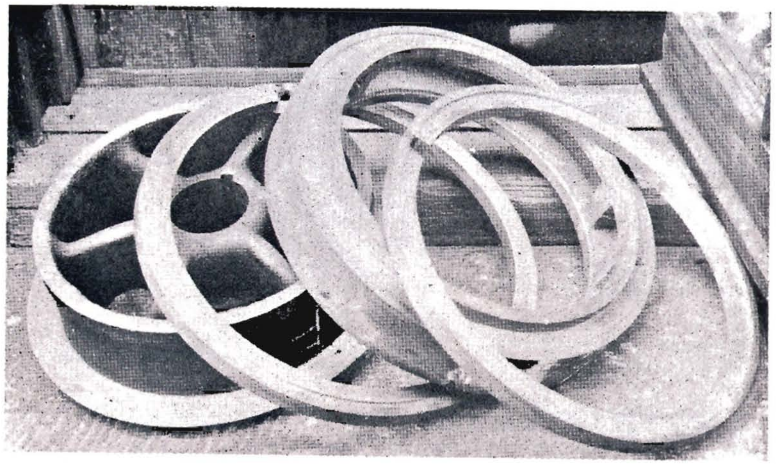

Fig. 11

23. Packing rings usually are made of a special grade of cast iron. They are turned to their true cross section in a lathe. In order to insure a good and permanent fit in the bushing, the rings are turned to a diameter slightly larger than the bushing. A short section then is cut from the ring so that the cut ends gap about $\frac{1}{32}$ inch when placed in the bushing. The natural spring of the cast iron rings maintains their snug fit in the bushing throughout the normal life of the ring.

24. The under side of each ring is notched out, at the gap, to fit loosely over a dowel pin in the bull ring. This keeps the rings from turning on the valve. It is customary to locate the dowel pins at the lower side of the valve, because the bull rings tend to ride the bottom

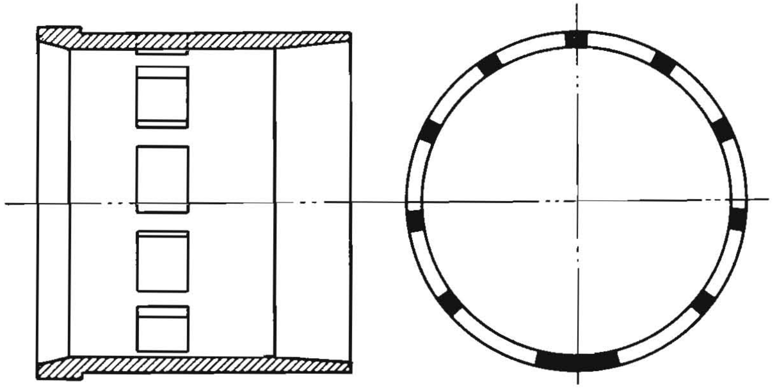

Fig. 12

of the bushing and help to form a tight joint with the bushing at that point. An extra-wide bridge across the ports at the bottom of the bushing presents a continuous surface on which the ends of the rings slide back and forth.

25. Two sectional views of a valve-chamber bushing are shown in Fig. 12. The left-hand view shows the shape of the steam ports and bridges. The right-hand view shows the proportionate sizes of bridges, with the extra-wide bridge at the bottom. A bushing such as that in Fig. 12 is pressed into each end of the valve chamber. Extreme care is taken to see that the steam ports in the two bushings are spaced the correct distance apart and that each port is the right distance from the center of the valve chamber. Bushings are bored slightly tapered on the inner circumference at each end so that the expansion of the valve rings will not interfere when the valve is being applied to, or removed from, the valve chamber.

26. In some cases, bushings are designed to extend clear to the ends of the valve chamber. Such bushings require additional ports to allow exhaust steam to escape near the ends of the chamber.

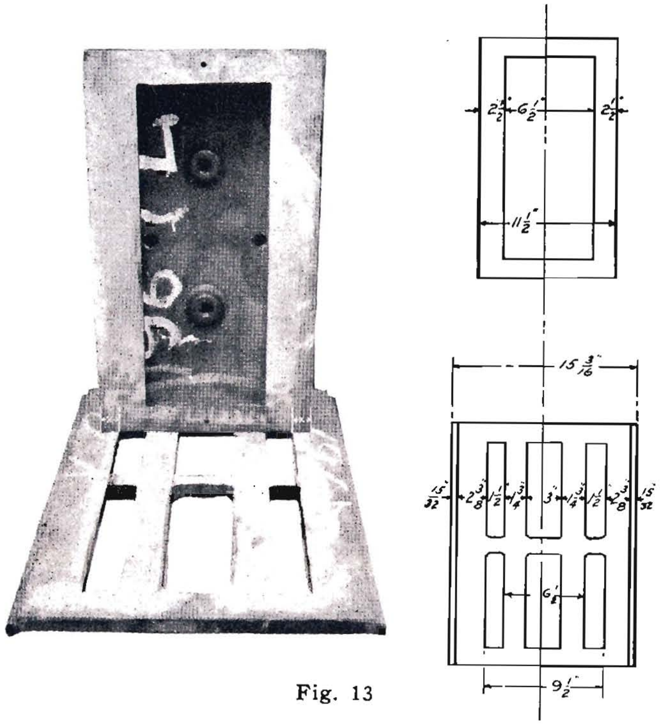

Fig. 13

THE LAP AND CLEARANCE OF VALVES

27. Figure 13 shows a slide valve standing on edge centrally over its seat. It will be noted that the length of the valve is greater than the distance from outside edge to outside edge of the steam ports by the sum of the distances marked X at each edge of the valve. The amount X by which *each* edge of the valve overlaps the outside edge of *its* steam port when the valve is in mid-position is called the steam lap. It is measured in inches and fractions of an inch. Its purpose, as well as the purpose of the clearance of the valve, is explained in the following paragraphs. The explanation applies both to slide valves and to piston valves, as will be apparent.

28. In Fig. 6 the piston valve is shown in its mid-position relative to the steam ports. This is an inside-admission valve. The inner sides of the inner valve rings form the steam (admission) edges of this valve; and the outer sides of the outer rings form the exhaust edges of this valve. The letter *X* indicates the steam lap of this valve just as the letter *X* of Fig. 13 indicates the steam lap of the slide valve illustrated.

29. Figures 14, 15, 16, and 17 are used to explain lap and clearance for both slide valves and piston valves. It must be remembered that the slide valve has outside admission; the piston valve shown has inside admission. In each case, each valve is in mid-position on its seat. Reference to Figs. 5 and 6 will aid the student in understanding just what is represented by these explanatory illustrations.

30. In Fig. 14, the steam (admission) edges of the valve are exactly in line with the steam (admission) edges of the steam ports, and the exhaust edges of the valve are exactly in line with the exhaust edges of the steam ports. If a valve of this construction were moved from its central position, steam would be admitted instantly to one side of the piston in the cylinder and exhausted from the other side. If the valve were moved in the opposite direction, the exhaust edge of the valve would uncover the exhaust edge of the steam port the instant the steam edge of the valve covered the steam edge of the port. With such a valve, steam could not be used expansively.

31. In order that steam may be used expansively, the steam or admission edges of the valve are extended. This addition to the valve is called STEAM LAP, and is illustrated at *A* in Fig. 15. Steam lap is defined as the

amount that the steam (admission) edge of the valve covers the steam (admission) edge of the steam port *with the valve in the center of its seat.* It is measured in inches

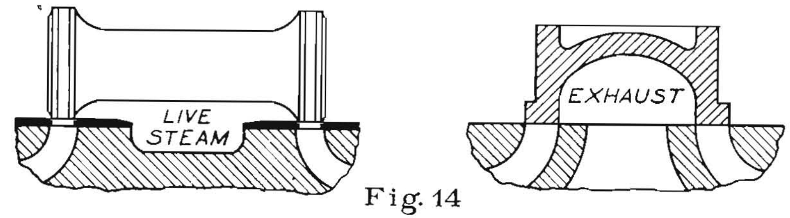

Fig. 14

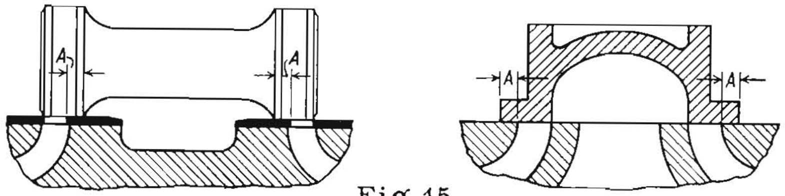

Fig. 15

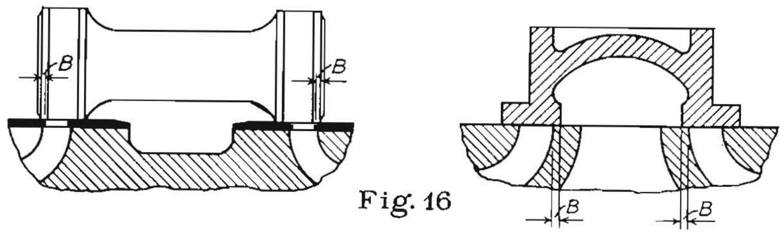

Fig. 16

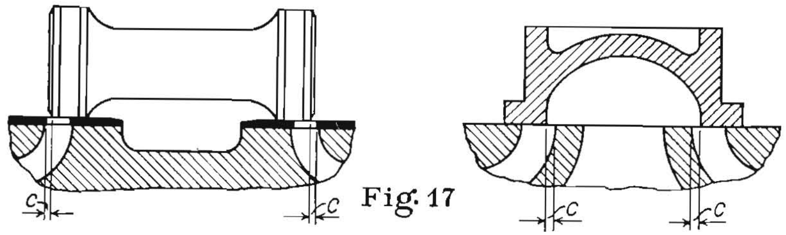

Fig. 17

and fractions of an inch. It must be equal on both ends of the valve, because it is measured with the valve in its central position.

32. Further expansion of the steam can be obtained by adding to the exhaust edges of the valve. This is shown at *B*, Fig. 16; such addition is known as EXHAUST LAP. It can be defined as the amount that the exhaust edge of the valve covers the exhaust edge of the steam port, with the valve in its central position. It is measured the same as steam lap and must of necessity be equal on both ends of the valve.

33. Conditions might arise, however, which would make it desirable to provide for a shorter rather than a longer expansion of the steam without changing the amount of steam lap. In such a case, instead of adding to the exhaust edge of the valve, the exhaust edge could be cut away so that, instead of its covering the steam port when the valve is in mid-position, it would fail to cover it by a certain amount, as shown at *C*, Fig. 17. A valve so constructed is said to have CLEARANCE, sometimes improperly referred to as "negative exhaust lap." Clearance can be defined as the amount by which the exhaust edge of the valve *fails* to cover the exhaust edge of the steam port with the valve in its central position. It is measured the same as lap, and must of necessity be equal on both ends of the valve. A valve having neither exhaust lap nor clearance is said to stand LINE AND LINE (see Fig. 15); or, it may be said that the exhaust lap is zero.

34. It can be seen from Fig. 13 that the distance between the outside edges of the steam ports is 9½ inches and the length of the valve 11½ inches, so that the *total* amount of lap is 2 inches, distributed equally on the two ends of the valve. The steam lap on either end in this case then would be one half of 2 inches, or 1 inch. Similarly, the distance between the inside edges of the steam ports is 6½ inches, and the distance between the inside edges of the valve also is 6½ inches, so that the valve stands line and line and the exhaust lap is zero. Steam lap and exhaust lap or clearance can be determined by measurement of any valve seat and its valve in a similar manner.

STEAM DISTRIBUTION

35. Frequent reference has been made to using steam expansively. To understand this, it must be explained that steam under pressure has great expansive power and that this expansive power is made use of in the locomotive in order to attain the greatest practical economy in the use of the steam. To explain this further,

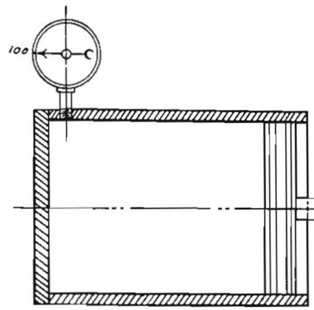

Fig. 18

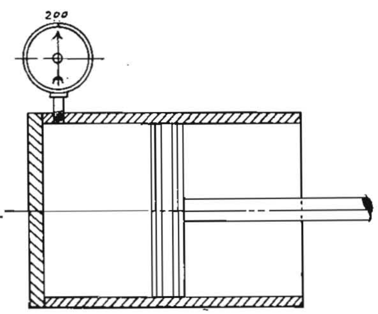

Fig. 19

it may be said that when water is boiled in a teakettle, 1 teacupful of water forms about 1,800 teacupfuls of steam. If this 1,800 teacupfuls of steam is compressed into a smaller space, the increase of pressure would be about in proportion to the reduction of space that the steam occupies. In other words, the volume is inversely proportional to the pressure. For example, take the cylinder shown in Fig. 18 and imagine it filled with steam at 100 pounds gage pressure with the piston in the position shown. Now if this piston is forced over one half of the length of the cylinder, to the position shown in Fig. 19, the volume of the steam will have been reduced one half, and as a consequence, the gage will show a change of pressure from 100 to about 200 pounds. However, it would be found in a case of this kind that it took a great deal of power to move the piston over. In other words, work must be done to compress this steam into a smaller space.

36. If the valve admits steam at 200 pounds boiler pressure to the locomotive cylinder during one half of the stroke of the piston and the admission of steam then is shut off, the steam will expand during the other half of the stroke. Work will be performed during this expansion, and the pressure will be reduced from the initial 200 pounds to about 100 pounds at the completion of the stroke. In other words, doubling the volume cuts the pressure in half. WORKING STEAM EXPANSIVELY means that boiler steam is admitted to the cylinder of a steam engine during only a part of the piston stroke. Expansion of this steam moves the piston the remaining part of the stroke.

37. The problem of valve and valve-gear design is to proportion the valve, steam ports, valve motion, etc., so as to obtain the most economical distribution of steam to take advantage of its expansive power. Speaking generally, a locomotive will show the most economical use of steam when it is designed so that it can pull its train at the required speed with the valves working at one-third cutoff, that is, so that the steam expands during two thirds of each stroke.

38. Before going further into the subject of expansion, it will be well to study the different events that take place in the cylinder during a back-and-forth stroke of the piston. This is explained by means of diagrams of a slide-valve locomotive. The explanation applies in a similar manner for a piston valve with either inside or outside admission. In Fig. 20, the piston of the locomotive is starting on its first stroke. The valve motion causes the valve to uncover the steam port and admit steam at boiler pressure to the piston, as shown by the arrows. As the piston moves forward, the valve opens wider until it gives full (or partial) port opening; then, the valve motion reverses the valve movement and the valve returns to close the port again while the piston still is on its first stroke, as shown in Fig. 21.

39. If steam is admitted during two thirds of the stroke, the valve motion will return the valve and close off

the steam port, or to use a common expression, *cut off* the steam when the piston has covered two thirds of its travel (see Fig. 21). The point in the stroke or travel of the piston at which the valve cuts off the steam is referred to as the POINT OF CUTOFF. Usually, it is stated as a per cent of the total stroke of the piston. For instance, if a piston has a 30-inch stroke and steam is cut off after the piston has moved 20 inches, the valve would be operating at $\frac{2}{3}$ cutoff, or $66\frac{2}{3}$ per cent cutoff.

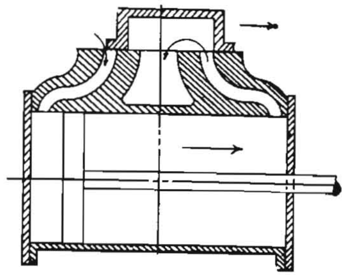

Fig. 20

40. The continued motion of the valve after the point of cutoff leaves all of this steam trapped in the cylinder until the valve has moved the amount of the steam lap, plus the exhaust lap (or minus the clearance). During this time, the steam exerts its expansive force and moves the piston through the remainder of its first stroke.

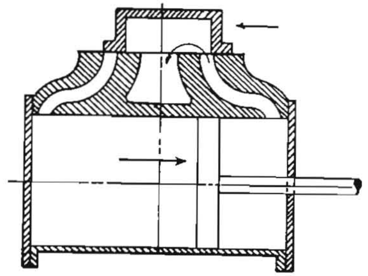

Fig. 21

41. The valve motion is designed so that just before the end of the first stroke the exhaust edge of the valve will uncover the steam port and permit the steam in the cylinder to escape to the exhaust (see Fig. 22). The point in the stroke of the piston at which the valve opens the steam port to the exhaust is known as the POINT OF RELEASE. It is expressed also as a percentage of the stroke. For instance, in the 30-inch cylinder already considered, if the point of re-

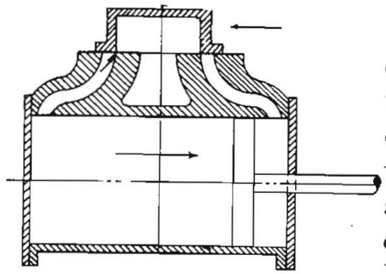

Fig. 22

lease occurs when the piston has moved 25 inches, it would be said that release occurs at ⅚ stroke, or 83⅓ per cent of the stroke.

42. The momentum of the locomotive carries the piston through the remainder of the first stroke and starts it on the return stroke. During the first part of the return stroke, while steam is being admitted to the opposite side of the piston, the valve moves so that the exhaust port is opened wide. This provides a direct connection from the cylinder to the exhaust. During the latter part of the stroke, the motion of the valve is reversed and it returns to close the exhaust port. The only pressure in the cylinder during this time is the back pressure, which is the small amount of pressure due to the friction of the steam as it forces its way through the passages and out of the exhaust nozzle.

43. Toward the end of the return stroke, the valve motion returns the valve and shuts off this exhaust opening. This operation locates what is known as the POINT OF COMPRESSION (see Fig. 23). When the valve shuts off the exhaust opening in this manner, there is no outlet for the steam remaining in the cylinder. Continued movement of the piston on the return stroke compresses this steam. The compression pressure forms a cushion for the moving parts, which must be stopped at the end of the stroke and then started on a new cycle. This compression pressure may be only a small percentage of the boiler pressure, or may run up to boiler pressure or above, depending on the design of the locomotive, speed, valve setting, etc.

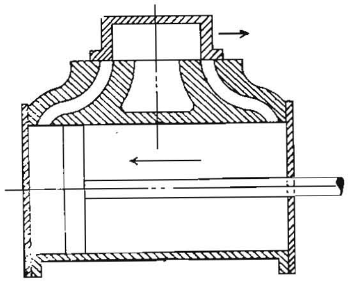

Fig. 23

44. Just before the end of the return stroke, at the end of the return stroke, or else a moment after the piston

has started back on its second cycle, the valve is opened again and boiler pressure is admitted behind the piston for the new cycle. This brings the valve to the POINT OF ADMISSION once more, as was shown in Fig. 20, and thus completes the cycle of events in the cylinder.

45. The period between the point of admission and the point of cutoff, during which steam is being admitted to the cylinder, is known as the ADMISSION PERIOD. The period between the point of cutoff and the point of release, during which the port is closed by the valve, is the EXPANSION PERIOD. The period between the point of release and the point of compression, during which the port is open to the exhaust, is the RELEASE AND BACK PRESSURE PERIOD. The period between the point of compression and the point of admission, during which the valve again has closed the port, is the COMPRESSION PERIOD.

Indicator Diagrams

46. A very interesting little instrument known as a STEAM ENGINE INDICATOR is used quite universally to study the distribution of steam in the cylinders of locomotives. The INDICATOR CARDS drawn by this instrument furnish a picture of what takes place in the cylinder. The different events of the stroke, that have been described, can be analyzed by means of these indicator cards.

47. A steam engine indicator, Fig. 24, has two main parts—a steam cylinder and a drum to hold the card. The indicator is connected by piping so that steam from either end of the locomotive cylinder will act directly on the bottom of a piston that is fitted in the indicator cylinder. The rod of the piston is attached to a special spring that regulates the up-and-down motion of the piston in accordance with the pressure below the piston. A system of levers connected with the piston rod moves a pencil point up and down in a vertical line in accordance with each change of pressure in the cylinder. The amount of pressure corresponding to the vertical movement of the pencil can be measured by means of a scale. A drum, around which is wound a piece of paper, is so connected with the crosshead of the locomotive being "indicated" that the drum turns back and forth in proportion to the stroke of the piston. When the pencil point of the indicator is pressed against the paper that is wound on the drum, the vertical movement of the pencil in combination

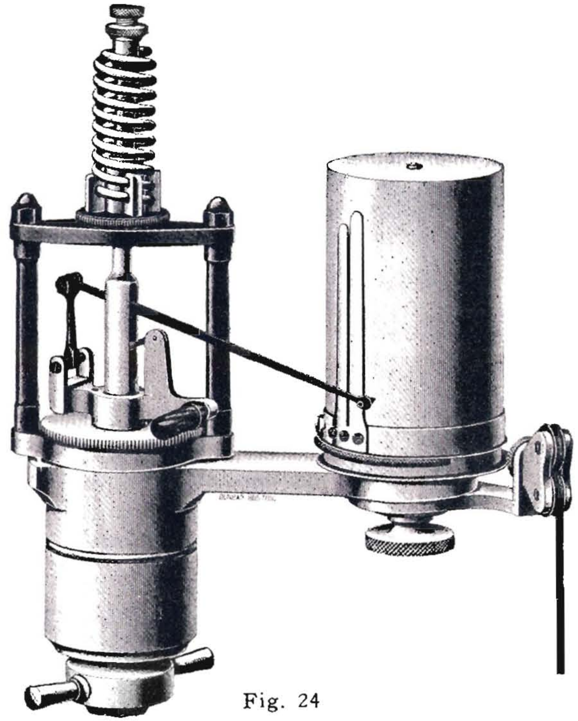

Fig. 24

with the back-and-forth motion of the drum produces an indicator diagram. This diagram shows the pressure of the steam in the cylinder at every point of the stroke.

48. Figure 25 illustrates an indicator card. Vertical distances on the card indicate pressure (shown by a scale at the left); horizontal distances indicate a proportional part of the stroke of the locomotive piston. At the beginning of the stroke X, the line indicates that the steam pressure is 200 pounds, or boiler pressure. As the piston moves on its stroke, the pencil traces an almost

horizontal line XA, indicating that boiler pressure is being admitted to the cylinder. As the point of cutoff is approached, the valve partially closes and causes a fall of this steam line to the point of cutoff A. From that point, the curve AB represents the expansion of the steam to the point of release B. When release occurs, there is a sudden drop of the pressure down almost to the base line EF of the diagram. On the return stroke the line YC is close to, and about parallel with, this base line. This shows the amount of back pressure during the return stroke. The pressure starts up again as the valve begins to close the exhaust port. When the exhaust port is closed, the point of compression C is reached on the

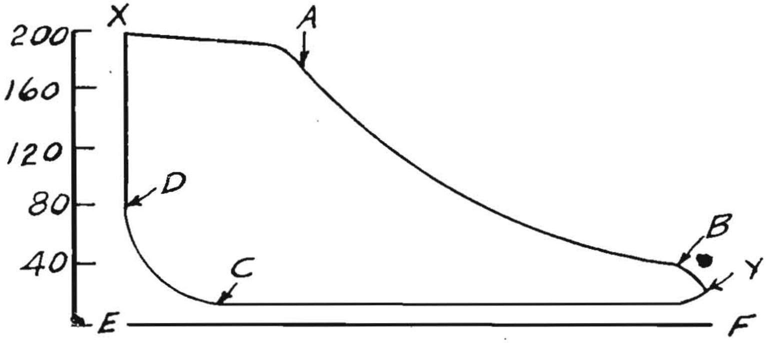

Fig. 25

diagram. The pressure increases rapidly as the steam that is trapped in the cylinder is further compressed, as shown by the compression line CD. The valve opens again at the point of admission D, and the line DX shoots up to boiler pressure once more.

49. The base line EF of the diagram mentioned is drawn by pressing the pencil point against the revolving drum before any pressure is turned into the indicator. This base line represents the line of atmospheric pressure, and all pressures on the diagram are measured with a proper scale from this atmospheric line.

50. The length of the card is obtained by drawing perpendiculars at the extremes of the diagram, as shown in Fig. 26. This length on the card represents the stroke of the piston. The direct ratio between the length of the card and the stroke of the piston makes it possible to determine the distance that any point on the diagram represents in the stroke of the piston. Fig. 26 shows a card such as might be obtained with the valve movements

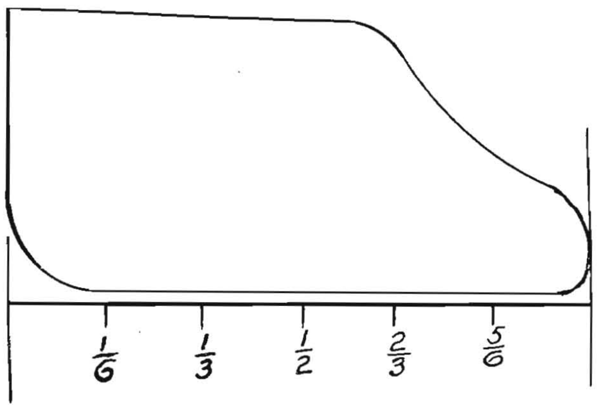

Fig. 26

described in connection with Figs. 20, 21, 22, and 23, that is, at two-thirds cutoff.

51. Names are given to the various points and lines mentioned in connection with the indicator diagram shown in Fig. 25, as follows: *D* is the point of admission; *A*, the point of cutoff; *B*, the point of release; and *C*, the point of compression. The admission line is represented by the line *DXA*; the expansion line, by the line *AB*; the release and back-pressure line, by the line *BYC*; and the compression line, by the line CD. The line *EF* is called the atmospheric line, and it is from this line that pressure measurements are made. The points *X* and *Y* represent the extremes of the diagram, and perpendiculars from the atmospheric line through these points give the length of the card. If the stroke of the piston is 30 inches and the length of the card 3 inches, horizontal distances on the card would be exactly one tenth of the corresponding distance that the locomotive piston had moved. If the point of cutoff *A* were 1 inch from the end of the card, it would

show that the cutoff occurred in the locomotive cylinder when the piston had traveled 10 inches, or one third of its stroke.

52. The indicator diagram makes possible a very complete study of the action of steam in the cylinder of a locomotive. The information gained from such study permits engineers to improve the design of the locomotive so as to obtain a greater economy in the use of steam. Indicator diagrams are used also to analyze and standardize the valve setting of locomotives.

LEAD

53. It was stated in paragraph 44 that the admission of the steam occurred shortly before the end of the return stroke, at the end of the return stroke, or else a moment after the beginning of a new cycle. This requires some explanation. The point at which the admission actually does occur depends on the setting of the valve. If, with the locomotive on the dead center, that is, with the piston at the extreme end of its stroke, the valve setting is such that the valve is just ready to open to admit steam, it is said that the valve is set LINE AND LINE.

54. If, with the locomotive on dead center, the valve already is open a certain amount, the opening is spoken of as the LEAD of the valve. Lead is the amount in fractions of an inch that the steam edge of the valve has uncovered the steam edge of the steam port *with the locomotive on the dead center*. Fig. 5 shows the piston at the extreme end of its travel ready to start a new stroke. The amount that the valve has uncovered the steam port is the lead.

55. It may be found that, with the locomotive on the dead center, the valve will have to travel $\frac{1}{32}$, $\frac{1}{16}$, $\frac{1}{8}$, or some other part of an inch, before the steam port is uncovered. In such a case the locomotive has no lead and is said to be set BLIND by the amount that the edge of the valve *covers* the edge of the steam port. In other words, admission will not occur until the piston has traveled some distance on the new stroke.

56. With modern types of valve gear, such as the Walschaert or Baker gears, the lead is the same in all positions of the reverse lever. In other words, these gears have CONSTANT LEAD. With the Stephenson link motion the amount of lead changes at each different position of the reverse lever.

57. The reason why modern valve gears have constant lead is that the lead movement which is transmitted to the valve depends on the design of the pin locations in the combination lever. The lead motion is transmitted to the valve by the movement of the crosshead. In the Stephenson link motion the principal movement transmitted to the valve comes from the forward eccentrics through the link. However, this movement is modified somewhat by the motion of the backup eccentrics.

58. The amount of steam lap and exhaust lap, or clearance, given by designers to any valve depends on the class of locomotive and the class of service for which it is to be used. The effect of valve action on locomotive performance is so important that a special text has been written on this subject.

POPPET VALVES

59. A poppet valve is a valve which is lifted from its seat by a cam and returned to its seat by a spring. It is the type of valve used almost universally in automobile engines. Poppet valves now being introduced in locomotive design are of the double-seated type which makes them nearly balanced. Two admission valves and two exhaust valves which move horizontally are located in suitable steam and exhaust passages above each end of each cylinder. A cam box fits at the top of each cylinder between the steam passages which lead to the valve chambers. There is *one* valve-gear box which is located on the center line of the locomotive either ahead of or behind the saddle casting. Levers from the valve-gear box extend to each of the cam boxes.

60. The levers of the valve-gear box are driven by a connection from the crosshead. A power reverse gear in the cab of the locomotive operates through a suitable mechanical connection to the gear box. The arrangement is such that the timing of the valves can be changed either to reverse the direction of motion of the locomotive or to give the steam distribution desired for long or short cutoff.

61. The advantage of poppet valves as compared with piston valves is that the admission of the steam and its exhaust are controlled by separate valves which can be timed independently. As a result, it is possible to obtain a much more effective expansion of the steam. Other advantages are the fast opening and closing of the valves and a considerable decrease in the back pressure at high speeds.

62. Students whose duties require them to work on poppet valve locomotives should ask their Foreman for a copy of the instruction book issued by the manufacturers of this system of steam distribution. Students who cannot obtain a copy from their Foreman can borrow a copy for study purposes from the Bureau's library.

LUBRICATION OF VALVES

63. Any apparently smooth surface when looked at through a magnifying glass shows a rough surface full of projections and recesses. When two of these surfaces are permitted to rub together, these projections strike each other and offer resistance. The resistance offered by two surfaces when rubbed together is called FRICTION.

64. Lubrication consists in placing a layer or film of oil or other lubricant between rubbing surfaces for the purpose of *keeping them apart*. Whenever these surfaces are allowed to stand under pressure, the minute projections become interlocked. This is one of the reasons why it requires more power to start a locomotive than to keep it going.

65. Lubricants for different purposes must have properties to suit the conditions for which they are used. A lubricant must have body to withstand pressure so as not to be squeezed out from between the rubbing surfaces; fluidity that will enable it to penetrate and reach all wearing surfaces; a flash point sufficiently high to withstand the temperature to which it is subjected; and a freedom from acidity so that it will not cause pitting and corrosion of the surfaces on which it is used.

66. Lubrication of the valves and pistons of a locomotive may be accomplished by distributing oil through the steam so that a film of oil is deposited on the rubbing surfaces while they are moving. Systems of force-feed lubrication have been devised whereby oil is introduced to the valve chamber independent of steam pressure. In any case, the valves and pistons should be supplied with lubrication constantly while the locomotive is in operation. Friction and wear are increased many times if the wearing surfaces are allowed to become dry.

67. The flash point of engine oil is about 300 degrees Fahrenheit; that of ordinary valve oil about 500 degrees F. Oils can be obtained having a flash point as high as 800 degrees F. As the temperature of superheated steam used in locomotives approximates 700 to 800 degrees F., a special grade of valve oil must be used for this particular purpose. This is due to the fact that lower-grade oils decompose at high temperatures and thus lose their lubricating qualities.

68. The usual oil feed for each valve of a locomotive is about 5 drops per minute. It would be well for the student to find out how much oil is allowed per hundred miles for different classes of service on the division on which he works. A question frequently asked is: "How many miles should a locomotive run to one pint of valve oil?"

46. Generally speaking, the required conditions for various classes of service may be summed up as follows:

FOR HIGH-SPEED HEAVY PASSENGER SERVICE: The valves must be set with ample lead, must have sufficient exhaust clearance to keep the back pressure down, and there should be as great a port opening as practicable during the period of admission.

FOR HIGH-SPEED HEAVY FREIGHT SERVICE: The valves are set the same as for high-speed heavy passenger service.

FOR ORDINARY PASSENGER SERVICE: The valves usually will be set with a moderate amount of lead and will be given a small amount of exhaust clearance or else will have the exhaust edges line-and-line.

FOR SLOW FREIGHT AND SWITCHING SERVICE: A small amount of lead and as great a port opening as practicable during the period of steam admission. Valves for such locomotives usually will be given a small amount of exhaust lap or will be line-and-line on exhaust.

It should be understood that all references to lead and port opening made above refer to such conditions with the motion in full gear, that is, with the reverse lever in the corner.

47. Table No. 1 shows the recommended practice of the American Locomotive Company for valve setting on locomotives of various sizes and for various classes of service when equipped with the Walschaert gear. In a general way, the information contained in Table No. 1 may be applied to the Baker, Young, and Southern gears, as well as to the Walschaert gear, because all of these gears have a constant lead; that is, the lead is the same for all positions of the reverse lever.

48. The correct amount of lead depends on the class of service for which the locomotive is designed. Table

VALVE SETTING—WALSCHAERT GEAR

CLASS OF SERVICE	CYLINDER DIAMETER	VALVE						
		Diameter (Piston Valve)	Travel Full Gear	Steam Lap	Clearance (Exhaust)	Exhaust Port Opened	Lead	Cutoff Full Gear Per Cent
Passenger and Fast Freight	16-17	9	5 1/2	15/16		1 7/16	1/4	84
	18	10	5 1/2	15/16		1 7/16	1/4	84
	19	10	6	1 1/16		1 9/16	1/4	83.5
	20	10	6 1/2	1 1/8		1 5/8	1/4	84
	21	11	6 1/2	1 1/8		1 5/8	1/4	84
	22	11	7	1 1/4		1 3/4	1/4	83.5
	23	12	7	1 1/4		1 3/4	1/4	83.5
	24	12	7 1/2	1 5/16	1/4	1 7/8	5/16	84
	25	12	7 1/2	1 3/8		1 15/16	5/16	83
	26	13	7 1/2	1 5/16		1 7/8	5/16	84
	27	13	7 1/2	1 3/8		1 15/16	5/16	83
	28	14	7 1/2	1 3/8		1 15/16	5/16	83
	29	14	7 1/2	1 3/8		1 15/16	5/16	83
	30	14	7 1/2	1 3/8		1 15/16	5/16	83
Freight and Light Locomotives	8	6	3 1/2	19/32		21/32	1/16	86.5
	9	6	3 1/2	19/32		21/32	1/16	86.5
	10	6	3 1/2	19/32		21/32	1/16	86.5
	11	7	4	5/8		11/16	1/16	87
	12	7	4	5/8		11/16	1/16	87
	13	8	4 1/2	3/4		13/16	1/16	87
	14	8	4 1/2	3/4		13/16	1/16	87
	15	8	4 1/2	3/4		13/16	1/16	87
	16	9	5	13/16		7/8	1/16	87.5
	17	9	5 1/2	7/8	NONE	1	1/8	87.5
	18	10	5 1/2	7/8		1	1/8	87.5
	19	10	6	1		1 1/8	1/8	86.5
	20	10	6 1/2	1 1/16		1 3/16	1/8	87
	21	11	6 1/2	1 1/16		1 3/16	1/8	87
	22	11	7	1 3/16		1 5/16	1/8	86.5
	23	12	7	1 3/16		1 5/16	1/8	86.5
	24	12	7 1/2	1 1/4		1 7/16	3/16	86
	25	12	7 1/2	1 1/4		1 7/16	3/16	86
	26	13	7 1/2	1 1/4		1 7/16	3/16	86
	27	13	7 1/2	1 1/4		1 7/16	3/16	86
	28	14	7 1/2	1 1/4		1 7/16	3/16	86
	29	14	7 1/2	1 1/4		1 7/16	3/16	86
	30	14	7 1/2	1 1/4		1 7/16	3/16	86
Switching	16-17	9	5 1/2	7/8		15/16	1/16	88
	18	10	5 1/2	7/8		15/16	1/16	88
	19	10	6	1		1 1/16	1/16	87
	20	10	6 1/2	1 1/16		1 1/8	1/16	87.5
	21	11	6 1/2	1 1/16		1 1/8	1/16	87.5
	22	11	7	1 3/16	NONE	1 1/4	1/16	87
	23	12	7	1 3/16		1 1/4	1/16	87
	24	12	7 1/2	1 1/4		1 3/8	1/8	86.5
	25	12	7 1/2	1 1/4		1 3/8	1/8	86.5
	26	13	7 1/2	1 1/4		1 3/8	1/8	86.5
	27	13	7 1/2	1 1/4		1 3/8	1/8	86.5
	28	14	7 1/2	1 1/4		1 3/8	1/8	86.5