The Walschaert Locomotive Valve Gear

A PRACTICAL TREATISE ON THE LOCOMOTIVE VALVE
ACTUATING MECHANISM ORIGINALLY
INVENTED BY EGIDE WALSCHAERTS

With the History of Its Development by American and European Engine Designers, and Its Evolution into the Mechanically Correct Locomotive Valve Gear of the Present Day.

IN FOUR GENERAL DIVISIONS, EMBRACING:

Analysis of the Motion.—Designing and Erecting the Gear.—Proof of the Superiority of the WALSCHAERT Gear in Locomotive Service. — Catechal Questions and Answers for Instruction and Examination.

Intended for the Engineer or Mechanic Who Wishes to Extend His Knowledge of Locomotive Valve Gears to the Type That is Rapidly Superseding the STEPHENSON Eccentric Motion of the Past Century.

BY

W. W. WOOD

Air Brake Inspector

Fully Illustrated with Ideal Sketches and Instruction Models, Line Engravings of Side Elevations and Plans of the Gear in Its Different Phases; Engravings of Locomotives of All Branches of Service Using the WALSCHAERT Gear.

Diagrams to Illustrate the General Text and Formulas; Large Folding Plates and Diagrams of Different Types of the WALSCHAERT Motion with Movable, Card-board Working Models of the Valves.

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CONTENTS

FIRST DIVISION

SECOND DIVISION

THIRD DIVISION

FOURTH DIVISION

PREFACE

In the capacity of an air-brake instructor, it has been the pleasure of the author of this book to endeavor to impart information on other mechanical and general railway subjects, as well as those relating to his special profession, to the railroad men with whom business has brought him in contact, and since the tendency of locomotive builders has been toward the introduction of the style of valve gear that was invented by Egide Walschaert many years ago, and never taken up in this country through sheer conservatism until the force of combined circumstances compelled its adoption, the many requests for information concerning that special device have revealed the fact that while there are legion of books devoted almost wholly to the so-called Stephenson link motion, there was not one book in existence given wholly to the subject of the Walschaert valve gear, and nothing in print that explained that style of motion to the satisfaction of the locomotive engineer, the shop man, and the master mechanic, alike; in fact, no treatise could be found that extended further than an elementary description of the gear, and this book is the result of a determination to supply the deficiency.

The American Locomotive Company, and the Baldwin Locomotive Works, have issued from time to time pamphlets illustrating and giving the general dimensions of their recently constructed engines, and they have very kindly permitted the use of many of those plates for the purpose of illustrating the text of this work.

In that portion relating to the laying-out of the Walschaert gear for any particular engine, from the designer's or the shop-man's point of view, I have quoted and borrowed several illustrations from the very able paper read at the 1906 convention of the American Railway Master Mechanics' Association, by Mr. C. J. Mellin, Designing Engineer of the American Locomotive Company. This paper was written on the subject of Special Valve Gears other than the Stephenson link motion, and contained in a condensed form an exposition of the Walschaert principle of valve actuation modified by the requirements of present-day railway practice and the improvements suggested by progressive American locomotive builders. The Baldwin Locomotive Works were of great assistance to the author in furnishing twin diagrams of the Walschaert gear in connection with valves of outside admission and inside admission that would undoubtedly be the chief and most interesting features of any treatise on this type of valve motion that could be written, and are reproduced directly from the models used in designing the valve gear at the greatest locomotive works in the world.

It would be natural to presume that the reader of this book, with interest enough in the Walschaert gear to prompt him to make an effort to secure information in regard to that style of valve motion, would already be possessed of at least a fair working knowledge of the principles of the common *valve* itself; therefore, the valve is herein treated superficially, except in its actions that may be peculiarly induced by the motion of the Walschaert gear.

THE AUTHOR.

NOVEMBER, 1906.

FIRST DIVISION

ANALYSIS OF THE WALSCHAERT VALVE GEAR

THE WALSCHAERT VALVE GEAR

FIRST DIVISION

ANALYSIS OF THE WALSCHAERT VALVE GEAR

FROM the time of the building of the first locomotive engine, the methods employed to actuate the valve that is required to supply steam from the boiler to the cylinder, and discharge it therefrom after it has performed its work, were experimental and crude, until along about the year 1840 the double-eccentric hook-motion had naturally evolved into the shifting link action, under the name it has ever since borne—the Stephenson link motion; and in spite of our general lack of conservatism, that gear is, to-day, the vital part of practically all American locomotives, although our engines have increased in weight during recent years to such an extent that the necessary enlargement of the parts of the valve motion has given them a *tonnage* to be started and stopped twice in every revolution of the driving wheels that should have prohibited the use of such heavy reciprocating parts before now.

For this and other reasons, our locomotive builders have been casting about for some time in search of a valve gear more suited to modern conditions, with the result that many railroads have recently received new engines equipped with what is known as the Walschaert valve gear, a motion that was originated almost as long ago as the Stephenson link, and that has been in continuous and highly satisfactory use on European railways ever since; given desultory trials in America at intervals in the latter part of the last century by those prejudiced toward it, and dropped from sight, it has risen into our view again through a sheer necessity, and there is a general desire, now, to get acquainted with the principle of its operation.

About the year 1844—the transition period in the development of valve motions from the undecided to the accepted principles—Mr. Egide Walschaerts (the final s in his name has been dropped in its application to that type of valve gear), who was acting at that time as Master Mechanic of the Belgian State Railways, seems to have been dissatisfied with the results obtained from the use of two eccentrics in governing the motion of one main valve, and most likely foreseeing the possibilities in the line of economy by using the expansive power of the steam in the cylinders—something that had always been impossible of attainment with the hook motion—he invented the form of valve gear that bears his name, and to-day it is uncommon to see a picture of a locomotive belonging to any railway of any country in Europe, that is not equipped with the Walschaert gear,—monuments of power, they are, proclaiming the genius of the inventor of that most vital part of the locomotive. Europeans have made the most of this device and have brought out its best points, and it is worth while to note that in practically every case their engines use the D-slide valve—or, at least, outside admission valves—in connection with the Walschaert gear: *There's a reason.*

Born in the little village of Mechlin, near Brussels, in 1820, Walschaert was but fifteen years old when the State Railway lines were extended to Malines, where the main shops were located; but railway mechanics appealed strongly to the young man, and it is known that he was employed in the State Railway shops in 1842, and that two years later, as locomotive foreman, he had gained an enviable reputation as a successful railway mechanical engineer. It was not long until he was appointed chief superintendent of the shops, and having gained this advancement at a bound, being still a young man and a master at his craft, it is a fact that has never been explained that Egide Walschaert remained at just this level in his profession for the rest of his life.

Neither did he patent his own device. It seems that the State Railways would not permit a foreman—as he was in 1844—to make personal profit out of his own invention; so, his friend, M. Fisher, an engineer of the same company, made application in Walschaert's name, on October of the above year, for a patent relating to an improved valve gear, of which our present-day Walschaert motion is a close duplicate. The patent was allowed, and M. Fisher never claimed any credit for himself. It was in 1848 that Walschaert applied the gear to one of his engines and the results were all that he had anticipated. His device attracted attention throughout the Continent, and in due time came into general use on the principal railways of Europe. His engine equipped with the trial valve gear was the first one on the State railways to have a variable cut-off, for all of their other engines had the old hook motion, and as Egide Walschaert had never seen—possibly had never heard of—a shifting link, the problem that he worked out was greater than we, of to-day, can realize at first thought.

He was awarded a gold medal, and a diploma and honorable mention for his improved valve gear at the Exposition at Paris in 1878, and also at Antwerp in 1883. His death occurred at Saint-Gilles, near Brussels, on February 18th, 1901.

It has been said of the man whose mind conceived this theory of valve-actuating mechanism, that "Egide

Walschaert wrought better than he knew, for this gear now seems indispensable to meet conditions recently arisen because of the development of the locomotive in this country, of which the inventor could not possibly have dreamed. His work now meets a need which did not exist during the lifetime of the inventor, and for this reason he is entitled to credit for solving a problem of, to him, a future generation."

It is purposed here to explain the theory and action of Walschaert's valve gear, showing that his principle was not only an improvement on the old hook motion, but even at that early date was a better device than the modern, and commonly used, Stephenson link motion; to show it in as simple and plain a manner as possible, going through the process of its evolution from the common sawmill engine, that some of the readers hereof may have tended, and we will build up the Walschaert gear from it, ourselves, with the help of a few drawings and photographic views.

In taking up the study, or entering into an analysis, of any particular form of locomotive valve gear, it must be assumed that the principle of the plain steam engine in its most primitive form is already understood—at least, the valve itself. We will, however, start, in this building-up of our prospective Walschaert motion, with the plainest pattern of valve-actuating gear, and explain its actions so far as may be necessary before its further evolution begins. As to the valve,—it is a study itself, separate from the subject of this article, but must be gotten acquainted with before starting into the subject of the mechanism that operates it; for, if the reader does not understand somewhat of the construction and functions of the valve, this is a step ahead of him—but a step that may easily be overtaken.

There are several different designs of steam valves, but all do practically the same work: that of admitting and releasing steam to and from the cylinder in which the energy of the steam is transformed into piston power—the power that makes the wheels go 'round.

With all of the common types of valve there are but two ports to the cylinder—one to each end—and while the valve is admitting live steam to the cylinder through one of these ports, it is discharging the exhausted steam from the other port, and *vice versa.* Usually, the direct exhaust port is located midway between the two steam admission ports. An outside admission valve is one that starts the piston moving in the same direction in which the valve is travelling at the time the admission port is opened, and the admission ports are opened *outside* of either end of the valve while during the same time the other end of the cylinder is discharging its exhausted steam through the cavity in the centre of the valve. Such a valve may be either of the round, "piston" type, or the flat, plane-faced D-slide pattern. An inside admission valve does its work in exactly the reverse manner to that of the one just described, and all inside admission valves in common use are of the piston type, which in construction are really two ordinary pistons with metal packing rings, and with a tubular connection from one piston to the other; this connecting cylinder is usually made hollow in order that the pressure against the outer ends of the pistons will be held in perfect equalization and the valve be thereby more uniformly balanced; in some cases, however, the opening through this "spool,"—as the whole valve, complete, is termed,—is closed. It is claimed for the piston valve, by its friends, that it is a perfectly balanced valve—with an "open spool"; but while it is evenly balanced "fore and aft," the frictional surfaces with the steam pressure bearing against them—the packing rings—are not *balanced* at all; while a D-slide valve may have nearly all of its bearing surface balanced.

Lap is the distance by which the valve *overcovers* the steam admission port—the distance the valve must be moved from an exact central position on its seat before the port begins to open to admit steam to the cylinder.

Lead is the distance that the admission port is specially opened at the time when the piston is at an end—either end—of the cylinder, at the prime start—

or finish, both are the same—of its stroke. Lead is given in order that steam may be admitted between the piston and the cylinder head, toward the completion of the stroke, as a means of cushioning the piston and thereby tempering the sudden reversion of its motion; the same effect is, however, more economically produced by closing the exhaust from the cylinder at an earlier period in the finish of the piston's stroke, thus making use of the confined *dead* steam in its

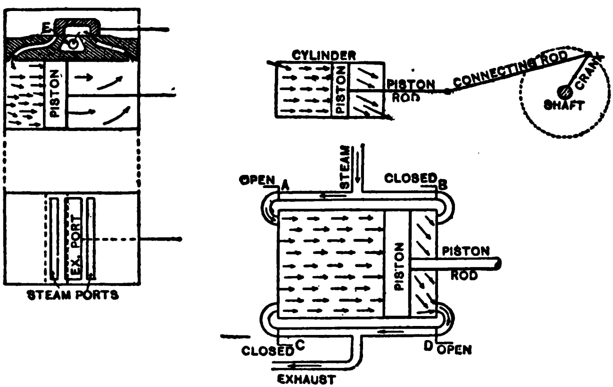

FIG. 1.—The Main Valve; showing admission and exhaust ports, the cylinder and piston.

compressible resistance as a cushion; this earlier closing is spoken of as the "cut-off" of the exhaust.

Cut-off more commonly has reference to the closing of the port for admission of live steam to the cylinder and the point in the travel of the valve at which the cut-off occurs is fixed by the position of the link in the link-block, as will be explained later—when we have taken up the action of the valve *gear;* this position of the gear is, in turn, determined by the notch of the quadrant in which the reverse lever is placed. Fig. 1 is a simple sketch illustrating the theory of the main valve of an engine.

But it doesn't make any difference what kind of a valve is used in connection with the Walschaert gear any more than it does with the Stephenson link motion, and the former may be substituted on any engine in place of the latter gear without making any change in the valve, or cylinders, or any part of the steam-distributing mechanism. But, although either inside admission or outside admission valves may be used with the Walschaert gear, as the user may prefer, a better all 'round design of this gear can be produced when an outside admission valve is specified.

There is a difference, though, in "setting-up" the Walschaert gear as between the valves of inside and outside admission; a difference only in the position of the eccentric in its relation to the main crank-pin, and the connections, as they must be made, between the radius rod and valve-stem, and the combination lever; these points, however, will be explained at the proper time.

Fig. 2 represents the idea of "direct motion" in the valve-actuating mechanism, and is the simplest form of the common steam engine, with fixed cut-offs and non-reversible, and it will be the engine in the

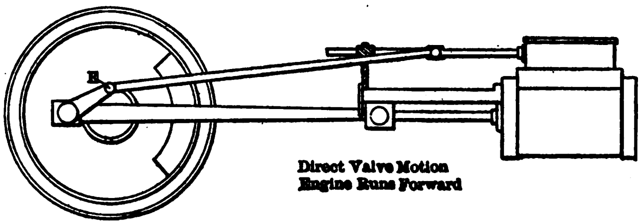

FIG. 2.—The Simplest Form of Steam Engine; Direct Valve Motion.

rough—the *rough ashlar*—that we are to develop, for, while this engine will run, and do very well under certain conditions, it is a wasteful power-producer and is limited to the last degree in the work expected of an engine: it can only turn its crank in one direction, and uses approximately as much steam each time that it turns that crank against a light load as it does when working against a heavier load. We are to supply those deficiencies noted, and bring it up to an equivalent of the engine that is on each side of a modern locomotive.

With any engine, the port opening for admission of steam to the cylinder must be one-fourth of the cycle of motion ahead of the piston. Therefore, if the connection from eccentric to valve is through a direct line of motion, as shown, without any levers interposed or "rocker-arms" to reverse the direction of movement, then, with the main-pin in the position as shown in Fig. 2, the eccentric must be located at *E*, one-fourth of the wheel's circle, or 90 degrees, *ahead* of the crank-pin—assuming the engine to be running forward—to the right.

But before going further it is best to explain how to take the expression, in hearing it said that an eccentric is "ahead" or "behind" the main crank-pin:

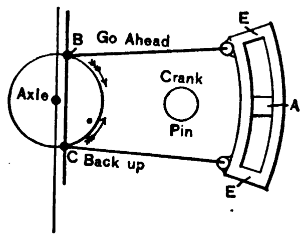

FIG. 3.—Location of Stephenson Eccentrics on Axle, in Relation to the Crank-Pin.

Fig. 3 is intended to represent the Stephenson link and eccentrics; any movement of the link-block *A*, gives a corresponding movement to the valve, so, if the link *EE* should be lowered, eccentric *B* would actuate the valve, and as this represents an "indirect motion" engine—that is, whichever way the link-block is moved it will cause the valve to travel in an opposite direction, on account of the rocker-arms—not shown—the engine would run forward. As the wheel revolved to the right eccentric *B* would follow in the same direction and one-fourth of a turn behind the main-pin, and be said to be "a quarter behind the main pin," which it always is with indirect motion and outside admission valves, while with direct motion, such as is shown in Fig. 2, the eccentric is always—with the same kind of valve—a "quarter ahead of the pin."

Referring again to Fig. 3, if the link *EE* was raised, eccentric *C* would control the motion of the link-block *A*, and, through a reverse action of the rocker-arms, the valve; the engine would run backward—to the left—and, through the changes in conditions, the "back-up" eccentric *C* would now be *following the main-pin;* so that whichever way the wheel is being turned the eccentric that actuates the valve is a "quarter" behind the pin, in common locomotive design.

On locomotives having but one eccentric, as with those of the Walschaert type, the eccentric follows, or precedes, the main-pin according to the direction in which the wheel is turning: it may do either; so, during the course of this article when the location of the eccentric is mentioned as being ahead of, or following, the main-pin, we will assume for the sake of clearer understanding that the engine is in all cases *running forward.*

It is understood that in Fig. 2 the valve is of outside admission; the eccentric *E* is just 90 degrees from the main-pin, and the valve is in an exactly central position on its seat—therefore without lead. If the steam throttle should now be opened, this engine could not move of its own volition, for two reasons: the valve being centred, all ports are covered and no steam would be admitted to the cylinder; working singly, the engine would have to be "pinched," or moved off the centre by hand, but in the case of double power, as in the locomotive, the engine on the other side would be in a position to start the wheels turning; they would turn to the right, the eccentric on the visible side would push the valve forward, and the back, or left, port would begin to open and admit steam to the cylinder against the back of the piston.

In starting the engine, if we should pinch the wheel backward, the eccentric would pull the valve backward also, and steam would be admitted to the *forward* end of the cylinder, pushing the piston back in spite of our efforts, and it would hold the main-pin on the back dead-centre point, as it was originally, as shown in Fig. 2. So that to make the engine run backward the turning of the wheel to the left must be made to push the valve forward—the direction in which the piston will have to travel: and to accomplish this, the position of the eccentric must be changed to a point on the wheel exactly its opposite in location—90 degrees *on the other side of the main-pin*—a quarter-turn ahead of the crank *with the wheel turning backward.* This would now give the proper motion to the valve for running the engine backward, and of course the direction is fixed: it can only run that way.

Besides having no power to turn the wheel when the main-pin is on the dead-centre regardless of how much pressure is in the cylinder, the other reason for the engine not starting promptly, even when assistance should be given by pinching the wheel, is that the valve has no lead; the edge of the valve and edge of the admission port are not even close to line-and-line, and the assisted rotation of the wheel would have to push the valve a distance equal to the amount of *outside*, or *steam*, *lap*, before the cylinder could begin to receive steam through the admission port. So that valve-advance, or lead, will be the first requirement in remodelling the engine of Fig. 2.

In these reference plates we are using a "return crank" eccentric, which shows the exact point at which the valve gear receives its initial motion, relative to hub centre and main-pin, much plainer than an eccentric of the Stephenson type would with its disk and strap around the axle; and in order to give this kind of an eccentric the advance necessary to secure lead, or overcome the outside lap, with outside admission valves we must *lengthen the return crank* slightly, but still keeping eccentric pin *E* the same distance from the hub centre.

Now, we find that the eccentric is more than 90 degrees from the main-pin, and that its advance that we have given has pushed the valve forward far enough so that the back—left port—is opened a very little—say, one-thirty-second ($\frac{1}{32}$) of an inch; steam is thereby admitted against the piston at the prime starting point of its stroke—while the main-pin is on the dead-centre, and the engine standing as in Fig. 2, with the exception, only, that we have given it *lead.*

Lead is not expected to help move an engine past the dead centre; it has somewhat the opposite effect—that of cramping, from the main-pin to the main shaft, or axle,—a braking effect, but this is not generally admitted. Lead not only cushions the piston at the end of the stroke, but also gets the power of the steam against the piston earlier at the beginning of the stroke, and the full opening of the admission port takes place sooner: The amount of advance of the eccentric necessary to secure the decided port opening for lead depends on the amount of outside lap of the valve, because the advance of the *valve* must be exactly the distance of lap plus lead.

In Fig. 4 we have taken the engine illustrated in Fig. 2, and interposed the double rocker-arms be-

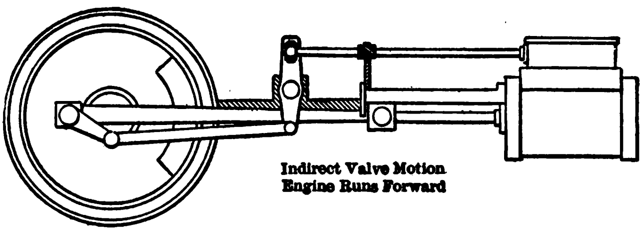

FIG. 4.—Simple Form of Steam Engine with Indirect Valve Motion.

tween the eccentric and valve, so that as the eccentric moves in one direction the valve travels in the opposite one; to make the engine still run forward the position of the eccentric is changed to a directly opposite point on the wheel—right straight across, through the centre of the hub, to the "lower quarter"; and as the main-pin moves up-forward, the backward motion of the eccentric will be reversed by the rocker-arms and the valve will, as required, still have a forward motion, admitting live steam to the back end of the cylinder and exhausting the contents of the front end,—either the *dead* steam that had been used in the preceding backward stroke, or the atmospheric contents of the cylinder if this forward movement of the piston represented the first starting of the engine. These changes taken together have not changed the direction in which the engine will run.

But notice: We had lengthened the return crank of the eccentric, placing it more than 90 degrees from the main-pin, in order to secure lead and overcome the outside lap of the valve; if we now use the same eccentric the lead will be *negative:* instead of pushing the valve ahead, as it would do in Fig. 2, it would pull the valve back, to the left, in an engine like Fig. 4, giving pre-admission to the front end of the cylinder and holding the piston back—with the crank on the back dead-centre. To obtain lead with engines having a double rocker-arm and outside admission valves, as in Fig. 4, the eccentric must be *drawn nearer* than 90 degrees to the main-pin: be *less* than a "quarter" from it. The return crank must be shortened to secure lead.

And this proves that with any kind of valve motion where but one eccentric is used, lead cannot be satisfactorily derived from advancing or receding the position of that eccentric on the main-shaft or its relation toward the main crank-pin, unless the engine is to run in but one constant direction; if there is to be any method of reversion, the lead must be gotten otherwise. The Walschaert valve gear is actuated by one eccentric only, and it is set, theoretically, at exactly right angles to the main-pin—90 degrees from it—and the lead is derived from the action of the piston, through suitable connections with the cross-head, the established lead remaining unchanged throughout the different points of cut-off in both forward and backward gear. The engine is of direct valve motion when the reverse lever is in the go-ahead position, and of indirect motion when the lever in the back-up notch, the reasons for this becoming apparent as the method for reversing the gear is understood.

Now, let's revert our attention to the crude type of engine shown in Fig. 2, again, for we are ready to begin the reconstruction of its valve gear into the Walschaert motion; we will take out the pin at the connection between the valve-stem and the eccentric rod and dropping the end of the latter slightly, connect it to the "combination lever,"—see Fig. 5.

With the combination lever in a plumb vertical position we will also connect the valve-stem to its extreme upper end, and while the combination lever remains at right angles to the valve-stem, the distance from eccentric to valve is not changed and its attachment has had no effect on the valve, which is central on its seat with both admission ports covered; but if we move the lower end of the combination lever forward it will shorten the distance from eccentric to valve, or move it backward and the distance will be lengthened, and this shortening or lengthening of the line of motion will cause the valve to be displaced,

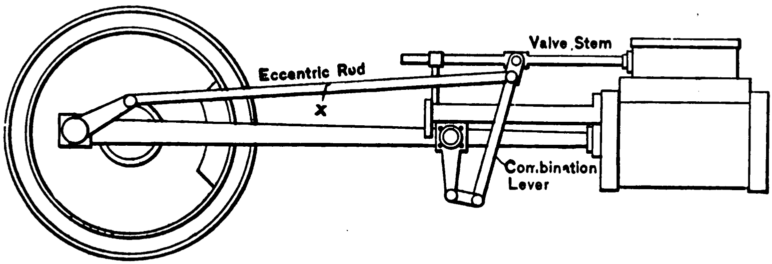

FIG. 5.—Simple Form of Steam Engine with the Walschaert method of Providing Lead.

either forward or backward, and open, somewhat, the front or back steam admission port enough for the lead.

All *true* levers have three points for the reception and delivery of power: at one point the original force is applied to the lever, while the other two are the resisting and transmitting points. We have the two latter points located as the connections of eccentric rod and valve-stem to the combination lever, while the point of application of power is at the lower end.

As it is the duty of the combination lever to modify the motion that the eccentric delivers to the valve, we must now connect the lower end of this lever to a source of power in such a manner that its "interference" with the valve will be in the proper direction.

We must now disconnect the main rod from the main-pin and move the cross-head forward until the piston is known to be in the exact centre of the cylinder, and then connect the lower end of the combination lever (still in a plumb perpendicular position) with the cross-head by means of a short link-bar; now draw the cross-head to the back end of the guides again, and re-connect the main rod to the main-pin; we have now developed the engine far enough to be represented by the sketch in Fig. 5; the angle assumed by the combination lever has pushed the valve forward a distance that slightly uncovers the back admission port; and thus the Walschaert valve gear derives its lead—permanent lead, too, unaffected by any further changes in the gear that may be necessary in shortening the cut-off by the introduction of reversing mechanism.

If the outside lap of the valve amounts to one (1) inch, and the required port opening for lead is one-thirty-second ($\frac{1}{32}$) inch, the distance between the vertical lines through the centres of the pin holes in the upper part of the combination lever must—as the engine stands in Fig. 5—be just one and one-thirty-second ($1\frac{1}{32}$) inches, equalling lap plus lead.

As the engine starts forward under her own steam we will note the results at each quarter-turn of the wheel. It must be remembered that the valve is acted upon by two distinct forces: the main propulsion, for its *long* travel, but this motion is qualified by the influence of the cross-head, exerted through the combination lever, and which would give a *short* travel to the valve even if the eccentric should be disconnected. When the crank—the main-pin—reaches the upper quarter where its leverage force is greatest the lower end of the combination lever is at the middle of its travel, and it would again stand plumb perpendicular but for the eccentric now being at its farthest point forward, and this has carried the valve to the finish of its forward stroke, leaving the back admission port and front port for exhaust wide open; the crank proceeds in its turning motion and when it has reached the forward dead-centre and the piston is at the front end of the cylinder, the eccentric will be at the lower quarter, and the valve *would* be once more centred on its seat—but for the alterative effect of that combination lever: its angle will be the reverse to the position of the lever as shown in Fig. 5, with the result that the distance from eccentric to valve will be *shortened* by that angle, and the valve drawn back exactly one and one-thirty-second ($1\frac{1}{32}$) inches (we are assuming that the valve has one (1) inch outside, or *steam*, lap, and one-thirty-second ($\frac{1}{32}$)

inch is expected to be the amount of port opening for lead), thus opening the forward port for the pre-admission of steam at the beginning of the back stroke just the same as it was given at the other end of the cylinder.

That is, the lead would be the same at the end of each piston-stroke, if the line of motion from eccentric to valve was a straight, horizontal level, which, in our *ideal* engine, it is not; in the practical design, however, this error is corrected, and our imagination must supply the deficiency until our valve gear is technically completed.

Just as the main-pin passes the bottom quarter and the eccentric is at its farthest point on the back stroke, the upper end of the combination lever still inclines backward and has drawn the valve to the finish of its backward stroke, with the front port opened for full steam admission and the back port open from the cylinder to the exhaust; a quarter-turn more brings the whole gear back to the original positions of the several parts as presented in Fig. 5.

We have described the action of the gear at four points in the revolution of the driving wheel—a complete cycle of motion—but those four points were taken at times when the steam ports were either wide open or only opened the distance required for lead; intermediately between those points occur the interesting phases of *cut-off* and *release*, and further along in this book diagrams will be found, illustrating in a way most easy of comprehension the positions of the different parts of the Walschaert valve gear at *nine* particular points: a technical but plain analysis of the gear, in connection with both inside and outside admission valves. (See folder plates, Figs. 35 and 36.) It would be better, however, to defer the study of those diagrams until we have introduced the reversing mechanism, and built up the complete engine.

We have already completed a very nice working engine of the stationary type, but we must supply a method of shortening the travel of the valve so as to restrict the steam port openings when the engine is running fast or under a light load,—this for the sake of economy; while the means provided for so shortening the valve travel will, further, permit the complete reversion of the direction in which the engine will run.

For this we will cut the eccentric rod at about the point marked *X* in Fig. 5, and that part of the rod that is still connected with the return crank we will continue to call the eccentric rod, but the front section of the rod that connects with the combination lever will be referred to as the "radius rod." The word *radius* is applied to the distance from the centre to the circumference of a circle: a spoke of a wheel, for instance, measured out from the hub centre to the periphery; one end of the *radii* is a fixed point,—the forward end of the radius rod is "fixed" at a point on the combination lever—with its other end rotating about it,—the back end of our radius rod will have a limited distance for rotation also.

The common double-eccentric gear—the Stephenson motion—has a "floating" link, with no fixed, unyielding point of resistance, and the pin by which it is suspended is not exactly in the centre of the link saddle, and from the latter fact and that at nearly every point in the cycle of motion, at any degree of cut-off, the action of the link is influenced by *both* eccentrics, the link describes those peculiarly curved lines of motion that are so mystifying to the student of valve gears.

With our single eccentric we are going to do away with a whole lot of those lines, and we will take that same old style of link and put the saddle-pin in the centre of the saddle and the link, and attach the pin to a fixed bracket, so that with no other connections the link could be rotated around on its pivoted centre.

With the Stephenson motion the curve of the link is made on a radius from the main axle upon which the eccentrics are mounted, so that as the link may be raised or lowered any point within it will be at a constant relative distance from the eccentric centre; the Walschaert eccentric, however, does not control the radius of the link, and because the link does not change its position in relation to the axle, the curve need not be as it was, and we have reasons for curving it in the opposite direction—reasons soon to be shown.

First, we will hitch-up the link; we have suspended it at a point where, by setting it in a vertical position, its lower end can be connected to the eccentric rod, and having made this connection we have given a definite motion to the link; it is somewhat as though we had left the "back-up" eccentric, only, of the Stephenson gear still in connection with the link.

The link-block too has been retained, and to it we will attach the back end of the radius rod (see Fig. 6); now it will be apparent why we curve the ends of the link forward: with the link in a vertical position, as it stands, it must be possible to slide the link-block up and down from one end of the link to the other, carrying the end of the radius rod with it without producing any motion whatever at the front end connection of the radius rod with the combination lever. To make this possible the forward curve of the link must have a radius equal to the length of the radius rod. We have now completed the design of the Walschaert valve gear so far as it is represented by Fig. 6, except in supplying the mechanism by which the reverse lever may shorten the cut-off and reverse the motion.

In Fig. 6 the link-block and radius rod are at the lower end of the link, and there is, in effect, a straight line of motion from eccentric to valve, by which we have for the time a direct motion engine. As the wheel turns forward the eccentric will move the valve forward, just as if the link was not in the gear at all. If, however, the radius rod should be raised to the upper end of the link, the link itself would perform

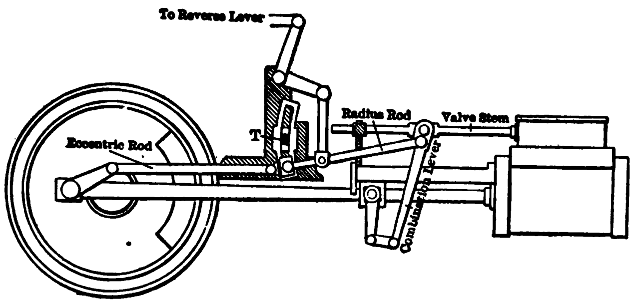

FIG. 6.—Building up the Walschaert Valve Gear.

the functions of a rocker-arm and the forward motion of the eccentric would draw the valve back; that would admit steam to the front end of the cylinder, and the wheel would have to turn the other way—backward—and *then* the eccentric would also turn backward, the link would change that direction of motion and again push the valve forward, admitting steam to the back end of the cylinder as it ought, showing that to reverse the direction in which the engine runs it is only necessary to change the position of the back end of the radius rod to the opposite end of the link.

This raising and lowering of the radius rod and link-block is accomplished by connecting the bar that was once the link hanger to the radius rod, and when the reverse lever is thrown in forward gear the link-*block* goes down in the link, instead of the link itself sliding down on the block as it does with the Stephenson gear; and when the reverse lever is placed in a notch back of the centre of the quadrant the link-block rises to a point above the centre of the link, carrying the radius rod with it, so that when the eccentric moves in any given direction it will move the valve in the same or the opposite way according to whether the radius rod is below or above the centre of the link.

In Fig. 6 the engine is in full gear ahead, and the valve is given its full travel; in order to shorten the travel and thereby secure earlier cut-offs of admission and release, the reverse lever is hooked up nearer to the centre of the quadrant, and the closer the link-block will be placed to the fulcrum pin at the centre of the link, the shorter will be its travel forth and back, with the consequent shortening of the motion of the valve until, with the reverse lever in the centre notch and the link-block pin centred exactly with the fulcrum pin of the link saddle, the radius rod has ceased its motion, and there will be no movement of the valve except that which is received from the motion of the combination lever.

With the Stephenson link motion the amount of lead given to the valve in full gear is steadily increased as the reverse lever is hooked up, and that is considered by many men to be one of its bad features; hooking-up with the Walschaert gear does not increase the lead, because it is obtained from the cross-head, and that is one of the desirable features that recommend this gear. If the motion work has been correctly designed and "set up," and particularly if the eccentric rod is of the correct length, when the engine is standing on either dead centre the reverse lever can be shifted from the farthest go-ahead position clear over to the back corner notch of the quadrant without disturbing the position of the valve, and this is because the eccentric at a point directly above or below the centre of the main axle holds the link in a vertical position, and any point in the link at which the link-block may be stationed will be at a common distance from the point represented by the pin connecting the front end of the radius rod with the combination lever—due to the curve of the link.

If we should set the reverse lever in the centre notch of the quadrant and have the engine moved by "pinching," or towing, as before stated, the eccentric would not give any motion to the link-block, radius rod, nor valve, but the cross-head would, by means of the combination lever, give the valve a short travel that would be equal to twice the distance of lap plus lead.

The connections from cross-head and valve are made to opposite ends of the combination lever, and it is plain to see that when the piston is at either end of its stroke, the valve will be as far in the opposite direction as the angle of the short end (distance between vertical lines through the upper two pin holes) of the combination lever will carry it; this, as has been explained, is the distance necessary to overcome the amount of lap and then give the opening for lead, at each end of the stroke.

This method of reversing the valve motion of a locomotive is referred to by the English Professor, Mr. W. E. Dalby, in his most interesting book on *Valves and Valve Gear Mechanism* as "The Heusinger Von Waldegg, or Walschaert, valve gear." Where, and how, Herr Von Waldegg gained a claim to the distinction of having his name used in connection with a gear for which a patent was indirectly granted to Egide Walschaert is not explained by Professor Dalby.

Our engine is not perfect yet, as it stands in Fig. 6; there is an error to be corrected. Let us refer again to Fig. 2, the simple form of engine that we built up from, and we will note that the total "throw" of the eccentric—the diameter of the circular path in which it travels—must be of the same length as the full travel of the valve, as there is nothing intervening to shorten or lengthen the motion; and this equality of motion is carried on, through Fig. 4 where both rocker-arms are of the same length to the nearly finished construction in Fig. 6—providing the engine shown in the latter plate is in full gear either way; and the *correct* full travel of the valve *should* be of the same distance as the throw of the eccentric, but—note the error:

If this engine should be moved one-quarter turn ahead, placing the main-pin on the upper quarter, the lower end of the combination lever would then be at about the middle of its path of motion, but the eccentric being at its farthest stroke ahead, the upper end of the combination lever would also have its farthest inclination ahead and the resultant angle would *lengthen the line of motion* between the eccentric and valve; this increases the travel of the valve at its forward stroke, and is the result of the method of obtaining that advance of the valve necessary in overcoming the lap, even if the lead, as pre-admission of steam, is not desired.

Move the engine so that the main-pin is on the lower quarter and the eccentric at the end of its backward stroke and the opposite effect will be produced;

the combination lever, centred at the lower end, will incline backward at its top end and the angle assumed in this case will *shorten* the distance from eccentric to valve, and this, on the backward stroke, increases the travel of the valve in that direction.

So, if the full travel of the valve and the full throw of the eccentric are to be maintained as equal distances—and they are—then the valve in Fig. 6 *overtravels* in each direction; we have not allowed for that and the question is, How can the travel of the valve be correctly shortened up and not create any other interference with the motion? Shortening the throw of the eccentric by changing it to a point nearer the hub centre would take away the increase of travel that was developed in securing the advance of the valve,—would it not?

Certainly; that would be a good way out of the difficulty—if we hadn't a better one: we can secure a double result in overcoming the error—"kill two birds with one stone."

With this gear the link generally sets rather high—higher than appears in the sketch—and when the eccentric is on the lower quarter there is a great and undesirable angle between the eccentric rod and the line of the valve-stem; horizontal lines through the centres of the main axle and the pin connecting the eccentric rod to the link are too widely apart, and the result is an angle great enough to disturb the correct transmission of motion. So, let's leave the throw of the eccentric and the required full travel of the valve remain equal, as they should be, and now extend an arm down from the lower end of the link and connect the eccentric rod to its lowest point instead of to the link itself. We have completed the Engine Practical now, as it appears in Fig. 7, in which it is seen that with the reverse lever in full forward gear, the radius rod as far down in the link as it will go is not in line with the eccentric rod; this change has shortened the swing of the link and the carry of the link-block, and on some engines this foot of the link is so long that the reduction in link-block travel amounts to a great deal, but it only affects the *long* motion of the valve and does not interfere with the amount of lead supplied by the combination lever.

We have completed our task of erecting a design of Walschaert's valve gear that is applicable to an ordinary locomotive, and it is presented in Fig. 7 for technical study; it is of the same general type as the one we built up, in Fig. 6, corrected, with the position of the piston changed to the forward end of the cylinder. A vertical line is drawn through the exact centre of the valve seat and another similar line through the centre of the valve. The valve is shown displaced the distance required to open the admission port the amount required for lead by the angle of the combination lever, and this advance of the valve is equal to the distance between the vertical lines through valve and seat; if now the combination lever were disconnected at its lower end from the cross-head—cut off from the influence of the piston—and drawn to an exactly vertical position, both pin holes at its upper end would be vertically even, and the centre lines through valve and seat would coincide, the valve being central on its seat and the lead eliminated. With an engine standing as in Fig. 7, the proportions of the combination lever must be such that the distance between vertical lines through the two pin-holes at its upper end must be the same as the distance between the vertical lines through the valve and seat as shown, with the valve moved back far enough to open up the admission port the resolved amount for lead; and this distance between centres of valve and seat must cover the measurements of both *lap and lead.*

Ideally, the position of the Walschaert eccentric is fixed at 90 degrees of the wheel circle from the main-pin, and if the foot, or lower extension that we have supplied to the link to which the eccentric rod is connected, was long enough that when the main-pin was on a dead point and the link was standing vertically the pin in the link-foot connection of the eccentric rod would be on a horizontal line through the centre of the main axle, then the relative positions of eccentric and main-pin would be as stated; but the link foot seldom extends so far down, and to correct the results of the angle so produced in its effect on the motion of the link and valve, the eccentric is set closer to the main-pin than 90 degrees; this point will be more clearly explained and illustrated later on.

The oscillating link of the Walschaert valve gear differs from the shifting link of the Stephenson type constructively as well as in the direction from which its curve radiates. Fig. *7a* illustrates a style of the Walschaert link that approximates the standard type that has been adopted by locomotive builders in this country, and is used, with only such variations as variance in the general engine design may render necessary, by the American Locomotive Company on all of their engines equipped with the Walschaert gear at this time, exactly as shown in the plate.

While the Stephenson link is an open, one-piece affair, and is simple in construction, suspended by a pin in the link-saddle on one side only, it is usually considered necessary for the Walschaert link to be supported by a trunnion on each side as a furtherance of stability. In Fig. *7a*, the piece that forms the link is shown in side elevation *A* as *1a*, and in end view *B* as *1b*, and is forged from wrought iron that is afterward case-hardened. Referring to view *B*, the two bracket pieces *2b* are shown to be bolted to the link piece, one on each side, their edges apparent in section *A* as *2a*, where they widen out to cover the link, although the central spread is to strengthen that part of the bracket which is the frame work of the link. These link brackets are cast steel, and each piece includes in its casting a trunnion, *3b*, in its exact centre, around which is pressed a case-hardened,

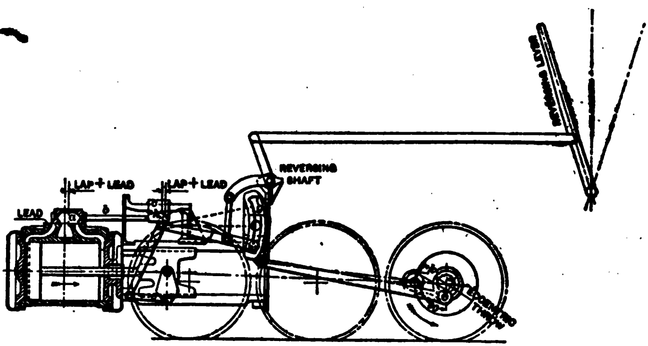

FIG. 7.—Walschaert Valve Gear Complete. Sectional elevation of valve and cylinder.

wrought-iron bushing; it is by these fulcrum-pins, or trunnions, that the link is suspended from a fixed point. At the lower extremity of the link piece—the link *foot*—is a pin hole, *4a* and *4b*, to receive the pin that connects the eccentric rod with the link, and this hole is fitted with a wrought iron bushing that is case-hardened. The reduction of the diameter of these pins and pin holes from wear is but slowly effected if kept well lubricated, and is one reason why lost motion is so slow to develop in the Walschaert valve gear. Just above the pin hole 4*a* there is an oil well finished in the top of the link foot, $1\frac{3}{4}$ inches in diameter by $1\frac{3}{4}$ inches deep, with a $\frac{1}{4}$-inch hole drilled down from the bottom and through the bushing of the eccentric rod pin hole for the feed of the oil; a threaded cap nut is screwed into the top of the oil well as a cover.

In section *A* the dotted arc lines 6*a* show the outlines of the opening, or slot, in the link in which the link-block travels, and the faces of this link-slot is kept lubricated from an oil well in the top end of the link piece, this oil well being shown in dotted lines at 5*a* and 5*b;* it is covered by a cap nut that is a mate to the cover of the other oil well in the link foot, and has a threaded tap $1\frac{3}{4}$ inches in diameter. In section *B*, the left side of the link is turned to the outside of the engine, and the hole in the outside bracket at 7*a* and 7*b* is to permit direct oiling of the link.

The link-block is represented in sections *C* and *D; C* is the side view and shows the block in the position in which it would lie in the view *A* of the link,—imagine the link-block *C* raised, following the arc of the link until it entered the slot shown by the dotted lines 6*a*. Taking an end view, if the link-block, as shown in the section *D*, should be placed in the slot of the link piece of section *B*, it would be seen that its edges were almost flush with the sides of the link piece—extending only $\frac{1}{32}$ inches out from each side of the link. It will be seen that the link-block contains an oil well, shown by the dotted lines at *9c* and *9d*, 1 inch in diameter by 1¼ inches deep, with a ¼-inch feed hole from it down to the link-block pin.

The radius rod lies in an exact line with the link, but at its union with the link the radius rod is forked, its jaws passing, one on each side of the central link piece, and inside of the bracket sections at *OO*. There is a pin hole through each jaw of the radius rod by which it is connected to the link-block, the pin that passes through the radius-rod jaws also going through the hole *8c*, *8d*, of the link-block, and this hole is supplied with a case-hardened, wrought-iron bushing as a protection against wear; but there will be no wear to the holes through the jaws of the radius rod for the reason that a bolt runs down through a hole in each jaw and through the link-block pin, thus holding the pin rigid with the radius rod and turning only in the hole through the link-block. The openings *7a*, *7b*, in the outer link bracket, besides giving access to the link slot for oiling, may also be used as an aperture through which the link-block pin can be removed.

Certain types of engines are so constructed that the eccentric rod is not in line with the link and cannot be

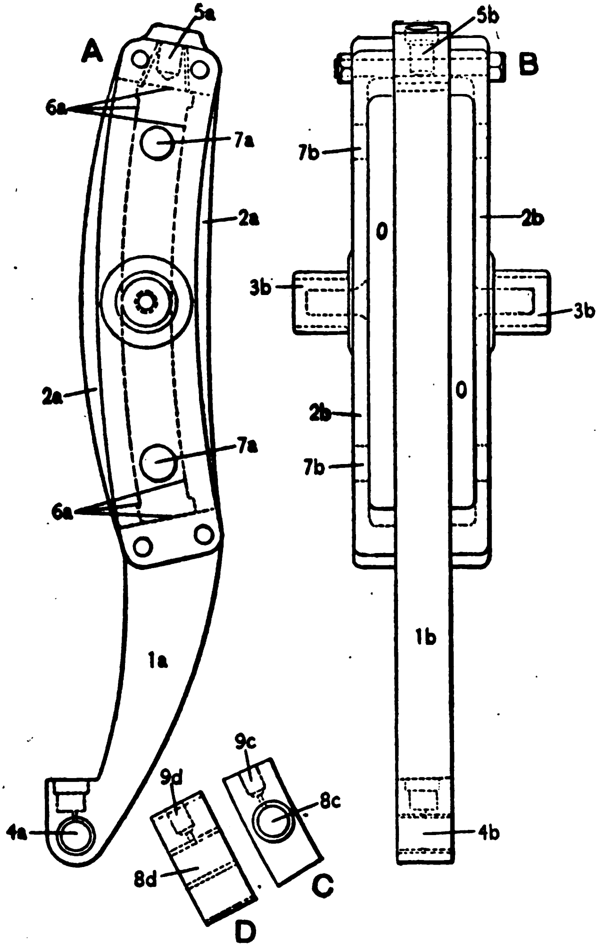

FIG. 7a.—The Walschaert Link.

connected directly with the link foot—such as the Baldwin engine built for the Rock Island Raiload, shown elsewhere in these pages—where the valve chest lies nearer the centre line of the engine than is usual; in such cases the link piece 1*a*, 1*b*, extends scarcely lower than its supporting brackets and there is no link "foot." The trunnion, 3*b*, on the *inner side* is also dispensed with, while the outer trunnion is made considerably longer and extends through a sort of journal box in the manner of the common rocker shaft, and to its outer end is attached an arm, or lever, to the lower end of which the eccentric rod is connected at the same distance below the centre of the link trunnion, or fulcrum, as it would be if regularly connected with the link foot.

While the foregoing matter covers the standard method of application of the Walschaert valve gear by American locomotive builders, there are variations, and referring to Fig. 8, it is seen that *Auchincloss*—whose book on various valve motions is considered an authority—sets the eccentric a quarter *behind* the main-pin instead of ahead of it as is usual with outside admission valves; but he reverses the effects of that change by carrying the link-block at the top end of the link when the engine is to run forward. The reversing shaft is below the link (like the old-time Rogers engines were fitted), with the lifting arm extending backward so

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that throwing the reverse lever forward raises the radius rod, and the valve's action remains the same as with the style of gear adopted by American builders that we have analyzed. The *Auchincloss* type is common on European engines.

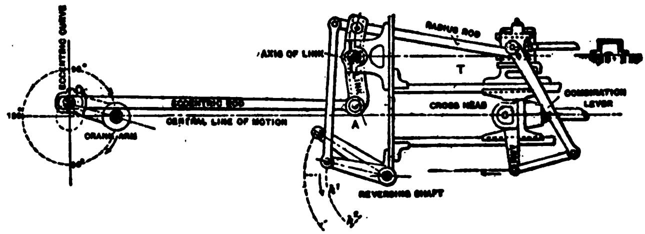


FIG. 8.—Walschaert Valve Gear. (Illustration from *Link and Valve Motions.*—Auchincloss.)

During the years that foreign railways have had the advantage of the use of this worthy device we have not been altogether blind to its merits: Certain progressive engine builders and master mechanics in America have endeavored to bring the Walschaert valve gear to trial, and some form of it was applied to quite a number of engines but never received a fair showing. Men were intrusted with setting-up the gear and maintaining it, and obtaining results from its use, that had found it the struggle of a half lifetime to master the mysteries of the Stephenson link motion, and, having learned it, placed an extravagant valuation on the mechanism that had been so hard for them to thoroughly understand: and to find something better, that was as simple as the motion of Walschaert was hurtful to their self-conceit, and it was this priest-craft among railroad mechanics, and even officials, that choked down the honest endeavor of those who did try to improve that most vital part of the motive power of our railways. When William Mason presented a design of the Walschaert valve motion finely suited to the conditions of American locomotive construction, together with a paper detailing the good features of the gear, to the Master Mechanics' Convention in 1885, it met with a cool reception; in fact, without data of actual performance in evidence, the Walschaert motion was there generally condemned. The time was not ripe; they could afford to neglect it.

Shortly after this the railroad with which I was connected was supposed to have tested the merits of the Walschaert gear by putting that style of link, reversing gear, and combination lever on an engine that had been equipped with the Stephenson motion, but instead of connecting the Walschaert link with an outside crank on the main-pin, one of the old eccentrics on each side was used to operate the links, and thereby one of the best features of the device was omitted, and neither was it erected with reference to a scaled model. After a short time the old gear was restored, and there were no data afterward obtainable to prove the success or failure of the half-constructed gear.

When it is decided to apply the Walschaert valve gear to any certain type of engine the design should be correctly laid out *and constructed from a diagram*, as the proportions cannot be tampered with by experimental changes without seriously affecting the correct working of the device. The only part capable of variation in length is the eccentric rod which connects the return crank with the link; this rod may be slightly lengthened or shortened, to correct errors in the location of the link centre, from centre of the driving axle which carries the return crank. This crank, representing the eccentric, must be permanently fixed to the main-pin, and the slightest variation in its position relative to the main-pin will be detrimental. When the engine is assembled, the throw of the eccentric should be checked up by the specifications, and any error should be at once reported in order that the mistake may be rectified by either correcting the position of the eccentric, or by a change in the design of the other parts to compensate for the error. It is probable that inattention to this absoluteness of detail required in the erection of the gear, as well as prejudice, is accountable for the condemnation of the Walschaert motion in the past.

Along in the early seventies the Mason Machine

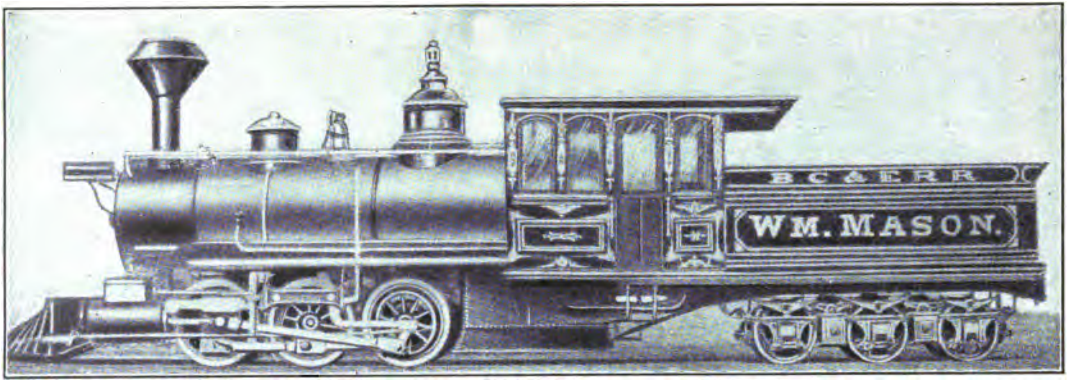


FIG. 9.—Mason Locomotive with Walschaert Valve Gear.

Company built quite a number of engines like the one in Fig. 9, and one—an exact duplicate of the one we present—was bought by the line on which I received my first railroad experience; her performance is a legend among the older employees of that road to-day; the work that engine was capable of doing as compared with other engines with the same-sized cylinders was almost unbelievable, and was never equalled before, nor since. Finally her boiler exploded near the roundhouse at the main terminal, and she was never rebuilt.

The engine was of the *double-truck* class, with boiler, cab, and tender on one common main frame, while the cylinders were carried on the separate driving-wheel frame that was free to rotate on its centre bearing that supported the forward end of the main frame, and it was through this centre bearing that the steam pipe passed, the exhaust pipe being made flexible. The entire weight of the *engine* was on the driving wheels, and the adhesion of those small wheels to the rails was unusually great and aided the power that was developed; but it is in the cylinders that the power of the engine originates, and they were not large—16 inches by 24 inches—and I believe that the correct distribution of steam by a properly designed and worthy style of valve gear had much to do with the production of power; the *results* were obtained, all right.

It will be noticed that the reversing shaft in this Mason engine lies over the top of the boiler, and the bar connecting the lifting arm with the radius rod is abnormally long, whereby, as the ends of the link are swung forth and back, the link-block is carried in a line very near to horizontal.

In Fig. 10 is illustrated the revised design of the Walschaert gear that was presented and described at

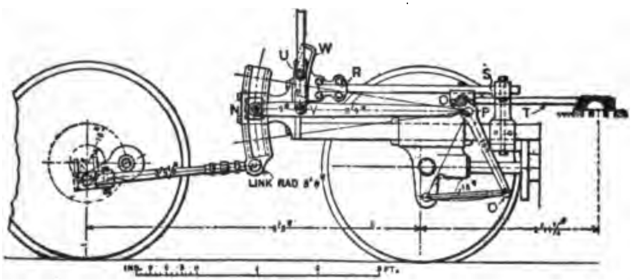


Fig. 10.—Mason's Improved Design of Walschaert's Valve Gear.

length before the Master Mechanics' Convention in 1885. Although a D-slide valve is used, the position of the valve chest is further in toward the centre line of the engine than is common, this inlying being more common to valves of the piston type. In order to deliver the motion of the combination lever to the valve-stem, the upper end of the combination lever is connected to the outside of the block *Q* which is bolted to the sliding guide-bar *RS* and a pin extends inside from block *Q* far enough to engage with the end of valve-stem *T;* this detail, however, is of the lesser importance.

The greater import attaches to the mode of suspension of the radius rod *NP:* While the suspension bar of the engine in Fig. 9 is longer than is found on any other engines using the Walschaert gear, Mr. Mason went to the opposite extreme in this, his later design, and in Figure 10 the suspension bar *UV* is not more than one-half of the length of the link itself. It was found that the point of suspension had a great influence on the motion delivered to the valve, and this point regularly varied in most types of the gear from the effect of the different angles assumed by the reversing arm that raises and lowers the suspension bar, and also, in the case of double-truck engines like the one represented in Fig. 9, by the rotation of the driving-wheel frame while rounding a curve in the track. In the plan of Fig. 10, however, there is a stationary, curved link, or guide *W* taking its radius of curvature, like the main reversing link, from the pin *P* and also containing a sliding block which is attached to, and worked by, the connecting bar from the reversing arm. The upper end of the short suspension bar is connected at *U* with this sliding block, and at *V* its lower end is attached to the radius rod;

the pin *U* becomes the suspension point, and its arc of movement is equidistant from the arc of the main link-block, as the engine stands in Fig. 10, during all points of cut-off. The effect of this arrangement was expected to be the nearly uniform distribution of steam to and from the cylinder. It causes a remarkable slip of the link-block at each end of its stroke in working gear, either going ahead or backward, that was expected to equalize the alternate port openings, and it certainly does delay the motion of the valve at the end of its travel, holding the admission and exhaust ports more nearly fully opened at the time that they should be so.

In American locomotive design outside admission valves are generally of the plane seat, D-slide type, while for inside admission piston valves are, of course, the only kind used, yet the piston valve may be, and in a few cases is, specified for outside steam admission; but, in the latter case, the balancing of the steam pressures against the valve pistons being less perfect on account of the lessened area exposed to the live steam pressure on the back valve piston, due to the entrance of the valve-stem at that end of the steam chest.

Up to this time we have considered the Walschaert gear in connection with outside admission slide valves, while as a matter of fact, at this date the majority of

American locomotives equipped with Walschaert's device have inside admission piston valves, the builders, or purchasers, not taking the hint from European practice that the D-slide type of valve may be a component part of the Walschaert theory. To those who only understand this motion as far as our article has progressed, it may seem only necessary to reverse the positions of certain points of the gear in order to make the change from outside admission to inside admission valves, or *vice versa;* but that is not quite all that is necessary to secure the same motion and valve events; the change made in the connections to the combination lever and shifting the position of the eccentric has a result on the motion imparted to the valve that must be corrected.

It may be unfortunate that the Walschaert gear is coming into its own—if it can hold it—at just the time when the piston valve is a "fad" that like the proverbial dog must have its day. The combination of the two devices is not pleasing and is likely to detract from the good reputation that the Walschaert motion unhindered can make for itself.

It may be a pertinent question, just here, to inquire what are the advantages of the piston valve that was tried and discarded years ago, over the D-slide, plane-faced valve that has given, and is giving, such good service on all classes of engines. It is claimed that the piston type is the only perfectly *balanced* valve. But *is it?* The parts to be balanced are those parts of the valve that confine the live steam; that the live steam presses against the valve seat; the parts that make the *steam joint*. Where is the piston valve balanced? It is only balanced where the live steam bears against its vertical sides, and in this respect, with outside admission, it has no gain over the D-slide valve, which also has sides fore and aft of equal area; and piston valves of inside admission have only the advantage in balance that is indicated by the absence of the interfering area taken by the valve-stem, and this is of small moment.

An unbalanced D-slide valve does have an enormous frictional resistance to movement on its seat due to the great area on top of it being exposed to the full pressure of live steam, but very few of such valves are in existence to-day, and probably none on the large, modern class of engines. The D-slide valve can be, and is, most nicely balanced, and may, if desired, have a balance of 100 per cent, which is not preferable, as the lifting effect of the exhaust steam under the valve must be counteracted upon.

With piston valves what stands between the enormous boiler pressure of steam that is now carried and the valve seat? The answer is "the packing rings." Are the packing rings balanced? They are not, and cannot be, balanced. The grooves into which the rings are fitted must not be made absolutely steam-tight, and they fit looser as they wear; the live steam against the rings will go either under or over them: If the steam passes between the rings and the walls of the valve chest there will be a bad blow, and waste of pressure,—no packing. If the steam finds the other side of the rings, the rings will be pressed against the walls of the valve chest and the opposite side of the groove, and *pack* with a steam-tight joint, but with enormous *unbalanced* pressure. Calipering the inside diameter of the valve chest after piston valves have been in service for some time will prove the very great wear—greater toward the centre—and I have had the opportunity for *feeling* how hard it is to hook up such an engine under heavy throttle.

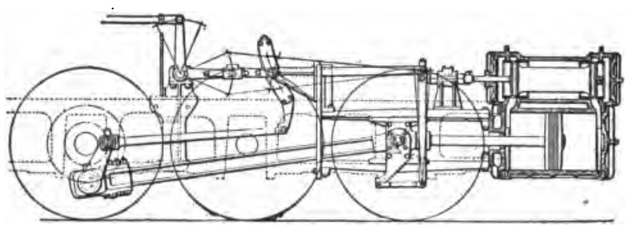


FIG. 11.—Piston Valve Actuated by Walschaert Gear.

In Fig. 11 we have presented a type of the Walschaert gear as applied to one of the latest built and heaviest freight engines in America, together with a section through cylinder and valve, the latter being of the piston style, of inside admission.

With the reverse lever and link-block on their centres, the combination lever will also be centred—in an exactly vertical position—as shown in the plate, with the main piston at the perfect centre of its stroke—exactly in the middle of the cylinder. But the main-pin, as may be noted, is not now *precisely* on the point of "lower quarter," the slight variation being due to the angular position of the main rod, and if the back end of this rod was disconnected from the main-pin, and raised, the opening in the stub-end would centre exactly over the hub centre.

This angular offset of the main-pin produces a corresponding offset in the position of the eccentric because the radii through the main and eccentric pins are theoretically 90 degrees apart; but the eccentric is at a point now, where its variation is at right angles to the eccentric rod, and the deflection is of no moment. If the reverse lever should be placed in full gear ahead, or back, one of the steam-admission ports would be wide open; it would, indeed, be a finely adjusted gear in which the valve would feel the effect of that variation.

In Fig. 11, notice that the eccentric *follows* the main-pin by 90 degrees instead of preceding the pin by that distance, as heretofore; also, the upper end of the combination lever is connected to the radius rod instead of to the valve-stem, the valve-stem and radius rod having changed places on the combination lever. These changes are made because the engine has inside admission valves, and as such, a valve must travel in an opposite direction, always, to the travel of a valve having outside admission, and the eccentric is placed a half-turn different, or a quarter *behind* the main-pin. When the piston is at the forward end of its stroke, the front steam port must be slightly open for the lead, and as the valve of outside admission must be pulled back in order to open the port, the valve with the inside admission must, conversely, *be pushed forward* to get the lead opening, to secure which action the valve-stem is joined with the combination lever *below* the radius-rod connection, thus having the effect of lengthening the line of motion between link-block and valve at this juncture, and thereby forcing the valve ahead.

With engines of the American type you can always tell, therefore, whether an engine with Walschaert gear has outside or inside admission valves by noticing the position of the eccentric in reference to the main-pin and the method of connecting the valve-stem and radius rod to the combination lever. This is nicely brought out in the plate representing the heaviest locomotive ever built (Fig. 12), the Mallet, Four-Cylinder, Articulated Compound built for the Balti-

FIG. 12.—Mallet Four-Cylinder, Articulated, Compound Engine. Built by the American Locomotive Co.

more and Ohio Railroad by the American Locomotive Company, in which the rear, or high-pressure, engine has a piston valve which we may know, by reason of the foregoing explanation, is of inside admission. The forward, or low-pressure, engine has a plane seat, D-slide valve, and is necessarily of outside admission, but anyhow, we should know this on account

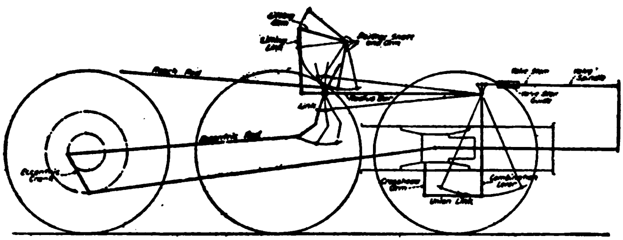


FIG. 13.—Diagram of Valve Gear, Low-Pressure Gear, or Forward Section of Mallet Compound Locomotive.

of the location of the eccentric and the connections at the upper end of the combination lever; and in Fig. 13 is shown an outline diagram of the latter—the low-pressure section of the engine—with the positions of the combination lever and link, and the lifting arm, at the different phases of a cycle of motion or revolution of the driving wheel.

As an illustration of the different ideas held by prominent American locomotive designers, compare Figs. 10 and 11: It concerns their opposite views in regard to the supposedly important point of radius rod suspension. The Mason theory in connection with the guide for the point of suspension is that the suspension bar must be so extremely short as to admit of a pronounced swing to the radius rod. The American Locomotive Company's very recent production shown in Fig. 11, has no swing suspension whatever. The lifting arm of the reversing shaft has a block pivoted at its end which acts as a guide for the extended end of the radius rod, so that with the reverse lever in either gear, forward or back, the motion of the link as the engine works cannot cause any vertical shift of the link-block, and the only variation of the block from a true horizontal motion will be the slight amount due to the angularity in the position of the radius rod and the effect of the oscillation of the short (upper) end of the combination lever.

The engine built for the Chicago, Rock Island & Pacific Railroad, that is represented by Fig. 14, was built by the Baldwin Locomotive Works, and has the Walschaert motion and external admission, D-slide valves, but there is a variation here from the general manner of making the connection from eccentric to link: the eccentric rod is not connected directly to the "foot" of the link, but the trunnion, or fulcrum-pin, of the link has become a shaft, working in bearings in a "box," and to the outer end of this shaft is

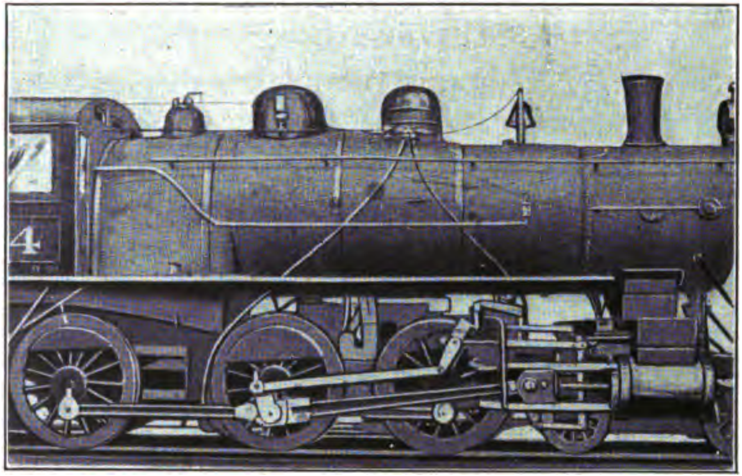


FIG. 14.—Engine with Walschaert Motion and Outside Admission Valves.

attached an arm extending downward and to the lower end of which the eccentric rod is connected, the radius rod and other parts of the gear remaining as usual. Such variations are sometimes found necessary for convenience in applying the gear to engines of peculiar construction, and one of the chief recommendations for the Walschaert motion is that it may be applied to any oddly designed engine with a minimum of change from the simplest model, and there is no conflict to expect with other parts of the machinery: An illustration of this, and the general adaptability of the Walschaert valve gear, is Fig. 15, a motor-car built for the Erie Railroad.

The locomotive exhibit at the Louisiana Purchase Exposition, at St. Louis in 1904, included the heaviest engine in the world, as represented by the Mallet Compound already referred to, and another one, typical of a class that has become renowned all over the world for swiftness—the French De Glehn Compound: Two engines, built for the extremely opposite in railway service—to be the fastest and to be the strongest; and that the valves of both are actuated by Walschaert's style of gear is proof that it was a mistaken theory, which was held by some, that it is only on certain types of engines, or those engaged in a certain class of work, that the Walschaert valve gear is in any way superior to the Stephenson link motion.

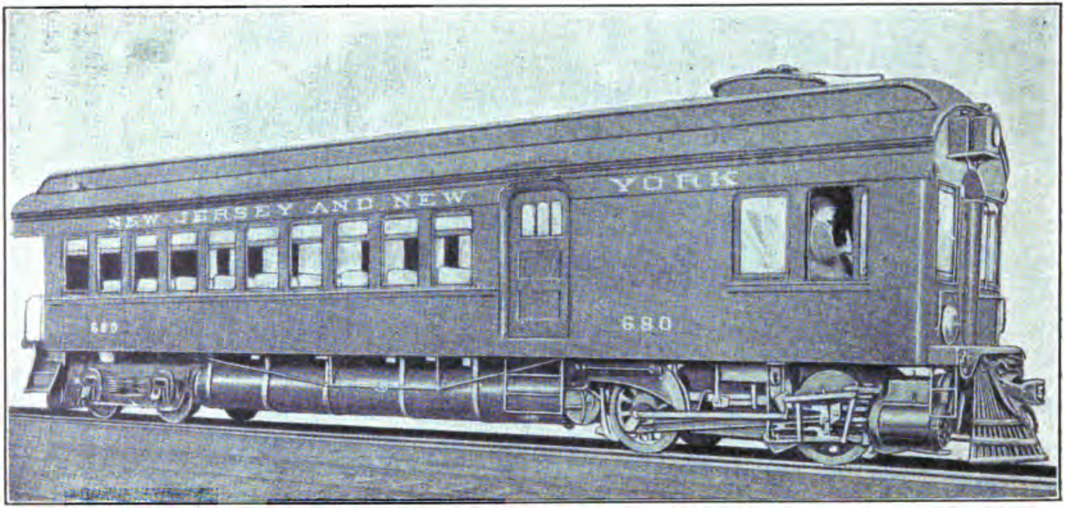


FIG. 15.—Erie Railroad Motor Car. Engine equipped with Walschaert Valve Gear.

The fame of the De Glehn Balanced Compound engine having reached America, the Pennsylvania Railroad ordered one from the French builders, and this is the one that was exhibited at the St. Louis Exposition.

The American purchasers specified that it should be exactly similar in design to the other engines of the De Glehn type running on the French lines, except heavier, as American express passenger equipment is much heavier than the European, and a few minor changes in detail were necessary in order to "make it fit" American tracks, and go where our engines will go. In spite of the fact, however, that this engine was built more heavy and powerful than the ones built for the French railways, it is hardly large enough to handle the very heavy passenger trains of the Pennsylvania lines, but with its proper load, with the lighter, but fast, service on certain divisions, it has been, and is, giving most excellent results; and the principle upon which the De Glehn engine is "balanced" is now being used with success by the Baldwin Locomotive Works in their Vauclain Four-Cylinder, Balanced Compound, and the Cole Balanced Compound engine built by the American Locomotive Works.

Fig. 17 represents the Walschaert gear that delivers the motion to the valves of the high-pressure cylinders

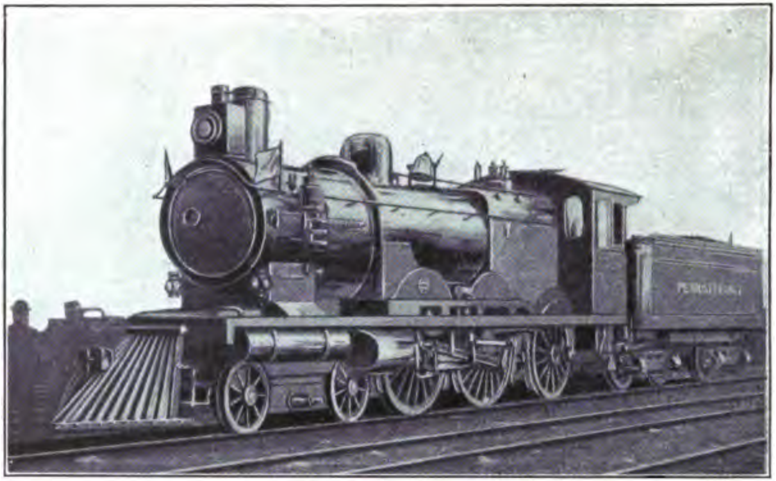


FIG. 16.—DeGlehn Balanced Compound. Pennsylvania Railroad.

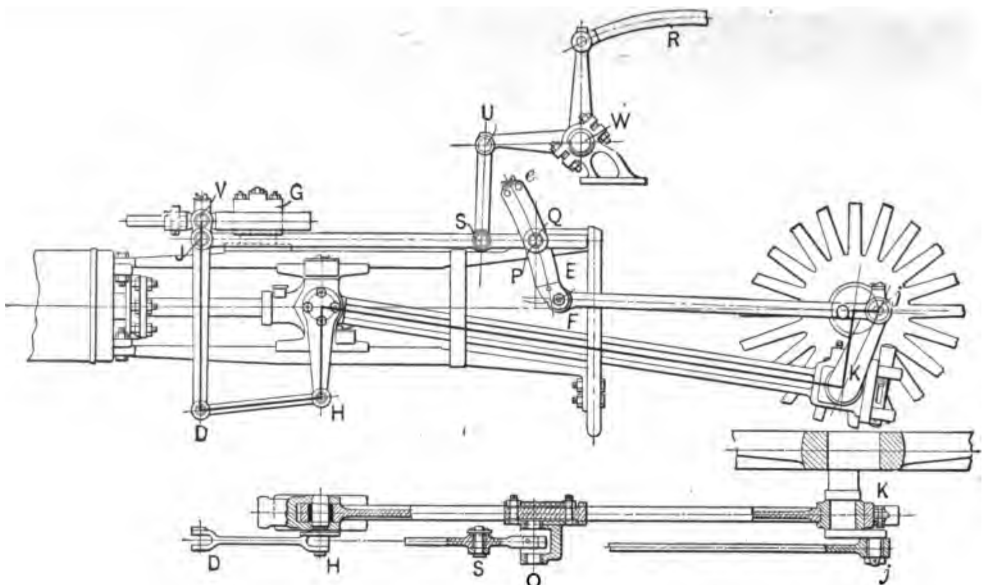


FIG. 17.—Walschaert Valve Gear for High-Pressure Cylinders of the DeGlehn Compound.

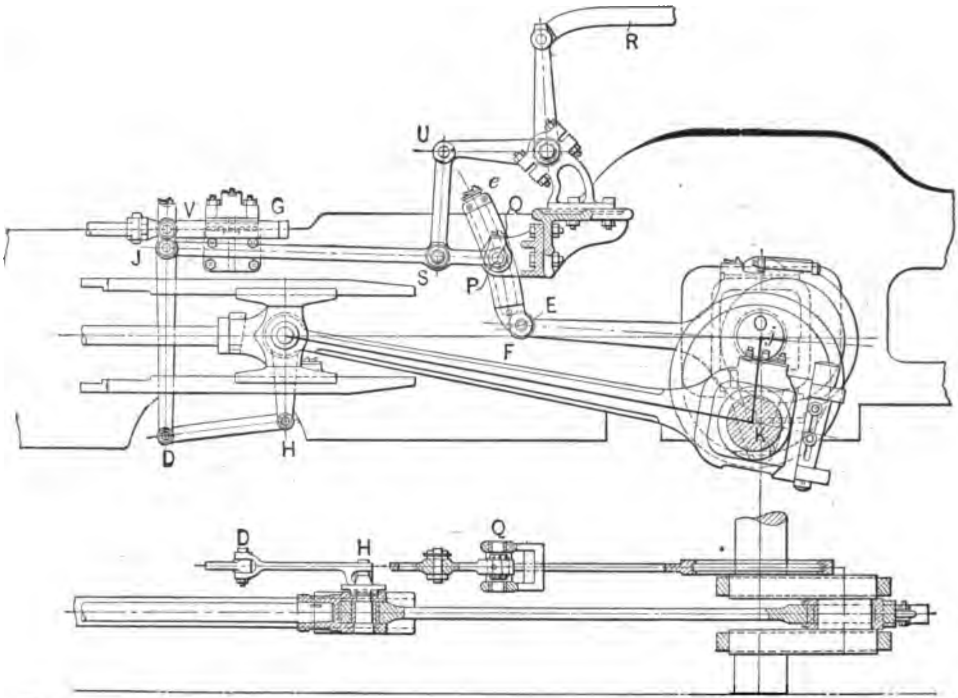


FIG. 18.—Walschaert Valve Gear for Low-Pressure Cylinders of the DeGlehn Compound.

of the De Glehn Compound, and Fig. 18 shows the same type of gear as applied to furnish the motion of the valves of the low-pressure cylinders. In the arrangement of the latter it is seen that the link is driven by an eccentric on the main shaft; this shaft is termed a "crank axle," because part of it is shaped to form two cranks to which the main rods of the two low-pressure cylinders (one on either side) are connected, and as the entire gear of the low-pressure, or *second expansion*, engine,—of the cylinders and valves,. both—are *inside* of the frame, it was clearly necessary that the eccentric should be placed on the crank axle inside the frame, with sheave and strap exactly like the Stephenson eccentric, except, of course, that but one eccentric is used for each link. Outside of the frame the return crank on the main-pin actuates the valve gear of the high-pressure engine, which is the only part that can be seen in the photo-engraving Fig. 16.

At this date the most powerful passenger engine ever built is the one depicted in Fig. 19, a recent production of the American Locomotive Company for the Lake Shore & Michigan Southern Railroad, and of which some of the principal dimensions are appended; here, again, the Walschaert valve gear is in evidence; and the heaviest and most powerful switching engine in existence at this time, built for the same road by the

FIG. 19.—Prairie Type Passenger Locomotive with Walschaert Valve Gear. Built by the American Locomotive Company. The heaviest passenger locomotive ever built.

Loaded Weights.

On leading truck	24,400 pounds
On driving wheels	167,800 pounds
On trailing truck	44,000 pounds
Total engine	236,200 pounds
Tender	158,500 pounds

Dimensions.

Diameter of cylinders	21 1-2 inches
Stroke of piston	28 inches
Valves, piston type	internal admission
Diameter of driving wheels, outside	79 inches
Total heating surface	3,905 sq. ft.
Grate area	55 sq. ft.

Working pressure per square inch, 200 pounds. Tender capacity, water 7,800 gallons, fuel 15 tons. Maximum tractive power, 27,850 pounds.

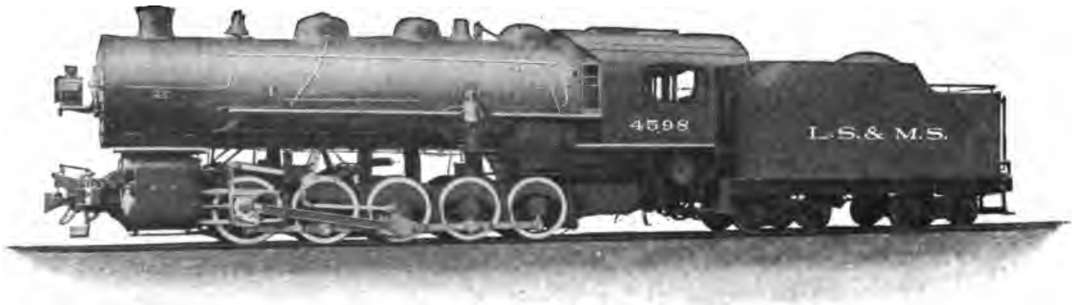


FIG. 20.—Decapod Switching Locomotive with Walschaert Valve Gear. Built by the American Locomotive Co. The heaviest and most powerful switching engine.

Loaded Weights.

On driving wheels	270,000 pounds.
Total engine	270,000 pounds.
Tender	149,600 pounds.

Dimensions.

Diameter of cylinder	24 inches.
Stroke of piston	28 inches.

Valves, piston type, internal admission. Diameter of driving wheels, outside, 52 inches. Total heating surface, 4,625.4 square feet. Grate area, 55 square feet. Working pressure per square inch, 210 pounds. Tender capacity, water, 8,000 gallons. Tender capacity, fuel, 12 tons. Maximum tractive power, 55,362 pounds.

same locomotive company, is shown in Fig. 20, and also is equipped with Walschaert's motion.

In all of the illustrations of Walschaert's valve gear so far shown, as applied to American locomotives, it will have been noticed that the link is invariably suspended from a bracket that is attached to the guide-yoke, and the valve-stem slide is also carried by the guides, this to insure permanency in the alignment of the gear; but with certain types of large freight engines it is sometimes inconvenient so to place the link bracket, and the American Locomotive Company have built quite a number of engines that have a very large casting extending across, under the boiler, that is really a strong cross-brace to the engine frame at the point where such a brace is most needed—an impossibility with the common link motion—and this casting is used to carry the link and reversing shaft. Some engines have this brace unattached to the guides, however, while with others it is attached rigidly to the guide-yoke, the latter type being represented in Figs. 20*a* and 20*b*, which are reproduced from the *American Engineer and Railroad Journal* and that journal gives the following description:

The illustrations show this new design so clearly that it needs but little explanation, and by reference to them it will be seen that the support for the small crosshead connecting to the valve-stem has been

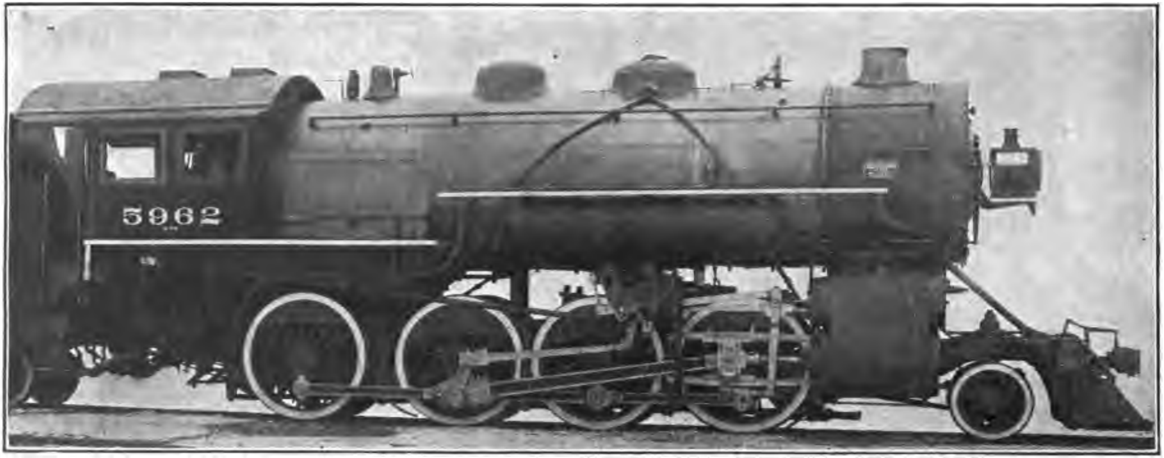


FIG. 20 *a*.—Engine with Walschaert Valve Gear and Strong Frame Brace.

placed on an entirely separate guide, which is fastened to the back valve chamber head and through an expansion link to the guide-yoke instead of having it supported directly from the main guide, as in previous designs. The bearings for the reverse shaft and the link have been placed near together in the same casting and the radius rod of the valve gear is operated through a hanger from the arm of the reverse shaft instead of a sliding joint, as was used before when the reverse shaft was supported in a bearing on the frame between the second and third pair of drivers (as in Fig. 11). The link itself has been made somewhat larger and more bearing surface given to the block. The casting forming these bearings is fastened to a massive but not excessively heavy steel casting extending across the frame. The construction of this casting and its dimensions are clearly shown in the illustration. To this is also fastened the yoke supporting the main guides. Another change is also noticed in that the arm from the reverse shaft, to which is connected the reach rod, extends downward instead of upward. This necessitates the reach rod being placed outside the driving wheels and on an incline from the reverse lever. It is supported and steadied by a guide at the throat sheet. A change has also been made in the return-crank connection at the main-pin for the purpose of permitting it to be more quickly and easily removed,

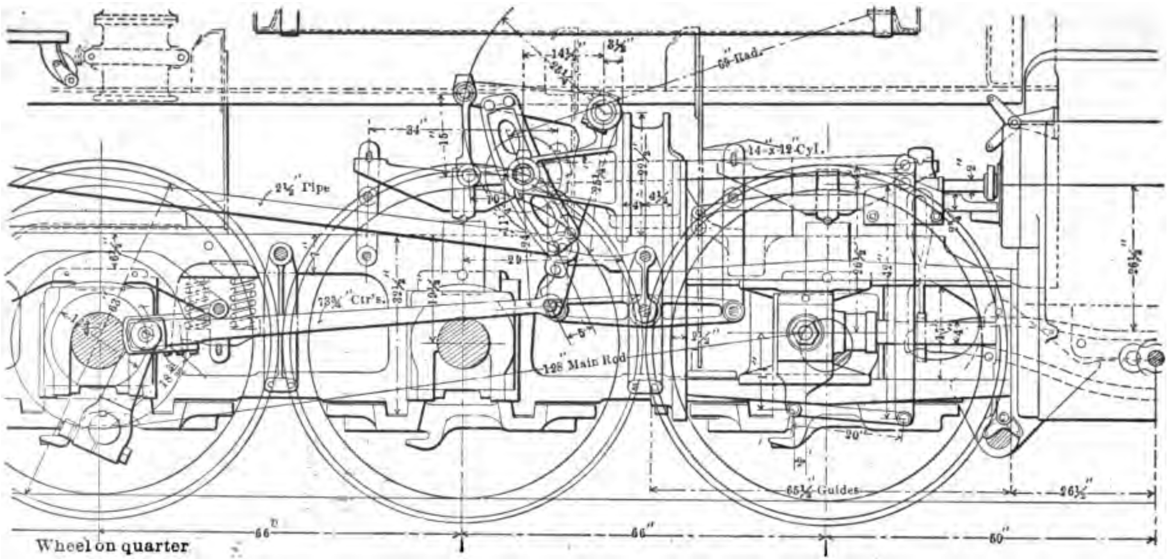


FIG. 20 b.—Sectional Elevation of Walschaert Valve Gear with Link and Reverse Shaft Carried on Heavy Frame Brace.

as it has to be whenever the rods have to be taken down. While the construction at the guide yoke appears to be very heavy and cumbersome, a careful examination of the drawings will show that it is really more simple than in previous designs of this valve gear, which were more open.

The most widely different classes of service have been represented thus far in the showing of modern engines that are equipped with Walschaert's valve gear, but as a further illustration of its adaptability to various conditions without serious alteration from the simplest design, as well as to bring to notice the fact that European railways are taking advantage of the possibilities that lie in the use of this gear, Fig. 21 is presented as one of a group of thirteen engines that were exhibited at the Exposition held at Liege in 1905, by the State Railways of Belgium—the same road that graduated the inventor of the motion—and this may be said to be a lineal descendant from Walschaert's successful experimental engine of 1848. It was constructed by the Societé Anonyme la Meuse, of Schenien, from the designs of M. Flamme, General Inspector, under the direction of M. Bertrand, Director of the State Railways, and is one of a number of engines built for experimental purposes.

The plate is reproduced directly from the June, 1906, issue of the *American Engineer and Railroad Journal*,

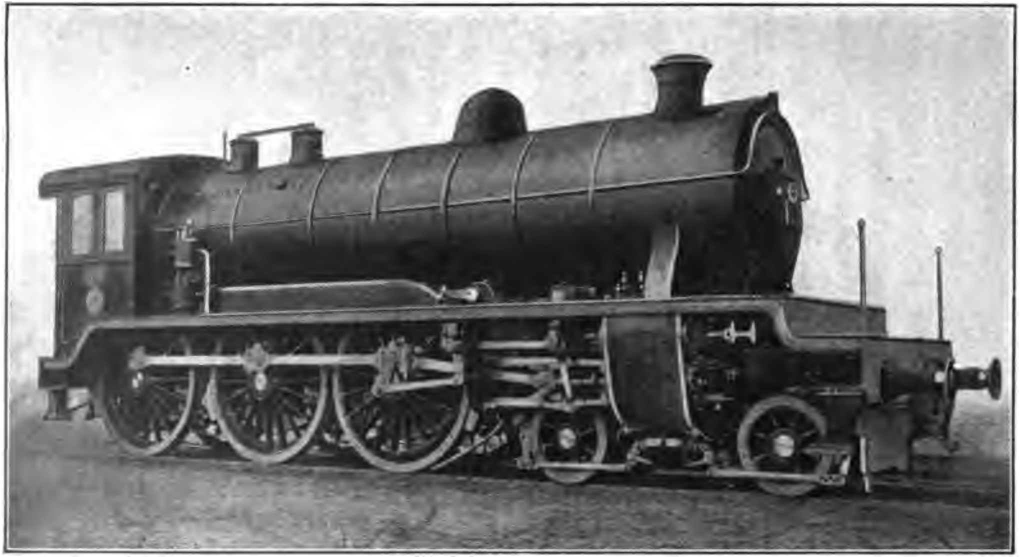


FIG. 21.—Four Cylinder, Simple, Balanced Passenger Locomotive, Belgian State Railways.

and represents a 4–6–2 engine with four *simple* ("simple," as the reverse of "compound," refers to the direct use of boiler pressure in all of the cylinders of the engine: where, no matter how many cylinders there are, their pressures are exhausted after the first expansive use) cylinders arranged on a horizontal line that centres through all four pistons and the main shaft, or axle; the main rods from all of the cylinders drive on the front axle, two of the cylinders outside of the frames—one on each side of the engine—having their main rods attached to the crank-pins, while the other two cylinders inside the frame are connected with a *built-up* crank axle; but with reference to their points of connection on the main axle the cylinders are arranged in pairs, the outside cylinder on each side and the one next to it just inside the frame are paired, with the crank-pin and the crank axle of each pair set 180 degrees apart, or just opposite each other on the shaft. With all moving parts in the cylinders, and the main rods, being exact duplicates in the matter of weights per pair, the motion on each side of the engine is perfectly balanced. The paired cylinders on one side of the engine are connected with the main-pin and axle crank at 90 degrees from the connections of the corresponding pair of cylinders on the other side for the same reason that the two main pins of the common two-cylindered engine are always set quarter-ing to each other—so that *both* forces can never be on the dead-centres at the same time.

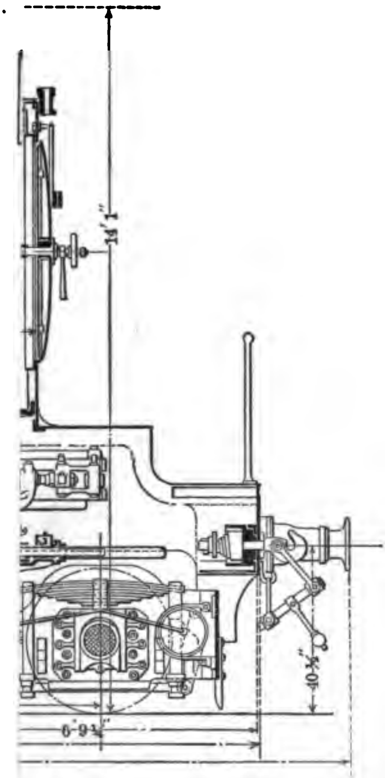
This plan of arranging the four cylinders and their delivery of power is being used on some of the most recently built American locomotives, but our engines are compounded, only two of the cylinders receiving boiler pressure direct: the Vauclain Balanced Compound, and the Cole Balanced Compound, both previously noted, are of this type, with the large, low-pressure or *second-expansion* cylinders outside the frame, and the smaller, high-pressure or *first-expansion* cylinders located inside, or between the frames; in *starting* a train—particularly a heavy one—the power of the cylinders termed *high-pressure* is temporarily suspended, thus removing an immensely twisting effect from the cranks in the axle at a critical time, and full boiler pressure at long cut-off is admitted to the large cylinders outside of the frame. After the train is under way, and the action is changed to *compound*, the inside cylinders receive direct boiler pressure and exhaust it into the large, outside cylinders in which the final expansive power of the steam is obtained, and from which the exhaust to the atmosphere takes place.

If the Stephenson valve gear is used on engines of this type it necessitates placing the eccentrics on some other than the crank axle, for there will not be room left after considering the main cranks; and taking the power to actuate the valve from any other pair of wheels is highly undesirable, both on account of the extra amount of lost motion introduced and the entire disability of the engine in case one side rod should break, if it should be the section between the wheels to which the main rod is attached and the pair carrying the eccentrics—*on either side of the engine.* The application of the Walschaert gear eliminates the possibility of such troubles, as this gear has no dependence on the axle for anything, and the eccentric can always be placed on the main pair of wheels.

The assertion that the Walschaert valve gear can be applied to engines of odd design without addition of complicated parts, where the Stephenson motion would have to include so much more weight of metal as to be almost prohibited, is proven in the case of this Belgian engine in Fig. 21.

In this engine *live* steam is used in all of the four cylinders and the operation of each is controlled by a separate *piston valve* of *inside admission*—a design of valve quite unusual in European practice—and *both valves on each pair of cylinders* are actuated by *but one set of Walschaert's gear.*

To glance at the set-up of the gear in Fig. 21,—the eccentric placed ahead of the main pin and the valve-stem connected at the extreme top end of the com-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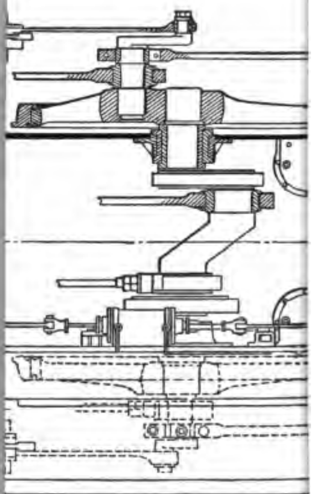
6' 9¼"
40⅜"



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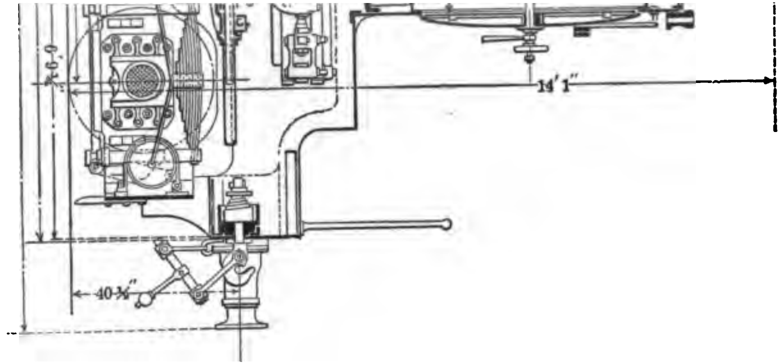
14' 1"
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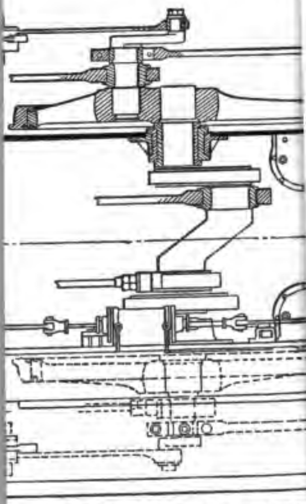

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bination lever—one would think that outside admission valves were indicated, but in this case things are not as they appear to the eye: the motion of the

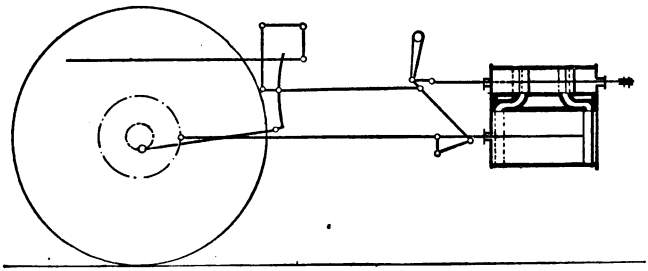

FIG. 24.—Side Elevation Diagram of Belgian Engine.

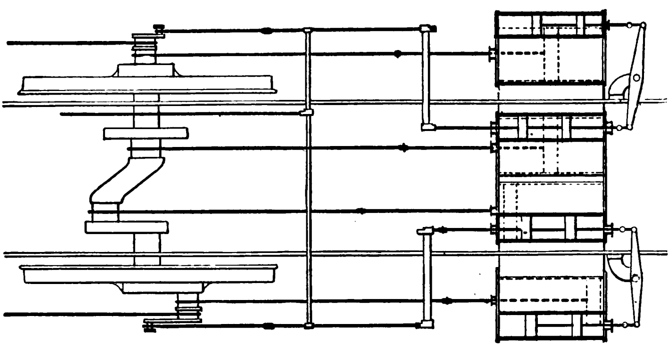

FIG. 25.—Plan Diagram of Above.

combination lever is not given to the stem of the outer piston valve, but is transferred through a rocker-arm to the valve operating the other cylinder of the pair—

the one inside the frame—and as the main rod from the inside cylinder is connected to the axle crank exactly opposite the main-pin connection of the outside cylinder—180 degrees apart—the set-up as shown is correct in its action on the *inner half* of the motion on that side of the engine.

Now, in order to supply a satisfactory motion to the valve of the outside cylinder it is only necessary to give it an exactly opposite movement to that of the inner one, and this is easily accomplished by extending the stem of the inner valve through the front head and connecting it to a lever that extends across the frame, a pin in the exact centre of the lever and a bracket attached to the frame forming its fulcrum, and to the other end of this lever is connected the extended rod from the outer valve, which also passes through its front steam-chest head. This action is the same for the pair of cylinders and valves on each side, and in the sectional views, on folding plates, Figs. 22 and 23, and the diagrams, Figs. 24 and 25, the valve connections are clearly seen.

In American practice the rocker-arm would undoubtedly be dispensed with, further simplifying the motion, and the gear so devised as to operate the outside valve and cylinder direct, using the lever connecting the extended valve-stems to actuate the inner valve.

The diameter of the cylinders is reduced to an extent that both pistons of one pair have an area exposed to steam pressure of about the same number of square inches as would be contained on a single piston of an ordinary two-cylindered engine of the same weight and steam-generating capacity, and therefore the amount of steam consumed is the same for each type of engine, but this Belgian locomotive with four cylinders is perfectly balanced, and the rods, pistons, etc., need not be much over one-half the weight of the corresponding parts of a two-cylindered engine.

. . . .

To the name of Egide Walschaerts belongs the credit and the honor of having first conceived the *principle* of the valve gear that rightfully bears his name, but that principle has been more highly developed by others, until the device as it is applied to locomotives at the present time is practically perfect; but in order to show that there has been no actual change in the original Walschaert theory, the following bit of history is here reproduced from the *Railroad Gazette* of November 24, 1905, and is contained in an article on the life and works of the inventor, by Professor M. J. Boulvin of the University of Ghent:

After Walschaert had obtained (through the assistance of his friend, M. Fischer) his Belgian patent, he took out another patent for the same invention, on October 25th of the same year, in France. There also exists among the documents left by the inventor a contract signed by Demeuldre, at Brussels in 1845, from which it appears that he undertook to obtain a patent of importation into Prussia for the new valve motion, subject to an assignment by Walschaert of half of the profits to be deducted from the introduction of the new valve motion in that country. It is probable, however, that this contract was never carried out.

The design attached to the Belgian patent is reproduced in Fig. 26. In this primitive arrangement the link oscillated on a fixed shaft, in regard to which it was symmetrical, but it had an enlarged opening at the centre so that only at the ends was it operated without play by the link-block, which was made in the form of a simple pin. There was only one eccentric, the rod of which terminated in a short T carrying two pins. The reverse shaft operated the eccentric rod and maintained it at the desired height. For one direction the lower pin of the T engaged in the lower end of the link, and to reverse the engine the rod was raised so that the upper pin engaged in the upper end of the link. The angle of oscillation of the link varied with the position of the pin in the link, and this oscillation was transmitted by an arm to the combination lever, which was also operated by the crosshead.

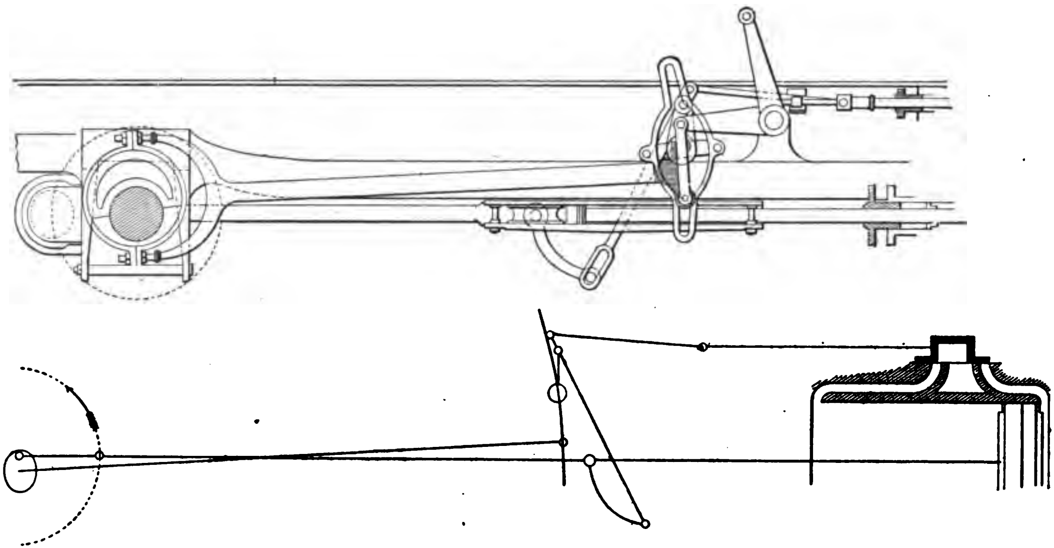

FIG. 26.—Original Design of Valve Gear as Patented by Egide Walschaerts. With Diagram.

The central part of the link could not be used for the steam distribution, as it was necessary to enlarge it to allow for the play of the pin which was not in operation. It may be asked why the inventor used two separate pins mounted on a crosspiece on the end of the eccentric rod instead of a single pin on the centre of the rod which would have served for both forward and backward motion without requiring the centre enlargement of the link. It must be borne in mind that the raising or lowering of the eccentric rod by the reverse shaft was equivalent to a slight change in the angular advance of the eccentric. Consequently, with a link of sufficient length, to keep down the effect of the angularity it was necessary to reduce as much as possible the movement of the eccentric rod. Notwithstanding its differences the mechanism described in the patent of 1844 is in principle similar to the valve motion with which every one is to-day familiar, and which the inventor constructed as early as 1848, as is shown by a drawing taken from the records of the Brussels shops, on which appears the inscription "variable expansion; E. Walschaerts' system applied to Locomotive No. 98, Brussels, September 2d, 1848."

Fig. 27, taken from this drawing, shows the valve motion as we know it to-day. For although it is true that the link and the combination lever are usually placed in a different position so as to shorten the

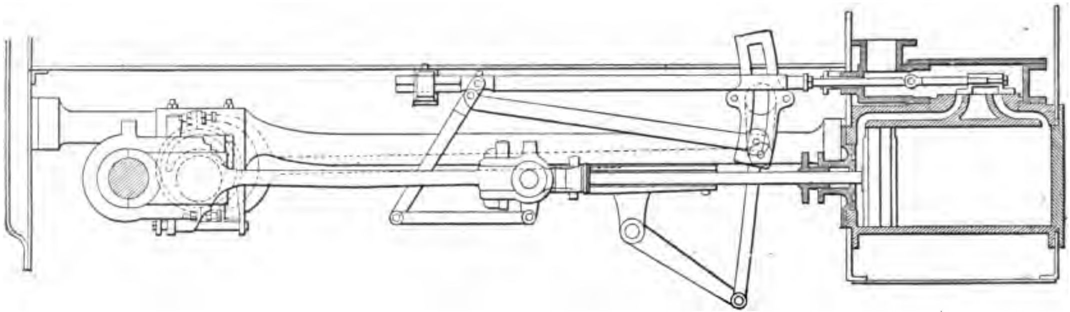

FIG. 27.—Modernized Arrangement of Walschaerts' Original Design.

eccentric rod and the valve-stem, yet the design of the locomotive often requires an arrangement similar to that shown above. The system which Mr. Heusinger Von Waldegg invented in 1849, and which he applied in 1850 to 1851, differs only in a few insignificant particulars from that shown in Fig. 27. Walschaerts had therefore preceded him.

SECOND DIVISION

DESIGNING AND ERECTING THE WALSCHAERT VALVE GEAR.

SECOND DIVISION

DESIGNING AND ERECTING THE WALSCHAERT VALVE GEAR.

WHEN a newly equipped engine with Walschaert valve motion is received by a railroad and after the gear has been set up complete at the roundhouse, everything should be carefully inspected, with the view of securing a perfect initial adjustment of the entire valve motion, and to eliminate, if found, any slight error whatever *while the other parts of the motion work of the engine are new* and of perfect fit and properly adjusted all around; especially in regard to the driving-boxes, rod brasses, and other bearings. It must always be remembered in *setting* the Walschaert valve gear that two otherwise separate and distinct motions are now brought into a working combination with each other in order to produce the desired movements of the valve, and these two motions are due to the piston's travel, delivered through the crosshead connection, and the throw, or turning movement, of the eccentric.

The piston's motion really governs the lead by offsetting the valve from its central position far enough to overcome its steam lap and enough further to give the amount of port opening desired for lead, and it will do this in both front and back positions of the piston, the lead being the same at the beginning of each stroke, both forth and back. The piston must move the valve in a direction *opposite* to its own position in the cylinder to secure lead with outside admission valves, but the piston must draw the valve further in the direction the piston lies in—toward the end of the cylinder—to give the advance for lead with a valve of inside admission; and this principle is made plain by the diagram in Fig. 28, in which it is seen that the piston is connected to one end of a common lever, and the connection to the valve-stem is either at the extreme opposite end, or at an intermediate point on the lever, according to whether the valve is of outside or inside admission. There are three points to a true lever, however, and the third point on the combination lever is its connection with the radius rod—the point where the valve, through the combination lever, receives the greater part of its motion due to the eccentric's action.

In Fig. 28, two combination levers are represented as being actuated by the piston and two radius rods, and are operating two valves,—one with inside admission and the other with outside admission; the latter, and upper, valve has its stem and the radius rod attached to the combination lever in such a manner that the angle given to the lever by the piston being at the extreme end of the cylinder has moved the valve from an otherwise central position a slight distance in an opposite direction from that occupied by the piston, as is required in order to open the proper admission port for lead.

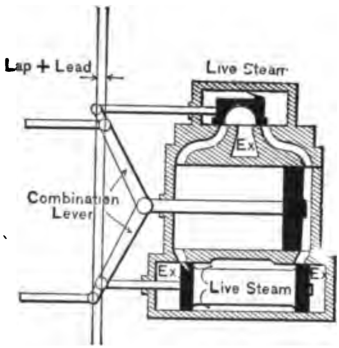

FIG. 28.—Comparative Diagram of Combination Levers Used with Outside Admission and Inside Admission Valves.

To give lead to the valve with inside admission the valve-stem and radius rod are connected to the lower combination lever in an exactly opposite manner to the way in which the same connections are made on the other combination lever just described. The angle of the combination lever in this case pushes the valve in the opposite direction, and the reason for this is plainly

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seen by reference to the plate: steam admission past the valve takes place externally with the upper valve and internally with the lower one, yet in each case the steam is admitted to the same end of the cylinder, and this requires that the two kinds of valves be advanced in opposite directions.

The Mason Machine Company undoubtedly were the pioneers in the attempt to introduce the Walschaert valve gear into this country, and if that company was still in the field, their experience would help greatly in the present-day application of the gear. The American Locomotive Company and the Baldwin Locomotive Works are, however, making a specialty of supplying the Walschaert motion to their heavier engines, and the Baldwin Company gives the following instructions for erecting the gear and setting the valves:

1. Check carefully the dimensions of the following parts, rejecting any that are not exactly to drawing:

a Valve.
b Valve-stem.
c Valve-stem crosshead, or slide.
d Combination lever.
e Crosshead link.
f Link radius rod.
g Reverse link.
h Location of combination lever on crosshead.
k Length of eccentric crank.

2. Check eccentric throw to see that it is exactly as specified.

3. Be sure that guide-bearer is correctly located from centre of cylinder, as the reverse link is usually attached to it, and variation in the location of the link cannot be allowed. If the link is attached to separate cross-tie, similar precautions must be taken to insure its correct location.

4. Exercise great care in the location of the link, so that the trunnion (fulcrum) centre is exactly to dimensions from the centre of cylinder.

5. See that the reverse shaft centre is correctly located to dimensions given, and that the lifting arm and link are of the exact lengths as specified.

6. Connect crosshead gear to valve, and radius rod to link, *without connecting eccentric rod to link.*

7. Hook up radius rod to exact centre of link, and then revolve driving wheels, seeing that crosshead gear gives correct lead as specified for both front and back admission ports.

(Say that $\frac{1}{32}$ inch is the required lead: with the steam chest open at this time—in the case of a D-slide valve —it should be seen that when the crank pin is at either dead-centre the admission port is open $\frac{1}{32}$ of an inch. With outside admission valves this will be plain, but with piston valves of inside admission a very little steam or compressed air can be used, and by marking the valve-stem and noting the blow from the cylinder cocks and the point at which the pressure ceases to escape, the amount of lead can be closely approximated. It should be possible, however, to obtain correct results in this phase of the motion with the eccentric rod connected with the link, for it is required that when the reverse lever is at mid-gear the radius rod shall be centred in the link, and the motion of the latter shall have no influence on the valve nor combination lever.)

8. Connect link to return crank by eccentric rod, and obtain full travel front and back, and in both forward and backward motions, correcting any errors by lengthening or shortening the eccentric rod as previously noted.

The valves may now be considered as definitely set, and may be tested to any cut-off points in the usual manner.

A simple additional check should be made as follows: Set one side of the engine so that the piston is at its extreme forward position in the cylinder, and check lead on the admission port.

In this position it should be possible to move the link-block through its entire travel in the link without in any way disturbing the movement of the valve.

This operation should then be reversed and the other side of the engine similarly tried with the piston located at its extreme *backward* position in the cylinder.

If an inspection of the Walschaert gear reveals an error it must not be regarded as a *constitutional* fault that cannot be corrected; go over the motion carefully and it will not be hard to find the cause—a cause that probably can easily be adjusted; for, while it must be realized that as it is impossible to perfectly "square the circle," and is as equally impossible to exactly convert the *circular motion* derived from the driving wheel or its axle into the *straight-line motion* of the valve without error—especially when the results from different points of cut-off are required to be the same in forward gear as with the engine reversed, in back gear—yet the designers have found means by which those inherent irregularities may be practically dissipated and the errors so far reduced that after the natural wear of the working parts has been taken up they cannot be detected, nor will they lessen the economy or power of the locomotive. It must not be inferred, however, that the foregoing statements are made to excuse any inaccuracies that may exist within Walschaert's type of valve gear when turned out of the builder's hands that render it inferior to the Stephenson motion as to the cut-off points, etc.; the Walschaert motion leaves the shop with an indication of truer locomotive valve performance than any other, excepting, perhaps, the Allan gear, which is generally regarded as the most perfect valve motion for locomotives in existence, but is not easily adapted to modern American locomotive construction.

In this connection it may be well to say that a great many persons confuse the Allan *valve gear* with the Allen *valve;* the former, as the words imply, refers to Allan's improved mechanism to operate any ordinary locomotive valve, while the Allen valve consists of a common D-slide valve with a supplementary steam admission port cored through it. The Allan gear is not used in this country, but the Allen valve is quite common.

In reviewing the Walschaert principle, or in direct inspection of the gear, keep these points in mind, always: The motion work once set up there is no regularly provided way for any readjustment except by the eccentric rod; when necessary, it may be lengthened or shortened until, with main pin on either dead-centre, the link has assumed its correct position, in which the reverse lever may be moved from the back corner notch to the farthest go-ahead position without shifting the valve, or moving it in the least. But, as lining, or shimming-up, the bearing supports, or carriers, affects the transmission of power, so it may be that parts of the Walschaert gear are not in perfect conjunction, and before the length of the eccentric rod is altered it is well to examine the length of the valve-stem, and it may be of advantage to either plane-off, or line-under, the foot of the link support, which might correct the rod measurements all the way from eccentric to valve, or else indicate the rod that remains to be changed.

In erecting or designing the Walschaert valve motion for new equipment it is of the utmost importance that it shall be correctly laid out and correctly set up. In individual cases the only accurate way is to have the motion plotted out by an expert, but that is a slow and laborious process, and in shops that make a specialty of supplying this gear a *model*, as a base to work from, is considered a necessity. With a complete understanding of the principle of the Walschaert gear, however, the use of certain formulæ will enable one to design the motion for any class of engine, because one of its greatest recommendations is that the most pronounced changes in locomotive construction need not involve any serious alterations in this valve gear.

Before presenting such formulæ the following suggestions are advisable:

The radius rod should be as long as it can be conveniently placed: at least eight times, or, better still, ten or twelve times the length of the travel of the link-block; and, of course, the radius of the link must be equal to the length of the radius rod.

The shortest length of the eccentric rod should never be less than three and one-half times the throw of the eccentric.

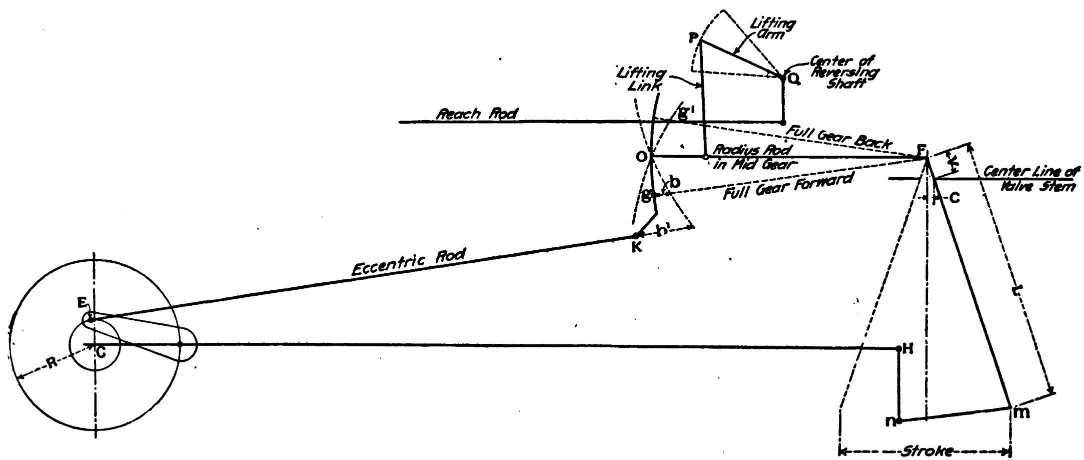

FIG. 29.—Reference Diagram, Walschaert Valve Gear.

R :C = L : V.
R = radius of the main crank.
C = lap and lead (one side).
L = distance between radius rod and crosshead connection (from F to M, Fig. 29) on the combination lever.
V = distance between the radius rod and valve-stem connections.

If it will not shorten the effective throw of the link too much the connection from eccentric rod to link should be brought down as near the centre line of motion of the main rod as can be done; but this is a point for compromise.

The length of the long division of the combination lever should not be less than 2¼ times the stroke.

The length of the combination lever must be taken to suit the conditions under consideration in each case, so that the angle through which it oscillates will not exceed 60 degrees, but less is preferable. The required horizontal movement or travel of the connecting point *F* of the radius rod to the combination lever for a given maximum valve travel must now be ascertained, and is found by the following formula in which *R* and *C* are the same as above, namely:

R = radius of main crank.
C = lap and lead.
a = half of the travel of the valve.
b = half the travel of point F.

$$b = \frac{R\sqrt{a^2 - C^2}}{R + C}$$ for outside admission, and

$$b = \frac{R\sqrt{a^2 - C^2}}{R - C}$$ for inside admission valve.

These may also be laid out graphically as per Fig. 30 for outside and Fig. 31 for inside admission valve by drawing a circle with *S* as a centre and *a* as radius (shown dotted in the figures). Lay out crank radius *R* to the left from $S = Sd$ and the lap and the lead dimension $C = Se$ on same side of *S* for inside admission (Fig. 31), and on opposite side of *S* for outside admission (Fig. 30). Draw *ef* and *Sh* perpendicular to *Sd* when *f* becomes the intersecting point between the valve travel circle and the line *ef*. Draw the line *df* and where this intersects the line *Sh* which point we will call *h* (found by extending *df* in Fig. 31); *Sh*

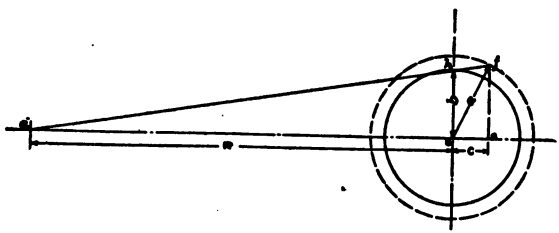

Fig. 30.—Laying-out Diagram, Walschaert Valve Gear.

is then the desired dimension *b* in the formula, or one-half the required movement of point *F*, the total of which is represented by the full drawn circle in the figures.

This is a most important function of the gear upon which practically all the others depend and is rather complicated to find by plotting. With a correct suspension of the link-block it will have the same horizontal movement as the point *F*, and by limiting the angle of the swing of the link to 45 degrees as a maximum we get the rise or depression of the link-block on either side of the link fulcrum the distance

$$Og = \frac{b^*}{tan.\ d}, \text{ (Fig. 29)}$$

where *O* is the link fulcrum, *d*=one-half of the swing of the link in degrees, and *b*=half the travel of point *F* in the previous formula.

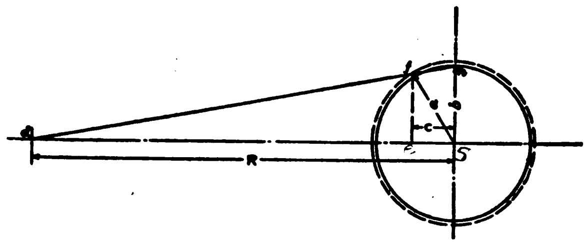

FIG. 31.—Laying-out Diagram, Walschaert Valve Gear.

The vertical location of the link fulcrum *O* should be, when practicable, on a line drawn through point *F* parallel with the valve-stem, and the eccentric rod connecting pin *K* to the link should be as nearly as practicable on the same level as the main axle in order to minimize the effect of the vertical play of the axle on the valve events, but on large engines it may be found necessary to lower fulcrum *O* and raise connection *K* to avoid excessive throw of the eccentric crank.

* As no suspension gives a perfectly equal drop of the block in both link positions, this formula is only approximate.

In locating the longitudinal position of the link fulcrum, consideration must be given to the lengths of the eccentric and radius rods so that both may be approximately of the same length. When these lengths fall below three and one-half times the total vertical sweep of the link-block the radius rod should be favored in preference to the eccentric rod. The exact position of the eccentric crank must be plotted as well as the longitudinal location of point *K*. The former must bear such relation to the main crank that it brings the link in its middle position when the main crank is on either side of its dead-centres and the connecting point *K* must be so located that it swings the link in the required angle *d* on either side of the middle position of the link; that is, in other words, the point *K* should be so located on the curve it must follow with fulcrum *O* as a centre that its deviation from the tangent of the eccentric rod to this curve is such that it, as near as practicable, compensates for the irregularities brought about by the angularities of the main and eccentric rods which in ordinary cases brings it from 2 inches to 5 inches in the rear of the tangent to the link drawn through the fulcrum *O*.

The locus of the suspension point of the radius rod lifting bar must also be plotted so that the link-block is at the same point of the link in its extreme positions at all cut-offs. This locus is a curve with its centre in the vicinity of the point *F* when in its mid-gear position. It would be impracticable, however, to have a lift arm of this length, and a curve of smaller radius must be substituted and so applied that it intersects with the former curve at points giving the least possible distortion to the motion, favoring the position of the link-block in which it is mostly used in service.

The sliding lifter shown in Fig. 11 meets these conditions better than any other method of suspension, but, due to wheel arrangements of various designs of engines, this is not always applicable but must be substituted by swinging lifters, as appear in use with nearly all the designs of valve gear that are illustrated in this book, and which, when properly plotted, give for all practical purposes equally good results.

The vertical height of lower connection *m* of the combination lever in relation to the crosshead connection has a slight influence on the port opening and should, therefore, in the centre position of the lever, be about in the same level as the crosshead connecting point *n* (see Fig. 11).

In Fig. 32 is the motion of the valve graphically represented by the Long diagram at different cut-offs, where the horizontal lines represent the port opening edges in the cylinder face, and the curves of the steam inlet edges of the valve, showing the opening and cut-off points where the latter intersect the former and the port openings at the various points of the stroke are measured by the height of these curves over and under the opening edges of the ports at both ends of the valve, respectively.

It will be noticed that these ellipses are slightly flattened on one side, which is caused by the slower lineal motion imparted to the valve relative to the angular

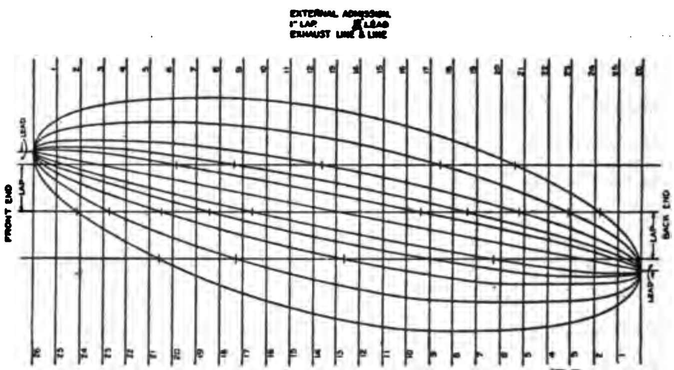

FIG. 32.—Long's Diagram of Valve Events Effected by Walschaerts' Motion.

motion when the eccentric passes its back centre compared with that of the front centre, due to the angularity of the eccentric rod, and is more marked the shorter the rod. Fully symmetrical ellipses are not obtainable, as this would require the eccentric and main rods to be of infinite length; this angularity, however, is of but little detriment to the distribution of the steam as long as the relation between the length of the eccentric rod and the throw of the eccentric is not less than the given limitations, and is present in all kinds of continuous valve motions derived from uniformly rotating cranks or eccentrics.

GENERAL NOTES FOR ADJUSTING WALSCHAERT GEAR.

1. Ascertain by the following method the position of the eccentric crank: Mark the position of the link relative to its middle position on both of the dead-centres of the main crank. If the position of the link is the same in both cases, the eccentric crank position is correct; if not, the eccentric crank should be shifted until this occurs, or as near so as possible.

2. After the eccentric crank has been correctly set the eccentric rod should be lengthened or shortened as may be required to bring the link in its middle position so that the link-block can be moved from its extreme forward to its extreme backward position without imparting any motion to the valve. It may be noted that the link position may be observed by the usual tram marks on the valve-stem, or direct by marks on the link pin, as may be found most convenient with the link-block in full gear—preferably ahead.

3. The difference between the two positions of the valve on the forward and back centres of the engine is the lap and lead doubled; it is the same in any position of the link-block and cannot be changed by changing the leverage relations of the combination lever.

4. The tram marks of the opening moments at both ends of the valve should be marked on the valve-stem and the latter lengthened or shortened until equal leads at both ends are obtained.

5. Within certain limits this lengthening or shortening may be made on the radius rod if it should prove more convenient, but it is desirable that its length should be so nearly equal to the radius of the link that no apparent change in the lead should occur in moving the link-block as stated in note No. 2.

6. The lead may be increased by reducing the lap, and the cut-off points will then be slightly advanced. Increasing the lap produces the opposite effect on the cut-off and reduces the lead the same amount. With good judgment these quantities may be varied to offset the irregularities inherent in transforming rotary into lineal motions.

7. The valve events are to a great extent dependent on the location of the suspension point of lifter of the rear end of the radius rod, when swinging lifter is used, which requires that this point should be properly laid

out by careful plotting, or, if convenient, it is preferably determined by a model, as irregularities due to incorrect locus of this point cannot be corrected by the other parts of the gear without more or less distortion of same. When this point is so fixed that a change of same is impracticable it may be better, however, to modify other elements if thereby the motion in general can be improved.

HELMHOLTZ MODIFICATION.

Among the various modifications of the Walschaert gear the one made by Helmholtz is probably of some advantage. This modification consists in making the link straight, and the radius rod is connected to the lifting link instead of to the link-block. The curving of the link is compensated for by the reversing shaft, or lifting-arm fulcrum, being located in a given position above the link, so that the locus of the suspension point of the lifting link forms an arc of a circle with its chord perpendicular to the centre line of the radius rod in its centre position. The radius of this arc bears the same relation to the length of the radius rod as the distance of the radius-rod connection above the link-block bears to the length of the lifting link, which results in that this connection is moving in an arc with a radius of the length of the radius rod, and the same motion of the valve is obtained as in the direct Walschaert gear.

Two advantages may be claimed for this modification, of which one is the straight link being simpler to make than the curved one, and the other is that on large piston-valve engines with inside admission the link fulcrum can be lowered by the amount the radius-rod connection falls over the link-block, whereby the eccentric-rod connection can be brought closer to the centre line of the axle with less length of link and eccentric throw. It has, however, the disadvantage that there is little choice in the location of the reversing shaft, or lifting-arm fulcrum, a proper position for which is hardly obtainable on all types of engines, and admits of no other method of lifting the radius rod in linking-up, or reversing, the engine.

Fig. 33 shows a combination of two diagrams: namely, those of Reauleaux and Zeuner, which coincide exactly as to the different valve events, which may be found as follows:

The distance *AB* represents the travel of the valve as well as the stroke of the engine, though in different scales, which makes no difference when the cut-off is always expressed in fractions or per cent of *AB*. The maximum cut-off is determined upon to be *AR*. Draw a perpendicular line *RC* from *AB* until it cuts the arc *ACB*. Next decide on a desired lead, and, with that as a radius, draw an arc with *A* as a centre. Draw a line from *C* tangent to the lead circle around *A*, when the lap of the valve is found to be equal to

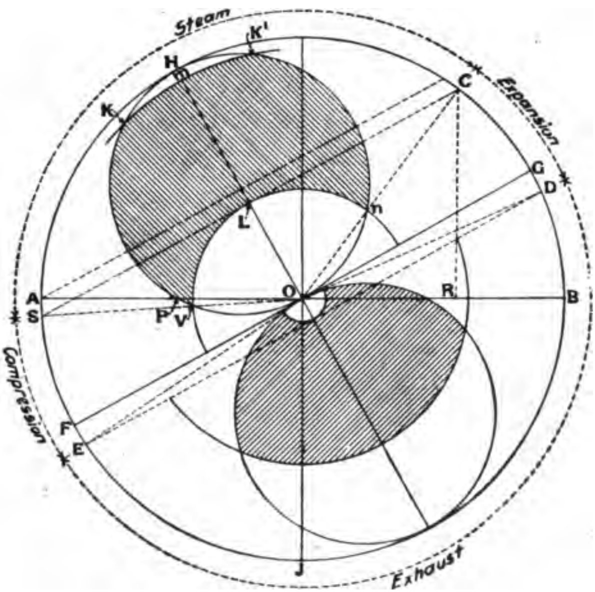

FIG. 33.—Combination of the Reauleaux and Zeuner Diagrams.

the perpendicular distance from the line *CS* to the centre *O* of the diagram. The crank will then be in position *OS* when the valve commences to open, or the angle *AOS* in advance of the dead-centre, and on *OC* at cut-off. Continuing, we find the valve in its middle position when the crank is on *OG* which is drawn parallel to *SC* through the centre *O*. Extend this line to *F*, and with the exhaust lap as a radius draw the exhaust lap circle on the opposite side of the line *GF* and draw *DE* tangent to this circle, when *OD* is the position of the crank at the release point. From this point the exhaust remains open until the crank reaches the position *OE*, when it closes and compression takes place until it again reaches *OS* for admission and one revolution is completed.

By placing the Zeuner diagram upon this, draw *HJ* perpendicular to *FG*, and with the radius *OH* of the eccentric circle as a diameter, draw the admission valve circle *OVHnO*, and the lap circle with the steam lap as a radius and find the intersection occurs at *V*, both with the circles and the previously laid-down admission line *OS* and the cut-off point at the intersections at *n*. On the line *OH* set off the width of the steam port from *L* toward *H* equal to *Lm*, and with *Om* as radius draw the arc *KmK*. The shaded figure enclosed by the letters VKK^1nL represents the steam port opening during the admission period, and the width of the port opening at any desired position of the crank is found by measuring the distance radially from *O* between the lap and valve circles on the port line, as the case may be, on the desired crank position.

The exhaust openings are determined in the same manner, and are shown on opposite side of *FG*, where the crank passes through the arc *DJE* during the exhaust period with a positive exhaust lap of the size *EF*. When the exhaust edge of the valve is line and

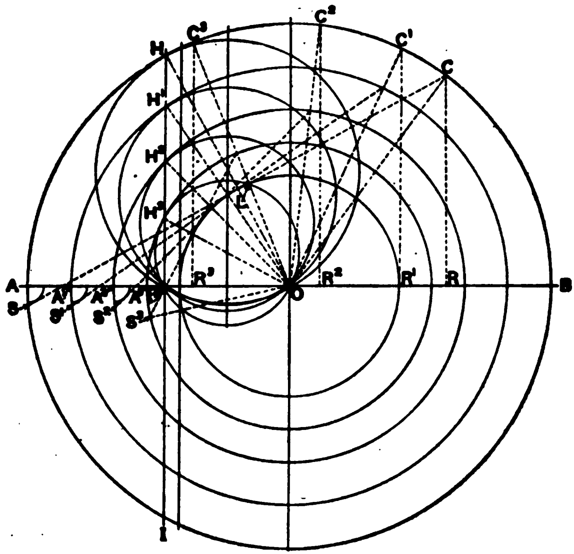

FIG. 34.

line this arc becomes *GJF*, or 180 degrees, and when a negative lap (clearance) occurs, the duration of the exhaust period exceeds the half revolution of the crank. The various events are indicated around the eccentric circle on the figure as they take place during a complete turn of the crank.

In Fig. 34 the eccentric and admission valve circles are shown at different cut-offs where each set of lines and circles is governed by the same explanation as those of Fig. 33 where the admission points S, S^1, S^2, and S^3 correspond to the closing positions C, C^1, C^2, and C^3, cut-off points R, R^1, R^2, R^3, etc. On *OH* we have the full-travel valve circle, and *OL* the lap, or radius, of the lap circle, the latter being the same for all cut-offs as well as the lead, the radii H^1, H^2, H^3, etc., of the eccentric circles, or diameters of the corresponding valve circles, terminate on a line *HI* drawn perpendicular to *AB* and at a distance from *O* equal to that of lap and lead.

When the reverse lever is in its centre position the diameter of the valve circle falls on the line *AB*, and is equal to lap and lead. Continuing in back position we have the same method repeated, and *OI* would be the full-travel valve-circle diameter, or the same as the eccentric radius for the valve travel. Any desired cut-off position may be laid out in same manner as that in Fig. 33, which shows all of the valve events for a complete revolution of the axle.

In actual practice the movements are not so regular as the circles indicate, as it is impracticable to obtain the various loci in their theoretical positions; besides,


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Fig. 35. Di
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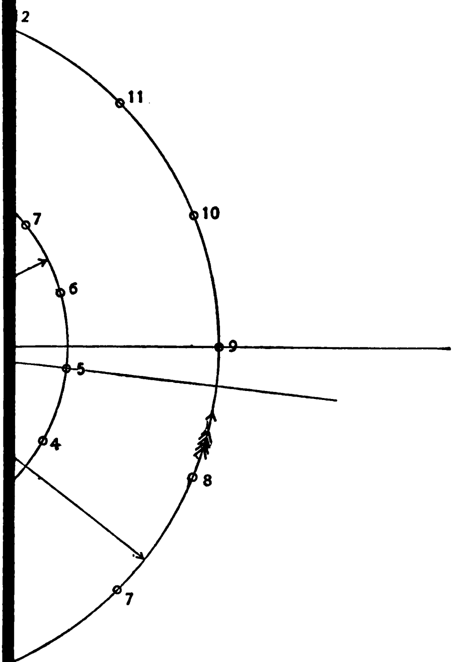

we have the angularities both of the main rods and the eccentric rods to contend with, and whereby irregularities are entering in the problem that must be compensated for, as referred to in the general description. It is not to be considered that a uniform circular motion is the best, but an approximation to it works with less shocks or jerks, and is therefore more desirable for so high-speed an engine as a locomotive. A few advantages can be taken, however, in selecting the suspensions and various connections, so that better results can be obtained than from a true circular motion, which are principally affected by three union points, and are, first, the connecting point of eccentric rod and link; second, the locus of the lifting-link suspension point; and third, the relative height of the crosshead-connection point of the union bar to the corresponding point of the combination lever.

It is not necessary to lay out the valve diagrams except where a given cut-off per cent is wanted. This is the most convenient way to find the required lap.

Fig. 35 and 36, the diagrams on the folding plates, represent the positions of the valve with the main crank at nine different points of the revolution of the driving wheel. In Fig. 35 the valve is of the piston type, with inside admission, and in Fig. 36 an outside admission valve is shown, of the D-slide pattern.

Cardboard models of each of those valves will be found in the pocket on the inside of the front cover, and these models may be placed on the horizontal lines representing the valve seats of the folder plates and a good idea can be obtained of the work done by the Walschaert gear in either of the two methods of applying it, namely, to actuate inside and outside admission valves.

Place one of the cardboard valves on its seat and imagine the main pin to be at any one of the nine numbered points of the first half of the wheel's revolution, turning forward, and then move the valve model until its index points even with the mark at the corresponding number of the scale that shows the different positions of the combination lever; this will be the correct location of the valve at that time, and the relative positions of a point on the piston rod—say the wrist pin—both pins in the union bar that connects the lower end of the combination lever with the crosshead, both ends of the radius rod, the reversing link, its point of connection with the eccentric rod, and the position of the eccentric are all shown by the same numbers.

These diagrams are—with the exception of the reduction in size—reproduced exactly from models used by the Baldwin Locomotive Works, through the courtesy of that company, and are quite interesting, not only in telling the story of the operation of the Walschaert valve gear, but also in settling to a certain extent any questions as to differences that may be thought to exist in the results obtained in the use of valves of internal admission vs. external admission.

Theoretically, the Walschaert eccentric is placed exactly 90 degrees of the wheel's circle from the main crank-pin, and it has been referred to in this book, in each instance, as so placed; but the diagrams, Figs. 35 and 36, show the eccentric as further and nearer to the main-pin than 90 degrees. This advance or recession of the Walschaert eccentric from a right angle to the main-pin is not for the purpose of securing lead, as it is with the Stephenson motion; if the connection of eccentric rod with the foot of the link was on a horizontal line through the centre of the main axle, then the eccentric would be set at just 90 degrees from the main-pin; and it is endeavored to get the eccentric rod to lie in as nearly a horizontal position as possible when the main-pin is on the upper or lower quarter, but this generally results in so great a length of the lower extension or foot of the link—the distance from link trunnion, or fulcrum, to the pin connecting the link foot and eccentric rod—as to cause an overshortening of the throw of the link. So, there must be a compromise; the foot of the link is not brought down, usually, as low as theory would place it; its connection with the eccentric rod is in most cases above a horizontal line through the driving-wheel hub centre, and to overcome the errors introduced by the resultant angular position of the eccentric rod the location of the eccentric in its relation toward the main-pin is changed accordingly. In Fig. 35, representing an inside admission valve, it is seen that the eccentric and main-pin are more than 90 degrees apart, while with the outside admission valve of Fig. 36 the eccentric is less than a quarter turn from the main-pin. The location of the eccentric as it is governed by the point of connection between the eccentric rod and link is exemplified in Fig. 37.

Squaring the centres of axle and link fulcrums, the angle indicates the point of connection from the eccentric rod to link foot with the link in a vertical position and main-pin on a dead-centre; continuing, the third side of the incomplete square furnishes the radius upon which the eccentric shall be placed, and it now depends upon which dead centre the main-pin stands and whether the valve is of inside or outside admission whether the eccentric shall be on one or the other side of the axle; in Fig. 37 the valve is of outside admission and the main-pin is on the back centre, so we place the eccentric on the wheel radius that brings it 45 degrees nearer to the main-pin than 90 degrees from it, because we find that a line from axle centre to the point of connection of eccentric rod and link foot is 45 degrees above the horizontal line through the hub centre. In other words, the wheel radius on

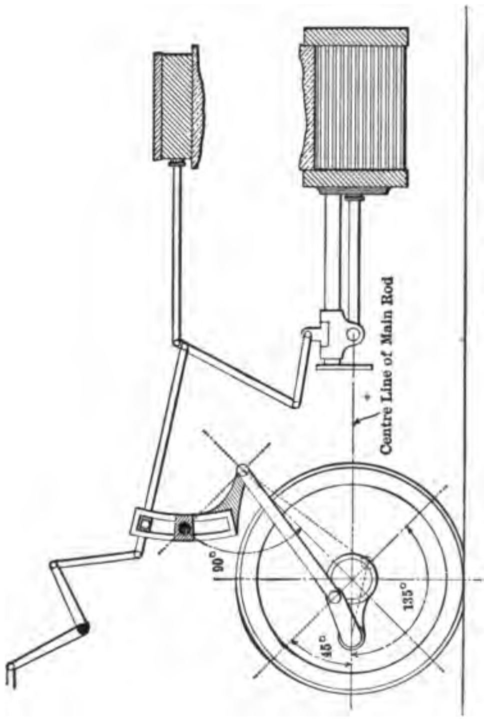

FIG. 37.—Hypothetical Design of Walschaert Gear.

which the eccentric is placed must always be 90 degrees from a line through the hub centre and link-foot pin when the link is in an exactly vertical position—a position in which the reverse lever can be moved between the farthest go-ahead and back-up notches on the quadrant without displacing the valve, and with the main-pin on a dead-centre.

With outside admission valves the eccentric and main-pin must be 90 degrees apart *minus* the number of degrees represented by the elevation of the link-foot pin above its normal position on the horizontal line through the hub centre. With inside admission valves, raising the link foot above the theoretically normal position places the location of the eccentric 90 degrees *plus* the number of degrees that the link-foot pin is raised, from the main-pin; thus, in Fig. 37 the position is shown in dotted lines in which the eccentric would be placed if the valve was of inside admission and the eccentric should *follow* the main-pin.

Fig. 37 represents an extreme case; but it would be possible to raise the link until the line through the hub centre and link-foot pin was perpendicular to the horizontal line through hub centre; in that case, and with outside admission valves, the eccentric would be 0 degrees from the main-pin: That is, the main-pin and eccentric would be on the same wheel radius. With inside admission valves the eccentric would be 180 degrees from the main-pin, or, just opposite it.

This supposititious case of extreme link elevation most plainly illustrates why irregularities in the valve motion are produced when the link-foot pin is raised above the centre line of the axle; and the erratic actions so introduced cannot be overcome. When this connection from eccentric rod to link is normally located, the rise and fall of the engine caused by the alternate yielding and exertion of the driving-wheel springs has no material effect on the motion delivered to the valve, but when that point of connection is raised above the normal, the interference to correct action is in proportion to the distance the link-foot pin is placed above the centre line of the axle. And if we imagine a case in which this connection point is raised to a position perpendicular to the axle centre, it is plain that while the engine is running and rolling from side to side over uneven track, for each inch of rise or fall of the link support there will be a full inch in the deflection of the connecting point between the eccentric rod and link extension, and this deflection will be in the direction of motion, causing alternate quickening and halting in the valve's action.

Fig. 37 represents the half-way between the case of extreme link elevation just considered and the technically correct position of the link in which the link-foot pin is on the same level with the centre of the axle; and while the former design would be practically impossible in locomotive practice it would work very well in stationary service. By reference to Fig. 37, and bearing in mind that the distance between the link fulcrum and axle centre is not invariable but greater or less when the engine is running, it can be understood why the link-foot pin should be as close to its theoretically established location as possible; also, why the eccentric in actual practice is not usually exactly 90 degrees from the main pin.

The folder diagrams, Figs. 35 and 36, show that by being properly designed the Walschaert gear in connection with piston valves of inside admission will produce valve events corresponding closely to those obtained from the use of the D-slide valve and outside admission. It will be noted that the action is practically identical in both cases, the steam admission taking place at the point 7, and the exhaust closure occurring and compression beginning at the point 8, with the main-pin at the same point in its revolution in each case.

THIRD DIVISION

ADVANTAGES OF WALSCHAERT VALVE GEAR

And Arguments for its Use as Against the Stephenson Link Motion

THIRD DIVISION

ADVANTAGES OF WALSCHAERT VALVE GEAR

And Arguments for its Use as against the Stephenson Link Motion

(1) *Accessibility.* There is not room enough for the Stephenson gear under a very large passenger or freight locomotive. The eccentrics are crowded, and proper inspection, not to speak of proper care, is difficult, except over a pit. Valve gear to be properly maintained must be accessible for inspection and lubrication. The accessibility of Walschaert gear should reduce engine failures.

(2) *Weight.* A saving of 1,745 pounds is possible by using the Walschaert gear, in the case of a very heavy passenger engine. The Stephenson gear, weighing as much as two tons, is far too heavy to be satisfactorily reversed twice in every revolution on fast running locomotives.

(3) *Directness.* Walschaert gear transmits the moving force to the valve in very nearly straight lines, avoiding the springing and yielding of the rocker arms, rocker shafts, and transmission bars, which

cannot be avoided in these parts of the Stephenson motion, even if they are made very heavy.

(4) *Permanence of Adjustment.* The advantage of permanence of adjustment lies with the valve gear which has no large eccentrics. This is proved by the statement of the Superintendent of Motive Power of one of the great trunk lines—a comparative statement covering the performances and condition of the valve gear of engines that differ only in having Walschaert vs. Stephenson gears. This statement appears in this book later on. All connections in the Walschaert gear are made with pins and bushings, which are designed specially to resist wear.

(5) *Wear.* Large eccentrics, besides occupying too large space, wear unevenly, and lubrication is difficult with the high surface velocities of the largest sizes. With hardened pins and hardened bushings the Walschaert gear has an important advantage in maintenance.

(6) *Smooth Operation.* Stephenson links, under the influence of two eccentrics, move through wide angles, resulting in a wedging action of the link-block, which strains the gear when working hard, and produces lost motion. Walschaert links oscillate through smaller angles, producing less lost motion. The effect of this angularity of the links is plainly discernible on the testing plant.

(7) *Frame Bracing.* The removal of the valve gear from between the driving wheels facilitates bracing the frames of the locomotive laterally.

(8) *Unvarying Advance of the Valve.* Lead, if present, is not altered by hooking-up the link.

(9) *The General Adoption of Walschaert Gear Throughout Continental Europe.* Its use there for over half a century.

As to accessibility, everything is in favor of the Walschaert motion. The common link motion is crowded in between the frames where it is very hard to get at; the space that it occupies could well be used for other purposes, and the valve gear requires too much attention to be stowed away in a somewhat inaccessible place. When break-downs occur on the road, time is lost in doing repair work, or in disconnecting, in the confined space inside the frame; and in the shop, the locomotive with the Stephenson gear requires considerably more time to have its valve gear set up correctly than does the engine equipped with the Walschaert motion. Imperfectly lubricated machinery is expensive, and the oil used on railroads represents a large sum annually. The double eccentrics require a large amount of oil, but their location invites carelessness in getting it properly applied, and the monthly strictures against the men as to the amount used results in an over-economy; the effect is that the eccentrics run hot and trains are delayed. I was fireman on an engine when an eccentric strap broke and a hole was punched through the water leg of the firebox, not only disabling our engine, but, through the complexity of train operation, delaying and tying-up other trains until the business of the whole division was disorganized. Oil was hard to get and hard to put on, else the trouble would not have occurred, but it could not have happened if our engine had been equipped with the Walschaert gear.

No matter how conscientious the engineer may be, it is a well-known fact that machinery placed where it can be gotten at is taken better care of, both as regards oiling and inspection, than where it is put in an out-of-the way and crowded place.

It is not uncommon for the valves to get "dry" on account of the lubricator choking, or becoming empty; in such cases the tremendous resistance of the valve under steam pressure throws increased labor upon the eccentrics that would have but very little tendency to over-heat the turned pin of the Walschaert gear; but the location of the Stephenson eccentrics hides from the engineman the first symptoms of trouble, and afterward stands in the way of receiving proper relief.

The amount that the Walschaert gear saves in weight over the common link motion is rather startling, being in some cases very close to one-half. The motion, from eccentric to valve, on a big, modern passenger engine is continually tearing itself to pieces. Is there any wonder due, when one considers the weight of it all, and that the joint action of two opposing eccentrics are throwing the link and transmission mechanism in one direction to be instantly stopped, started, thrown the opposite way and stopped—only to be re-started and stopped again—and so on with the rapidity engendered by a speed of seventy or more miles an hour? It is a wonder that eccentric straps, rods, bolts, etc., stand the strain at all, and a weight of metal must be there to give strength to the parts that is one of the principal reasons for the adoption of the Walschaert gear on so many newly built engines; the load has been lightened.

"It is understood that the Walschaert gear was applied to the Lake Shore & Michigan Southern Railway locomotives at the suggestion of The American Locomotive Company, to whom belongs the credit for the present tendency toward the introduction of this gear in this country."—*American Engineer and Railroad Journal.*

Now, therefore, as the above-named road has purchased a great many new engines of various types, and as a number of those engines of each type has been furnished with the Walschaert valve gear while the others have the Stephenson link, it is possible to show the figures regarding the weights, proportionately, of the two gears, on engines that are in all other respects exactly alike.

Following, in parallel column, are presented in detail the weights of the several parts of the valve gears, Stephenson and Walschaert, of the L. S. & M. S.—New York Central, Class D, 2–8–0 freight engines, built by the American Locomotive Company:

	Stephenson. lbs.	Walschaert. lbs.
Crank pins, main	520	490
Crank-pin arms		100
Crosshead arms		60
Eccentric	600	...
Eccentric strap	800	...
Eccentric rods	200	220
Link	280	260
Link support		280
Link lifter	45	...
Reverse shaft and arms	260	400
Rockers	260	...
Rocker boxes	240	...
Transmission bar	300	140
Transmission-bar hanger	80	72
Valve rod	80	70
Vibrating rod		220
Vibrating link		70
Total, pounds	3,665	2,382
Saving in weight, pounds		1,283

One thousand two hundred eighty-three pounds is a tremendous weight to be included unnecessarily in rapid-acting machinery; especially when the deflection of one-thirty-second of an inch may change the motion sufficiently to blind one of the events—lead, for instance. And in substituting the Walschaert gear it means cutting off thirty-five (35) per cent of the weight of the old link motion.

But some of the above are fixed, immovable parts. If we want to find the difference in weight of the *working* parts we should cut out such as the reversing shaft, rocker boxes, link support (Walschaert), etc., and we then find the weight of the Stephenson *motion* gear to be 3,120 pounds, and that of the Walschaert gear 1,702 pounds—a saving in weight of the parts that thrust and take of 1,418 pounds, amounting to the still more interesting figure of over forty-five (45) per cent.

Of the heaviest passenger engines ever built, at this date,—the class shown in Fig. 19—some have Stephenson link, and some the Walschaert gear. The comparative weights of the valve gears of this class, J 2–6–2, are:

	Stephenson. lbs.	Walschaert. lbs.
Crank pins, main	390	365
Crank-pin arms		80
Crosshead arms		50
Eccentric	740	...
Eccentric strap	880	...
Eccentric rods	200	175
Link	260	240
Link support		250
Link lifter	120	...
Reverse shaft and arms	350	375
Rockers	280	325
Rocker boxes	300	300
Transmission bar	270	160
Transmission-bar hanger	120	65
Valve rod	130	100
Vibrating rod		180
Vibrating link		60
Total, pounds	4,040	2,725
Saving in weight, pounds		1,315

or 32½ per cent.

Amount per cent saved in weight of the *motion* parts of gear, nearly 47.

Another type of Classs J 2–6–2 carries the following weights:

	Stephenson. lbs.	Walscharet. lbs.
Crank pins, main	440	415
Crank-pin arms		90
Crosshead arms		50
Eccentric	740	...
Eccentric straps	1,120	...
Eccentric rods	280	200
Link	300	275

	Stephenson. lbs.	Walschaert. lbs.
Link support		260
Link lifter	120	...
Reverse shaft and arms	385	390
Rockers	280	350
Rocker boxes	300	325
Transmission bar	300	170
Transmission-bar hanger	120	75
Transmission-bar bracket	200	...
Valve rod	100	100
Vibrating rod		180
Vibrating link		60
Total, pounds	4,685	2,940
Saving in weight, pounds		1,745

Cutting out the non-moving pieces there is a difference in the weight of the *working parts* of the two gears applied to Class J 2–6–2—of this particular Prairie type of engine—of 1,835 pounds, equalling a saving by the use of the Walschaert valve gear of *Forty-eight plus per cent* (48 + %). The *motion part* of the latter gear, then, is but little more than one-half as heavy as the corresponding part of the common link motion used on other engines of the same class.

The energy consumed in keeping going all of the *superficial* weight of the Stephenson valve gear on our modern locomotives might just as well be expended in carrying several more tons of train load. Its reciprocating motion at high speeds is destructive. On engines of large size the eccentrics are of such weight, on account of their increased size made necessary by the extraordinary diameter of the axles, that in spite of an expensive amount of lubrication a braking power is exerted, and *they will run hot.* These weights of the valve gear make engines hard to reverse or hook up, and there is a certain lack of economy when, in spite of careful counterbalancing of the shifting parts of the valve gear, any engine "handles" hard.

Freight engines run as fast as passenger engines do. By that is meant that a freight engine has smaller wheels, and to make the running time required of the freight trains of to-day the smaller wheels of their engines must make about as many revolutions per minute as do the bigger wheels of the passenger engines to make their time; and for this rapid action of the machinery the lesser weight of the Walschaert gear makes that type of valve motion most desirable. And no change in locomotive design will call for any increase in the number of reciprocating parts of the Walschaert gear, thus saving the weights, and errors in the motion due to vibration and lost travel that are present in common with "transmission bars," etc.

This latter point is covered in the matter of *directness.* There are but few motion parts to the Walschaert gear, and they are of the same number for all engines in all classes of service, except that sometimes the connection from combination lever to valve-stem, or from eccentric rod to link, has to be carried over by a sort of rocker-arm arrangement on account of the steam chest being rather far inside from the centre line of the cylinder.

A motive-power official will inform us that an engine with the common link motion has a certain amount of lead, in full gear, but he knows that that matter of lead is decidedly uncertain—a variable quantity—considering the interference of the numerous joints in the gear from eccentric to valve, the slackness from wear of the two eccentrics and their encircling *straps*, of the many pins and rockers and the vibration of the transmission bar. And this lost motion is further acted upon by the practice on many roads of using piston valves of inside admission with closed "spools," instead of having the valves open from end to end; at the instant of *steam release* from the cylinder the exhaust pressure acts directly against but one end of the double piston, and with a power approximating the steam pressure that is admitted to the low-pressure cylinder of a compound engine, forcibly closing in all slackness of the motion from the valve clear back to the eccentric.

In regard to permanence of adjustment, and the effects of wear, the results obtained from the L. S. & M. S. engine proves the superiority of the Walschaert valve gear; the following statement is from the Superintendent of Motive Power of that road, Mr. H. F. Ball:

"In reference to the Walschaert valve gear, engine No. 912 has now a total of $\frac{1}{16}$ inch lost motion in the valves. This is the total lost motion in the whole motion work; the engine has made, approximately, 39,000 miles. Engine No. 5924 (with link motion), examined the same date, had $\frac{5}{16}$ inch lost motion in the valve-stem, and has made, approximately, 32,000 miles. This seems to be very much in favor of the Walschaert valve motion."

As to smoothness of operation, it is only necessary to understand the construction of the Walschaert gear and to compare it with the double eccentric motion, or to watch it in action, to realize its niceness of operation.

Removing the valve gear from between the frames permits a cleared inside space for other uses that has always been wished for. One of the common causes of engine failures in recent years has been weak engine frames, very often resulting in their breaking. At the very point where strong cross-bracing is necessary—between the cylinder casting and main driving-axle—there has been no room for it, the space having been taken up by the eccentric and link mechanism. With the Walschaert gear, as much heavy frame bracing as is desired may be put in—or anything else. There are engines like that of the Erie motor car, previously illustrated, where much inside space is needed for the spring arrangement and main car-body bearing.

Some very heavy Atlantic type passenger engines with the Stephenson link motion were received by a certain road, and trouble that was experienced at the start from hot driving-boxes never ceased. The underneath construction of these engines compelled placing the links in such a position that the eccentrics, to be in line, were crowded outward, making necessary the use of a too narrow driving-box, and a brass of insufficient bearing surface for the great weight that it had to support. The next delivery of engines to that road were of the same class except that they had the Walschaert valve gear, and wider driving-boxes that had bearing surfaces proportionate to the weight of the engine, and these engines ran cool from the first trip. Nothing about the engine needs to be sacrificed to make room for the Walschaert valve gear.

The improved design of the De Glehn Balanced Compound has been adopted by the American Locomotive Company, and the Baldwin Locomotive Works, in their *Cole*, and *Vauclain*, balanced compound engines, respectively, and in each of which a *crank-axle* is a principle feature. The manufacture of this type of engine is increasing in America since European practice has shown us the absence of danger from that bugaboo—the crank-axle. Instead of crowding four eccentrics and the rest of the valve motion—with its heavy interference with perfect balance—among the gear of the inside engines, it can be replaced, as with the De Glehn engine, with the lighter, more accurate, Walschaert gear on the outside of the frame and wheels.

The possibilities that lie in the use of this valve gear are not generally realized in this country; it can be applied to engines of any type without material alteration, and without the use of transmission mechanism. The line of motion is nearly straight, and the longer the eccentric rod and radius rod—the greater their radius—the more perfect will be their work. Europeans know these things; they seem to believe, also, that the desired results from the use of this valve motion are best secured in connection with the outside admission, D-slide valve. On the main lines of Continental Europe 90 per cent of the engines are equipped with the Walschaert gear, and the remaining 10 per cent represents but a fraction of Stephenson link motion. At the Liège Exposition, out of 31 engines on exhibition, 25 were fitted with the Walschaert valve gear.

Its adaptability is great. If it is desirable, in order to simplify the reversing mechanism on any particular type of engine, to *raise* the radius rod and link-block when the reverse lever is thrown forward, it will only be necessary to change the position of the eccentric 180 degrees—from a quarter ahead of the main-pin, with outside admission valves, to a quarter behind the pin.

And now, as one of the chief peculiarities of the Walschaert gear lies in the manner in which lead is secured, and maintained unchanged throughout the different points of cut-off, *the general effects of lead* are worthy of speculation. Self-opinioned men, men who think for themselves and are not too over-conservative, are beginning to question if the advance of the valve, any further than is necessary to overcome the steam lap, is really a help or a hindrance. If not a help, can it fail to be a hindrance? There doesn't seem to be any reason why, with any class of engine in any branch of service, the amount of lead opening in full gear should *increase* as the speed increases, as does occur when the engine with the Stephenson link motion is hooked up. With the Walschaert gear the amount of lead suitable to the speed at which a particular engine will be expected to run or the work it will be required to do can be decided upon and the valve advanced to permit that opening, and that lead remains positive, unaffected by hooking-up, and almost entirely free from the shifting of results due to lost motion and vibration.

An expert on valve motion has the following to say in regard to this question; it is an extract from an article in one of our leading technical journals:

"Opinion has grown, as error is apt to grow, that an admission of steam is absolutely necessary to create a cushion upon which the piston and connections may gradually come to rest before beginning the return stroke. Those who are accustomed with the running of locomotives know that when the throttle valve is closed the rods and reciprocating parts run smoothly, even if loose. No pounding is observable at any rate of speed.

"Is it not reasonable to expect that the piston meeting with steam resistance before it has completed its stroke should rudely affect the bearings of the rods and crank-pins, and induce an excess of friction? It has been repeatedly shown that if the pre-admission of steam amounts to a sufficient quantity to cause compression, a marked increase in steam consumption is shown.

"The real need is the readiness of admission of steam at the time when it is required to move the piston in the other direction, and while the ordinary valve has this advantage in a marked degree, this rapidity of opening compensates in some degree for its other defects.

"Assuming, however, that lead is desirable for slightly cushioning the piston while the working parts of the engine are being subjected to intense friction, is it not reasonable to assume that the same amount would be sufficient for different rates of speed? Upon what hypothesis can it be assumed that one-thirty-second of an inch is sufficient opening at a moderate rate of speed and that three-eighths of an inch is necessary at a higher speed?"

Exactly; and if a small amount of lead is demanded by those who think it necessary at certain times, the use of the Walschaert gear will prevent that amount from increasing as the speed increases and the reverse lever is hooked up.

One night the writer was firing a little 4–4–0, 17-inch by 24-inch engine pulling a very heavy passenger train, when we broke down and had to disconnect the engine on one side. After fixing things up in good shape we proceeded; there was only one more stop to be made short of our journey's end, but in spite of the efforts of the engineer, we came to a standstill at that station with the working engine on an exact dead centre.

It was decided to unlock the Janney coupler behind the tender, leaving the safety chains coupled, and "pinch" the engine ahead and off the dead centre, and with the Janney set to couple, to pull the train a few feet by the safety chains and allow the coupling to "make"—trusting to luck to stop again with the crank-pin off the centre, in order to re-couple the air hose.

The trainmen took turns operating the pinch-bar, but their efforts were in vain. I noticed, however, that just before their groans began to indicate the application of cause toward hoped-for effect, the engineer had opened the throttle-valve pretty strong. The engine would not move, however, and the engineer finally shut off steam, jumped down from the engine and took the bar: "Now, Billy! Give 'er steam—here she goes!" he promised; but she wouldn't move; he kept on trying, with no better results, so I shut off steam and opened the cylinder cocks.

The conductor had about decided to send for the section men, when the engineer concluded to try the pinch-bar again, and calling to me to open the throttle, he threw himself at it once more: "Lay on, Macduff!" thought I, with a sudden idea, and I did not open the throttle valve this time; the result was that the engine responded to the pinch-bar as promptly, and was kept moving with as much ease as if it were an empty flatcar.

That night, then and there, I lost all of my confidence in the theory of *lead*. It was proven that lead not only fails to be of any assistance in carrying an engine past the dead centre but *offers resistance* to the crank-pin's movement past the dead point. The force that lead causes to be exerted when the engine is on a dead centre absorbs, or nullifies, much of the energy furnished by the other source of power at its zenith—the *engine* on the other side, with its admission port wide open and the relation of crank-pin to driving-axle giving the maximum leverage.

If the pre-admission of steam to the cylinder, that is referred to as lead, is finally conceded as necessary only for cushioning the piston at the completion of its stroke, any argument for it is now clearly fallacious, for the reason that the exhaust may be cut off at any point toward the finish of the piston's stroke and the resultant compression will produce the cushioning effect just as well—and more economically,—as evidenced by the quoted authority, than by means of any pre-normal opening of the admission port.

Motive-power officials often try to induce engineers to run their engines with full open throttle and reverse lever hooked up to the limit, claiming that an engine would run faster and work more economically that way. That method has been tried, fairly, and also the other one of using a lighter throttle and a little longer travel of the valves, and invariably the latter way gave the best results, both in speed and fuel economy. It is not imagination, and might be attributed to the fact that the lower down the link is worked the less the lead, with the Stephenson motion, and the less "friction on the bearings of the rods and crank-pins" there will be. Of course, it may be said in answer, that there is but a slight increase in the amount of lead from the point where the engineer worked the lever up to the point at which the master mechanic wanted it worked; yet *there was a difference*, and an otherwise unexplained variance in the performances of the engine—favorable to the position of the reverse lever in which it is claimed by some that the steam is "wire-drawn."

The simplest test to prove the superiority of the Walschaert valve gear, and the easiest to make, yet most convincing to the practical mind, is, where there are engines of the same general type except that some are equipped with the Stephenson link and others have the Walschaert gear, to note the boiler pressure required to move each of these engines from its stall in the roundhouse, with its cylinders "cold." The test with big "battleship" engines has shown that eighty-five pounds on the steam gauge were required to get the engine with the old link motion on the turn-table, while the engine having the Walschaert valve gear was moved out, easily, with the gauge showing thirty-five pounds of steam.

FOURTH DIVISION

QUESTIONS AND ANSWERS

Relating to the Walschaert Valve Gear

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Relating to the Walschaert Valve Gear

Question 1.—What is meant by "Valve Motion"?

Answer.—Valve motion, or valve gear, refers to the system of rods, levers, etc., that transmits motion to the main valve that is used to admit steam to, and exhaust it from, the cylinder of an engine; it is the action of the steam in the cylinder that empowers the piston.

Q. 2.—From where does the valve gear receive its initial motion?

A.—The valve gear receives its motion from some point, or points, in the machinery that is actuated by the piston.

Q. 3.—What kind, or style, of valve is used in connection with the Walschaert gear?

A.—Any valve that is used with any other form of valve gear. Strictly speaking, the valve is not a part of the *valve gear*.

Q. 4.—What is the difference, then, between the

Walschaert gear and the Stephenson link motion so generally used, until recently, in America?

A.—The difference is in the manner in which the initial source of motion from the turning of the driving-wheels is secured, in the way the gear is reversed to change the direction in which the engine shall run, and the method of securing *lead.*

Q. 5.—Do not both the Stephenson and Walschaert gears secure their initial motion through eccentrics actuated by the turning of the main pair of driving-wheels?

A.—Yes; the Stephenson link is given its motion by two eccentrics keyed upon the main-axle, one of which is thrown into gear to so actuate the valve that the engine will run forward, while throwing the other eccentric into gear will cause the engine to run backward. In the Walschaert motion the link receives the main, or initial, valve-actuating power through a single eccentric, not on the axle but in the form of a "return crank" fixed upon the main crank-pin, and this eccentric is in full gear and works the link at its full throw always, and with the engine running in either direction.

Q. 6.—How is the Walschaert motion reversed?

A.—The position of the *radius rod* that directly actuates the valve-stem is shifted from one to the other end of the link to cause reversion; the radius rod is raised or lowered for this purpose by the regular reversing gear, the link being suspended from a bracket by a fulcrum pin, or trunnion, at its exact centre.

Q. 7.—What is the position of the valve in relation to the piston?

A.—*Theoretically*, the valve is always one-fourth of a complete stroke, or cycle of motion, ahead of the piston, when the engine is running in either direction.

Q. 8.—What is meant by *Lead?*

A.—If the valve *was* exactly one-fourth of a cycle of motion in advance of the piston, the eccentric that actuates it would necessarily be placed at a point on the axle just 90 degrees ahead of the main crank-pin in respect to the direction in which that eccentric should cause the engine to run, but, if so placed, when the piston was at the beginning of its stroke—at one end of the cylinder—the valve would be exactly centred on its seat, with both ports, or steam passages, to the cylinder covered and closed. In actual practice the valve is advanced slightly, but far enough, in the direction of its required travel, to open, by a very short distance, the admission port at the piston end of the cylinder; this gives a pre-admission of steam against the piston *just before its stroke has been completed*, and has the double effect of cushioning the piston and hastening the full opening of the steam admission port. This preliminary port opening to the cylinder is termed the Lead.

Q. 9.—What further effects are produced in advancing the valve to create the lead opening, that cannot be regarded as beneficial?

A.—The advance of the valve causes an earlier closing of the exhaust of the used steam from the cylinder, thereby creating higher compression ahead of the piston—between the piston and the cylinder head toward which it is travelling; the cut-off of *live* steam that is being admitted to the cylinder occurs sooner during the piston's stroke, and this detracts from the turning power of the main crank when the engine is working in full gear with a heavy load; and, as giving lead hastens all of the valve events, the steam that is driving the piston is retained in the cylinder during a shorter part of its stroke, and this earlier steam release is a loss of a certain per cent of the steam's expansive force.

Q. 10.—After the cut-off of the exhaust has occurred, will not the compression between the piston and cylinder head provide the cushioning effect that may be necessary as the working parts approach the reversing point in their motion?

A.—Yes, the very slight amount of compressible resistance that is deemed necessary may be so obtained, by a suitable design of valve motion.

Q. 11.—How is the advance of the valve to create lead opening secured with the Stephenson link motion?

A.—By advancing both the "go-ahead" and the "back-up" eccentrics in the proper directions, on the axle.

Q. 12.—How is lead obtained with the Walschaert gear?

A.—In the Walschaert valve gear lead is obtained from the straight-line motion of the *piston*, instead of from the circular motion of the *axle* with its errors incidental to the angularity of the conveying rods. Walschaert's vertical *combination lever* has its lower end connected to the crosshead and the upper end to the valve-stem where an outside admission valve is used; intermediately, the radius-rod connection with the combination lever forms its fulcrum, and the motion derived from the crosshead so modifies the motion imparted by the single eccentric, through the radius rod, as to produce the required lead in either forward or back gear. With the use of inside admission valves the points of connection of the radius rod and valve-stem to the combination lever are reversed, the radius rod being connected to the extreme upper end of the lever and the valve-stem connected intermediately.

Q. 13.—Does the lead, as derived by the Stephenson method, remain constant?

A.—No; each eccentric is separately adjusted, or advanced, to give the decided amount of lead *when in full gear*, but as the link is hooked up the lead automatically increases.

Q. 14.—Is this increase of lead to be desired?

A.—It is not, in any class of service.

Q. 15.—Does the lead vary with the Walschaert gear?

A.—No; with the Walschaert method lead, if present, remains unvaryingly the same at all points of the cut-off.

Q. 16.—Is the position of the valve advanced for any other purpose than that of securing lead?

A.—Yes. The steam edges of the valve are widened beyond the outside edges of the admission ports, and the first advance of the valve is for the purpose of overcoming the delay of port opening in consequence of this overlap. The distance the edges of the valve extend beyond the port openings is termed the *lap*, and the valve must be moved far enough to overcome the lap before the opening for lead can begin.

Q. 17.—Is the further advance of the valve to secure lead necessary?

A.—Whether lead is a necessity or not is a matter of argument, but it is being conceded by many expert men that lead, as a port opening, is not necessary, and by some it is considered a detriment.

Q. 18.—Explain the manner in which lead is derived through the action of the Walschaert combination lever.

A.—The Walschaert eccentric is set exactly 90 degrees, in effect, from the main crank-pin, and if the combination lever were not present the valve would always be a "quarter" from the piston, and would be centred on the seat with both admission ports covered when the piston was at either end of the cylinder. Now we introduce the combination lever: The connection of radius rod near, or at, the upper end of the combination lever represents its fulcrum; the lower end of the lever is connected with the crosshead which is now at one end of its travel in the guides. Now, if the valve-stem is connected to the combination lever *above* the fulcrum (radius-rod connection) it is plain that the angle of the short (upper) end of the combination lever will throw the valve, slightly, in a direction *opposite* to the position of the piston in the cylinder, and this is the correct movement to be given the valve with outside admission to secure the port opening for lead. If, however, the valve-stem is connected to the combination lever *below* the fulcrum, or radius-rod pin, the valve will be *drawn in the direction of the piston's position* in the cylinder by the angle of the short end of the combination lever, and this is the proper direction for the valve of inside admission to be advanced in order to permit the pre-admission of steam against the piston, called *lead.*

Q. 19.—Suppose that an engine should be designed to use the Walschaert valve gear, and lead was not desired: That is, with the crank-pin on a dead centre and piston at an end of its stroke the admission port would not be open any,—steam edges of the valve and port line-and-line—are we to infer that the combination lever would not be necessary—that it could be dispensed with?

A.—Not at all. The combination lever must be included in the Walschaert gear on any engine and with any style of valve. As explained, an advance of the valve is necessary to move it the distance of the lap, so that the steam edge of the valve and the outside edge of the admission port will be line-and-line when the piston is at the start of its stroke and lead not required. The amount of advance of the valve derived from the action of the combination lever is equal to *the distance of lap, or lap plus lead,* according as the design of the engine calls for.

Q. 20.—Is there not a great deal of confusion as to the actual meaning of lead?

A.—Yes. The angular advance of the Stephenson eccentric upon the axle and the angular inclination of the Walschaert combination lever are often referred to as the lead, because it is known that they cause an advanced motion of the valve, when, as just shown, an advance of the valve is highly necessary even although it gives no actual *lead.*

Q. 21.—Assuming an engine to be running forward, is the Walschaert eccentric placed a quarter ahead, or a quarter behind, the main crank-pin?

A.—This is a variable matter, depending upon the construction of the reversing gear; if, with the reverse lever in the forward gear the radius rod is worked by the lower end of the link, with outside admission valves the eccentric is placed a quarter ahead of the main-pin and with valves of inside admission the eccentric is just opposite, or a quarter behind the main crank-pin.

Q. 22.—Is the Walschaert valve gear of the type referred to as of "direct motion"?

A.—The Walschaert motion is either direct or indirect, according as to which direction the engine is running. When the radius rod is working below the centre, or fulcrum, of the link there is a single direction of motion from the eccentric to the valve and the motion is direct; but with the radius rod working above the centre of the link, the motion is indirect, for the reason that the link then acts as a double rocker-arm, and when the eccentric throws the lower end of the link in one direction the upper end of the link moves the valve the opposite way.

Q. 23.—Reversing the engine, then, changes the

motion from direct to indirect, and *vice versa*, does it not?

A.—Yes.

Q. 24.—The answers to Questions 13 and others, refer to shorter cut-off and "hooking-up" the link: What is meant by those terms?

A.—Together, those terms represent cause and effect; hooking-up is the cause and shorter cut-off is the effect. Referring to the Walschaert gear, when the radius rod is working in either extreme end of the link, it is giving the valve its longest travel and steam is being admitted to the cylinder with the maximum limit of port opening; *hooking-up* really means drawing the reverse lever from a full-gear, corner notch of its quadrant to a notch farther up, nearer the centre, and this hooking-up of the reverse lever draws the radius rod to a point nearer the centre of the link, with the result that the motion of the radius rod is reduced and it, in turn, by its shortened travel shortens the whole travel of the valve; the effect of this is that the admission port is closed earlier during the stroke of the piston, and the expansive force of the steam is utilized to drive the piston during the remainder of the stroke. The closing of the admission port is referred to as the *cut-off*, and therefore this earlier closing of the port is termed *shorter cut-off*.

Q. 25.—When the reverse lever has been hooked up

to the centre notch of its quadrant how much travel will the radius rod give to the valve?

A.—None. When the reverse lever is in the centre notch the link-block (to which the radius rod is attached) is exactly centred in the link—its pin centred exactly with the fulcrum pin of the link—and the link can impart no motion to the radius rod. The valve will have a short motion at this time, however, the motion produced by the combination lever, and its full travel with the reverse lever on the centre will be just twice the distance of lap plus lead.

Q. 26.—With the reverse lever in forward gear the radius rod is carried at the lower end of the link, and in back gear at the upper end of the link, is it not?

A.—Yes, this is American practice, but it can be arranged otherwise, if more convenient, and will make unnecessary the multiplicity of levers in the reversing gear that is sometimes seen where the above arrangement is adhered to. The radius rod may be carried in the upper end of the link to make the engine run forward and at the lower end to run backward, and in such case it is only necessary, for further change, to move the position of the eccentric 180 degrees—from a quarter ahead to a quarter behind the main pin, or *vice versa*.

Q. 27.—Is it easier to secure equal cut-off at both

ends of the cylinder with the Walschaert gear than with the Stephenson link motion?

A.—Yes. The Walschaert motion is more simple and direct, and through the regular action of the link and combination lever the cut-off is maintained equal at both ends of the cylinder, in either gear and with the reverse lever hooked up to any notch in the quadrant.

Q. 28.—Why is the Walschaert link curved in an opposite way to the curve of the Stephenson link, and what is the radius of the curve of the link?

A.—The radius of curve of the Walschaert link is equal to the length of the radius rod, and the reason for this and the reason for the link curving in the direction it does, is, that as the radius rod is raised or lowered to shorten or lengthen the cut-off, the valve will not be erroneously affected. The theory of this is nicely exemplified by setting the engine on either dead centre, when the reverse lever may be moved from one corner notch to the other extreme end of the quadrant without changing the position of the valve, the link-block having the same curve to its path as the curve of the link.

Q. 29.—Is it possible to make any changes in the adjustment of the Walschaert gear on the road, or any such roundhouse experiments as are often made with the common link motion?

A.—It is not; sometimes, however, a slight irregularity in the motion may be corrected by lengthening or shortening the eccentric rod, only, but even this is usually a "back shop" job.

Q. 30.—**Is it not possible for the length of the eccentric rod to become slightly changed?**

A.—Only as it may through a change in the adjustment of the bearings at the back-end connection to the eccentric crank; such change may have been made intentionally, or may be due to service conditions.

Q. 31.—**Can any other part of the Walschaert gear, except the eccentric rod, be changed or adjusted, outside of the machine shop?**

A.—No. Neither is it ever necessary, and as the lost motion from wear is hardly perceptible after many months of service an engine may be run for a longer time between shopping.

Q. 32.—**Does any part of the Walschaert gear have a tendency toward heating?**

A.—The Walschaert valve gear is peculiarly free from any inclination to heat, except that occasionally the gear is not properly designed to meet unusual conditions of track and service, and eccentric rod pins will heat from the twisting effect between the driving-wheels and engine frame. This, however, is not a constitutional disorder, and may be cured, or prevented.

Q. 33.—**In order to insure correct action of the**

Walschaert valve gear what parts of the engine outside of the valve gear should be kept up in good condition, and as free as possible from lost motion?

A.—No form of valve motion will show good results if the other working parts in general of the engine are not kept up, but in particular, the driving-boxes should not sustain lost motion.

Q. 34.—**Is it a fact that lost motion in the driving-boxes induces greater error in the motion of the valve with the Walschaert gear than with the Stephenson link motion?**

A.—Such is *not* the fact, whatever; although the Walschaert eccentric is a greater distance from the centre of the driving-box, usually, than the eccentrics on the axle are, and any lost motion between the driving-box and engine frame will have a slightly greater effect *at the Walschaert eccentric pin* than it would have at the link-motion eccentrics on the axle; yet, with the Stephenson eccentrics the full amount of this lost motion is delivered to the valve with the link working in full gear; while in the Walschaert motion the amount of the variation is greatly decreased through the long leverage of the link foot.

Q. 35.—**Does the up-and-down motion of the engine on its springs affect the steam distribution of the Stephenson link motion?**

A.—Yes, to a very noticeable extent.

Q. 36.—Does this motion of the engine have an equal disturbing effect on the valve's motion with the Walschaert gear?

A.—No, it has no effect, unless the connection of eccentric rod to link foot is placed at too high a point above the centre line of the axle.

Q. 37.—When the crosshead is at the exact centre of its travel, main-pin on the upper or lower working quarter, reverse lever in centre notch, and the combination lever in a plumb vertical position, at what point in its travel should the valve be standing?

A.—The valve at this time should be perfectly central on its seat, with both admission ports covered.

Q. 38.—What is meant by the above expression of the main-pin being on the " working quarter " ?

A.—When the main-pin is on the *actual* quarter—either the upper or lower—it is on a perpendicular line through the centre of the axle, but the piston will not be in the exact centre of the cylinder, owing to the angularity of the main rod. On the other hand, if the piston *is* at the true centre of the cylinder—as was supposed in the foregoing question—the main-pin will be a slight distance away from the perpendicular line through the centre of the wheel, or axle, but it is now on the *working* quarter because, technically, it has half completed a single stroke; if the back end of the main rod should now be disconnected from the main-pin and dropped, or raised, as the case demands, until it was on a horizontal line, the opening for the main-pin in the stub-end of the main rod would centre, exactly, over the centre of the wheel hub, proving that it was half-way in its stroke. The longer the main rod the less its angularity and the lesser will be the difference between the actual and the working quarter-positions of the main-pin.

Q. 39.—The engine standing with piston at the true centre of the cylinder on one side and the reverse lever in the middle notch of the quadrant, suppose that the valve was *not* exactly centred—opening the throttle would cause steam to blow from one of the cylinder cocks on that side of the engine: What could be the cause, and how remedy it?

A.—First, be sure that the reverse lever *is* in the middle notch; a mistake may have been made in laying out the notches of the quadrant, or in setting it up; when the link-block pin and the link-fulcrum pin are centred together the reverse lever is in the proper middle notch, and when they are so situated and the valve is not covering the admission ports completely with piston in exact centre of the cylinder, undoubtedly the link bearer, which is attached, commonly, to the guides, varies a little in its position, either fore or aft, and should be moved enough to correct the error; or the valve-stem can be lengthened or shortened, but as this induces other minor errors the other method would be preferable.

Q. 40.—**Would not moving the position of the fulcrum that carries the link produce other error in shifting the distance between it and the eccentric?**

A.—Re-setting the link fulcrum might correct the whole motion, if it had been set up untrue; but if correcting the position of the link fulcrum should cause the error suggested, that, again, can be corrected by adjusting the length of the eccentric rod. Here is a fundamental point to remember: The gear from the link forward, inclusive, is permanently set up, all motion bearers being in rigid attachment to the guides. Back of the link, however, there may be changes in distances due to wear and consequent lost motion, and for that reason the eccentric rod, alone, may be lengthened or shortened as may be found necessary.

Q. 41.—**On the big, modern engines that are being equipped with the Walschaert valve gear there does not seem to be any convenient way of changing the length of the eccentric rod except in the adjustment of the bearings at its back end; how, then, could the length be altered as advised?**

A.—Outside of the method just referred to, as stated before, it is a "back shop" job to alter the length of the eccentric rod, and there is where it should be done. The earlier built engines, with much lighter rods, and foreign locomotives of the present date, had, and have, adjustable eccentric rods. In Fig. 10, Wm. Mason's improved design of the Walschaert gear, the eccentric rod is shown to have adjusting nuts near the connection to the link foot.

Q. 42.—Then, if the eccentric rod is the only part of the Walschaert valve gear that *can* be changed outside of the machine shop and the only part that *should* be altered at any time in the shop, this motion is not likely to be tampered with, nor to get "out of square"?

A.—That is right. The Walschaert valve gear will not wear away in its bearing parts enough to make it necessary to have adjusting devices.

Q. 43.—Explain when it will be necessary to correct the length of the eccentric rod.

A.—Set the engine with the main crank-pin on the forward dead centre on one side, and have the reverse lever moved from the go-ahead corner notch up toward the centre of the quadrant; while the link-block is rising, if the valve-stem is pushed forward slightly the eccentric rod should be lengthened; but if the valve-stem should be drawn backward by the rise of the link-block the eccentric rod needs to be shortened. In either case make but slight changes in the length of the rod, and keep on testing until hooking up the lever to the centre has no effect on the valve-stem nor radius rod. Then test, and alter if necessary, the other side in the same way, but with the main pin on the *back* dead centre.

Q. 44.—The numerous engravings of locomotives equipped with the Walschaert valve gear show that the link bracket is invariably attached to the guide-bearer, or yoke, and the slide for the valve-stem is mounted on the upper guide-bar: Does this just happen so, and as a matter of convenience, or is there a reason why the main supports of the Walschaert gear should always be so contained?

A.—It is very important that the trunnion upon which the link oscillates should be fixed at an unvarying distance from the cylinder, and for assurance that the distance will be permanently maintained, the link bracket should be rigidly fastened to the guides; and as the valve-stem slide supports the combination lever and front end of the radius rod, it represents a point where no variation in the motion is permissible, and it, too, is secured fixedly to the guides.

A type of heavy-freight engine has recently been built on which it would have been inconvenient to hang the link as recommended, and a large, hollow, cast-steel bracket was laid across, joining the bars of the engine frame on both sides just back of the guide-yoke, to act both as a frame binder and brace and a carrier for the link bracket. With one class of this general type the big shell casting is bolted to the guide yoke as well as the frame, and becomes a most substantial engine frame and valve-gear stiffener, but with another class of engines the casting referred to is separate from the guides yet carries the link, and as the American bar-frame is not altogether unyielding, this big, powerful freight engine will in time, no doubt, develop certain irregularities in the valve's action that may be attributed by some to the fact that the engine is equipped with the Walschaert valve gear.

Q. 45.—If an engine breaks any part of the machinery while on the road, is there any great difference in the method of disconnecting the disabled side and setting things right so as to proceed, as to whether the valve gear is of the Walschaert type or the Stephenson link motion?

A.—Yes; and if the break occurs within the valve gear the difference in time consumed in making the temporary repairs necessary to get the engine moving under its own steam is so greatly in favor of the Walschaert as to be one of the good reasons for its adoption, because it means less time lost in delays to the railroad's one source of revenue—the *turning* wheels.

When railway motive power was not so large and heavy as at present, and any part of the machinery on one side of an engine was broken so as to disable that side, it was the rule to take down the main rod and block the valve after disconnecting the valve-stem; the main rod had to come down from one side, always, when the engine was only able to work steam on the other side. The piston was then held at the back end of the cylinder by blocking the crosshead, and the valve on that side was set so as to cover both steam ports by blocking it or clamping the valve-stem; not a great deal of knowledge or ingenuity was required; simply follow the custom.

Now, however, the enormous weight of the main rod generally prohibits taking it down on the road; leaving it up in place suggests that the piston will "drift" in the cylinder while the engine is running dead on that side, and that the crosshead will impart motion to the combination lever, *et al.* So that a few questions asked and answered on the subject of common breakdowns and the accidents that might happen to the parts of the Walschaert valve gear would be appropriate.

Q. 46.—In discussing the subject of breakdowns and the methods of procedure in consequence, "blocking the valve" will be mentioned several times; what is meant by that expression, and when and how should it be done?

A.—When any part of the valve gear is disabled on one side of the engine so that the valve will not receive its correct motion, or if any other part of the machinery on that side of the engine is in such a damaged condition that steam must not be delivered to the cylinder of that side while the engine is working on the other side, the gear must be disconnected so far on the disabled side that the valve shall not be disturbed, after which the valve must be placed in a central position on its seat, by moving the valve-stem, whereby both admission ports to the cylinder are covered. After the valve has been correctly centred, if the throttle is slightly opened no steam will blow from the opened cylinder cocks on the disabled side of the engine. The cylinder cock rigging should then be disconnected on the damaged side of the engine, so that they could be set permanently open while the engineer opened or closed the cocks on the other side without interference; one reason for doing this is that if the valve should get moved far enough to start uncovering one of the admission ports steam would blow from the cylinder cock at that end of the cylinder and announce the shift of the valve when the throttle was opened.

On many roads a clamp is furnished and carried on every engine, by which the valve-stem can be secured immovably in a position that places the valve squarely over the ports. When such clamp was not at hand, it was formerly the rule, with a D-slide valve, to raise the steam chest cover and place retaining blocks ahead and back of the valve; but it is almost an impossible task to raise the steam chest cover on one of our big, modern engines, and it is not at all unsafe to neglect the inside blocking; just centre the valve, and when steam is used it will put such a great weight upon the valve that its frictional resistance will cause it to adhere to the seat beyond any danger of its moving, unless the engine receives a hard bump as in switching or coupling to cars, and in that case the engineer will quickly discover the fact from seeing the steam at one of the cylinder cocks.

Inside admission piston valves are so perfectly balanced—*fore and aft*—that one need not hesitate to trust them to "stay put" without clamping; still, if there is a clamp provided, *use it.*

Some engineers with a high reputation for keeping the wheels turning in spite of mishaps, refuse to block the valve on the disabled side of the engine and they leave the main rod up, also; it is out of the question to take down, on the road, the heavy main rod that we now find on most engines, and if the engine subsequently stops with the live side on the dead centre, the disconnected valve can be temporarily moved far enough to open the desired steam port and enough steam then used to start the engine and get the working side off the centre; the air brake can then be applied to stop the engine with the live side off the centre, and with the throttle closed the disconnected valve is again put on centre, and the train proceeds.

When the main rod is left up, the fixed-open cylinder cocks will generally give relief enough to prevent compression and vacuum in the cylinder as the piston churns forth and back, but for further relief some engineers always unscrew the cylinder cocks to provide an increased opening in each end of the cylinder. If the cylinder has by-pass valves they can be made to take care of the churning of the piston. The piston will run dry, however, and needs lubrication; oil must be introduced to the cylinder if the engine is to be run for any considerable distance. The lubricator may be allowed to feed oil to the steam chest on the broken-down side about the same as usual, and at certain stops along the road the valve can be moved by the valve-stem—if not blocked—enough to open one, or each alternately, of the admission ports and given a little steam, the oil collected in the steam chest will be blown down into the cylinder.

Q. 47.—If a side rod breaks, or should otherwise be removed from the engine equipped with the Walschaert valve gear, and no other damage results to the machinery, could it have the effect of totally disabling the engine?

A.—No. The engine would still work all right on the uninjured side in all such cases.

Q. 48.—Could the breaking of a side rod totally disable an engine with the Stephenson link motion?

A.—Yes, on certain types of engines where the eccentrics are attached to other than the main-axle—and this is quite common on engines with three or more pairs of driving-wheels—if a side rod connecting the main pair of driving-wheels with the pair that mounts the eccentric axle should break, the same section of side rod on the other side of the engine should be taken down, and this would render the valve motion inoperative. With the Walschaert gear the eccentric is *always* on the main pair of wheels, and therefore is unaffected by any damage to side rods.

Q. 49.—In cases requiring the valve to be blocked, the valve-stem should, of course, first be disconnected, or at least disconnection made at some point between the valve and the regular source of its motion, and with the Stephenson link motion the valve-stem is the most convenient place: Is it, with the Walschaert gear?

A.—No; it is practically out of the question to disconnect the valve-stem itself on most engines having the Walschaert gear, as it usually has a crosshead working in a guide and there is no place between the crosshead and the packing gland for its separation, but the same effect is produced by disconnecting the radius rod.

Q. 50.—If disconnection of the radius rod in the Walschaert gear has the same effect as disconnecting the valve-stem of the common link motion, then the radius rod will have to come down whenever the engine is so disabled on one side that the valve must be blocked; so you will explain in detail how one should go about it.

A.—The radius rod need not be *taken down* in all such cases of disability, but will always have to be, at least, disconnected.

Remove the pin from the joint of radius rod and combination lever and raise the disconnected end of the radius rod just above any chance of interference with the combination lever, suspending the rod by strong wiring or rope of such length as to permit it to swing freely to the motion of the link, taking particular care that the suspended end of the radius rod will not strike anything else. This method should only be resorted to, however, when the engine has only a short distance to go to reach its terminal and can be run at a moderate speed, only. In answer to subsequent questions on breakdowns the following instructions for disconnecting the radius rod should be observed:

If the engine is to be run any considerable distance, or may be speeded up at times, with one side disabled, a safer and more commendable method is, first, place the reverse lever in the centre notch of the quadrant in order to get the back end of the radius rod and the link-block in the exact centre of the link; then saw a couple of pieces of wood to fit, and insert them between the bottom of the link and the link-block, and secure them in position in order to support the back end of the radius rod at the centre of the link; now disconnect the hanger between lifting arm and radius rod and take out the pin from the front end of the latter at its connection with the combination lever, wiring the radius rod up, as previously directed, or suspending it by anything that will support its weight, as there will be no motion imparted to it now. After centering the valve, and blocking it or clamping the valve-stem—or trusting that the pressure of the steam will hold it in its central position—it will not be necessary to do anything with the combination lever, as the motion imparted to its lower end will not be likely to affect the valve, even if not clamped; but,—after disconnecting the radius rod from the combination lever, always watch the first movement of the crosshead *to see that the combination lever does not strike the wrist-pin*—the pin by which the front end of the main rod is connected to the crosshead—as the motion of the lever is altered by the disconnection and pause of its upper end. Blocks of the proper size to hold the radius rod in the centre of the link, and with their upper ends shaped half-round, should be carried on all engines equipped with the Walschaert valve gear.*

Q. 51.—What should be done in case of a broken radius rod?

A.—The best plan is to take down all of the pieces of the broken rod, disconnecting them from the combination lever, suspension bar, or hanger, and link-block; but if there is very much left of the rod forward of the link, it can be blocked up in the centre of the link, disconnected from the suspension bar, and its front end wired or tied up as before mentioned, and the valve centred and secured.

Q. 52.—When the suspension bar, or hanger, is connected to an extension of the radius rod back of the link, and that back extension of the rod should get broken off, or the suspension bar or lifting arm should break, what should you do?

A.—These troubles should be treated about alike. If the engine is to run forward, place a short block in the link under the radius rod or the link-block, so that the forward section of the radius rod will be held at about the same position in the link as the one on the

* The construction of the Walschaert link is a little different in detail as designed by the different locomotive builders, and the shape of the blocks to be used in the link when it is desired to carry the radius rod and link-block without motion, varies enough that it would not be practicable to illustrate a pattern.

other side when the reverse lever is in the notch that it will be expected to work in. An average should be struck in regard to this, as the reverse lever should neither be hooked up any further, after the positions of the radius rods have been matched, nor dropped a notch lower. Of course, the broken parts should be detached, and another block placed in the link *above* the link-block or radius rod to prevent their slipping up.

Q. 53.—An eccentric rod seldom breaks with the Walschaert gear, while it is not uncommon in the Stephenson link motion; if, however, the Walschaert eccentric rod should break, what then should be done?

A.—After removing the broken parts of a Walschaert eccentric rod throw the reverse lever to the forward corner notch in order to lower the radius rod and block to the bottom of the link; then disconnect the suspension bar from the radius rod, and the radius rod from the combination lever; raise the front end of the radius rod above interference, and, wiring through the pin hole, attach its forward end firmly and immovably to anything convenient and solid in order to keep the link from rotating, as with the eccentric rod detached there will be nothing but the radius rod to keep it steadied. Block the valve, etc., in the manner heretofore described, and proceed.

Q. 54.—If the valve-stem should break what course should you pursue?

A.—Disconnect the radius rod in the recommended manner and centre the valve, blocking or clamping the valve in this case if it were possible, and leave the combination lever in place, providing that as the lower end swings forth and back it does not strike the projection of the pin that connects the main rod to the crosshead, for its motion will be somewhat changed since there is no action of the slide at its upper end; this slide—from which the valve-stem has been disconnected by breakage—may be placed at any position on the slide bar that will provide a safer swing to the combination lever, and *should be blocked in that position* so that the motion of the lower end of the combination lever could not induce a movement of its upper end that would result in the valve being pushed off centre.

Q. 55.—If the long (lower) section of the combination lever or its connecting link to the crosshead, should get broken, what should be done?

A.—Detach the pieces of the link bar, or the broken-off, lower piece of the combination lever; disconnect the radius rod as explained before, and centre the valve. The remaining stub of the combination lever must be drawn out of the way, forward or back, so that it will not be struck by the pin in the crosshead to which the main rod is connected, when the main rod is not taken down and the crosshead has its regular motion in the guides.

Q. 56.—In all of these cases of breakage it has been assumed that we proceed, after doctoring up the temporary disability, by using steam on the other side of the engine but running with the main rod in place on the disabled side, and the reasons for it have been given; but suppose that the disability is the result of a ***broken main rod*****, and no other damage has followed: What should be done?**

A.—In case of a broken main rod on an engine equipped with Walschaert valve gear, take down the parts of the broken rod and disconnect the radius rod as has been detailed before; if the valve is of inside admission, push it to the forward end of the steam chest and clamp the valve-stem or block the slide to hold it in that position, or, if the valve is of outside admission it should be drawn to the back end of its travel and secured there, the intention in either case being to keep the front admission port open for steam to enter the cylinder and the back port open to the exhaust. Then, with a bar, draw the crosshead as far as it will go toward the back end of the guides—until the piston is against the back head of the cylinder. This is termed "steam blocking," and while steam is being used the piston will stay placed, but in drifting down hill, or receiving a jerk from the rear end of the train at an application of the air brakes—bumps in switching, etc., while steam is shut off, the piston is liable to get moved ahead and a sudden opening of the throttle would send it back with force enough to break the back cylinder head and ruin the guides; so, after placing the valve and piston as directed, it is best, also, to block the crosshead in that position. There will, of course, be no movement of the combination lever, and it should not be disturbed; the only motion of the valve gear on the disabled side will be that the eccentric rod will continue to give the regular motion to the link, but with the radius rod disconnected from its suspension bar and the combination lever, and centred in the link, the action of the link will have no effect.

Q. 57.—Suppose that the piston should get broken, or detached from the piston rod in the cylinder: What should be done in that case?

A.—Usually the result of this accident is to carry away, or break, the front cylinder head; the head should be removed, in either case, and the piston taken from the cylinder. If the piston rod is not bent leave the main rod up and disconnect the radius rod in the recommended manner, centre the valve, and go on. The cylinder cocks, in this case, need not, of course, be taken down as the cylinder is opened through the removed head and piston.

Q. 58.—In connection with the preceding accident suppose that the piston rod should be bent in the

cylinder: Would you leave the main rod up in place in that case?

A.—Certainly not. In addition to disconnecting the radius rod and covering the ports by centering the valve, as before stated, the main rod should always be taken down—no matter how slight the bend may be in the piston rod.

Q. 59.—What should be done in case of simply blowing out a front cylinder head?

A.—The radius rod should be disconnected in the regular manner, the valve centred, and the back cylinder cock, only, removed. About the only objectionable feature in running with the main rod up on the disabled side of an engine is not present in this case: It is not an easy matter, usually, to keep the piston lubricated, but with the cylinder head removed, oil can be introduced as often as may be necessary.

Breakage, or blowing-out, of the back cylinder head is of rather infrequent occurrence, but when it does happen, if the head is so slightly broken—say a piece knocked out—that it will stand the pressure of the piston under steam, the main rod can be taken down (for undoubtedly the piston rod would cramp in the stuffing-box if allowed to work) and the same process followed as with a broken main rod, as previously described, *steam-blocking* the piston, etc., as this saves time. In case the back head is completely destroyed, however, the valve should be centred, covering both steam ports, the main rod taken down, and the radius rod disconnected and centred in the usual manner.

Q. 60.—If the link bar connecting the lower end of the combination lever with the crosshead should get broken and lost, from both sides of the engine, how could you measure for new ones?

A.—The length of these link bars could be closely approximated as follows: Move the crosshead into a central position that would indicate that the piston was in the exact centre of the cylinder, and place the reverse lever in the centre notch of the quadrant so that the link-block pin and the link fulcrum pin, or trunnion, are centred together; then move the lower end of the combination lever until the lever is in an exactly plumb, perpendicular position, and measure from the pin hole in its lower end to the pin hole in the crosshead arm to which the link bar should be connected, this distance being the required length of the link bar.

It is to be presumed that any one who is thrown into association with the Walschaert valve gear is familiar with the locomotive in general, and is already well-informed as to the methods of procedure in cases of breakdowns of the different parts of the machinery other than the valve gear, and for that reason no troubles have been made the subjects of questions except those that are peculiar to this style of gear, or that must receive different treatment from that which they would in connection with the Stephenson link motion. There are many troubles that can, and will, occur on the road that are not noted here, but by understanding that which has been explained in this book, any engineer that can keep the wheels turning in the presence of the common disabilities that occur to engines of the link-motion class, can also be ready to meet any troubles that may possibly happen to the Walschaert gear.

INDEX

A

B

C

D

E

F

G

H

M

N

O

P

Q

R

S

T

U

V

W

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