THE VALVE SETTER'S GUIDE

The Valve-Setter's Guide

THE

Valve-Setter's Guide

A TREATISE

ON THE CONSTRUCTION AND ADJUSTMENT OF THE PRINCIPAL VALVE GEARINGS USED ON AMERICAN LOCOMOTIVES

BY

JAMES KENNEDY

NEW YORK:

ANGUS SINCLAIR COMPANY

114 LIBERTY STREET

PRICE FIFTY CENTS

CONTENTS

PREFACE

It would be difficult indeed to write anything particularly new on a subject that has been so much commented on as the valve gearings of steam engines; but it will be readily admitted that things that are already familiar to us may be seen in a new light. It will also be observed that in this age of rapid changes even the steam engine is found to be capable of improvement. The recent application of the Walschaerts valve gear to American locomotives, and also the more recent invention of the Baker-Pilliod valve gear has given a new interest to the subject. It is to be hoped the result will be that a greater degree of reliability in the harnessing of steam in locomotive service will be accomplished. It is with the hope of adding something to the general mass of information, especially with a view of being helpful to young railway men, that these articles have been written.

Other valve gearings claim attention. Many others besides those described in this little book are in successful operation. Some still in embryo are full of promise. In selecting those that are the most popular forms of locomotive valve gearings in use in America, it is not with the intention of ignoring or belittling other ingenious devices, but with the assurance that a fair knowledge of the organic structure and methods of adjustment of valve gearings commonly in use will readily help the thoughtful mechanic to a more easily acquired knowledge of the mechanism of any valve gearing, no matter in what shape the parts may appear.

Not only so, but as the valve gearing is the most intricate part of the reversible steam engine, so the study of valve gearing is calculated to develop the faculty of giving thoughtful attention to the details of all forms of involved mechanism.

A word may be added in regard to the brevity with which the subject has been treated. In an experience of many years among apprentice machinists and young railway men, I never found it advantageous to pour a mass of tedious information into the ears of listeners however willing they might be to hear. In fact, the more anxious they were to learn the less they needed to be told. A hint in the right direction was generally enough. Many exceptions arise in practice which can hardly be foreseen in imagination. The intelligent mechanic or engineer learns much that does not appear in print. Practical experience unfolds the mysteries of all arts. The object of a book of this kind should be to help the beginner to help himself. In the hope of aiding in kindling this noble aspiration these brief articles were written for the pages of Railway and Locomotive Engineering and met with much popular favor, and are now collected in more convenient form in the belief that they may be of further service to railway men. J. K.

New York, Jan. 1, 1910.

I. THE STEAM ENGINE

Apart from the many varieties of form in which steam engines are made, there are two general divisons into which they may be classified, those of the condensing and non-condensing engines. The locomotive and nearly all the factory engines are of the non-condensing type. In this class the steam after it has done its work in moving the piston, is exhausted into the open air. An engine of this kind is readily discerned by the puffing sound of the exhausted steam, each re-percussion indicating the completion of the piston stroke, and sudden release of the pent-up steam, which it may be observed has still much more than sufficient force left in it to overcome the pressure of the atmosphere. In a condensing engine the steam after passing through the cylinder is admitted into a box or receptacle called a condenser on account of its being cooled by contact with water or with pipes through which cold water is passing. The condensation of the exhausted steam has the effect of producing a partial vacuum in the condenser, which permits the steam being used until it has reached a lower pressure than in a non-condensing engine. Marine engines are mostly of this type, as a constant supply of cold water can readily be obtained.

It will be remembered that the atmospheric engine previous to James Watt's invention of the steam engine, was operated by the admission of steam into a vertical cylinder, while the piston was at the upper end of the stroke and when a jet of cold water was admitted into the cylinder, the steam was condensed, thereby producing a vacuum and the weight of the atmosphere acting on the uncovered upper face of the piston was sufficient to press down the piston. Watt conceived the idea of condensing the steam in a separate vessel, thereby effecting a great saving and also made the important advance in applying steam alternately to both sides of the piston, thereby creating or inventing an entirely different engine from that of Newcomen.

The rapid condensation of steam into water renders suitable openings into all steam cylinders a necessity. These openings, or cylinder cocks, as they are called, are usually operated by a hand lever which is placed in the open position when starting the engine. This should be carefully attended to, as water unavoidably gathers in the cylinders while engines are not running, that is if a pressure of steam is in the boiler.

The most important openings into the cylinder, however, are the ports by which the steam is admitted and that by which it escapes after its work is accomplished. This leads us to the slide valve, the most common form of valve used in steam engines, and although simple in construction it is a most ingenious contrivance for admitting and cutting off the supply of steam at the desired instant of time. The cylinder is so constructed as to form a flat portion on a part of its outer surface on which there are three rectangular openings, the middle being the exhaust port, is wider than the other two, and leads directly from the cylinder face to an opening on which the exhaust pipe may be bolted. The two other ports are the steam ports, one leading to one end of the cylinder and the other to the other end. The slide valve is so constructed as to cover these three openings and is shaped like a hollow rectangular dish with an inner cavity, the edges of the dish forming the face of the valve. This face is carefully fitted so that when the valve is placed in position it forms, in conjunction with the surface of the cylinder, a steam-tight joint. It may be added that in the early days of the steam engine much care was taken in fitting the valve face and valve seat together so that every part of the metals were bearing equally on each other. It was latterly found that the friction incident to the movement of the valve very quickly caused the valve to adjust itself to the valve seat so that a fine bearing at the start is not essential, the bearing being perfected in the course of a few hours' service.

The slide valve, when in the central position, covers the two steam ports and leaves the middle port open in the inner cavity of the valve. If the valve was so constructed as to cover the two steam ports exactly it can be readily perceived that a movement of the valve in either direction would open one of the steam ports leading to the cylinder and open the other steam port to the inner cavity of the valve, thereby opening the communication to the exhaust pipe. A valve so constructed would admit steam during the entire length of the piston stroke, so that when the piston stroke was completed the steam in the cylinder would be at or near

FIG. 1. SLIDE VALVE WITHOUT LAP.

boiler pressure and when released by the opening of the exhaust port, as already alluded to, the loss of steam at each stroke would be equal to the full capacity of the cylinder and steam spaces. In its primitive form the slide valve was constructed in this way and was used on some of the earlier engines of James Watt. Fig. 1 shows such a valve in the central position.

This form of valve had several serious objections. The smallest degree of lost motion had the effect of admitting the steam in a sufficient quantity to obstruct the piston at the end of the stroke. The tendency to create severe pounding was very great. The most important drawback was in the fact, already alluded to, that the steam was released while at full pressure, and no advantage could be taken of the expansive power of steam. During Watt's lifetime the pressure of steam as applied to steam engines was extremely low, so that the loss was not so very great as it became when, with the improvement in boiler construction, higher pressures of steam became available. In the early days of the locomotive fifty pounds pressure of steam per square inch did not admit of much advantage being taken of the expansion of steam in the cylinder. The change of the form of the slide valve was very simple, but very important. It consisted merely of lengthening the valve face, so that when the valve stood in the center of the seat the edges of the valve extended a certain distance over the steam ports, as shown in Fig. 2.

This extension of the valve faces is called outside lap, or simply lap. It has the effect of closing the steam port at a certain distance before the piston reaches the end of the stroke, and this point, which with the variations incident to the action of the radial link is a variable point, usually called the point of cut-off. It can be readily understood that when the supply of steam is cut off from the boiler before the piston stroke is com-

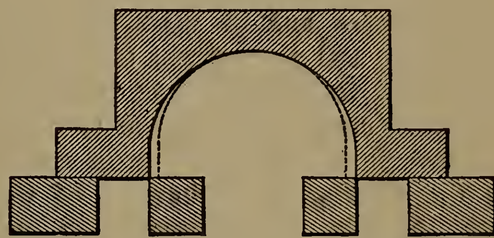


FIG. 2. VALVE WITH OUTSIDE LAP.

pleted, the piston is moved on its further course by the expansive power of steam, and when the stroke is completed the steam in the cylinder having increased in volume is correspondingly reduced in pressure and when released the loss is not great, as the pressure of the steam is not greatly in excess of the pressure of the atmosphere.

II. THE SLIDE VALVE

Having described the construction of the slide valve and its relation to the steam ports, and pointed out the advantage derived from the face of the valve being made more than sufficient to cover the steam ports, it remains to be stated that the opening and shutting of the steam ports by the movement of the valves is of the utmost importance in the running of the steam engine. It will be readily understood that when the piston is at one or other of the extreme ends of the cylinder and it is intended that it should be moved in the other direction, the steam port should be rapidly opened so that the steam may exert its full pressure on the face of the piston. Many eminent engineers held the opinion that the opening of the port should occur in advance of the arrival of the piston at the end of the stroke. This is what is known as the *lead* of the valve. It has been the subject of much discussion and is still an open question. At first sight it would appear to be a hindrance to the piston to meet with a pressure of steam working adversely to the direction in which the piston was moving, but when it is borne in mind that even steam at high pressure, moving at a high velocity, requires some small instant of time to move through the intervening space between the steam chest and cylinder, and also that the piston itself may be moving at a high speed, it is easy to understand that it may be an advantage to begin to open the valve slightly in advance of the reversing of the movement of the piston.

This is more readily apparent in the case of engines running at high speeds than otherwise, because the velocity with which the steam moves through a certain space at a certain pressure may be safely called a constant velocity, while the rate of speed at which the valve or the piston travels varies according to the kind of work accomplished. This fact has led to the claim that the increase in the amount of lead in the valve which is caused by the shortening of the travel of the valve in the case of engines equipped with the Stephenson valve gear is an advantage to locomotives running at high speeds when the reverse lever is "hooked up." The action of the steam in striking with sudden force at the beginning of the piston stroke may be likened to what is known as "advancing the spark" in gasoline engines, which has the effect of increasing the velocity of the engine partly from the more complete compression of the inflammable gases, and partly from the fact that the gasoline engine piston receives the full shock of the explosion before it has moved any considerable distance from the end of the cylinder.

The parallel between the action of steam pressure and gasoline explosion, however, is not an exact one. The variation is very great, steam being a constant pressure and gasoline explosion an intermittent shock. Increasing the amount of lead in the valve of a steam engine does not by any means increase the speed of the engine. It has the contrary effect, and it is a growing fact that the idea which obtained in many quarters that a locomotive could not run freely unless

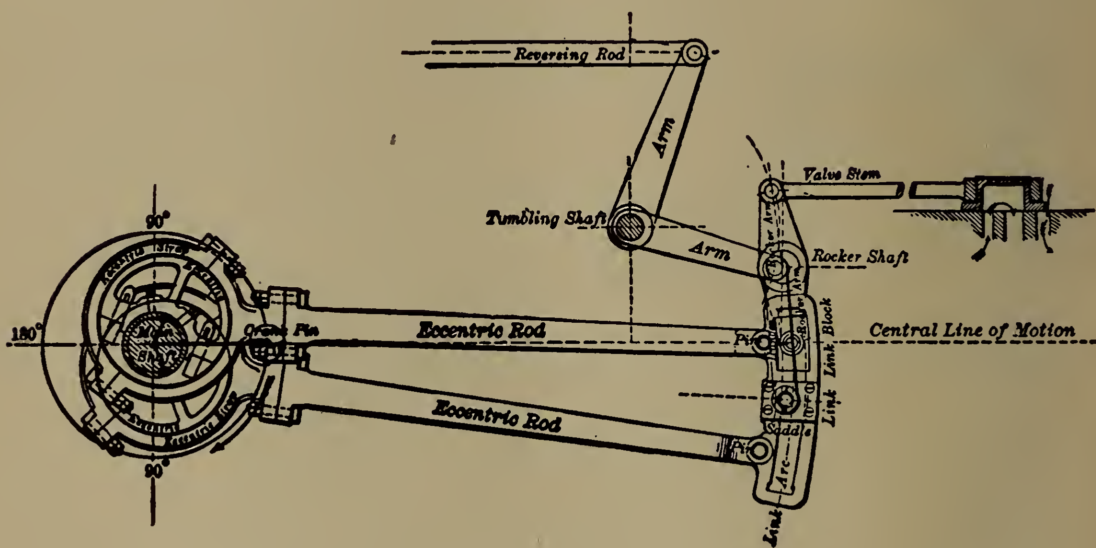
SLIDE VALVE SHOWING LEAD.

the valves were set with considerable lead is rapidly losing its adherents. This fallacy may readily be dispelled by marking the degree of smoothness with which a well-balanced locomotive will run when an opportunity occurs to shut off steam altogether. The alleged shock which a certain amount of lead of the valve is said to overcome is not apparent, and there is undoubtedly a growing opinion that the older methods of having a valve opening of one-eighth of an inch is gradually losing ground, and this amount after being cut down to one-sixteenth is now reaching the thirty-second mark, and if the present trend of thought continues the so-called lead of the valve will have become a minus quantity.

It may be added that the idea that the increase in the amount of lead of the valve caused by the shortening of the valve travel, in the case of the Stephenson valve gearing, was an advantage, has lost credence largely from the fact that since the rapid introduction of the Walschaerts valve gearing, with which many of the new and larger locomotives are equipped, it has been clearly demonstrated that the constant lead maintained by the latter valve gearing at varying amounts of valve travel and speed, is a decided advantage in its favor. Indeed, many experienced engineers do not hesitate to assert that the excessive amount of lead formerly allowed in locomotive practice, and the large increase in that amount occasioned by the shortening of the valve travel, was the chief cause of much of the troubles incident to the involved mechanism of the Stephenson valve gearing. Be this as it may, the opinion is rapidly taking firm root that the amount of valve opening at the end of the piston stroke should be kept at the lowest possible amount, and that better results in locomotive and engine running generally could be obtained by having the valve closed at the end of the piston stroke than by having an opening wide enough to admit sufficient steam that cannot do other than counteract the motion of the piston as it approaches the dead center.

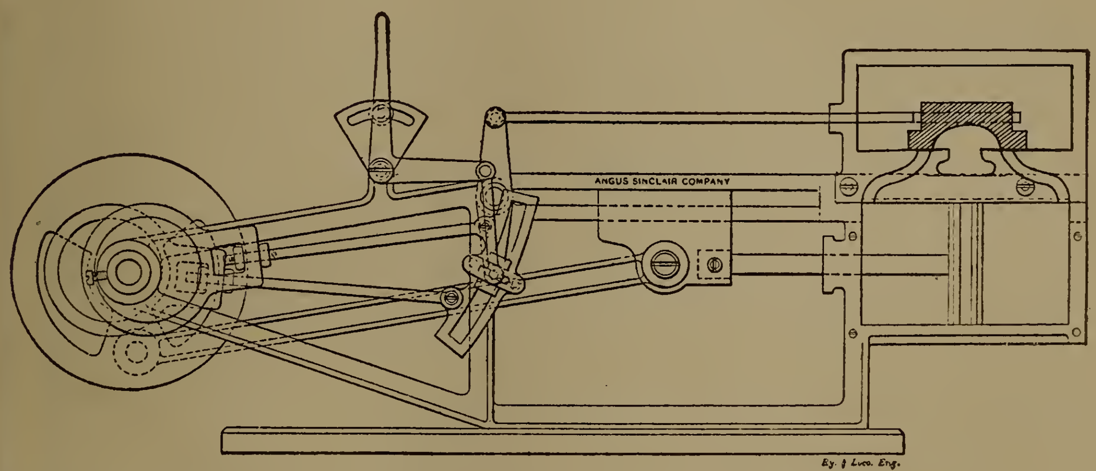
III. THE LINK MOTION

A peculiarly important quality of the steam engine is the fact that it lends itself with ease to perfect control. That motion of such amazing force can be suddenly stopped and reversed within a brief period of time is one of the most wonderful results of applied science.



The most common form of reversing gear is what is known as the link motion. The combination of levers and rods and eccentrics and radial link have an involved air of mystery to the young engineer, but a little attention will show that the movements are simple enough, and if taken into consideration one by one can be readily understood by the average student in a short time.

The invention of the link motion has been the subject of much controversy, but it is now universally conceded that Mr. William Williams, a young Welchman, a draughtsman employed in the Stephenson Locomotive Works at Newcastle, England, submitted the first sketch showing the idea of a movable link suspended from the arm of a movable shaft and equipped with means of being attached to two eccentrics, the movable link being attached to the valve rod, effecting the reversing of the engine and also a variation in the valve travel and consequent variation in the expansive use of steam. It was a masterly invention and the unconscious young inventor, to whom the thought had come as an inspiration, had evidently no comprehension of the momentous importance of the device. It may be said to explained his device to some self-seeking shopmates who were not slow to take advantage of his ingenuousness. Claims of improvements were made by others, but the fact is that Mr. Williams' finished invention was incapable of any improvement. The device was not patented. The Stephensons began applying it to their locomotives in 1842. It came into immediate favor and has been the most popular form of valve gearing used on



REPRESENTATION OF THE ANGUS SINCLAIR CO. VALVE MODEL WITH D-SLIDE VALVE.

have completed Watt's wonderful engine. At one stroke the harnessing of the titanic force of steam was completed. Engines could henceforth be run backward or forward. Variable expansion, variable speed, with all the delicate varieties in force and velocity, were at once accomplished.

It is a matter of regret that so little is known of the gifted mechanician. With the frankness of youth he seems to have locomotives ever since. In the absence of any legal claim to the invention the device became generally known as the Stephenson valve gearing or shifting link, the latter name being used in contradistinction to link motions where the link oscillates on a fixed center as in the Walschaerts valve gearing.

In the excellent model before us, a duplicate of which can be procured from the publishers of Railway and Locomotive Engineering, and a drawing of which is reproduced for illustration, it will be noted that the piston is in the middle of the cylinder. Both steam ports are closed, and if it is desired that the engine should be moved forward it will be necessary that the steam be admitted at the front so that the piston should be pressed backwards and so move the wheels forward on the rails. In order to admit the steam to the front end of the cylinder the valve must be moved backward. It will be readily noted that by moving the lever forward on the quadrant the radial link is dropped downward until the upper eccentric rod is in line with the lower end of the rocker. To accommodate itself to this movement the lower end of the rocker has been pushed some distance forward, the upper end of the rocker consequently moving an equal distance backward and carrying with it the slide valve. This has the effect of opening the steam port leading to the front end of the cylinder and the pressure of the steam is admitted to the front face of the piston.

If, on the other hand, it is desired to move the engine backwards, it will be found that by moving the lever to the back of the quadrant, the link is raised until the lower eccentric is in line with the lower end of the rocker. To admit of this movement the lower end of the rocker is drawn back with the consequent result that the upper end of the rocker has been moved a corresponding distance forward, thereby opening the steam port leading to the back of the cylinder and so admitting the steam to the back of the movable piston, which moving forward has the effect of moving the wheels backward upon the rails.

There are several important factors rendering these simple movements possible and which, if carefully observed, will readily impress themselves upon the memory of the attentive student. The first is that with the rocker in perpendicular position, the valve rod should be of the exact length so that the valve should be in the central positon in regard to the steam ports. Presuming that the piston has moved forward in the cylinder until it has reached the extreme end of the stroke, it is necessary that the valve should be beginning to open the front port in order that the steam may be admitted to the front face of the piston for the purpose of moving the piston backward. At this particular point it is well to turn our attention to the position of the eccentrics and their relation to the driving crank. It will be understood that with the piston at the front end of the cylinder the main crank pin is at the forward center. If the valve was so constructed as to cover the steam ports exactly, the two eccentrics should be standing with their extreme points at right angles to the main crank pin, the forward eccentric with its extreme point being on the top or above the crank, and the eccentric controlling the backward motion on the bottom or below the crank.

As previously described, however, the valve in modern use is so constructed that the extreme ends of the valve when in a central position overlap the steam ports. In the modern locomotives this amount of lap extends to three-quarters of an inch, and if to this is added some amount of valve opening it will be readily understood that the eccentrics must be moved sufficiently from the position at right angles to the crank to a position nearer to the crank by an amount equal to the lap and lead combined. The effect of this movement toward the crank on the part of the eccentric has the effect of pushing the lower end of the rocker toward the cylinder and consequently drawing the upper end of the rocker with the valve rod backward a sufficient distance to overcome the lap of the valve.

It need hardly be stated that the sliding valve alluded to is the common D-shaped valve, but the operations of the outside admission piston valve are identical with the action of the valve described. In the case of an inside admission piston valve a change of the position of the eccentrics in their relation to the main crank is necessary, as it will be readily seen that the edge of the valve at the point of admission is at the opposite side of the port and the valve also must necessarily travel in the opposition direction to that of the outside admission valve. The relative merits of the various forms of valves are not pertinent to a general discussion of the link motion.

It will be observed that the radial link is simply a contrivance for the purpose of detaching one eccentric and placing the other in operation, besides which it has the advantage of varying the amount of travel of the valve, thereby allowing a supply of steam to be admitted for a long or short space of the piston stroke. This is accomplished by moving the lever toward the center of the quadrant and it will be easily understood that as the eccentric rod in operation is moved some distance from the end of the rocker it has the effect of shortening the movement of the rocker arm and consequently shortening the stroke of the valve. Such are the chief features of the link motion and with these clearly in mind, other less important details may be readily mastered by the thoughtful student.

IV. ADJUSTING THE STEPHENSON VALVE GEAR.

The importance of correctly adjusting and maintaining the position of the valves cannot be overestimated. Like the valves in the hearts of animals their perfect operation is the very life of the moving force of the machine. The work of adjusting the mechanism has been absurdly overestimated, and the idea assumed by many that the operation is a difficult one is a gross error. Like other alleged mysteries that owe their importance to the lack of opportunity of witnessing their true inwardness, familiarity soon begets a spirit of common regard. There is just the same degree of accuracy necessary in adjusting the attachments of the throttle valve. Both are a simple matter of careful experiment and exact measurement. In adjusting the ordinary sliding valve it may be said at the outset that there are degrees of proficiency required from the designing of the parts of the gearing to the simple matter of squaring the eccentric rods in a brief roundhouse examination. The working machinist is very safe to assume that the designer's part is correct and he can safely proceed with the adjustment of the valve gear, which is generally among the last operations in the building or repairing of a locomotive.

Assuming that the four eccentrics are loose upon the driving axle of an ordinary 8-wheel locomotive, the best plan is to move the engine until one of the crank pins on the axle to which the eccentrics are placed is on the forward center, that is the point nearest to the cylinder. We will assume this is on the right side. If the eccentric which is designed to move the engine in a forward direction is intended to be next the frame, the eccentric may be promptly put in place somewhere about 85 degs. above the line of the crank pin, the exact position need not be ascertained at this time, the eccentric being temporarily held in place by one or more set screws. The eccentric intended for the backward motion is placed a simlar distance below the crank pin or center line of the axle. The eccentrics on the other side of the engine can be similarly attached temporarily in their places. Assuming that the links have been already attached to the rockers and the link hangers adjusted to the arms of the lifting shaft, the forward eccentric rod should then be adjusted to the top of the link and the back eccentric rod to the bottom of the link. We are now ready to begin the operation of correctly adjusting the entire gearing, and it may be stated that inasmuch as the preparatory markings of centers and openings are of prime importance, it is proper that the locomotive should be levelled. It does not follow that because the engine is new or newly repaired it is exactly level. The tendency is to drop slightly in front, which is generally rectified when the water is placed in the boiler. When the engine is level the rocker should be placed exactly plumb. This can readily be done by moving the reverse lever while a fine line is hung over the rocker end with two small weights attached and the lever stopped at the exact point where the two lines are equidistant from the center of the rocker. The valve rod should then be adjusted so that the valve is exactly in the middle of the valve seat. A neglect of this important point will cause variations in the valve travel that can never be entirely overcome. At this time it should be noted whether the valve yoke is properly adjusted to suit the thickness of the valve, as in the case of an engine being frequently repaired the valves and valve faces wear rapidly and a liner may be necessary under the valve yoke to prevent undue strain upon the valve rod packing as well as a tendency to tilt the valve.

Before finally attaching the valve rod to the rocker, the best method of marking the exact positon of the valve openings is by a tram reaching from the guide yoke or other fixed part of the engine to a suitable position on the valve rod. Both ends of the tram are sharpened, one end to adjust itself to a center punch mark on the guide yoke, and the other end, which is bent so as to scratch a mark readily on the valve rod. The points marked are necessarily where the valve is beginning to open at the front and back steam ports. The marks on the valve rod should be marked lightly with a fine center punch. The steam chest lid can then be put on the steam chest and any danger of material or articles falling into the steam chest can be entirely avoided.

The next operation should be the ascertaining of the exact dead centers or positions when the crosshead and piston are standing still at each end of the piston stroke. This point should be located very carefully. If the rim of the main driving wheel is near the guide yoke the same tram may suit to locate the center, but generally a longer tram is necessary with both ends bent. The engine may then be moved to a point where the crosshead is about half an inch from the back or forward end of the stroke. A fine center punch mark may be made on the crosshead and guide yoke or guide block as the case may be, and a pair of compasses carefully adjusted to the two points. Accompanying this adjustment, the tram should be extended from the guide yoke or other point to the rim of the wheel and an arc drawn by the sharp end of the tram. The engine should then be moved over the center until the crosshead returns to the exact point where the compasses touch the center marks on the crosshead and guide yoke or block. Another arc or line should be drawn on the wheel rim and a point between those two arc lines is the dead center. It will be noted by those who have time to try the experiment that it is difficult to obtain this center mark in a positively correct positon. A repetition of the experiment with the crosshead at a greater or lesser distance from the end of the stroke will show a slight variation. This arises from the fact that while the crosshead is moving very slowly near this point the rim of the wheel is moving rapidly, and it may be added that the valve is also moving rapidly at this time. Hence the utmost care should be taken in ascertaining the dead centers. It is often noted that in looking over the valves, it may be only a few days after the engine has been running, that the exact center, as newly discovered, may show a considerable variation in the rim of the wheel. This arises from the lost motion already caused by the incidental wear of the engine bearings, so that old markings on wheel rims instead of being of any value are often misleading. Variations in the dead center marks will also show in marking while the engine is moving forward as compared with markings that are made while the engine is running backward.

It is seldom that the wheel rim variations in marking are heeded, but they are of real value if a serious effort is maintained to keep the valves in correct positions.

Having the valve rods marked and the dead center points located, we now proceed to ascertain the position of the valves. As one at a time is good work, at least for a beginner, we may as well proceed with the right forward. Place the reverse lever in the extreme forward notch and move the engine forward until the tram touches the dead center point. Then proceed to make a mark on the valve rod. If you are on the forward center observe if the mark made on the valve rod is near the forward opening mark. Keep in your mind's eye the location of the end of the piston stroke and steam port you are working on. Move the engine ahead till you reach the other end of the stroke where it is assumed marks have been made on the wheel rim in the same manner as before. With the tram at the center try the tram

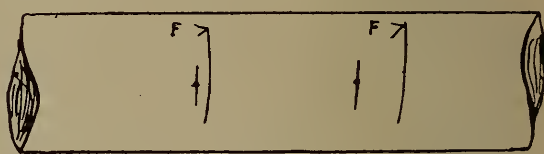


FIG. 1. FIRST MARKING.

on the valve rod and make another scratch. It is not to be expected that the scratches will be equidistant from the marks showing the valve openings. We will suppose that Fig. 1 is about the location of the scratchings and opening marks.

It will be seen at a glance that the valve opening at the front end of the stroke is about three-eighths of an inch, while at the back end there is about one-eighth of an inch of lap, or in other words there is no opening at the back end of the stroke until the valve rod has moved at least one-eighth forward. It will readily be seen that no matter which end of the stroke we are at the valve rod must be moved about a quarter of an inch ahead in order to equalize the opening at both ends of the stroke. Assuming that both ends of the rocker are of equal length, the right forward eccentric rod must be shortened a quarter of an inch. It is not necessary at this time to make the alteration perfectly exact, but we shall suppose that the rod is moved and that the opening on each end is about a quarter of an inch. Another trial of the tram at both ends should show something resembling Fig. 2.

We will assume that the amount of opening desired at the end of the stroke is one-eighth of an inch. It will be seen that presuming we are at the front end opening the valve rod must be moved ahead one-eighth, but it must be evident that while moving the eccentric rod would accommodate us at this end of the valve

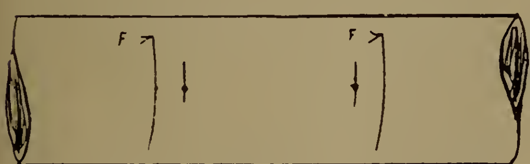


FIG. 2. ECCENTRIC ROD ADJUSTED.

stroke, it would have the effect of increasing the opening at the other end, as was seen in the previous experiment, it is, therefore, necessary when the eccentric rod has been evenly adjusted that the eccentric itself should be moved in order to increase or diminish the amount of opening at both ends of the valve stroke. In the present instance the eccentric must be moved further away from the crank and approach more nearly to right angles or 90 degs. from the crank. While the eccentric is being moved, the valve rod should be carefully watched and the eccentric secured at the desired point, which after experimentally moving the engine and marking the dead centers will show something like Fig. 3.

Turning our attention to the backward movement of the engine, it is necessary to place the reversing lever in the notch

FIG. 3. ECCENTRIC ADJUSTED.

furthest back and proceed with our experiments as before. Very likely the discrepancies will be greater than what is shown in Fig. 1, but the same methods will bring the desired results, and it will be noted that after having made the necessary changes on the backward eccentric rod and eccentric, the effect of the changes, in addition to bringing the openings of the valve to the desired amount, will have had the added effect of slightly changing the amount of openings on the forward motion. This is easily explained by the fact that in changing the position of the eccentric or the length of the eccentric rod the position of the link is slightly changed, thereby affecting the exact distribution of the motion in a ratio to the amount of change made. There are other disturbing causes that must not be overlooked. The length of the reach rod is an important factor, and while the experiments are going on in regard to adjusting the eccentrics and rods, it is well to observe the amount of clearance that the link block has at each end of the link. It is safe to allow at least a quarter of an inch more clearance at the top of the link than at the bottom. In links where the amount of clearance is limited it is perfectly safe that the link block may approach within one-eighth of an inch when the link block is at the bottom of the link, as the tendency of the link is always to drop lower down as the joints begin to wear and as the heat expands the length of the boiler without materially expanding the length of the frames.

Another important consideration is the fact that while the valves may be carefully adjusted to open correctly at the extreme length of the travel of the valve, it does not follow that when the lever is hooked up nearer the center of the quadrant that the openings retain their exact ratio to each other. The tendency is in addition to increasing the amount of opening or lead as it is called, to create variations in the amount of opening at each end of the valve stroke. In engines that are used with short valve travel, as in light running engines, it is often necessary to sacrifice the exact adjustment at the extreme end of the stroke in order that the valve openings may be squared at the point where the engine is called upon to perform most of its work. It need hardly be stated that the same remarks in detail apply to the left side of the engine, and that in common practice both sides are being adjusted while the engine is being moved or while the wheels are being revolved.

It has already been noted that an examination of the exact position of the valves after the engine has been running a short time will show more or less variation corresponding in a great degree to the quality of the general workmanship exhibited in the construction or repair of the engine. Repeated examinations and readjustments are invariably necessary. The number and variety of joints through which the motion has to come before reaching the slide valve, renders the retention of the exact position of the valve for any length of time a physical impossibility.

Assuming that the rods and eccentrics have been carefully adjusted to suit the extreme travel of the slide valves and that it is necessary to adjust the amount of valve opening or travel at some hooked-up point, the common practice is to begin the operation by marking the extreme travel of the crossheads on both front and back end of the stroke. This can be readily done with a pencil marking a line on the guides. It is immaterial at what point we begin, but for simplifying the matter, suppose we begin as formerly at the right front end, and, moving the engine forward until the crosshead has moved six inches from the pencil mark, the valve tram can be used to locate the position of the valve. With the reverse lever in the front notch it will be found that the front steam port is wide open.

By drawing back the reverse lever the valve port is gradually closed and when the tram is exactly at the shut point on the valve rod the reverse lever latch should be dropped in the nearest notch and allowed to remain there. It is well to repeat the operation of finding the exact position of the valve by moving the engine a short distance backward and forward again to the point where the tram exactly enters the mark on the valve rod, showing that the steam port is at the closing point. The distance from the extreme front end of the crosshead to the pencil mark on the guide may not be exactly six inches, but this is immaterial. Suppose it is 6½ ins., this should be marked down with chalk or otherwise and the operation continued on the other side of the engine in the same way and so on until the four separate and distinct distances are discovered and marked down for reference. Suppose the right side shows 6½ ins. in front and 5½ ins. in the back and that the left side shows 7 ins. in front and 4½ ins. back. A general summing up of these distances would show that something near six inches would be the best average that could be obtained. Now if the link saddles are not new and are already bolted in place, the only course open to remedy the variation in the cut-off is to sacrifice the exact adjustment of the eccentric rods and make such changes in raising one of the tumbling shaft blocks or lowering one of the rocker boxes as may best meet the compromise object at which we are darkly aiming.

Returning to our familiar position on the right front where the distance from the crosshead to the pencil line is 6½ ins., suppose we stop the engine a little before we reach 6 ins., say 5⅞ ins., and try the valve tram in order to ascertain how far we are from the valve opening mark. It will be found that there is probably $^1/_{32}$ of an inch of a valve opening at this point, and it will readily be seen that if the valve rod has to move forward a short distance in order that the tram will touch the mark as desired the shortening of the forward eccentric rod will have the desired effect. After effecting this slight change in the forward eccentric rod the crosshead distance from the pencilled lines on the guide can be again ascertained, and confining ourselves to the right side, suppose the distance at the front end shows 5⅞ ins. and at the back end the distance is 6⅛ ins., it is well to remember that a slight increase of the amount at the back end as measured from the crosshead to the pencilled line is a necessary arrangement in the case of a piston where the piston rod does not extend through the front cylinder head.

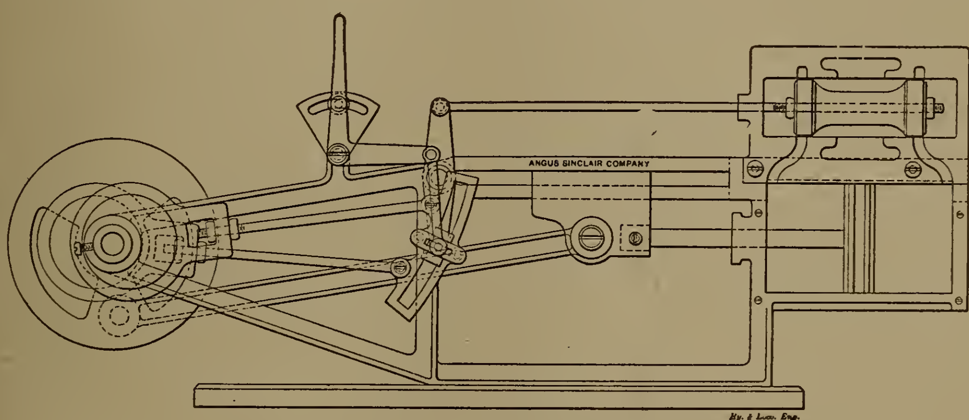
In the case of the ordinary single-ended piston the variation in steam pressure at the different ends of the piston can be readily determined by calculating the area of the piston rod and deducting it from the area of the piston. Suppose the diameter of the cylinder is 20 ins., then $20 \times 20 \times .7854 = 314.16$ sq. ins., the area of the face of the piston. If the piston rod is 4 ins. in diameter then $4 \times 4 \times .7854 = 12.56$ ins., the amount to be deducted from the area of the back end of the piston. This is equal to one twenty-fifth of the entire area, and in any adjustment of the valve gearing this factor of pressure area should be considered. It would be very safe, therefore, to allow the figures to stand that we have already found on the right side and turn our attention to the important variation discovered on the left side.

In this case where the difference in the measurement of the crosshead from the pencilled lines is much greater it would be inadvisable to adjust the eccentric rod so as to make up the entire difference. If we did so, it would be found that an excessive amount of lead or valve opening would occur at one end of the stroke when the reversing lever was placed at the extreme end of the quadrant and there would be no opening at the other end of the stroke. Apart from this involved problem, another one equally important arises from the variation occurring in the amount of the distances at which the cut-off occurs. Even if it were advisable to adjust the eccentric rod to equalize the distribution of the amount of distance traveled by the piston at each end of the cut-off, the total amount at each end would still be greater than the distance already equalized on the right side. Now if we will observe the angle at which the link is hanging as held by the ends of the two eccentric rods it will readily be seen that if the link could be raised or the link block be lowered the effect would be to move the lower end of the rocker arm towards the eccentrics while the valve rod would be moved a corresponding distance in the opposite direction, thereby effecting an earlier closing of the valve.

There are two methods by which this can be accomplished. A liner can be placed between the rocker box and frame or between the tumbling shaft block and frame. The effect in both cases is alike, although both remedies should be avoided if possible. A third remedy lies in the shortening of the link hanger, but this is a delicate and difficult operation, owing to the brittleness of the ends of the link hanger, and of the three evils the readjustment of the height of the rocker box is the best. The exact thickness of the liner can best be discovered by experiment.

It need hardly be said that in the case of a new link, or new link saddle, the saddle can be temporarily adjusted and move experimentally to the correct position. It is usual in describing the exact location of the position of the pin by which the link is suspended to produce an array of figures and selections from the alphabet to illustrate the true position of the point of suspension. The illustrations and formulas are of little use, as is well known to all who have placed the parts of the Stephenson valve gearing in position, and in spite of the calculations having been very accurately made by the most accomplished mechanical engineers, there are almost invariably changes to be made in regard to the exact location of the link saddle pin. There are several causes that lead to this involved problem. The angular advance of the main rods, together with the same feature in the eccentric rods, have a singularly conflicting effect on the action that moves the rocker arm. It may be remarked that when the link is suspended exactly by the center of the link the large variation in the cut-off occurring under such conditions is caused largely by the angularity of the link caused by the action of the eccentric rod that is not supposed to be in gearing, but is nevertheless affecting in a marked degree the action of the eccentric rod that is in gearing. It is usual to ascribe the variations in the cut-off to the angular advance of the main rod. This would doubtless be true if the eccentrics were set at the same point as the crank is set, but as they are set nearly at right angles to the crank the angular advance of the main rod has a corrective effect on the peculiarities of the link motion.

In common practice it is not necessary to trouble ourselves about these involved problems. They may very safely be set down as being among those that are past finding out. The effect of moving the point of link suspension can readily be seen by the most casual observation. In the accompanying illustration showing the Angus Sinclair valve model with piston and reverse lever in the center it will be seen at a glance that by moving the suspension point of the link, as can readily be done in the model, either forward or backward, the effect is to raise or lower the link, as the case may be, as the line of the center of suspension is not in the same plane as the engine frames. In fact, the only points where the link is in a perpendicular position is at the two centers when the piston is at the extreme ends of the stroke. It may be noted that moving the saddle pin backward or forward affects the distribution of the cut-off and has the effect of equalizing or distorting the points of cut-off according to the direction in which the pin is moved, while moving the link saddle higher or



VALVE MODEL WITH PISTON VALVE.

lower upon the link increases or diminishes the distance of the cut-off point from the end of the stroke or pencilled mark. Indeed it may be remarked that in the case of a new saddle it is merely a matter of careful experiment which necessarily requires repetition, as the movement of the link saddle affects the valve opening at the extreme ends of the stroke so that the reverse lever should be placed in the end notches and the valve openings re-examined after each saddle experiment.

It might be added that after the forward cut-off has been carefully adjusted it does not follow that the backward cut-off will be found to be correct. Other changes and compromises may have to be made, but it should be noted that if we have disposed of the right and left sides of our engine, and have the cut-off adjusted, say at 6 ins. in the back and 5¾ ins. in front, it is not necessary that the same figures should be established as an absolute necessity for the backward motion of the engine. It is enough that the points are equalized to each other, and while the forward and backward motions of the engine can be equalized exactly if there is a new quadrant to be made it will be found that where the notches are already made in the quadrant it will be hardly possible to arrange the cut-off points so that they will exactly correspond.

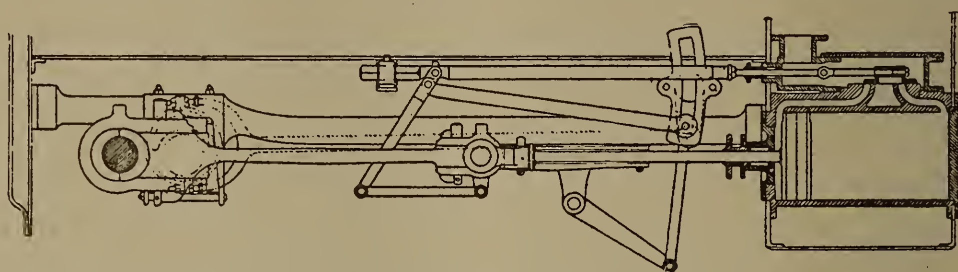
This leads us to observe that which will be noticed, that no matter how carefully the entire valve gearing may be adjusted it will be found that when the locomotive is overhauled for general repairs variations have occurred that seem to the casual observer extremely puzzling. It is common to belittle the orignal construction and set down the apparent errors in organic construction to a lack of ability or care in the first adjustment of the mechanism. This is a gross injustice, and if we could only dimly discern the vicissitudes through which the mechanism has passed and measure the blows of circumstance that have fallen upon the multiplex parts of the elastic contrivance we would perhaps recognize the fact that it is remarkable that machinery so involved and so subject to disturbing influences has retained such a degree of perfection as it is often found to possess after service so peculiarly exacting and so painfully strenuous.

V. THE WALSCHAERTS VALVE GEAR

In treating of valve gearing as applied to steam engines generally, it is presumed that it is scarcely necessary to dwell at any great length on the fact that all such gearing is designed with a view to admit steam readily to the reciprocating piston at a time when the steam pressure will be most effectual in moving the piston in the cylinder, which movement is readily conveyed through a connecting rod attached to the piston at one end, and to a crank at the other end, thereby inducing a turning or revolving motion to a wheel and axle. In the economic use of steam, and incidentally of fuel, it is advisable to shut off the supply of steam as early as possible during the piston stroke, so that the steam admitted to the cylinder at a high degree of pressure may have an opportunity to spend its force before being permitted to pass into the outer air. It will be readily understood that in a cylinder two feet in length, if the supply of steam is cut off at a point when the piston has only traveled six inches on its course toward the other end of the cylinder, the steam pressure will only amount to one-half of the original pressure when the piston has traveled twelve inches, because the steam will then occupy twice the space, and so on until the piston has reached the end of the stroke, when the pressure will be four times less than when admitted. Other causes, which need not now be dwelt upon, will have reduced the pressure even more than this, so that steam admitted at 180 lbs. of pressure per square inch at the beginning of the piston stroke will be less than 40 lbs. per square inch by the time the piston stroke is completed.

In the early days of the steam engine the necessity for this economical or expansive use of steam, as it is called, was not so great as it is now, for the reason that steam was used at a much lower presscure at that time, and the loss of steam at the end of the piston stroke was small in comparison with what it is now, when steam is admitted during the entire length of the stroke. Other causes soon arose calling for a variable supply of steam. With the locomotive the difference in grades to be climbed and in loads to be hauled necessitated an increase and a diminution of the steam pressure, and the brightest minds among steam engineers were early at work on this important problem. As boiler construction improved and higher steam pressures became possible, the necessity for a variable valve motion increased. Egide Walschaerts, a young Belgian engineer, was among the first, and perhaps the most successful, in solving this intricate mechanical problem.

Eccentrics were already in use for the simple purpose of reversing the movement of the engine. This was accomplished by having two eccentrics set in such positions that when their rods were in operation on a rocker that moved the valve rod, one rod was adjusted so that it would act in advance of the main crank, while the other, when in operation, would follow the crank. One rod could be lifted off the rocker pin and the other one attached by a simple appliance similar to the lifting shaft now in use on locomotives, the rods being furnished with hooks adapted to catch the rocker pin.



WALSCHAERTS' VARIABLE EXPANSION VALVE MOTION APPLIED TO LOCOMOTIVE 98, AT BRUSSELS, BELGIUM, SEPT. 2, 1848.

This reversing contrivance attached to the early locomotives is alluded to in order that the condition of the valve gearing at the time that Walschaerts brought his keen intellect and engineering skill to bear upon the problem may be understood.

The valve then in use, known as the D-slide valve, the steam ports leading to the cylinder and the method of exhausting the steam through the inner cavity of the valve were not in any way affected by the work of the young Belgian engineer. The perfect adjustment of an eccentric or crank set at right angles to the main crank is the primal necessity in the construction of the Walschaerts gearing. It can readily be understood that a connecting rod attached to an eccentric or crank so fixed and so adjusted in point of length that it would reach exactly to the movable valve while the valve was in the central position would, by continuing the movement of the engine, continue to place the valve in the middle of the valve seat when the piston was at the end of the stroke, and also move the valve to the extreme end of its stroke at the moment that the piston was in the middle of the cylinder.

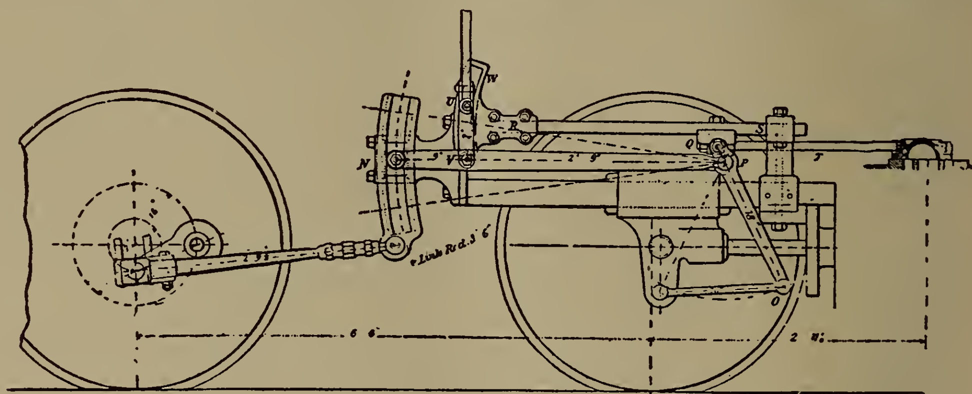
With the piston at either of the extreme ends of the cylinder and the valve in the central position, it would be found that a certain portion of the valve face overlapped the steam ports and it would be necessary to move the valve a distance equal to the amount of lap in order that the steam might be readily admitted to act on the piston in the early part of its movement towards the other end of the cylinder. The mechanism invented by Walschaerts in moving the valve the required distance from the center at either end of the piston is one of the cleverest devices in use in steam engineering, and is generally looked upon as the crowning feature of Walschaerts' masterly invention. It should be noted that the overlapping of the valve is an essential requisite in the economic use of steam. If the valve exactly covered the ports any movement of the valve would cause an immediate opening of one port at the instant of the closing of the other port. The amount of lap makes a period of closure of the ports possible, and consequently renders the expansive use of steam already alluded to a mechanical possibility.

This moving of the slide valve toward the desired point is effected by the engaging of the valve rod by an intervening combination lever which is connected to the crosshead by a union link, and which will be fully described hereafter. The correlation between the combination lever and a radius bar driven by an oscillating radial link, which is driven by the eccentric rod, becomes the determining factor in moving the valve from the central position to the point desired.

The shortening of the valve stroke, making it possible to close the supply of steam at any desired point of the piston stroke is effected by the oscillating radial link into which the radial bar attached to the valve rod and cross-head is movable by the lifting shaft, and it will be readily seen that as the radial link suspended centrally oscillates furthest at the extreme ends the radial bar will travel further when near the extreme ends of the link, and as it is made to approach the center the motion of the bar will be shortened. At the center of the link it will cease moving altogether, and after passing the center it will move in the opposite direction, thus reversing the movement of the engine. The moving of the valve towards the opening point by the use of the cross-head connection, as well as the intervention of the oscillating radial link, together with the use of the single eccentric or crank, are three distinct and separate features of this valve gearing, and these, together with their connections and relation to each other, will be treated in detail in the forthcoming chapters describing the construction and adjustment of this steam-engine attachment, as applied to the locomotive.

VI. VARIATIONS IN FORM IN THE WALSCHAERTS VALVE GEAR

It will be noted that the construction of the Walschaerts valve gearing as originally applied by the inventor to the locomotives of the Belgian State railways differs somewhat in detail from the forms in which it is now made applicable to twentieth century locomotives. These changes do not in any way affect the organic principles of the device, but are merely matters of convenience made to suit the increased size of the engines. Among the changes in form it will be observed that the original method of causing the radial link to oscillate on its central suspension stud was by an eccentric attached to the main axle to which a rod was attached, one end of the rod being fastened to the eccentric strap, and the other end attached to the lower end of the radial link. This eccentric was set at right angles to the main driving crank, that is while the piston would be at the extreme back end of the cylinder and the main crank pin consequently on the back center, the extreme point of the eccentric would be on the top center, or 90 degrees ahead of the main crank while the engine was running forward. It must be borne in mind that the original invention was applied to an outside admission D-slide valve. In the case of a modern locomotive equipped with an inside admission piston valve the eccentric would be set 90 degrees behind



WALSCHAERTS' VALVE GEAR, AS APPLIED TO LOCOMOTIVES BY WILLIAM MASON.

the main crank, that is on the bottom center. This change of position is made necessary from the fact that an inside admission piston valve must necessarily move in the opposite direction from that of the ordinary outside admission slide valve.

In addition to the change of position in the eccentric there is also a change necessary in the relative positions of the radius bar and valve rod, the outside admission valve requiring that the valve rod should be attached to the combination lever above the radius bar as in Walschaerts' original design, whereas with an inside admission valve, the valve rod attachment is made beneath that of the radius bar. The cause and effect of this change of position will be fully explained hereafter, the present reference being merely the need of calling attention in a general way to some apparent changes in the construction of the valve gearing, which in reality are not changes at all, but simply varying modifications of the same general principles.

With this idea in mind it will be readily understood that the eccentric fulfilled the same purpose in the original design as the return crank does that in the larger locomotives with the advantage that the crank being attached to the outer end of the main crank pin its motion can readily be imparted to the oscillating link by a rod moving in the same plane, thereby avoiding the necessity for extended attachments which would be necessary if the eccentric was attached to the main axle inside of the engine frames while the oscillating link would necessarily be at some distance outside of the frames.

Other changes of less importance have occurred, among which is the placing of the lifting shaft above the frames so that the radius bar is hung by a short hanger or suspended by an adjustable sleeve, instead of being sustained by a bar from beneath which in the case of the modern locomotive would be of considerable length and add to the degree of unwieldiness of the mechanism.

Among the first to adopt the Walschaerts valve gearing to the expanding form of the modern locomotive was William Mason, an American engineer. The changes in the position of some of the parts of the mechanism made by him have been closely followed by subsequent engineers. In his application of the device he not only made the valve rod adjustable by the use of threaded ends on the valve rods on which nuts were movable to equalize the position of the valve, but he also applied turn buckles to the eccentric rods so that the inevitable wear of the return crank bearing could be readily rectified in case of the lengthening or shortening of the rod occasioned by the refitting of the brasses.

It will be noted that in the modern use of the radial link there is an attachment extending beyond and underneath the bottom of the link. This attachment is variable in extent, and is adapted to form a suitable connection for the eccentric rod. The exact location of the connecting point must be carefully considered by the constructor on account of the relation of the amount of throw of the crank to the travel of the valve. In ordinary practice a locomotive with a piston stroke of 28 ins., would have a valve stroke of 5½ ins., while the path of the return crank would describe a circle 12 ins. in diameter. The center of the eccentric rod attachment to the link would thus be describing an arc 12 ins. in length while the radius bar being considerably nearer the centre of the link would move through a smaller arc which continues to grow smaller if the radius bar is moved towards the centre of the link.

In the construction of some kinds of locomotives there are two lifting shafts connected by a transmission bar. It will be readily found that variations of this kind are made necessary in order to accommodate the location of other parts of the engine, the additional lifting shaft not in any way affecting the action of the valve gearing.

Such briefly are the principal changes in form which have occurred in Walschaerts valve gearing since its original introduction. These changes illustrate its ready adaptability to changing conditions and stamp it as one of those few mechanical contrivances that have come to us as nearly perfect as any kind of mechanism involving the changing of circular motion in some parts to linear motion in other parts can be expected to be, and not surpassed in the fine quality of reliability.

VII. CONSTRUCTION OF THE WALSCHAERTS VALVE GEAR

In view of the fact that the Walschaerts valve gearing does not possess that flexibility of adjustment common to shifting link valve gearings, there is greater need for perfect accuracy in construction. Not only must the design be carefully laid out, but in fitting up the gearing a degree of exactness must be attained that approaches as nearly as possible to perfection. As a general rule it is very safe to presume that the design, as far as the draftsman's work is concerned, is correct, but the same cannot always be said of the machinists' work. Shopmen are well aware that in the process of hardening the wearing parts of machines there is a tendency to irregularities, owing to the variations in the sizes of the parts. This is particularly true in regard to the parts where the greatest degree of exactness is required, and it should be carefully observed that the radial link attachment, extending as it does some distance beyond the link proper, has not moved in one direction or the other during the hardening process. The application of a turnbuckle or other device to the eccentric rod, although not now used, was a ready corrective to variations of this kind, but it was not a complete remedy, as it will be readily understood that any variation in the paths described by the moving parts have some disturbing effect on the constructor's design.

Errors of this kind are more easily detected than remedied, and it may be accepted as a rule that organic defects in the construction of the Walschaerts valve gearing can rarely be altogether remedied. It is a well-known fact among shop men that in the construction of locomotives there is a tendency to what may properly be called dramatic flourishes in the beginning of the building of a locomotive. The frames and saddle and cylinders are bolted together with a degree of rapidity that fills the eye that is pleased with superficial appearances. The exact alignment of the parts, however, is never correct by chance. Whatever is correct in mechanism is always difficult of accomplishment, and it is time well spent to note that the pedestal jaws of the frames are not only exactly square to each other, but that the shoes are also perfectly parallel. It should not be supposed that the simple matter of adding or subtracting a certain quantity of metal to or from the shoes will restore or maintain a just relation of the parts to each other. The least variation in the setting of the frames has the pernicious effect of throwing the bolt holes in the frames out of position, and braces and guide yokes and rocker boxes are more or less strangers to the truth from the first day of their industrial existence, and no amount of temporary tinkering can ever bring them back to where they properly belong. This is especially true of the relation of the center of the main driving axles to the various parts of the Walschaerts valve gearing, and it cannot be too strongly instilled into the minds of those who are engaged in this important work that every precaution should be taken to maintain the exact mathematical relation of the parts to which the valve gearing is attached and from which it derives its accuracy of movement. This is the highest kind of constructive work, and to which the work of the draughtsman is merely preliminary. It is a singular circumstance that error multiplies as it proceeds from point to point, and that which is only a small fraction at the main axle becomes a considerable quantity by the time that it has reached the valve opening.

In the designing of the Walschaerts valve gearing the length of the piston stroke being given, together with the amount of valve travel and the extent to which the valve overlaps the steam ports, and also the amount of opening or lead which may be deemed necessary, the combination lever is designed in such proportion as to move the valve the exact amount of lap and lead away from the central position at the time that the piston is at the extreme end of the stroke. The union link and crosshead arm are so constructed that the combination lever will be in the perpendicular position when the piston is in the center of the cylinder. The radial link is so constructed that its arc or curve corresponds to the circle described by the length of the radius bar; that is, measuring from the point to where the radius bar is attached to the combination lever along to the center of the link block. The radius bar should be at least eight times the length of the space in which the link block is designed to travel. The longer the radius bar is the more direct its thrust will be on the valve rod, and consequently less subject to the disturbing and distorting effect of a short angular movement. The length of the link is such as when oscillated by the eccentric rod the radius bar will move the slide valve the desired amount of travel; that is, when the link block which is attached to the radius bar and moves freely in the link is at either end of the link.

As we have already stated in the case of engines equipped with the ordinary slide valve or with outside admission piston valves, the radius bar is connected to the combination lever below the valve stem, and in the case of piston valves where the steam is admitted from the inner edge of the valve, called inside admission, the connection of the radius bar is above the valve stem. It should be noted that in order to maintain the perfect equality of the valve travel both in the forward and backward motions the suspension point of the link should be in line with a point between the combination lever's connection with the radius bar and valve rod, the line being drawn parallel with the valve rod. The same alignment should be maintained as nearly as possible in regard to the eccentric rod and the center of the driving axle. The point of connection of the eccentric rod with the link should be parallel with the axle centers. In the construction of some classes of locomotives, especially with the largest kind of cylinders, the perfect lever, which being attached to the cross-head, maintains the position of the valve with a degree of accuracy rarely equalled by any kind of mechanism where circular motion is changed to linear or reciprocating motion.

A working model of the Walschaerts valve gearing is a good aid to a clear understanding of the mechanism, and

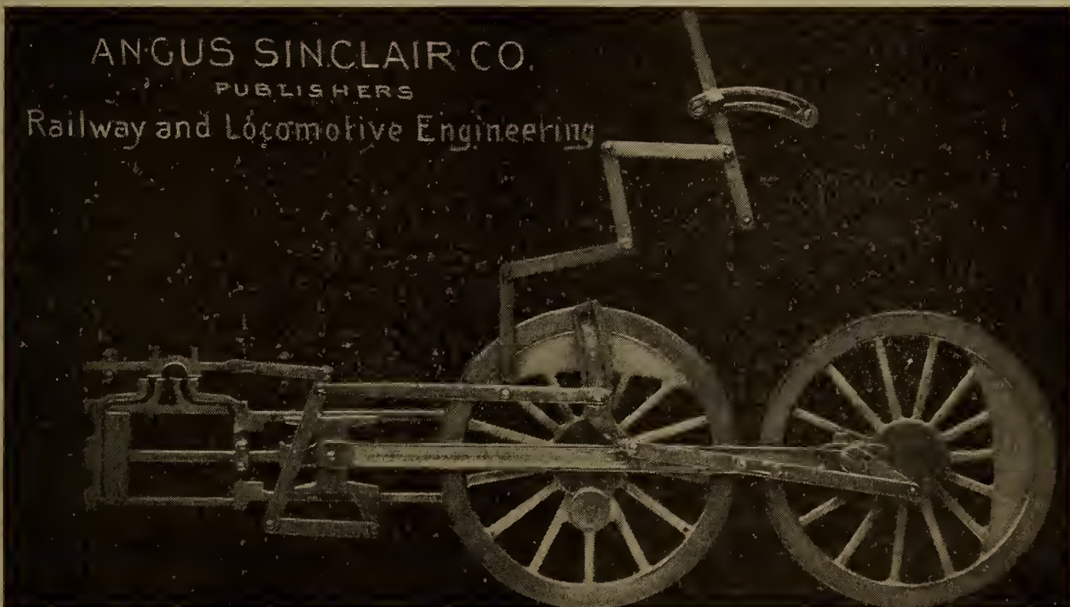


FIG. 1. FORWARD GEAR, LINK-BLOCK AT BOTTOM OF LINK.

alignment of these points would necessitate an extra extension of the link arm, which in turn would require an excessive amount of eccentric throw, and hence the point of eccentric rod connection with the link arm is often at some distance above the centre line. The distorting influence of these variations is reduced to a minimum by the action of the combination readily reveals not only its essential features and advantages, but shows at a glance some of the seeming contradictions to other valve gearings that its actions exhibit. Thus, in Fig. 1 an illustration of the model before us, it will be noted that in the forward motion the link block is in the bottom of the link. This is opposite to what occurs in the Stephenson shifting link, but it will be observed at once that it is the link block and attached radius rod that moves, and the action is direct and simple in comparison with a floating link passing through a variable arc, disturbing the exact position of the valve as it passes from point to point. It may be stated here that in Walschaerts' valve gear in the position shown in Fig. 1 the reverse lever may be moved from one end of the sector or quadrant to the other end without disturbing the position of the valve. If the eccentric rod is of the proper length it will be readily proved at either end of the piston stroke by moving the reverse lever and thereby moving the link block in the link. If the valve remains stationary the rod referred to is of the correct length. If the piston is at the extreme front end of the cylinder and the valve moves forward as the link block rises in the link the eccentric rod is too short. If on the other hand the valve moves backward the eccentric rod is too long. The eccentric rod controls the position and motion of the link, and should be so adjusted in point of length that the link block and accompanying radius bar should not disturb the valve when the piston is at the extreme end of the stroke.

A peculiarity of the gearing may be noted at this point which affects the movement of the valve advantageously. As shown in Fig. 1, the eccentric rod is on the bottom center, and when in motion moves the link at a comparatively high rate of speed, the motion of the link being reduced to a minimum as the eccentric rod passes around what are properly called the dead centers in its circular path. It will thus be seen that at the moment when the eccentric or return crank is at the lowest or highest point of its path the valve, having its motion conveyed to it by the oscillating link, is traveling at its highest velocity. This is at the exact point where the opening of the valve occurs, and coincident with the rapid movement induced by the location of the eccentric or return crank the velocity of the valve travel is further induced by the action of the combination lever, which, acting on the radius bar connection as a fulcrum, has moved the valve in its path the increased distance required to overcome the space occupied by the lap and lead. The opening of the valve, therefore, occurs more rapidly on account of the movement of the combination lever, and if we follow the movement until the middle of the piston stroke has been reached it will be found that there is a diminution of speed not only on account of the return crank passing the dead center, but this pause in the valve's motion is further accentuated by the combination lever passing the vertical dead center of its connection to the radius bar and valve rod. This double eccentricity, as has been stated, emphasizes the rapid opening and closing of the steam ports and prolongs the period of full opening. These features are of decided advantage in any kind of valve gearing used in steam engines.

In overcoming defects in construction the eccentric rod is usually the part in which any change is made. This rod may be lengthened or shortened to correct errors in the location of the main axle center or link center. The central position of the valve or the exact amount of opening of the steam port at each end of the piston stroke can readily be adjusted by lengthening or shortening the valve rod, which is usually fitted with adjustable threaded nuts. It may be added that the slightest variation of the return crank from its proper position at right angles to the main crank will be readily discovered by comparing the action of the valve as shown in the forward movement of the engine with the action and position of the valve in the backward movement. Referring again to Fig. 1, it will be readily recognized that in the event of the valve showing a greater amount of opening in the forward motion than in the backward motion the variation may be divided by moving the return crank connection the required amount nearer to the main crank, or by moving the point of suspension of the link nearer to the valve; both of these organic changes having the same effect, neither of these changes should be made except under very pressing conditions, and after repeated experiment and identical results.

VIII. ADJUSTING THE WALSCHAERTS VALVE GEAR

The operation of adjusting or setting the valves, as it is called, may be most readily begun by connecting all the levers and rods with the exception of the eccentric rod which connects the crank pin to the link arm. This admits of the valve being moved backward or forward in order to obtain the markings on the valve rod showing the exact points of the valve opening. These markings on the valve rod as well as the markings in the rims of the driving wheels showing the dead centers or points where the piston is at the extreme ends of the stroke, are made in the same manner as the markings on locomotives equipped with the Stephenson shifting link. The same trams may not suit in both cases as the guide yokes or bearings or other fixed parts upon which a tram may be steadily held vary in their positions according to the location of the parts, but the dimensions and form of a suitable tram will readily suggest itself to an intelligent mechanic. A fine centre punch mark should be made on the valve rod at the exact points where the port edges of the valve are exactly square with the admission port edges of the valve seat.

The eccentric rods may then be connected and the work of moving the driving wheels may be begun. Assuming that the reverse lever is at the extreme end of the quadrant in the forward motion, it will be readily seen whether the valve rod is of the proper length, as soon as the two valve rod markings are made when the main rod has reached the dead centres. Whatever variation there may be can readily be rectified by dividing the apparent variation by the adjustable nuts usually atached to the valve rod. When the forward motion has been corrected in this manner, suppose the markings on the valve rod should be as shown in Fig. 2, it will readily be seen, apart from the variation observable in the markings in the back motion, that the opening of the valve has to be increased in the case of the forward motion, and diminished in the back motion. Now assuming that the change is to be made on the left side of the engine and that the main rod is on the forward dead center as in Fig. 1, it will be readily observed that in order to increase the opening of the valve it must be moved backwards toward the link. To accomplish this movement the eccentric rod must be shortened, and if it were convenient to remove the pin connecting the forward end of the eccentric rod from the link arm, allowing the rod to remain in position, and moving the valve the required distance it would be seen by the variation in the edges of the hole in the link arm from that of the eccentric rod how much the eccentric rod would require to be shortened. This method, however, is not entirely to be depended upon, as there is a certain amount of lost motion both in the valve and radius rod connections, as well as on the central pivot upon which the link is suspended. These, in addition to the link block would admit of a slight motion backward or forward of the extreme point of the link arm without showing any motion of the valve. Generally speaking the eccentric will require to be moved or shortened as in the present case between two and three times more than the amount required in the opening of the valve. The exact ratio can be determined by measuring the distance from the central stud upon which the link oscillates to the center of the link block, and supposing this distance to be 8 ins., then measuring the distance from the central stud to the center of the link arm connection with the eccentric rod, and supposing that to be 20 ins., it will thus be seen that the eccentric rod must be moved two and a half times the amount that we desire to move the valve or increase the opening. So if the increase desired, as in the present instance, should be one-sixteenth, it will require a shortening of the eccentric rod amounting to five-thirty-seconds of an inch.

It may be stated at this point that there is no need of experimenting with the union link. It might be imagined at first glance that by lengthening the union link the opening of the valve could be increased. Any change made in this lever, however, with a view to open the valve at one end of the piston stroke, would have the effect of closing the valve a corresponding amount at the other end of the stroke. After rectifying the variation as shown in Fig. 2, as nearly as possible, by shortening the eccentric rod, it may be found that there is still a slight variation between the amounts of openings. This is proof of a slight organic defect probably in the position of the eccentric or return crank, and if the defect does not exceed one thirty-second it is as well to adjust the forward motion as nearly correct as possible and allow whatever variation there may be to remain with the backward

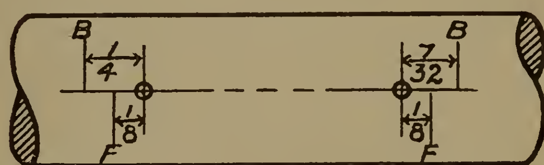


FIG. 2. FORWARD MOTION F; BACKWARD B.

motion of the engine, which as a rule, is not so frequently in use as the forward motion.

In the case of adjusting the valve gearing of a locomotive equipped with the Stephenson shifting link, it is possible under any condition to arrange the eccentrics and eccentric rods to bring about an exact opening of the valve at the desired point of the piston stroke on either the forward or backward motion of the engine. On an engine equipped with the Walschaerts valve gear this is not always the case, but unless the organic defect in the Walschaerts valve gearing is of a serious kind, the gearing may be adjusted so nearly correct that it will likely be in much better condition during its period of service than the shifting link gearing will be after a few weeks' service. In any kind of valve gearing it is well that the point at which the engine will likely do the greatest amount of work, should be most carefully adjusted. In passenger locomotives this point is usually with the valve cutting off the supply of steam at some point considerably less than the full stroke. It will generally be found that in the case of the Walschaerts gearing the cut-off point will be nearly correct. In the event of the variation from the exact clos-

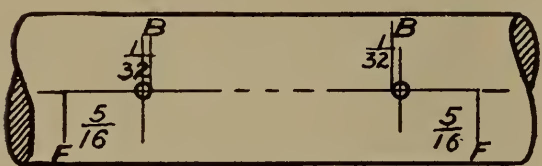


FIG. 3. B, BACK; F, FORWARD.

ing of the valve at each end of the piston showing a more continued opening at the front end, thereby admitting steam a longer period of time, the valve rod may be slightly changed by the adjustable nuts, as it is more desirable to have a slightly prolonged opening in the back of the piston to make up for the space occupied by the piston rod.

Turning our attention to the right side of the locomotive and proceeding by the same method to mark the valve rod when the crosshead is at the dead centers on the forward and backward motions, we shall presume that the markings are found to be as shown on Fig. 3; it will be observed that the valve shows an opening of five-sixteenths on the forward motion, while the valve is lapping one thirty-second on the backward motion. We shall assume that the central position of the valve on both motions is nearly correct. The position of the link when the main crank is on the dead centers should be carefully noted, and if the link retains its exact position when the engine is on either centres, the eccentric crank position may be assumed to be correct. If a variation of the position of the link is observed, it is safe to assume that there is an error in the position of the crank. Placing the engine on the back centre as in Fig. 4, it will be readily seen that the valve must be moved forward in order to obtain the desired amount of opening. As the eccentric rod is now acting indirectly on the valve rod, the eccentric rod must be moved in the opposite direction, and hence the crank connection must be moved a sufficient distance backward or toward the main crank to effect the required change. The exact amount may be ascertained by the same process as used in shortening the eccentric rod on the left side of the engine. As the changing of the position is a matter of some difficulty involving the fiting of a new key to hold the eccentric crank in place, it is well to secure the crank temporarily in place and move the engine from centre to centre to ascertain if the desired effect has been obtained. A change of the position of the eccentric crank may involve a slight change in the length of the eccentric rod, and even with the most careful adjustment it is rare indeed to secure the perfect coincident amount of valve opening at each of the four points of admission, and also to arrange the points of cut-off so that the steam pressure may be most advantageously used in meeting the various requirements of locomotive service.

It may be added that the amount of clearance between the link block and link at the extreme ends of the travel of the lengthening or shortening the radius rod, but as the length of this rod should coincide exactly with the arc of the link it is not good practice to change the length of this rod; that is, if its length be correct. In closing it is well to remember that when locomotive boilers are filled, and all the parts of the engine more or less heated, there is a tendency to slightly distort the

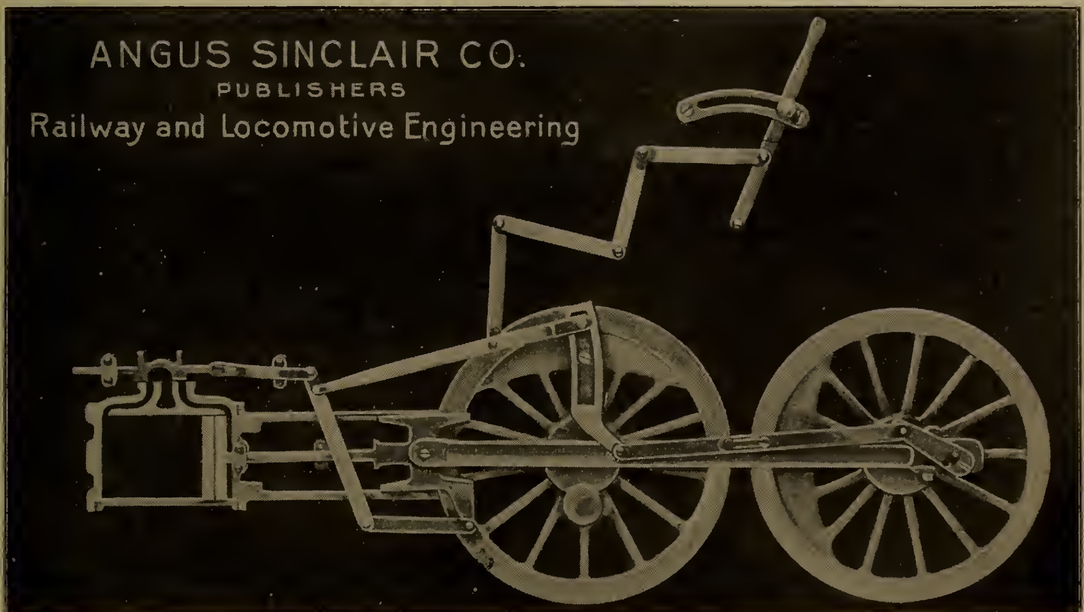
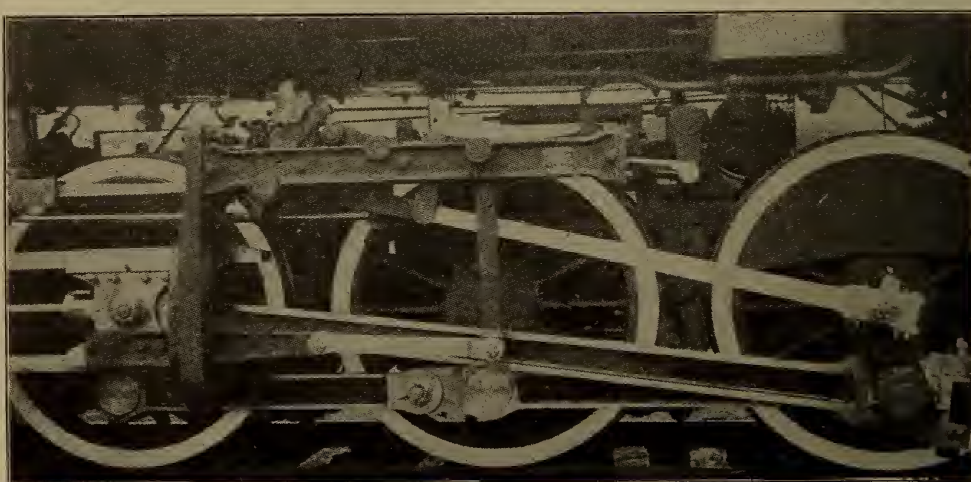


FIG. 4. WALSCHAERTS VALVE GEAR IN BACK MOTION.

block should be carefully noted. It is usual to allow a greater amount of clearance at the bottom of the link as the tendency of the link block is to approach nearer the bottom of the link as the parts wear. Any marked deviation from an equable centre affects the travel of the valve. Slight variations in the amount of valve opening may also be remedied by operations of the valve gearing and it is well that the skilled mechanic should take an opportunity to observe the changes if any, as such tendencies are very often in the direction of magnifying any slight shortcoming from the exact points to be desired, and a final skillful change may be made that may make a nearer approach to perfection.

IX. THE BAKER-PILLIOD VALVE GEAR

The twentieth century locomotives have grown to such colossal proportions that the arrangement of the valve gearing outside of the frames has become a primal necessity. The limited space between the frames with the increasing size of axles and eccentrics renders it particularly difficult to adjust and examine the Stephenson shifting link gear under such conditions and doubtless this was the chief cause that called the Walschaerts valve gearing into prominent use in American locomotive service. As we have endeavored to show in the preceding chapters the Walschaerts gearing has several advantages over that of the shifting link. It also has its drawbacks, which in these days of rapid construction and hard usage are not far to seek. It is not to be wondered at therefore that in the atmosphere of American enterprise many clever mechanicians have been at work devising means of actuating and controlling the valve gear of the modern locomotive. Perhaps the most successful attempt in the present century in this direction has been the combination known as the Baker-Pilliod valve gear. The device resembles the Walschaerts gearing in several features. It has the eccentric



THE BAKER-PILLIOD VALVE GEAR.

crank attached to the main crank pin, and a combination lever deriving its motion from the crosshead. With these two factors in the motion the resemblance ceases, the chief variation being the absence of the radial link. As is well known the movement of a radial link whether shifting or fixed is a source of error in all motions. These errors are caused by the slipping of the link-block and are especially marked in the case of the shifting link as it travels through a longer arc than is usual in the case of links oscillating upon a fixed center.

In view of this fact, it will be readily understood that if the motion of a sliding valve can be perfectly controlled and the length of stroke varied without the intervention of a radial link, a real gain in the economical use of steam will be made. The best proof of this is shown in the use of the Corliss valve on stationary engines. This kind of valve gearing with its delicate governor and complex mechanism is not suited for the incessant vibrations and distorting strains of locomotive service. The ideal valve gearing for a locomotive must have the element of rigidity in a marked degree, and at the same time possess that flexibility of adaptation essential to the various requirements of the service. The best use of steam pressure is possible only when under perfect control.

X. CONSTRUCTION OF THE BAKER-PILLIOD VALVE GEAR

Coming to the valve gearing under consideration it will be observed that there are a number of rods in addition to those we have alluded to, besides levers and bell cranks and brackets which in appearance form a complex combination, but which when followed one by one lead from the circular movement of the eccentric crank and the reciprocating movement of the crosshead to the simple reciprocating motion imparted to the valve rod. It will be readily understood that neither of these primary movements are regular in their linear velocity, the crosshead travels with an increasing degree of rapidity toward the center and diminishes in velocity toward the ends of its stroke. The same irregular linear movement is made by the eccentric rod, and in Fig. 1 it will be seen that the crosshead is near the center of its stroke, the swiftest part of its motion, while the eccentric crank which is set at right angles to the main crank is experiencing its slowest movement. The union link attached to the crosshead and the eccentric rod are attached to the separate ends of a bell crank. The end of the bell crank attached to the eccentric rod describes a circle or ellipse, according to

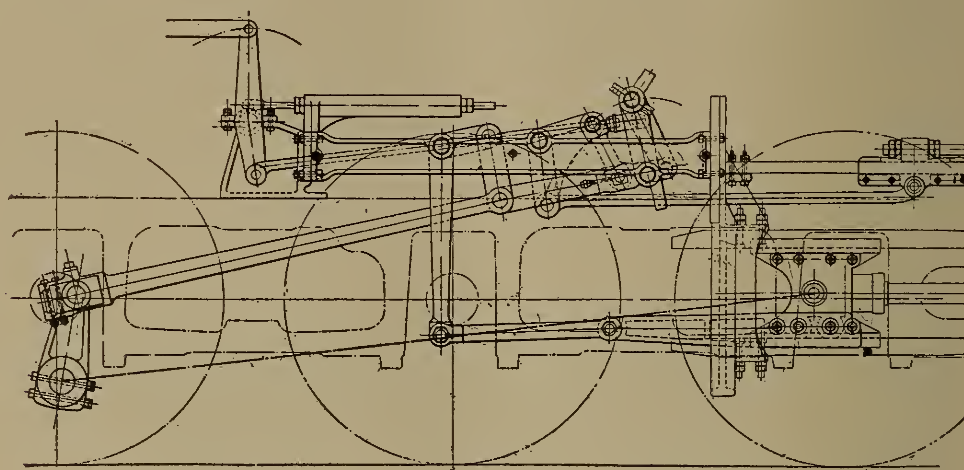


FIG. 1. OUTLINE OF BAKER-PILLIOD VALVE GEAR.

the relative proportions of the arms of the bell crank, but always at irregular velocity. This varying motion is conveyed by a coupling and hanger to another bell crank, the lower end of which is attached to the valve rod, which in turn is attached to the valve rod crosshead to which the valve stem is attached and held in place by adjustable nuts. The result of the two initial motions conveyed through this double system of bell cranks is such that the valve travels as fast as the piston at the beginning of its stroke and by the time that the piston has moved about one-twentieth of its stroke the valve is wide open and the valve then moves very slowly during the period while the piston is traveling with increasing rapidity during the first half of its stroke. As the piston approaches the release point the valve again travels with increasing rapidity and closes with a speed equal to that of the piston.

In regard to the reversing gear it may be shown more clearly by referring to Fig. 2, which represents a skeleton sketch of the Baker-Pilliod valve gear, shaded, and which we have purposely distorted to show more clearly the movable and fixed parts of the gearing. It will be observed that the continuance of the eccentric arm after passing the two bell cranks already described is attached to a hanger G, at the point F. This hanger is suspended from the upper end of a radius yoke J, which is attached to a fixed point at K. The point F therefore swings about the point H. This radius yoke J is suitably attached to the gear reach rod which is connected to the reversing shaft. Assuming that the piston and slide valve and reverse lever are all in the central position, it can be seen that in the event of the reach rod being moved to the front end of the quadrant,

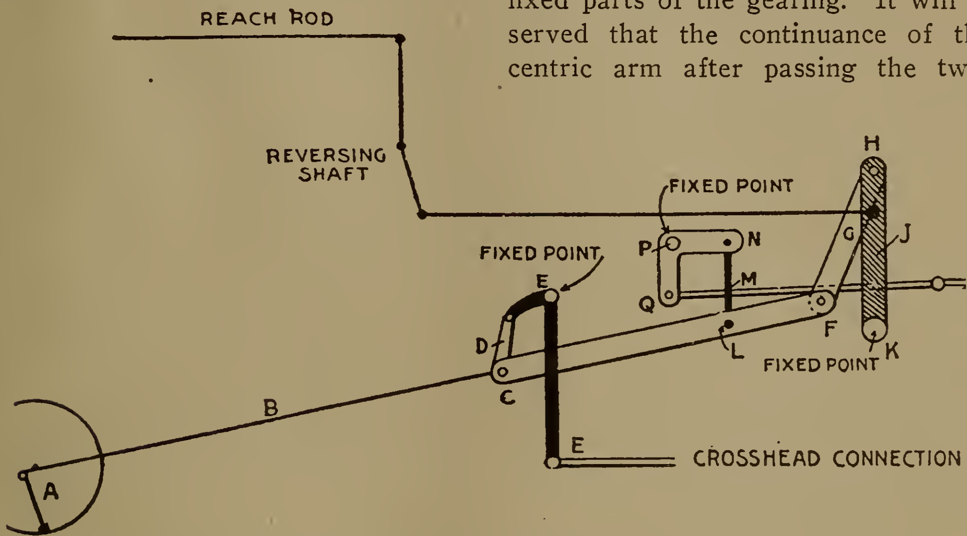


FIG. 2. PURPOSELY DISTORTED SKELETON SKETCH OF GEAR.

the lower arm of the reversing shaft will be drawn backward, carrying with it the radius yoke, which hangs from the top of the reverse yoke. This backward movement of the radius yoke has the effect of lowering the hanger G, so that the point F will be considerably lowered, carrying with it the point N of the second cell crank and consequently drawing the valve rod backward and opening the front steam port.

If on the other hand the reverse lever is drawn backward to the back end of the quadrant the radius yoke will be moved forward, carrying with it the hanger G, and raising the point F, the effect being to raise the bell crank at N, which moves on the fixed point P. Thus the lower part of the bell crank at Q will be moved forward, carrying with it the valve rod and opening the back steam port in the cylinder, thereby inducing a backward motion of the engine. This description presumes an outside admission valve with the main rod at the lower or bottom center.

Having thus shown the action of the radius yoke on the second bell crank and its effect on the valve rod, it can be readily imagined that the placing of the reversing lever at any of the intervening spaces between the center of a quadrant and its extreme ends, have their relative effect on the position of the bell crank and the corresponding effect on the motion of the valve rod.

It will thus be seen that there are a large number of joints through which the motion must necessarily pass from the main crank pin and crosshead connection before the movement reaches the slide valve. This is one of the drawbacks in the Stephenson shifting link, and it is one of the chief merits of the Walschaerts valve gearing that the crosshead connection is immediately attached with only one joint between the combination lever and valve stem. There is this particular advantage, however, in the Baker-Pilliod gear, that the parts lend themselves readily to massiveness and rigidity of construction which is impossible in the case of the Stephenson shifting link gear and is only partially so in the case of the Walschaerts gearing.

The diagram Fig. 3 shows the shape of the distorted elliptical path of point L, and the portions of the ellipse passed over by the point L for port openings and for lap and lead. The same letters that are used in Fig. 2 are used in Fig. 3. The ellipse marked Y is the path followed by point L when in forward gear, and the ellipse X is that followed in backward gear. The curves in Fig. 3 marked 1, 1, is that followed by the point F in full forward gear, the curve 2, 2 is that followed when the reverse lever is in the center, and curve 3, 3 is that for full backward gear.

It may be added that the lead or opening of the valve at the end of the piston stroke is an unvarying or constant quantity, so that the length of the valve stroke or point of cut-off of steam supply does not in any way affect the exact amount of opening at the beginning of each piston stroke, while the degree of rapidity with

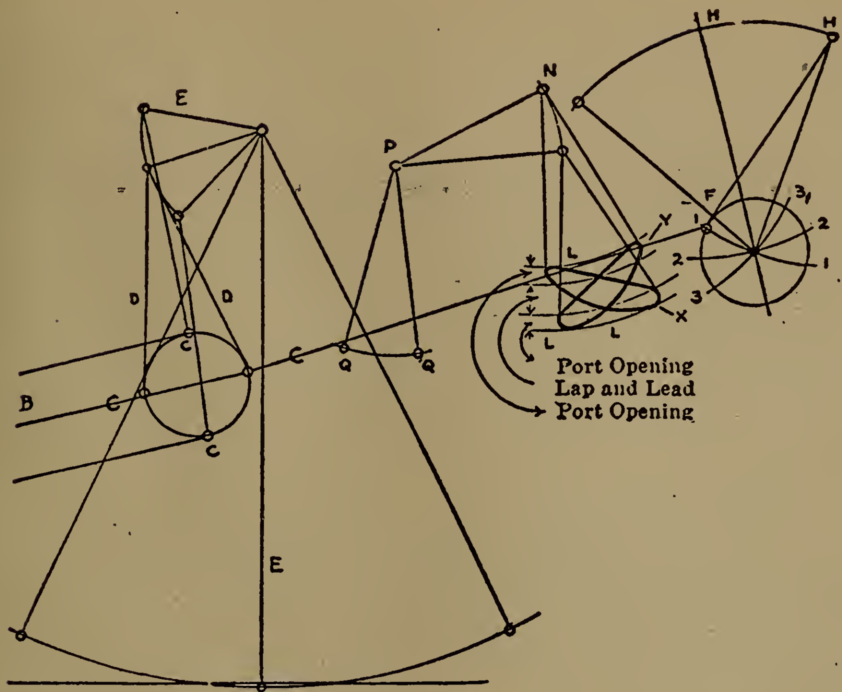


FIG. 3. DIAGRAM OF MOVEMENTS OF PARTS OF BAKER-PILLIOD GEAR.

which the valve opens during the early part of the piston stroke or the rapidity with which the valve closes at the desired point of cut-off is not surpassed by any kind of valve gearing applied to locomotives.

XI. ADJUSTING THE BAKER-PILLIOD VALVE GEAR

In the adjustment of the gearing it may be noted that it is essential that the proportions of the various parts be correctly designed by following a precise formula, aided, if possible, by an adjustable model. The setting of the valves, in the same sense of the words as is used in the care of the Stephenson gearing, would be an idle experiment. This is one of the advantages of the Baker-Pilliod gearing that when properly constructed and adjusted to the locomotive the valve gearing passes outside of the pale of the constant consideration of the engineer or mechanic, and while liable, of course, to a certain amount of wear and possible fracture, it is not subject to those erratic variations so peculiar to some forms of valve gearing. Generally speaking, the eccentric rod is the only part that may occasion a renewal of adjustment, as the wear of the bearings at the main crank or in the main driving boxes may occasion a slight variation in point of length of the eccentric rod. The gear reach rod and eccentric arm as well as the valve rod are all fitted with means for adjustment in regard to length, so that the equalization of the travel of the valve can be readily effected in the original assembling of the parts.

The amount of lead or opening of the valve at the beginning of the piston stroke can be increased or diminished by lengthening or shortening the lower arm of the bell crank. It can be readily seen that by lengthening the arm of the bell crank attached to the valve rod connection that an increase in the length of the valve stroke will be made, and this increase will be added to the amount of valve opening at the end of the piston stroke. A corresponding decrease will occur in the case of shortening the bell crank arm. These organic changes are rarely necessary, and it is questionable whether in the instance of a change in the amount of valve opening being necessary it would not be advisable to make a slight change in the length of the combination lever. It will be readily noted that by shortening or lengthening that lever the stroke of the valve would be affected in a lesser degree.

The exact position of the eccentric crank in relation to the main crank is a variable point to the designer, and is adapted by him to suit the requirements of the valve gear construction. In the case of an inside admission valve, the return or eccentric crank follows the main crank when the engine is running forward. In the case of an outside admission valve, the eccentric crank is set a corresponding distance ahead of the main crank. The length of the eccentric crank is also a variable quantity to the designer. The eccentric crank used in the case of an inside admission valve being longer than that used in the case of an engine equipped with a valve having outside admission. The necessity for this variation is apparent when it is observed that the angle of inclination of the eccentric rod is an ascending one towards the lifter bar and bell crank. These necessary variations will be readily observed in comparing the illustration of the different positions of the eccentric crank, as shown in Fig. 1, which displays the arrangement of the eccentric crank and lifter bar adapted to an inside, admission valve, with that of Fig. 4, which shows the parts arranged from an outside admission valve.

An admirable feature of the gearing is the fact that all the connections are mechanically positive and the exchange of hardened pins and bushings affords an opportunity of retaining the action of the gearing with a degree of accuracy which leaves little or nothing to be desired in the ready application of means for the maintenance of the wearing parts. This is a marked advance over the use of sliding blocks and cumbrous rockers which cannot be overestimated and reflects much credit on the practical ingenuity of the accomplished inventors.

It need hardly be stated that the gearing is capable of many changes in organic structure and is readily adaptable to any length of valve stroke. In its present form as applied to a large number of American locomotives the throw of the eccentric crank is such as describes a circle of seven inches in diameter producing a valve travel when in full gear of six inches. This could be easily increased or diminished to suit the requirements of any size or design of locomotive. The

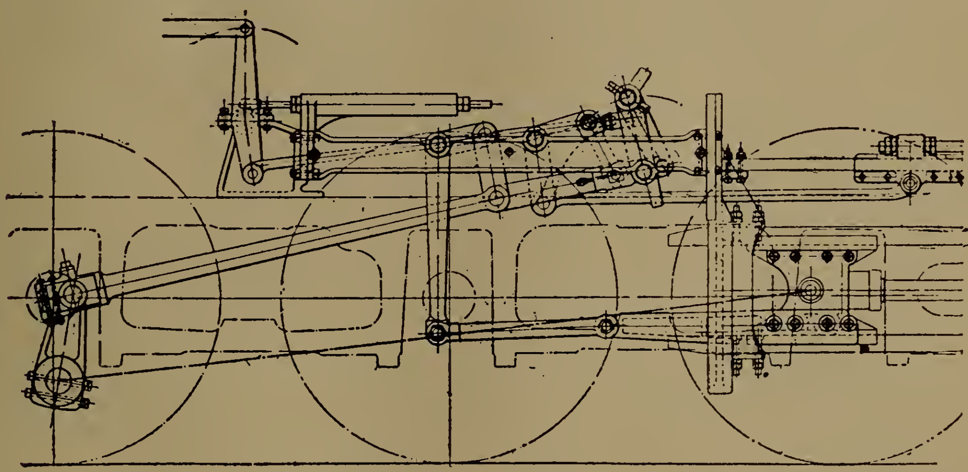


FIG. 1. BAKER-PILLIOD VALVE GEAR ARRANGED FOR INSIDE ADMISSION.

equable motion of the eccentric rod traveling as it does in parallel precludes the possibility of any of that peculiar variation in motion incident to all movements where circular motion is changed into linear motion and which is such a disturbing factor in the action of the Stephenson shifting link motion, and is not altogether absent in the Walschaerts valve gearing. This regularity of movement is fully and completely secured by the carriage of the gearing, which is almost entirely supported in a substantial, channeled cradle set between the guide yoke and a cross tie extending over the frames, and which prevents the motion of the valve gearing from having a distorting effect on the frames, and adds much to their necessary rigidity.

In brief assuming that the design of the valve gearing is correct, the adjustment of the parts is a matter comparatively easy of accomplishment, while the completed, clever contrivance, when once adjusted, has the rare quality of retaining that degree of accuracy which approaches as near to perfection as can be expected in the strenuous segregation of diverse forces that have their being in locomotive service.

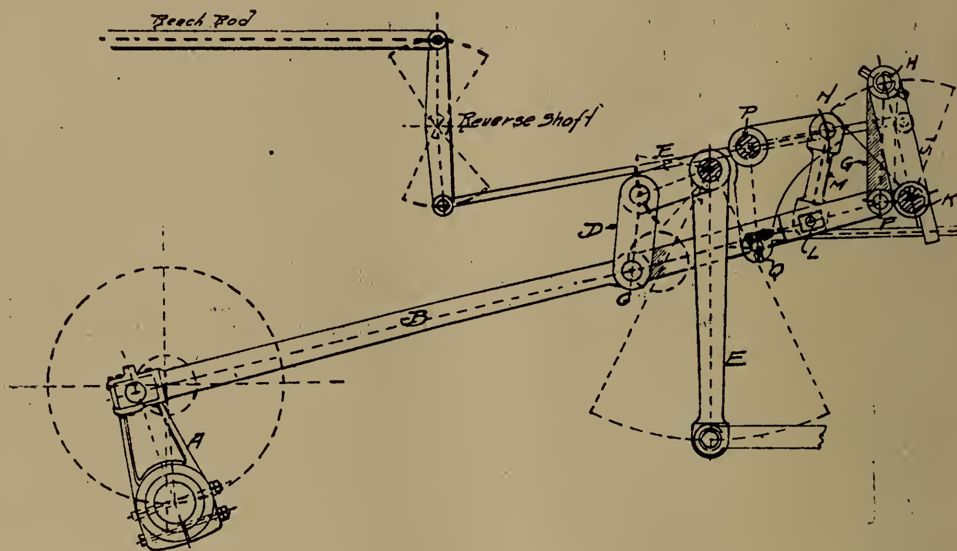


FIG. 4. BAKER-PILLIOD VALVE GEAR ARRANGED FOR OUTSIDE ADMISSION.

XII. THE JOY VALVE GEAR

In Dr. Angus Sinclair's monumental work "Development of the Locomotive Engine," there are about fifty different types of locomotive valve gearing described and illustrated, and, while many of these are merely variations of two distinct types, all of them bear evidences of a high order of mechanical ingenuity, and it would seem as if the problem of steam distribution is one that has engaged the attention of the brightest minds in the realm of steam engineering and that the complete solution of the problem, like the squaring of the circle, is one that eludes and ever will elude the seeker after perfection. Even the survival of the fittest is often hindered by ignorance and prejudice, and it is marvelous with what tenacity the mechanical mind will cleave to established institutions. It may be remarked that the most successful inventions and variations in locomotive engine valve gearing have been made by skilled mechanicians whose experience in actual work has sharpened their intellects and in many cases rendered the application of their theories comparatively easy by giving an opportunity in the locations where they were employed to test the merits of their devices.

David Joy, an English locomotive superintendent, patented a valve motion in 1879. Although belonging to the radial gear variety of valve motions, it has several features distinctively its own. It has neither eccentric nor crank, the valve deriving its movement from a system of levers connected with the main rod and varied by the application of a sliding link.

The motion for the valve is taken directly from the connecting rod and by utilizing independently the backward and forward action of the rod, due to the reciprocating motion of the piston, and combining this with the vibrating action of the rod up and down, a movement results which is used to actuate the valves of engines having any combination of lap and lead, and giving an almost mathematically correct cut-off for both sides of the piston for forward and backward motion, and for all points of expansion intermediately. The action of the gear may be understood by reference to the engravings, Figs. 1, 2, 3 and 4, which are respectively an elevation, plan, a transverse section on *XY* of Fig. 1 looking forward, and modified arrangement of the gear.

From a point, *A,* Fig. 1, in the connecting rod, motion is imparted to a vibrating link, *B,* constrained at its lower end, *H,* to move vertically by the radius rod, *C,* which is pivoted at *I.* From a point, *D,* on this vibrating link, *B,* horizontal motion is communicated to the lower end of a lever, *E,* from the upper end of which lever the motion is transmitted to the valve spindle by the rod *G.* The center or fulcrum, *F,* of the lever *E,* partakes also of the vertical movement of the connecting rod to an extent equal to the amount of its vibration at the point *A;* the center F is for this purpose carried vertically in blocks which slide in slots in the links *JK,* which are curved to a radius equal to the length of the rod *G,* connecting the lever *F* to the valve spindle. These links are attached to a shaft, *L,* Figs. 2 and 3, corresponding to the ordinary lifting shaft of a link motion. The center of this shaft corresponds to the position in which the fulcrum, *F,* of the lever, *E,* is represented in Fig. 1. The shaft, *L,* and the links can be partially rotated on the center of the former, so that the slots in the links will be inclined over to either side of a vertical position, as shown at *W* and *X.* This is done by means of an ordinary reverse lever connected to the upper arm, *M,* attached to the shaft, *L.* When the links are thus inclined, the vertical movement of the lever, *E,* causes the blocks in the links and the center, *F,* to traverse a path inclined to a vertical center line; and to diverge from it to either side. The center, *F,* therefore, has a horizontal movement, the extent of which depends upon the degree of inclination of the links, and the direction of which is governed by their position.

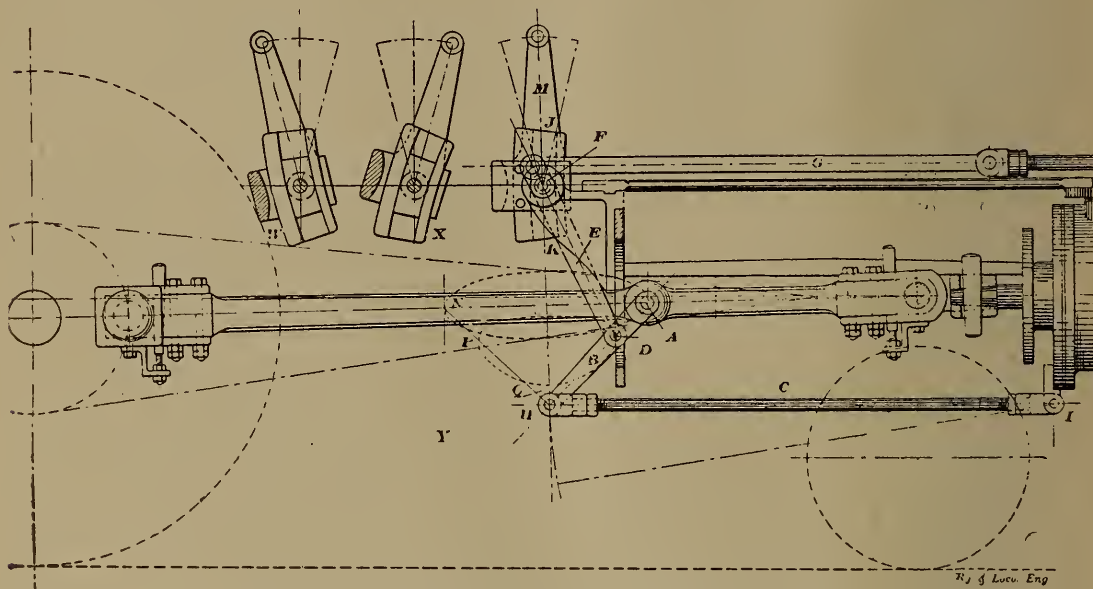


FIG. 1. ELEVATION OF JOY'S VALVE GEAR.

The forward or backward motion of the engine is governed by giving the slots this inclined position on one or other side of the vertical center line; and the amount of expansion depends on the amount of the inclination, the exactly central or vertical position being "mid-gear." In that position steam is admitted at each end of the stroke to the amount only of the lead; and this is done exactly equally on each side of the center line, the amount of lead being constant for forward and backward motion, and for all degrees of expansion. Thus when the crank is set at the end of the stroke described by the lower end, *D,* of the lever, *E,* and this would give an unequal port and unequal cut-off for the two ends of the stroke. But this error is corrected by attaching the lower end, *D,* of the lever, *E,* to the vibrating link, *B;* for while the point *A* in the connecting rod is performing a nearly true ellipse, the point *D* in the vibrating link *B* is moving in a figure, *DOPQ,* Fig. 1, like an ellipse bulged out on the lower side, and this irregularity is so set as to be equal in amount to the versed-sine of the arc described by the lower end, *D,* of the lever, *E,* thus correcting the above error,

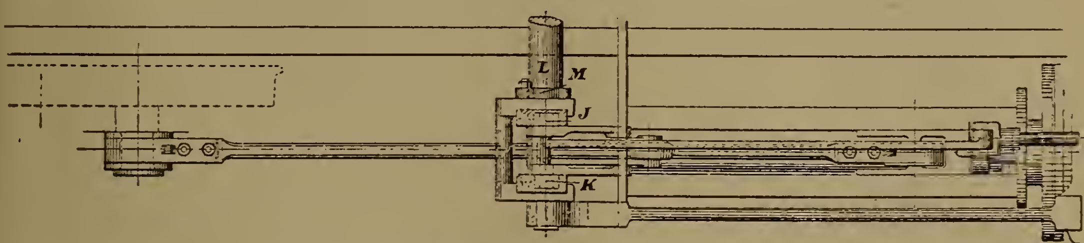


FIG. 2. PLAN OF THE JOY VALVE GEAR.

either way, the center, *F,* of the valve lever coincides with the center of the slot, and, therefore, the slot may be moved over from forward to backward gear without affecting the valve at all.

It will be seen at a glance that if the lower end, *D,* of the lever, *E,* were attached directly to the point, *A,* on the connecting rod, it would travel in the path of the ellipse, *AN,* represented by dotted lines, and there would be imparted to the center, *F,* of that lever, an unequal vibration above and below the center of the links, *JK.* The extent of inequality would be twice the versed-sine of the arc and giving an equal travel to the center, *F,* of the lever above and below the center of the slot. At the same time the error introduced by the movement of the end of the valve-rod, *G,* is corrected by curving the slots or links, *JK,* to a radius equal to the length of *G.*

Referring again to the equalizing of the traverse of the center, *F,* of the lever, *E,* in the slot, *JK,* the unequal traverse may be either under corrected or over corrected by shifting the point *D* in the vibrating link, *B,* near to or further from *A*; by this means a later point of cut-off may be given to either end of the cylinder at will, and the engine may thus have more steam admitted to one side of the piston than to the other, if required. The same thing may be done for the lead. By altering the position of the crank for which the lever center, *F*, coincides with the center of the slots, *JK*, an increased or diminished lead may be given. The central positions and exact connections

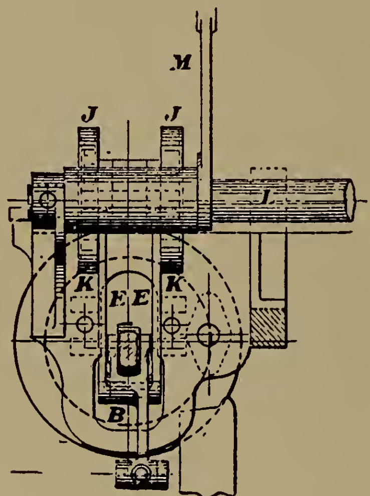


FIG. 3. SECTION OF GEAR.

are, however, in all cases standard and equal.

Hitherto the center, *F*, of the lever, *E*, which gives motion to the valve spindle, has been described as carried in curved slots. This plan is given as the most simple to manufacture, but if preferred the center, *F*, may be carried by a radius rod so that its vibration will make the center, *F*, of the lever, *E*, describe identically the same arc as if moving in the slots *JK*.

In locomotives with small wheels the link, *C*, may come so low down as to be in danger of being knocked off. For such cases, and for others when it may be considered desirable, Mr. Joy proposed the plan shown in Fig. 4, in which the link, *B*, is cut off at the center, *D*, and is connected at that point by a rod, *S*, to a crank, *T*, on the end of the crankpin. The movement of the valve produced by this mechanism is almost identical with the other.

The Joy valve gearing has met with considerable favor on a few of the British railways, notably on the Great Western Railway of England. This railroad, constructed by the justly celebrated engineer, Brunel, is among the best built and maintained railways in the world. The long, straight stretches of flat lands over which most of the road passes form an excellent opportunity for fine roadbeds, and consequently the locomotives are comparatively free from those vibratory oscillations which are a severe test on the rigidity of almost all forms of valve gearing. It will be readily observed that any vertical disturbance on the main rods of locomotives equipped with the Joy valve gear would have a particularly distorting effect on the gearing, and this is the cause of the very limited use to which the gearing has been put on American railroads. As roadbeds improve, the gearing may come into more popular favor. It unquestionably takes its place among the leading devices used in steam distribution. Like the Corliss valve gearing and others of real merit, the Joy valve gearing has advantages peculiarly its own, but its best work can only be done under conditions which we are not likely to reach for many years to come.

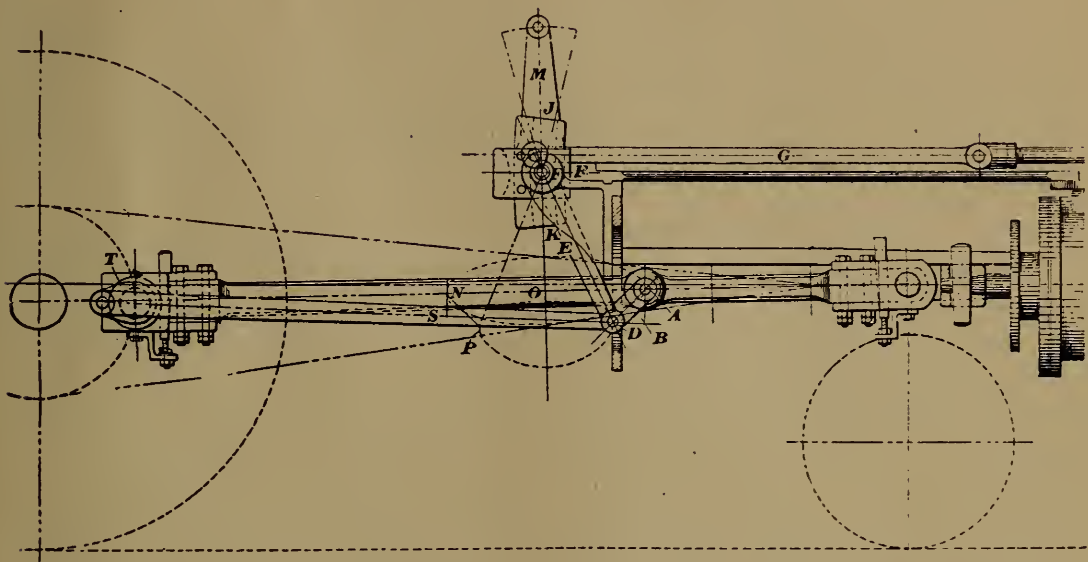


FIG. 4. JOY'S GEAR MODIFIED SO AS TO RAISE PARTS FROM TRACK.

NOTE ON SETTING THE SLIDE VALVE OF A STATIONARY ENGINE

The valve rod connections being properly adjusted, place the crank on the dead center and move the eccentric around on the axle, in the direction in which the engine is intended to run, until the valve begins to open at the same end at which the piston is then placed, or would be if it was attached to the crosshead. Then fasten the eccentric on the axle. It is usually held by one or two set screws. Next turn the engine, in the direction intended to be run, until the crank pin is on the opposite center, and if the opening of the valve at the other port is the equal to the opening of the first, it proves that the valve is correctly set. The lead or opening, need not exceed one thirty-second of an inch for engines of less than twenty horse power, but may be increased in the case of larger engines.

In determining the proper length of the valve rod, the eccentric may be left loose on the axle and after being connected to the valve rod the eccentric may be readily moved around on the axle and the extreme points of the travel of the valve marked on the steam chest or valve face. If the points of travel are at equal distances from the ports the length of the valve rod is correct. If the distances are unequal, the valve rod should be lengthened or shortened, as the case may require, half the amount of the variation. The experiment of turning the eccentric around on the axle should be repeated and care should be taken that the valve rod is exactly the required length.

A good method of finding the dead centers of stationary engines is by using a surface gauge which may be set conveniently on the bed-plate of the engine and the pointer adjusted to the center of the shaft. The engine can then be turned until the center of the crank corresponds to the height of the pointer. In the absence of a surface gauge, a bent rod of iron, pointed, or a thin board or other convenient device adapted for pointing to the center of the shaft, may be used. Where the bed-plate of the engine cannot be utilized the dead centers can readily be found by markings on the crosshead and rim of the wheel when near the center and moving the engine slowly and carefully, catching with a tram or compass the same mark on the crosshead after it has passed the center. The crosshead need not be moved more than a quarter of an inch backward and forward. Meanwhile the rim of the wheel will have moved a considerable distance and a point exactly between the two markings on the rim of the wheel will be the dead center. This operation was more fully described in our article on the adjustment of the Stephenson shifting link gear.

A direct acting engine, so called because of the eccentric acting on the valve rod without the intervention of a rocker, requires that the eccentric should be set ahead of the crank, the exact amount depending upon the lap of the valve and the amount of lead or opening allowed at the beginning of the stroke. In the case of an engine equipped with a rocker, which is an indirect acting engine, the eccentric follows the crank pin at a corresponding distance.

It need hardly be reiterated that the exact relation of the eccentric to the crank, as well as the correct adjustment and careful maintenance of all the parts of the valve gearing is of the utmost importance in all kinds of steam engines. The exact location of the valve at the end of the piston strokes should be occasionally ascertained with a view to make corrections if necessary. In all changes it is well to note carefully that the valve moves evenly and freely on the valve seat. The tendency to twist the valve rod in blacksmithing operations is very great, and a hasty or careless adjustment of any part of the valve gearing, and especially of the valve rod, is almost certain to be fraught with the most pernicious consequences.

The tendency among engineers to meddle with the valve motion is happily passing away. A growth in technical education has hushed the cry for more lead. One would think that common sense would suggest to any intelligent mechanic the fact that a large quantity of steam admitted into the end of the cylinder toward which the piston was moving could not be other than a hindrance to the piston, but so rooted was this mistaken idea in the minds of many enginemen that the exploded fallacy still lingers in the minds of some.

It could not be expected in this brief article to describe the endless variety of forms in which the valve gearing of stationary engines appear. As we have previously stated, a knowledge of the elementary principles that govern the relation of the valve and piston of all reciprocating engines will naturally lead the intelligent mechanic or engineer to a ready understanding of any kind of valve motion that may come to his attention. The introduction of what are known as inside admission piston valves on many locomotives as well as on stationary engines does not present any new problem to those already familiar with the operations of the older sliding valve. The location of the eccentric on the axle may readily be found by experiment. In the case of an inside admission valve with a rocker operating between the valve rod and eccentric rod, the location of the eccentric on the axle is identical with that of a direct acting engine, equipped with an outside admission valve. In brief, with the proper adjustment of the valve rod, as has been already stated, and with the crank pin in either center, the mechanism may be moved until the valve begins to open at the proper port, and it will be found that the succeeding operations that may be necessary are merely in the direction of making the adjustment of the gearing as near an approach to perfection as is possible in a complex and rapidly moving engine exerting forces of variable magnitude.