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"THE MODERN 3-CYLINDER LOCOMOTIVE"

BY

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The use of three cylinders is by no means a modern development of the locomotive, but the circumstances calling for their use were rather different in the past to those prevailing at the present day.

Perhaps the earliest three-cylinder engine was that built by Robert Stephenson, in which the two outside cranks were placed in the same position on the axle, with the inside crank at right angles to them. The area of the inside piston was equal to the combined area of the two outside pistons; so that the engine was virtually a two-cylinder machine, in which one cylinder was split and placed on each side of the other. The object was to eliminate the reactions producing swaying and rolling.

In more recent times, with the same object in view, a similar arrangement was used in Germany for a high speed steam locomotive. This engine was enclosed in a housing to reduce air resistance to a minimum, and with the attainment of speeds of 80 to 100 miles per hour, it was desirable to avoid unbalanced couples arising from the usual arrangement of cranks.

Another use for three cylinders was in compound locomotives. Two cylinder compounds suffered from the defect that the horse powers developed by high and low pressure cylinders were not always equal, so that one side of the engine did more work than the other. The obvious remedy was to make the arrangement symmetrical by the addition of another cylinder, dividing either the high or low pressure cylinders into two and placing them on the outside. Examples of these were to be found among the early French compounds, Webb's engines on the London and North Western Railway, Riekie's engines in India, and the compounds on the Midland and North Eastern Railways.

Three high pressure cylinders have also been employed in locomotives built for special purposes. The Great Eastern Railway "Decapod" was an instance of this. The engine was built with ten coupled wheels of small diameter and a large boiler, the object sought being to produce rapid acceleration in suburban train services, similar to that obtainable with electric traction. By introducing three cylinders, with cranks at 120 degrees, the available adhesion was used to the greatest advantage, owing to the even torque, and consequently greater tractive effort was possible. The position of the cranks allowed prompt starting and good balancing. Unfortunately, the concentrated weight on a limited wheel base proved too great for the permanent way.

Another example of the special use of three cylinders is to be found in the banking engines for the Wath concentration sidings on the Great Central Railway, where heavy goods and mineral trains are pushed up over the top of a hump in order to run by gravity into sorting sidings. Here again, maximum tractive effort for the adhesion available is sought.

At the present day the three-cylinder high pressure engine is no longer confined to special cases, but is becoming general for all kinds of traffic. In fact, this type of engine may now be said to be standard on the North Eastern Railway, and partly so on the Great Northern. On the former railway three cylinders are used in passenger, mixed traffic and mineral engines, both tender and tank; on the latter railway, in the largest passenger, mixed traffic and mineral tender engines. Other railways, such as the Caledonian and South Eastern and Chatham have also built three-cylinder engines.

During the War, engines of the 2-10-0 and 4-6-0 type were built in Germany with three high pressure cylinders, and others were supplied to Turkey for use in Asia Minor. Since the War, further engines of these types, and others of the 4-6-2 and 2-8-2 types, have been made as standard German engines. More recently, English built engines of the 4-8-0 type have been supplied to Spanish railways. Three-cylinder engines of the 4-6-0 type have been made for Danish railways by a German firm.

The railway locomotive works under such arduous conditions that the simplest, most straightforward and robust construction is essential. In the two-cylinder high-pressure locomotive the moving parts are reduced to a minimum, and, within limits, it stands unrivalled. The inside cylinder engine has, however, reached its maximum size on the 4ft. 4½in. rail gauge, on account of the difficulty of finding room for large cylinders between the frames and insufficiency of bearing surfaces on the crank axle. The larger engines, therefore, have outside cylinders, and a number of advantages follow, together with a few disadvantages. The motion, being on the outside, is very accessible for oiling, examination, and repairs. On the other hand, it is more exposed to grit and sand, and wears more quickly. The large piston thrust acting at a leverage on the axle boxes produces heavy pressures on bearings and horn cheeks, and slight wear quickly develops into a knock if not attended to. The heavy weight of reciprocating parts necessitates careful balancing, and hammer blows on the rail are increased. The reaction of the steam pressure on the cylinder covers and on the slide bars is applied at a greater leverage, due to the wide centres, so that the running of the engine is not so steady, and tyre wear is greater. Again, the increase in the diameter of the cylinder to be gained is usually very limited, owing to the loading gauge. It is owing to these difficulties that the multi-cylinder engine becomes a practical proposition.

When a departure is made from the two-cylinder engine the question at once arises—whether to adopt three or four cylinders. Each system has its own characteristics and advantages, and there is not much to choose between them in the matter of reducing the number of parts to a minimum. It is not, however, proposed to enter here into any comparison, or to discuss the four-cylinder engine, but it will suffice to say that for high speed passenger work on fairly level roads the four-cylinder arrangement is probably the better, whilst for goods, mixed traffic and heavy passenger work over more severely graded roads the three-cylinder system present advantages.

The usual arrangement of three cranks is at equal intervals of 120 degrees when the cylinders lie in one plane. Some compounds, however, have the outside cranks at 90 degrees to one another and the inside crank at 135 degrees to each, in order to get four exhausts per revolution at equal intervals.

When the inside cylinder of a non-compound engine is inclined so that the crosshead and connecting rod can clear an axle, the inside crank is moved round by an amount equal to the angle of inclination. Thus, if the inside cylinder is inclined 7 degrees, the middle crank is at 113 degrees to one outside crank and 127 degrees to the other, so that the impulses of the pistons follow one another at equal intervals, as also do the exhaust beats, and the result is the same as if all cylinders were in one plane with the cranks at 120 degrees.

Six impulses per revolution of the wheels, instead of four, bring about several advantages. In the first place, when working slowly the six light exhaust beats produce a more even draught on the fire for a given weight of steam per revolution than four heavier ones. In fact, it is possible in a three-cylinder engine to run with full regulator and full gear without unduly disturbing the fire. In any case, the greater number of beats tends towards fuel economy by reducing unburnt fuel in the form of cinders, and loss by carbon monoxide. On the admission side steam is drawn more regularly from the boiler and generation of steam is more even, thus tending to reduce moisture and increase superheat.

The six impulses enable maximum loads to be taken, and the engine will continue to move slowly without stalling, due to the even torque, the drawbar pull departing very little from the mean (Fig. 1). This can be maintained for a lengthy period in practice because, as pointed out before, it is possible to run in full gear without pulling holes in the fire.

Another factor assisting in the maintenance of maximum tractive effort is its relation to adhesion. The point at which slipping takes place is when the torque is at its greatest. The variation of torque is small in a three-cylinder engine, so that the mean tractive effort can approach nearer to the available adhesion, and this is about 15 per cent. greater than in a two-cylinder engine. (Compare curves in Fig. 1).

The same characteristics that are advantageous to heavy mineral and goods traffic are also beneficial in suburban train services where maximum acceleration is required, but there is little scope for the use of three-cylinder locomotives on such services at the present day, as electrification is resorted to when the traffic becomes at all dense.

Locomotives built for mixed traffic purposes must be suitable for a wide range of duties. In order to permit of speeds of 60 miles per hour a driving wheel of 5ft. 6in. to 6ft. is desirable, while to develop large drawbar pull at slow speeds, as when hauling heavy goods trains, large cylinder capacity is needed. For this type of engine three-cylinders again prove beneficial. The good balancing and lightness of the reciprocating parts conduce to easy running with fast trains, while for slow and heavy service, the adhesive qualities, even turning moment and frequency of exhaust beats are valuable assets.

In the case of the intermediate services, such as fast vacuum-fitted goods trains, another characteristic is brought out. In the two-cylinder engine the balance weights in a pair of wheels are at right angles and the resultant of the two weights tends to lift the wheels and diminish the adhesion when they are at the top of the wheel and to increase it and cause a hammer blow, when at the bottom. In the case of an engine running at a moderate speed, the turning moment is somewhat irregular. At the same time the adhesion is no longer constant but is varied by the influence of the balance weights. At one point per revolution the curves approach closely or may overlap so that slipping occurs. In the three-cylinder engine not only are the balance weights smaller, but the components for the reciprocating balance are placed about 180 degrees apart, and therefore, while the weight on one side tends to lift the wheel that on the other side holds it down, so that there is no variation in adhesion, and therefore less chance of slipping. (See Fig. 2). This is specially valuable when on up grades in tunnels, where the rails are usually in a greasy state.

For fast and heavy express passenger working the three-cylinder engine shows to greater advantage on hilly roads, as many of the features that have already been discussed in connection with other services remain of much value for fast passenger work, especially the smoother running due to smaller disturbing forces.

The construction of a multi-cylinder engine differs from a two-cylinder in frame, cylinder and valve gear design. In an ordinary cylinder engine the two cylinders are either contained in a single casting or in two castings permanently bolted together and forming a unit. This is simply bolted between the frame plates and itself forms a rigid frame stay. In the case of outside cylinders, these are usually separate castings bolted to the outside of the frame. The space between the frames is either filled by a box casting or by vertical and horizontal stay plates, so as to resist the racking strains. An alternative to this is the American practice of casting each outside cylinder with a half saddle, thus supporting the smokebox end of the boiler and forming a frame stay. A bar frame is used in conjunction with this design.

A multi-cylinder engine combines features of both inside and outside cylinder design. The position of the inside and outside cylinders in relation to one another depends to some extent on the number of driving axles. In the case of a four-cylinder engine the usual British practice is for the inside cylinders to drive the crank axle of the leading pair of driving wheels and for the outside cylinders to be attached to the outside crank pins of the second pair of drivers. By this arrangement the tractive effort is equally divided between two pairs of wheels and only small differences in the torque are spread among the other coupled wheels by the coupling rods. In the case of the three-cylinder engine this happy state of affairs does not occur, for two-thirds of the driving force is applied to the second pair and only one-third to the first pair. Also the turning moments of the two pairs are very different as they do not synchronise. Therefore, it is more usual to find in three-cylinder engines only one pair of wheels driven.

When the first pair of coupled wheels are the drivers a four wheel bogie supports the front of the engine, and the connecting rods are rather short unless the wheel base is spread a little. The alternative is to drive on the second pair of coupled wheels, inclining the inside cylinder so that the crosshead and connecting rod will clear the axle of the leading pair of wheels.

When only one axle is driven the cylinder design is simpler than where the inside cylinder has to be set ahead of the others, so as to get reasonable connecting rod length, since the steam and exhaust passages are more direct and no additional frame staying is necessary.

There are several distinct designs of cylinders and frames. The North Eastern adopt a mono-block casting containing three cylinder barrels and three piston valves. Of these one cylinder and all three valves are inside the frames and only the two outside cylinders project through. In some cases the main frames merely have oblong holes cut in them large enough for the outside cylinders to pass through. The arrangement is simple and compact, but it does not allow of an outside valve gear being used, and in the event of a cylinder casting breaking or being worn out, replacement can only be made by taking down one frame to release the cylinders. A gap in the frame in place of the hole overcomes this difficulty, but the frame is then not so strong. All cylinders are in one plane and have the same inclination and drive the same axle. (Fig. 3).

In the case of the Great Northern, the cylinders comprise three castings bolted together as a unit. The main frames have a large gap and the cylinders drop in this and fill it, the frames being bolted to the cylinder flanges of the outside cylinders along the bottom and up each side of the gap. The outside cylinders have piston valves on top and the inside cylinder has its valve on one side. As the inside cylinder is inclined about 1 in 8, it is raised above the outside cylinders and lies approximately in the plane of the valves. (Fig. 4).

The South Eastern and Chatham design (Fig. 5) consists of two castings, the larger one containing the left hand and middle cylinder with their valves while the smaller casting contains the right hand cylinder and valve. The joint between the two castings is immediately to one side of the middle cylinder barrel and only about 12 inches from the centre line of the engine. When the two castings are permanently bolted together they form a block similar to the North Eastern design, but differ from it in having the piston valves outside the frames. The boiler is carried on a separate saddle casting fixed to the top of the cylinders. The main frames have gaps into which the cylinders are fitted. When in place the gap is closed by a frame splice, so that only a hole is virtually left in the framing. The top of the cylinders and the saddle casting are bolted to the frame splice and the whole forms a rigid job.

In another design, of which the Caledonian is an example, the inside cylinder, fixed between the frames, forms a frame stay and support for the boiler.

The outside cylinders are bolted on the outside of the frame as separate pieces. Exhaust steam from the outside cylinders passes through holes in the frames to passages in the centre casting. Live steam is conveyed to the outside steam chest through a loose piece, a cast iron bend connecting the breeches pipe on the base of the steam pipe to the outside steam chest. (Fig. 6).

Although, in the case of the Caledonian engine, the inside and outside cylinders drive separate axles, the cylinders are all in line. This is accomplished by lengthening the outside piston rods and connecting rods and shortening those on the inside to a minimum, and so allows of simpler cylinder design. In the case of the Spanish engines in which separate axles are driven, the inside cylinder is set ahead of the outside, and the steam and exhaust pipes are more complicated. (This is shown in Fig. 7).

The question of valve gear is an important one in three-cylinder engines. In the case of the North Eastern engine where all the cranks are on the driving axle, there are six eccentric sheaves, four on one side for the outside and inside valves, and two on the other side for the remaining valve.

With spring and axle box centres at 3ft. 6in. the space on the axle between journal and crank web is only about $9\frac{1}{2}$ inches, giving $2\frac{3}{8}$ inches for each sheave, or say, $2\frac{1}{4}$ inches for each eccentric strap, a very limited width, resulting in rapid wear. The six eccentrics also set up considerable friction owing to the high surface velocity, and the four eccentrics cramped on one side make the axle very rigid in one section. (See Fig. 8).

For outside valves Walschaerts gear is favoured, but the provision of such a gear inside presents difficulties. An independent inside Walschaert gear requires an eccentric of large diameter and throw. Also an arm on the crosshead is needed, but an inclined cylinder centre line that only just clears the leading axle will not permit of an arm extending below the crosshead.

A link motion, besides requiring eccentrics, has a variable lead and does not pair up with the outside gears.

It is now usual with Walschaert gear on the outside to operate the inside valve by means of a combination of motions derived from the outside gears. There are a variety of ways of effecting this. Perhaps the simplest case is that of the Great Northern design. In this all three steam chests are brought into the same plane and inclination, and a long 2 to 1 lever worked from one gear carries a short floating lever having equal arms. The outer end of this lever is attached to the other outside gear and the inner end to the inside valve. The connection is through the spindles of the outside valves and short connecting links. The front steam chest covers have guides similar to those on the back covers. In order to remove the valves for examination or repairs it is necessary to dismantle the gear. (See Fig. 9).

In the case of the South Eastern and Chatham design the Walchaerts gear is suspended from pendulum links. The inner end of the link drives the outside piston valve. The steam chest is brought closer to the frame so that an extension rod from the pendulum links can pass to the front end. Each extension rod couples to a suitably proportioned rocking lever, and the combination gives the inside valve its proper motion.

This arrangement (Fig. 10) permits of all piston valves being withdrawn without uncoupling any gear, and the inside piston is also very accessible. The absence of gear inside the frames enables the rigid horizontal frame staying, a feature of the two-cylinder engines, to be retained, and large holes are cut in the plates to permit of access to the big and little ends of the inside connecting rod and to the slidebar.

In conjunction with a loose saddle casting on top of the cylinders, this arrangement of gear enables the whole to be applied to any size of driving wheel from 4ft. 8in. to 6ft. diameter, and with any diameter of smokebox and varying height of boiler centre. The same Bissel Truck can be retained, and the cylinders and valve gear are therefore standardised for a number of future designs of engine.

One arrangement of valve gear used in Germany is shown in Fig. 11. Walschaerts gear on the right hand side of the engine is attached to the arm of a rocking shaft extending across to the left hand side. This has three bearings, one at each end and one near the centre. The left hand end is cranked and carries a long sleeve having two arms. The lower and outer one is attached to the Walschaert gear on the left hand side, and the upper and inner one to the middle valve. The outer valves are linked up to the rocker arms. This is a simple and compact device but its application is rather limited, as the middle valve has to be located at some height above the outer ones, in order to get a reasonable length for the lever arms. It is therefore suitable for small wheeled engines having the middle cylinder inclined and can only be applied to larger wheels when the boiler centre is abnormally high.

Another form used in Germany in 4-6-0 type engines is similar to Fig. 12, and consists of a rocking lever on each frame having arms in the ratio 1:2. The shorter arms are connected to the Walschaerts valve gears and the longer arms to a combining lever, to the centre of which the middle valve is connected.

The combination of the motion of two valve gears gives a third motion almost identical with the generating motions and at the phase of 120 degrees to each. If valve ellipses are plotted there is usually a small difference between the original and the derived motions at 75 per cent. cut off (see Fig. 13), but at running

Note: In the original, three large pages of Figures are pasted between these pages. For reasons of continuity, in this version they have been relocated to the end of this document.

cut off of 25 per cent. it is difficult to find any differences. The closeness to which the ellipses approach one another depends on the valve gears themselves. The closer their movement to a pure harmonic motion, the better the derived movement. If the two outside gears gave their valves pure harmonic motion, then the inside valve would also have a pure harmonic motion.

The proportions of the lever arms to give the requisite travel and angular advance to the third valve can be determined very easily by a simple geometric construction. For instance, the gears in Figs. 9 and 11 are shown by Fig. 14A. A circle is drawn and the three cranks represented by points at 120 degrees apart. Two points are joined by a line, which represents, in the case of Fig. 9, the floating lever, and in Fig. 11, the floating sleeve with lever arms. From the third point a line is drawn through the centre and intersects the line representing the floating lever at its middle point. The centre of the circle represents a fixed point and so the line passing through it represents a lever working on a fixed centre. This is the long lever in Fig. 9, and the long shaft in Fig. 11. The ratio of the arms is seen to be 2 to 1 and the floating lever is pinned at the short end of the long lever.

In the case of the S.E. and C.R. gear in Fig. 10, a second circle is struck outside the circle on which the cranks are spaced. The radii of the two circles are in the same proportion as the arm of the pendulum link, to which the Walschaert gear is attached, bears to the point of attachment for the extension rod connected to the rocking lever. Lines from the centre in Fig. 14B, pass through two of the points on the inner circle in order to intersect the outer circle, thus locating new points on the outer circle. One of these is joined to the remaining point on the inner circle, and this again represents the floating lever. From the second point on the outer circle a line is drawn through the centre to intersect the first line. This gives the proportions for the long fixed lever. The actual proportions used on the S.E. and C.R. engine are pendulum link 1 to $1\frac{1}{3}$, floating lever $1\frac{1}{3}$ to 1, long lever $2\frac{1}{3}$ to 1. The arrangement in Fig. 12 has two fixed levers and is represented by Fig. 14C. Therefore, from two points on the circle two lines are projected through the centre, and another line is drawn tangentially to the third point to intersect the first two lines. With cranks at 120 degrees the proportions are found to be 1:2 for the fixed levers and the floating lever gives the third motion at its centre point.

Characteristics of Three-cylinder Engines.

Before concluding it would be as well to summarise and amplify the previous remarks on the characteristics of three-cylinder engines. In Fig. 1, the even turning moment is shown. Its principal value lies in the better use made of the adhesive weight, because the point of slipping depends not upon the mean tractive effort exerted, but upon the maximum. It is obvious that a greater mean effort is possible the more even the torque.

If an engine has a tractive effort of 12 tons and an adhesive weight of 60 tons, the factor of adhesion is 5, a normal ratio for two-cylinder engines. In the case of a three-cylinder engine this factor is worth 15% more than in a two-cylinder engine, that is, it is equivalent to 5.75, thus indicating a smaller tendency to slip. On the other hand, if an equivalent factor of 5 is considered to be sufficient, the tractive effort may be raised to 13¾ tons by enlarging the cylinder capacity, giving a more powerful engine without increasing its total weight.

The even torque results in a steady drawbar pull, and this is exhibited on dynamometer car records. Fig. 15 compares the results of two and three-cylinder engines of similar type and size. Under ordinary circumstances the fluctuation of the pull does not affect the hauling power, but in extreme cases it does. For example, suppose the pull of a train on a gradient is so heavy that it is only just preventing from stalling with the minimum tractive effort in each revolution while with the maximum tractive effort the engine is on the point of slipping. If the pull needed to keep the train in motion is 10½ tons then, in a two-cylinder engine with a variation in drawbar pull of 1½ tons the maximum pull will be 12 tons, so that a mean pull of 11¼ is exerted. In the case of a three-cylinder engine having a variation of half a ton, the train can be kept in motion with a pull of 10¾ tons, but as the adhesive limit is 12 tons, the mean pull may be increased to 11¾ tons, giving a range of one ton and an increase of half a ton in hauling power.

In the case of slow, heavy traction, the steaming capacity of the boiler enters into the problem. The rate of evaporation depends automatically on the blast pipe, that is to say, the weight of exhaust steam discharged in a given time. The blast is, however, intermittent in character, the impulses coming at regular intervals. When the intervals are short the draught is almost continuous, so that above a certain critical speed the maximum boiler capacity is practically constant and is independent of the speed. Below about 60 revolutions of the wheels per minute the draught fluctuates in a two-cylinder engine, causing a corresponding variation in the rate of combustion, with loss of furnace efficiency. The steaming capacity of the boiler is thereby affected and this limits the horse power by restricting the maximum supply of steam to the cylinders. With a 5ft. 6in. wheel the speed corresponding to 60 revolutions per minute is 12 miles per hour, and in a two-cylinder engine the boiler will not reach its full capacity below this speed, but becomes less and less as the speed decreases.

A three-cylinder engine having 6 exhaust beats per revolution requires only 40 revolutions of the wheel per minute to produce the same effect on the fire as 60 revolutions in the case of the two-cylinder engine, so that the full steaming in a three-cylinder engine occurs as early as 8 miles per hour with a 5ft. 6in. wheel.

Thus, in the case of slow, heavy traction, the three-cylinder engine presents marked advantages. Full steaming at low speed, maximum drawbar pull for a given adhesive weight, and a lesser tendency either to stall or to slip.

In fast goods and passenger service the engine gives rapid acceleration, good hill-climbing powers and greater reliability where there are tunnel sections having greasy rails. The balancing is good, the engine is easy on the road and is comfortable to ride on.

For stopping passenger trains, particularly those which are sharply timed on busy sections of the road, prompt starting and rapid acceleration are most desirable. This the three-cylinder engine supplies. The starting effort diagram, Fig. 16 is made from Fig. 16, by suppressing the expansion of the steam and showing only tractive effort resulting from live steam. Although the three-cylinder engine usually has a maximum cut off of 60% as against 75%in the two-cylinder the minimum effort, or dead centre as it is termed, is rather more. On the other hand, it will be observed that there are six of these "dead centres" as against four in the two-cylinder, but it will also be seen how rapidly the tractive effort rises out of these six centres. It requires only a small angular movement of the wheel to reach the mean effort and there is usually enough stretch in the couplings for this with a driving wheel of moderate size.

In general, three-cylinder engines wear well, as the ordinary forces are considerably less and frame stresses are lowered. The smokebox action reacts beneficially on the coal consumption, the blast being soft, quiet and almost continuous. All parts of the motion are light and easily handled, rendering the fitter's work easy in the running sheds when dealing with pistons, piston valves, crossheads, connecting rods, and cylinder covers.

The fact that the coupling rods are at 120 degrees to one another presents no disadvantage, but on the contrary the engine appears to run with greater freedom on that account.

The three-cylinder high pressure engine fitted with superheater has now obtained a firm footing on British railways and in Germany, and other countries are adopting the type as its good qualities become more fully recognised and appreciated.

DISCUSSION.

In opening the discussion, the CHAIRMAN (Mr. F. W. Hawksworth) said he could assure the Author that they were very grateful to him for the information he had put before them. The Author had compared the three-cylinder locomotive chiefly with the two-cylinder type and the former undoubtedly possessed certain advantages over the latter. With regard to the effect of the number of exhaust beats upon the fire, the two-cylinder and the four-cylinder engines were identically in the same position, since with the cranks set at 180 degrees, the four-cylinder engine gave the same number of beats as the two-cylinder engine. The cranks being set at 180 degrees, however, resulted in a more perfect balancing of the four-cylinder engine than as possible with either the three or two-cylinder engine with a corresponding reduction in hammer blow. In the four-cylinder type it was possible to effect a balance in the reciprocating parts themselves to a very large extent, and so to reduce the balance weight in the wheel with a consequent reduction in the tendency to lift and resultant slip. It seemed to him there must be great difficulty in arranging the valve gear for the inside cylinder in the case of certain three-cylinder engines on account of the necessity for clearing the leading axle. In the case of the Caledonian and the N.E. (4-6-0 type engines), however, it was possible to get the cylinders in one line and drive on the leading axle only. Unless separate gear was resorted to for each cylinder it became necessary to adopt a system of levers, involving the use of a number of pin joints, the introduction of which would always be debatable. When the G.N. three-cylinder engine was first put on the road there was much controversy as to whether present-day pin joints constituted a serious disadvantage, and it was held by a certain section of the Technical Press, that pin joints produced but little loss of motion. He thought, however, that Running Shed Staffs might hold different views. With regard to starting capacity, it was undoubtedly a fact that with two or four-cylinder engines the impulses were further apart than with the three-cylinder type. The maximum impulse, however, was greater and, in starting a heavy train away from a station, gave the former a great advantage. So far he had only referred to four-cylinder engines in which the inside cranks were set at 180 degrees to the outside cranks. Recently, however, an engine had been built on the North Stafford Railway in which the angle was 135 degrees. With cranks set in such a manner it was possible to get 8 beats per revolution and a more even torque, but difficulty was experienced in arranging the gear. In the particular engine referred to, each valve was separately driven by Walschaerts gear. He would like to ask the Author if the arrangement of the cylinders in line across the frame did not result in an excessive weight at the leading end, and also whether it were easily possible to make corrections for obliquity.

Mr. C. T. CUSS said that he had been looking through some very old literature and had found that about 87 to 90 years ago the three-cylinder engine was one of the principal topics of the day, but he believed all the engines of this type, which were built at that time, had since disappeared. Could the Author give them any information regarding these engines. He believed that the first three-cylinder engine was designed and patented by William Siemens and not by Robert Stephenson, as suggested by the Author. The three-cylinder engine was now being revived, and he thought, as the Chairman had suggested, that they might look upon the Author as one of the pioneers of this revival. He did not agree with the Author as to the desirability of the balance weights being arranged at 180 degrees. He thought that when the effect of the other wheel was taken into consideration, it would be found to be a disadvantage. He would like to know whether any trouble had been experienced with broken axles with this arrangement? He thought that one of the most serious disadvantages of the three-cylinder engine was that only one pair of wheels could be driven advantageously. He would have been glad if the Author had given them some comparative figures of fuel consumed per H.P., by two and three-cylinder engines respectively. Nearly 90 years ago William Siemens claimed that his locomotive only required two-thirds of the fuel required by the ordinary locomotive to do the same work.

The AUTHOR, replying to the Chairman with regard to pin joints, said that in the gear referred to there were undoubtedly a number of these, but they were all fitted with bronze bushes which could be renewed very quickly and cheaply. Any wear could thus be readily taken up.

Regarding the North Stafford engine with four cylinders and the arrangement of cranks described by the Chairman, he had gone into the question about three years ago, when reading a paper before the Institute of Locomotive Engineers. In many ways it was superior to the three-cylinder engine, because there were eight beats per revolution of the wheels instead of six and the turning movement was more even. The balance, though good was not equal to that which would have been obtained had the cranks been at 180 degrees. The balance weights were unsymmetrical, but this was not a very serious matter.

Regarding the weight distribution of the three-cylinder engine, he said that, in the case of the S.E. and C. engine the additional weight on the front end was about 2½ tons, three-quarters of which was carried by the pony truck and the remainder by the leading pair of drivers. The total additional weight was about $3\frac{1}{2}$ tons. The weight on the leaders, however, did not appreciably exceed that on the drivers since the heavy crank axle, attached to the latter, maintained a good distribution. Some of this additional weight was available for adhesion, thus increasing the hauling power of the engine. With regard to the correction of the valve gear for obliquities, he did not think that this was necessary. Other valve gears had been considered, but that selected had several advantages. The work performed on the front and back strokes was almost identical, and the gear could very easily be corrected in any way necessary. One advantage of the three-cylinder engine was that the maximum cut off need not exceed two-thirds resulting, in the case of a shunting engine, in a saving of 10% in the steam consumption when compared with an engine working in 75% cut off.

Replying to Mr. Cuss with regard to the earliest three-cylinder engines, he thought that they had died out because the need for their existence was not pressing and the simplicity of the two-cylinder engine was a big point in the latter's favour. With the growth of traffic requirements, however, the need for the three-cylinder engine became more prominent and consequently it had been re-introduced. With regard to the balance weights being set at 180 degrees, though not an ideal arrangement it was certainly preferable to that with the cranks at right angles. He had not heard of any broken axles. The reciprocating parts of the three-cylinder engine were very light and it was only necessary to balance 50% as against the usual two-thirds or three-quarters. Regarding the question of driving one pair of wheels only, this was the case with the North Eastern and the recent Great Northern Pacific engines, but the Caledonian engines did have a divided drive. In this drive the piston and connecting rods were short on the inside and long on the outside. Although there was no difficulty in such an arrangement, the single drive was generally preferred. The Author was unable to give coal consumption figures of the S.E. and C. Railway, as the engine had not been long in service. Favourable reports had, however, been received from the engineman.*

Mr. K. J. Cook asked if increased axle loads had been permitted with the three-cylinder engines, because of the smaller hammer blow. In the case of the four-cylinder engine the axle load was still restricted to the original maximum, although the effect on the line was undoubtedly very much less than that of a two-cylinder engine with the same loading.

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*Subsequent trials have showed a saving of 15% in fuel for the three-cylinder engine, as against a similar two-cylinder engine, on heavy goods work.

Mr. H. G. Kerry asked if there were any particular reason why the maximum cut off should not be taken to 75% and so increase the steam volume for starting purposes.

Mr. E. H. Gooderson asked if, in view of the small balance weights, the tyre wear was less on three-cylinder engines. He would also like further information relating to broken axles and to the nature of the steel from which the axles were made.

Replying to Mr. Cook, re restricted axle loads, the Author said that the point was recognised by the Locomotive Department, but although it had been pointed out to the Permanent Way Engineers, the maximum loading had not yet been altered.

In reply to Mr. Kerry, the Author said that the point of cut off could be raised to 75%, but he did not consider that too great a steam volume was desirable.

Replying to Mr. Gooderson, the Author regretted that no definite information could be given, but he thought that the tyre mileage would be considerably more with the three-cylinder than with the two-cylinder engine. He had not yet experienced a broken axle.

Mr. C. K. Dumas said that, in speaking of valve gear, the Author mentioned that there were difficulties in the way of providing an inside Walschaert gear and that an inside Stephenson gear was objectionable because having a variable lead the same distribution could not be obtained in the inside as in the outside cylinders. Was that a very serious point? He would not give a definite opinion but, if three gears were desired, he thought an inside Stephenson gear would be, at least, worth consideration.

The Author, replying to Mr. Dumas, said that the Caledonian engines had been built with two Walschaert gears and one Stephenson, as an experiment. He did not think that it was a very good arrangement. There was nothing to equal the simplicity of the gear shown in the sketches.

Replying to the vote of thanks, which had been proposed by the Chairman, the Author said that he had been enthusiastic regarding three-cylinder engines for many years, and had been fortunate in having had experience in the designing and subsequent running of such an engine. He had been very pleased with the results as all his hopes had been justified.

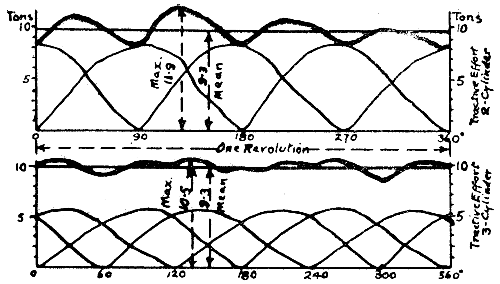


Fig. 1—Variations in Tractive Effort for 2-Cylinder and 3-Cylinder Locomotives at Slow Speed.

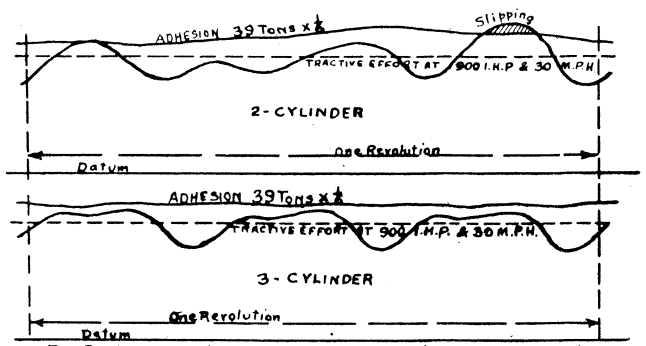


Fig 2 - Variations in Tractive Effort & Adhesion at 30 Miles per Hour showing Effect of Balanceweights.

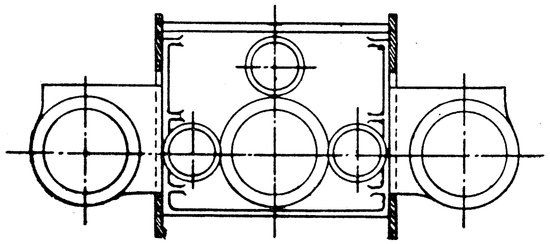


Fig. 3 - End View of Cylinders, N.E.R. with Cross Section of Frame.

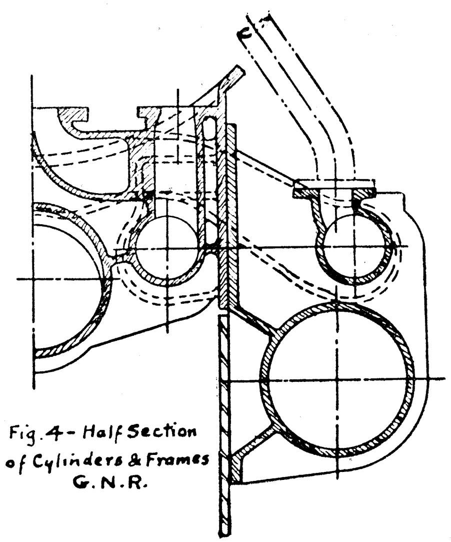


Fig. 4 - Half Section of Cylinders & Frames G.N.R.

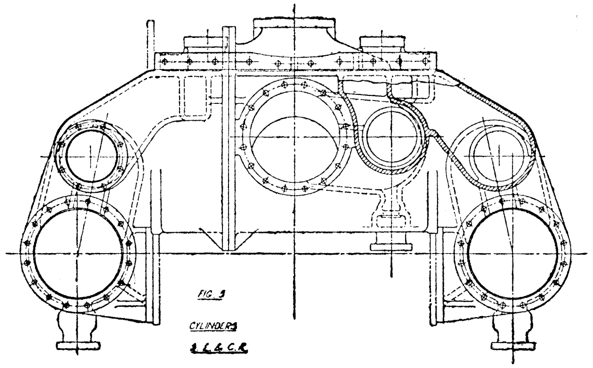


FIG. 5
CYLINDERS
L.&Y.R.

—THE MODERN THREE-CYLINDER LOCOMOTIVE—

PAPER READ BEFORE THE G.W.R ENGINEERING SOCIETY, SWINDON, WILTS.

ON 13TH FEBRUARY, 1923, BY H. HOLCROFT, C.M.E. DEPT, SOUTHERN RLY (S.E.&C.S.)

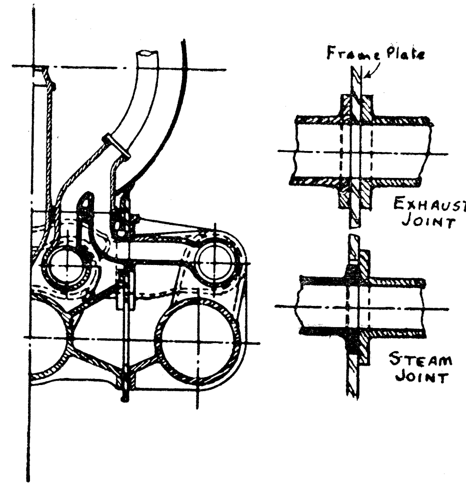


Fig. 6 - Cross Section of Cylinders, Cal. Rly. and Details of Joints.

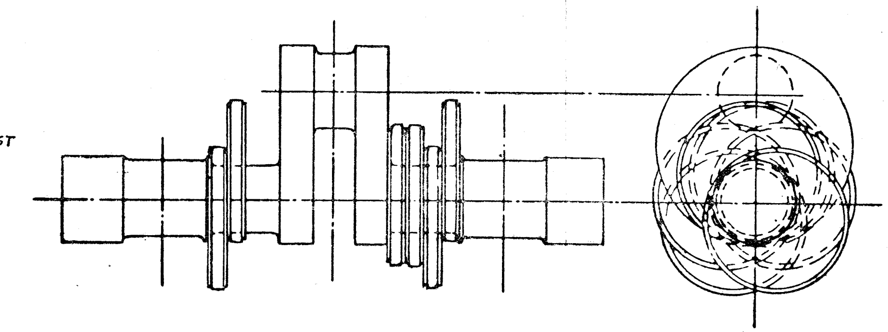


Fig. 8 Crank Axle and Eccentric Sheaves, N.E.R.

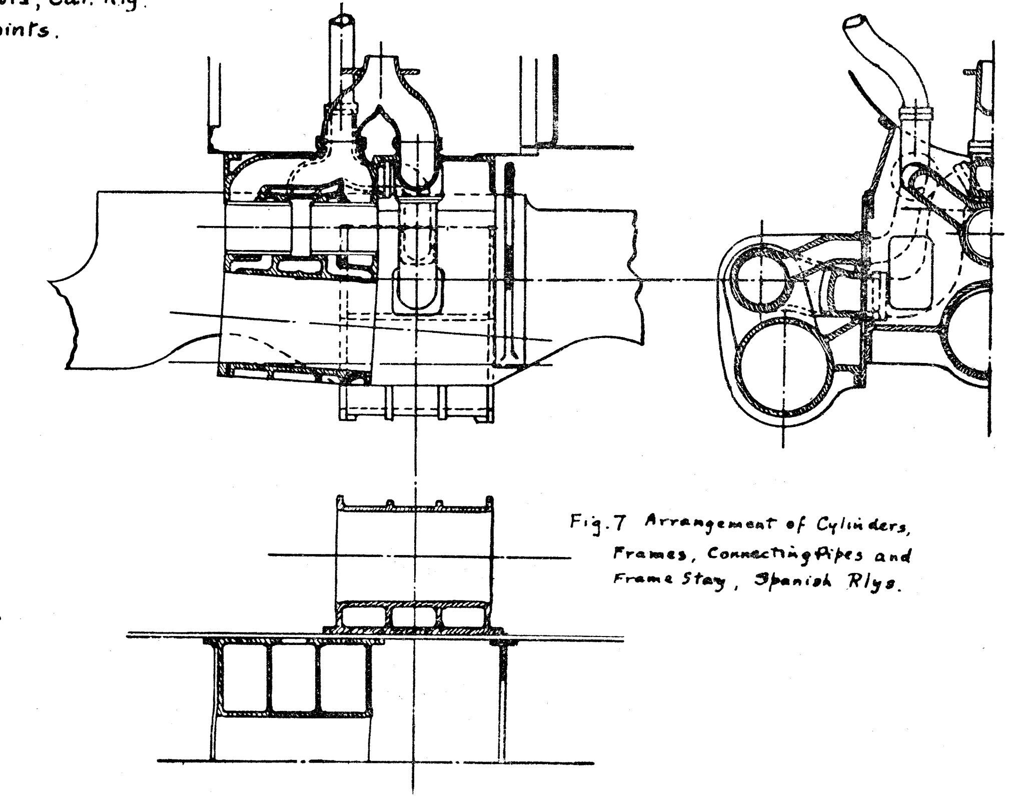
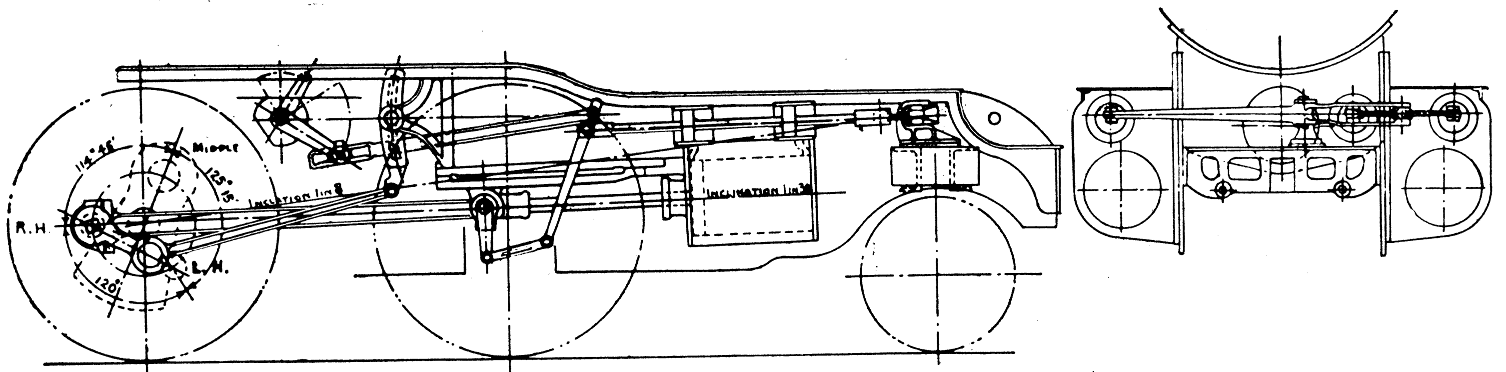


Fig. 7 Arrangement of Cylinders, Frames, Connecting Pipes and Frame Stay, Spanish Rlys.



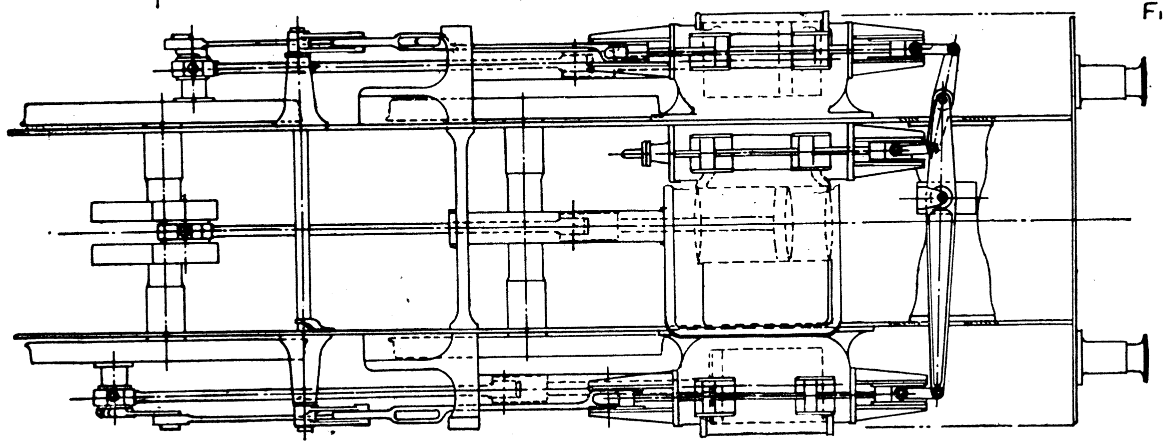


Fig. 9 - Arrangement of Valve Gear, G.N.R.

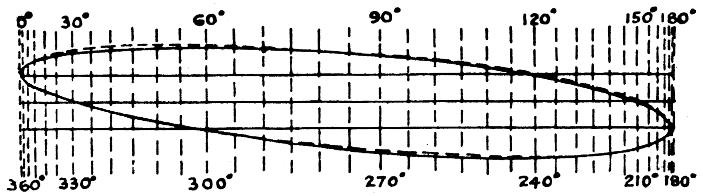


Fig. 13 - VALVE ELLIPSES - Outside Valves to Full Line, Inside to Dotted.

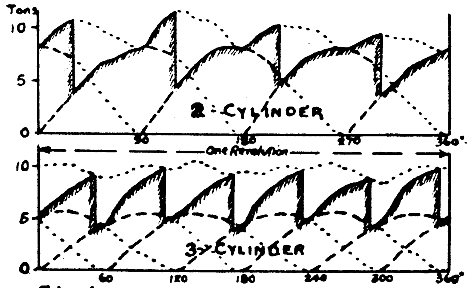


Fig. 16 - Available Starting Effort for All Positions of Cranks.

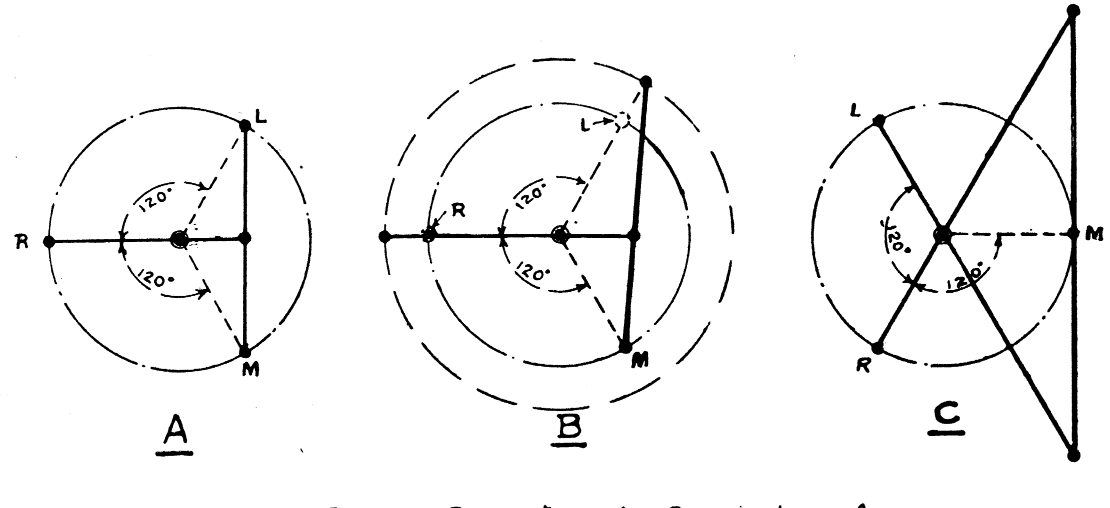


Fig. 14 - Proportions for Rocking Lever Arms.

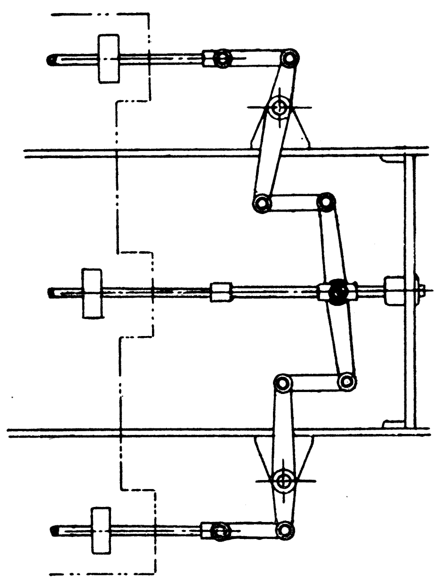


Fig. 12 - Valve Gear suitable for 3 Horizontal Cylinders.

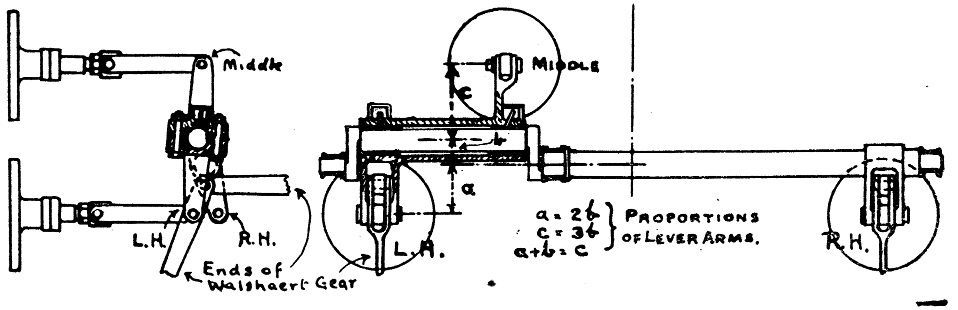


Fig. 11 - Valve Gear as used on 3-Cylinder Engines in Germany.

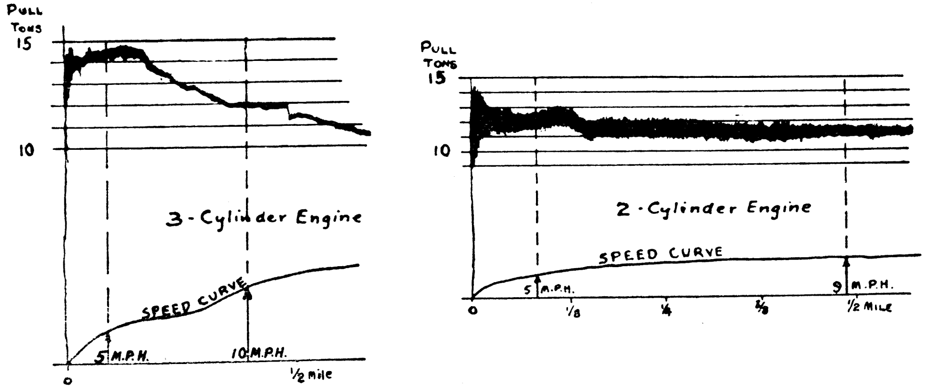


Fig. 15 - Comparison of Drawbar Pulls

- THE MODERN THREE-CYLINDER LOCOMOTIVE -

PAPER READ BEFORE THE G.W.R ENGINEERING SOCIETY, SWINDON, WILTS

ON 13TH FEBRUARY, 1923, BY H. HOLCROFT, C.M.E. DEPT, SOUTHERN RLY (S.E.&C.S.)

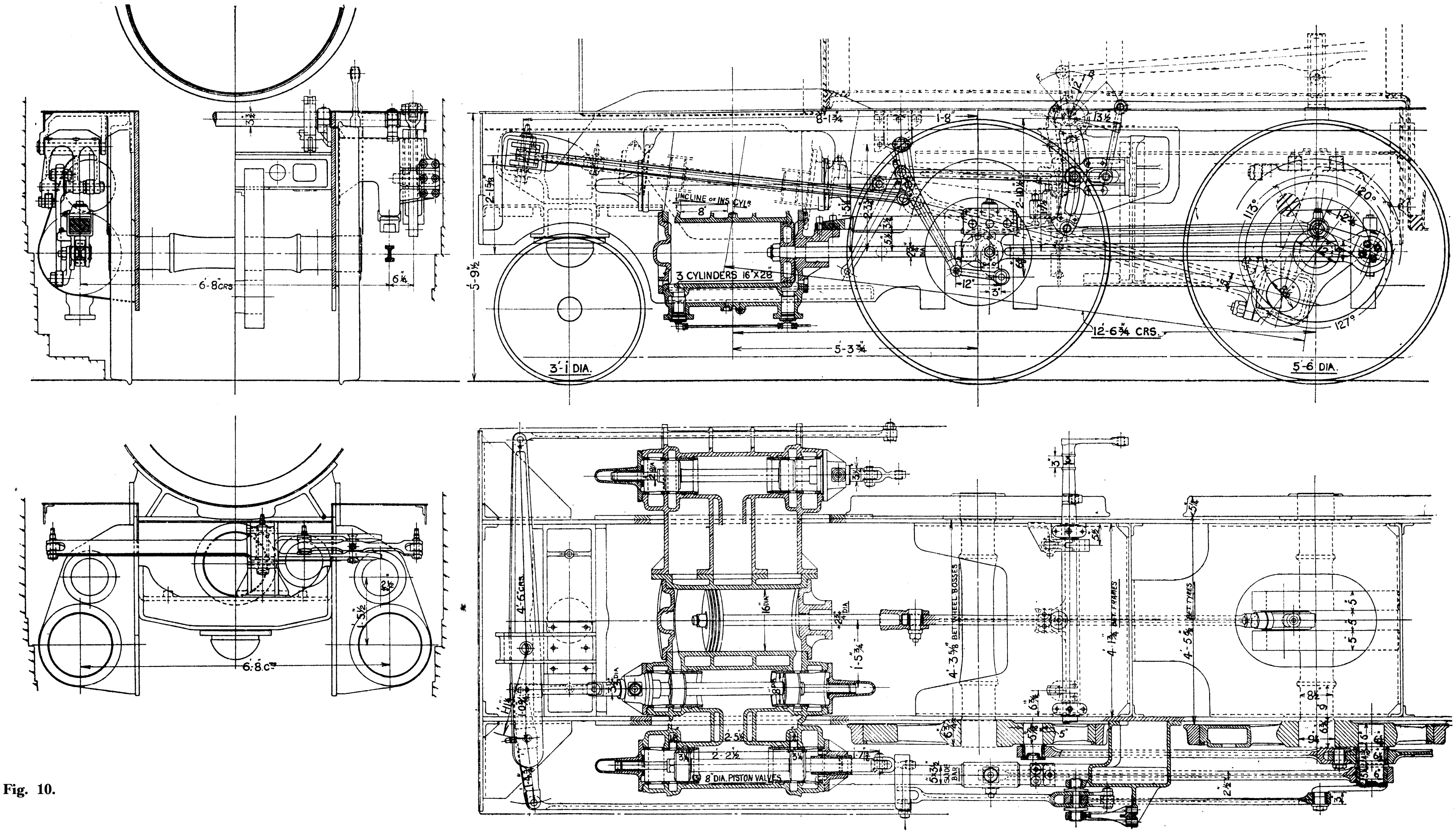

INCLINE OF INS. CYLR.
3 CYLINDERS 16" X 28"
3'-1 DIA.
5'-6 DIA.
12'-6¾ CRS.
5'-3¾
5'-9½
6'-8 CRS
6'-8 CRS
4'-6 CRS.
8" DIA. PISTON VALVES
BET. WHEEL BOSSES
BET. FRAMES
BET. TYRES

Fig. 10.