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Chairman – Mr. G. H. Burrows, Assoc.M.I.Mech.E.

" THE CONSTRUCTION of STEAM RAIL MOTORS,"

BY

A. H. NASH (Member).

With Discussion

The success attending the use of Rail Motor Cars as a convenient means of transport, and their utility in suburban traffic as competitors with rate-aided electric trams, has been fully established. It is the object of this paper to explain the construction of the steam motors at present in use upon the Great Western Railway. The rail motors designed and constructed at Swindon, though not the pioneers on English railways, are acknowledged to be the finest in Europe. They have reached a state of perfection rarely attained on any other railway in the world.

To fulfil the object for which rail motor cars were primarily designed, they must be able to satisfactorily accomplish varying speeds up to 40 miles per hour ; they must also possess the power of rapid acceleration, and be able to haul one or two trailer cars during rush hours, and if necessary, to do this continuously. To these requirements may be added sundry shunting operations in yards where spare locomotives are not kept.

The Traffic Department of a railway will do its best to obtain the whole of these requirements. The Author has heard of a rail motor hauling seven or eight horse boxes and two or three coal wagons in addition to its full complement of passengers. Under such conditions it is not to be wondered at that these cars occasionally require a rest ; yet one car regularly runs 220 miles a day — a performance worthy of one of the 4-6-0 class of engines.

The General Arrangement of the Great Western Railway rail motor cars is too well known to need any detailed description. Figures 1, 2, and 3 show the arrangement of engine and boiler. The outline diagram, fig. 4, shows more clearly the boiler and car suspension arrangements. The car body is carried on an underframe running its whole length. At the trailing or vestibule end, the underframe is carried on a standard carriage bolster bogie, built up of plates and rolled sections. The motor end of the car is, however, carried in a different manner. Large scroll irons are riveted to the underframe and are tapered at their lower ends to receive the cross carrying girders. These cross girders are slung on spiral springs, which in turn are carried upon brackets fixed to the main engine framing. The suspension bolts connecting the girders to the springs are fitted with washers at their lower ends, having convex surfaces engaging in a concave bearing on the underside of the girders. A similar class of ball and cup joint is interposed between the spring and the bracket on the frame, so that there is perfect freedom of movement between the underframe and the engine bogie. The engine weight is supported upon a small pattern of standard type laminated spring. It will thus be seen that the motor end of the body is carried upon eight springs altogether, four spiral and four laminated. It has been suggested that this arrangement is to some extent responsible for the vibration in some of the cars which have been running some time and need overhauling. The vibration is of a curious nature, and is often very irritating if one is subjected to its effects for a long time. One or two cars have come under the Author' s notice in which the vibration could be best represented by the curve shown on fig. 5, in which displacements are plotted vertically and time horizontally. The rise and fall gradually increase to a maximum, and then decrease again to a minimum (in some cases to zero), and then again to a maximum, and so on in a regular cycle — at one instant no rise, at another a considerable vertical displacement.

Now, a loaded spring has a natural periodic time of vibration which, it has been found, is not the same for different sizes of the same type, nor for different types, so that while the laminated springs have one periodic time of vibration, the spiral springs may have another.

If this should be the case with springs upon any one car, it would so happen that when the spiral and laminated springs are vibrating in unison, the vertical movement of the car body would be the sum of the vibrations of each. Again, when the springs are vibrating in opposition, the rise and fall of the body would be the difference of the vibrations, and between these two limits there will be gradually increasing or decreasing values. The curve in Fig. 5 is only diagrammatic, and has not been drawn to any scale.

The boiler is arranged in such a manner as to be the centre pin of the engine bogie, and the rubbing plates which are riveted to the front and back of the boiler, communicate the thrust of the engine to the underframe of the car. To give the engine bogie the necessary flexibility on curves, the cross girder suspension is arranged to permit of the engine having an angular displacement of about five degrees in either direction, amounting to about 8″ right or left at the cylinders. A lateral movement of $\frac{3}{4}''$ right and left is also allowed.

To prevent any shock to the underframe and car body, due to the driving and to the forces set up by the unbalanced reciprocating masses, laminated buffing springs are fitted between the boiler and the underframe at the trailing end, and a spiral spring fitted with a plunger buffing head at the other. The spiral spring is capable of adjustment by means of a nut on the plunger, but in the event of the nuts slacking back the spring is useless, and the underframe receives a severe blow in alternate directions twice every revolution, which soon reveals any defects in the woodwork of the body. A ride in a car with a slack buffing spring is not easily forgotten. On later cars the spiral spring has been removed and a laminated spring substituted. The use of the laminated springs front and back has so far been attended with excellent results. The rubbing plates on the boiler are casehardened, and they should always be thoroughly lubricated. The ball and cup bearings on the suspension bolts should be well covered in, as they are exposed to ashes and dust from the road. In riveting the scroll irons to the underframe great care is taken to ensure that the centres at the lower ends lie on a circle, the centre of which coincides with the boiler centre. When otherwise arranged there will be much straining action whilst traversing curves.

The Boiler.—Fig. 6 illustrates the type of boiler adopted by three or four railways in addition to the Great Western as the standard type. Some railways have adopted the loco. type boiler. The boiler shell is of steel plate, the two conical plates being pressed into shape from solid plate. Fig. 6 shows its general construction. The majority of boilers at present in use have steel fireboxes, but the cracking of the plates at the riveted joints occasions some trouble. Copper fireboxes give better all-round results, though increasing the initial cost. The tubes are $1\frac{1}{8}''$ diameter and are beaded over the tube plates at both ends. At normal water line $5''$ of the tubes are out of the water, which assists in the production of fairly dry steam.

The chief drawback to the vertical boiler appears to be the difficulty of properly supporting it on the frames. This will be readily seen from Fig. 4. It is carried on the frames by means of angleirons riveted to the shell and held down by bolts. The maximum bearing of the angle-iron on the frames is 74° each side, leaving a total arc of 212° unsupported in a fore and aft direction. Its position on the frames renders it also rather unstable. The weight of the boiler and fittings, etc., is, roughly, 6 tons, and when the engine sways on the springs, due to the irregularities in the road, the strains upon the frames must be very great, since the weight acting with an arm of about $4'\,0''$ from the point of support must exert a considerable moment. It is probable, too, that, in spite of the rigid connection to the frame, there is a slight sway on the boiler in a fore and aft direction.

The boiler is remarkable on account of its excellent steaming qualities. These are no doubt due to the large number of small diameter tubes. It may be thought that small diameter tubes would exercise a throttling effect upon the gases. It has the effect, however, of producing an increase in the velocity of the gases passing through, and Prof. Reynolds has demonstrated that increasing the velocity of hot gases passing through a tube brings about an increase of temperature outside it. This may seem somewhat of a paradox, but is quite borne out by results. The efficiency of a boiler does not depend upon mere heating surface alone, but also upon the velocity of the gases over that surface.

In the earlier boilers, trouble was experienced owing to the tubes becoming scaled badly round the feed pipe inlet, but since a deflector pipe has been fitted inside the boiler, the scale is thrown down to the foundation ring, whence it may be easily removed.

The engine frames are of mild steel plate, $\frac{7}{8}''$ in thickness, and are well stayed, as they are subjected to severe racking strains set up by the vibration of the machinery and the inertia effects of the boiler. These strains have also a very disastrous effect upon the rivets, causing them to rapidly become loose if not thoroughly closed down. To obviate this, it has been suggested to increase the frame thickness to 1″, but this should be quite unnecessary if the riveting has been well done in the first instance.

The Walschaert valve gear is used for the steam distribution, as it is readily accessible and is mechanically superior to the Stephenson gear. The valves have $1\frac{1}{8}''$ steam lap and $\frac{1}{16}''$ positive exhaust lap. The valve travel is about $4\frac{1}{2}''$ in full gear, and a lead of $\frac{1}{8}''$ is allowed, which is constant for all grades of expansion. The Walschaert valve gear is an easy gear to set, and when once put right it keeps its setting. It will be noticed that the lap of the valve is relatively a long one, and the advantages claimed for this over the short lap are (1) greater velocity of valve at point of cut off and admission, and (2) greater port opening to steam in the same interval of time. These produce an increased economy as far as steam distribution and coal consumption are concerned. The long travel produces, however, a greater wear in the valve gear, since to obtain it the quadrant must vibrate through a greater arc, increasing its angularity. The upward and downward thrusts in the reversing rod when the quadrant is in extreme positions will also be proportionately increased, as shewn on Fig. 7. Here the thrust along the radius rod has been resolved at right angles as shewn, and it is the vertical component of this force that puts considerable torque in the reversing shaft. The stress thus produced is an alternating one, varying with the point of cut-off, and, what is more important, with the pressure on the back of the slide valve. It will be seen, then, that in an engine having no balancing arrangement on the back of the valve, or with these balancing arrangements in an imperfect condition, the stress in the reversing shaft will be considerable and, in some cases, large enough to produce fractures. It has been found that alternate stresses in steel will produce a crystalline structure, which probably accounts for the appearance of the fractures in reversing shafts. The slide valves are balanced with the well-known Richardson' s strips. Some engines were at first fitted with gun-metal strips, but as they wear so rapidly the use of cast iron strips has become universal.

The Barry Railway Co. built some cars fitted with 5″ diameter piston valves. The piston valve is difficult to arrange on the majority of cars, but it permits the use of the long lap and is not open to the objection of serious back pressure on the flat valve.

Owing to the limitations imposed by the loading gauge, it is difficult to arrange the Walschaert gear without a considerable amount of offset. The gear is at its best when it is what is known as a straight line gear : that is to say, when all the moving parts, from return crank to valve rod, lie in the same vertical plane. The effect of the offset is to produce in time a side wear upon the slide valve, bringing about loss of steam past the valve, thereby increasing the coal consumption.

The cylinders are 12″ diam., × 16″ stroke, and are bolted to the main frames with centres 1″ below the wheel centres. The back cover carries one end of the motion bars, the rear end being carried on a " C " or open type motion plate of cast steel, shewn in Fig. 3. The piston and valve rods are fitted with metallic packing. The motion plates also carry the valve quadrant brackets and reversing shaft brackets, which will be clearly seen on the arrangement of valve gear, Fig. 7.

The crossheads are made of cast steel, and have $\frac{1}{8}$″ of white metal bearing surfaces. Lugs are cast on the crosshead to carry the guiding link arm. The connecting and coupled rods are made of forged steel of I section, and are provided with adjustable bronze bearings.

With regard to the remainder of the details, they call for no special mention. The wheels, axles, axle-boxes, injectors and boiler mountings being of the Standard locomotive type.

In conclusion, the Author considers that the amount of work obtained from the engines described and the manner in which they have completely fulfilled the objects for which they were designed, entitle them to the fullest measure of praise.

DISCUSSION.

The Chairman pointed out that the cars were designed for 30 miles an hour, not 40 as given by Mr. Nash. The spiral buffing springs were being taken off and laminated springs substituted on both sides of the boiler. With regard to the difficulty of supporting the boiler, if a locomotive type boiler were put on a motor car it would be found that the centre of gravity was higher. On the cars with locomotive boilers the boiler was propped up very considerably. With regard to the water being 5″ below the top of the tubes, he did not think this occurred in actual practice, as the bubbles would more or less reach the top of the tube. He expected the tubes were practically covered with water ; and although there was no " solid " water, the tubes were wet the whole of the time if the evaporation was such as he expected.

Mr. C. T. Cuss asked if it were not possible to make the boiler more stable by introducing some tie rods or steel wire rope guys connected to a long base on the frames ? He remarked that although the boiler looked top heavy, it was not quite so bad as it appeared, owing to the volume in the top being mostly steam space.

The Author, in reply, said that guying in the manner suggested by Mr. Cuss would mean going through the footboarding and also through the footspace provided for the fireman and conductor. The doorways would also be blocked. The engine and boiler were quite independent of the car except at the points of attachment by means of scroll-irons. The underframe was quite free, being suspended on the engine bogie. If the boiler were attached to the car body it would be necessary to provide flexible steam pipes to the engine cylinders, as flexible joints could not of themselves take up the play between the bogie and car.

Mr. Cuss said he expected that numerous difficulties would be met with, but still thought that some such method might be adopted by a little sacrifice in other directions, or, as an alternative, the boiler might be supported at back and front instead of at the sides, and thus increase the base of support in the direction of the greatest tendency to tip.

The Author said the firehole door, regulator and other fittings would come in the way of this.

Mr. Cuss then made a sketch showing how it might be done by the method suggested. He proposed carrying two channels across the frames upon which the boiler could be supported above the firehole door, and remarked that this appeared to be a point for investigation owing to the frequency of tube leakages and general repairs.

Mr. L. A. Brewer, referring to the flexible steampipes, said when the driver was holding the regulator at the far end of the car and a breakage occurred the fireman had a difficulty in shutting off the steam ;

in fact, he could not do it all. Was there any provision made for this?

The Author replied that the fireman was quite isolated and had no means of communicating with his mate. Should a pipe break it was a serious matter to be unable to shut off the steam.

Mr. Cuss suggested that means for communicating one to the other should be provided.

Mr. C. C. Henry asked if the ventilation of the cars could not be greatly improved. Had the great amount of heat given off by the boiler anything to do with the bad ventilation ?

The Author said a great deal of the trouble was due to the heat which must necessarily come from the boiler, but he did not see that it was any more difficult to ventilate a motor car than an ordinary coach.

Mr. Brewer referred to the vibration of the engine and bogie, and said he thought if some spring controlling arrangement were fixed at either end of the bogie, so that slighter movement was given when running, the trouble would be lessened to a considerable extent.

The Author remarked, that as pointed out in the paper, the engine was quite free except for the suspension bolts, but the controlling force was that due to the suspension bolts being out of the perpendicular. It was, however, not to be compared with the two point arrangement for controlling.

Mr. H. Holcroft said it would appear from the paper that motor cars were quite new. He thought they were in use 50 years ago on the Bristol and Exeter Railway. They must have been of somewhat similar design to those of the present day, but, of course, all the details were different. With regard to piston valves, he thought it was necessary to have a good size cylinder relief valve with a vertical boiler. A good deal of water would get trapped in the piston valve. As to the question of reversing gears, he said cars were supposed to be driven from either end. One end was off the control of the expansion gear when the driver was at the vestibule end. The driver should have the control of the engine, and not trust it to the fireman, as in case of emergency he would want to reverse the engine. The boiler, frames, and engine constituted a self-contained locomotive, and were only dependent upon the car body for the brake and water ; all locomotives had not less than six wheels, and this particular locomotive had only four wheels with an

8ft. base, with outside cylinders, and the reciprocating parts partly balanced. A boxing action was brought about on the bogie, which got transformed into a vertical movement in the car. When the vertical vibration did occur it was quite continuous. As to the wheel base, he thought that to extend it by putting either another pair of coupled wheels or a carrying pair would improve matters, as the engine bogie was quite uncontrolled for turning about the bogie pin, and another pair of wheels further back would prevent some of the boxing action. There was $\frac{3}{4}''$ play between the flanges of the wheels and the rails, and this must allow the balance weights in the wheels to set up the boxing action.

The Author said piston valves did trap water, but there was a method of getting it away by means of relief valves. With regard to the difficulty of the driver having no control of the reversing arrangement, cars usually worked in about two notches. When the car was about to stop the fireman automatically put the lever in full gear, and it stayed there until the car was well under weigh again, and the fireman then pulled it back into the second notch, the others being but rarely used. There was a considerable amount of boxing action on the frames, but if they were going to put in another pair of wheels they may as well have a locomotive at once. Another carrying wheel would certainly prevent it, and the Port Talbot Railway had constructed a car with six coupled wheels for the motor end, with an ordinary coach bogie at the other end.

Mr. Brewer asked if it were not possible to have the exhaust pipe with less bends than at present, as this must be responsible for a considerable amount of back pressure in the cylinders. There were one or two points in the construction of the car which made it very expensive for maintenance, e.g., the horn blocks and the cylinders. The horn blocks were bolted straight on to the main frame, and as no flanges were provided the tendency was to shear the bolts. A shearing strip put on the back of the cylinders would also be an advantage as, consequent upon the racking strains set up, the cylinders became loose on the frames.

The Author thought it would be rather a good idea to get the exhaust pipe away from its present position. A suggestion had been made to carry it through the water-way and get a straight pipe, but a lot of tubes would be lost if this were done. He, however, thought this was not worth doing. The cylinders and horn blocks were not provided with shearing strips. It was desirable to provide these wherever possible. The difficulty of the cylinders working loose had been overcome by putting more bolts through the flanges. A lip could easily be placed on the forward side, however, and make a better job. The same applied also to horn-blocks.

Mr. Holcroft asked if the Author knew anything about French motors. The Serpollet type of engine, fixed somewhat like an electric motor, was used on several lines. The engines were single acting and had four or eight cylinders, something like a petrol motor. Such an engine would be fairly easy to balance, and it seemed to him that where the passengers and engine were on the same car, a motor of this kind would be much more suitable than the locomotive type. In case of break-down, the engines could easily be changed like an electric motor, and also the cars would be lighter. He had not heard what results were obtained.

The Author was not acquainted with the type of car referred to, but remarked on one strong point in its favour — interchangeability. The Taff Vale Railway also made a strong point of this. The gearing was a source of trouble on heavy motor cars of this type.

Mr. Holcroft referred to the immense number of electric tramcars in use which had a spur wheel on the axle and a pinion on the motor. They ran in an oil bath and the efficiency of the gearing was pretty high. He did not think they gave much trouble. There ought to be no trouble with machine-cut gear wheels.

Mr. Cuss believed that the petrol-driven motor car received a great deal of attention in the early days. Was it on the ground of cost or defects of construction that the idea had been abandoned ?

The Author pointed out that of course with the petrol-driven car petrol had to be carried. This was not desirable on a rail motor. There was the same trouble with regard to the gearing. On the Serpollet 'buses petroleum was used.

Mr. Brewer asked if the coach body of the motor lasted as long as the trailer car, or did the motor body become worn out sooner through the excessive vibration due to the engine, and require more frequent repairs ?

The Author thought that owing to the additional vibration they had to withstand, the bodies would require something extra in the way of repairs.

Mr. E. T. J. Evans asked why sandboxes were provided on the vestibule end as well as on the engine end. He thought the function of the sandboxes was to supply sand to the driving wheels to prevent slipping. With regard to the interchangeability of engines, he thought our car engines could be changed in a day, if it were necessary to do so. He thought that a day was quick enough for ordinary purposes, but of course, to be able to do this properly, it was necessary to have a number of spare engines.

The Author said that sandboxes were necessary on the trailing end. When the car was going forward, the driver applied the sand to get the wheels on the motor end to bite. This also helped the brake blocks on the carriage bogie. The driver must be able to apply the sand without signalling to the fireman.

Mr. Cuss asked if the sand was fed between the block and the tyre.

The Author replied that it was fed in the ordinary way by means of a pipe led down to the front of the wheel.

Mr. Holcroft remarked on the difficulty of lifting the boilers out of the car body at out-stations for repairs or exchange. He thought it would be a good thing if more of the roof could be removed, because something like a 23 feet lift was required. There were very few cranes that would do this, and, in fact, a breakdown crane was generally used. If the coal bunker could be removed, and the boiler taken out through the front, the lift would not be so much. He further remarked that this brought about a good deal of empty running, as the boilers were often coming out for attention.

The Author pointed out that a locomotive boiler could not be got out of the frames in every shed. There was the same difficulty in regard to the motor boilers.

Mr. Holcroft said that if new tubes were required the boiler had to be taken out of the frames. At Wolverhampton, a large number of boilers came out. He believed a manhole was provided for getting at the tubes. Could not the boiler be taken out through the side.

Mr. Evans said, with regard to lifting the boiler out from the side, he bad heard the same idea mentioned in the erecting shop. It would only be necessary to lift the boiler just as high as the carriage frame and bring it out sideways, but perhaps the coach would not be strong enough to permit of this, as the cant rail and roof sticks would have to be cut.

The Author agreed that the cutting of the cant rail would be a great disadvantage.

Mr. W. H. PEARCE said it certainly looked as though the valve gear wanted defending. The trouble was due to the large lap and increased travel of valve. It had come about through the increased throw and the angularity of the quadrant link. In the Walschaert gear the more lap obtained, the more work the combining lever had to do, and only a small percentage of the work was taken by the quadrant. In that particular case the angularity of the link was rather excessive, and it would be an advantage to decrease the angularity of the link and increase the angularity of the radius rod. The offset in the gear of 5″ from the return crank centre to the valve spindle centre had been a bad point from the first ; but the action was due to a practical difficulty in the first design. The Author had made no reference to the regulating gear. The method of driving from the trailing end of the car to the motor itself, and also getting on a couple of trailers, and still being able to drive from the trailers, he thought was worthy of mention. With regard to the balancing and the production of horizontal vibration, different percentages of balance of the reciprocating parts had been tried, and the results pointed to the fact that the higher the percentage of balance the better the motor cars ran. On the illustration, the Author had shown spiral springs for the buffing gear at the leading end. He (Mr. Pearce) had recently been looking at a prospectus of the Westinghouse Friction Draft Gear, and thought it would be a great improvement, and take off the horizontal vibration considerably, if a miniature arrangement were were adopted at both leading and trailing ends, and the laminated springs dispensed with. The vibratory effect in the coach would be greatly diminished.

The Author said that the question of the angularity of the quadrant was a serious one. The thrust on the reversing shaft and the shuddering at the quadrant should be avoided at all costs. The regulator gear was excellent. It served its purpose wonderfully well, especially through two trailers and a car. The reciprocating weights were balanced with rather more than the usual percentage for locomotives. This ought to have the effect of steadying the engine, for the reciprocating weights produced a hammer blow in a vertical direction, which would tend to have a damping action on the laminated springs and check their vibration.

The Author also referred to the thickness of the frames, and said some cars built on another railway had come under his notice in which the motion bars had seized due to the frame yielding when the coach body and underframe were placed in position after the engines had been finished.

Mr. Brewer, referring to the buffing springs, asked if it were not a fact that the hunting action only occurred when the car was going down hill engine first.

Mr. J. R. Yule said the hunting action was always felt when going down hill. Referring to the round end of the valve spindle, he asked if it would not be better to provide a square or V-shaped end, as any slack on the valve-strap would then be taken up.

The Author said that this difficulty was practically eliminated in the latest design, in which the valve spindle guide had been brought in line with the combining lever centre, thus considerable reducing the original offset.

Mr. Evans thought that as the frames were " bellied " out to receive the firebox, this would tend to make the frames stiffer in that direction. He thought the bare weight of the coach would not cause the motion bars to seize.

Mr. Holcroft, speaking of balanced valve packing being ineffective, due to leakage past the strips, asked, was there no leakage hole behind, because there must always be a slight amount of steam getting by ? Was there no hole to take the pressure off at the back ?

The Author said a hole was provided, but this was sometimes plugged up to prevent excessive wastage of steam.

Mr. Brewer asked if it would not be better to put the car in the middle of the train, instead of at the end, *i.e.*, put the trailer up against the engine end.

The Author thought the cars worked as at present for convenience in coaling and watering.

Mr. Holcroft pointed out that the cars had rather small coal bunkers, and the car would have to be uncoupled from the motor every time more coal was wanted.

Mr. J. R. Yule remarked that the cars were generally coaled by means of bags.

The Committee here record their indebtedness to the Proprietors of the " Railway Engineer " for the loan of printing blocks used in illustrating this paper.

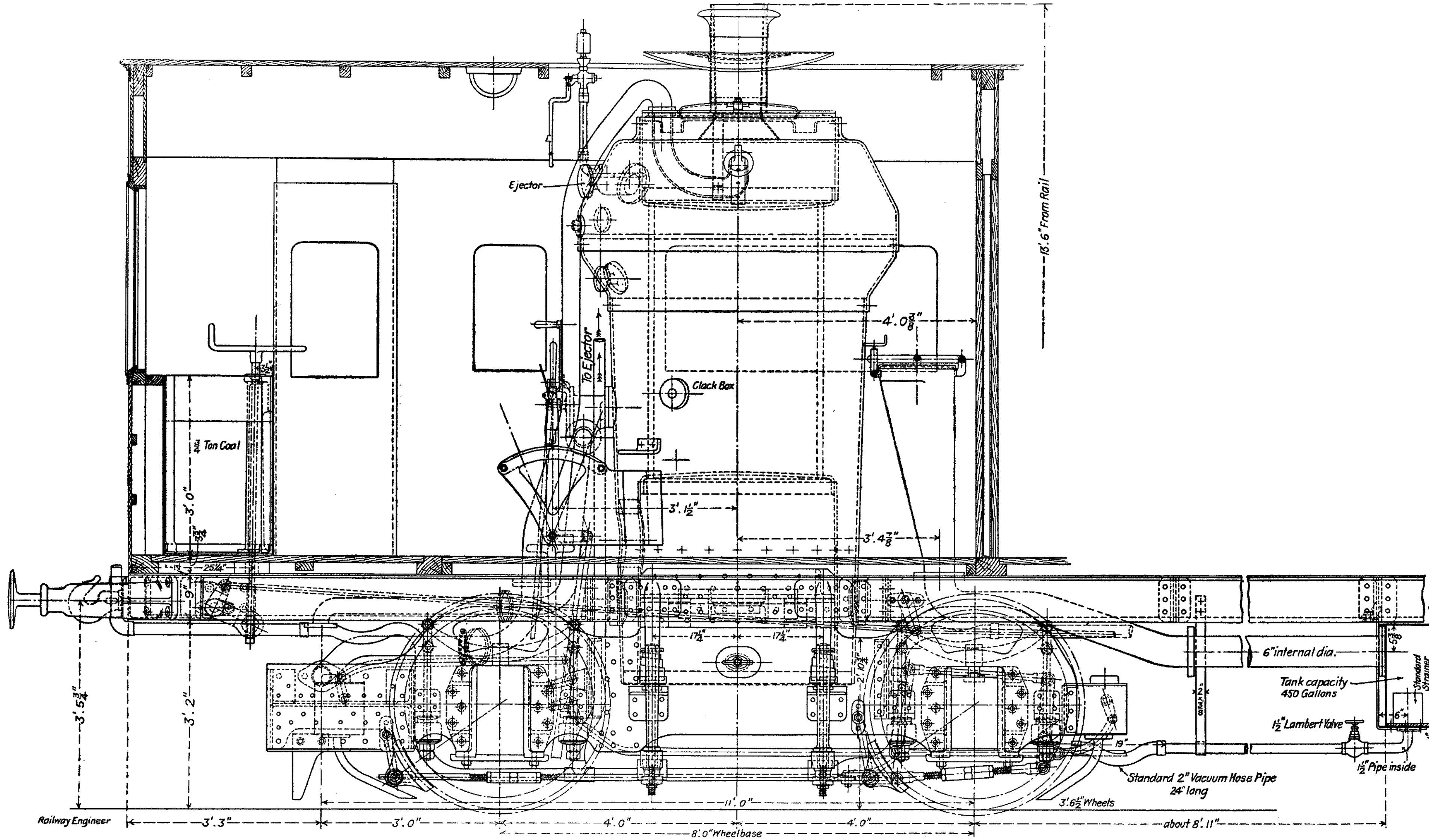

Fig. 1.— Arrangement of Steam Motor.— Sectional Elevation.

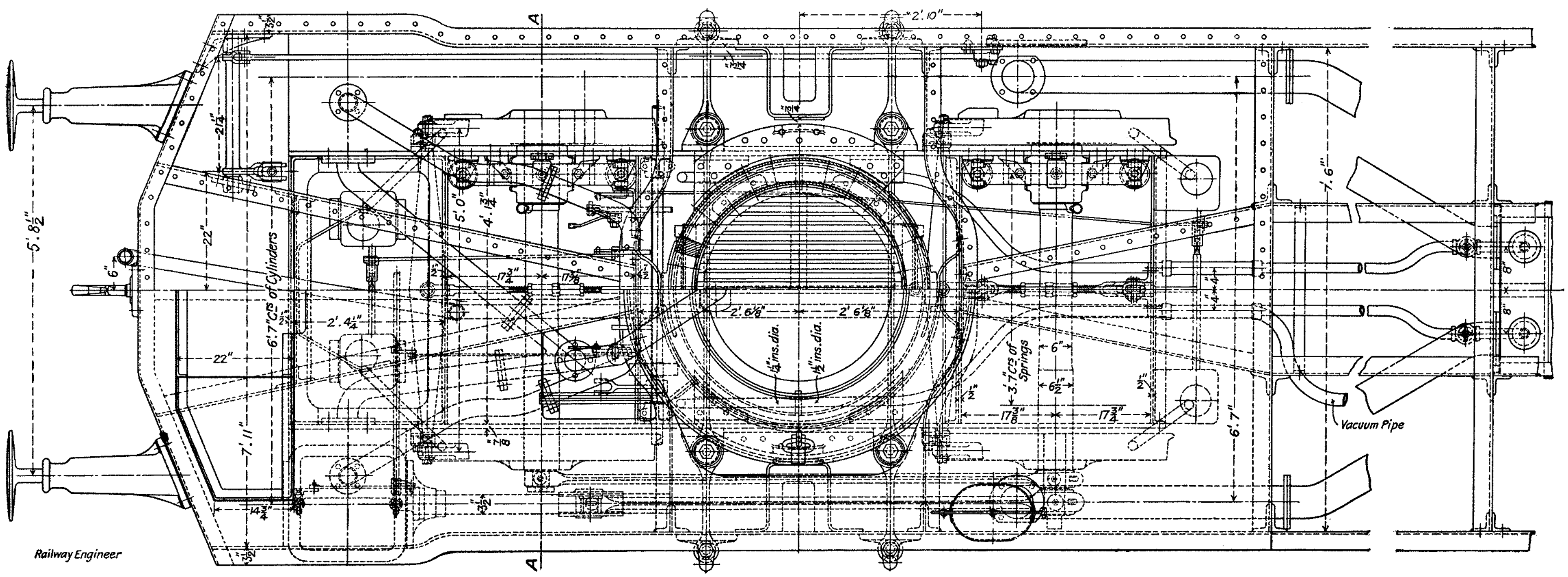

Fig. 2.— Arrangement of Steam Motor — Plan.

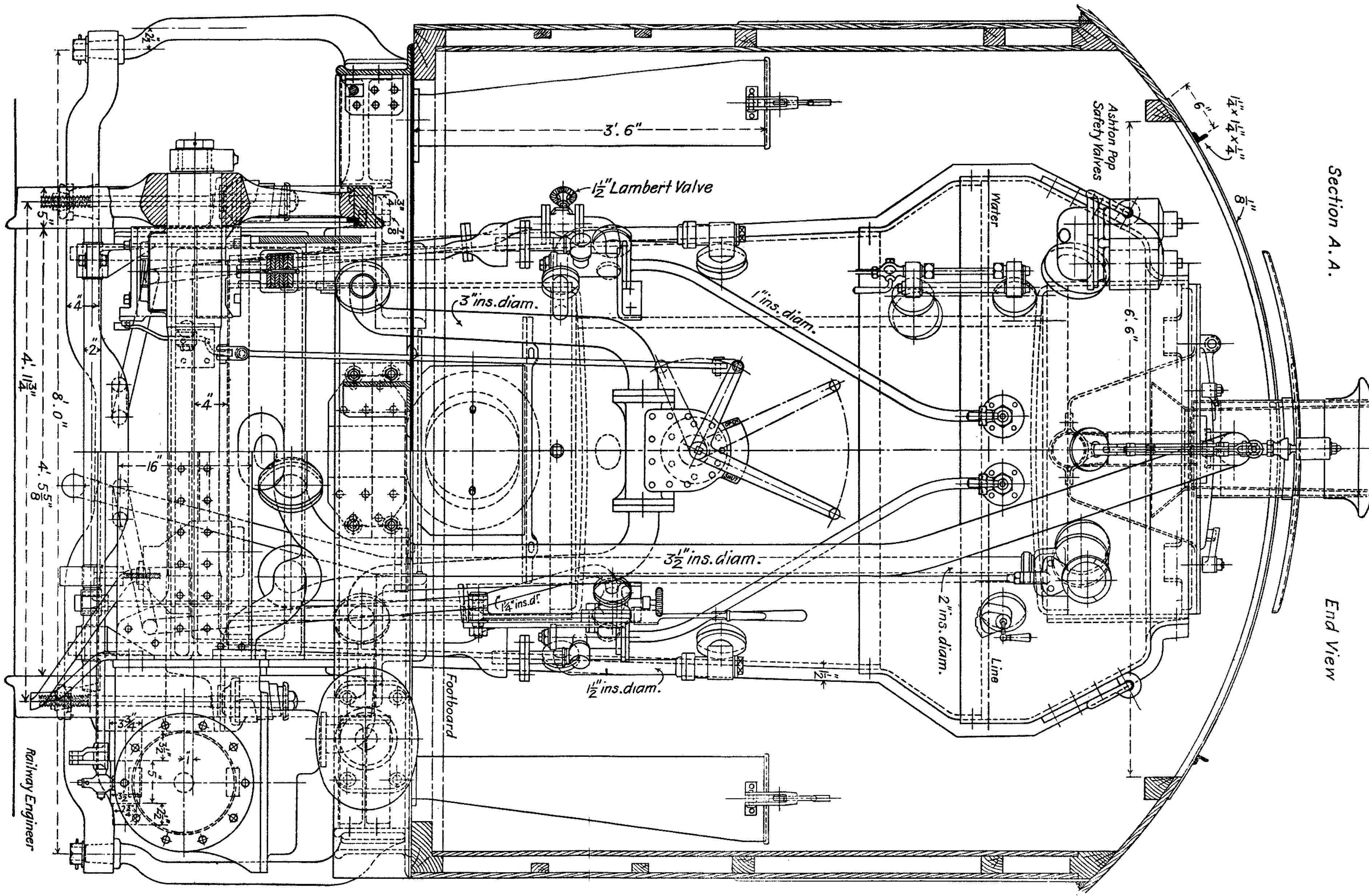

Fig. 3.— End View of Cross Section.

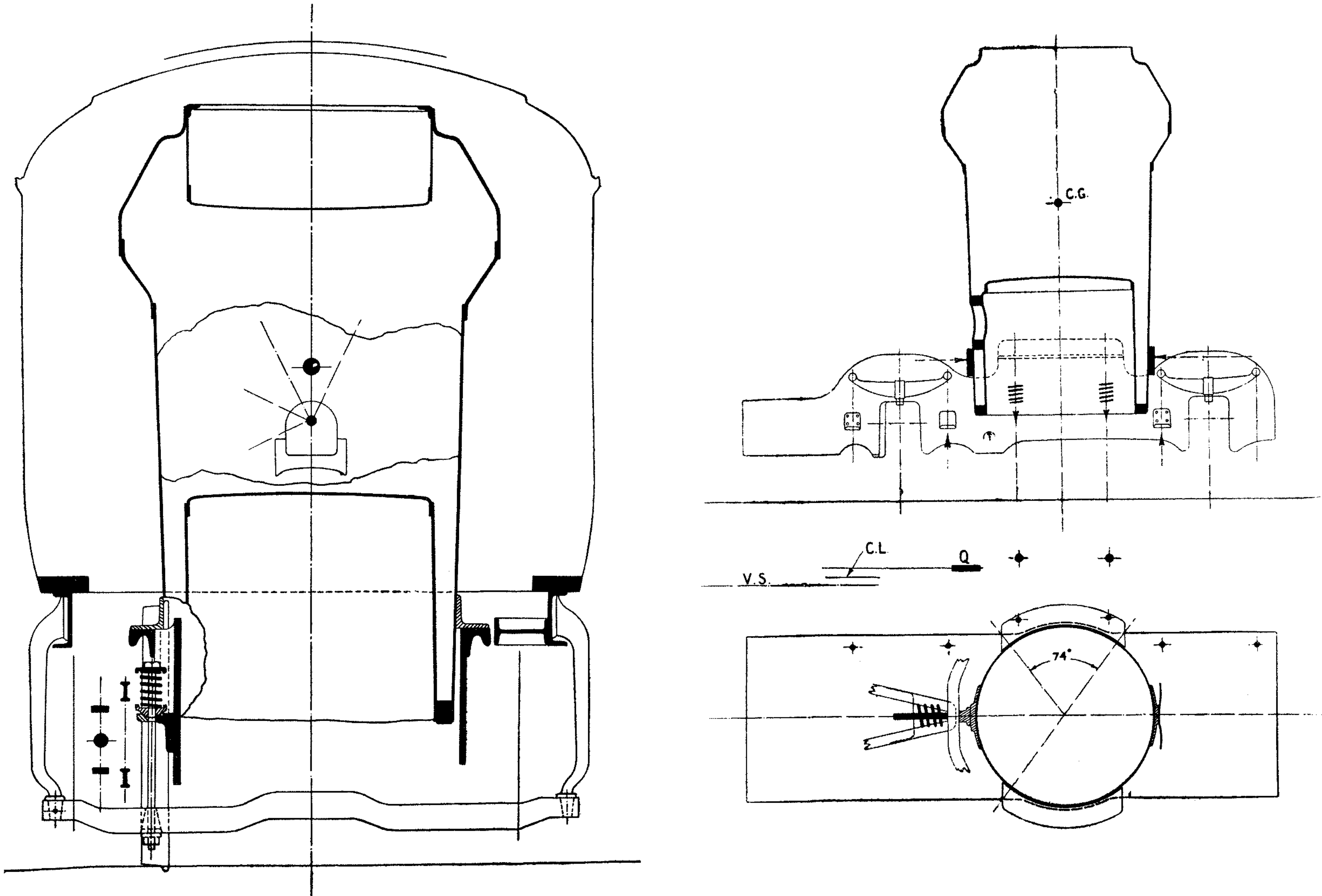

Fig. 4.

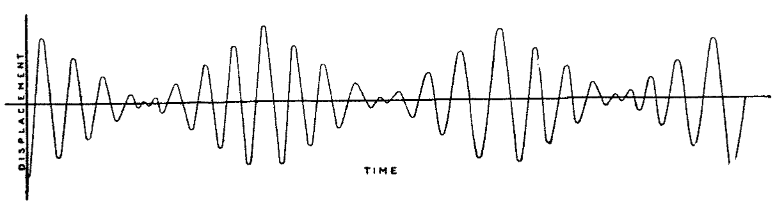

Fig. 5.

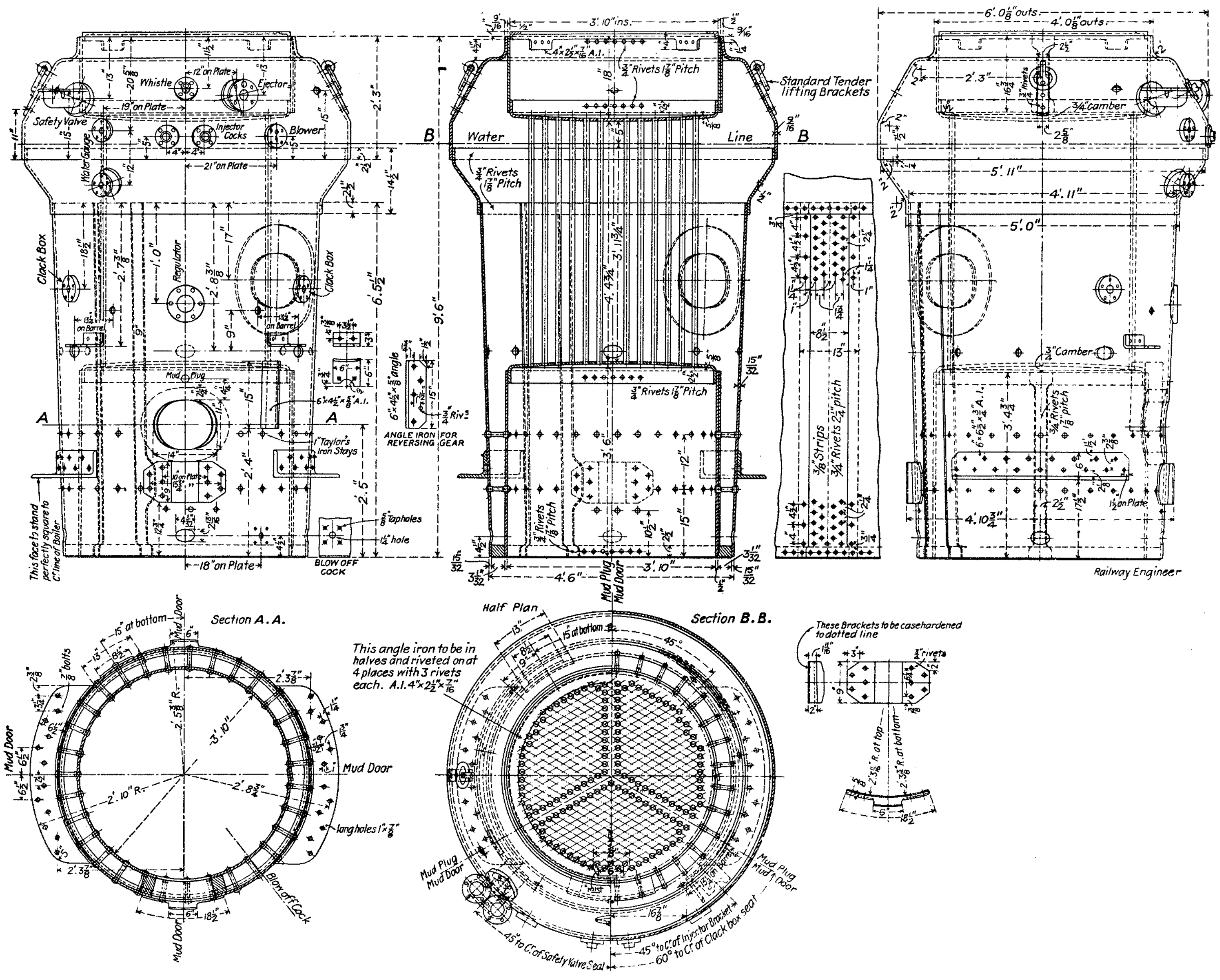
Section A.A.
Half Plan
Section B.B.
Water Line
Safety Valve
Whistle
Ejector
Injector Cocks
Blower
Water Gauge
Clack Box
Regulator
Mud Plug
1" Taylor's Iron Stays
ANGLE IRON FOR REVERSING GEAR
BLOW OFF COCK
Tapholes
This face to stand perfectly square to C. line of Boiler
Standard Tender lifting Brackets
3/4" camber
This angle iron to be in halves and riveted on at 4 places with 3 rivets each.
These Brackets to be casehardened to dotted line
Mud Door
Blow off Cock
Railway Engineer

Fig. 6.— Boiler.

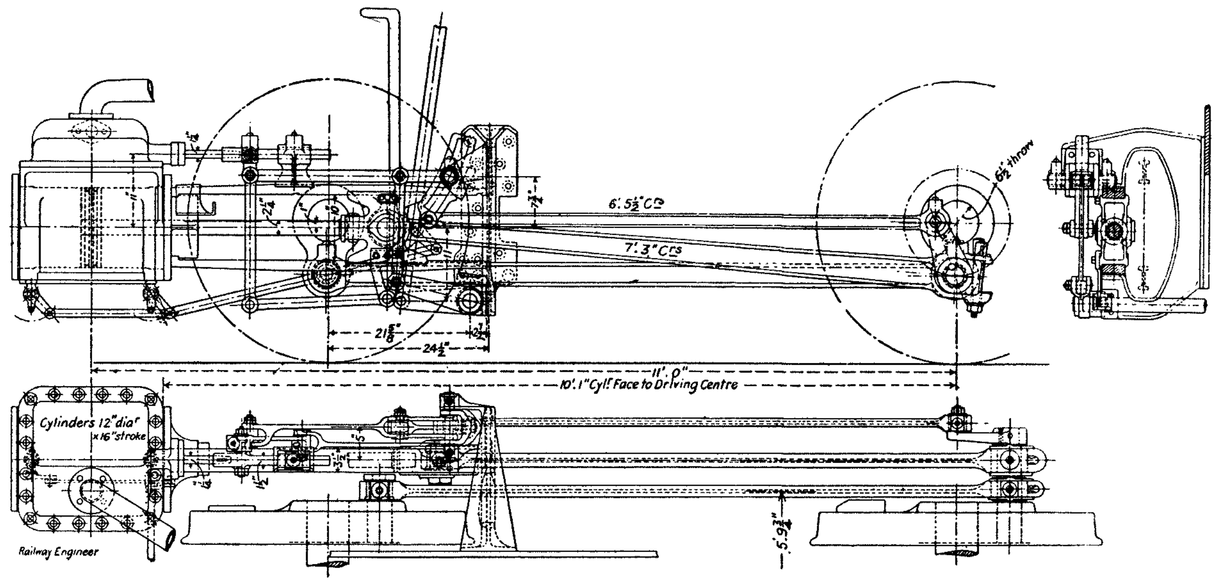

Fig. 7.— Arrangement of Valve Gear.

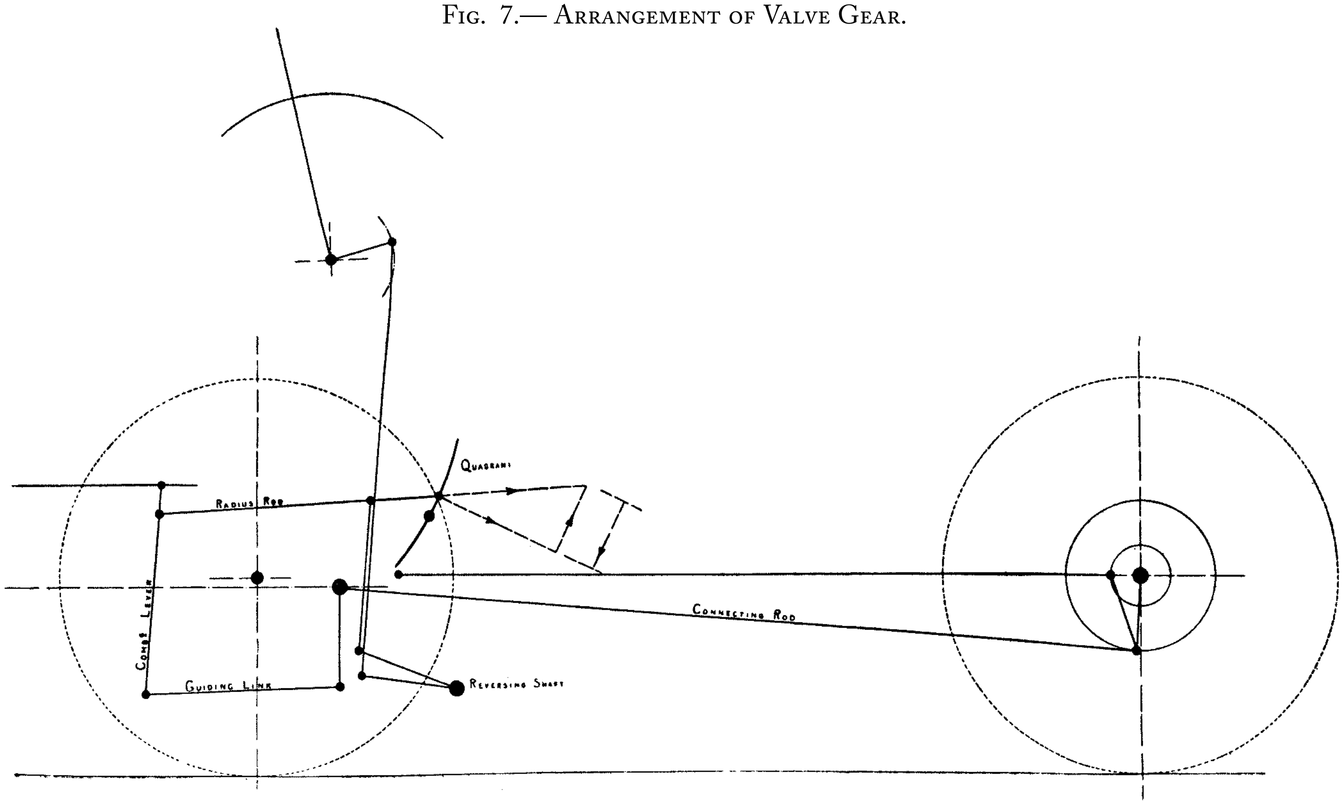

Fig. 8.