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THE STRONG LOCOMOTIVE.

BY GEORGE S. STRONG.

(FIRST PAPER.)*

JOSEPH M. WILSON, President, in the chair.

MR. STRONG:—This locomotive has been the outgrowth of a preconceived determination of its designer and inventor, to overcome the radical and well recognized defects existing in locomotives of ordinary construction, while retaining all the admirable qualities to be found in the running gear and minor parts.

Much discussion has taken place in the last few years regarding the possibilities of the future, as to fast train service, and much ink has been wasted, without any practical results, in stating what could and what could not be accomplished. It still remains a

* Read before the FRANKLIN INSTITUTE, Wednesday, March 16, 1887.

fact, that there is no regular scheduled train to-day on the American Continent, or in England, or in Europe, that travels at a speed of sixty (60) miles per hour, for any considerable distance. We hear of fast runs being made occasionally, but when we come to make enquiries, we find that it has been with a very light train, or for a very short distance.

The *Railroad Gazette*, of February 11, 1887, speaking of a recent locomotive turned out by one of our Eastern builders, intended for very high speed, and in questioning the ability of the locomotive to do the work for which it was intended, says: *

"The locomotive in question is specially designed to run a train regularly at a higher speed than has ever been attained before. A speed of forty miles per hour, including stops, is a high speed on a first-class line, and is rarely attained for any distance in regular running. Special trains are, of course, often run at higher speed, but the rate of forty miles per hour, including stoppages, can only be maintained with any punctuality in daily running when the circumstances are favorable, the train not inordinately heavy, the grades and curves easy, and the average distance between stoppages at least thirty miles. When the train has to slack frequently at drawbridges or railroad crossings, such a speed cannot be maintained. The fact that such speeds are only attained by a very small number of trains in this country, shows the difficulty of maintaining a high velocity for a considerable distance. The fastest train on the New York Central runs from New York to Buffalo, 440 miles, in ten hours and forty-five minutes, or at the rate 40.93 miles per hour. This can be done because the grades are remarkably favorable, and the stopping stations average no less than 110 miles apart. The Pennsylvania runs the limited express from Jersey City to Pittsburgh, 443 miles, in eleven hours and seventeen minutes, corresponding to a speed of 39.27 miles per hour, the average distance between stoppages being 110.34 miles. The speed is fully one and one-half miles slower than on the New York Central, showing the effects of the more unfavorable grades and curves. On a straighter track, the Pennsylvania attains a considerably higher speed, the fastest train between Jersey City and Washington covering the distance, 226.7 miles, in five hours and two minutes, which gives a speed of

* This engine has since been acknowledged a failure, and has never run over the line intended for it. (S.)

45.04 miles per hour. The distance from New York to Boston by the Boston and Albany route is 234 miles, and notwithstanding the keen competition and great through travel, the speed is only thirty-nine miles per hour by the fastest train on this route, which covers the distance in six hours.

"The fastest runs in regular work between any two stopping points give a speed of slightly over fifty-three miles per hour. Higher rates of speed have been obtained when making up time, but at present the average speed while in motion seems to be considerably under sixty miles per hour. Many trains doubtless fully attain that speed on a large portion of the run, but the time occupied in getting up speed after starting, and slackening before stopping, reduces the average speed to about fifty-three miles per hour.

"These figures show the highest speeds attained on this continent for any considerable distance, and clearly demonstrate that the speed proposed on the New York, Providence and Boston, 62.5 miles in 62.5 minutes—including a stop at a drawbridge—is altogether exceptional in regular running.

"The principal peculiarity of the engine that is to run at this exceptional speed is the enormous weight on the drivers, 72,000 pounds. Why such a weight should be necessary to attain a high speed is somewhat of a mystery. Adhesion is very necessary to enable an engine to start a train or to haul a heavy train up a steep grade, but complaints about engines slipping at high speed are seldom heard. The difficulty is more generally the impossibility of getting the required speed out of the engine. In whatever position the reverse lever may be placed, the engine will not run to time. The reason has often been pointed out in these columns, and consists in the fact that at excessive speeds the steam is so wiredrawn in passing through the ports that the steam line is attenuated, and sufficient pressure cannot be put on the piston to overcome the resistance of the train. The back pressure, too, is greatly increased, still further diminishing the size of the diagram. These difficulties can, however, be overcome in great measure by using slide valves with the Allen internal passage and large ports and exhaust nozzle. The more serious difficulty of making steam then remains, and can only be overcome by a liberal allowance of heating surface."

As to the question of the Allen valve being able to help them

out, the writer is led to believe, from experiments made with the indicator, and from the experience of some leading lines where this valve is used along with other valves, that little benefit is to be derived from its use, as it does not help the locomotive where it is the weakest, *i. e.*, on the exhaust side of the piston.

When we seek for the reasons we find that to run a very heavy train at a very high speed, for any considerable distance, takes a very large power, and a continuous development of that power. To obtain this we must have a very high mean effective pressure on the piston, and this must be maintained during the journey.

When we examine the link motion, we find it is not well adapted to give this high mean effective pressure without making a very heavy draught on the boiler. If we then go to the boiler, examine its construction and calculate its capacity for economical evaporation of the necessary quantity of steam from cold water, we find it is not well adapted for burning the large amount of coal required to evaporate this quantity of water. We also find that it is not well adapted to carry the pressure demanded. It is therefore evident that the boiler, valve gear and valves are found wanting, and that these are the vital parts of any locomotive. A high mean effective pressure is absolutely essential, and anything which tends to hinder the attainment of this is a weak point in the design or construction of a locomotive intended for heavy and fast train service.

The price paid in obtaining this much desired end must be carefully considered. This price consists of first cost, coal consumption, running expenses and maintenance of the locomotive and all its parts.

Let us see what are the necessary conditions to secure great economy of coal, steam of high pressure, and the use of this steam to the best advantage. There are certain well-known laws which control the production and burning of gases from coal, whether it be anthracite or bituminous, and if these conditions are complied with, complete combustion is as certain as the burning of gunpowder, or the combination of any elements which have an affinity for one another. If these conditions are not complied with, complete combustion cannot be expected. These laws are so well understood that it is hardly necessary to go into their explanation here; all that is required is, a grate of ample area to

first distil a sufficient quantity of gases from the coal, in a given time, to produce the necessary quantity of work. In a locomotive where 1,200 to 1,500 horse-power is required this cannot be done, as it could be in a gas producer, and a partial combustion goes on as the gas is produced; the grate, however, must be large enough to permit the coal to be burned on it without any being carried over and through the tubes. The second step and essential condition is the uniting of the gas so produced with a quantity of heated air large enough to cause complete combustion, and to maintain a temperature sufficiently high to ignite and burn the mixture of air and gas. Enough time must be allowed for a complete mixture to take place, before the gases or products of combustion go to the tubes in which combustion cannot take place, but where the heat generated by combustion is utilized and reduced.

In designing a boiler to meet these conditions, we have combined some very novel features, and have made use of the highest development of both the steel makers' and the boiler makers' art. This is emphatically the age of steel, and with it we entered on a new era in the art of boiler making, and the manipulation of steel plates. We are able to do things now, that a few years ago would have been regarded as impossible, and even now are so regarded, except by a few leaders who are always to be found with the courage of their convictions.

We have also taken advantage of well-known mechanical principles in designing shapes as near as possible to those that Nature would make, if she were undertaking work of this kind. That is, we have done away with all flat and square forms, to resist pressure by transverse strength alone, and have adopted those that give the greatest resistance against internal as well as against external pressures. We have also banished all stays and crown bars, and as a result we have a boiler that is not only strong, but one that will always remain so, and when finished and ready for work, will always be ready and not a constant source of expense and annoyance.

It will be readily understood from an examination of the accompanying illustrations, that the outer shell of the boiler is, as nearly as may be, the shape it would take if it were made of canvas, and then inflated. Therefore, under full working pressure it

is of the same shape as when it has no pressure on, and the metal in all parts of the shell is under direct tensile strains, there being no tendency to bend the sheets. There can be no tendency to crystallize, and the parts should last as long as the natural life of the steel in other structures under similar light tensile strains, providing there is no corrosion going on. The factor of safety in the boiler illustrated is five.

The interior part of the boiler is so clearly shown as scarcely to require description. Departures from the ordinary construction call for a word of explanation: There are two fire chambers, discharging the gases generated in them over a hollow bridge, where they receive the supply of heated air necessary to cause complete combustion, and by alternate firing an incandescent fire is always maintained on one side to burn the gas from the opposite fire-chamber where coal has last been charged. The air which is to mingle with the gases is heated by the hollow grate bars and hollow bridge, and as a very thin fire is carried, air can pass up through it readily.

The fire chambers or furnaces are welded and corrugated steel cylinders, joined on to the combustion chamber by a welded and corrugated steel junction piece. This piece may be made of one plate formed on dies in a hydraulic press and flanged out to join the ends of the fire and combustion chambers, so as not to expose a single rivet to the direct action of the fire.

The combustion chamber is also a welded and corrugated steel cylinder, flanged out to receive a full-sized tube sheet. These internal parts are capable of standing eleven hundred (1,100) pounds per square inch external pressure. The longitudinal seams on the outer part of the boiler are all welded, and the circular seams, the only ones riveted, are united by a double row of rivets. It will be readily understood that we can safely carry almost any pressure, and the boiler shown is designed for steam of 175 pounds per square inch.

As we have shown how it is possible to construct a boiler to meet all the requirements of a very powerful and very fast locomotive, *i. e.*, maintain a very high steam pressure at a low cost for coal and repairs—let us see how the best use can be made of that steam, and in doing this we shall again make use of well-known mechanical principles.

It is a well-recognized fact in steam engineering that the best engine is the one that gives the highest initial and lowest terminal pressures, provided she is tight and is working up to her full capacity (*i. e.*, has a full load). To do this she must have a good admission, an early cut-off, a late release, a free exhaust, and a late closure of exhaust, with enough compression to bring the pressure of the confined steam up to that of the boiler at end of stroke.

Much has been written on this question of compression, and some have asserted that it was impossible to run a locomotive at a high speed with any less compression than that given by the link motion, but they have not taken into account the question of clearances. We have found that when clearances are reduced, compression must be reduced, and that with an engine having small clearances, a very small amount of compression answers every purpose, and that more will deaden the engine.

Here was a great problem to solve, and one that has taken years of careful experiment and investigation. We are required to produce an engine with independent steam and exhaust valves, which is at the same time simple, durable and practical.

Many attempts have been made before, and many failures recorded. Careful investigation soon satisfied the writer that the flat slide or gridiron valve was the only one that would answer the purpose. Valves of this kind have stood the test for years with high pressure steam in both stationary and marine practice; but to be a success, these valves must be allowed to come almost to rest while the load is upon them; wherever previously used, some form of cam or tappet motion had been employed to actuate them. In our first experiment we tried a device of this kind, but soon found that, with the rapid motion of a locomotive, it would not do at all. We then devised the very simple arrangement of rocker shown, which is so adjusted that after a valve has travelled its lap, it comes to nearly a full stop, while the corresponding valve at the other end of the cylinder is doing its work, and as the load comes upon the valve during this period of rest, there is very little wear. As the steam of compression comes up under the valve at its period of opening, there is a still further relief, while the exhaust valve does not move until it is relieved by expansion.

The method of introducing the valves and seats is clearly shown by the drawings. The valve seats are plugs, fitting in holes bored in the passages from the saddle to the cylinder, the ordinary steam-chest being dispensed with. The valves are let into grooves milled or planed in the seats, so arranged that the valves are free to move up and down in the seats.

There are ten (10) ports in each seat on a 19 x 24 inch, or a 20 x 24 inch cylinder, each port being $4\frac{5}{8}$ inches, giving a total port length of $46\frac{1}{4}$ inches, in each valve. This length is also, of course, that of the lead line, as against the sixteen-inch of an ordinary locomotive. This arrangement, even when the engine is making 250 revolutions per minute, gives an initial pressure within two pounds of boiler pressure, and does not allow more than five pounds drop to the point of cut-off; while the ordinary form of valve will entail a loss of fifteen pounds between boiler and initial pressures, and another fifteen during the period of admission, making a loss of thirty pounds between boiler pressure and that at the point of cut-off; while under similar circumstances, we do not by any chance lose ten pounds. We cut off at four inches, and hold on to the steam until the last inch of piston travel, thus getting six expansions. The exhaust does not close until three and one-half inches from the end of the return-stroke, avoiding excessive compression. An ordinary locomotive loses thirty-three per cent. of the mean effective pressure from compression, which necessitates a late cut-off and not more than three expansions, in order to maintain the same mean effective pressure that we get with six expansions. Now it will be readily seen why the link-motion is not good for very fast and heavy work. It can neither get the steam in nor out properly. In losing at both ends, it exhausts at too high a pressure, and does not allow an initial pressure at all near that of the boiler. All these objections are entirely overcome by the valve-gear shown, which is of the radial type.

The motion for all the valves on one side of the engine is obtained from a single eccentric, one motion of the lever attached to the eccentric moving the valves, the amount of their lap and lead, and another motion produces the opening in addition to the lead. There are two levers worked from the same eccentric strap; one being bolted rigidly to it, while the other has a pin forged on

the end of it. This pin has a bearing in a bushed hole in the strap itself, at a certain distance from their ends. Both these levers have a fulcrum pin, connected with one end of a link, whose other end is hung by means of a pin from a block, capable of being moved along a sector or arc. The path of the pin when moved along this arc is radial to the fulcrum pin already mentioned. Thus the position of this block on its sector, which is regulated through the medium of a reach rod, by the lever in the cab, determines the inclination of the travel of the fulcrum pin. When the block stands in the centre of the sector, as shown on the drawing, there is no inclination to the travel of the pin, and the valve is moved only the amount of lap and lead. If, however, the block is moved forward on the sector, the fulcrum pin travels over an inclined path, which incline represents the opening of the valve in addition to the lead, and the engine moves forward, and if the block is moved forward to the end of the sector, the full travel of the valve is given, and steam follows the piston twenty inches of its twenty-four-inch stroke; if, on the other hand, the block is moved back past the centre, the path of the fulcrum pin is reversed, and the engine will run backwards. Thus it will be clearly seen, that by varying the position of the block on the sector, the travel of the valve is varied as well as the point of cut-off, which latter may be anywhere between four inches and twenty inches. In all cases the exhaust valve is allowed to travel its full stroke, and as it is worked by the lever having the pin forged on its end, and from a separate fulcrum pin, with an independent link, block and sector, its travel may be varied at will, and so, of course, may the steam valve. In ordinary working, however, the exhaust block is never moved on its sector, except for reversing, when both steam and exhaust-blocks are moved at the same time; after the engine is started, the steam valves are hooked up, but the exhaust is not disturbed. The steam valves are given one-eighth inch lead and the exhaust five-sixteenths inch.

(SECOND PAPER.)*

As the result of the trials of the Strong engine on the Lehigh Valley road, made in April and May, 1887, to develop the strong and the weak points of the engine, certain small alterations in detail have been introduced, which will considerably improve the engine as originally designed.

Of these alterations, one is the change in the method of riveting the seams in the furnaces. None of these are now made with the lap-joint, but instead, the Adamson flanged seam is employed. This is made by flanging outwards the cylinders forming the furnaces, combustion chamber and junction pieces, at right angles to the plate, and connecting the pieces thus flanged by rivets passing through each flange and an intermediate ring about five-eighths inch thick. This joint, therefore, exposes no rivet to the action of the fire, and nowhere is there a greater than a single thickness of plate between fire and water. Tightness and freedom from burning are thus secured, as well as strength and stiffness against collapse, for which the Adamson joint is so suited that it is almost universally employed in the great steam-using centre, Lancashire, England, as the furnace seam of Lancashire boilers which carry safely 100 pounds of steam, outside furnaces of three feet diameter, the joint occurring at every two feet, or 2 feet 6 inches. Another alteration in the boiler, is the welding of all the longitudinal seams. This operation, hitherto looked upon as uncertain, has been rendered completely safe by the introduction, into modern practice, of gas for all the operations of the forge and rolling mill. By suitable application of gas, surfaces to be welded may be heated to a proper temperature, and kept clean and free from dirt and scale. By this, there is a certainty in the welding operation hitherto unattainable, and sound welding, having the full strength of solid plate, may now be regularly effected. By this means, a boiler may be constructed in which all the waste of rivet heads and overlaps is avoided.

Further than this, as a riveted seam never has above eighty per cent. of solid plate strength, we effect a very large saving by welding, in the possible twenty per cent. reduction of plate thickness,

* Read at the Stated Meeting of the INSTITUTE, Wednesday, Dec. 21, 1887. Being a Summary of the Results of Trials of the Engine on the Lehigh Valley Railroad, made by Mr. E. D. Leavitt; with comments thereon.

or, if we adhere to the same plate thickness, our boiler is twenty-five per cent. stronger than when riveted. By employing the Adamson seam also for the last seam to be riveted of the boiler shell, we are able to say that we have a boiler, every rivet of which may be closed by power, no hand work being required for any rivet of the outer shell. By a suitable design of the various connecting pieces of the furnace parts and outer shell, we shall in all future construction press these parts, which are of irregular form, from single plates instead as we are now doing from four parts, and by so doing will do away with any riveting or welding on these parts, as well as to save a large amount of stock, which is now waste in fitting these parts.

In present designs, there is a greater steam space over the furnaces than in the experimental engine, and the diameter of the boiler barrel has been increased to sixty inches, so affording larger steam space. Means also have been taken to utilize a portion of the waste heat of the exhaust steam to heat up the feed water, branch pipes being taken from the exhaust passages in the cylinder saddles and a portion of the exhaust steam led through a species of injector to combine with the feed supply to the boiler pump. The trials of the experimental engine have demonstrated the fact that, as a material for valves, cast iron is superior to steel, a set of steel valves tried for experiment having proved inferior to cast iron.

Since the reading of a paper on the Strong Locomotive before this INSTITUTE, in February, 1887, extended tests have been made on the Lehigh Valley Railroad, by Mr. E. D. Leavitt, of two locomotives fitted with the Strong valve gear, and of one ordinary locomotive. These engines were Nos. 357, 383 and 444. No. 357 was of the ordinary type; No. 383 had the Strong valve gear; No. 444 had both the Strong gear and the Strong boiler.

Engine No. 383 has an ordinary straight-top boiler, with fire box over instead of between the frames, and anthracite coal grates. Engine No. 357 has an ordinary boiler, similar to that on engine No. 383, but with a "wagon top" of eight inches, and the link motion, with plain slide valves having DeLancey's balancing device.

Annexed are the leading particulars of the three locomotives!

It will not here be necessary to detail the manner in which the tests were made. It is sufficient to remark that coal weights and water measurements were made with all the care and accuracy

customary in engine tests, and indicator diagrams were carefully taken with the Tabor indicator, and proper notes made of steam pressure and speeds, so as to insure the accuracy of the results obtained. In estimating the amount of steam consumed per indicated horse-power, as shown by the diagrams, the gross amount was first computed from the pressure in the cylinder, just before the opening of the exhaust valve. From this was subtracted the amount of steam remaining in the cylinder when the exhaust port closed. In each case, the volume of the clearances was taken into the calculation, and the result shows the net amount of steam consumed. To this, of course, it is necessary to add a certain percentage for cylinder condensation, in order to arrive at an approximately correct estimate of the water consumption per horse-power, which, of course, cannot be obtained from direct measurement of the cards. As, however, the percentage to be added cannot, in any case, vary appreciably in any of the engines from the same amount, we may take the card measurements of dry steam as representing pretty accurately the relative consumption of the various engines. Comparing on this basis No. 383 and No. 357, we find that an average of six cards from No. 383 show a consumption of 22.34 pounds per horse-power, and that a similar average from engine No. 357 shows 26.73 from five cards. The horse-power shown by these cards is for No. 383, 540.8, and for No. 357 is 380.2, the larger power showing considerably less water consumption. An examination of the cards shows that the link motion of engine 357, though of the best design, has the fault common to all link gears, namely, over-compression. From this the Strong gear is free, and the compression line in the cards of No. 383 show a marked difference from those of No. 357, especially, of course, at the earlier grades of cut-off. This reduction in compression greatly increases the area of the cards, and may have several results. First, it admits of earlier cut-off, and so saves steam for equal power developed. Secondly, for same point of cut-off it increases the mean effective pressure, and therewith the tractive power of the engine, so allowing of a heavier train at same speed, or of a higher speed. Generally it increases the efficiency of the engine as a motive-power, it enlarges the range of power, and increases the tractive force at high speeds per ton of weight.

It is true that by compressing the residual steam in a cylinder, we may render an engine more economical, but to this economical compression there is a limit, especially in locomotives. In a stationary engine, specially designed for certain work, we may fix our compression and proportion our cylinder accordingly, but in a locomotive which is required to work with fair economy through a very wide range of power, the conditions are very different, and in any case the great amount of compression given by the link motion at the earlier grades is unnecessary and harmful.

The cards from No. 383 show quite enough rounding of the lower corner of the diagram and compare most favorably with those from No. 357. It is equally noticeable that the cards from No. 383 show a much closer approach of the initial steam line to the boiler pressure than do those of No. 357, and the steam line is better maintained up to the point of cut-off, thus proving the great superiority of the Strong gear all round. This higher initial pressure is due to the great length of port opening given by the multiported or grid-iron form of valve, and the more defined cut-off is due to the peculiar arrangement of the rockers which actuate the valves and give a very rapid opening and closing of the ports. The final result is a card of large area and therefore a high mean effective pressure, which cannot be obtained with over-compression, and it is plainly visible from the cards 7 and 11, how, with a much earlier cut-off, a very much greater power is developed from No. 383 than from No. 357. All the cards shown were taken on up grades; the maximum being ninety-six feet per mile, between Sugar Notch and Fairview going south, and sixty-nine feet per mile going north between White Haven and Glen Summit. Though usual on the north trip to have a helper, none was allowed during the tests, so that the performance of each engine was accurately gauged. Each engine was made to run its best between the two points, hence the time spent by each upon this run may be taken as a good index of its capacity.

Taking the two fastest runs of Nos. 383 and 357 between Sugar Notch and Fairview, namely those on the 9th and 10th of May, the mean initial pressure of nineteen sets of diagrams is as follows:

No. 383, May 10th, mean boiler pressure, 159 pounds; No. 357, May 9th, mean boiler pressure, 151 pounds. These figures multiplied

by the tractive force per pound give for No. 383, $159 \times 131.3 = 20877$, and for No. 357, $151 \times 149.1 = 22514$, as the relative powers of the two locomotives. In other words, No. 357 should be 7.8 per cent. better than No. 383. Actually, however, No. 357 was 9.4 per cent. slower than No. 383. From this we can only draw the inference that the superior valve gear of 383 was nearly twenty per cent. more efficient than the link gear of 357. With boilers so nearly similar, the tests showed that the water consumption of 383 was 20.3 per cent. less than that of 357, and as the train loads were the same for each engine, it is clear that the superior form of the diagram from the Strong gear is to be credited with the difference.

The tests further developed the fact that No. 444 consumed very much less coal than either of the other engines, and this clearly indicates the superiority of the Strong boiler. The engineer of No. 444 kept the throttle partially closed, being generally rather nervous and unacquainted with the engine, and hence the water consumption was greater than it should have been. Notwithstanding this drawback, the work was done with 23.7 per cent. less coal than used by No. 357, and 8.7 per cent. less than that used by No. 383. Now, the cards from No. 383 are superior to those of No. 444, owing to the foregoing facts, and further to the fact that the blast nozzle of No. 444 was much too small and caused a heavy back pressure. It may then be fairly reasoned that, though No. 444 consumed more water than No. 383, she used less coal as a result of the new type of boiler.

In engines now constructing, we shall obtain cards fully equal or even superior to those of No. 383, and a boiler which will show an efficiency far superior to that of the ordinary type.

There is no reason whatever why the Strong boiler should be expensive to construct, for in place of the multitude of screwed stays and the riveted rectangular box with massive roof-bar stays, we substitute machine-made furnaces and combustion chamber, and abolish at a stroke all fire-box stays with their attendant labor and cost of repairs and maintenance. Our boiler has in fact the fewest possible number of parts, all formed by machinery and power riveted. Such a structure cannot but be stronger and cheaper than the old type of boiler which has such large surfaces exposed to transverse stress, for which thin plates are so unsuited, and hence

require the aid of screwed stays to resist by tension the steam pressure, which cannot possibly be carried by flat, unsupported plates.

The modern necessity for high pressures calls for some different form to resist such pressures than the rectangular stayed box, which contains within itself the elements of destruction, from the unequal expansion of parts heated to different degrees of temperature.

With acquired experience and in the light of modern methods of work and with modern materials and tools, it is time to depart from methods and types which were the best possible thirty years ago, when the locomotive was not developed to its present state of efficiency.

This thirty-years'-old practice we have been following until to-day. Without in any way reflecting upon the qualities of a machine which met the requirements of a generation back, in respect to speed and cheapness, it may be said that the time has arrived to make a fresh departure to meet present-day demands. We have now at our command the newer material, steel, which, whether forged or cast, is better than wrought iron for boilers, wheels, and moving parts generally. By the use of powerful hydraulic presses, steel plates of large size may be pressed into almost any form, and thus we can construct boilers well and cheaply, and containing few parts, few rivets or stays.

We have carefully worked out our locomotive and determined upon our standards for different classes of work, designing these standards so as to employ the greatest number of interchangeable parts, and each class is specially designed for its work with such proportion of parts and ratios of expansion, wheel diameter, piston speeds, etc., as experience and investigation have shown us to be suitable and economical. With these proportions once determined, and a sufficient number of standard types settled, it is a simple matter to manufacture locomotives of any class cheaply and well by the modern method of work. To-day, more than ever, are special tools employed in special work, machines designed for accurately and rapidly finishing any detail which, as it comes from the tool, is ready for the erector.

To follow out this system with our locomotive, we should employ a special machine for boring and facing up the cylinders, which,

with two settings, would not only do this, but also mill the frame recesses and bore out the valve-seat chambers, and generally leave the cylinder complete for its position in the locomotive. In a similar manner, at one setting, we may finish the frames, and generally, by a free use of the milling tool, drop press and steel castings, cheapen the cost of production very considerably. Indeed, the improvements in the manufacture of steel, both cast and wrought, have opened up a very wide field to the machinist and rendered possible methods of work hitherto out of reach.

The revolution in marine practice, effected by the introduction of the corrugated furnace, has not been greater than it will effect in locomotive practice, where the use of high pressure first commenced. Formerly very far behind, marine boiler pressure is now ahead of locomotive practice, which has remained practically stationary, but there is no reason why an advance should not now be made.

It has been shown by the tests made, that a horse-power may be obtained from 21.33 pounds of dry steam, and an evaporation of 8.56 pounds of water per pound of coal has been also shown from a feed temperature of only 64° to a pressure of 170. By means of the arrangement for heating the feed by a portion of the exhaust steam, an evaporation of 9.84 pounds from feed at 212° should be secured. Now with an evaporation of 9.84 and a pressure of 175 dry steam and as we have shown that a horse-power can be had for 21.33 pounds of dry steam or water evaporated into dry steam, which was found by actual measurement of the water used and not calculated from the card, we may safely count on a horse-power from $21.33 \div 9.84 = 2.16$ pounds of good coal per hour, as it has been shown by these tests that the re-evaporation takes up all the losses from cylinder condensation as accounted for by the card, and our water by measurement and by the card do not differ.

No. 444, when run on the Northern Pacific Railroad by an engineer who kept a fairly open throttle, developed at high speed over 1,800 horse-power, or over one horse-power from a square foot of heating surface, or thirty horse-power per foot of grate and a horse-power per every seventy-five pounds weight. She has boiler-power sufficient to hold out at this high speed indefinitely, and could do the same with a heavier train with a larger blast nozzle. No. 357 could probably not show higher than 764 horse-

power, which would make her weight per horse-power 118 pounds, and show only nineteen horse-power per foot of grate. No. 444, therefore, though with a large grate, shows a still larger power per foot of grate, which proves that the principle of the boiler with the extended combustion chamber is good. No. 383 also, though heavier per foot of grate than 357, owing to heavier general build, developed a horse-power for each 112 pounds weight and twenty-three horse-power per foot of grate surface, and this plainly shows the superiority of the Strong valve gear.

The complication of balanced valves and the difficulty in keeping them in order and tight has prevented their introduction, and we recently heard of a case where the steam consumption of the balanced valve was ten per cent. above that of unbalanced valve engines. With the Strong quadruple valves, all the advantages of balancing are secured without its complications, for, by the peculiarity of the motion given by the rocker gear, it is so secured that when the load on the valves is greatest, they are mostly at rest, and when they are moving, the compression coming beneath the steam valves so relieves them of load that they are to a large extent balanced, whilst similarly when the turn comes for the exhaust valves to move, they are exposed only to the pressure from the expanded steam. The fact that in actual work the wear of the valves is found to be almost *nil*, confirms these views and shows that the grid-iron form of valve, long successfully employed in stationary practice, has been wisely chosen, and that the use of four separate valves, each moving when needed, is better than one large valve, which is constantly on the move and with which a proper steam distribution is impossible. The question of balancing has thus been very satisfactorily settled.

The engravings herewith show clearly the various details of the boiler and valve gear, and the form of the indicator cards obtained from the different engines tested