CERTAIN POINTS IN THE DEVELOPMENT AND PRACTICE
OF
MODERN AMERICAN LOCOMOTIVE ENGINEERING.

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[Continued from Vol. ciii, page 315.]

The resistance of the atmosphere also varies as the square of the speed. The train displaces a volume of air somewhat wider than the cars, which it carries along with it, and which causes an additional resistance by its friction against the surface of the ground.

The following are the directions and velocities of the wind during the three days on which data were taken, which I have obtained from the U. S. weather signal office in Boston.

Record of Wind.—Wednesday, March 15: general direction, W.; velocity, at 11:30 A. M., 36, at 12:35 P. M., 48 miles per hour.

Thursday, March 16: direction, veered to E., at 9:40 A. M.; velocity at 11 A. M., at Boston, 20 miles per hour. Thursday night at midnight, 30 miles per hour.

Friday, March 17: direction, wind continued E. till Friday noon; velocity, at 11 A. M., the maximum, 24 miles per hour, when the direction changed to N. E., and at 12:43 P. M., to N. W.

The formula employed by the U. S. signal service, by which to calculate the pressure of the wind from its velocity, is one used by Col. Henry James, R. E. F. R. S., and derived from a *Meteorological Paper of the British Board of Trade*,¹ in which the pressure per square foot, $P = v^2 \times .005$.

On this day the wind was almost dead against the train, and if we take its velocity at 36 miles per hour, the resistance due to this cause, calculated by this formula, was 6.48 lbs. per sq. ft., while that due to the velocity of the train itself, which was 30 miles, was 4.5 lbs. If we take the front exposed to this pressure at 13 feet in height and 9 in width we should have for the total atmospheric resistance, 10.98×117 sq. ft. = 1285 lbs.

¹ Third No., page 99. See also a table calculated by same formula in Alex. Buchans' "Handy Book of Meteorology," and Loomis' "Meteorology."

The resistance of the atmosphere, wind, and of curves under one mile radius, are usually taken together and allowed for in the formula. Mr. Zerah Colburn, in "Locomotive Engineering," estimates that these increase the resistance one-half, or 50 per cent. Applying this correction to our resistance of 2296 lbs. previously found, we find for the total resistance, constantly overcome by this engine, reduced to the rail, 3444 lbs. If we add instead, our calculated atmospheric resistance, we get $2296 + 1285 = 3581$ lbs., which agrees pretty well with the above rule. But we have calculated that the tractive force, here, was 5671 lbs., and if we take the velocity of the wind at 48 miles per hour, instead of 36, we have the corresponding resistance, 1872 lbs., and the total resistance 4168 lbs., leaving 1503 lbs. unbalanced force for other resistances which must have existed as we have seen before, if the train was at a uniform velocity. This can be easily explained, for if the wind was ever so little upon one side of the train, a greatly increased area would be presented, upon which it would act.

The Efficiency of the Engine or Mechanism can now be found. The efficiency of the engine or mechanism

$$= \frac{\text{Useful work}}{\text{Useful work} + \text{the lost work}},$$
 or, it is the ratio of the useful resistance overcome, to the total energy of the fluid on the piston. It is the product of the efficiencies of the pieces which transmit the power, and if the discussion of these parts of the engine had been taken up, it might be so found, by reducing the resistance overcome by each, to the driving point, or piston, by means of the principle of virtual velocities.

The formula for the efficiency of the mechanism as a whole, was originally proposed by the Count de Pambour, and is given by Rankine as follows:—

$$e = \frac{R_1 \text{ (Useful load)}}{R \text{ (Total resistance reduced to piston)}}$$

$$= \frac{R_1}{(1+f) R_1 + R_0} = \frac{1}{1+f + \frac{R_0}{R_1}}.$$

The total resistance R , consists

of a constant part, R_0 , which is the resistance unloaded, and a part increasing as the useful load, R_1 . Now, the unloaded resistance, R_0 , in the best engines, is, on an average, 1 lb. per square inch of piston,

or $R_0 = 1 \text{ lb.} \times A \times 2 = 1 \times 201 \text{ sq. in.} \times 2 = 402 \text{ lbs.}$ upon the two pistons. The value of the coefficient, f , the Count de Pambour takes at $\frac{1}{7} = .143$. Now, if we take the resistance overcome in moving the train at 30 miles an hour, as the useful load, or

$$R_1 = T = \frac{4 p A S}{\pi D} = 3444 \text{ lbs. and reduce it to the piston, we}$$

$$\text{obtain } 2 p A = \frac{R_1 \times \pi D}{2 S} = \frac{3444 \times 16.36}{4} = 11,585.9 \text{ lbs., and}$$

$$\frac{R_0}{R_1} = \frac{2 A}{2 p A} = \frac{402}{11,585.9} = .0347. \text{ The efficiency of the mechanism}$$

$$\text{is accordingly, } \frac{R_1}{R} = \frac{1}{1.143 + .0347} = .85 \text{ or } 85\frac{1}{2} \text{ per cent. But}$$

this appears to be too high. From the speed and pressure given, the tractive power of 5671 lbs. which we found, must have balanced the resistances, and not have exceeded them, as the condition of uniform speed. Hence, if we take the resistance at 5671 lbs., at the circumference of the driving wheels, in the same manner as above, we find the effective pressure upon the pistons to be 23,194 lbs., the effective energy exerted per revolution, 92,778 ft. lbs., and the efficiency, 80 per cent.

But we may calculate it by yet another method. The tractive power exerted was 5671 lbs., the power consumed in overcoming the machinery friction, reduced to the rail, we have found to be 714 lbs.

The efficiency of the mechanism is therefore, $\frac{5671 - 714}{5671}$, which gives 87 per cent.

In completing what I have had to say upon certain points in locomotive engineering, I have endeavored to present, not a finished essay upon the subject, but, perhaps, the less interesting results only, of the study and time devoted to it. Nothing has been said upon those important branches of locomotive engineering,—the permanent way, railway plant, watering stations, and shops, surveys and location of road, bed and ballasting, masonry, tunneling, the superstructure, rolling stock, or railway management. Nor upon the construction of locomotives in the workshop, and their draughting. Taking simply a single example of the finished product of our New England loco-

¹ From experiments by Mr. Wm. More and others, as stated by Rankine, the friction of the pistons alone was estimated at one-tenth the effective pressure, or 10 per cent.—“Mach. and Millwork,” pp. 399 and 406.

motive establishments, I desired to apply to it some of the principles which we have been studying during our four years' course.

What I have been able to take up seems to me only suggestive. The subject is capable of indefinite development; it is inexhaustible.

To review, we have found the efficiency of the apparatus by which a portion of the energy in the coal is transferred to the working fluid; next the efficiency of this fluid has been ascertained; and finally, the efficiency of the mechanism, by which a portion of the energy utilized in the latter, has been finally given out as useful work, at the circumference of the wheels. The absolute efficiency of the locomotive is therefore the product of the three factors found, and is as follows:

1. Efficiency of Furnace and Boiler, 557.
2. Efficiency of Steam, 71.
3. Efficiency of the Engine or Mechanism, 800.

Efficiency of the Locomotive engine, $.557 \times .71 \times .8 = .316$, or *three and two-tenths per cent.* Of the power in the coal, *ninety-six and eight-tenths per cent.* is lost. Of the 10,316,236 foot pounds of work in each pound of coal, but 339,120 are utilized. For every ton of coal, costing \$6.00 per ton, $19\frac{2}{10}$ cents are usefully invested, and $\$5.80\frac{8}{10}$, ineffectually applied. Of this, however, the greater portion, perhaps nearly 70 per cent.,¹ is lost by reason of natural conditions beyond our control.

The projects by which the locomotive engine is to be improved, by this remaining 20 or 30 per cent., relate to nearly all its parts. The boiler is an extremely wasteful piece of apparatus; its efficiency will be increased as the difference between the limits of temperature employed for the working fluid is greater, and hence when high pressures can be used, such as 200 or 400 lbs. to the square inch, and which depends in turn upon the introduction of seamless steel or welded boilers, or when means for condensation or for utilizing pressure below that of the atmosphere shall be rendered practicable, and when fuel shall have become more expensive, doubtless, eventually, other means will be employed for the production of power.

The defect in the use of steam seems to be radical. But a small proportion of the heat absorbed by it can be utilized. Although its use may sometime be abandoned, and the theoretic superiority of air,

¹ Art. "Losses of Power in the Steam Engine," *Scientific American*, Jan. 11, 1873.

as the absorbing and transmitting fluid can be easily shown,¹ and engines for its use have already been constructed, their complexity, and the other difficulties that stand in the way of their construction have as yet prevented them from exhibiting any superiority to the steam engine in its usual form.

In the mechanism it seems as if the limit of improvement had nearly been reached. The beauty and simplicity of the Stevenson link motion, the crank and its connections, leave nothing to be desired. The various forms of rotary engines have all disappeared before it. It is not to be doubted, however, that the action of the ordinary slide valves is imperfect, and here improvements, such as the "central exhaust," are from time to time being made.

The advantages or disadvantages of using superheated steam, or jacketing the cylinder with live steam, have been briefly considered in the part on steam.

Outside of these questions lies that of gauge. It has been affirmed that the expense of locomotive power and permanent way has been found to vary nearly as the gauge. In regard to this much disputed question, it has been my intention to work out further data, similar to those which have been given, for comparison, from one of the most successful of the narrow gauge roads—the Boston, Revere Beach and Lynn Railroad.

There can be good reasons given for altering nearly every detail for improvement in the locomotive engine, in directly opposite ways, and the excess of advantage of one over the other will determine in which direction the improvement shall lie.

To quote again from Professor Thurston, on this topic: "The direction of improvement has been marked by a continual increase of steam pressure, greater expansion, provision for obtaining dry steam, high piston speed," and "careful protection against loss of heat by conduction or radiation." To store the energy wasted by the brake, and to dispense with the present necessity of dragging a heavy tender weighing nineteen or twenty tons, would be steps in improvement relating to the locomotive as a whole. It would be to more effectually apply whatever power is already obtained in its final form.

There seems to be little inducement to perfect and economize in the operation of the locomotive at the present time, on account of

¹ Bourne's Treatise.

the indifference of those most concerned in regard to its practical efficiency. The value of making locomotive tests has, until now, been apparently little appreciated. Where the supply of motive power is unlimited, there is no practical value in a test whereby the possibility of a reduction in the amount of power required to do the same work may be indicated. If there was at Lowell more water power than could be possibly used, it is not likely that such care would have been bestowed and expense incurred, by the mill corporations, in accurately testing the water power and turbines there employed.

But with the locomotive engine, coal is not only a large item in the expense of railroads, but it also occupies space and consumes power in its transportation, and involves the expense of labor in applying it to its use. On railroads every shovelful, after it is landed in the coal sheds, is usually handled over from two to four times. Hence arises the practical value of tests by which the actual economy or wastefulness of the engine is indicated, and the direction in which to look for further economy and reduction in the necessary amount of coal pointed out.

Let us for a moment consider what should constitute such a test. A kind of test that has been at times employed for locomotives, has been to ascertain the number of cars, of known weight, that a given locomotive will haul up a certain grade or around a given curve, the speed being ascertained by noting the time occupied by the train in going a certain distance. But this really tells only the gross power of the engine, and does not inform us at all of how this power is distributed in the engine, what parts are efficiently working, and what not. A real test would be one carried on while the engine is doing its regular work, such as, for instance, carrying a train of a certain weight from Boston to Portsmouth and return. Let all the instruments of precision used for making tests—weighing scales, measuring scales, for the coal and water; a standard clock or watch for the time, a bell to indicate the time for the simultaneous taking of observations, the barometer, thermometers and pyrometers for the indication of temperature in the boiler, steam dome, steam pipes, steam chest, cylinders, tank, furnace and smoke box, the elegant recording steam gauge for the pressure, the friction brake, the dynamometer, the speed recorder or the counter, and the indicator—be employed, that are practicable in the limited space available by the construction of the locomotive. Let posts of observation for the

reading of these instruments be established at the points indicated—at the cylinders, in the cab, tender, and on the train—and complete logs kept of all the circumstances relating to the engine, without regard to their apparent irrelevancy to the subject, for it is owing to insufficient data that many records now obtained are rendered nearly valueless. And, finally, let the refined methods of physical science be applied to the data for the corrections; analyses made for the combustible matter in the coal, and especially the amount of moisture, the instruments re-tested, their errors ascertained and corrections applied.

From the data obtained at such a test, the details of which I might elaborate to a much greater extent, but the nature of which is sufficiently indicated in the outline above, when worked out and compared, we should obtain such a knowledge of the deficiencies in the locomotive as to show at once in what direction to look for further improvement and economy. It would place locomotive engineering upon a level with that of the other branches of mechanical engineering, and be of general scientific service besides. For it is only the exact facts that scientists and theorists require, in order to obtain a new insight into the working of the physical laws by which all our machines are governed, and produce results to which practice alone would never attain.

I cannot conclude with a more important observation than that of the real need of strict, accurate scientific tests. When such tests are made upon locomotives as that made in Jan., 1876, upon the pumping engine for the Providence Water Works, locomotive practice will not remain stationary, and locomotive engineering science will progress, ensuring results of practical benefit to all.

Cutting Cast Iron Tubes of Large Calibre.—An apparatus for this purpose, invented by Reishauer and Bluntschli, of Zurich, is described in the *Schweizerisches Gewerbeblatt* for 1876, p. 130. It is constructed of three cutting wheels, resting in stirrups which are pressed upon the tube by a connecting vice-screw. A cutting iron, between two of the cutting wheels, is pressed against the tube by a second screw, and the whole apparatus is turned around the tube by hand.—*Ding. Polyt. Jour.*, 223, 4. C.