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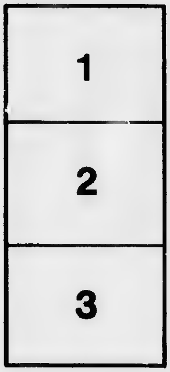

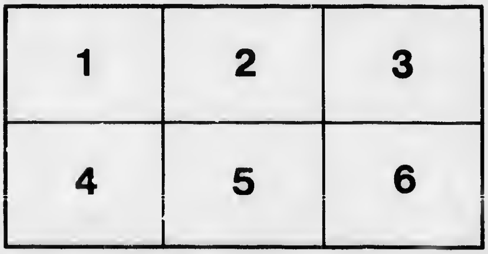

NOTE.—This paper will come up for discussion at the meeting on October 22nd. You are respectfully requested to contribute.

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Canadian Society of Civil Engineers.

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THE STEAM ENGINE.

BY W. H. LAURIE, M. CAN. SOC. C. E.

To be read on Thursday, October 8th, 1891.

In tracing up the history of the steam engine, considered as a train of mechanism, we find that the modern steam engine has been fully developed within the last 200 years—or since the year 1690. and its advance during that time, may be divided into four stages, or periods of 50 years each.

1690—FIRST STAGE OR PERIOD—1740.

As a rule the great majority of inventions when first introduced to the public are more or less complicated and cumbersome, the object of subsequent improvements being to simplify and reduce the number of parts. To this rule the steam engine forms a striking contrast, it having been first introduced in its simplest form, each consecutive stage in its history being marked by an increase in the number of its parts and in the complication of its construction, and a corresponding reduction in the consumption of steam per horse power.

About the year 1690, Denys Papin invented the first steam engine, or rather steam cylinder with a piston. When first introduced, the cylinder performed the functions of steam boiler, steam cylinder, and condenser. It was operated as follows:—A small quantity of water was placed at the bottom of cylinder, a fire built beneath it, the steam formed raising the piston to the top of cylinder, where a latch engaged a notch in the piston-rod holding it up until it was desired that it should drop.

The fire being removed. the steam condensed forming a vacuum below the piston, the latch being disengaged the piston was driven down by the pressure of the atmosphere, raising a weight which had been in the mean time attached to a rope from the piston rod over pulleys. This machine made *one stroke* per minute. The inventor calculated that a 24" cylinder would raise 8,000 lbs., four feet, per minute, or develope nearly one horse power.

A few years after his first invention Papin made another important invention which increased the efficiency of his engine by using a seperate steam generator, as described at the time, a kind of fire box steam boiler, in which the fire, completely surrounded by water, made steam so rapidly that his engine could be driven at the rate of four strokes per minute by the steam supplied from it.

The Papin engine was further improved and developed by Newcomen, Beighton & Smeaton, producing a combination of several of the elementary parts of the modern engine, making it capable of transmitting force directly to the resistance to be overcome, the object being to make it better adapted to pumping mines, &c., the piston being connected to the pump by means of the overhead beam.

During the first period of development the steam engine was used almost entirely as a pumping machine, and might more properly be considered an atmospheric engine, as steam was used only to produce a vacuum, the power being supplied by the pressure of the atmosphere and that on one side of piston only.

1740—Second Period—1790.

The second stage or period in the development of the steam engine may be considered entirely as the work of James Watt (that stage being marked by more rapid development than any other). He, among many other important inventions and improvements, added to the engine of the first period, the separate condenser, air-pump, fly-ball governor, crosshead, guides, parallel-motion, rotary-motion, double-action, and non-condensing, high-pressure steam engine. With these additions completed, it embodied nearly all of the essential features of the modern engine. He also discovered the advantages to be derived from the use of steam expansively, and specified a cut-off at ¼ stroke as the most ecomomical. This discovery has proved to be most important in the development of the economical application of steam. although shortly after its first introduction, it had to be discontinued, owing to the trouble and annoyance Watt experienced with proprietors and their engineers altering the valves. He intended to resume it at a later period when workmen of greater intelligence and reliability could be found.

1790—Third Period—1840.

The distinguishing feature of the third period was the introducing of the compound, or two-cylinder engine. Although the first compound engine was invented in 1781, by Jonathan Hornblower, it was not a success, owing to the steam pressure used at that time being so low that no advantage was gained by the device.

In 1804 the Hornblower compound engine was again introduced by Arthur Woolf, and, by using steam at a higher pressure, and expanding it from six to nine volumes, a very great advantage was gained over the Watt and other engines of that time. Other engineers followed in Woolf's footsteps, designing modifications of the compound engine, so that by the end of the third period which we have considered, the compound had become a standard engine.

1840—Fourth Period—1890.

The most important features in the development of the economical use of steam during the fourth period, or that of the immediate past, has been the invention and introduction of the automatic engine, and the system of expansion (in two cylinders during the former period) being carried to three or four cylinders.

The first automatic engine was invented by George H. Corliss, about the year 1850. An adjustable drop cut-off had been invented ten years earlier by F. E. Sickels, but Corliss was the first to attach the governor directly to the cut-off mechanism, and, by so doing, regulate the speed of the engine by adjusting the point of cut off, and also using steam in the cylinder at nearly boiler pressure up to that point.

To form an idea of the advantages of modern steam practise as compared with that of the earlier stages of its use, and to note the advance made during the four different stages that we have considered, we will have to assume an average indicator card from each period from the information we have, and, by analizing each, form a comparison.

For that purpose we will assume a steam cylinder of 13⅝" diameter, or a net area of 144 square inches in each, and for the first period a guage pressure of 1 lb. or 16 lbs absolute—i.e.

CARD No. 1.

Allowing 1 lb. to raise weight of piston, rod, etc., and that a vacuum be produced equal to a M. E. P. of 7 lbs. below the atmospheric line, and allowing a piston travel of 100 feet per minute, the power developed will be 144 × 100 × 7 = 100,800 ÷ 33000 = 3·05 horse power, and the theoretical consumption of steam will be 100 cubic feet per minute or 6,000 cubic feet per hour, and as steam at 16 lbs. absolute weighs ·0411 per cubic foot, then 6000 × ·0411 = 246·6 lbs. of steam per hour, and as we have found that the power developed will be 3·05 H. P. then 246·6 ÷ 3·05 = 80·85 lbs. of steam per hour per H. P. as the consumption for the first period.

For the second period with same cylinder area we will assume 200 feet of piston travel. (Steam at this period was used above atmospheric pressure, and double acting.)

CARD No. 2.

For this card we will assume a steam pressure of 15 lbs. and a terminal of 26 lbs. absolute, a M. E. P. of 22·4 lbs., the power developed will be 144 × 22·4 × 200 ÷ 33000 = 19·5 H. P. and the amount of steam consumed will be 200 cubic feet per minute or 12,000 cubic feet per hour and as steam at the terminal pressure, viz.: 26 absolute, weighs ·0650 per cubic foot then 12000 × ·0650 = 780 lbs. per hour, this divided by 19·5 = 40 lbs. of water per hour per H. P. for the second period, or about one-half of that required to develop a horse power 50 years earlier.

For the third period a still higher steam pressure was used, and expansion carried to 6 and 9 volumes.

CARD No 3.

For this card we will assume, same cylinder area, 400 feet piston travel 40 lbs. steam pressure expanded 7½ volumes and a M. E. P. of 16 lbs., the power developed will be 144 × 400 × 16 ÷ 33000 = 27·93 H. P. and the steam consumption measured from terminal of 9 lbs. will be 400 × 60 = 24000 × ·0239 ÷ 27·93 = 20·5 lbs. of steam per hour per horse power, or about one-half of the cost of same power during second period and one-fourth of cost of same power during first period.

For the fourth and last period of steam engine practice we have in many instances a steam pressure of 200 lbs., also cylinder steam jacketed with superheated steam, and other refinements that tend to reduce steam consumption.

CARD No. 4.

For this period we will assume a steam pressure of 150 lbs., expanded 20 volumes, a M. E. P. of 31 lbs. referred to same cylinder area as in other cards, viz. 144 inches and a piston travel of 800 ft., this will develope 108 horse power, and the steam consumption will be abcut 10 lbs. per hour per horse power.

In reviewing these four periods we have in the first, steam used at a little over atmosphere pressure, without expansion, a piston travel of 100 ft. per minute, a power developed of 3.05 H. P., at a cost of 80 lbs. of steam per hour per H. P.

In the second period we have steam at 15 lbs. above atmosphere, without expansion, a piston travel of 200 ft. per minute, a power developed of 19·5 H. P., with a steam consumption of 40 lbs. per hour per H. P.

In the third period, we have steam at 40 lbs. above atmosphere, expanded to 7½ volumes, a piston travel of 400 ft a minute, a power developed of 27·93 H. P., with a steam comsumption of 20 lbs. per hour per H. P.

And in the fourth period we have steam at a pressure of 150 lbs. above atmosphere, expanded to 20 volumes, a piston travel of 800 ft. per minute and a power developed of 108 H.P., with a a steam consumption of 10 lbs. per hour per horse power.

Cyl. Area.	Piston tr'vel.	Steam P.	Power.	Theoretical Consumption
1st....144	100	1	3·05	80 lbs.
2nd... "	200	15	19·5	40 "
3rd ... "	400	40	28·0	20 "
4th.... "	800	150	108.0	10 "

From these figures we find that the tendency through all the different periods, has been increased steam pressure, and higher ratio of expansion or high initial and low terminal, *i.e.*, theoretically the higher the initial and the lower the terminal, the greater the economy. But practice has established it to be a fact that the higher the initial and the lower the terminal, or the greater the ratio of expansion in a *single cylinder*, the greater the loss both by *clearance* and *condensation.*

Clearance is the space between the piston and valve face when an engine is on its centre (including area of ports, passages, etc.) which has to be filled with steam each stroke before the piston moves forward, and is computed by the percentage its volume bears to the area of piston multiplied by the length of its stroke. This percentage varies from 2 p.c. in long stroke engines to 15 and even 20 p.c. in short stroke engines.

The loss by clearance is quite a serious one where expansion is carried to extremes in a single cylinder and also in short stroke engines, where it forms a high percentage of the volume of cylinder.

If we take as an illustration a condensing engine card, with steam pressure 80 lbs., expanded 20 volumes without loss by clearance, we get a mean effective pressure of 15 lbs.

Card No. 5.

Then expand the same volume of steam in a cylinder of same area, but with 5 per cent. clearance, we find that the card shows the steam to have been cut off at the time the engine was on its centre; we get the same expansion line and same terminal, but the area is minus the initial pressure, or a mean average pressure of 10.5 lbs. instead of 15 lbs., as in the first instance, representing a loss of 30 per cent. in power.

Then, again, if the same pressure, viz., 80 lbs.. be expanded 10 volumes, the loss is reduced to 16.66 per cent.; expanded 5 volumes, the loss is reduced to 9.75 per cent., and if only expanded 3 volumes, the loss is reduced to about 7 per cent.

Therefore the greater the ratio of expansion in a single cylinder the greater the loss by clearance, and the less the expansion in a cylinder the less the percentage of loss by clearance. The loss by clearance may be reduced to a certain extent, but not entirely overcome by compression or cushion.

Condensation.

The loss by condensation is due to the variation in the temperature of steam during expansion. If steam at 80 lbs. gauge pressure, or 95 absolute, be expanded 20 volumes, the initial temperature would be 324 degrees Fahrenheit and the terminal about 160 degrees.

During expansion, as the temperature of the steam falls, the temperature of the metal of the cylinder falls in proportion, so that when the boiler pressure is again admitted to the cylinder it takes a certain proportion of the steam admitted to raise the temperature of the surrounding metal to the initial temperature; the greater the ratio of expansion the greater the variation in temperature in the cylinder, and the greater the proportion of steam required to raise that temperature; the less the expansion in a cylinder the less the variation of temperature, and the less steam will be condensed in raising that temperature each stroke; or the smaller the volume of steam admitted to the cylinder each stroke the greater will the percentage "of loss by condensation" bear to that volume, and, on the other hand, the greater the volume of steam admitted to the cylinder each stroke the less will the percentage "of loss by condensation" bear to that volume.

From experiments carried out these losses have been computed approximately for unjacketed single cylinder engines with low percentage of clearance as follows, viz.:—

Expansions.	Power	Loss.
20	55 p. c.	45 p. c.
10	65 "	35 "
5	75 "	25 "
3	80 "	20 "
2	85 "	15 "

With 5 per cent. added for condensing engines.

Another serious objection to high ratios of expansion in a single cylinder, is the very great variation in the working strains throughout the stroke. For example, if we expand 80 lbs. steam pressure to 20 volumes in a single cylinder Condensing Engine, we have a pressure of 92 lbs. per square inch of piston at the beginning of the stroke, 1.75 lb. at the end of the stroke, and a M. E. P. of 15 lbs., and as the strength of an engine in all its working parts must be in proportion to the greatest pressure to which it is subjected, then the weight of the working parts must be entirely out of proportion to the power actually developed, and the fly wheel especially must be very much heavier than that required in an engine where steam is expanded from 3 to 5 volumes.

The theoretical gain by expansion in a condensing engine is approximately as follows, taking 80 lbs. gauge pressure without expansion as a basis.

Expanded to	20 volumes,	70	per cent.
"	10 "	65	"
"	5 "	60	"
"	3 "	50	"
"	2 "	40	"
"	$1\frac{1}{3}$ "	20	"

To obtain the economical advantages resulting from high ratios of expansion, and at the same time avoid the enormous losses attending its expansion in a single cylinder, is the object of the introduction of the compound, Triple and Quadruple expansion engines. For example, in a compound engine with low pressure cylinder four times the area of high pressure, 16 expansions may be obtained with four expansions in each cylinder. In this way the high pressure cylinder works with steam between limits of temperature, such as occasion comparatively small losses by condensation, and the low pressure cylinder works between the temperature of the exhaust from high pressure and that of the condenser; these temperatures not varying very widely the loss by condensation is correspondingly small. Another great advantage of the compound over that of the single cylinder engine (expanding steam to the same number of volumes), is the better distribution of the work throughout the stroke, admitting of the working parts being made much lighter in proportion to the actual power developed.

It would almost appear as if the economical limit in expansion had been reached, as by our example for the last period, the theoretic consumption for 150 lbs. expanded 20 volumes, was 10 lbs. of water per hour per H. P., whereas, if we raise the pressure to 200 lbs. and expand 30 volumes, the gain is only about 5 per cent.; if raised to 400 lbs. and expanded 40 volumes, the gain is about 20 per cent.; and if to 800 lbs. expanded 40 volumes, about 25 per cent.

But to counteract this apparent gain, we have increased coal consumption in raising the water to the temperature due to the increase of pressure, and also increased losses by condensation in using steam at that temperature.