NOTE RELATING TO THE PROPER METHOD OF EXPANSION OF STEAM AND REGULATION OF THE ENGINE.

By PROF. R. H. THURSTON.

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It has long been well known, to every engineer experienced in the construction and management of the steam engine, that when working under known conditions and at a given pressure of steam, there is a certain ratio of expansion which gives highest efficiency, *i. e.*, least expenditure of fuel in proportion to work done. It has also been long known that the most economical ratio of expansion, all things considered, when studied from the commercial standpoint, is to be determined not simply by studying those conditions which affect the efficiency of the engine, but by consideration of all the elements of cost of steam power, including first cost, interest on capital expended, wear and tear and running expenses for fuel supply and management.

In the design of an engine it thus becomes necessary, if the designer would consult the best interests of the purchaser of the engine, first to determine as best he can what is likely to be the cost of each series of engines of the style proposed and of graded sizes; next must be determined the cost of power in weight of steam used in each of these engines at various pressures and ratios of expansion; finally, by comparison, he must select that engine which at the least ratio of expansion, all things considered, will give the required power.

When the steam pressure and the cost of power in steam consumption are known, it becomes possible to determine the best point of cut-off. But no engineer has yet been able to say with certainty what, in any given case, will be the ratio of expansion giving highest efficiency, or what, at any given rate, will be the probable expenditure of steam or fuel. The writer has endeavored, in an earlier paper,* to show what are the causes of this uncertainty, what determines the most efficient adjustment of expansion, and what, on the whole, have, in his judgment, proved to be the ratios of expansion giving maximum effi-

*"On the Ratio of Expansion at Maximum Efficiency," Trans. Am. Soc. Mech. Engrs., 1881; Journal Frank. Inst., May, 1881.

ciency, and, finally, what efficiency may probably be anticipated in cost of steam and of fuel in good engines, adjusted for maximum efficiency.

When these points are settled the engineer may, by a proper use of the factors, ascertained as above indicated, determine what is the best ratio of expansion to adopt, or rather what is the best size of engine for the case in hand, and what the best type of valve gear and regulating mechanism. The size and kind of engines is therefore determinable from a knowledge of conditions, which are partly physical and incidental to construction, and partly commercial.

The solution of this second and broader problem may be effected either by a tentative process of trial and repeated estimation, or by an approximate, and for some cases—*e. g.*, where cylinder condensation is reduced to a minimum, as in efficiently jacketed or in fast-moving engines, or at low rates of expansion—nearly exact method, first indicated, so far as the writer is aware, by Professor Rankine,* who applies to the case one of those beautiful graphical constructions in the devising of which he was so ingenious and successful.

This method has been studied and has been applied to representative examples in recent practice in steam engineering by Messrs. Wolff & Denton,† who have shown that the commercially profitable grades of expansion are ordinarily restricted to a very narrow range, and always somewhat less than the ratio for maximum efficiency.

Having, then, fixed upon the size of engine and ratio of expansion, it is evident that this ratio of expansion should generally be kept invariable, so long as the steam pressure remains unchanged.

The usual changeable condition with a given engine is the demand for power, and to meet this variation it becomes necessary to adopt some method of regulation. The simplest forms of regulating apparatus usually consist of a “fly-ball” governor set to operate a “throttle-valve” or other kind of regulating valve; the most usual method of regulation with the better class of engines is that adopted by Corliss—the attachment of the governor to the expansion gear in such a manner as to cause a variation of the ratio of expansion, adjusting the point of cut-off to the demand for power. This latter is the most sensitive regulating mechanism yet devised, and where the variation

* Phil. Magazine; Trans. R. S. E.: Theory and Practice of Shipbuilding; Miscellaneous Papers.

† Trans. Am. Soc. Mech. Engr's, 1881; The American Engineer, 1881.

is small is very effective even at low speeds. The writer has counted the revolutions of a Corliss engine making about sixty revolutions per minute, with steam at 90 lbs. by gauge (7 atmospheres), and found a variation of but two revolutions per minute when the whole load was thrown off or on, the minimum being about 35 horse-power (driving shafting) and the maximum about 150.

Since, however, the proper ratio of expansion for the engine when once installed is determined mainly by the steam pressure, and since any variation from that point is usually productive of reduction of efficiency, it would seem that the ratio should be fixed at the best proportion for the steam pressure adopted and never changed. This being the case, the question arises, how shall regulation be effected? The adjustment of a throttle-valve by the governor is inadmissible, as it involves variation of the steam pressure in the steam chest and consequently reduced efficiency; the steam and expansion lines must be permanently fixed for all loads.

It becomes at once evident that any allowable system of regulation must now affect the back pressure or the cushion line. To throttle the exhaust by the action of the governor would undoubtedly give a means of regulation, but a costly one; since any increase of back pressure during the exhaust would involve serious increase in the amount of rejected heat and of waste of power.

It then becomes evident that the only admissible plan is the variation of the net power of the engine by an alteration of the compression line. This is done where one very well known and generally used valve gear is adopted—the Stephenson Link Motion. When the link is down the ratio of expansion is determined by the lap and lead, and is usually not higher than $\frac{1}{3}$; as the link is raised this ratio is increased, and with this change of the steam line occurs a simultaneous alteration of the point of release and of closure of the exhaust passages, resulting in increased compression. This double effect gives the indicator diagram a peculiar modification of form, familiar to engineers who have taken cards from the locomotive or the usual type of marine engine. The smoothness of working of such engines when running with high steam and a raised link has probably been observed by all experienced engineers, and it may not have escaped notice that under such conditions the expenditure of steam is often so low as to indicate some source of economy other than simple change in the ratio of expansion.

The writer, at least, when in charge of naval steam machinery during the war of 1861–5, was led to suspect a gain from this distribution of steam, which could only be attributed to what was considered excessive compression.

His attention has recently been called to this matter again by the interesting results of a series of experiments made upon a large engine fitted with variable expansion gear. The valve motion is so arranged as to permit adjustment of compression without change of either steam, expansion or exhaust lines. The results will be reported in a later paper. It is only necessary here to state that a decided gain is found to follow the adjustment of the compression to a far higher ratio than is indicated as best by the simple geometrical conditions usually studied and generally taken as those determining the proper ratio of compression. This beneficial effect of a high ratio of compression has been attributed by the writer to the action of the compressed fluid in heating the passages and the cylinder head and piston, thus checking to a very great extent that initial cylinder condensation which is the greatest source of avoidable waste in nearly all engines.

It may be asserted that the best compression, where no such transfer of heat occurs, is not far from that which makes the ratios of expansion and compression equal, and the engineer will usually set the exhaust valve to close at the point corresponding to maximum expansion. For the reasons just given, however, and as shown by direct experiment, maximum efficiency is obtained with higher ratios of compression, and what would have been considered excessive cushioning gives less loss than equal variation from the point of cut-off giving maximum efficiency. As compression is increased, the area of the indicator diagram decreases and the work developed in the engine becomes less.

It would seem, then, that we have here an admissible method of regulation and one which should be, on the whole, that best fitted to give high efficiency, since any excess of work of compression results simply in the transfer of heat back to the steam side. The steam engine should, therefore, be worked with a fixed cut-off,* so attaching the governor as to determine the point of closing of the exhaust valve—in other words, making the “cut-off” operate on the exhaust

*The writer has devised methods of automatic readjustment of the ratio of expansion when variations occur in the steam pressure, which methods would in the case here taken replace the usual adjustment by the governor.

side, the ratio of compression being determined by the governor—instead of attaching the cut-off mechanism to the steam valves. Properly constructed relief valves will prevent all danger from the influx of water with the steam, an accident which, however, should never occur where provision is made for securing dry steam. With exhaust ports beneath the cylinder, drainage is rarely imperfect.

In slowly moving pumping engines it has sometimes been found beneficial to extend compression until boiler pressure is exceeded, and the writer has indicator diagrams taken from such engines in which the compression line crosses the steam line before the end of the return stroke has been reached. He has, as probably has every engineer who has been accustomed to handle locomotive or marine engines, often set the link motion so as to give such high ratios of expansion and compression as to reduce the card to a comparatively narrow band, without perceiving the slightest evidence of objectionable loss of smoothness of working and with decidedly improved efficiency. It seems to the writer doubtful whether, in practice, objectionable or "excessive" compression ever occurs in such cases, and the advantages of this method of regulation and of securing a lessened variability in the ratio of expansion would appear to be decided and to be obtainable without meeting with serious difficulties.

The plan is probably not entirely a novel one and may have suggested itself to many engineers independently; but no attempt has previously, so far as the writer is aware, been made to determine its advantages in actual work. The writer indicated this as the proper method of adjusting expansion some years ago,* and has since had it presented to him by other engineers with whom the thought was also original.

Where the plan here suggested cannot be adopted conveniently, maximum economy of steam should be obtained by an expansion gear in which, as in locomotive valve gear, increased expansion is accompanied by increased compression, but without that serious throttling along the steam line which usually characterizes the distribution by the link-motion.

The best among existing forms of valve gear should be, if judged from the standpoint here taken, that which—combining a variable expansion with a variable compression—is also capable of prompt and exact adjustment by a sensitive and efficient governor.

* *History of the Steam Engine*: D. Appleton & Co. (International Series), N. Y., 1878, p. 473, foot note.

The economy to be expected from the suggested change in methods of regulation of the steam engine will evidently be dependent upon the manner of operation of the engine. Where engines have a nearly invariable load, and when they are well adjusted to their work, the advantage would probably be found inappreciable; but in cases in which the engine is much too large for its work or when the demand for power is very irregular, as in rolling mills or in rough weather at sea, and where cylinder condensation occurs to a great extent, the increased efficiency may be found to be very considerable. The gain by decreased internal condensation will, perhaps, often be found to be an item of no small importance.

Hoboken, N. J., June, 1881.

ON THE LAST EXPERIMENT (19TH MARCH, 1881) WITH THE PERKINS MACHINERY OF THE STEAM YACHT "ANTHRACITE."

By Chief-Engineer ISHERWOOD, U. S. Navy.

In the January, February and March numbers of the present year of this journal will be found a description of the Perkins system of steam machinery in the steam yacht *Anthracite*, together with an account of the two experiments which had been made with it to determine its economic efficiency. The first experiment was made in England, with the vessel in free route, by Mr. F. J. Bramwell, an engineering expert employed for that purpose by the "Perkins Engine Company," and the second was made by a Board of Chief-Engineers of the United States Navy with the vessel secured to the dock of the New York Navy Yard.

There being a wide discrepancy between the results of these two experiments, the "Perkins Engine Company," on the return of the *Anthracite* to England, caused Mr. Bramwell to repeat his original experiment; and it is the object of this paper to give the data and results of the repetition—which are substantially the same as those of his original experiment—as a further contribution to a knowledge of what economy may be expected from the employment in a steam engine of steam of exceptionally high pressure used with a correspondingly great measure of expansion.