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GAS ENGINES AND THE DETERMINATION OF  
THEIR COMMERCIAL EFFICIENCY.

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In determining the title of this brief paper, the writer met with considerable difficulty in deciding upon the wording to be adopted, which had necessarily to be short, but at the same time defining the matter to be considered, and he fears that the title ultimately adopted, that is, "Gas Engines and the Determination of Their Commercial Efficiency" does not express quite what was intended. Therefore, before entering upon the actual matter of the paper, he proposed to explain what it is intended to discuss. We here in Australia are at the present time entering upon a new phase in the course of our development, in the introduction and building up of new industries. In place of the continued importation of the foreign manufactured article, and by the word "foreign" is meant all those manufactures from outside Australia, whether British or not, we are beginning to manufacture many of these articles in our own factories. Whilst there are numberless items which for many years to come cannot, and will not be profitably manufactured here, yet there are also very many, which, whilst now imported into the country, could equally well be produced in our own small workshops, and there are some few which could be manufactured here to even better advantage than by importation, in that the article so produced should and would be more fitted to meet some of our own special requirements. In all such industries one of the main items to be considered, and one of first importance, is the determination of the form of prime mover to be adopted to drive the factory machinery. In general work also, such as in engineering repair shops, saw mills, printing establishments, etc., this factor is of equal importance, and whilst in the past, the good, honest old steam engine has been almost exclusively used, either by direct application, or through the medium of electric generator and motor, yet latterly another class of

prime mover has come forward—namely, the gas engine, which, although by no means a new invention, is now making such an extraordinary advancement in successfully carrying out duties formerly borne entirely by the steam engine, that it is now just as essential for the engineer to have a sound knowledge of this machine and its capacities and peculiarities as has been for many years the case with the steam engine and boiler. Gas engines, and for that matter all explosion engines, exact more care in their selection for the work to be done, and in their subsequent operation and development than steam engines. The pressure and temperature conditions in the former are much more severe than in the latter, the necessity for high initial compression of the charge before ignition to ensure low fuel consumption, thereby requiring gas tight pistons and valves; the exact timing of the ignition, the proper setting of valves and valve openings to ensure correct gas and air mixtures; all are points of vital importance. Necessarily, therefore, the likely causes of trouble are more numerous in a gas, than they are in a steam engine, and further, any improper operation or want of care of the former will increase the fuel consumption, and cause a waste in power to a very much greater extent than in the latter, to such an extent indeed as is hardly appreciated by the steam engineer. Unfortunately also, gas engines have been installed here and elsewhere without a proper consideration of the requirements of each case. Sufficient allowance has not been made for the relatively low overload capacity of the gas engine, and totally incorrect figures have frequently been taken for the amount of the steam power previously installed, with the result that in many cases the gas engine has not proved satisfactory, chiefly through an inadequacy of power, and has, as a result, gained an extremely bad name. One comes across the most condemnatory notices and even unfavourable press articles, concerning them. In the majority of cases these are entirely unjustifiable, the bad results instanced being due not to any inherent deficiency in the gas engine, but to an insufficient consideration of the requirements of the case in the first place, and just as frequently to subsequent improper operation arising from



either ignorance or carelessness. The gas engine will not stand the abuse which the ordinary small factory owner is accustomed to deal out to his unfortunate steam engine.

One of the most useful and reliable methods of ensuring the efficient operation of gas engines lies in the periodical testing of the plant, particularly where large units are installed, since by so doing running expenses and maintenance charges may be reduced and maintained at a minimum, and the life and reliability of the machine materially increased. Further than this, such testing frequently provides the most useful information to the factory owner regarding the power absorbed by the different operations in his plant, enabling him to reduce line shafting losses, etc., and affording an excellent criterion as to the relative efficiency of various appliances, all of which is invaluable as plant expansion becomes necessary. Realising, therefore, the importance of the question, and believing that some information concerning the methods adopted in the testing of gas engines might be of interest to members, this paper has been prepared with fairly numerous illustrations, with the assistance of which, after briefly considering the main particulars of gas engine operation, the author will describe the methods and appliances employed in the testing of these machines. He should like it to be clearly understood, however, that he is not in any way attempting to compare the utility and efficiencies of steam and gas engines, but only wishes to put before members a few facts relative to the efficient use of the latter machine, realising that whilst there are numberless cases in which steam plant is better fitted to meet the various requirements, there are probably also just as many others in which, with all due respect to the "confirmed steam user," the gas engine could be installed with more satisfactory results.

The fundamental difference between the gas and steam engine lies in the fact that in the former the combustion of the fuel takes place within the working cylinder, with resultant rise in temperature and pressure, the oxygen necessary for its combustion being led into the cylinder at or about atmospheric pressure; whereas in the steam engine the working fluid is raised to a high pressure and tempera-

ture by the burning of fuel in an external vessel before being delivered into the cylinder to do its work.

Almost all gas engines are comprised within two general classes, one known as the 4-cycle and the other as the 2-cycle. The majority of small engines are of the four cycle type, generally limited to one working cylinder, and doing work in one end of that cylinder only. In such machines, therefore, there is only one working stroke in every two revolutions, that is, in every four strokes made by the piston. In a single-acting single-cylinder two-cycle machine every second stroke is a working stroke, that is, the charge is fired once in every revolution of the crank shaft. Large machines are built just as frequently on the two, as on the four cycle system, sometimes single, sometimes double-acting, and frequently with more than one working cylinder. To fix the two types clearly in your minds before discussing the results obtained by each, the following slides are shown, illustrating a small engine of each of the two types and the typical indicator diagram obtained from each machine.

Plate XXVII., Fig. 1, shows a single-acting gas engine working on the four stroke cycle. In such a machine the charge of air and gas, in correct proportion, is drawn into the cylinder through the upper valve by the forward motion of the piston. During the next following back stroke this charge is compressed, both valves being then closed. Just before the end of this stroke the compressed charge is fired either electrically or otherwise, driving the piston forward on the 3rd stroke; the lower valve, the exhaust valve, is then opened and the burnt gas is expelled from the cylinder during the back motion of the piston on the 4th stroke of the cycle, the operation as described being then repeated.

Plate XXVII., Fig. 2, shows a typical indicator diagram from an engine working on the cycle just described. Starting at the point marked "P", the charge is drawn into the cylinder up to the point "Pa". On the next back stroke it is compressed to the point "Pc" and fired at the end of that stroke, point "Px," expanding and doing work during the next forward stroke to the point "Pe", when the exhaust port is open, and maintained open until the piston

has reached the end of the fourth stroke ready to start the cycle and operate again at the point "P".

Plate XXVII., Fig. 3, shows a small gas engine designed to work on the two stroke cycle. In this engine the piston is shown at the end of its forward stroke, at which point the piston has opened the exhaust port "E" and the inlet port "I," the gases from the previously fired and expanded charge passing out through "E" to the atmosphere, and the incoming charge of gas and air previously compressed on the front side of the piston passing into the cylinder through the port "G". As the fly-wheel carries the piston back, closing the ports "I" and "E", it compresses the charge in the back or working end of the cylinder, and at the same time draws in a fresh supply of air and gas through the valve "A" into the front or pump end of the cylinder. At the end of this back stroke the compressed charge in the working end is fired, driving the piston forward, thereby doing work and also slightly compressing the mixture of gas and air in the front end of the cylinder. Just prior to the end of this forward stroke the edge of the piston passes the opening "E" in the side of the cylinder wall, allowing the burnt gas to pass away into the atmosphere, almost immediately afterwards opening the port "G" and allowing the slightly compressed charge from the pump end of the cylinder to pass into the working end of the cylinder, mixture of the incoming unfired charge and the outgoing burnt gases being prevented by deflectors shown at "G" on the back end of the piston. In such a machine, therefore, a charge is fired on every forward stroke of the piston.

Plate XXVIII., Fig. 1, shows a typical indicator diagram from such a two cycle engine. Starting with the fired charge at the point "Px", the piston moves forward until the point "Pe" is reached, and at which point the exhaust port is opened, allowing the gas to escape into the atmosphere. At the point "Pi", the piston still moving forward, the inlet port is opened, admitting the fresh charge from the front end of the cylinder, and it remains open until the point "Pb" is reached on the back stroke. The exhaust port closing at the point "Pa", the charge is then compressed to the point "Pc" at the end of the back stroke

at which point it is fired and the cycle repeated. The lower diagram shows the pump work done in the front end of the cylinder. At the point "G" this end of the cylinder is full of a mixture of gas and air, the inlet valve automatically closes, and on the forward motion of the piston this charge is compressed to a pressure of from 3 to 4 lbs. to the square inch; when the piston reaches the point "A", the inlet port in the working end of the cylinder is opened, and the compressed charge passes into the working end until the point "B" is reached on the return stroke, from which, until the point "8" is again reached, a further mixture of air and gas is drawn into the front or pump end ready to be compressed.

The main principles involved in the operation of these small machines of each type are maintained in the larger units.

Plate XXVIII., Fig. 2, shows a machine by the Premier Gas Engine Company, in which the auxiliary cylinder for compressing the scavenging charge is fitted above the front working cylinder instead of in line with it, as in their original engines. Before leaving this diagram it will be interesting to note the device installed for water jacketing piston heads and the piston rod, this being essential in all large units.

Plate XXVIII., Fig. 3, shows a cross section through a typical two cylinder tandem double acting four-cycle gas engine. This engine represents practically the high water mark of large four cycle design. The writer shall have occasion to refer to its efficiency later.

Plate XXIX., Fig. 1, shows a three crank six cylinder tandem vertical machine built by the British Westinghouse Company. In these machines each cylinder is single acting, the valves arranged to work vertically as shown.

Plate XXIX., Fig. 2 shows one of the most successful of this type, viz., that designed by Ernst Korting. This machine is built by Korting himself, in Germany, by Mather & Platt and Fraser & Chalmers in Great Britain, and by the De La Vergne Company in the United States. In this machine the working cylinder is double acting, every stroke being a working stroke. The incoming gas and

air are separately compressed in a set of externally fitted tandem pumps, as shown in the lower part of this diagram. In the Mather & Platt type of this machine two air pumps are fitted, both single acting, and one double acting gas pump, the air and gas passing away to the mixing valves at either end of the working cylinder. In these machines, of course, the piston head and piston rod are water-jacketed. The great length of the piston head may be noticed, it being slightly less in length than the working stroke so as to uncover the exhaust ports at the end of each stroke. These ports may be seen at mid length on the working cylinder.

Before coming to the testing of gas engines, it may be of interest to briefly discuss a few essential differences between machines of the four and two cycle types. Each machine has its own strong advocates. In Great Britain the majority of the large makers favour and build the four cycle machine, turning out such well-known engines as the National, Crossley, Tangye, Hornsby, Premier, Campbell, and many others. Messrs. Mather & Platt and Frazer & Chalmers, on the other hand, are builders of two cycle engines of the Korting type, and Wm. Beardmore, those of the Oechelhauser type. It must be remembered, however, that whilst the majority of makers in Great Britain are advocates of the four cycle machines, relatively very few very large gas engine units have been built in England, and it is particularly in these units that the two-cycle machine has been largely advocated. In Germany, the birthplace and home of the large gas engine, opinion is divided as to the merits of the two machines, and great numbers of each type have been built. In America, where the two cycle machine has been largely used in small units, the tandem four-cycle double-acting type has been almost exclusively adopted for large powers, with the exception only of the Korting machine built by the De La Vergne Company.

From a theoretical standpoint the thermal efficiency of the two-cycle machine is precisely the same as that of the four-cycle. Speaking practically, however, there are several conditions governing the real, or actually obtained, thermal efficiency, and some of these conditions are materi-

ally in favour of the two-cycle machine. Whilst unable in this paper to do more than briefly consider these points, yet the writer thinks such brief mention will enable a better understanding to be reached, when subsequently considering the test data from the various types of machines. Briefly, the most important are as follows:—

(a.) The capacity of the two types for the same power is as 1 for the two cycle engine to 2 for the four cycle machine, and the relatively greater radiation surface power for power of the smaller two cycle cylinder results in a greater transfer of heat to the cooling water during the compression stroke, thus permitting the use of higher compression pressures, without fear of the premature ignition of the charge, and with resultant increased efficiency.

(b) Again, it has been found that the charge temperature at the beginning of compression is rather lower in two cycle than is the case in four cycle machines, due probably to the fact that the heat absorption by the incoming charge in the latter case is greater than in the former, since it occupies the time of an entire stroke, as against about 1-8th of the stroke in the two-cycle machines. In the two-cycle type, not only is the charge admitted to the working cylinder at a pressure of from 2 to 3 lbs. per square inch above that of the atmosphere, but the inlet ports are also quickly closed before the incoming charge can become materially heated. Hence the actual weight of charge drawn into the cylinder is considerably increased, and has been calculated by Guldner in a typical case to be 16 per cent. greater than in the nominally similar four-cycle machine, with a resultant and very nearly proportionate increase in specific capacity.

A further consideration in the application of gas engines, particularly where required to drive electrical generating plant, lies in the necessity for close speed regulation, and this not merely a uniform speed as recorded in revolutions per minute, and which uniformity is determined chiefly by the "governor", but more particularly a minimum variation in the angular velocity of the crank shaft throughout each cycle, that is, "cyclic regularity," which is practically entirely dependent in any given machine upon the weight of the fly wheel. This aspect of the question



has been closely studied by various authorities, notably by Guldner, in connection with the design of large gas engine units, and the results obtained again speak strongly in favour of the two cycle machine.

Whilst the question is one that cannot be discussed at length in a brief paper such as this, yet a few figures may be of interest. The allowable cyclical variations have been stated by various authorities, who are in fairly close agreement on the matter, to be as follows:—

For ordinary power purposes, such as for engines used in industrial processes, in driving ordinary workshop machinery, etc., a variation of from 1-25th to 1-35th is allowable; for driving direct current electrical generators and lighting service 1-60th to 1-75th is required, and for driving alternating current generators, particularly where such machines are driven by separate gas engines, and are required to run in parallel, cyclical variations of from 1-125th to 1-160th should not be exceeded. This factor has been termed the co-efficient of regulation, and in discussing the testing of gas engines, is again referred to.

The weight of fly wheel is determined from a consideration of this co-efficient of regulation, the speed of the fly wheel rim, and the relationship between the mean forward pressure on the piston due to the explosion and the mean back pressure during the initial compression of the charge. Working on this basis, taking an allowable cyclical variation of 1-40th, a rim velocity of 66 feet per second, and an average value of .33 for the relationship between the main forward and the main back pressure, a single cylinder four-cycle machine would require a fly wheel weight of approximately 150lbs. per I.H.P., whereas a two-cycle cylinder would only require 60lbs. per I.H.P., and a double acting single cylinder two cycle machine only 16 lbs. per I.H.P. A "side by side" type of single acting two cylinder four cycle machine would require 60lbs. per I.H.P., or nearly four times the weight required by a double acting single cylinder two cycle machine. The importance of this question, both in regard to first cost and efficiency is vital, and it can readily be recognised, from the preceding figures, that to obtain an efficient regulation such as is

required for electrical work in large four-cycle gas engines, either double acting machines must be employed or a multiplication of cylinders.

The various points in favour of the two-cycle type, particularly in large units, lie, therefore, in its relatively lower weight, reduced first cost, and lessened amount of space required, power for power, and in its regularity of operation. As against these relative advantages, however, of the two-cycle machine of present day design is its lower mechanical efficiency, the increase in friction losses being due chiefly to the work done in the gas and air pumps during the charging portions of the cycle. At present the pump work, as it may be called, represents from 8 per cent. to 10 per cent. of the I.H.P. in two-cycle engines, as against 6 per cent. to 7 per cent. in four-cycle machines, in the former case this work being divided between two cylinders, and in the latter case being done in one only. But it is the expressed opinion of many of the foremost gas power authorities that this discrepancy of from 2 per cent. to 3 per cent. will be wiped out by improved design, and that for large units the two cycle type will ultimately displace the four-cycle machine as a better, lighter, more regular, far less expensive and equally efficient appliance. The following opinion was expressed by one of these authorities:—

“The successful construction of two-cycle machines either single or double acting is almost a necessity in the development of large units such as are required in the operation of steel works. The weight of the various machine parts and their dimensions increase so enormously, when it is attempted to generate these powers in one four-cycle cylinder, and further, the growing complexity of the machine, and the unreliability of operation become so serious when it is attempted to get the same power by the combination of four single acting four-cycle cylinders, that either type of construction can only be considered as a makeshift until an efficient and reliable two-cycle machine appears on the market.”

In the foregoing notes no attempt has been made to consider the design of the gas engine, but the author has endeavoured to give briefly a general outline of the two

main types so as to make clear the methods and results obtaining in the testing of these engines. The extent to which such testing may profitably be carried varies greatly, and one must be guided by the particular circumstances surrounding each case. Where the machine is a small one, and where the uses to which it is put are relatively non-important, the simplest of tests only are justifiable. It sometimes also happens that time will not permit of an elaborate test, and one must by experience endeavour to make sufficiently correct deductions from such tests as it is possible to carry out.

As a general rule, however, in any gas engine doing continuous work, large or small, it is undoubtedly in the interests of economical working to keep a close check upon the operation of the machine by occasional testing, since it is quite commonly the case that engines are run in such a manner and condition as to be unable to develop their full rated capacity. And further, that the amount of fuel consumption for the work actually done is double what it should be. Such a condition not only greatly increases the working costs, but also throws undue wear and tear upon the machine, and shortens its life. Of still greater importance in this respect, however, is the necessity for carefully testing the capacity of the gas engine immediately after it is "left running" by the contractor. At the present time the greatest laxity exists in the preparation of specifications for the supply and erection of such plant, and this is not only against the best interests of the purchaser, but also severely handicaps the supplier of high-class machinery, who frequently finds himself unsuccessful in securing orders, because his price is an honest one, and covers the supply of everything necessary to ensure satisfactory operation, and is, therefore, higher than that of his less scrupulous competitor, who either is supplying a smaller or inferior machine, or who fully intends to take every advantage of omissions in the contract specification.

In the following descriptions of apparatus and methods, therefore, have been included tests which it may not always be either profitable, or even possible, to apply, but the majority of which, however, should be insisted