12TH SEPTEMBER, 1889.

THE OPERATION OF POWER COMPANIES AND POWER TRANSMISSION BY COMPRESSED AIR.

By NORMAN SELFE, M.I.C.E., M.I.M.E., ETC.

(PAST PRESIDENT.)

INTRODUCTION.

THE subject of "Compressed Air and its applications" was first brought before this Association in a paper read by the author at the monthly meeting in March, 1886, and soon after his return from a tour of nearly two years duration in the United States and Europe.

In the course of those travels, the author's practical acquaintance with the applications of compressed air was very much extended; and his knowledge of the machinery used in connection with it, greatly increased.

The primary object of the former paper was to bring before the Association a new application of air under comparatively low pressure, which had then been recently invented by Mr. Pardy, of San Francisco, and actually witnessed by the author in successful operation as the motive power for tram cars in that city.

Some of the special advantages which compressed air possesses for the purposes of power transmission were also pointed out, and among others the following passage bore on that part of the subject: —"If a company were to start in Sydney to supply compressed air "to work elevators, sewing machines, and the thousand and one "applications that are now worked in the city by hand power, or "by little kicking and often dangerous steam engines, what a con- "venience and saving both in cost and worry would be effected, "a saving that would many times compensate for the mere loss of "power between the source and its application."

Attention was also directed in that paper to a proposition then being initiated in England, at Birmingham, to establish a Compressed Air Power Company for similar purposes, the author holding then, as he does now, very decided opinions as to the many advantages which compressed air possesses over hydraulic pressure for the tranmission of power by a Public Company, some of the more prominent of those advantages were referred to.

POWER SYSTEMS IN ACTUAL USE.

There are four mediums of power transmission which during recent years have attracted a great deal of attention from engineers.

First: Wire Ropes.

This system has been carried out on a large scale at Schaufhausen, on the Rhine, to transmit the power from turbines to mills and factories in the neighbourhood, and also in other places in a similar way. There is also another and perhaps more important way, that is for traction in the various forms of cable roads, both railways and tramways. Although it is abundantly proved that under certain conditions wire cables are admirably suited for tramcar propulsion, it has never, it is believed, been seriously proposed that any modification of the wire rope system with its enormous wear and tear and loss by friction, could be profitably adapted to supply power to a great number of independent customers and small factories distributed over the streets of a city; wire rope or cable transmission will, therefore, not be again referred to.

Secondly: The Electric Current.

The electrical distribution of power is already in practical use, and under certain conditions with assured success. It may be conceded at once that electrical power transmission is both theoretically and practically the most efficient system known so far as the percentage of useful effect which the power given off by the secondary motor bears to the prime mover, and it is probable that electric light and power companies would soon have the field to themselves for such supply if it were not for several serious drawbacks attending electricity which there does not appear to be any likelihood of being overcome.

One of the objections to electrical power transmission is the enormous expense of the conductors if a current with a low difference of potential is used, that is, a current not dangerous to human life. It is well known that great skill and care is necessary to prevent accidents when currents of high tension are applied, and that great numbers of lives have been already lost. The instantaneous death of an attendant at the electrical installation of the Inventions Exhibition at London made a great impression on the author, being caused by the spout of an oil can accidently touching a conductor.

In the thousand and one power requirements of a large city the utmost safety and simplicity are first requisites, and a current that carries sudden death in its contact would be very undesirable, whether applied directly or through a transformer.

Dynamos for private installations of the electric light where low potentials are admissable are, however, now being successfully driven through the agency of a compressed air power company, and under the system adopted they give profitable employment during the night time to the same air compressing engines, which during the day operate the machinery of manufactories and other industrial establishments, therefore, we may dismiss electricity from our present consideration as the medium for a power company in such a case as Sydney.

Thirdly: Hydraulic Power

(meaning a water supply under an artificial pressure or head); and

Fourthly: Compressed Air.

It will be attempted in this paper to draw some comparisons between these two rival systems, after first referring to what has already been done in New South Wales. The author trusts that the importance of the subject will induce the fullest criticism on the part of members, and that all the light possible may be thrown on the question—What is the most promising and suitable system of power transmission for the climate and conditions of Australian towns and cities?

In the year 1861, the Harbours and Rivers Department of the New South Wales Government invited contractors to send in designs for a dredge for the Shoalhaven River, accompanied by their tenders for its construction. The author was at that time the draughtsman to the late well-known firm of P. N. Russell and Co., of this city, and prepared a design for such a dredge. Messrs. Russell's tender was accepted on that design, and in the year 1862 the vessel was built.

In this dredge the ladder was raised and lowered by hydraulic power, the stroke of a ram being doubled by sheaves and chain. The circumstance is now mentioned (although the author has not seen the dredge for twenty years past), because it is believed that it was the first application of hydraulic power for such a purpose ever made in Australia, and, so far as has been ascertained, it was the first application of the kind to a dredge, although, as is well known, many dredges are now made with hydraulic appliances. Hydraulic cranes were not introduced into the colony even ten years after this dredge was built, but in the year 1874 the author submitted to the Government certain proposals for the improvement of the Circular Quay, which have in their essence since been adopted, and in connection with those improvements he recommended the use of hydraulic cranes. Particulars and prices for complete hydraulic installations were obtained at the time by him from eminent firms in England. The Government cranes at Newcastle had up to that time been worked by steam, but after the author's proposals were published, hydraulic cranes were recommended, and were subsequently introduced at Newcastle, where they have quite left the old steam cranes in the shade. In recent years hydraulic machinery has not only made great strides in its varied applications generally, but it has come largely into use in this colony, especially for hydraulic rivetting, and for working cranes, lifts, or elevators.

The first hydraulic passenger lifts working in this colony were erected at the Government Works Office and Messrs. Young and Lark's in Moore Street, and they were designed by the author. This was about ten years ago, and consequently they are now by comparison rather antiquated machines, so rapidly do improvements take place. Since that time it has fallen to his lot to design and carry out a very great number of hydraulic lifts, constructed on nearly every recognised system, and operated by pressures varying from 30lbs. to 800lbs. per square inch. These hydraulic lifts, with hoists or elevators on other systems, (amounting in the aggregate to over a hundred in number) that have passed through the author's hands, have sometimes been worked by steam, but in far the greater number of cases they have been driven by means of gas engines. A more or less skilled attendant to each outfit is of course necessary when steam or gas engines are used, and as a consequence the advantages which would result from a Power Company have been very forcibly presented to him from an early period of his lift and elevator career, and it has also led him to see and appreciate the advantages which would attend having these lifts operated by the large and economical engines, and also many other applications of power for domestic and public use, which can be operated in a similar way.

At an early stage the author made himself acquainted with what had been done by the Hydraulic Power Companies of Hull and London, and in 1881 and 1883 he formulated a proposal to establish an Hydraulic Power Company in Sydney, which was submitted to two or three influential citizens who had gas engines at work in their warehouses. Whether it was that he did not possess the power of flowery description, and had no ideas as to that utter disregard for truth which appears to be a distinguishing characteristic of so many enticing prospectuses now met with, he is unable to say, but he certainly failed to interest anyone in the matter to any great extent. And his interest in the formation of a Hydraulic Power Company for this city soon after died a natural death, for the best of all reasons, that he found something a great deal better.

From that time to the present the application of hydraulic power has been practically at a standstill, and owing to the peculiar lifeless properties of water, if the term may be applied, it does not seem likely that any great advance is possible in the use of water; but with air how very different. Water is inert and dead—a mere bar of iron between the ram of the accumulator and the piston of the water-engine, and not affected practically by change of temperature. Air is elastic, full of life, responding to the slightest change of temperature, and the mains to carry it become great storehouses of power which can be used like steam, expansively and economically against varying loads, instead of always requiring the full cylinder of full pressure to move the unloaded piston as with water-engines.

For such reasons, the author recognised the advantages of air over water for a Sydney Power Company before particulars of the Paris and Birmingham Companies were made public.

By the year 1884 he had seen something of the uses of compressed air, and had designed machinery for cold air refrigerators, rock drilling, etc., etc.; and after having made himself more acquainted with its theoretical bearings from a study of thermo-dynamics, he became further convinced that compressed air, and not hydraulic pressure, was the system more suitable to meet the requirements of Sydney. From that time to the present, he has carefully watched the great strides continually being made in its application.

It appears that during the time the author was seeking information as before referred to with regard to the application of compressed air in America and England, the question of a Hydraulic Power Company was again taken up in Sydney, and with some earnestness, for a gentleman was specially sent to England to acquire information concerning it, which had already been obtained and was in the colony. Subsequently to this, about two years ago, the matter of power companies excited some public interest, for a number of letters appeared in the Sydney daily press discussing the pros. and cons. of these two rival systems of power distribution—water and air.

Since his first conviction of the greater number of advantages appertaining to the compressed air system, and his belief in its ultimate certain triumph over hydraulic power, the author has patiently waited developments in Europe. The most serious difficulty which he foresaw at that time to the extension of the compressed air system, was with regard to keeping the joints or the main conduits tight. It is easy to see that the temperature of compressed air is likely to vary much more than that of water, for the air itself is heated by compression, and the pipes for its transmission are relatively large and thin as compared with those for hydraulic power; the expansion and contraction of the pipes would therefore be much more serious with air. While waiting for reports of the completion and working of the great Birmingham Power Scheme, a relatively smaller Compressed Air Company, but still on a large scale, has been established in Paris under Mr. Victor Popp, which has been so successful in its operations that it has since been doubled and quadrupled in power and extent, and it is now worked on such a scale that it is safe to say Compressed Air Power Companies have passed the experimental stage. The joints of mains used in Paris are shown by Plate X., Fig. 1.

The Birmingham Company propose to put down fifteen compressing engines of one thousand horse-power each, commencing operations with nine of them only. There are three of "Lane's" gas-fired water-tube boilers working to 160lbs. pressure to each engine. The engines are triple expansion, with cylinders 20in., 30in., and 49in., and 4ft. stroke operating three beams, over the ends of which there are six inverted single-acting air compressing cylinders 2ft. 2in. diam., and 4ft. stroke. These compressors are capable of delivering 2000 cubic feet of air per minute, at 45lbs. above the atmosphere from each engine.

The complete installation contemplates forty-five boilers, all gas fired, and a power of 30,000 cubic feet of air per minute. The air-pumps or compressing cylinders, are single acting, and water-jacketed with trunk, pistons, or rams, on Sturgeon's system. The delivery valve of each compressor is the whole area of the cylinder end, and is made hollow, with a water circulation through the stem. The principal air main is 24in. diam. The minimum price proposed to be charged to consumers is 4d. per thousand cubic feet, and the maximum price 1s. 8d. per thousand. At the rate of 5d. per thousand feet, the cost of power to customers is put down at from £7 to £18 per horse-power per annum of 2700 working hours, according to the class of engine used, and whether expansive working or reheating is applied. Taking a mean case where there is no reheating of the air, and where intensely cold air is exhausted (which would be a great boon in this climate for hotels, theatres, and other large buildings) and where it could be mixed with ventilating air for cooling purposes, the cost per horse-power is £10 12s. per annum, that is 2544 pence for 2700 hours or less than one penny per hour.

It must be particularly noticed that an air engine to give off ten horse-power will cost only about one fourth as much to purchase as a gas engine for the same power, and it would require comparatively no skill to work it. Those of our members who are practically acquainted with the working of gas engines therefore, can easily figure out for themselves the advantages of the air system for such purposes as driving pumps for lifts, printing machinery, dynamos for the electric light, sewing machines, domestic motors, etc., etc.

Owing probably to the magnitude of the scale on which the Birmingham Company started they have had to "go slow;" in the meantime, Mr. Popp, of Paris, who some years ago initiated a system of operating clocks by pneumatic power, has had the demand for his company's air increased faster than he can supply his customers, and the company which has obtained a charter from the municipality of Paris has increased its plant until there are now about 20 compressors aggregating 3,000 horse-power at work in one establishment, which are fully described and illustrated in the *Scientific American* supplement for February 9th of this year.

So much interest has been taken by scientific people in Europe in these works, that the Society of Civil Engineers was invited to visit them in the summer of 1888; and last month they were visited by the English Institution of Mechanical Engineers when over in Paris at the Exhibition.

Very full descriptions of this Parisian installation, accompanied by illustrations, appear in *Engineering* for June 7th, 21st, and 23rd last, which are now in the library, so it is not necessary to transcribe all particulars as to details.

The subject has attracted such attention in Germany that Professor Radinger, of the Technical School of Vienna, and Mr. Riedler, of the Royal Polytechnic, Berlin, both gentlemen of high scientific reputation, have also recently examined into, and reported on, this Paris installation; they have made their own calculations in the matter, and have furnished particulars as to the actual present efficiency of the plant and the possibilities of the system in the future.

From the reports of these gentlemen, copies of which the author has been fortunate enough to see, some extracts will be given, and as the French horse-power or cheveaux-vapeur is 75 kilogramme metres per second, or only .9863 of an English horse-power, this must be borne in mind in any comparison or checking of the figures which follow.

According to the reports of the German experts, it is shown that with the engines of two of the compressors, the C.V. or horse-power, was 341, and of the compressors themselves 296, giving the compressor in terms of the steam engine an efficiency of 86 per cent.; and Professer Radinger estimated that with compressors of 500 horse-power the efficiency would reach 90 per cent.

All the losses by the dissipation of heat and the imperfections of the valves, brought the efficiency of the compressors down to 66 per cent., but it was thought it might be increased to 76 per cent, so that the loss would then be only one-fourth instead of one-third.

These double compressors of 341 horse-power each, six of which are at work, when making 38 revolutions per minute compressed 3,000 cubic metres from atmospheric pressure to 6 atmospheres.

The consumption of coal is .8 of a kilogramme of coal per cheveaux-vapeur per hour, the fuel costing two francs per 100 kilos. In English measures, taking a kilogramme at 2.2lbs., it equals 1.76lbs. per C.V., and 1.78lbs. per I.H.P., which shows a very high efficiency for stationary machinery of such moderate power. The result is that to compress one cubic metre of air requiring theoretically 0.11366 C.V., the cost is 0.18 centime or .018 of a penny.

After compression there is the loss in the working of the air engine to be taken into account; the loss by friction in mains being practically disregarded, as it is found a main of 300 millimetres, say 12 inches diameter, will transmit from 4 to 5000 horse-power.

From actual trial at Paris with a ten horse-power motor it was found that the theoretical work was ... 9·8 horse-power
and the useful effect ... ... 8·6 " "
making the efficiency ... ... 88 per cent.,
and a belief is expressed that it could be brought up to 92 per cent.

However, taking the efficiency of the engine at 88 per cent., and of the compressor, as before stated, at 63 per cent., the combined loss = 63 × 88, or 55.4 per cent. and that is the efficiency of the motor to the prime mover that can be depended upon, it is expected, however, that 70 per cent. could be realised.

The most characteristic and important features of compressed air as a medium for power transmission are (1.) the the great range of temperatures between which it can be worked, and (2.) its great increase in volume with increase of temperature. These have long been known as abstract facts, but it is only by the development of the science of thermo-dynamics in recent years that it has become possible to understand how greatly the power of an air engine may be increased by the direct application to the air of supplementary heat before or during expansion. In the early compressed air engines great inconvenience was experienced from the formation of ice in the exhaust passages and the ends of the cylinders, to the destruction of covers and valves. In heating to prevent this freezing of the moisture in the air on its expansion, a great accession of power was gained, but it does not seem to have been realised, and up to the present the author has never seen the point specially referred to, that there is hardly any conceivable way in which a larger percentage of applied heat can be converted into useful work, than it can by this supplementary application to the supply of a compressed air engine. This heat may be applied before expansion in one engine, or in the case of a compound air engine it could be applied in the intermediate or receiver stage after the air had been reduced to a very low temperature by the first expansion.

Want of time has prevented a calculation being made to see what amount of power could actually be gained by conduction of the atmospheric temperature through the walls of a specially constructed receiver of a compound engine, for if the first expansion reduces the temperature below that of the atmosphere, heat can certainly be taken up without expenditure of fuel.

Let us now consider the effect of the combustion of fuel under different conditions.

In a steam engine burning 1¾lb. of coal per horse-power per hour, the actual proportion of the heat converted into work against the moving piston may be taken as one-tenth of the whole heat given off by the combustion of the fuel; the chimney, the condensing water or exhaust, and leakage, actually carrying off the great bulk, or other nine-tenths.

With the best gas engines about 84% instead of 90% is estimated to be lost and 16% the ratio of efficiency.

The late Mr. Jenkin calculated that 51% was lost in the water jacket, 31% in the expelled products of combustion, and 2% by general conduction.

According to Professor Reynolds, Mr. Perkins has succeeded in utilizing about one-ninth of the possible realizable portion of the heat in fuel between 3,000 degrees Fah. and the temperature of the earth's surface.