MINUTES OF PROCEEDINGS,

11th FEBRUARY, 1886.

Walter Shellshear, President, in the Chair.

The following candidate was balloted for and duly elected as

MEMBER:

GEORGE A. HARRIS.

Mr. J. M. Small read part of his paper on "Healthy Dwellings."

11th MARCH, 1886.

Walter Shelshear, President, in the Chair.

The following candidates were balloted for and duly elected as

MEMBERS:

CHARLES E. WATKINS.
GEORGE T. RITSO.

Mr. Norman Selfe then read the following paper, the discussion on which was held at a special general meeting on the 25th March:—

COMPRESSED AIR AND ITS APPLICATIONS,

WITH PARTICULAR REFERENCE
TO
PARDY'S LOW PRESSURE TRAMWAY SYSTEM,
AND A NOTICE OF
THE HYDRO-PNEUMATIC ELEVATOR.

By NORMAN SELFE, M. Inst. C.E., Etc.

INTRODUCTION.

The subject brought under your notice this evening is of undoubted importance to engineers, yet this is the first time it has ever been considered at the meetings of the Association (and the author speaks as a member of it from the foundation). He therefore hopes now to open out a field for discussion and interchange of experiences that will prove mutually pleasant and profitable.

It may be safely said that engineers, as a body, are much better acquainted with hydraulic machinery than they are with pneumatic or compressed air appliances, although the latter are probably more varied in their uses; for while it is true that compressed air can never take the place of water in presses, lifting jacks, and such other machines as are specially dependent on the non-elastic properties of water for their operation, still there are many purposes to which hydraulic power is now applied, and notably the transmission of power to long distances, for which compressed air as well as being like water suitable for transmission through pipes ; possesses the further advantage of being in itself a store of power, and, in other ways to be pointed out, has advantages over water pressure.

The laws that govern the use of water in hydraulic machinery are very simple, there is no compression and expansion, and no storage of power in the water itself ; such storage must be made by a natural head as an elevated tank or reservoir, or be created artificially as in a loaded accumulator. With a knowledge of the laws that govern the friction of water in pipes, and the losses appertaining thereto, you have nearly all the theory you want to enable you to make hydraulic machinery. But, on the other hand, before you undertake the compression of air, and its transmission to a distance, to work an air engine, you are brought to a face with the complex laws of thermodynamics, and two great outlets for loss of power present themselves. These losses are so important that were it not for other and more than compensating advantages which it possesses air; could never rival water as a medium for the transmission of power.

The losses arise thus : First, in the compression of air the whole of the energy exerted to effect its compression is converted into heat, which raises its temperature, and therefore its relative volume, and as a consequence, the relative power to effect the compression is increased, unless this heat is dissipated as fast as it becomes sensible. In a good compressor, as much heat as possible is got rid of during the operation of compressing, the remainder is dissipated through the walls of reservoirs and pipes as the compressed air returns to atmospheric temperature ; so that before the air is employed to work an engine, all the power or heat that was put into it to effect the compression is practically lost.

Secondly. In the expansion of compressed air against the piston of an air engine and the performance of work, the air must part with heat equivalent to the work done (and on this law all cold air refrigerating machines depend for their action), but this loss of heat brings about a diminution of volume in the air expanded in the cylinder, and a reduction in the work done, so that in the practical compression and expansion of air, an indicator diagram taken from the cylinder does not shew a curve that follows Marriott's law.

The combined losses from the two operations, compressing and expanding air, are not of great importance at very *low pressures* above the atmosphere, but they rapidly increase as the working pressure goes up, until at 10 atmospheres they perhaps amount to 75 per cent. of the whole power. For want of knowledge that is now accessible to all, a great deal of mystery used to surround experiments made with compressed air; and before the mechanical equivalent of heat was understood, much money was wasted in constructing useless machinery, not only in the older countries, but also in this colony. Twenty-five years ago the author made the working drawings of a machine patented here and intended to produce cold by the expansion of air. The whole plant was made by Messrs. P. N. Russell and Co., and tried in Margaret-street close by, and it proved a total failure. He knows *now* that as the air in that machine did no work in expansion, it did not fall in temperature, and no sign of ice from it ever gladdened anxious eyes; but nobody in the colony (in those days, probably) knew where the defect was. At the present time, thanks to the researches of such men as Joule, Carnot, Rankine, and others, the laws of thermo-dynamics are established on a basis that is confirmed by every day practice; and such futile schemes and costly experiments as were made in this colony under the patents of Messrs Sloper, Mort, and Nicolle for producing cold by the compression and expansion of air, are not likely to be repeated.

It is not purposed to import deep theoretical matter and mathematical formulæ from the text books, into this paper. Having, however, paid considerable attention to the use of compressed air for years past, and in order to present the results of theory at a glance, the author lately compiled, from the best authorities available, the two tables marked A and B which indicate, in most instances the sources of his information. The transpositions into English weights and measures, and to Fahrenheits temperatures have been made, as the originals were in French measures. With these few remarks it is proposed to divide the subject into three portions, dealing respectively with: The past and present use of compressed air; The principles involved in dealing with it; and Some recent improvements in its application.

PAST AND PRESENT USE OF COMPRESSED AIR.

Up till about the year 1839, say 47 years ago, the principal application of compressed air was in connection with diving bells. The earliest reliable record of their use is given by Taisner, who records that in the year 1538 two Greeks descended in one at Toledo, in the presence of the Emperor Charles V., although there is some reference in the problems of Aristotle to show that the principle was understood four centuries B.C. About 1620 Dr. Halley, in England, improved the appliances used, and sent down supplies of fresh air to his diving bell by means of specially constructed casks; But the first introduction of a compressor or pump to send down a continuous supply of air to the diving bell, we owe to Smeaton in the improved appliances, invented by him for the works at Ramsgate Harbour, in Kent, about 1788. Smeaton's work at Ramsgate, and the diving bell itself are still much as he left them. Diving dresses or Scaphandres, as the French call them, owe their origin principally to John Lethbridge, 1721, Klingert, at Breslau, 1797, Siebe, of London, 1829 (still the best known maker), and later to Cabirol, 1857, and Rouquarol and Denayrouse, 1867. Submarine boats have been designed since 1776 by scores of inventors, but the author is not aware of one yet being constructed that he would care to go down in; they would all, however, have to depend on compressed air for their existence, and are thus just mentioned. Coming now to 1839 again, in that year, M. Triger, a French engineer, proposed the use of compressed air for sinking the cylinders or piles of bridge piers. He did not, however, carry out his ideas, and it was left for two English engineers, William Cubitt, at Rochester Bridge, in 1851, and Brunel, at Saltash, in 1854, to have the credit of the first application of Triger's proposals. As most of you are aware, numbers of bridges in this colony have had their cylinders sunk by this means.

One of the latest applications of Triger's proposals, and in some respects the most notable, is the sinking of the great cylinders 70 feet in diameter for the Forth Bridge, in Scotland. The author had the pleasure a few months since, of descending by the air locks to the bed of the Forth, about 50 feet under water mark, in one of these caissons, where the excavation was going on in a chamber 70 feet in diameter, thoroughly lit up by the incandescent electric light. He also saw here a novel application of power, being a hydraulic spade, which operated inside the air chamber. The sinking of these cylinders is very ably described in a paper recently read before a Society in Scotland.

In 1840, M. M. Andraud and Du Tessay, appear to have experimented with compressed air to drive a carriage on a small circular railway in France, and in 1845, M. Triger, conveyed compressed air 230 metres from the compressor to do work. In 1849 compressed air was used at Govan, near Glasgow; the compressor being designed by the late Mr. Randolph, and it was of the type that used water on the pistons. The first grand application of compressed air on the continent of Europe was due to Professor Colladon, of Geneva, who, in 1852 proposed to use it for the piercing of the great Alpine tunnel through Mont Cenis. An English engineer, Mr. Bartlett, of the firm of Brassey and Co., has the credit of designing, in 1855, the first pneumatic rock drill. M. Sommeiller, a Piedmontese engineer, who was connected with the tunnel works, brought out an improved perforating machine in 1860, that was used in driving the tunnel, and in 1861 he brought out a design for new compressors with water pistons that were succesfully adopted, and are now known as Sommeiller Compressors. This type of compressor has been used both in Victoria and this colony, introduced by Mr. Ford, of Melbourne.

The success attained in Mont Cenis led to the application of compressed air to the Perseburg mines, in Sweden, and the Vielle Montagne mines, in Rhenish Prussia, in 1863. Next year, in 1864, M. Cornet, after a voyage to England, set up a plant in Belgium, to carry the air 1000 metres from the compressor; and the use of compressed air then began rapidly to extend, up to the piercing of the Great St. Gothard Tunnel, undertaken in 1872. This tunnel is 14,920 metres in length, and without compressed air its construction would have been hardly possible. Professor Colladon here first introduced the injection of water to the compressing cylinders, so as to take up the heat of compression, and that type of compressor is still called after him. From the experience thus gained, up to say—1872-74—by Messrs Colladon and Sommeiller, and the increased knowledge of thermo-dynamics, as connected with the subject, that was available, a foundation was laid for hundreds of successful applications of compressed air that have since been made.

One of the principal applications of compressed air to which your attention should be drawn is its special suitability for the propulsion of vehicles on trams or railroads; and a great many people in Sydney have lately expressed their doubts as to whether it could be so applied. I have already mentioned the attempts of Messrs. Andraud and Tessie du Motay, in 1840, and M. Triger, in 1845. Clegg's atmospheric railway was actually in use in London about 1839, but the principle there adopted, under which a piston attached to the carriage worked through a continuous cylinder between the rails, has been long abandoned. Something of the same sort, however, is the pneumatic dispatch system, as used at the Post Office, London; there the carriages are actually blown through the tubes by air pressure, positive or negative, and this system has lately received a great development.

In 1858, M. Sommeiller constructed a small air locomotive. In 1874, the contractor for the St. Gothard Tunnel, M. Favre, employed ordinary locomotives with enormous air reservoirs to draw out the excavated materials, and in 1875, M. Ribourt, an engineer connected with the St. Gothard works, patented a compressed air locomotive, which worked satisfactorily at a pressure of fourteen atmospheres.

At the present time numbers of mines in England and on the continent of Europe employ compressed air locomotives (like the photograph exhibited) as a regular part of their plant. It is to be hoped we shall soon hear of them being in use in N.S. Wales.

The principal inventors who have, up to the present, applied compressed air with success to the propulsion of street cars, are M. Megarski in France, Colonel Beaumont and Scott Moncreiff in England, Messrs. Hardie and James and Mr. Bushnell in America, and latterly Mr. Pardy also in America.

The compressed air tramway of Colonel Beaumont, has been for some years before the public; it was tried on a branch of the North London Metropolitan Tramway in 1881. The author saw it (as improved) at Bootle, near Liverpool, last year. Under this system the air is stored at the great pressure of 1000 lbs. to the square inch; but by means of compound engines most ingeniously constructed, and the application of a supplementary fire and steam jacket to warm the air, it is sought by the advantages of expansion, to make up for the enormous loss in compression. It is said that to draw 56 passengers a single journey of eight miles on a practically level road, the locomotive weighs 8 tons, this great weight being principally due to the size and strength of the air receivers. The whole machine is complicated, and looks to have very delicate mechanism for rough work.

The Megarski system has had a much greater measure of success than any other air tramway yet adopted. It has had a continuous trial of five years at Nantes, in France, and was tested on the Wantage Tramway in England; it is now being adopted by the North London Tramway Company. M. Megarski only uses 30 atmospheres, or 450 lbs. per square inch, and he heats the air by passing it through hot water, in a special vessel on the driver's footplate, and like Colonel Beaumont, he gets expansive working without freezing up all the exhaust passages of his cylinders. The engine and receivers are all carried on the car itself instead of on a separate locomotive. One of the cars built for the Caledonian Road Tramway, London, was exhibited at work, in the South Promenade, and, in fact, obtained the gold medal at the late Inventions Exhibition, held at South Kensington. The author took several opportunities of riding in the car, and also made an arrangement by which he had a thorough look into the details when the car was stopped for re-charging.

Mr. Scott Moncreiff has made a tramway car with the reservoirs and engines all under the floor as in the Megarski system, nis six reservoirs held air at 350 lbs. per square inch. It was first tried in 1875, on the Vale of Clyde Tramway, and subsequently in 1877 it resumed regular duty. The weight of car was 6¾ tons empty, and it carried 40 passengers three miles on one charge of air.

A trial has been made on the New York elevated railways, of the Hardie air locomotive, by Messrs. Hardie and James, and with very fair results, the pressure being about the same as that used by Megarski, viz., 450 lbs.; but at Newhaven, Connecticut, a Mr. Bushnell has invented a system, and has worked his engine at the enormous pressure of 3500 lbs. per square inch, which is something like that used in Torpedo practice. Mr. Zahner, the author of a work on compressed air, states that he rode over a mile on a Bushnell engine, during which journey the pressure guage only descended from 1800 to 1500 lbs. per square inch.

In all these tramways systems, the principal object of the designers has been to carry as much stored up power as possible, so as to be able to go the greatest distance without requiring to recharge the reservoirs; and this is done at the sacrifice of efficiency, for although it is now known how much more economy is the result of using low pressures, yet owing to its greater volume some of these engines could not carry low pressure air to go the distance they now do without taking up the whole of the passenger space with reservoirs. Again, in these tramway systems the charging is done at special stations, and is a tedious process, as the power to be stowed away is proportionate to the load and distance run. In the cases seen by the author it took about twenty minutes, and was effected by coupling on copper pipes. It is hardly necessary to say that the weight of the receivers is almost directly as the pressure carried, that is to say a cylindrical receiver to carry 500 lbs. would be nearly five times as strong and heavy as one of the same dimensions to carry 100 lbs.; it would then propel the same gross load five times as far as the 100 lbs. cylinder. But as the weight of the stronger cylinder would be five times as much as the weaker one, the net carrying power for passengers would be correspondingly reduced. In fact the limit of distance is soon reached in the resisting power of the metal of the receiver, which determines the maximum distance a given receiver will carry power to propel itself. Beaumont's engine of eight tons is said to draw 56 passengers eight miles on one charge; no doubt this would be on good level roads. The Megarski car seen, carried 40 passengers, and weighed nearly seven tons empty, and the company claim that it will run ten miles under favourable conditions.

With all the drawbacks, however, of having so large a proportion of non-payable load, the great loss from using high pressures, and the complication of having to carry a heating apparatus, the Megarski system at any rate is a practical success, and having been on trial since 1879 it would not now obtain an extended application in London if it were otherwise. We will now consider the second part of the subject—

SOME OF THE PRINCIPLES INVOLVED IN THE USE OF COMPRESSED AIR.

From experiments made years ago by M. M. Regnault, Rudberg and others, on the expansion and pressure of gases between the temperatures of 32 deg. and 212 deg. Fah., certain laws have been deduced, and it is ascertained that the absolute zero of temperature is −461 deg., that is 461 deg. below the zero of Fahrenheit. The four principal laws to interest us now are these: *First*, (what is generally known as Marriott's Law), The pressure of air varies inversely as the volume with a constant temperature. *Secondly*, The pressure is directly as the ***absolute temperature*** with a constant volume. *Thirdly*, The volume is directly as the ***absolute temperature*** with a constant pressure; and *Fourthly*, The product of the pressure and volume is proportional to the absolute temperature. That is to say, if we double the temperature of a given volume of air, and the pressure remains the same, we double the volume; but if the volume remains the same we double the pressure. Thus, one pound of air at atmospheric pressure and at 70 deg. Fah. = 13·342 cubic feet. If we double the temperature, that is double (70 deg. + 461 deg.) = 531 deg. absolute, it becomes 1062 deg. absolute, and this with 461 deg. deducted again, makes it = 601 Fahrenheit. At this temperature, or say 600 deg., one pound of air = 26·659 cubic feet, or double the bulk it occupied at 70 deg., and is nearly at the melting point of lead, 617 deg.

When the temperature is uniform, the product of the volume and pressure is uniform, that is, if the pressure is doubled the volume is halved, and so on; and the curve or diagram follows Marriott's law, and is called an *isothermal curve*. When, however, a certain quantity of air is compressed by a piston in a cylinder so that no heat is given out, the work of compression as internal work is converted into heat, which raises the temperature of the air and thereby the pressure or volume, and the curve of the resulting diagram is called an *adiabatic curve*. The diagram, Figure 4, is from a Sommeiller compressor with a hydraulic piston, by M. M. I. Francois, a Belgian engineer. The line A B C D shews the actual work done, the line B E is the Marriott or isothermal line that would be shewn if no increase of heat took place, and the intervening space represents the power actually lost in the compresser. The line B F is the adiabatic line that would have been followed if some of the heat had not been conducted away by the water. You will notice this diagram only extends to five atmospheres.

M. Cornet, another Belgian engineer before referred to, published at Mons, in 1875, a remarkable work on compressed air, in which he gives the relative volumes of a given weight of air at a constant temperature, and the increased temperatures due to compression, for a range up to fifteen atmospheres. A M. Mallard has also written a paper, entitled "A Study on the Theory of Compressed Air Machinery," in which a great deal of information is contained.

The most complete work on the subject yet published, so far as the authoris aware, is in French, and is by M. M. A. Pernolet Ingenieur, it is entitled *L'Air Comprimé et ses Applications, Production, Distribution, and Conditions d'emploi.* He obtained a copy of it in the French Court of the Garden Palace Exhibition, in 1879-80. M. Pernolet was sent by a French company to study the use of compressed air in England, Austria, Belgium, and other countries, and in 1876 he published his exhaustive work, There is also a small book in Van Nostrand's science series, on " The Transmission of Power by Compressed Air," by Robert Zahner, M.E., New York, 1878, and some information in the latest edition of D. K. Clark's rules and tables. From these several works the tables A and B been have compiled, which show at a glance the theoretical conditions which attend the compression and use of compressed air. It will be observed, on reference to table A, that when air is compressed with increase of temperature, say to four atmospheres, the volume instead of being ·25 is ·374 of its original volume, the temperature having risen to 330 degrees Fahr., and that the work to compress a cubic foot, instead of being 2909 foot pounds requires to be 3618 foot pounds, the difference representing loss of work. Further, at eight atmospheres the volume instead of being one-eighth the original, becomes ·229, or nearly one quarter, and the work for a cubic foot 6021 foot lbs. instead of 4370. At a little over ten atmospheres the temperature rises to 600 degrees Fahr., or that of melting lead, and the relative volumes with and without increase of temperature are nearly as two to one. This increase of heat and volume is also shown by the diagram, Figure 4, where the black line is the actual diagram taken by the indicator, the red line is the isothermal or Marriott line, and the blue line the adiabatic curve, or the line that would be followed if some of the heat was not conducted away during the operation of compression. Figure 4 is taken from a Sommeiller compressor with hydraulic piston, and Figures 5 and 6 are from the high and low pressure cylinders, 11 and 18 inches diameter, of a compound compressor, designed by the author for specially economical working. In this compressor a surface condenser is introduced between the two stages of compression, the air compressed one stage is thus brought down to atmospheric temperature before it receives a second compression, and you will observe how close, for this reason, the black, or working, line keeps