Mr. Stephenson, President, said the distribution of power was of considerable importance in all large undertakings, especially with a view of saving manual labour, which was frequently a source of greater trouble than all the machinery put together.

Mr. E. A. Cowper believed this was the first instance in which a good arrangement for the distribution of power by water in a town had been described at the Institution. The way in which the work had been carried out appeared to be excellent. In considering the question of hydraulic machinery, what Joseph Bramah had proposed, and what he actually did, ought not to be forgotten. In a letter to the late Mr. Robert Mallet, dated November 10th, 1802, he distinctly foreshadowed this way of distributing power, and his letter seemed almost like an original suggestion of the plan which had been described.[1] Mr. Cowper thought not only would such useful applications of hydraulic power be much extended, but that other applications would be made of the principle, which was one that entailed very little friction, even when great force was generated. He had applied a "hydraulic reservoir," as early as 1846, to work hydraulic presses for bending, shearing, punching out large plates, and welding iron. All the large end adjustment links for the Kieff bridge, in Russia, were cut out of 1-inch plate by a press so worked. But the idea of a "hydraulic reservoir" was not new, even then, as it had been used years before in a paper mill for working presses. The hydraulic press was a valuable tool, and easily managed. There was no difficulty about the leathers, pipes, valves, or any of the appliances, if properly carried out.

Mr. C. Greaves said the accumulator, as commonly constructed,

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[1] Referring to the hydraulic press, Mr. Bramah wrote:—"I think much might be done in Ireland in the press way if the excellence of the principle was but known; I have also now applied it with the most surprising effect to every sort of crane for raising and lowering goods in and out of warehouses. So complete is the device, that I will engage to erect a steam engine in any part of Dublin, and from it convey motion and power to all the cranes on the quays and elsewhere, by which goods of any weight may be raised at one-third of the usual cost. This I do by the simple communication of a pipe, just the same as I should do to supply each premises with water. I have a crane on my own premises which astonishes every person to whom it has been shown—as they see the goods ascend and descend fifteen or twenty times in a minute to the height of 18 or 20 feet, and at the same time it is impossible for any person unacquainted with the principle, to discover how or where the power comes from. I also show them pumps raising water with huge force, and a press squeezing wood, &c., to atoms, and not the smallest discovery can be made of the cause. I believe I shall have all the cranage of the London wet dock warehouses to undertake, and which will be the grandest job perhaps ever done before."

resembled the loaded plunger of the pump of a Cornish engine. The loss of power in the dissemination of hydraulic pressure must of course be greatly affected by the friction on the ram. In Cornish pumps it had been found advisable to have very deep packings to the plungers; not by ramming down the packing and greasing it as in the case of an ordinary piston, but to plat the gasket into a large square, soak it with grease, and so fit it into the groove made to receive it. It was not desirable afterwards to put any grease upon the packing—which had a tendency to make it set—but rather to trust to the first greasing. It was not advisable to grease the plungers, with oil, tallow, or other similar matter, but to trust entirely to water; the packing being set just so tight that a small quantity of water could pass round the plunger: then as the plunger rose (which it did much more rapidly than in the case of the accumulators of hydraulic presses) it carried the water with it, and as it descended the water fell and the cup became again filled. A small quantity of waste might be allowed, which it was easy to regulate. In that way he believed the friction was reduced to a minimum. There always had been great hesitation in regard to the idea of conveying hydraulic power by suction to any distance from the point where a pump was placed. It was generally believed that it was desirable to place a pump immediately over the water, and to get the action from the pump to the well as direct as possible, no angles or other irregularities being allowed. In a certain sense that was of course true, where there was an established well and pump, and where the continual presence of water in the well could be maintained. Some years ago, in constructing a large quantity of reservoir work, where he had miles of sunk puddle wall to make, at the depth of 12, 20, or 25 feet, instead of using portable engines and moving the pumps about in the course of the work, he employed fixed engines and pumps, and by a particular arrangement of suction pipes from the pump to the place where the water had to be lifted, he found that he could draw water 200, 300, or 400 yards; and if it had been necessary, he believed he could have drawn it $\frac{1}{2}$ mile. Such a thing was generally considered preposterous among engineers and contractors, but he had found it to answer well, and to be extremely convenient and economical. He believed, if it had been seen earlier that the suction pressure exerted by a pump could be carried to a distance of $\frac{1}{4}$ or $\frac{1}{2}$ mile, the idea of getting pressure the other way by pushing would have come into vogue earlier than it had done

Dr. SIEMENS thought the discussion should not be limited to that portion of the Paper which referred to hydraulic transmission and hydraulic presses. The Author had dwelt upon the subject of the transmission of power, and Dr. Siemens desired, therefore, to make a few observations on the general question. Hydraulic transmission, as had been correctly stated, was the most economical mode at present known. It had the advantage that in forcing water forward very little power was lost. As had been explained, the friction of the hydraulic ram could be reduced almost to a minimum, and the steam power was applied in the most direct manner to that resistance; in that respect, therefore, hydraulic power could be produced very economically, and the loss of power in transmission could be reduced to a small amount. But in regard to the application of the power to cranes or presses there was a loss—a loss which might be exceedingly small if the resistance to be overcome was nearly equal to the available force multiplied into the area of the working piston or ram; but if the load was small, the power expended remained the same as it would be if the maximum resistance was applied, and there was consequently great loss. It was interesting to compare that with the case of transmitted power by elastic fluids. In compressing air great power was lost, because the steam in urging the piston forward in the air-compressing pump reduced its volume and raised its temperature, and the rise of temperature occasioned increased resistance and loss. The elastic condition of the air was a source of great diminution of power in the first instance, but it was recoverable, inasmuch as the air engine at the other end could be made to work expansively, and thus recover that portion of power which was consumed in compression through loss of volume. But there remained the double loss of heat—the heat generated in the compressing pump, which augmented the resistance, and the heat lost in the working of the air engine, which lessened the pressure towards the end of the stroke of the piston. These losses could never be entirely avoided, but they might be reduced, he believed, to 50 per cent., by injecting spray into the compressing cylinder, so as to keep the temperature in compression and in expansion as uniform as possible. Professor Rankine gave the loss as 62 or 64 per cent., but that was under the condition of injecting no water, of compressing air and generating heat in its compression. There was no reason why the air engine should not be made to work as economically as steam. The air did not condense, but there was a loss of steam by condensation in the cylinder and in the pipes leading towards it. By injecting warm water into the cylinder the loss of refrigeration might also be avoided;

but that had never been done practically. In transmission air certainly would be less economical than water, for this reason, that water could be transmitted under a pressure of 1 ton or ½ ton to the square inch, whereas air could scarcely be compressed to such a degree; therefore it was necessary to deal with larger volumes requiring larger pipes and greater frictional surface. Nevertheless for many purposes air would be a preferable medium, as in the case of coal-cutting machines in mines, tunnelling machines, and machines in building, where water would be inconvenient. One mode of transmitting hydraulic power had only been partially alluded to in the Paper, such as that which took place at Schaffhausen, where turbines gave motion to quick-working pulleys, on which steel ropes worked, transmitting power to a considerable distance. Another mode in which such rotating power might be obtained, and which was obtained more frequently perhaps on the Continent than in this country, was by sending the water through high-pressure mains, and then making it work rotating hydraulic engines, such engines generally working with oscillating cylinders; that, he thought, was a handy way of getting rotative power. He might also refer to another mode of transmitting power to a distance, which, did not seem to have occurred to the Author, perhaps because it was of recent date, viz. by electric conductors. If the dynamo-electric machine were employed for the production of intense currents, such currents could be used for giving motion to electrical engines for precipitating metals and for producing light. The latter application was of practical interest, as it had actually been employed for the illumination of lighthouses, as well as to electric lamps armed with reflectors, so as to enable public works, such as bridges, to be carried on during the night, and for lighting large buildings. One or two facts might be interesting with regard to that mode of transmission. A 4-HP. engine would produce per hour a light equal to 1,000 candles; therefore 100 HP. exerted in that way would produce a light equal to 25,000 candles, or to 1,250 Argand burners, which would be equal to 25,000 cubic feet of gas burned per hour, representing a value, at 4*s.* 6*d.* per thousand, of £5 12*s.* 6*d.* The 100 HP. converted into an electric current could be conveyed through a copper rod 2 inches in diameter, and say a mile long; such a rod would give a resistance of only about ¼ electrical unit, which would not in any way impede the electric power. Therefore the power could be transmitted to a distance of 1 mile by means of such a rod of copper, and give there an aggregate amount of light equal to 25,000 cubic feet of gas. He thought that the method was of sufficient interest to be added to the other modes of transmission, especially as it was gradually coming into use.

Mr. E. MATHESON said while most engineers would agree that power could be transmitted by water more effectively than by compressed air, or by wire rope, for any but short distances, it was questionable how far the establishment of a special pumping apparatus for general use would be beneficial or desirable. The water companies had their mains in the streets, and the public might object to give to another power the right to take up the roadway and lay down their pipes. There had been a sufficient number of examples in this country already to enable engineers to form a judgment on the subject. Twenty years ago, at Leicester, the cranes in the goods station of the Midland Company were worked by water from the mains. At Burton-on-Trent, where the water was brought 12 miles from Lichfield, engineers were able to use the water from the mains to prove their boilers at 120 lbs. to the inch. Although the water companies in England did not generally favour the use of their water as power, there was no reason why the system should not be introduced. With regard to the use of water engines on the Continent, he had been much struck with the admirable manner in which they had been applied. At Zurich, at the point where the waters of the lake flow into the river Limat, the stream, being very rapid, was used for driving water-wheels and turbines. Lake water for the supply of the town was pumped up, partly by means of the water power thereby obtained, and partly by auxiliary steam engines. The water was taken from the lake about ½ mile from the pumps, to which the water flowed through cement pipes and filters constructed in the bed of the river. Two systems of pumps were employed; one forcing the water to a reservoir 140 feet above the lake, and the other to a reservoir 280 feet above the lake. The higher-level reservoir was established principally to supply houses situated in the higher part of the town; but the mains in the lower part could be charged with the high-pressure water, and were so charged in cases of fire. The average pressure in the mains at the different levels was about 50 lbs. to the square inch. The water, besides being used for domestic and municipal purposes, was utilised as power by means of small engines, the private property of the users. The engines served also as meters; and by ordinary engine counters the consumption of water was registered, payment being made at a tariff of 50 centimes (*5d.*) per indicated HP. per hour. The engines varied in size from ⅓ HP. to 4 HP., and in 1875 one hundred and thirteen were at work for the following purposes: nineteen in nine printing-offices; fifteen by lithographers, bookbinders, dentists, and for sewing-machines; seventeen by pianoforte-makers and joiners; eighteen for working lathes, bellows, &c.; nineteen for weaving, sausage-cutting, &c.; four in the laboratories of the Polytechnic and University; one for the bellows of an organ; six for hoists, cranes, and miscellaneous purposes; four for portable wood-sawing machines in the streets; and ten for portable winches for hoisting materials for buildings in progress. The portable machines and the winches for hoisting building materials were worked in a peculiar manner. In the first case, a band-saw machine was fixed with a small water engine on a carriage with wheels, and perambulated the town to saw firewood in the streets. The engine was attached in a few moments by a canvas hose to the nearest street hydrant; another hose took the exhaust-water to the gutter. The sawing being finished, the engine was speedily disconnected and moved on. Where a new building had been commenced, a winch with water engine was fixed at some convenient place for hoisting the materials, and by means of hose attached to a street hydrant, the requisite power was obtained during the weeks or months the building was in progress. The water engines were very popular in Zurich; and although the tariff of prices much exeeded the cost of fuel necessary to produce similar power in a steam engine, the convenience to the user of having power available at any hour, and of paying only for what he actually consumed, without the trouble, dirt, or inconvenience of boiler, furnace, chimney and stoker, was very great. The tariff compared favourably with that at Hull. Of the one hundred and thirteen engines classified above, sixteen were below ½ HP.; thirty-nine ½ to 1 HP.; eighteen 1 to 1½ HP.; thirty-two 1½ to 2 HP., and eight above 2 HP. Of the one hundred and thirteen, ninety-two were made according to the system of A. Schmid, an engineer of Zurich. In 1876 the number of Schmid's engines had increased from ninety-two to one hundred and ten, and the number would have been greater if the pumping machinery had been equal to the demand. New works on a large scale had been commenced to increase the water power, by pumping to a reservoir at a level 500 feet above the lake. Water-wheels or turbines, equal to several hundred HP., were to be driven by the river, and in the night employed for pumping the water to the high-level reservoir, which by day could be used for industrial purposes, the power being transmitted across the river by wire ropes to various manufactories. Besides the system at Zurich, water power was conducted through pipes at other places in Switzerland, notably at Geneva, Neufchatel, and Berne. At

Schaffhausen an almost unlimited supply of power was afforded by the river, and, in addition to the system described by the Author, the plan had been under discussion of utilising the water power in air-compressors, and to take the compressed air in pipes through the town, to work small engines in private factories. If this were carried out, a comparison between the air and water systems might be made. For these statistics he was largely indebted to Dr. Emil Schinz, an eminent man of science at Zurich.

Of course, if water were used in England in the manner just described, there would be much less pressure than by Sir William Armstrong's accumulator system. It was, however, quite sufficient for ordinary purposes to work engines at 50 or 100 lbs. to the inch, and if a higher power were wanted it could be increased by what the Author had called an intensifier, but which, under the name of a "differential accumulator," he had used seven or eight years ago for working hydraulic presses.

Lieut.-Col. Clay remarked that the difficulty arising from the alleged necessity of exerting as much power to raise a small load as the maximum load which the machinery was intended to lift, had been got over to a great extent by a novel description of accumulator invented by Mr. Brown, in which steam was used instead of dead weight. By means of a differential valve the pressure of steam could be made to vary according to the load to be lifted. Another difficulty had been experienced in that as much power was required to lower a load as to lift it. In two lifts which he had made to raise 20-ton wagons 50 feet, one lift being 20 feet and the other 30 feet, after the load was lifted, and when the lift with or without a load was descending, instead of exhausting the water into the atmosphere without any pressure, he led the water back to the pumps which were feeding the accumulator, by which means the back pressure resulting from the descending load was to the advantage of the engine, and effected a saving of fuel. If, for instance, there was a full ascending load of 20 tons requiring 800 lbs. pressure, and if the next operation was to lower a 10-ton wagon, there would be a pressure upon the cylinder of 400 lbs., and, by leading that back to the valves of the pumps, the full advantage of the weight of the descending load was given to assist the pumps to raise the accumulator to do the work it had next to perform. That mode had been in operation for many years, and had acted satisfactorily in many ways.

Sir John Hawkshaw said Dr. Siemens appeared to suppose that hydraulic power to produce rotatory motion was applied on the Continent and not in this country. That was a mistake. In many cases, oscillating cylinders worked by hydraulic power had been used to obtain rotatory motion. As far as his experience had gone, they were, for the purpose to which they had usually been applied, more economical than any other method of applying power. He was now employing compressed air at a distance of nearly 3,000 feet, and using hydraulic pressure for about the same distance. There was, of course, a difference in the cost, but there were many cases where it was necessary to use compressed air. It was impossible to use water in places already flooded with water, and where it had to be pumped out again. Air was also wanted for ventilation, and in many cases, though it might be expensive, yet it was necessary.

Mr. Bramwell remarked that the room in which they were assembled was ventilated by a fan driven by a three-cylinder oscillating engine worked by water.

Dr. Siemens explained that he did not mean to say that rotatory power was not obtained in this country by oscillating cylinders, but as special reference had not been made to it in the Paper, he had thought it desirable to refer to it. The system was certainly used on the Continent to a much larger extent, and for commoner purposes, than in England.

Dr. Pole stated, as a matter of historical interest, that the idea of conveying power to a distance by pneumatic means arose before the invention of the steam engine, a scheme for this purpose having been published by the celebrated Denys Papin in 1688. The late Mr. Farey, an eminent mechanical authority, writing of Papin's proposal in 1827, said: "It is rather surprising that so simple and advantageous a method of exerting power at a distance from the first mover, should have remained neglected and unnoticed so long" Among the successful and useful applications of this principle in modern days might be cited the pneumatic tubes used for telegraphic and postal purposes, and the working of rock-boring machinery in long tunnels, and Dr. Pole believed it was capable of still more extended application.

Mr. Robinson pointed out on an Ordnance map, the line of main of the Hull Hydraulic Power Company in connection with the Queen's Dock of the Hull Dock Company (to which a branch had been taken off the Hydraulic Company's main), as there seemed to be an impression that the hydraulic systems of the two companies were in some way connected with each other; but it was not so, beyond the mere fact that the Hull Dock Company took advantage of the Hydraulic Company's main.

Mr. Ellington observed that the Hull Hydraulic Company as carried out had originated with himself, and he had prepared the preliminary plans and estimates. It was not claimed for it that there was any particular novelty in the machinery, or in the system of pipes and other appliances; which consisted simply in supplying power at a high pressure along the line of mains for cranes or other appliances. There had been a few difficulties, arising from old mains, drains, and so on, which might, of course, be met with in laying mains in any street; beyond that, the works did not present any special feature. The question had been raised as to whether the ordinary domestic service of the town would not supply sufficient power to do that which this line of mains was supposed to accomplish. In the first place, the water mains of a city were usually only charged with from 70 to 150 feet head, giving a pressure of 30 to 65 lbs. to the square inch, whereas the pressure in these mains was 610 lbs. The New River Company charged for water for the purpose of working hoists, &c., at the rate of 1*s.* 3*d.* per 1,000 gallons, which they insisted should be paid for by the amount of water delivered into a tank on the top of the building, seldom above 70 feet high. That would give a rate of 25*s.*, as against 4*s.* proposed to be charged by the Hull Company for the same amount of work. The ordinary domestic service required much larger machines, and consequently increased cost in the first instance. Moreover, the speed of work from the low pressure was not so great as from the higher. Means sometimes existed of supplying power on the high-pressure system without the use of steam engines, namely, where the water was laid from a high main brought down to low-level reservoirs, and then distributed to the town. In such cases it might be arranged to use the water from the high-level reservoirs to keep up a higher pressure on the mains specially laid. With regard to the useful effect of the water supply in high-pressure services, the Author had assumed throughout that 80 per cent. of the effect of the water pressure was obtained in actual work. That could only apply where the multiplying power was low; and it would be found that the actual consumption of water, to do a given duty, was much greater than he had stated. With the Hull Dock Company's cranes, although at the maximum rate the percentage was about 70, in actual work it was 40 or 50; and moreover, that percentage of effect was not directly in proportion to the multiplying power of the cranes. In some instances the percentage of effect, when the multiplying power was as high as 6 to 1, had been 90 per cent.; whereas the direct-acting ram had not given a higher percentage, that being due to the fact that the higher percentage, when the multiplying power had been 6 to 1, had been gained when the ram was much larger than in the case of the direct-acting ram. There was, therefore, a compensation to be introduced in accordance with the diameter of the lifting ram. Mr. Carson, Engineer of the Wallasey Local Board, had lately made some experiments with a view of getting rid of the danger from frost, in some hydraulic machinery under his charge, which was in an exposed position. He had tried soft soap, starch, glue, and glycerine and water, and found that glycerine and water, in the proportion of 1 to 4, was sufficient down to a temperature of 16° Fahr.; but the glycerine should have a specific gravity of 1·125, because refined glycerine would not bear that temperature. Having considerable difficulty in getting the glycerine to the requisite specific gravity, he, in the first instance, mixed methylated alcohol with glycerine and water, but the spirit evaporated, and therefore was expensive. He afterwards found that, if the glycerine and water were thoroughly well mixed, in the proportion of 1 to 4, it would do without any spirit. He accomplished that object by putting glycerine in a tank, and blowing a steam jet through it.

Mr. WAWN thought the Author was particularly fortunate in having to apply the principle of co-operative power to supply the town of Hull, a place well adapted for such an experiment. With few exceptions, the whole of the mills and private warehouses were arranged in one close line down the side of the river, so that the proportion of unproductive pressure main should be small. As had been said, no doubt water could be drawn a considerable distance along a horizontal pipe, but he did not see that water so put in motion could be of much use for the transmission of power to machinery. Obviously it could not be applied to turbines; and as the pressure could not exceed 10 or 12 lbs. per inch, it would be of no use in hydraulic machines such as those referred to in the Paper. The loss of power in lifting varying weights by hydraulic machinery had been a source of difficulty from the first. The combination of water and steam in Mr. Brown's arrangement of the accumulator was all very well, so far as it went, but the application was necessarily limited. The defect in this principle was that the most heavily loaded crane or machine for the time being regulated the pressure throughout the whole system, and in fact became to a certain extent the accumulator. In a large plant of machinery it was seldom indeed that one crane at least was not working up to its full power, and so there was an end to any idea of economy. It appeared to him, in order to effect economy, that the power should be proportioned to the load at the machine itself, and not at the accumulator. Experiments of that kind had been carried out to a considerable extent. Cranes had been made with two or more rams, one within the other, and other cranes with a combination of the ram and piston. Another obvious way of getting up the power was by doubling the lifting chain. The ordinary rotary hydraulic engine had been made with three powers by the combination of the ram and piston. In 1864 a hydraulic coal lift of peculiar construction was erected at Goole, by Sir W. G. Armstrong and Co., for the purpose of lifting the canal boats, and tipping the coal down a shoot into sea-going vessels. The weight of coal to be lifted each time was 33 tons, the boat weighed 8 tons, and the working parts of the machine to be lifted about 35 tons. This large proportion of dead load made it necessary to provide special means for economising the water. The lift, a distance of 28 or 29 feet, was taken by two cylinders, so close together that either of them was nearly over the centre of gravity. In lifting, both were open to pressure, and in lowering, one only was open to the exhaust, the other forcing back its water into the pressure main. For the last foot or two of the lowering it was necessary to open both cylinders to exhaust, on account of the empty barge floating, and parts of the machinery being to a certain extent water-borne. Special lowering machines had been made in some cases, where the power given out by the descending load had been stored in the machine itself, and used over again for lifting the light chain, the only power taken from the pressure mains being that required to lift and swing the load clear of the hatchway. Allusion had been made to the manner of packing the stuffing box of the accumulator. He had seen it done in many ways, and foremen and enginemen had their own ideas on such subjects. Many simply twisted up the hemp like a common hay band, and thrust it into the stuffing box, and a very good joint it made. A slight leakage at the gland certainly reduced the friction.

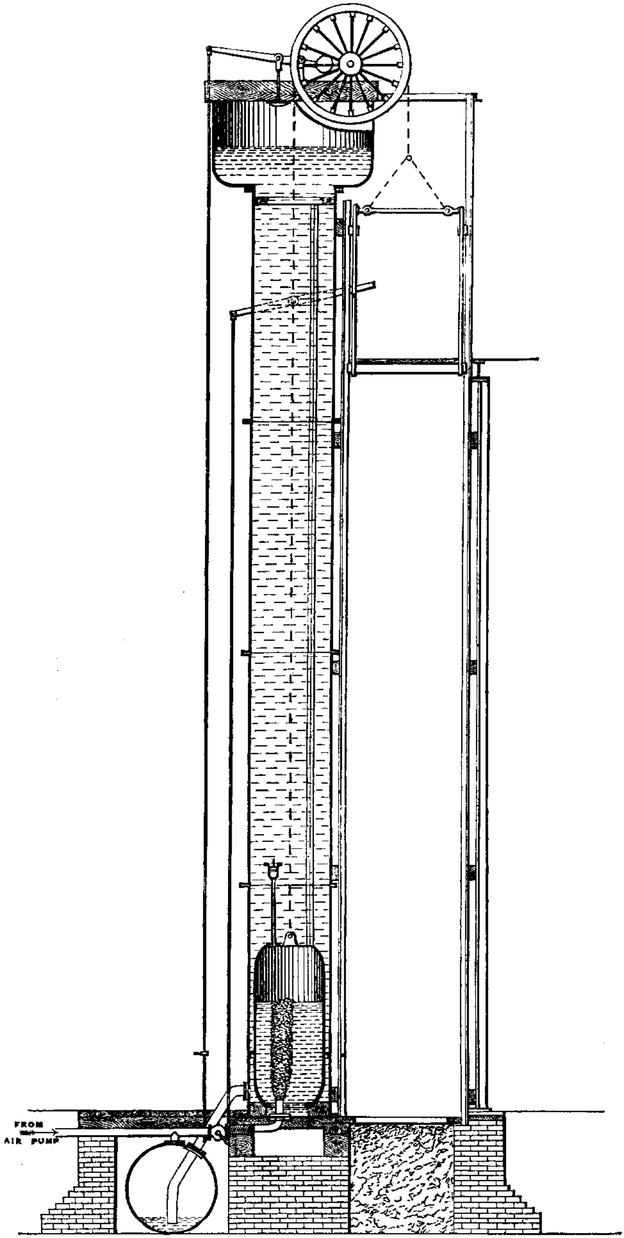
Mr. J. Mackenzie observed that when the transmission of power by compressed air was effected by pumping from the atmosphere and conveying it under pressure in pipes to an air engine, after driving which the air was allowed to escape into the atmosphere, a portion of the power was expended in the air pump in compressing the air to the required pressure, and at the same time in heating it; and while this compression was going on the discharge valves of the air pump remained closed, and no air was propelled through the pipes. If the temperature to which the air was heated by compression could be maintained, and the air conveyed at this temperature to the air engine, and if the air could be expanded in the engine down to atmospheric pressure before escaping, no loss of power would be entailed by the operation; but these conditions were not attainable, and the higher the pressure the more difficult was it to approximate to them, so that it was not practicable to work beyond a moderate pressure. If, however, to obtain a certain working pressure the air pump was used to pump from one receiver containing air at a considerable pressure to another at a still higher pressure, the difference between the two being the working pressure, the power expended in compressing the air was much lessened. For instance, an air pump drawing from the atmosphere and delivering at a pressure of 5 atmospheres would compress air for four-fifths of its stroke, and propel air through the pipes during only the remaining one-fifth; while, in pumping from a receiver charged with air at a pressure of 16 atmospheres to another containing air at 20 atmospheres, the pump would compress air for only one-fifth of its stroke, and propel air through the pipes for the remaining four-fifths. In both cases the working pressure would be 4 atmospheres. In this estimate no account was taken of the increased volume of the air due to heating, as the apparent advantage from this cause would be counterbalanced by a corresponding diminution of pressure in the air engine through cooling during expansion. Neither was any account taken of air left in the passages at the end of the stroke; the effect of which, in reducing the quantity pumped, would be to a great extent obviated by working with a back pressure. The power expended in compressing during one-fifth of the stroke could be recovered by working expansively to the same extent in the air engine, as the necessary amount of expansion would correspond with the working of an ordinary slide valve. By working with back pressures it would be possible to use working pressures which could not be approached under the ordinary system, and which would only be limited by the increased loss from leakage at high pressures. With higher pressures the pumps, pipes, and air engines could all be made smaller; but against this would have to be set the cost of the exhaust pipe and of the superior workmanship which would be necessary. With long pipes no receivers would be required, as the pipes themselves would act as such. There would, therefore, probably be little difference in the first cost of the two systems, leaving all the economy in power to be set to the credit of the proposed system of working with a differential pressure.

Mr. TWEDDELL said he had seen the engines, and other works at Hull, and could speak to the excellent character of the work throughout, and the credit due to the Author as the Engineer. There was nothing novel in the machinery itself, which was of the usual Armstrong type; it had the defect of that style of engine, namely, too slow steam-piston speed, and he considered better efficiency would never be attained from the pumping engine itself until the engine ran at a faster piston speed than that of the pumps. The advantages would be obvious to any mechanical engineer; 76 per cent. was, in his opinion, a high efficiency, and higher than was borne out by previous experiments, which averaged generally from 70 to 72. Referring to hydraulic power as employed in docks for working cranes, jiggers, hoists, &c., the Author stated that cranes capable of travelling were preferred to stationary ones. The general experience, in this country at all events, was that travelling cranes had not up to now been preferred. There were few docks in England where travelling hydraulic cranes were in use, or at all events they bore no proportion to those in which fixed ones were used. At the same time, they were used in Hamburg and other places, and had their advantages. The fact had been alluded to, that with hydraulic power rivets were closed by a squeeze instead of by the blow of a hammer. As far as he was aware, in the most approved machines the effect of a blow could be obtained, quite as efficiently by using an accumulator of suitable form as by any other means, and by the intervention of such an accumulator, namely, one which by its proportions gave a sharp blow as well as steady pressure, the field for the employment of water power was even larger than that shadowed forth. He had devoted some attention to the use of hydraulic machinery on board ship for lifting and discharging goods; but he would be glad to hear where such machinery was in actual use. There was ample field for its employment on board ship. His idea was, that having already mains along the dock and quay to make a connection to the ship lying alongside, the hydraulic cylinders and crane being on the vessel itself, there would be nothing to do when the ship came alongside but to couple up to the main, provision being made for the rise and fall of the ship when there was a tide. As to the friction of water in pipes, some interesting facts had been mentioned to him by M. Barret, the Engineer to the Marseilles Dock. It had been proved by experiments made with considerable care that the results obtained in practice, as compared with those by various known formulæ, showed great differences. For instance, the pressure of water in Marseilles was 760 lbs. per square inch. The main was divided into straight lengths, and in one length of 350 yards the loss of pressure was 63 lbs. per square inch, whereas D'Arcy's formula would give a loss of only 24 lbs. to the square inch, or a difference of nearly 39 lbs. Such discrepancies as these made the question of friction in pipes appear still uncertain at these high pressures. The next point was as to the cost of water power, and on this he could not agree with the Author. The average cost of water delivered in the mains was stated to be 1·22*d.* per 100 foot-tons, or after deducting interest on appliances nearly 6*s.* per 1,000 gallons, and yet the Hull Power Company were supplying it at 4*s.* Of course there might be circumstances which would account for this, but on the face of it the figures seemed impossible to reconcile. There could be no question that for transmitting power to a great distance water pressure was the most practicable method, but its relative economy, as compared with other methods of transmission, could not be judged of from any figures given in the Paper; nor could any fair comparison be made from the cost of the water delivered into the mains, but only as was done in the case of steam, from estimating the cost at the end of the crane chain when lifting the load itself, in other words the cost per 100 foot-tons of actual weight lifted—not per 100 foot-tons of work done in delivering the water into the dock mains.

Mr. T. Wrightson observed in reference to the the loss of pressure in the passage of water through pipes, that the Author had remarked that " water passing from a small pipe through a large one, and then to a similar sized small pipe, will return to its original pressure after the interval of increased pressure, provided there are well-tapered junctions at the points of change" (*ante*, p. 8). The power which water exerted in pressing its way through an opening must be regarded as potential energy possessed by the water. If a certain amount of this potential energy were developed in the form of velocity in passing through the constricted aperture of a valve, this represented so much work done by the water. Given a certain weight of high-pressure water passing through a small valve at a high velocity; then the number of foot-lbs. realised in the form of velocity was represented by the weight of the water in lbs. multiplied by the height in feet from which it would have to descend to attain that velocity. And the whole of this disappeared as mechanical energy except that represented by the velocity of the water after it had passed the valve and moved in the enlarged cylinder where its work was performed. Thus, if 100 feet per second were the velocity through the valve, and 2 feet per second the speed of the liquid in the cylinder, the difference, 98 feet per second, was entirely lost in fluid friction. This would represent a loss in head of $\frac{98^2}{64} = 150$ feet. If, however, the valve were doubled in area, so as to halve the velocity, the loss of head in feet was only one quarter, varying as it did with the square of the velocity. Hence the desirability of having large valves to reduce as much as possible the element of loss.[1] When he was at Elswick, fifteen years ago, it was the practice to take the effective pressure generally at 450 lbs., or 64 per cent. of the original 700 lbs. accumulator pressure; and 64 per cent. of the Author's 76 per cent. efficiency of engine left 48½ per cent. as the efficiency of the whole system of transmission, which compared fairly with the average results of Mr. Hawthorn's experiments at Marseilles.[2] As the subject of the pneumatic transmission of power had been touched upon, he wished to draw attention to a system he had introduced some years ago for utilising air-pressure in lifting weights. It was one which worked out with extreme simplicity, and possessed some novelty (Fig. 1). It was a hoist made for lifting weights to a cupola. Over a sheave a chain was passed with a balance weight at one end and a cage at the other. This balance weight was made hollow, and worked up and down in a vertical tube of water. When the cage was at the top, the balance weight was the heavier. In order to make it lighter than the cage, to enable the cage to come down, he introduced a charge of compressed air inside the balance weight, which at once displaced part of the water, thus making the weight so much lighter than the cage, that the cage descended by its own gravity. The light barrow was taken off, and the charged barrow put on. As soon as the man was ready to go up he pulled a valve-rod, and the air whistled out at the top; the water entering at the bottom of the balance weight, it became the heavier of the two, and drew up the cage. The whole operation was first making the balance weight heavier, and then lighter than the cage. As it rose, of course all the water had to pass the side of the balance weight; at the top and bottom of the tube he contracted the passage so that as it came near either end of the stroke the water had to pass through a reduced area. This made a most effective brake, so that as it came

[1] *Vide* Rankine's "Manual of Civil Engineering," p. 677, edition of 1862.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., p. 159 *et seq.*

Fig. 1.



Hydro-pneumatic Hoist.

to the top or got to the bottom, the cage was gradually brought to a stand. Having had the hoist at work for some years, he found there was so little to get out of order that the repairs were absolutely nil. The air was compressed into a reservoir worked by a 9-inch pump attached to the engine, which also blew the cupolas. He had taken out the quantity of coal used by the engine, and estimated the amount of power taken up in driving the small air pump which kept it going, and the proportion was 6 per cent. of the whole of the coal used. The number of foot-lbs. expressed by a diagram of the air cylinder was 6 per cent. of the number of foot-lbs. expressed by a diagram of the steam cylinder. The quantity of coal burned per day was 15 cwt.; the hoist raised 60 tons per day, and consequently for 0·82*d.* (taking the cost of coal at 10*s.* per ton), he could lift 100 foot-tons. A larger quantity could no doubt be raised at less tonnage cost, and there appeared no reason why the system should not be worked in higher lifts than had already been so successfully tried. The advantages of this arrangement were :—First, the small engine power required, the air pressure accumulating in the reservoir being given out as needed, any overflow of air simply bubbling up through the tube and escaping. Secondly, that no attendance was required beyond that of the chargers. Thirdly, that the brake being automatic, and not liable to get out of order, the hoist could not run away, and was therefore safe. Fourthly, that the power exerted was exactly in proportion to the work done, as immediately the bell moved from the bottom or the top, the valve closed. Fifthly, that as the apparatus worked in water any escape was at once detected and easily remedied. Sixthly, that the valves were so simple, and the moving parts so few, as to be little liable to derangement. As allusion had been made to the transmission of the force of light to distant points, he might mention that he had lately introduced Dr. Siemens' system of lighting into the bridge-building works of Messrs. Head, Wrightson, and Co., in order to enable the men to work by night. So far the application had been successful, a large area being lighted by a lamp of 1,000-candle power actuated by the electrical currents from a dynamo-electric machine of 1½ HP. The light was intense, and in order to distribute it properly, reflectors of a special form had been necessary.

Mr. Benjamin Walker said, as far as the application of hydraulic power to large towns was concerned, he fully agreed with the Author. For large centres of industry, as Leeds and Manchester, hydraulic power might be usefully employed, but it should be done not by separate companies, as at Hull, but by the people who supplied the drinking water. For many years Leeds had been accustomed to allow the public to use water for the purpose of driving hoists or small machinery, at 6*d.* per 1,000 gallons. The pressure amounted to 70 lbs. to the square inch, and for many purposes it was useful and economical; with 700 lbs. to the square inch, the original cost of the machinery would be materially reduced. So far as the general use of hydraulic cranes was concerned, the old-fashioned hydraulic jigger, invented by Sir William Armstrong, with one long ram and several chain pulleys had as yet no equal; no other contrivance could be compared with it for doing work rapidly and cheaply. When the same hydraulic power was applied to drive a small rotary engine it came to be a different business. A defect in the Paper was that a comparison was made between ordinary shafting for driving machinery and hydraulic power for performing the same object. Having paid a great deal of attention to driving woollen machines, he found the friction arising from the steam engine and the shafting was not more than 15 per cent., while in some cases it was as low as 10 per cent., whereas the Author put it at 37 to 32. Taking a large mill in Leeds with 3,000 feet of shafting driven by about 600 HP., and with hundreds of belts, the friction of the compound engine, the shafts, the belts and pulleys, was only equal to 120 HP., or less than 20 per cent., and that was above the average of the large mills in the district, many of which did not give more than 10 per cent. It was further stated that the depreciation and interest in hydraulic machinery were to be taken at 15 per cent. This was far too much. He knew several hydraulic engines erected by Sir William Armstrong that had been ten or twelve years at work, and they were as good now as on the day they were erected. His firm had put up, at Marsh Lane, on the North-Eastern system, four years ago, hydraulic machinery for working goods warehouses, which had only cost £32 for repairs. Ten years ago he erected four or five of the largest hydraulic accumulators for the Bessemer apparatus in Sheffield, and they were as good now as on the day they were erected. Eight years since he had the pleasure of erecting, in Russia, a large Bessemer plant on the hydraulic principle, the water used being that out of the river; and the only pipe that had burst from frost was a small one belonging to the cupola. There was no difficulty at all, provided the cold was kept out. He believed if the Author were to attempt to drive Briggs's mill with a hydraulic engine at the end of each shaft, and do away with all the gearing, it would take six or seven times the quantity of coals, and would cost twice as much money to begin with. Reference had been made to the use of compressed air at Portsmouth. Having made the capstans to be driven at Portsmouth by compressed air, he believed they would consume a great deal less coal than if they had been driven by hydraulic power. That did not prove that hydraulic power was not a good thing, yet for many purposes compressed air was the more advantageous medium for conveying power.

Colonel MARTINDALE, C.B. (General Manager of the London and St. Katharine Docks), said extensive additions were in progress at the Victoria Dock, opposite Woolwich, which would make it $2\frac{1}{2}$ miles long; and of course it had been under consideration what description of hydraulic crane should be used. He had been in communication with Mr. Birt, the General Manager of the Millwall Docks, and he, after a lifetime of experience, said if he had to recrane that dock he should use nothing whatever but movable hydraulic cranes; that the advantage of bringing the crane to the hatchway, instead of having to bring the hatchway to the crane, more than counterbalanced any disadvantages of the movable as compared with fixed cranes. In the St. Katharine, London, and Victoria Docks at present fixed cranes were used entirely, but reports of the movable hydraulic cranes at Calcutta were extremely favourable. The result of these reports and of the information received from Mr. Birt was that the company were about to try two movable hydraulic cranes in the London Docks, and had at present under serious consideration the question whether the cranes in the great addition to the Victoria Dock were to be movable or fixed. They had not arrived at any decision, and were seeking the best information as to their relative merits. The difficulties arising from almost every ship having hatchways differently placed, and the vexation given to shipowners and the trade generally by having to move ships to use the cranes, or the loss of power by the use of leads, were great arguments in favour of the movable cranes. Allusion had been made to the cost of working hydraulic power in the St. Katharine Dock. In that dock, owing to the want of space for the boilers, the peculiar construction of the engines, and the necessity of using gas coke instead of coal, the cost was considerably in excess of the cost in the London Dock, and that again was considerably in excess of the cost in the Victoria Dock, where some new compound engines had been erected by Sir William Armstrong, which had largely reduced the cost of hydraulic working. For the last twelve months experiments had been going on in each dock with different kinds of fuel, and the result had been considerably to reduce the cost of working, and he believed it would still further be reduced.

Mr. H. DAVEY said the subject of the Paper implied three distinct operations. First, the production, secondly, the transmission and distribution, and, thirdly, the application of power. It was obvious that in transmitting power by shafting or wire ropes little loss of efficiency could occur in the production of the power and in its application; the greatest loss would be experienced in its transmission. On the other hand, it was also obvious that with compressed air or water, used as media, there must be considerable loss, both in the production of the power and in its application, because in addition to the steam engine, which was the prime mover, there must be the compression pumps to produce the power, and there must be an engine to work by means of compressed air or water pressure to apply it; but in the transmission of the power there was much less loss than was occasioned by the use of shafting. The transmission occasioned little loss of efficiency provided the pipes were sufficiently large; but there was great loss in its application, especially in the cranage of goods. Several expedients had been tried to reduce the loss due to the system by the introduction of rams, using one or more as necessity required. Some years ago he put a hoist to work with two rams, precisely in the manner described by Mr. Ellington, and until the present time he had been totally unaware that such an arrangement had been carried out by others. In cranes he also introduced a small ram for the purpose of lifting the chain and hook alone, so that when the crane was used as a delivery crane no more water was used in the operation than that necessary to lift the load from the platform. When it was used as a landing crane the loss of efficiency was precisely similar to that of the ordinary crane. The Author gave 80 per cent. as the efficiency of the hydraulic system, but in the cranage of goods he did not think the real efficiency would amount to more than 25 per cent. One of the principal losses due to the use of hydraulic machinery was owing to the great velocity of the water through the valves. In using water at high pressure it became difficult to work the valves if they were actuated by metallic connections, and therefore the valves of hydraulic machines were usually small, and the water was driven through them with great friction, causing great loss. This was a subject to which he had given considerable attention for some years in connection with the application of water pressure to the drainage of mines. The main engine pumped water from a point in the vertical shaft, say two-thirds of the distance from the surface, and the other third of the lift was performed by a stationary hydraulic engine. For draining the "dip" and distant workings a small hydraulic engine was mounted on wheels, and connected by a pipe with the rising main, and it pumped the water back to the large hydraulic engine. In carrying out this system the loss of efficiency should be reduced to a minimum, and to accomplish that object he schemed for some time to obtain a valve of sufficient area to allow the water to pass through the engine without undue friction. He selected a velocity for the water of 200 feet per minute, such a low velocity producing little loss from friction; and the hydraulic engines made on that principle had been provided with valves, having their areas sufficiently large to reduce the speed of the water to 200 feet per minute. It was quite easy to estimate from the proportions of the engines what was their efficiency, because there was a constant pressure to deal with, and a constant head to pump against, and the efficiency of the machine was found to be 80 per cent. In the smaller dip engines the efficiency was 75 per cent. How the valves were to be constructed to bear such heavy pressures, and still to be worked easily, was the problem he had before him. The valve was entirely inclosed within the pipe supplying water to the engine. There was no metallic connection between the engine and the valve, but there was a plug working at the side of the pipe. The lever being actuated by reciprocation of the engine caused the plug to admit water and exhaust it alternately to and from the space in the centre, and the result was the large valve copied the motion of the small one. A valve made on that construction might be provided, without any mechanical difficulty, with passages sufficiently large to prevent the great loss usually experienced by the use of small valves. If hydraulic engines were to be applied to various other purposes indicated by the Author, it was quite necessary to have rotative hydraulic engines. He was not aware that there was a rotative hydraulic engine in existence capable of working with varying quantities of water to suit the requirements of the machines driven by it, and that was one of the most important considerations connected with the subject. He had designed two hydraulic cylinders, and connected with the plunger, which entered the two cylinders, was the connecting rod driving the crank. In the valve boxes he proposed to place valves similar to those just described; and the valves, by means of a conical pendulum governor, could be made to admit water through any portion of the stroke. As water was unexpansive, unless there was some means of filling up the cylinder the scheme would be impracticable, owing to shocks from the plunger suddenly striking the water. To keep the cylinder thoroughly charged with water and obviate those shocks, he proposed to have two pipes going from the cylinders dipping into the exhaust water tank, the pipes having valves opening towards the engine. The result would be that as soon as the admission of water had been stopped through the main valve, the plunger continuing its motion by virtue of the momentum acquired in the fly-wheel, would cause water to be drawn in, keeping the cylinder perfectly charged and preventing the admission of air.

Mr. J. O. Butler disagreed with the statement that hydraulic power was the best for working cranes at a railway goods warehouse. He was not prepared to say what was the relative cost of hydraulic power and of shafting; but he could refer to several instances in Liverpool, where the shaft principle for working cranes had been adopted, and the way it was done was this: there were shafts in tunnels underground, where all the bearings and gearing and hoisting and lowering apparatus were fully exposed, and could be got at for lubricating and for attention to the working parts. The power was taken thence to the upper floors by upright shafting, and the hoisting and lowering done by friction drums and apparatus driven from the line shafting in each floor. If it was the better system railway managers would adopt hydraulic power in preference to the shafting. He believed the shafting principle, for working cranes in stations, was far preferable to hydraulic power; for it must be remembered that power was required to work the hydraulic system; and what with the leakage of the pipes and the accumulator, and the expense in the first instance, he questioned whether it was the more economical.

Mr. Rich observed that by far the larger portion of the Paper was devoted to the discussion of high-pressure hydraulics, and comparatively a small space to compressed air. Now, though he by no means claimed that compressed air was so suitable as high-pressure water for many purposes where hydraulic power was now used, there were circumstances in which air might be employed on a large scale in preference to water. For tunnelling and mining operations most engineers were agreed as to its advantages; but for warehouses and wharves also it possessed many good qualities, for it avoided all risk of damaging goods by leakage; the pipes might be exposed without fear of frost, no return pipes or drains were necessary, and the heaviest or lightest loads could be raised with comparatively little difference in the economy of the power medium, while hydraulic cranes only worked economically under maximum loads. The size of the pipes for conveying compressed air about the Erith Ironworks, viz. 8 inches and 12 inches in diameter, had been commented upon. Those sizes were by no means necessary to minimise the friction, but had been adopted to serve as accumulator or storage room. For the same reason 12-inch mains had been used in the large compressed-air plant at Portsmouth Dockyard; and similarly at the General Post Office, the large mains constituted the only reservoirs of the low-pressure air used for the pneumatic despatch system. The power derived from town mains for working hoists was also an important question. A 10,000-gallon tank at the top of an hotel 100 feet high stored in a simple manner 4,464 foot-tons of energy, or thirteen times as much as a 10-inch accumulator with 14 feet stroke, 700 lbs. pressure; while a small steam engine and pump would return the water used to the high tank at a much smaller cost per foot-ton than could be done with a high-pressure accumulator and pumps. Under such arrangements virtually no water was required to be purchased from the water company for power purposes.

Mr. W. H. Barlow, Vice-President, said when acting as one of the judges at the Centennial Exhibition at Philadelphia in 1876, one of the matters which came under his attention and special jurisdiction was the subject of transmittors. It was quite true that the exhibitors did not show water pipes, and therefore the question of transmission by water had not been raised; nor did they show telegraph wires or transmittors of electricity; but what they did show was belting, wire rope, and other things. The belting was of a remarkable kind, large numbers of belts being 28 inches in width and $\frac{1}{4}$ inch in thickness, and so beautifully made, that in working over the drums the contact between the leather of the belting and the metal was so great that all the air was pressed out, and the atmospheric pressure upon the belt was sufficient without any straining between one shaft and the other. The drums were 10 feet in diameter, were often made in one casting, with two sets of arms, the turning of the drum being very accurate, and the manufacture of the belt being very good. The principal shafting exhibited in the building was peculiar. It was of very good iron, rolled in the first instance while hot, then subjected to an acid process which took off the scale, and after that rolled cold. The result was a most perfect production of a circular shaft, with a completely polished surface. There were more than 2,000 feet of this shafting at work in the building, with an extremely ingenious contrivance for connecting the shafting at the ends, whatever might be the diameter. The next thing in the way of transmittors was wire rope. The wire-rope exhibition was remarkable; it was by Roebling, whose name was well known in connection with bridge-building in America. One rope now being made, for the bridge to be constructed between New York and Brooklyn, had a diameter of 16 inches, and the span of the bridge was 1,595 feet. It was composed of six thousand strands of cast-steel wire, each wire being capable of bearing a strain of 75 tons to the inch.

Mr. VALPY observed that the Hull Act had been spoken of as the first of the kind. That was an error, as there were others before it. He himself, and his partner, Mr. Burrell, were engineers for a similar Act for London, which was still in force, though it was passed a year prior to the Hull Act. The Hull Bill was promoted by the same solicitor who obtained the London Act, contrary to the understanding that had been entered into. Sir William Armstrong's firm gave evidence in support of the London Bill, and the directors had such confidence in the undertaking that they were prepared to subscribe one-half the capital; but the action taken by the solicitor in promoting the Hull Bill with other parties had destroyed that confidence which was essential in such matters.

Mr. LEE THOMAS observed that of the three methods of transmitting power over long distances treated of in the Paper, viz. by water pressure, compressed air, and wire rope, the two former had been fully and ably discussed; whilst the latter had been the subject of only a passing allusion. Yet the transmission of power by wire ropes running at high velocities was not altogether unworthy of the attention of engineers. In this country its application was novel, but it had been largely adopted on the Continent and in America. Continental engineers had investigated fully the theory and conditions of its action, and from their inquiries it would appear that power could be transmitted by a single rope a distance of $\frac{1}{2}$ mile with a loss not greater than 6 per cent. He was aware of no other method of transmitting power by which a similar result could be shown. In the case of transmission by water pressure there was the friction of the force pumps charging the accumulator, of the accumulator itself, of the high-pressure water in the pipes between the two terminals, and of the machine using that water; an amount of friction that would vary in each case according to the nature of the application, but would always be considerable. He would direct attention to an example of the application of the wire rope system of transmission of power to mining purposes which had come under his observation whilst travelling in Portugal. The case was of interest on account of the steep gradients over which the power was carried, the hill traversed having an altitude of 600 feet. The source of power was a fall of water of 40 mètres, distant 888·80 mètres horizontally in a direct line from the mine to which it was desired to convey the power for pumping and drawing purposes, and as the mine was at a considerably higher elevation the water could not be conveyed to it by the ordinary means of a mill race and launders. The fall of water was utilised by a turbine, on the axle of which the first pulley of the system was keyed—this pulley consequently making one revolution for one of the turbine. The horizontal distance of 888·80 mètres between the centres of the first and last pulley of the system was divided into seven spans as under:—

	Horizontal Measurements between centre and centre of Pulleys.	Vertical Rise from centre to centre of Pulleys.
	Mètres.	Mètres.
Between pulleys No. 1 and 2 . . .	85·00	58·84
„ „ „ 2 „ 3 . . .	93·50	37·25
„ „ „ 3 „ 4 . . .	160·00	35·00
„ „ „ 4 „ 5 . . .	160·00	52·00
„ „ „ 5 „ 6 . . .	75·00	about 5·00
		Fall.
„ „ „ 6 „ 7 . . .	157·65	46·50
„ „ „ 7 „ 8 . . .	157·65	31·50
	888·80	

so that in the horizontal distance, 573·50 mètres, between pulleys No. 1 and 6 there was a vertical rise of approximately 188 mètres, and in the distance 315·30 mètres between pulleys No. 6 and 8 a vertical fall of 78 mètres. The pulleys were 4·12 mètres in diameter, say 13 feet 6 inches, and the wire rope was of steel galvanised, composed of thirty-six wires of No. 18 B.W.G. With the turbine making 80 revolutions per minute, the speed at which the rope travelled would be about 38 miles per hour. At the mine there was a simple machine by which, through the medium of bevel and spur gearing, the requisite alterations in direction and speed for pumping and drawing were obtained. Sir William Armstrong, with whose name hydraulic machinery would always be inseparably connected, had made use of a fall of water at Allenheads to drive water-wheels working force pumps charging accumulators, the high-pressure water being conveyed in pipes to the point required for working machinery at the mines. It would be very interesting to mining engineers if they had sufficient data to enable a comparison to be made of the economic and other results of the two systems of working. He quite coincided with the conclusions of the Author that each of the three systems had its own particular field of application, and that no hard and fast line could be drawn prescribing the universal application of either of them. For such purposes as the Author had used water pressure at Hull, it was, he believed, the most suitable. Indeed, where the machinery to be put in motion was intermittent in its action, and when the connections and ramifications were numerous, they were made with great facility under this system, and the wear and tear were small. Again, transmission of power by compressed air, although the loss of power was considerable, had a special value for mining purposes, and the progress it was making in this field of application was a sufficient proof of this. The Author had not alluded to an old system of transmitting power, that of flat rods, which had in its day been somewhat extensively applied to mining purposes. By this method power developed by a steam engine, water-wheel or other prime mover, was conveyed to a distance by a bar of iron, with a rectilinear reciprocating motion, running on pulleys. It was usually regarded as a somewhat clumsy contrivance, but it was a useful means of conveying surplus power to a distance for temporary or exploratory purposes, and when the work was truly fixed and balanced, and kept properly lubricated, it was not attended with an inordinate degree of friction. Messrs. West and Darlington had some years ago proposed to take advantage of the incompressibility of water for effecting the same object, so confined as to constitute as it were a hydraulic bar acted upon by means of plungers or pistons.

Mr. Robinson, in reply, said the reason he did not refer to some other systems was owing to the length to which the Paper had reached, thus preventing any, or only a brief, allusion to several methods. Many interesting points were also necessarily omitted for the same reason, so that he wished it to be understood that many of these points had not been left out from any want of appreciation of them, but to enable the Paper to be brought within reasonable limits. With regard to what Mr. Valpy had said, he was quite aware of an Act of Parliament having been obtained to carry out hydraulic power in London. All he said in the Paper was, that at Hull it was first practically used. More than ten years ago, he was engaged in obtaining an Act of Parliament for Liverpool and Manchester, but the bill had to be withdrawn on account of the opposition of the corporations of those towns. He had also proposed it for London long before the time referred to. With regard to Bramah's introduction of the hydraulic press, and the fact that he had foreshadowed the hydraulic crane as it was now known, it would be found that Bramah had been alluded to in the Paper; while at the same time it was stated that the hydraulic system, in its present wide field of application, was due to Sir William Armstrong. He had himself applied the system of sucking water in underground operations, though not to so great an extent as had been mentioned. It was a means of drawing water, rather than of conveying power, and was familiar to all who had had anything to do with underground operations. As the statement that hydraulic transmission was the most economical method at present known, had been challenged, he was glad to have it on record that his opinion had received the confirmation of Dr. Siemens, who also referred to the transmission of power by ropes at Schaffhausen. A considerable amount of information with regard to that would be found in the Paper. Dr. Siemens likewise gave an interesting account of the transmission by electric conductors; and that system would undoubtedly be much used in the future—even now it was employed in the North of England to light up a bridge yard at night, and was found to be extremely efficacious. As to the objection to special pressure mains being laid in towns where there were already gas and water pipes, that a third pipe would be necessary, he did not know that that was a good argument against the system. If the convenience of the public required a third pipe, it was certain they would have it. If there was any town where such an objection would apply, it was Hull, as the High Street, where the pressure pipe was laid, was narrow, and the traffic over it was similar to the traffic in Thames Street, London. But the corporation of Hull threw no obstacle in the way whatever, in fact, they gave every possible assistance. He did not think the objection to additional pipes could be urged in other places more than in Hull. A description had been given of an accumulator in which steam was used instead of dead weight.

It was, no doubt, very ingenious; but he did not think it would be of great use on a large scale, for the pressure, although capable of being varied, would after all be ruled by the greatest pressure in the main. In alluding to the utilisation of existing water mains, an instance was cited where the New River Company charged at the rate of 15*d.* per 1,000 gallons for water, and that was compared with the rate of the Hull Hydraulic Power Company, the result being in favour of the Hull rate as 4*s.* was to 25*s.* That was an excessive rate to compare with the Hull works, and was too much in favour of the Hull works. The Chelsea Water Company charged 6*d.* per 1,000 gallons, and he had some data with reference to the application of water to appliances at Surbiton, worked from their main at 140 feet head. These appliances he had erected when with Sir William Armstrong nearly twenty years ago, for the late Mr. James Simpson. He was indebted to Mr. Arthur Telford Simpson, the present engineer of the Chelsea Company, for the following figures. Mr. Simpson gave a case of a crane and direct-acting hoist, each lifting 2 tons (the former 20 feet and the latter 27 feet) at a cost of 0·68*d.* per ton 40 feet lift. The direct-acting hoist alone gave 0·52*d.* for 1 ton lifted 40 feet. Both these appliances were, however, capable of lifting 3½ tons, in which case the cost would be reduced to 0·30*d.* per ton lifted 40 feet. A 2½-HP. engine at the same pressure would cost 18*s.*, working ten hours a day; and if worked at 610 lbs. pressure, as at Hull, the cost would be only 14*s.* These figures were, he thought, more fair to both systems than comparing 4*s.* per 1,000 gallons, and 25*s.* It appeared to be thought that he had rather overlooked, or, at all events, had not dwelt sufficiently upon, the use of the pressure of the water companies' mains. The reason was the curtailment of the Paper, which at first had a great deal in it applying to that particular subject which had been left out. An interesting account had been given of the hydraulic machinery at Goole. That machinery well deserved attention; and there was an appliance for lifting canal boats, which was very ingenious. It had been said that in this country travelling cranes were not preferred to fixed cranes. In answer to that, the statement of Colonel Martindale might be quoted. That gentleman said "he had been in communication with Mr. Birt, the General Manager of the Millwall Docks, and he, after a lifetime of experience, said if he had to recrane that dock he should use nothing whatever but movable hydraulic cranes" (*ante*, p. 48). He also said reports of the movable hydraulic cranes at Calcutta were extremely favourable. The result was that the company were about to try two movable hydraulic cranes in the London Docks. He believed Colonel Taylor, of the West India Docks, and Mr. Manning held the same views, and therefore he thought he was justified in saying that movable hydraulic cranes were preferred. In future they would, no doubt, be more commonly used than they had been. The next part of the Paper to which exception had been taken was as to the cost of hydraulic power, and it was said there was a contradiction between the cost of water power in the eight different cases given, namely 1·26*d.* per 100 foot-tons, and the cost at which the water power was to be supplied at Hull, namely 4*s.* per 1,000 gallons. He himself could not see any contradiction in those figures. At Hull the cost to the consumer of water from the main was 4*s.* per 1,000 gallons, equivalent to 0·76*d.* per 100 foot-tons. In the tariff the cranes were given as costing rather less than ½*d.* a ton lifted 40 feet. If 0·76*d.* was taken as the cost of 100 foot-tons, at 4*s.* per 1,000 gallons, and 72 per cent. was taken as the co-efficient of effect of the cranes according to the table given in the Paper, it would be found that the cost was a little over 1*d.* per 100 foot-tons, while the Paper gave less than ½*d.* per ton lifted 40 feet, or less than 1¼*d.* per 100 foot-tons. Thus the figures precisely confirmed each other. In another part of the Paper the cost of the water power in eight different cases was given at 1·26*d.* per 100 foot-tons, but that included depreciation of plant and interest upon capital; whereas the cost of the water power to the consumers at Hull was irrespective of interest on capital and depreciation of the appliances of the consumer which had been included in the eight cases. Again, it had been said that the Paper contained a comparison between shafting for driving cotton mills and hydraulic power for accomplishing the same object, whereas in reality there was no such comparison. Objections had also been made to the allowance of 15 per cent., evidently because it was not noticed that it was to cover both interest on capital and depreciation of plant. He might mention, that in the eight cases he had given the costs were worked out on the old engines. The compound engines, such as were now being introduced, gave better results. It was, therefore, possible that the cost of hydraulic power would be reduced under those circumstances to nearer 1*d.* per 100 foot-tons; and it had been stated that at the London and St. Katharine Docks the compound engines produced better results.

Mr. STEPHENSON, President, expressed the pleasure he had felt in hearing Mr. Davey describe the valve which had been shown to the members. The description was exceedingly clear, and the ingenuity evinced in the valve was of the first class. The hoist (Fig. 1) was also an exceedingly pretty piece of mechanism. So much pleased had he been with it, that he thought before many months he should have two or three of them at work at his collieries. With reference to the transmission of power by rope, he thought he could go a great deal farther back than Mr. Lee Thomas; for he could recollect, nearly forty years ago, having worked a double-cylinder vertical engine, driving a wheel high up in the air, 24 feet in diameter, upon which was a flat hemp pit rope, working for about a distance of 80 or 90 feet. He worked the engine for twelve months; but he was not quite sure that he should like to use it again. The transmission of power was by no means a new subject; but all would admit that Sir William Armstrong was its pioneer in modern times, and had advanced the science of hydraulics, as applied to moving masses, probably more than any other man in the country. In his works at Newcastle power had been, for many years, transmitted by steam pipes. The boilers had been localised and small vertical engines placed against the walls for driving sections of the shafting. That was done with a view to get rid of long shafting, which was unsuitable, if the engine, the boilers, and the power had all to be kept at one spot. By having several small engines, in case of overtime or break-downs, any particular section could be worked without using the whole plant.

Mr. C. J. Appleby remarked, through the Secretary, that valuable as was the hydraulic system under certain conditions, such as for working fixed cranes and lifting machinery, it would be far too costly a mode of supplying power to motors at any tariff of charges which could be commercially profitable. In his opinion for this purpose compressed air offered advantages over the hydraulic system on account of its elasticity, which resembled that of steam, the absence of risk of damage to goods when a pipe burst, and not being liable to freeze in the pipes; but neither of these systems would compete in point of economy with the atmospheric gas engine, the heated air engine, or even with boilers in which steam was generated by a series of gas jets. None of these machines had been mentioned by the Author, although all were now extensively used, and were considered not to add to the fire risk of a warehouse or factory. It would almost appear that the cost of working steam cranes was 6·43*d.* per 100 foot-tons, whilst the cost of working a hydraulic crane was put down as low as 0·70*d.* per 100 foot-tons; but that seemed to be arrived at by estimating how many foot-tons a hydraulic crane could be made to lift in a given time, not what had been done on an average of many months; and he had been unable to gather from the Paper what was the cost per ton, or of 100 foot-tons of work actually performed by hydraulic cranes. This would be interesting and valuable information; from some investigation he had made several years ago he knew it would be much more than 0·70*d.* per 100 foot-tons; in fact more costly than if steam were used directly. The Author referred to the great risk which was supposed to arise from the use of steam cranes; but locomotives were constantly running about goods stations, surrounded by trucks carrying all kinds of inflammable materials, and if the sharp blast of the locomotive carrying with it hot cinders, failed, as it did, to be a source of great danger, it seemed hardly likely that a steam crane would be. As a matter of fact, so far as he was aware, no accident of this character had occurred, although steam cranes were extensively used in docks and railway depôts in all parts of the world. There could be no doubt that the hydraulic system was invaluable under many conditions, and that it was very economical as regarded the cost of maintenance; but there was little difference in the cost of performing a given amount of crane work, whether hydraulic or steam power was used.

Mr. R. Carr stated, through the Secretary, that the transmission of power by the hydraulic system had been in use at the London docks upwards of twenty years. He could not recollect any stoppage by breaks-down or otherwise of even a single day during that time. It had been predicted that stoppages would occur in frosty weather; but although there were difficulties during a severe frost, with ordinary precautions, such as laying exposed pipes in such a manner that they could be easily drained out at night, and with cocks or valves for emptying cylinders, this difficulty could be, and had been overcome. As a safe agent for the transmission of power through dock warehouses, in which valuable goods were stored, and where the value in many cases amounted to thousands of pounds, and occasionally millions; and where insurance regulations as to fires or lights were stringent and restrictive, the hydraulic system commended itself before any other, inasmuch as it carried with it an element of safety that could be used to extinguish fires. At the St. Katharine Docks the warehouses were very lofty, the upper floor being 75 feet above Trinity datum, where neither manual nor steam engines could render effective service by throwing water through hose and jets to the upper floors. To meet this difficulty vertical hydrant pipes 4 inches in diameter were fixed in the well-hole of each warehouse staircase, with a valve and attachment for hose at each floor-level. These hydrants were connected to the hydraulic main, and in the event of a fire the engine-driver was communicated with, who opened the valve connecting the air vessel loaded to 120 lbs. per square inch, which changed the system at once to a fire-extinguishing one. The advantage claimed was, that in a few minutes from an alarm of fire being given, an abundant supply of water was ready for service on the upper floor of the warehouse, which otherwise would have taken a much longer time in drawing up hose to be of any service in putting out a fire at that great height. He admitted there was waste at times when the goods to be lifted were of a light and bulky character, and each load much below the capacity of the crane. But this to a great extent could be obviated by restricting the power of the cranes to the work they had to perform. There were, indeed, cargoes in which the weights to be lifted each time were almost equal. In such cases there was an equivalent to what might have been lost by the goods of variable weights. But in any case the rapidity of action, combined with the safe and easy working by unskilled labour, and the promptness of starting and stopping rendered the hydraulic machine an indispensable agent for transmitting power. He assumed that the great difference between the cost per 100 foot-tons at London and Swansea was partly owing to the cost of fuel being cheaper in Wales. The charge, 15 per cent., for interest and depreciation was, in his opinion, much too high, a sum of 10 per cent. was ample. The wearing parts requiring renewal were the pulleys and chains. The other parts required very little repair, and lasted a great number of years.

Mr. W. Daniel remarked, through the Secretary, that compressed air apparatus had been at work at the Powell Duffryn collieries for nearly two years. Before the system was introduced, hauling at these collieries had been performed by steam engines, the steam being taken from boilers on the bank to the engines, some of which were several hundred yards from the bottom of the shaft. All these engines were now worked by compressed air, which was taken through the pipes formerly used for the steam. The compressors were supplied with steam from the boiler that used to supply steam for the underground engines, and no more coal was required to raise steam for the compressors than formerly, an equal amount of work being done. Similar results had been obtained at other collieries, affording conclusive proofs that, for long distances, compressed air could be conveyed and used as economically as steam.

Mr. J. DURIE observed, through the Secretary, that in his Paper on "Rope Gearing for the Transmission of Large Powers in Mills and Factories," read at the Institution of Mechanical Engineers,[1] he had scarcely given an adequate idea of the extent of power transmitted by hemp ropes. In one case a list of the principal powers transmitted by ropes, erected by one firm of engineers alone, showed a total of 5,030 indicated HP. This system for large powers originated with Messrs. Combe and Barber, of Belfast, who at the beginning of their practice used to make the sides of the grooves serrated, for the purpose of enabling the ropes to take sufficient hold on the pulleys, and used to drive round corners and at all angles by means of guide pulleys. It had, however, been found by experience, that sufficient friction could be obtained by properly proportioning the sizes and velocity of the ropes to the power to be transmitted; and also that the serrations in the grooves, and the guide pulleys at the angles, cut and wore out the ropes so much, that both plans had been long ago abandoned, and now only plain V grooves and direct drives were employed. In the employment of ropes as motors at Logelbach, in Alsace, the tension on the ropes transmitting 50 HP. at a speed of 31 miles per hour, or 2,728 feet per minute, due to the load would be $\frac{33,000 \times 50 \text{ HP.}}{2,728} = 605$ lbs. The loss sustained in transmitting 120 HP. 150 yards, was estimated to be $2\frac{1}{2}$ per cent. (or 3 HP). In Rankine's "Machinery and Millwork,"[2] the loss of power in overcoming the axle friction of the driving and following pulleys was stated to be $\frac{1}{40}$ of the power, which agreed with the loss as given above. He was of opinion, with the Author, that when the direction of transmission had sometimes to be changed, it was better done by introducing bevel wheels than by directing pulleys, for the latter were destructive to the rope. At Schaffhausen wire ropes were said to transmit 750 HP. over 15-feet pulleys running at a velocity of 100

[1] *Vide* Proceedings, 1876, p. 372.
[2] First edition, p. 448.

revolutions per minute, and the tension was given as 5,807 lbs. Now the tension due to this load would be—

$$\frac{33{,}000 \times 750 \text{ HP.}}{4{,}700} = 5{,}266 \text{ lbs.};$$

the difference between this and 5,807 lbs. being only 541 lbs. for preliminary tension, which seemed to be a small amount, in comparison with the next mentioned works at Fribourg, where the pulleys were 14 feet 9 inches, and made 81 revolutions per minute, giving a speed of rope of 3,750 feet per minute, not 65 feet per minute, as stated in the Paper. The tension on the ropes due to this load would be—

$$\frac{33{,}000 \times 300 \text{ HP.}}{3{,}750} = 2{,}640 \text{ lbs.};$$

the difference between this value and 5,198 lbs. mentioned was 2,558 lbs. for preliminary tension, which was about the amount of tension stated by Rankine to be necessary for the transmision of the power. By means of Table No. 2 he had been enabled to make a comparison between the amount of power transmitted by wire and hemp ropes. He had only compared a few of the cases, which would, however, be sufficient:—

Diameter of Wheels.	Number of Revolutions.	Diameter of Wire Rope.	HP.	Diameter of Hemp Rope.	HP.
Feet.		Inch.		Inches.	
7	80	$\frac{1}{2}$	16·9	$2\frac{1}{8}$	17·6
7	100	$\frac{1}{2}$	21·1	$2\frac{1}{8}$	22·0
7	120	$\frac{1}{2}$	25·3	$2\frac{1}{8}$	26·4
7	140	$\frac{1}{2}$	29·6	$2\frac{1}{8}$	30·8
8	80	$\frac{5}{8}$	22·0	$2\frac{1}{8}$	20·0
8	100	$\frac{5}{8}$	27·5	$2\frac{1}{8}$	25·0
8	120	$\frac{5}{8}$	33·0	$2\frac{1}{8}$	30·0
8	140	$\frac{5}{8}$	38·5	$2\frac{1}{8}$	35·0
15	80	$\frac{3}{4}$ and $\frac{7}{8}$	217	$2\frac{1}{8}$	37·6
15	100	$\frac{3}{4}$ " $\frac{7}{8}$	259	$2\frac{1}{8}$	47·0
15	120	$\frac{3}{4}$ " $\frac{7}{8}$	300	$2\frac{1}{8}$	56·4

It would be noticed that the amount of power transmitted by the $\frac{1}{2}$-inch and $\frac{5}{8}$-inch wire, and the $2\frac{1}{8}$-inch hemp ropes was about the same; but with the $\frac{3}{4}$-inch and $\frac{7}{8}$-inch wire ropes there was a wide difference; and on comparing the last case given, the HP. on the $\frac{3}{4}$-inch wire rope was 300, whilst that on the hemp rope was only 56·4. It would be interesting to know whether this rope had been meant to run on cast-iron grooves, or grooves lined with wood,[1] because the co-efficient of friction of iron rope on iron would probably be only one-half of hemp on iron, but iron on wood would be the same as a hemp rope on iron. The tension on the $\frac{3}{4}$-inch wire rope in the last case, due to the load, would be 1,755 lbs.; and multiplying this by two, to include the preliminary tension, the strain would be 3,510 lbs., or a strain of 8,000 lbs. per square inch for $\frac{3}{4}$-inch rope. Rankine gave the breaking strain of iron wire rope as 90,000 lbs. per square inch; therefore this strain of 8,000 lbs. was a long way under the breaking strain of the rope; but it must be remembered that the great point in rope driving was to obtain sufficient friction of the ropes on the pulleys; and in order to obtain this, only a moderate strain must be put upon the ropes, to prevent their stretching, or the bearings of the pulleys heating, therefore the above load appeared to be too high. The Author made no mention of the transmission of power to a distance by Fowler's Clip Pulley, which was employed to a large extent for working travelling cranes, &c. By means of the self-acting clips on the circumference of the pulley, a great amount of hold on the rope was obtained, approaching to the safe working power of the rope, thus enabling the power to be transmitted at slow speed, and also insuring greater durability of the ropes.

Mr. MICHAEL SCOTT observed, through the Secretary, that so long ago as the year 1846 he had submitted plans for the establishment of works at Liverpool, in order to supply water for power, and had then pointed out that water was a more suitable agent than steam for giving motion to machinery in the following cases: where the power required was too small to admit of the profitable application of steam; where the power was only required intermittently, or at intervals; where the locale of the power was variable, including cases in which the power-engine must be portable; and where the presence of fire would be dangerous, or in which the presence of water would be advantageous. The plans included machines not unlike a high-pressure steam engine in form, to be moved by water, and employed in raising and lowering goods in the warehouses, &c.[2] Again, the Author had

[1] Mr. Durie has since learned that the cast pulleys are lined either with wood or gutta-percha.—*Vide* Inst. Mech. Engineers; Proceedings, 1874.

[2] *Vide* "Occasional Papers," by Michael Scott, vol. i., p. 33.

stated that a special crane to lift the 100-ton gun at Spezia had recently been arranged, the novel feature of which consisted in the employment of a hydraulic cylinder, suspended from the jib head, the load being suspended directly from the piston working in this cylinder, so that by the admission of water under pressure into the cylinder, the load could be raised, and by allowing the water to escape the lowering of the load could be regulated, and all without the use of chains or gearing (*ante*, p. 5). In a communication to the Institution on the construction of breakwaters,[1] Mr. Scott had described hydraulic apparatus designed by him in the year 1858, which included the lifting and lowering of loads by means of an inverted hydraulic cylinder, interposed between the load and the point of suspension, and by means of three tubes motion in every direction was obtained. Drawings of the apparatus would be found in the "Report of the Commissioners on Harbours of Refuge," vol. i., plate 3 (folio; London, 1859). Once more, the Author had referred only to the loaded or weight "accumulator"; but Mr. Scott had designed and patented other kinds in 1851, namely the water and steam "accumulators," arranged so as to operate with or without pumps. Suppose a steam cylinder and a smaller water cylinder placed in line, the steam piston and the water piston being fixed on the same rod, this would form an "accumulator," the water-pressure being augmented by the superior area of the steam piston. With one such machine water would be pumped continuously into the water cylinder, the piston or ram of which, by moving up and down, would compensate for an irregular demand; but if two machines were employed, that was, two steam cylinders, each with a water cylinder, it would not be necessary to pump water into them, because if one ram was down the supply could be obtained from the other water cylinder, and the steam being shut off from the first machine and allowed to escape from its cylinder, the piston could either be raised by forming a vacuum above it, in which case water could be drawn into the water cylinder until it was full, or by water being admitted below the water ram under a slight head, both ram and steam piston would be raised, then the steam being turned on, the water would be again under pressure, ready for use.

About forty years ago a Mr. Lang had described a plan for working engines in deep mines, by water conveyed from the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 88.

surface under great pressure. His idea was, that water being incompressible, every stroke made by the pump at the surface would be responded to by a stroke of the water engine below.

March 20, 1877.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

The discussion upon the Paper No. 1,500, "The Transmission of Power to Distances," by Mr. H. Robinson, occupied the whole evening.
