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GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,500.—“The Transmission of Power to Distances.”¹
By HENRY ROBINSON, M. Inst. C.E.

It is proposed in this Paper to record some facts that have come within the Author's experience, or have been communicated to him, respecting the various methods employed to transmit motive power, with a view of considering the circumstances under which one system would be preferable to another. Hitherto the economical production of power in the motor, and its utilisation in the appliance to which it is conveyed, have been made the subject of more general and careful investigation than the means of economical transmission.

Water pressure was recognised by Bramah as affording, on account of its incompressibility, a favourable medium for the transmission of force; and it was utilised by him by means of a small pump at a high pressure, acting with the least possible loss by friction on a large piston or ram, thus obviating the necessity for gearing.

The hydraulic system, in its present wide field of application, owes its origin, however, to Sir William Armstrong, Vice-President Inst. C.E. (to whom the Author desires to acknowledge indebtedness for his earliest experience in this branch of engineering), who in the year 1846 erected on the Newcastle Quay the first hydraulic crane. This has been followed by the application of

¹ The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

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water pressure to a variety of purposes with great advantage, especially where the appliances are intermittent in their requirements. The success which has attended the working of the system has suggested its extension to towns, on the co-operative principle, by laying power mains. The first of this kind has recently been carried out by the Author, of which the following is a description.

In the year 1872 an Act of Parliament was obtained for the purpose of establishing, at Kingston-upon-Hull, what was termed in the preamble "a system for applying motive power by hydraulic pressure to waterside and land cranes, used for the purpose of raising and landing goods; and for working dock gates and other machinery." The powers granted under this Act were to be exercised over an area of 60 acres, and they authorized the abstraction from the old harbour of the river Hull (a tributary of the river Humber) an amount of water not exceeding 1,000,000 gallons a day, for distribution within the company's district, for which a payment was to be made to the Corporation of £12 10s. per annum for each 250,000 gallons; the water to be used for no other purpose than as a motive power, except with the consent of the Corporation.

A 6-inch pressure main has been laid from the northern boundary of the defined area, near the Cottingham Drain, in a southerly direction along Wincolmlée, Trippett, Dock Office Row, under the Old Dock Basin (which forms the eastern or river Hull entrance to the Queen's Dock), and crossing this entrance it is laid along the whole length of High Street, terminating close to the western approach of the South Bridge across the river Hull. The length of pressure main, exclusive of the dock crossing, is altogether 1,485 yards, that on the north side of the dock entrance being 673 yards in length, and that on the south side 812 yards. Except at the dock crossing the main consists of cast-iron flanged pipes, of 6 inches internal diameter, 1 inch thick, with the usual spigot and faucet, and with gutta-percha ring joints tested to 2,800 lbs. per square inch before being laid, and afterwards to 800 lbs. per square inch.

Stop-valves at intervals, having a waterway equal to that of the main, divide the main into sections. Air-cocks are fixed on all summits, by which the air is displaced in charging the main. T-pieces for 2-inch, 3-inch, and 4-inch branches are placed at convenient points, from which service-pipes can be carried to the various warehouses, works, &c.

The main was laid across the dock entrance, in a trench dredged to the inverts forming the dock bottom, the solid obstructions met with being removed and the bottom levelled by a diver. The pipes

across the dock are of 6 inches internal diameter, made of welded wrought iron $\frac{3}{4}$ inch thick, bent to template to suit the curves of the sides and bottom of the dock, and were tested to 3,000 lbs. per inch at the manufacturer's. They were put together at the side of the dock, and tested to $\frac{1}{2}$ ton to the inch before being lowered into the trench. This was done from barges, and when the pipes were in position they were well concreted, to protect them from being injured by anchors or by weights falling overboard from ships. This part of the work has been tested in an unexpected way by the stranding of a large ship over the pipes, which, however, were in no way injured.

The power to supply the water pressure is concentrated at one pumping station in Machell Street, where an engine-house has been built to receive four 60-HP. engines (Plate 1). The ground being silty and bad, the foundations were carried down to the hard clay, a depth of 24 feet, the walls being built on arches resting on concrete piers. The engine-house is covered by a tank fitted with filtering boxes, through which the water pumped from the river Hull passes before it is delivered to the engines. Two pairs of high-pressure horizontal pumping engines have been erected, each engine being of 60 HP., and capable of pumping 130 gallons per minute at 700 lbs. pressure per square inch, with steam at 100 lbs. pressure. The steam cylinders are $12\frac{1}{4}$ inches in diameter and the length of stroke 24 inches; the force pumps, which are double-acting, have a $4\frac{1}{8}$ -inch piston, the piston rod being $3\frac{1}{2}$ inch in diameter. Space is provided in the engine-house for two additional pairs of 60-HP. engines, which can be erected at a future time when the demand for the water pressure requires further engine power. Two Lancashire boilers, 22 feet 6 inches long and 6 feet 6 inches in diameter, supply steam to the engines.

An Appold centrifugal pump (in duplicate), fixed in the engine-house, draws the water from the river Hull, a distance of 125 yards, through a 10-inch pipe, and delivers it into the tank, the lift being 35 feet from low tide. The pump has an 8-inch suction, and is driven by a Brotherhood's 4-inch three-cylinder engine, also in duplicate. Each engine and pump supply 800 gallons of water per minute, with 100 lbs. steam pressure. A 6-inch return pipe is laid from the tank to the river, serving both as an overflow pipe and as a means of cleaning out the tank.

In connection with the hydraulic system, the "accumulator" fulfils an important office, and may be described as an apparatus to accumulate at a constant pressure, which is obtained by a load the power given out by a steam engine. A cast-iron cylinder has

a ram working in it, from the top of which a weighted case is suspended by a crosshead. The weight in the case is adjusted to give the desired pressure on the column of water pumped by the engine into the cylinder of the accumulator, from which it is conveyed through the main to the points of consumption. The accumulator, besides serving to produce an artificial head, also stores up the water pumped when it is in excess of the water consumed; and, in fact, performs in the hydraulic system the functions of the fly-wheel of a steam engine. As the consumption of water by the machines connected with the main falls below the supply of water pumped by the engine, the ram rises and stores in the cylinder the excess, until the ram has risen to the top of its stroke, when it cuts off the steam from the engine by closing the throttle valve. On the other hand, when the consumption of water by the machines is greater than is being supplied at the time by the engine, the ram falls and supplies the deficiency, at the same time opening the steam throttle valve by which the full power of the engine is brought into operation. The accumulator thus acts both as a reservoir of power and as a conservator of its distribution.

One accumulator is erected at the pumping station in Machell Street. It has a diameter of 18 inches, and a stroke of 20 feet. The case is loaded with $57\frac{1}{2}$ tons of copper slag and sand, which produce a pressure of 610 lbs. per inch in the main. Provision is made for an additional accumulator at the pumping station when required. Another accumulator will be placed at Grimsby Lane, towards the southern extremity of the line of main.

Several observations were made to ascertain the useful effect of the engines and accumulator, and the mean was found to be 76 per cent., 5 per cent. being the loss in the pumps.

The outlay has been £17,000.

In carrying out these works, the Author received every assistance from the Hull Dock Company, and their Engineer, Mr. Marillier, M. Inst. C.E.; from the Corporation of Hull and their Engineer, Mr. J. Fox Sharp, M. Inst. C.E., and from Mr. Thornton, who acted as Resident Engineer. The pipes were supplied by the Staveley Coal and Iron Company; the machinery by the Hydraulic Engineering Company.

The Dock Company has taken a 4-inch branch off the power main to work cranes and appliances on the south side of the Queen's Dock, for which it pays 4s. per 1,000 gallons of water, with a minimum charge of £200 per annum for the first fifteen connections, and a further charge of £15 per annum for each connection above that number.

The following tariff has been issued by the Company of the rates at which it is proposed to supply the water power :—

	£.
" 1 crane in one warehouse	52 per annum.
2 cranes " " 	94 "
3 " " " 	132 "
4 " " " 	166 "

"Each crane will have a counter attached to it to register the amount of work done. One hundred tons may be lifted 40 feet, or 200 tons 20 feet, and so on each day by each crane for the above charge, which is under $\frac{1}{2}$ d. per ton for a lift of 40 feet. If more work than this is done, the extra work will be charged at the rate of 4s. for every additional 100 tons lifted 40 feet. Special rates will be made for working presses, hydraulic engines, capstans, small cranes, &c., as occasion arises."

The numerous purposes to which hydraulic power is applied may be briefly referred to. It is employed in docks in working cranes, jiggers, hoists, in opening dock gates and sluices, and for capstans to haul ships. Cranes capable of travelling along the side of the dock, so that they can be adjusted to suit the holds of ships, are preferred to fixed cranes, the power being taken off the main by hydrants connected with the crane by pipes having union joints. In railway yards it is applied to capstans for hauling wagons and making up goods trains, saving both space and horse power; also to wagon hoists, swing and draw bridges, traversing machines, &c. It is employed to work shop tools, flanging presses, riveting machines (the rivets being closed by a squeeze instead of by the blow of a hammer), also to forging iron by pressing it at a welding heat, into the desired shapes in moulds, resulting both in a saving of material and subsequent shaping, and in causing the fibre of the iron to follow the form of the object produced to an extent not possible under the hammer. In the moulding shops of a foundry, hydraulic power is found preferable to the ordinary gearing, owing to the absence of vibration in its working. It is used on board ship to work the steering gear, to raise the anchor, and to lift and discharge goods. The 100-ton gun recently made at Elswick for the Italian Government has hydraulic apparatus applied to it, by which the recoil is taken up in less than 46 inches. A special crane to lift this gun at Spezia has been arranged, the novel feature of which consists in the cylinder being suspended from the jib-head, and acting directly with the load, enables the lowering of the gun to be regulated by the escape of the water from the cylinder.

Where the ordinary pressure of about 700 lbs. to the inch is insufficient to work shop tools or presses, it can be increased by the intervention of an intensifier, which is a machine having two cylinders in line with each other. In the one the pressure of 700 lbs. is received on a piston of large area, acting directly on a ram of lesser area in the second cylinder. The areas of the piston and ram can be proportioned to increase the pressure to any required degree.

In cold climates the pipes and machines are, as a rule, placed either underground or in buildings. Where the parts are unavoidably exposed, the usual precaution adopted is either to run out the water when the machines are not working, or to keep a gas jet burning near them. Where water is scarce, a return pipe conveys the waste water from the machines back to the engines for use over again.

The advantages that will accrue from the introduction of a main, to distribute power by means of water pressure, are considered to be as follows: The consumer will effect a great reduction of expense where he is using hand power; and where steam power is employed the engines, boilers, and the skilled labour required to attend to them, can be dispensed with, the space saved being made available for other purposes; while at the same time the risk of fire is removed. In Hull the substitution in warehouses of hydraulic power for steam power will cause a reduction in the rates of insurance of 1s. per cent. per annum, which would represent a considerable saving in the numerous warehouses storing grain, seed, &c., disastrous fires in them being of frequent occurrence. In the bonded warehouses of docks, steam power is not, as a rule, permitted; but where steam cranes are employed it involves considerable increase in the fire risk to those warehousing in the buildings served by them.

Great acceleration of business will be produced compared with hand power, as goods, whether from ships or wagons, can be discharged with increased rapidity, hydraulic cranes lifting, from 6 to 10 feet a second, an average of about 1,000 foot-tons per hour. The number of men on the premises can be reduced, hydraulic appliances being worked by a few unskilled labourers. The upper floors of warehouses can be more utilised, and higher floors can be advantageously added to existing buildings. The power will be always and instantly available to meet the requirements of the consumer, and at a cost to him only in proportion to the power absolutely consumed. The system can also be utilised to extinguish fires, by pumping against a loaded valve and air-vessel at about 100 lbs. to the inch. At the St. Katharine Docks a complete

system of this kind has been carried out, and has, in several instances, enabled fires to be promptly overcome.

The pressure in Water Companies' mains has been used to work lifts and other machines. The cost however of pure water, added to its low pressure, prevents its being employed except to a limited extent.

Before leaving the subject of the distribution of power by water mains charged to a high pressure, it may be interesting to quote the following opinion of the late Sir W. Fairbairn, Bart., M. Inst. C.E., with whom the Author and Mr. J. S. Wilkinson, M. Inst. C.E., were in communication, in the year 1867, as to the application of the hydraulic system by means of power mains in Manchester. "Your proposal to erect steam engines and lay down pipes for the purpose of working accumulators for supplying hydraulic power in different localities of the city of Manchester seems to have several advantages over the system now in use in the different warehouses where steam is employed. In the first place, it would remove steam engines and boilers from the premises, lessen the risk from fire and boiler explosions; and, secondly, it would supply the necessary power to work cranes, hoists, hydraulic presses, &c., in these dépôts on principles of increased security."

In the transmission of power by water at a high pressure, the loss due to friction in the main is but trifling, compared with the total pressure, when the main is well proportioned with reference to the position and amount of power required to be consumed, and when accumulators are placed at proper intervals to maintain the pressure. Where the original smoothness of the pipe is destroyed by deposits taking place on its inner surface, an increase in the skin friction will result, together with a diminution in the size of the pipe. As the loss of head varies inversely as the fifth power of the diameter, the loss will from this cause in time become appreciable. In the case of the 6-inch main at Hull, the loss of pressure due to friction at a point 1,500 yards from the engine, would be about 5 lbs. per inch, with one pair of engines working at its maximum speed, delivering 130 gallons of water at 700 lbs. pressure per minute, or four times that loss if both engines were working delivering twice that amount of water. The erection of a second accumulator at the end of the main, remote from the engine, as intended, will practically place that part of the main in the same position as to pressure as the main near the engines. This arises from the fact that the water pressure being withdrawn from the main in an intermittent manner, the intervals between the periods of water abstraction, however short, enable the continuity of pres-

sure between the engine and the distant accumulator to be maintained, and the effect of the loss of head due to friction to be practically compensated for. At a point midway between the engine and the second accumulator, it can only reach $1\frac{1}{4}$ lb. and 5 lbs. per inch, or about $\frac{1}{4}$ and 1 per cent. as maxima, when one or both engines are at work.

Gauges have been placed on a main composed of 4-inch, 3-inch, and 2-inch pipes, in the Great Western railway yard at Paddington, at points from 1,000 to 1,600 yards apart, and the pressure has been found to be practically the same during the working of the machines in the usual way. At Swansea, wherever the pressure in the main has been tried, it has been found to be uniform; close to the accumulators it is greater, and at the accumulators themselves the pressure has been raised to 900 lbs. by keeping the engine going.

Contractions in the main, either through the waterway of the valves being less than that of the pipes, or through a reduction in the size of the pipes, give rise to fluctuations of pressure at variance with the uniformity attainable when the main is properly proportioned. These fluctuations are explained by the fact that, where a fluid passes from a large to a smaller pipe, a diminution of pressure takes place corresponding with the diminution of sectional area. The converse applies to the case of the passage of a fluid from a small to a larger pipe. The fluid, on entering the larger pipe, travels at a diminished velocity, which implies the existence of a greater pressure in front than behind it. 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. It follows, then, that changes in the sizes of the main result in changes of velocity, and therefore of pressure, by Bernoulli's law that the pressures vary with the differences of the squares of the velocities. Disregarding friction, the pressure in a main of uniform size will be constant if the water pumped into it is sufficient to replace that withdrawn; in other words, where the velocity is constant, but where contraction takes place, a diminution of pressure will be experienced throughout the contracted length unless an accumulator is placed there—in which case it practically remedies the inequality of pressure by preserving the uniformity of flow.

This subject has been considered with respect to ship resistance by Mr. Froude, M. Inst. C.E.¹

¹ *Vide* Report of the British Association for the Advancement of Science, 1875, p. 221.

Water power may therefore be regarded as capable of transmission with but trifling loss. In the machines themselves, the useful effect is as high as 90 per cent. in direct-acting apparatus, and as low as 50 per cent. in cranes with great multiplying power.

Mr. Percy Westmacott, M. Inst. C.E., has enabled the Author to give some information respecting the practice at Elswick, where the co-efficients of effect obtained in hydraulic machines of ordinary make are taken as follows:—

Direct-acting	93 per cent.
2 to 1	80 "
4 „ 1	76 "
6 „ 1	72 "
8 „ 1	67 "
10 „ 1	63 "
12 „ 1	59 "
14 „ 1	54 "
16 „ 1	50 "

These co-efficients are based on ordinary hemp packing (well-made cupped leathers increase the efficiency), and with sheaves and wrought-iron pins, there being no exceptional arrangements for lubrication. Where, however, special precautions have been taken, such as in the traversing machines which were at work some years ago at St. Pancras goods station, where a large diameter of sheave and a small diameter of hard steel pin were employed, together with careful fitting of parts, the efficiency multiplying 20 to 1 was as high as 66 per cent. This machine had a travel of 200 feet with a load of $17\frac{1}{4}$ tons.

It is considered that the co-efficient of effect obtained from a steam engine pumping into an accumulator may be taken at 81·7 per cent., the amount lost by friction in the accumulator gland being 8·3 per cent. It is found by experiment that the difference of pressure with the accumulator at 700 lbs. rising or falling is about 30 lbs., representing 2·14 per cent. of effect. The compounded efficiency will, therefore, be ascertained by combining the efficiency of the engines, which has been shown to be 76 per cent. at Hull, with the above varying rates of efficiency.

In 1865, Mr. Hawthorn, in his Paper on Docks and Warehouses at Marseilles,¹ gave, as the result of some experiments, the compounded effect as 30, 45, and 60 per cent. In explanation of these admittedly low results, it was shown that the machines on which the experiments were made were all new; and further, that the water, after being used, was forced back through a considerable length of piping to a cistern over the engine-house. In

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xxiv., p. 144.*

1862, Mr. Abernethy, Vice-President Inst. C.E., in a Paper on the Port of Swansea,¹ made a deduction of 20 per cent. from the water delivered by the engines to work the hydraulic machinery as an allowance for friction and leakage.

Hydraulic appliances cause a waste of water when the maximum capabilities of the machine are not exerted. In the case of a hoist to raise a loaded goods wagon, the hoist may occasionally be used to lift only an empty wagon, when as much water is consumed as would be required to lift the loaded one. It must, however, be remembered that no power is being consumed in any way during the intervals between the operations, and the conservation of power in these intervals may be considered as compensating for the occasional wasteful consumption at the moments of its employment. The load to be lifted by cranes can be adjusted by an arrangement of valves so that the amount of water used is regulated to single or double power. If this adjustment could be carried further, it would enable the variations in the work to be still better equalised, and would lessen the objection to water not admitting of being worked expansively.

In the Albert Dock² of the Hull Dock Company a 60-HP. engine supplies water for working an 80-foot swing-bridge, nineteen hydraulic engines working gates, sluices, and capstans, three 20-ton coal hoists, one 15-ton crane, one 3-ton crane, and thirty-four 1½-ton cranes. By permission of Mr. Marillier, the Engineer of the Company, the following data have been obtained. These machines are worked at a pressure of 775 lbs. per inch, through 5,350 feet of 5-inch pipe, 1,400 feet of 4-inch pipe, with 3-inch and 2-inch branches to the dock gates and warehouses. The cost of supplying water power for the year 1875 was £1,367 3s. 1d., which gives, after taking 80 per cent. as the useful effect of the water after delivery into the main:—

Engine power	0·24 per 100 foot-tons
15 per cent. for interest on capital and depreciation.	0·88 " "
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	1·12 " "
Add for repairs	0·13 " "
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	1·25 " "

At Cotton's Wharf, London, there are ten 25-cwt. hydraulic

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 309.

² A descriptive account of this dock, by Mr. J. Clarke Hawkshaw, M. Inst. C.E., is given in the Minutes of Proceedings Inst. C.E., vol. xli., p. 92.

cranes lifting 40 feet, four 2-ton single-power cranes, one 4·2-ton double-power crane and one 48-ton press worked at a pressure of 700 lbs. per inch; the cost when only six cranes were in operation, which is the average number, was—

Engine power	<i>d.</i> 0·63 per 100 foot-tons.
15 per cent. for interest and depreciation	1·26 " "
	<hr/> 1·89 " "

The cost of labour at the cranes was 0·46*d.* per 100 foot-tons. If the whole of the sixteen appliances were working, the cost would be—

Engine power	<i>d.</i> 0·23 per 100 foot-tons.
15 per cent. for interest and depreciation	0·47 " "
	<hr/> 0·70 " "

The labour at the cranes being the same as before, namely 0·46*d.* per 100 foot-tons.

At the St. Katharine Docks, engines of 140 HP., nominal, pump 5,000,000 cubic feet of water annually at 600 lbs. pressure through 1,200 yards of 7-inch main, supplying power to work a swing-bridge and upwards of seventy-five cranes, hoists, and presses. The power exerted annually is nearly 193,000,000 foot-tons, or, taking 80 per cent. efficiency, more than 154,000,000 foot-tons.

<i>£.</i>	
The cost of the engines, boilers, accumulators, pipes, and appliances	= 35,000
Foundations of engines and boiler house	= 12,000

The cost of water delivered into the main, including coal, wages, repairs and supervision, is 10*s.* per 1,000 cubic feet. The cost of the water power is therefore as follows:—

Engine power	<i>d.</i> = 0·39 per 100 foot-tons.
15 per cent. for interest on capital and depreciation	1·10 " "
	<hr/> 1·49 " "

At the London Docks, engines of 185 nominal HP. pump 7,000,000 cubic feet of water per annum, of which 4,250,000 cubic feet are pumped at 750 lbs. pressure through 1,450 yards of 5-inch pipe, 640 yards of 4-inch, and terminating with 550 yards of

3-inch. The remaining 2,750,000 cubic feet are pumped at 650 lbs. pressure through 750 yards of 6-inch pipe. These jointly work the swing-bridges, lock gates, and upwards of eighty cranes, hoists, presses, &c.

The cost of water delivered into the main, including coals, wages, repairs, and supervision, is 10s. per 1,000 cubic feet. The cost of the power will therefore be as follows:—

Engine power	^{d.} 0·33 per 100 foot-tons.
15 per cent. for interest and depreciation	0·88 " "
	<hr/>
	1·21 " "

At the Victoria Docks, engines of 280 nominal HP. pump 8,000,000 cubic feet per annum at 780 lbs. pressure through 700 yards of 5-inch pipe, 2,000 yards of 4-inch, terminating with 200 yards of 3-inch pipe. The power exerted is 401,000,000 foot-tons, or 321,000,000 foot-tons at 80 per cent. efficiency; and this power is applied to working a swing-bridge, lock gates, capstans, and upwards of one hundred cranes and hoists.

The cost of water delivered into the main, including coals, wages, repairs, and supervision, is 10s. per 1,000 cubic feet. The cost of the power will therefore be as follows:—

Engine power	^{d.} 0·30 per 100 foot-tons.
15 per cent. for interest and depreciation	0·88 " "
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	1·18 " "

At the Great Western railway station at Paddington, a 70-HP. engine supplies water at 700 lbs. per square inch to two wagon hoists, three hauling machines, twenty turntables, fifty-four 25-cwt. cranes, sixteen hoists, three capstan engines, three traversing tables, two draw-bridges, one ticket-printing machine, and four dropping platforms. According to Mr. H. Kirtley, the average consumption of water is 25,600,000 gallons per annum, obtained from the Water Company at 4d. per 1,000 gallons, one-fourth being returned and three-fourths run to waste. The cost of supplying this appears to be 1·10d. per 100 foot-tons, taking 80 per cent. efficiency of water delivered, and allowing 15 per cent. for interest and depreciation, or adding 0·13d. per 100 foot-tons for repairs = 1·23d. per 100 foot-tons.

At the Swansea Docks, the amount of water pumped in the year

ending Midsummer 1876 was 20,750,000 gallons, at 700 lbs. per inch, and the working expenses were:—

	£.	s.	d.
Coal and fuel	1,056	19	9
Stores	134	15	5
Wages	699	14	1
	<hr/>		
	1,891	9	3
	<hr/>		
Wages and repairs	412	6	10
Materials	244	7	6
	<hr/>		
	656	14	4
	<hr/>		

The cost will therefore be, taking 80 per cent. for the useful effect of the water delivered into the main:—

	d.		
Engine power	0·38	per 100 foot-tons.	
15 per cent. (on £22,000) for interest and depreciation	0·66	"	"
	<hr/>		
	1·04	"	"
	<hr/>		

The extra cost for wages, repairs, and materials would be 0·13d. per 100 foot-tons, making the total cost 1·17d. per 100 foot-tons.

The following is a summary of the foregoing data, and represents the cost of water power at pressures varying from 600 to 780 lbs. per square inch, taking 80 per cent. as the efficiency of the water pressure after delivery into the main, and allowing 15 per cent. for interest and depreciation.

	d.		
Albert Docks, Hull	1·25	per 100 foot-tons.	
Cotton's Wharf (maximum)	1·89	"	"
Cotton's Wharf (minimum)	0·70	"	"
Paddington	1·23	"	"
Swansea	1·17	"	"
St. Katharine Docks	1·49	"	"
London Docks	1·21	"	"
Victoria Docks	1·18	"	"
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Mean	1·26	"	"
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Herr Pfahler has given particulars of the employment of water at the Sulzbach Altenwald colliery, near Saarbrücken,¹ to transmit the power from a steam engine at the surface to work pumps at the bottom of a shaft 306 yards deep. The steam engine has

¹ *Vide Zeitschrift für das Berg-, Hütten- und Salinen-Wesen*, vol. xxii., p. 179, and vol. xxiii., p. 60. Also, *Minutes of Proceedings Inst. C.E.*, vol. xliii., p. 404.

a cylinder 53 inches in diameter and 61·5 inches stroke, connected with pressure plungers 9 inches in diameter and the same stroke, and these plungers are brought into connection with an underground pumping engine, consisting of four pressure pumps, with plungers 6 inches in diameter and 66 inches stroke, arranged in pairs, and put in motion alternately by the surface plungers. Between each pair of plungers, which are connected by a crosshead, is placed the working plunger of one of the mine pumps. The engine at the surface transmits the effort of each plunger through its rod tube to the corresponding pair of pressure pumps under ground, and this actuates the working plunger connected with it, either drawing or forcing water, the other pair acting conversely. The water is forced into an air-vessel, and thence through the rising main in one lift to the surface, the power supplied by the descent of water in one column being nearly sufficient to effect its return in the other. The tubes were proved to 100 atmospheres; the working pressure on the underground pumps, due to the difference between their areas and those of the pumps at the surface, is 50 atmospheres, and the hydrostatic head in the rods being 27 atmospheres, the total working pressure, including friction, is 77 atmospheres, or about 1,155 lbs. per inch. The engine is worked at a speed of 10 double strokes per minute when the discharge is permanent and continuous. Careful observations were made to ascertain the work absorbed by the friction of the different parts of the machinery, and it was found to be from 25 to 29 per cent. of the total power developed. The effective work of the pumps at 10 double strokes per minute was 100 HP., and the indicated HP. of the engine, with a mean pressure of 20 lbs. per square inch on the piston, was 136 HP., which gives the combined duty = 0·73 of the total power expended.

In the lead mines at Allenheads, in Northumberland, the power for working the machines is derived by water wheels from a natural fall of water at a considerable distance from the points of application, the power being transmitted through pipes charged to a high pressure by accumulators.

The power derived from natural falls of water in mining regions is frequently transmitted by draw rods connected with a crank, exerting a direct pull against a weight during half its revolution, thus storing up power for the return stroke, the rods being in tension throughout. Although this is a simple method of conveying power to considerable distances, it is not an economical means of producing rotary motion.

The other chief methods of transmitting power are steam, compressed air, shafting, and ropes.

In conveying steam to a great distance loss of power occurs through condensation, although, where the pipes are properly proportioned and protected, no appreciable loss has been found in the pressure at a distance of 1,000 feet from the boiler. For any extensive system of transmitting power steam is under disadvantages, as, besides the liability to condensation, there is the difficulty of keeping good joints, owing to expansion and contraction, and the fluctuations of pressure where the main is tapped at many points. In working appliances intermittently by steam, the parts get cold whilst they are not in use, and on the admission of steam condensation takes place, resulting both in loss of power and liability to breakage from starting with water in the cylinder.

On the 25th of May, 1841, a Paper was read at this Institution by the late Mr. John Grantham,¹ M. Inst. C.E., on the working of the Lime Street tunnel on the Liverpool and Manchester railway. This was completed in 1836, and was worked by two pairs of stationary non-condensing engines supplied with steam from boilers situated (in compliance with the provisions of an Act of Parliament) at the mouths of the Crown Street and Wapping tunnels, a distance of 448 yards, the steam being conveyed in 10-inch pipes laid in a tunnel cut in the solid rock. The length of the incline was 2,370 yards, 2,220 yards being in tunnel having a mean gradient of 1 in 92. The average weight of the trains drawn up was 55 tons, and the time occupied was six minutes. The engines were side-lever, having cylinders 25 inches in diameter and 6 feet stroke, working a drum 21 feet in diameter, making usually twenty-two revolutions per minute, drawing a train up the incline at the rate of 15 miles per hour. The pressure of steam was generally from 50 to 60 lbs. when the engines began to wind, and fell gradually to 30 lbs. From experiments made at the time, Mr. Edward Woods, M. Inst. C.E., found that each lb. per square inch pressure of steam upon the pistons, above 7·56 lbs. required to overcome friction, was capable of drawing one carriage weighing 5 tons up the incline. Also that when the engine was standing still the difference of pressure between the boiler and the steam reservoir was about 3 lbs., and when working 13 lbs. The quantity of steam condensed was on an average 156 gallons per hour, and this was collected in a small receiver in the engine-room, the pipes being laid with a fall in that direction. Eventually boilers

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1841), p. 146.

were placed close to the engines, and the transmission of steam from the old boilers was discontinued.

A steam crane of Messrs. Appleby has been at work at Harwich since 1865, and particulars were obtained of the cost of working for six months. The weight lifted was 18,375 tons, or 118 tons a day raised an average height of 20 feet, and the cost was as follows:—

	<i>d.</i>
Labour, fuel, oil, waste, &c.	3·98 per 100 foot-tons.
15 per cent. on £500 (the cost of crane)	2·45 " "
for interest on capital and depreciation	
	<hr/> 6·43 " "

This includes the cost of labour at the crane, which, if taken at 0·46*d.* per 100 foot-tons, reduces the cost to 5·99*d.* per 100 foot-tons. This crane, however, was not working continuously, and it was stated to be capable of performing three times that duty. If so, the cost would be reduced to about 2½*d.* per 100 foot-tons, or deducting the labour at the crane, to 2·03*d.* per 100 foot-tons.

Some direct-acting hoists made by the same firm lift 6 cwt. to a height of 40 feet in seven seconds, the steam pressure being 50 lbs. per square inch, and the consumption of steam 14 cubic feet. The time required to lift and lower a bale weighing 12 cwt. is twelve seconds, and the consumption of steam is 27 cubic feet. The apparent discrepancy between these two results is accounted for by the fact, that, in lowering, the steam is used only as a brake, so that the consumption is but little in excess of what would be required to lift the weight to the height above indicated.

Mr. Maxwell (under whose superintendence the improvements to the river Medlock were carried out in 1869–70) states that a steam crane lifted 563 tons of excavated material to a height of 33 feet, and discharged it into carts in ten hours. The cost of the crane was £300. The fuel came to 2*s.* 2*d.* and the labour to 4*s.* 6*d.* a day. The cost was therefore:—

	<i>d.</i>
Engine power	0·43 per 100 foot-tons.
15 per cent. on capital for interest and depreciation	0·18 " "
	<hr/> 0·61 " "

The labour at the crane came to 2*s.* a day, or 0·13*d.* per 100 foot-tons. These conditions may be regarded as exceptionally favourable.

A 6-ton steam crane at the Llanelly Dock raised 10,321 tons an average height of 27 feet in nine months at a cost of £87 19s. 6d. The cost was therefore :—

	<i>d.</i>
Working expenses	7·57 per 100 foot-tons.
15 per cent. on capital £478 (cost of crane) for interest and depreciation)	4·63 " "
	<hr/> 12·20 " "

The crane, however, was not working to its full capabilities, and may be regarded as an unfavourable example.

Compressed air is largely employed to transmit power, especially for underground operations, where the conditions are more favourable to its employment than either steam or water pressure. Considerable loss of power arises in the operation of compression, when, as the temperature increases with the density cooling is necessary, and the heat thus abstracted represents power lost. In performing work by expansion the temperature of the air falls, the work done being in proportion to the heat that has disappeared during expansion, therefore the less the degree of compression the greater the efficiency. For pressures of from 1 to 10 atmospheres, M. Paul Piccard states¹ that the efficiency, when the air is not worked expansively, but is admitted for the whole of the stroke, varies from 100 to 39·1, and that taking into account the efficiency of the machines themselves at 70 per cent., the compounded efficiency is about 50 per cent., although, in practice it rarely exceeds 30 per cent.

The late Professor Rankine states² that the loss of power seldom amounted to less than from 65 to 75 per cent. of the whole power of the compressing engine, and that the loss in transmission through well-proportioned pipes was about 10 per cent. per mile. Dr. Siemens has stated that his investigations led him to the conclusion that the attainable limit of the useful effect of compressed air was about 50 per cent. of the power exerted in compression.

In collieries under the charge of Mr. Thomas W. Jeffcock, near Sheffield, compressed air is employed in hauling coal on levels and inclines, and for pumping up an inclined plane underground. The air is taken down to the bottom of shafts 320 and 350 yards deep respectively, and conveyed to distances of 630 and 1,614

¹ *Vide* Bulletin de la Société vaudoise des Ingénieurs et des Architectes, 1876, p. 10. Also, Minutes of Proceedings Inst. C.E., vol. xlv., p. 273.

² *Vide* Transactions of the Institution of Engineers and Shipbuilders in Scotland, vol xvi., p. 78.

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yards. In the first case the safety-valve on the surface is set to blow off at 48 lbs. to the inch, and when this is blowing off, the gauge in the workings, at 630 yards from the pit bottom, registers 50 lbs., showing a gain of 2 lbs. This was observed whilst the engine was employed in pumping water and hauling coal. In the second case the pressure of 30 lbs. at the surface is also increased 2 or 3 lbs. at 1,614 yards from the pit bottom; when at 45 lbs. at the surface it is 47 lbs. underground, and when at 60 lbs. at the surface it is 63 lbs. underground. The tests in the second case were made when the engine was pumping water and running at a regular speed. At another place the air is conveyed nearly 2,000 yards. In these cases it is found there is a loss of 50 per cent. between the boilers and the air receiver at the surface.

At Ryhope Colliery in Durham, Mr. W. F. Hall uses compressed air for underground haulage, and enables the Author to give the following data:—The air is compressed at the surface by an engine having two steam cylinders 32 inches in diameter working direct two air-cylinders 33 inches in diameter and having 5 feet stroke. The air is forced into a first receiver on the surface, which is 30 feet long by 6 feet in diameter, and from there it is conducted down the pit, 518 yards deep, in 9-inch malleable iron pipes $\frac{3}{4}$ inch thick, to a second receiver 12 feet long and 4 feet in diameter, and adjusted to blow off at 50 lbs. pressure. The air is taken from the second to a third receiver, distant 101 yards, in 8-inch pipes, and 861 yards farther to a fourth receiver, and thence to the first hauling engine. The distance from the receiver on the surface to the first hauling engine below is 1,505 yards. This engine has a double 14-inch cylinder of 22 inches stroke, and the rope-drum, which is 4 feet in diameter, works through 3 to 1 spur gear. It hauls thirty-six 1-ton tubs up the first engine plane in ten minutes when full, and in seven minutes when empty. In some parts of this incline the gradient is about 1 in 10 against the load, and is a steeper plane than the one next referred to. A second engine, of the same size, but geared $2\frac{1}{4}$ to 1, is supplied with air from the receiver at the bottom of the pit, by a 6-inch pipe having two receivers on it. This engine, which is 1,308 yards from the receiver on the surface, hauls thirty-eight 1-ton tubs a distance of 2,200 yards up 1 in 18 and 2 in 18 in six minutes when full, and in five minutes when empty. A third double engine, having 10-inch cylinders, works a rope-drum 3 feet 6 inches in diameter through 5 to 1 gearing. This hauls thirty-six 1-ton tubs 750 yards in four minutes with full sets, and in three minutes when empty. Particulars of the temperature and pressure of the

air at this colliery under varying circumstances, are given in the Appendix, Table 1.

The cost of working has been ascertained to be as follows :—

	Per day.
Wages, stores, and coals for engines, boilers, and compressors } at surface }	5 13 10
Wages of engine-men and rope-winders, and stores for under- ground haulage }	3 4 4
	<hr/> £8 18 2 <hr/>

The average number of tons raised is 2,200 per day. The cost of working is therefore 0·97*d.* per ton. This is exclusive of the ropes, which, if allowed for, would raise the cost of haulage to about 1½*d.* per ton.

Compressed air is used at the Gartsherrie works of Messrs. Bairds for coal-cutting machines, and to a small extent for underground haulage. It is worked at a pressure of from 30 to 50 lbs. per square inch; 2½ cubic feet of steam at 40 lbs. pressure are found to give 1 cubic foot of air at 50 lbs., which makes the useful effect of compressed air about 50 per cent. that of steam. The compressed air has been conveyed 800 yards in ordinary cast-iron flanged pipes, faced and bolted with india-rubber joints, with but little loss by transmission. It is considered that about 80 per cent. of the power is wasted through loss of heat and friction.

Compressed air has also been extensively employed at the Powell Duffryn collieries, particulars of which Mr. Daniel, of Leeds, gave at the Cardiff meeting of the Institution of Mechanical Engineers.¹ In these collieries it was intended to dispense with all horse power underground, portable hauling engines being substituted for ponies and boys to bring the coal from the working faces to the branch roads. The pressure at which the air is worked is 40 lbs. per square inch, and experiments were made to ascertain the useful effect with steam at 28 lbs. pressure through nearly $\frac{7}{8}$ of the stroke, and it was found to be only 25·8 per cent. with air at 40 lbs. pressure, and 45·8 per cent. with air at 19 lbs. pressure. If the steam pressure had been 70 lbs., and cut off at $\frac{1}{4}$ stroke, better results would have been obtained, and the useful effect at 40 lbs. raised from 25 to 50 per cent., which is in agreement with results elsewhere.

French engineers have given considerable attention to the em-

¹ *Vide* Institution of Mechanical Engineers ; Proceedings, 1874, p. 204.

ployment of compressed air for locomotive purposes, and an engine on this principle, designed by M. Mékarski, has been tried on the Courbevoie tramway at Paris. Particulars of this are given in the "Portefeuille Economique des Machines," and also in "Engineering" for August 18, 1876.¹ The air is stored at a pressure of 25 atmospheres in thirteen charcoal-iron cylindrical reservoirs, under the floor of the tram-car, and is passed through a vessel containing hot water, which increases its elasticity, and thence through a reducing valve, where the pressure is controlled by a hand wheel, to the cylinder where it is utilised. This tram-car is stated to have run $4\frac{1}{2}$ miles with forty-five people on it without being recharged. Experiments with similar objects are now being made at Woolwich Arsenal by Major Beaumont, R.E., M.P. He has arranged a compressed-air locomotive, consisting of about seventy steel cylinders 4 inches in diameter and 6 feet long, containing air at a high pressure. These are piled together in an oblique stack, and supply sufficient air to draw light loads a considerable distance. Mr. Scott-Moncrieff has introduced a compressed-air car on the Vale of Clyde tramways, particulars of which were given by Captain Douglas Galton in a Paper on "Street Tramways," read at the Society of Arts on the 7th of February, 1877.² It is stated that this car travels a distance of 3 miles with each charge of compressed air at a cost of 3*d.* per mile, the consumption of fuel for compressing the air being estimated at 3 lbs. per HP.

Compressed air has been used since 1864 in the shops of Messrs. Eastons and Anderson at Erith to work a hammer, riveting machines, and other tools. The pumps supply the air through 6-inch and 12-inch pipes, and are fitted with automatic contrivances for stopping them when the pressure of air rises to 40 lbs. The consumption of coal necessary to produce a given quantity of compressed air, by means of air-pumps driven by a condensing steam engine, is about 69 per cent. more than to produce the same quantity of steam of a like pressure: for example, to produce 100 cubic feet per minute of air, at 45 lbs. pressure above the atmosphere, would require 53 indicated HP., and a consumption of 159 lbs. of coal per hour. To generate 100 cubic feet of steam at 45 lbs. pressure, 293°, per minute, would require the evaporation of 845 lbs. of water per hour, at the expense of 94 lbs. of coal.

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 383; and vol. xliv., p. 254.

² *Vide* Journal of the Society of Arts, vol. xxv., p. 219.

The same firm have employed compressed air to pump the sewage at Windsor. They have also applied it in H.M. Dockyard at Portsmouth to work capstans for hauling the largest ironclads in and out, and about the docks, as well as for opening the dock gates and sluices. It is understood to have been adopted there partly on the ground that it would not be exposed to the risk of damage through leakage, as either steam or water pressure might be, and partly because the power consumed would be more in proportion to the load to be moved than hydraulic power. As hydraulic power has been hitherto so extensively employed to perform operations of this intermittent nature, it will be interesting to know the results of using compressed air under the same conditions.

At the Tincroft mine a Doering drill was worked by compressed air, conveyed in a 2-inch wrought-iron pipe, down a shaft 1,200 feet deep. Observations showed that the pressure in the air-receiver on the surface was reduced from 26 lbs. to 23 lbs. at the drill when at work, and when standing idle the pressure at the drill rose to 28 lbs. At the Dolcoath mine, where the same drill was used, the loss between the engines and compressor when new was from 30 to 40 per cent., as ascertained by indicator cards on the pump and compressor.

Another and early method of transmitting power is by air exhaustion. About the years 1827-30 Hague exhibited a pneumatic crane which it was contemplated to apply to the St. Katharine Docks, with the view of seeing if the whole dock could be worked on that principle. Exhausted air has been employed for a variety of purposes, a well-known instance being its application to work the machinery at the Mint. The pneumatic system, in its application to the transmission of postal messages, was the subject of several communications to the Institution in the year 1875.¹

Where manual labour is used, as in working hand-power cranes, the cost of lifting and lowering goods is much greater than by other means. At Cotton's Wharf, London, a 10-cwt. crane lifting 40 feet requires on an average eight men at the handles, and it was found that the cost of lifting 100 foot-tons was 10.19d. (allowing 15 per cent. for interest and depreciation), and that the maximum speed of lifting the chain without weight was 100 feet in three and a half minutes. The capabilities of the crane did not exceed 10 tons an hour, 40 feet high. Experience of late years at wharves and such places shows that men are difficult to keep to

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xliii., p. 53 et seq.*

perform this class of work, and that an important diminution of energy is apparent in working hand-power cranes.

A comparison between manual labour and machinery has shown that the cost in the former is, in the case of cranes, about nine times that of the latter. Work done in collieries by hand is estimated by Mr. Emerson Bainbridge, Assoc. Inst. C.E., to cost about thirty-seven times as much as by machinery, and the diminishing rates of work done by men is shown by the fact that whereas in 1866 the number of tons of coal raised was 314 per man, in 1873 it was only 279, or more than 10 per cent. reduction.

Shafting is employed to transmit power within a limited area. The extent, however, to which it is applied may be judged by the fact that at the cotton mills of Messrs. Clark and Co., at Paisley, 4,000 HP. are thus transmitted. Where the consumption is intermittent there are objections to shafting, as power is being constantly exerted to drive it, and in addition there are the wear and tear and friction, and the attention for lubrication and repairs necessitating the ready accessibility of the parts. The amount of power lost in transmission by shafting varies widely with the state in which it is maintained. M. Vigreux¹ calculates that on a line of shafting running at 250 revolutions per minute, the loss due to friction of bearings is not less than 37 per cent. Several trials of engines for cotton mills and sheds, made by Mr. Joseph Clayton, of Preston, gave the friction of engine and shafting at about 32 per cent. of the gross load. A length of 300 feet of shafting working punching and shearing machines had been observed to consume 3.14 HP. In another case a length of 1,200 feet of $2\frac{3}{4}$ -inch shafting absorbed 1 indicated HP. for every 100 feet of shafting, when the driving-belts were thrown off. In an extensive range of warehouses an engine of Messrs. Appleby's drives about 1,000 feet of shafting with a boiler pressure of 5 lbs. per square inch, the power being transmitted by a vertical shaft and bevel gear from the basement (where the engine is placed) to the upper story where hoisting machinery is fixed.

The transmission of power by ropes, an extension of the belt and pulley method, will next be considered. M. Achard describes the transmission of motive power by wire ropes² at Oberursel, near Frankfort on the Main. At this place a waterfall of 263 feet, discharging from 12 to 31 gallons per second, is

¹ *Vide Annales du Génie civil*, 2^{me} série, tome v., p. 171 *et seq.* Also, Minutes of Proceedings Inst. C.E., vol. xlv., p. 264.

² *Vide Annales des Mines*, 7^e série, tome viii., p. 229. Also, Minutes of Proceedings Inst. C.E., vol. xlv., p. 267.

utilised, and 94 HP. transmitted a distance of 3,153 feet, divided into spans of about 393 feet each, by means of a turbine actuating a wire rope working over pulleys 12·3 feet in diameter. The effective tension on the rope varies inversely as its velocity; it is 1,400 lbs. at the pulleys, and the velocity 73·8 feet per second. An advantage in transmitting power in this way is pointed out by M. Achard to be, that where the power has to be distributed amongst various lessees it can be controlled, and any attempt to take more than the lessee is entitled to would only result in the slipping of the rope, inasmuch as the power to be given out at any point depends on the tension.

Mr. Henry M. Morrison has given particulars¹ of the employment of ropes as motors at Logelbach, in Alsace, where several printed calico factories, separated from each other, were supplied with 50 HP. from one steam engine, the power being conveyed a distance of 256 yards by means of light steel wire ropes $\frac{1}{2}$ inch in diameter, passing over grooved pulleys of 9 feet 6 inches diameter, running at an average speed of 31 miles an hour. The loss sustained in transmitting 120 HP. 150 yards was estimated to be $2\frac{1}{2}$ per cent. (or 3 HP.) due to friction of large pulleys. If the distance is greater supporting pulleys have to be used, which entail a further loss of nearly 1 HP. for every 1,100 yards. The direction of transmission has sometimes to be changed, and this is done either by directing pulleys, or by bevel wheels, the latter being considered the best.

Another instance of the employment of the wire rope system occurs at Schaffhausen, where, by constructing a dam across the river, the hydraulic power of the Rhine is utilised. Three turbines, $9\frac{1}{2}$ feet in diameter, are driven by a fall of from 12 to 16 feet of water, and are capable of developing 750 HP., which is transmitted by iron wire ropes, $\frac{3}{4}$ inch in diameter, over grooved pulleys 15 feet in diameter running at an average speed of 100 revolutions a minute, or 53 miles an hour. The tension necessary to transmit 326 HP. is, according to M. Achard, 5,807 lbs. The cost of the power to consumers is stated to be about 40 per cent. below the cost of steam power.

Similar works have been carried out at Fribourg, where, by constructing a dam across the river Saane, the valley above is converted into a reservoir, and a fall of 34 feet 6 inches obtained. This fall is utilised both for the water supply of the town and to supply power to manufactories, the latter being obtained by a Girard turbine and 300 HP. transmitted a distance

¹ *Vide* Institution of Mechanical Engineers; Proceedings, 1874, p. 57.

of 2,510 feet (divided into five equal spans of 502 feet) to the manufactories on the banks of the river by wire ropes. The pulleys are all 14 feet 9 inches in diameter, and make 81 revolutions a minute, which corresponds to a velocity of 65 feet per minute of the rope. The tension necessary to transmit 300 HP. is 5,198 lbs., or 6 tons 10·6 cwt. per square inch on the rope. The loss of power in transmission by a single wire rope is estimated to be about 6 per cent.

The advantages accruing from these systems would appear to be not only in the use of rope transmission, but more particularly because the power is obtained without the use of fuel.

Comparing wire ropes running at high velocities with belting, shafting, and pipes for water or compressed air, the first cost is in favour of ropes. Mr. Morrison states that the cost of ropes is only $\frac{1}{15}$ that of an equivalent amount of belting, and only $\frac{1}{20}$ that of shafting. The wear and tear of ropes, together with the necessity of avoiding steep inclinations where the distances are long, lessen the advantage of that system; on the other hand, the loss of power in transmission by ropes varies only as the velocity, whereas either by compressed air or by water the loss due to friction increases as the square of the velocity.

In the Appendix, Table 2 contains a statement of the transmission of power by wire ropes, compiled by Mr. W. A. Roebling, for an article on that subject by Mr. Albert W. Stahl.¹

A report was made in the year 1869 by the North of England Institute of Mining Engineers on the four principal systems of underground haulage in collieries, namely, the tail rope, endless chain, endless rope No. 1, endless rope No. 2. These different systems are employed to suit the varying circumstances of the curves, gradients, and number of branches in the workings, and the results show that the amount of power absorbed in transmission is respectively 45, 25, 23, and 8 per cent.

The application of rope gearing, to transmit the power from the prime mover to machinery in a factory in substitution of toothed gearing, has been recently advocated by Mr. James Durie.² The friction of rope gearing for high speeds is much below that of toothed gearing, and it is considered to have advantages over belts, inasmuch as the power can be distributed over several ropes, either of which can be repaired without stopping the system; but where only one belt is employed, the

¹ *Vide* Van Nostrand's Engineering Magazine, February 1877, p. 171.

² *Vide* Institution of Mechanical Engineers; Proceedings, 1876, p. 372.

whole of the system is stopped when the belt fails. The result of several experiments between flat leather belts and round ropes led to the conclusion, that the latter have a greater hold on V-shaped grooves per square inch than the former have on pulleys. Mr. Paget has found that the highest co-efficient of useful effect with the least wear to the rope is obtained when the angle of the groove is 40° , and at this angle Mr. Cowper gives the friction of the rope upon the two sides of the grooves as being three times as much as if the rope were working on the surface of a plain drum.

In considering the several means of transmitting power, it must be admitted that the convenience of a system of pipes to convey steam, water pressure, or compressed air, through the ramifications generally met with in supplying a variety of appliances, is great compared with shafting or ropes.

Compressed air, like steam, has an advantage over water when it can be worked expansively, as the power consumed by the appliances is then in proportion to the work done.

Steam must be considered to have economical advantages where the power has to be exerted continuously and within a limited area, and where the avoidance of fire risks is not essential.

At the usual pressure of 40 lbs. to the inch, it has been shown that, with compressed air, a loss occurs of about 50 per cent. between the boilers and compressors. The loss in transmitting air is greater than that of water, owing to the volume of air, at 40 lbs. to the inch, requiring to be $17\frac{1}{2}$ times greater than that of water at 700 lbs. to the inch, to convey the same power. The friction varying as the squares of the velocities, and directly as the densities, it will be found that, after allowing for the density of air at 40 lbs. above the atmosphere being about 220 times lighter than water, the loss of power with air will be much greater than with water, the amount depending on the size of pipe.

Mr. Daniel, of Leeds, calculates that the useful effect of air, at 40 lbs. pressure per square inch above the atmosphere, is only 48·8 per cent. of steam at the same initial pressure. Table 3 in the Appendix gives 44 per cent. as the maximum percentage that can be utilised of the original power expended, taking 66 per cent. as the efficiency of the compressing apparatus. Tables 4 and 5 in the Appendix give the theoretical effects at various pressures, according to Mariotte's and Poisson's laws. If the power necessary to compress air could be obtained without expense—as by a natural fall of water—the maximum useful effect would be 66 per cent. of the power expended.

Compressed air may be adopted with advantage in mining and tunnelling operations, notwithstanding the small useful effect obtained, as it enables boilers and underground steam engines to be dispensed with, thus diminishing the risk of explosion; it further aids ventilation. On the other hand, steam can only be used in parts of the mine where the exhaust can be conveyed to the bottom of the upcast shaft, as both steam and heat act prejudicially on the stone, timber, &c., in the workings. It also tends to the greater employment of labour-saving appliances, the introduction of which is productive of the double advantage of dispensing with manual labour and of enabling underground operations to be carried out more expeditiously, resulting in a quicker return on the capital sunk in such undertakings.

Systems of power co-operation, similar to that carried out at Hull, might advantageously be established to effect a better conservation of motive power by its concentration to supply entire districts. At present independent establishments are maintained to work the machinery and appliances, in most cases intermittently, thus involving waste of power, space, time, and money. By adopting power co-operation, the expense of production would be spread over many consumers, like the ordinary gas and domestic water services.

A comparison of the various systems shows that there are circumstances to which each is suitable, and that as these do not admit of being dealt with always on the principle of economy, but rather of appropriateness, each case must be decided by the conditions governing it. Where, however, the work to be done is intermittent, as in the case of cranes and dock work, the hydraulic system, on the ground of speed, safety, steadiness, and general convenience, is considered by the Author to be superior to any other.

The communication is accompanied by a series of diagrams, from which Plate 1 has been compiled.

APPENDIX.

TABLE 1.—EXPERIMENTS with COMPRESSED AIR made at RYHOPE COLLIERY, DURHAM, for WORKING an UNDERGROUND HAULING ENGINE.

Time of Measurements.	Number of Strokes of Steam Engine at Bank.	Bank Steam Pressure.	Bank Air Pressure.	Temperature of Air at Outlet.	Temperature of Air in the Outlet Pipe 6 ft. 10 ins. from the Cylinders.	Temperature of Air at No. 1 Receiver, bottom of Pit.	Pressure of Air at No. 1 Receiver.	Temperature of Air in No. 2 Receiver, top of the Engine Bank.	Temperature of Air at Air Engine in bye Receivers.	Pressure of Air at Engine.	Remarks.
H. M.		lbs.	lbs.	°	°	°	lbs.	°	°	lbs.	
10 15	14	15	40	216	236	75	46	66	58	45	Engine standing.
10 20	14	15	41	214	234	75	46	66	58	39	Engine running empty sett in-bye.
10 25	14	16	39	216	236	74	44	66	58	40½	
10 30	16	17	42	216	236	74	46	66	58	41½	Engine running full sett out-bye from No. 4 landing.
10 35	14	17	33	208	228	75	47	66	58	35	
10 40	14	18	34	206	226	74	35	66	58	30	

TABLE 2.—TRANSMISSION of POWER by WIRE ROPES.

Diameter of Wheel.	Number of Revolutions.	Trade No. of Rope.	Diameter of Rope.	Horse Power.	Diameter of Wheel.	Number of Revolutions.	Trade No. of Rope.	Diameter of Rope.	Horse Power.
Feet.			Inch.		Feet.			In. In.	
4	80	23	$\frac{3}{8}$	3.3			(19)		64.9
4	100	23	$\frac{3}{8}$	4.1	11	80	(18)	$\frac{5}{8}$ $\frac{11}{16}$	75.5
4	120	23	$\frac{3}{8}$	5.0			(19)		81.1
4	140	23	$\frac{3}{8}$	5.8	11	100	(18)	$\frac{5}{8}$ $\frac{11}{16}$	94.4
5	80	22	$\frac{7}{16}$	6.9			(19)		97.3
5	100	22	$\frac{7}{16}$	8.6	11	120	(18)	$\frac{5}{8}$ $\frac{11}{16}$	113.3
5	120	22	$\frac{7}{16}$	10.3			(19)		113.6
5	140	22	$\frac{7}{16}$	12.1	11	140	(18)	$\frac{5}{8}$ $\frac{11}{16}$	132.1
6	80	21	$\frac{1}{2}$	10.7			(18)		93.4
6	100	21	$\frac{1}{2}$	13.4	12	80	(17)	$\frac{11}{16}$ $\frac{3}{4}$	99.3
6	120	21	$\frac{1}{2}$	16.1			(18)		116.7
6	140	21	$\frac{1}{2}$	18.7	12	100	(17)	$\frac{11}{16}$ $\frac{3}{4}$	124.1
7	80	20	$\frac{1}{2}$	16.9			(18)		140.1
7	100	20	$\frac{1}{2}$	21.1	12	120	(17)	$\frac{11}{16}$ $\frac{3}{4}$	148.9
7	120	20	$\frac{1}{2}$	25.3			(18)		163.5
7	140	20	$\frac{1}{2}$	29.6	12	140	(17)	$\frac{11}{16}$ $\frac{3}{4}$	173.7
8	80	19	$\frac{1}{2}$	22.0			(18)		112.0
8	100	19	$\frac{1}{2}$	27.5	13	80	(17)	$\frac{11}{16}$ $\frac{3}{4}$	122.6
8	120	19	$\frac{1}{2}$	33.0			(18)		140.0
8	140	19	$\frac{1}{2}$	38.5	13	100	(17)	$\frac{11}{16}$ $\frac{3}{4}$	153.1
9	80	(20)	$\frac{1}{2}$ $\frac{5}{8}$	40.0			(18)		168.0
		(19)	$\frac{1}{2}$ $\frac{5}{8}$	41.5	13	120	(17)	$\frac{11}{16}$ $\frac{3}{4}$	183.9
9	100	(20)	$\frac{1}{2}$ $\frac{5}{8}$	50.0			(17)		148.0
		(19)	$\frac{1}{2}$ $\frac{5}{8}$	51.9	14	80	(16)	$\frac{3}{4}$ $\frac{7}{8}$	141.0
9	120	(20)	$\frac{1}{2}$ $\frac{5}{8}$	60.0			(17)		185.0
		(19)	$\frac{1}{2}$ $\frac{5}{8}$	62.2	14	100	(16)	$\frac{3}{4}$ $\frac{7}{8}$	176.0
9	140	(20)	$\frac{1}{2}$ $\frac{5}{8}$	70.0			(17)		222.0
		(19)	$\frac{1}{2}$ $\frac{5}{8}$	72.6	14	120	(16)	$\frac{3}{4}$ $\frac{7}{8}$	211.0
10	80	(19)	$\frac{5}{8}$ $\frac{11}{16}$	55.0			(17)		217.0
		(18)	$\frac{5}{8}$ $\frac{11}{16}$	58.4	15	80	(16)	$\frac{3}{4}$ $\frac{7}{8}$	217.0
10	100	(19)	$\frac{5}{8}$ $\frac{11}{16}$	68.7			(17)		259.0
		(18)	$\frac{5}{8}$ $\frac{11}{16}$	73.0	15	100	(16)	$\frac{3}{4}$ $\frac{7}{8}$	259.0
10	120	(19)	$\frac{5}{8}$ $\frac{11}{16}$	82.5			(17)		300.0
		(18)	$\frac{5}{8}$ $\frac{11}{16}$	87.6	15	120	(16)	$\frac{3}{4}$ $\frac{7}{8}$	300.0
10	140	(19)	$\frac{5}{8}$ $\frac{11}{16}$	96.2			(17)		
		(18)	$\frac{5}{8}$ $\frac{11}{16}$	102.2			(16)		

TABLE 3.—PRACTICAL RESULTS OF EXPERIMENTS WITH COMPRESSED AIR.

Pressures.		Work re- quired to produce 1 cubic foot. Compress- ing appa- ratus giving 86 per cent. efficiency.	Work done by 1 cubic foot of air at pressure given, expanding to atmospheric pressure.		Percentage realised of work expended.			
Atmo- spheres above atmo- spheric pressure.	Lbs. per square inch above atmo- spheric pressure.		Without addition of heat during expansion.	With addition of heat.	Including both opera- tions, viz., compressing and expanding.		Expanding only.	
					Without heat.	With heat.	Without heat.	With heat.
2	29·4	Foot-lbs. 4,401	Foot-lbs. 1,366	Foot-lbs. 2,156	30	44	45	66
3	44·1	10,458	3,048	4,648	29	44	44	66
4	58·8	17,577	4,962	7,812	28	44	42	66
5	73·5	26,451	7,028	11,756	27	44	41	66

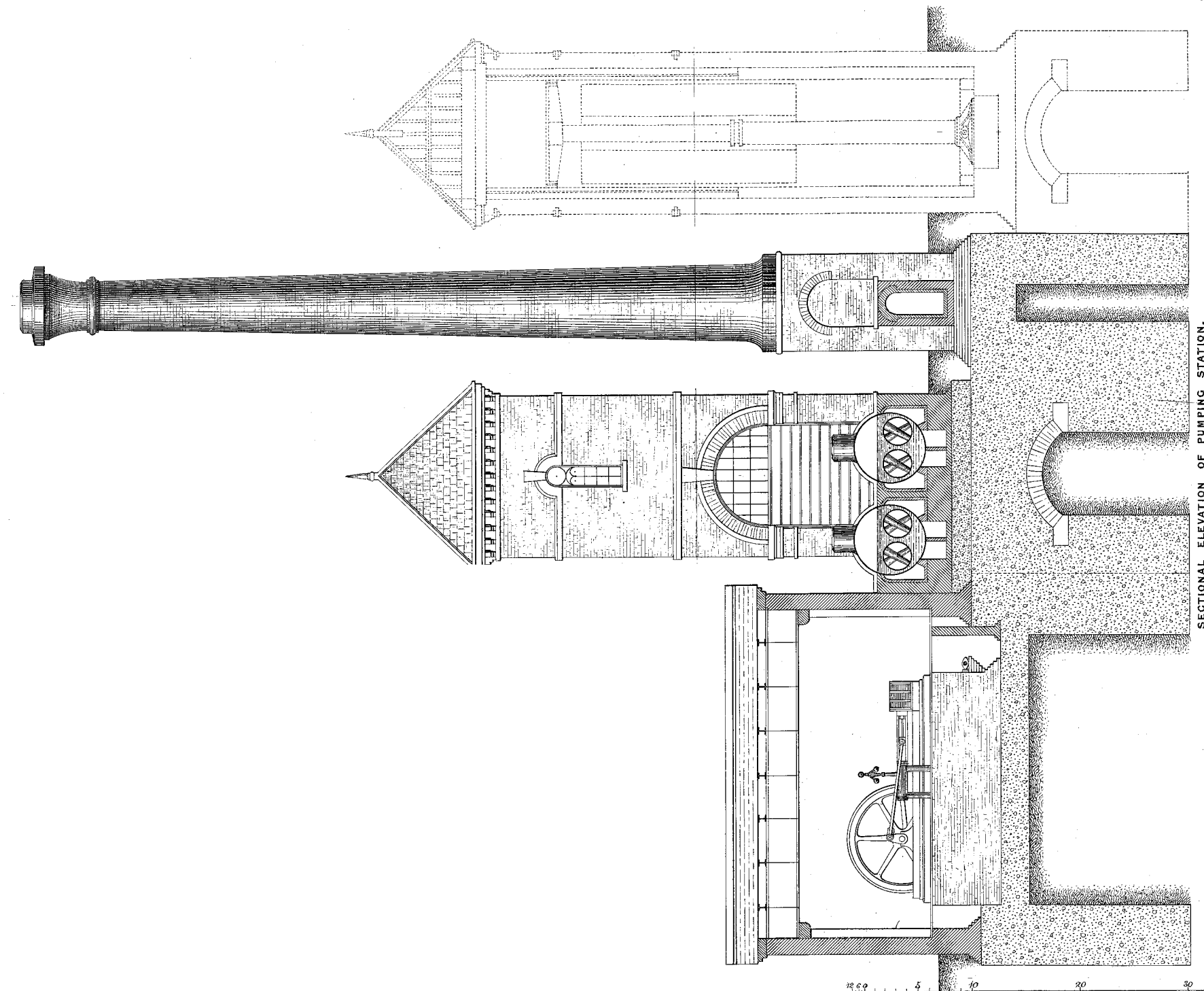
TABLE 4.—THEORETICAL WORK DONE BY COMPRESSED AIR ACCORDING TO MARIOTTE'S LAW, which supposes that the temperature of the air remains constant throughout the operations of Compression and Expansion.

Pressure.		Theoretical work in 1 cubic foot ex- panding to 1 atmosphere.	Number of cubic feet produced by 1 HP. per hour.	Units of Heat equivalent to work given in third column. 1 unit = 772 foot-lbs.
Atmospheres above 1 atmosphere.	Lbs. above 1 atmosphere.			
2	29·4	Foot-lbs. 2,934	678·2	3·80
3	44·1	6,972	285·4	9·03
4	58·8	11,718	168·9	15·17
5	73·5	17,034	116·2	22·06

TABLE 5.—THEORETICAL WORK DONE ACCORDING TO POISSON'S LAW, which supposes that when air is compressed, none of the heat due to compression is allowed to escape, or *vice versa* when compressed air is allowed to expand, no external heat is added to it.

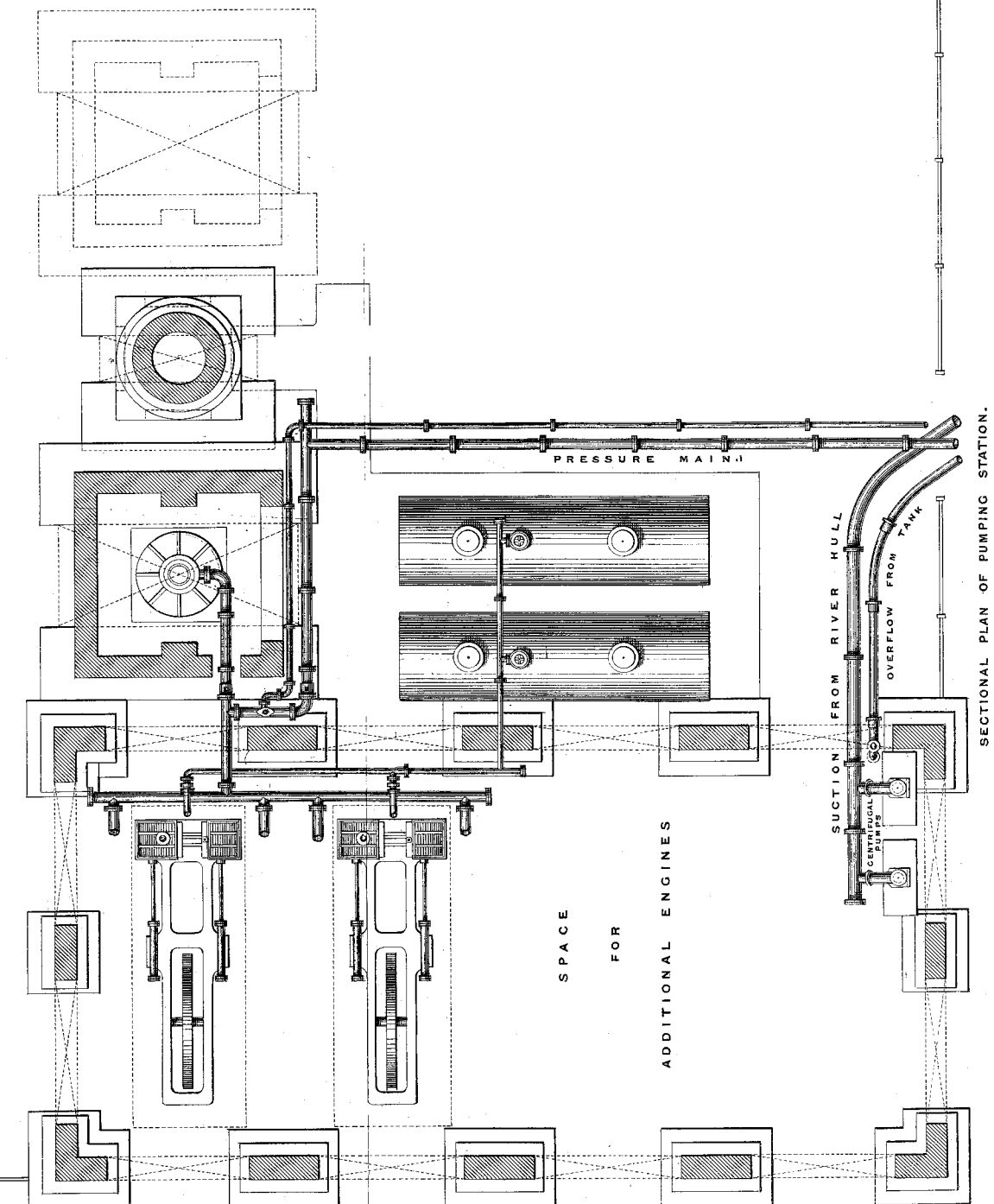
To reduce the given quantity to 1 cubic foot.			Work done by 1 cubic foot at pressures given, expanding to 14·7 lbs. per square inch.		
Cubic feet at 14·7 lbs. per square inch.	Foot-lbs. re- quired.	Final pressure in lbs. per square inch.	Pressure in lbs. per square inch.	Work done in foot-lbs.	Final volume in cubic feet.
2	3,200	37·044	29·4	2,048	1·682
3	8,524	63·651	44·1	4,572	2·279
4	14,920	93·345	58·8	7,442	2·828
5	22,533	125·685	73·5	10,541	3·344

Mr. STEPHENSON,



SECTIONAL ELEVATION OF PUMPING STATION.

10 5 10 20 30 40 50 Feet.



SECTIONAL PLAN OF PUMPING STATION.