

## ON THE VARIOUS MODES OF TRANSMITTING POWER TO A DISTANCE.

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The Author proposes in this paper to furnish a summary of the practical results obtained in the Transmission of Power to a distance, a subject on which some articles of his have appeared in the *Annales des Mines*, between 1874 and 1879.

While the interest attaching to this subject is unquestionable, the Author is nevertheless very doubtful whether a successful result can be attained in one particular application, namely the establishment of large undertakings for distributing hydraulic power to a number of factories, either existing or contemplated, similar to the undertakings at Schaffhausen, Fribourg, and Bellegarde, which the Author has elsewhere described in detail.\* At the first of these places, in spite of favourable circumstances, rapid extension of working, and good management, the profit has been very small on the capital outlay. The manufactories at the two other places, being much less favourably situated, have failed after a short and profitless existence. Their failure has shown very clearly that their founders laboured under a strange delusion, in supposing that cheap motive power was in itself sufficient to create industries in localities where their essential elements were wanting. The Author accordingly considers there is not much to be gained from this particular application of power transmission, and that it can only succeed financially under exceptionally favourable conditions.

He now proceeds to examine the various methods used, or proposed, for transmitting power to a distance. .

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\* For a description of the Schaffhausen undertaking, see Mr. Morrison's paper, *Proceedings*, 1874, p. 56.

## I. TRANSMISSION OF POWER BY WIRE ROPES.

Transmission by wire ropes is merely an extension of the simplest case of transmission by ordinary hemp ropes, and the same principles apply to both. These principles may be briefly stated as follows:—

Let A and B be the axes of two parallel shafts carrying two pulleys whose planes coincide. The driving power  $P$  acts on A, and the resistance  $Q$  on B. For simplicity let it be assumed that these two forces act tangentially at the circumference of the pulleys. The motion is communicated from A to B by means of the rope passing round the two pulleys; of this the part which is passing towards the driving pulley is called the driving span, and the part which is passing from the driving pulley is called the trailing span. Let  $T$  be the tension of the driving span, and  $t$  that of the trailing span. Neglecting friction &c. we should have  $Q = P$ ; and the values of the tensions in the two spans are given by the equations  $T - t = P$  and  $\frac{T}{t} = k$ ; denoting by  $k$  the smallest practicable value of  $e^{fa}$  for the two pulleys, where  $e$  is the base of Napierian logarithms,  $f$  the coefficient of friction between the pulley and the rope, and  $a$  the ratio between the arc encircled by the rope and the radius of the pulley. Accordingly the values of  $T$  and  $t$  are given by the following equations:—

$$T = \frac{kP}{k-1}; \quad t = \frac{P}{k-1}.$$

If the ratio  $\frac{T}{t}$  be greater than  $k$ , the rope will slip on the driving pulley. The values of  $T$  and  $t$ , as above calculated, when  $k$  has its exact value, are only just sufficient to prevent slipping, which would occur on any accidental diminution of friction. For safety therefore it is necessary to assign to  $k$  a somewhat lower value than its real one: which practically amounts to increasing the tensions  $T$  and  $t$  a little beyond what is requisite in theory. The tension common to the whole rope when at rest is somewhere intermediate between the tensions  $T$  and  $t$  of its two spans while running; and by adjusting the rope while at rest to this intermediate tension, its two spans

assume of their own accord the required tensions  $T$  and  $t$ , as soon as it begins to run.

The sectional area  $w$  to be given to the rope, so that it may possess the requisite strength, is regulated by the driving tension  $T$ , and must be such that the quotient  $\frac{T}{w}$  shall not exceed the working strain which the material of the rope is suited to bear in practice. It is evident that, in transmitting a given amount of power, the driving tension, and consequently the section of the rope, may be diminished by increasing the speed; for if  $N$  denotes the power transmitted, and  $v$  the speed of the rope, then  $Pv = N$ , and  $T = \frac{kP}{k-1} = \frac{k}{k-1} \frac{N}{v}$ . In practice the rope elongates under the continuous pull, and requires shortening from time to time to keep the tension up to the proper amount.

We will now take into account the useless resistances, hitherto neglected for the sake of simplicity. The useful resistance  $Q$  is now necessarily less than the driving power  $P$ , and the ratio  $\frac{Q}{P}$  represents the efficiency of the transmission. The useless resistances are two in number. The first is the rigidity or stiffness of the rope, due to its imperfect flexibility. This effect however is insignificant in the case of rope transmission, on account of the large size of the pulleys employed. The other useless resistance is the friction of the two shafts  $A$  and  $B$  in their bearings, of which one of the factors is the resultant  $F$  of all the external forces acting on each shaft. It appears from the principles enunciated above that the employment of rope transmission renders this friction considerable. In fact, under average conditions of adhesion, the value to be allowed for  $k = e^{\mu}$  is not more than 2; and since in the limit  $\frac{T}{t} = k$ , and  $T = \frac{kP}{k-1}$ , we have as the least possible values  $T = 2P$ , and  $t = P$ . These tensions are parallel to each other; and as the driving power  $P$  may also act in the same direction, the total pressure  $F$  on the shaft may be  $T + t + P = 4P$ , as a minimum, where the conditions are the most unfavourable; while under the most favourable conditions the pressure on the bearings will be given by  $F = T + t - P = 2P$ , as a minimum.

Hence the average pressure may be taken as at least  $3 P$ . It is evident therefore that rope transmission renders the shaft friction much greater than does transmission by toothed wheels. But the effect of this friction is much reduced by the large diameter of the pulleys in comparison with that of their shafts, in consequence of which the pressure on the shaft bearings has to be multiplied by a number not exceeding at most  $0.003$ , in order to obtain the resulting friction on the shaft.

The introduction of iron wire ropes for transmitting power to a distance has arisen from the necessity of replacing leather or india-rubber by some material less expensive, less affected by atmospheric influences, less extensible, and especially possessing a much higher tensile strength. The large amount of the power which must exist to make special machinery advantageous for transmitting it to a distance does not constitute one of the reasons for the change of material, inasmuch as belts of leather and india-rubber are capable of transmitting very considerable power. In reality they owe this capability to a special property which they possess; and which releases them completely from the theoretical laws to which attention has just been directed in the case of ropes. If the belt is wide, a partial vacuum is produced between the belt and the rim of the pulley, by the aid of an adequate velocity, which causes the atmospheric pressure to press the belt close against the pulley. An adhesion is thereby produced which is totally independent of friction, and enables the tensions to be considerably reduced. Accordingly the tension  $T$  of the driving span, instead of attaining the value  $2 P$ , need only equal  $P$ . A great reduction of the friction on the bearings is thereby effected, and there is a greater power of transmission with the same section. Thus, whilst formerly in large factories the belts served only to transmit the power from the main driving shafts to the different machines, they are beginning to be employed to drive the main shafts themselves from the prime mover. The Americans were the first to adopt this course. This extended use of belts is regulated by certain practical rules which it may perhaps be useful to point out. It is advisable to make the belts travel at a high speed, 4000, 5000, and even 6000 ft.

per minute, which leads to the adoption of large diameters for the pulleys. As flexibility is essential, it is preferable not to double the leather, but to rest satisfied with the greatest single thickness, amounting to  $\frac{5}{16}$  or  $\frac{3}{8}$  inch, and to resort to large widths. As the adhesion does not depend on the friction, the roughness of the surfaces in contact is more injurious than useful; and accordingly, contrary to the old practice, the hair or grain side of the leather, being the smoothest, is turned to the pulley. Since the even motion of the pulleys is a very important condition, it is advisable to employ, as far as possible, light and perfectly-balanced pulleys, and supports with a wide base and movable bearings. It is for this reason that American pulleys are sold by the piece and not by weight. The widths which the Americans give to belts put up on this principle are such that the circumferential strain,  $P = \frac{N}{v}$ , is 50 lbs. to 67 lbs.

per inch of width, which represents a strain of 156 lbs. to 185 lbs. per square inch of section. There was a leather belt at the Philadelphia Exhibition of 1876 which had a width of 5 ft.; but generally they barely exceed  $3\frac{1}{2}$  ft. or 4 ft.; while for greater widths several belts are employed, placed side by side.

The invention of iron wire ropes for power transmission is due to M. Ch. Ferdinand Hirn, of Colmar in Alsace. These ropes are composed of a certain number of strands, each having a core of hemp, which are rolled round a central core, also of hemp. They are wound on in the opposite direction to that of the wires in each strand. The pulleys are of large diameter, which tends to the preservation of the ropes, helps to render the effect of the stiffness insignificant, and diminishes the effect of the friction of the bearings. If the distance is considerable, the transmissions are divided into several relays, with a separate rope for each. The relays are separated by stations. Each station is provided with a horizontal shaft upon which a double-grooved pulley is fixed, which is the driven pulley as regards the relay terminating there, and the driving pulley in reference to the succeeding relay. The stations are usually arranged on masonry pillars, more or less raised according to the configuration of the ground, for it is necessary that the rope should be in no danger of

touching the ground. Sometimes the power has to be partially distributed in its course: under these circumstances the shafts at the stations are made use of for the purpose. Frequently also it is necessary to place intermediate pulleys along a relay, which differ from the end pulleys of the relay in serving merely to support the rope. Occasionally a relay has been made 650 feet long, but usually 420 to 500 feet is the limit.

The weights of the most ordinary sizes of pulleys employed, including their shafts, are on an average as follows:—

DIAMETER.		WEIGHT.			
		Single-groove Pulley.		Double-groove Pulley.	
metres.	feet. in.	kilogrammes.	lbs.	kilogrammes.	lbs.
5.50	18 0	2775	6232	3750	8267
4.50	14 9	2350	5180	3170	6988
3.75	12 4	1100	2425	1850	4078
2.13	7 0	362	798	528	1164

The pulleys have grooves of the shape of a V, rounded off at the bottom, and having there a swallow-tailed notch in which the lagging is fixed. Experience proves that the best lagging is made of pieces of leather, cut from the hide in the form of the notch, and placed in it end upwards. When these are filled in all round, the pulley is once more placed in the lathe, so as to turn down the bottom of the groove to the section required. This lagging lasts on an average three years. It wears out most rapidly on the intermediate pulleys; it has been observed that the rotation of these pulleys is more rapid than the motion of the rope, which occasions slipping.

The iron wires of which the rope is made have to bear two distinct molecular strains. The first, designated by  $s$ , is the tension resulting from the maximum tension  $T$  necessary to transmit the motion, and its value, in lbs. per sq. in. is accordingly  $s = \frac{T}{\frac{\pi}{4} d^2 i}$ ,  $d$  being the diameter of the wires, and  $i$  their number. The second strain results from the flexure produced by the winding upon the pulley, and may

be expressed with sufficient accuracy by  $z = E \frac{d}{2R}$ ;  $R$  being the radius of the pulley, and  $E$  the modulus of elasticity of iron, say 20,000 kg. per sq. mm., or 28,445,000 lbs. per sq. in. It is clearly necessary that the sum of these strains,  $s + z$ , should not exceed a certain limit, which is fixed at 18 kilogrammes per sq. mm. (25,600 lbs., or say 11 tons, per sq. in.) In most of the ropes with which the Author is acquainted the values allowed are approximately  $s = 10$  kg. (14,220 lbs. per sq. in.), and  $z = 8$  kg. (11,380 lbs. per sq. in.) The speed of the ropes may without any inconvenience attain, and even exceed, 20 metres per second (4000 feet per minute, or 45 miles per hour). To preserve the ropes from oxidation and improve their adhesion, they are coated with a heated mixture of grease and resin. A special machine, invented by M. D. H. Ziegler, engineer at Winterthur, enables the ropes to be subjected to a preliminary squeezing to increase their length; by this means the subsequent elongation from wear and tear is diminished, and the number of shortenings which become necessary is reduced.

It is difficult to lay down any general rule as to the duration of the ropes, for this depends upon the conditions under which they work. In practice it must not be assumed that a rope in constant use will last more than a year. In fact Professor Amsler-Laffon recently wrote to the Author on the subject of the ropes at Schaffhausen: "A rope lasts about one year, some a little more, some a little less. But it must be understood that we do not wait till our ropes break, but replace them as soon as we can no longer depend on their strength. They might therefore last rather longer, if we chose to run the risk of interruption in our work." The same duration has been found at Zurich in the case of a rope transmission, established by the municipality to supply a manufacturer whom they had deprived of his water power. The short life of the ropes is certainly a defect in this mode of transmitting power. According to M. Ziegler, who has considerable experience on this subject, horizontal oscillations are very injurious to the duration of the ropes, and they appear to last longer on pulleys with wide grooves than with narrow grooves.

The curve in which the rope hangs is a catenary; and it is upon the form of the particular catenary in which it hangs, whether more or less deep, as well as upon its lineal weight, that the tension to which it is subjected depends. By fixing the weight of the rope and its length, the form which its two spans assume in common, when at rest, is determined, and consequently their common tension; which latter must be such as to produce in running the two unequal tensions,  $T$  and  $t$ , necessary for the transmission of the power.

Moreover, the tension in either span is not the same throughout its whole length; it is a minimum at the lowest point of the curve, and goes on increasing towards the two extremities. The calculation of the tension at the lowest point is very complicated if based upon the true form of the catenary; but by substituting a parabola for the catenary, which is allowable in almost all cases, the calculation becomes very simple. If the two pulleys are on the same level, the lowest point is midway between them, and the tension at this point is  $S_0 = \frac{pl^2}{8h}$ ,  $p$  being the lineal weight of the rope,  $l$  its horizontal projection, which is approximately equal to the distance between the centres of the pulleys, and  $h$  the deflection in the middle. The catenary possesses the remarkable mechanical property that the difference between the tensions at any two points is equal to the weight of a length of rope corresponding to the difference in level between the two points. The tensions therefore at the two ends will be  $S_1 = S_0 + ph = \frac{pl^2}{8h} + ph$ . By substituting for  $S_1$  in the above equation the required values of  $T$  and  $t$ , and solving it with relation to  $h$ , the deflections  $h_1$  and  $h_2$  of the driving and trailing spans will be obtained. The deflection  $h_0$ , common to the two spans at rest, is given by the equation  $h_0 = \sqrt{\frac{1}{2} h_1^2 + \frac{1}{2} h_2^2}$ . If, as before,  $w$  represents the sectional area of the iron portion of the rope,  $s$  the unit strain which the maximum tension  $T$  produces on it, we have  $ws = T = \frac{pl^2}{8h_1} + ph_1$ . Taking the sectional area  $w$  of the rope in square inches, and its weight  $p$  in lbs. per foot run, the ratio  $\frac{w}{p}$  differs little from a mean value of 0.24 (104 in French measures);



and as previously stated the safe limit of working tension usually assigned for iron-wire ropes is  $s = 14,220$  lbs. per sq. in. (French measures  $s = 10$  kg. per sq. mm.) Hence  $\frac{w}{p}s = 0.24 \times 14,220 = 3410$ ; and we have the approximate equation  $\frac{l^2}{8h_1} + h_1 = 3410$  (French measures 1040), which is useful as giving a relation between the length  $l$  and deflection  $h_1$ , for the driving span of a rope. In the case of leather,  $\frac{w}{p} = 2.53$  approximately (French measures 1100); and as it is impossible to give  $s$  a higher value than about 355 lbs. per sq. in. (0.25 kg.), the relation obtained would be  $\frac{l^2}{8h_1} + h_1 = 900$  (French measures 275), which with equal deflections would give much shorter spans. If the working tension  $s$  were reduced to the American limit of 185 lbs. per sq. in. (0.13 kg.) for leather belts, the above figure 900 would be reduced to 470 (French measures 143), which would further shorten the span nearly one-half.

It is therefore owing to the great strength which iron wire ropes possess in proportion to their weight that they admit of long spans, with a smaller number of supports, and consequently smaller loss of power by friction. They may therefore be expected to yield a high efficiency. As a matter of fact the experiments of M. Ziegler on the transmission of power at Oberursel give for the mean efficiency of a single relay  $\frac{Q}{P} = 96.2$  per cent. The efficiency of transmission by relays, including  $m$  intermediate stations, is approximately obtained by raising the efficiency of a single relay to the power of  $\frac{m+2}{2}$ .

It often happens that the two pulleys of a single relay are at different levels, in which case neither span of the rope has the same tension at its two extremities: the tension at the upper end of each exceeds that at the lower by the quantity  $pH$ ,  $H$  being the difference in level between the two extremities, or, which is approximately the same, between the centres of the two pulleys. It is evidently the tension of the driving span at its lower end which must be regulated so as to obtain the proper driving tension  $T$  for the

transmission: so that there is a certain excess of tension at the upper pulley.

When power has to be transmitted to the top of a very steep incline, the establishment of a relay station exactly at the top of the incline is generally avoided; intermediate pulleys are put there in preference, one for each span, the relay itself being prolonged for a certain distance on the level. This is the course which has been adopted for the transmission of power from the two turbines at Bellegarde, where a height of about 115 feet has to be surmounted. The Author would refer to his published article for the description of the transmission by ropes at Oberursel, Schaffhausen, Fribourg, and Bellegarde, as it would be impossible to abridge the account sufficiently for the present paper.

## II.—TRANSMISSION BY COMPRESSED AIR.

Hitherto the method of transmission by compressed air has only been used, so far as the Author is aware, for boring the headings of mines, and the long tunnels through the Alps. In these cases, as is well known, the work to be done consists in a rapid boring of holes for the purpose of blasting the rock with powder or dynamite. As this kind of work requires a high pressure of air, and almost entirely precludes the employment of expansion, the utilisation of the motive force is necessarily defective; but in consequence of the peculiar convenience which compressed air offers for the work, and particularly the improved ventilation which it affords, the advantage of its employment is undoubted, and leaves in the background the question of efficiency. If however this method were resorted to for driving through rock soft enough to be excavated directly by the mining tool, it is possible that expansion might be used in the machine working the tool.

In the case of the transmission of power for general industrial purposes, the question of efficiency is usually of great importance. The ultimate efficiency of transmission is the product of three partial efficiencies: (1) that of the air-compressing machine; (2) that of the pipes by which the compressed air is conveyed; and (3) that of the machine which the compressed air works. The efficiency of the

prime mover, and that of the tools worked by the compressed-air machine, should not be brought into this estimate.

The air-compressing machines, generally called compressors, are piston pumps,\* having self-acting inlet and outlet mitre valves, controlled by springs and worked by the air pressure itself.

The essential condition to be fulfilled by an air-compressor is that the temperature of the air during compression should as far as possible be kept constant: the reason, as is well known, being as follows. Let  $P$  be the power expended in compressing a given initial volume of atmospheric air into a given final volume, whilst fulfilling this condition. If the air were compressed in a cylinder impermeable to heat, the heat resulting from the compression would remain in it, and would raise its temperature and pressure, thus involving the expenditure of a power  $P_1$ , greater than  $P$ , for its compression. But after the compression had been effected, the temperature of the compressed air would rapidly fall to the surrounding temperature, and would only represent a store of power  $P_2$ , less than  $P$ ; thus the powers  $P_1 - P$  and  $P - P_2$ , making together  $P_1 - P_2$ , would be lost. Even if the metal barrel of the compressing pump is not absolutely impermeable to heat, it is impossible to avoid not merely important losses of power, but also an amount of heating that is very injurious both to the working and to the durability of the machine. It is only by the help of water that the rise of temperature can successfully be kept down within moderate limits.

The Seraing or water-piston compressor was first tried with this object. The great defect of this apparatus is the loss of power resulting from the alternating movement imparted to a large body of water. This loss is approximately proportional to the volume displaced by the piston, raised to the power  $\frac{5}{3}$ , and to its speed raised to the power  $\frac{4}{3}$ . To reduce this loss it would be necessary to

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\* The impact compressor, combining the functions of a hydraulic motor and a compressor, which was employed at the commencement of the driving of the Mont Cenis tunnel, need not be included in the list. In spite of its apparent simplicity, it was found to be costly, cumbersome, inefficacious, and easily deranged, and was very soon abandoned. It would unquestionably require further improvements to render it applicable even in very special cases.

divide the required production of compressed air amongst a great number of compressors, and to make them work slowly, by giving them large dimensions. This renders the first cost of erection, and the space required, comparatively large. The speed of the compressors working on this system at Mont Cenis was limited to 8 or 10 revolutions per minute; and that of the smaller compressors, which have been used for headings in mines, has been generally limited to 15 or 18 revolutions.

It was next attempted to employ the water for cooling in a manner which, whilst efficacious, should not entail the above loss of power, and should admit of a higher speed of working. The object was accomplished by two methods, which can be used separately or together. One consists in making the water circulate through a casing surrounding the pump-barrel, and through cavities formed inside the piston and piston-rod. The other method, which is still more efficacious, consists in injecting a very fine spray into the pump barrel, whereby the water is brought into direct contact with the air to be cooled. Both these methods, suggested by M. Colladon, have been applied, under his instructions, to the St. Gothard compressors, and have furnished excellent results. These machines have perfectly answered their purpose, and have worked at a speed of 60 to 80 revolutions per minute, producing only a very limited rise in temperature.

The efficiency of the St. Gothard compressors has been approximately from 78 to 80 per cent. The Author regrets that he is unable to give more precise figures; but M. Colladon, the consulting engineer of the tunnel works, informed him, only a short time ago, that no experiments had been made as to this efficiency; and more particularly that the effective force of the hydraulic motors which work them had never been measured. M. Colladon had however the kindness to furnish the results of a trial made with one of his compressors at the works of Messrs. Sautter and Lemonnier of Paris, the makers of the machine. These experiments would show an efficiency of 86 per cent. Nevertheless it is not possible to place implicit reliance on this result, because the effective power of the motor was not determined by experiment. But allowing that the

figure of 22 H.P., assumed for this power (the result in calculating the work with compressed air being 19 H.P.), may be somewhat incorrect, it is unlikely that the error can be so large that its correction would reduce the efficiency below 80 per cent. Messrs. Sautter and Lemonnier, who construct a number of compressors, on being consulted by the Author, have written to say that they had always confined themselves to estimating the power stored in the compressed air, and had never measured the power expended in compressing it.

Compressed air in passing along the pipe, assumed to be horizontal, which conveys it from the place of production to the place where it is to be used, experiences by friction a diminution of pressure, which represents a reduction in the mechanical power stored up, and consequently a loss of efficiency. The loss of pressure in question can only be calculated conveniently on the hypothesis that it is very small, and the general formula employed for the purpose is—

$$\frac{p_1 - p}{\Delta} = \frac{4L}{D} f(u),$$

where  $D$  is the diameter of the pipe, assumed to be uniform,  $L$  the length of the pipe,  $p_1$  the pressure at the entrance,  $p$  the pressure at the farther end,  $u$  the velocity at which the compressed air travels,  $\Delta$  its specific weight, and  $f(u)$  the friction per unit of length. In proportion as the air loses pressure its speed increases, whilst its specific weight diminishes; but the variations in pressure are assumed to be so small that  $u$  and  $\Delta$  may be considered constant.

As regards the quantity  $f(u)$ , or the friction per unit of length, the natural law which regulates it is not known, and it can only be expressed by some empirical formula, which, whilst according sufficiently nearly with the facts, is suited for calculation. For this purpose the binomial formula  $au + bu^2$ , or the simple formula  $b_1 u^2$ , is generally adopted;  $a$ ,  $b$ , and  $b_1$  being coefficients deduced from experiment. The values however which are to be given to these coefficients are not constant, for they vary with the diameter of the pipe; and in particular, contrary to formerly received ideas, they vary according to its internal surface. The uncertainty in this respect is so

great that it is not worth while, with a view to accuracy, to relinquish the great convenience which the simple formula  $b_1 u^2$  offers. It would be better from this point of view to endeavour, as has been suggested, to render this formula more exact by the substitution of a fractional power in the place of the square, rather than to go through the long calculations necessitated by the use of the binomial  $au + bu^2$ . Accordingly, making use of the formula  $b_1 u^3$ , the above equation becomes,

$$\frac{p_1 - p}{\Delta} = \frac{4L}{D} b_1 u^3 ;$$

or, introducing the discharge per second,  $Q$ , which is the usual figure supplied, and which is connected with the velocity by the relation  $Q = \frac{\pi D^2 u}{4}$  we have

$$\frac{p_1 - p}{\Delta} = \frac{64}{\pi^2} \frac{b_1}{D^5} L Q^2.$$

Generally the pressure  $p_1$  at the entrance is known, and the pressure  $p$  has to be found; it is then from  $p_1$  that the values of  $Q$  and  $\Delta$  are calculated. In experiments where  $p_1$  and  $p$  are measured directly, in order to arrive at the value of the coefficient  $b_1$ ,  $Q$  and  $\Delta$  would be calculated for the mean pressure  $\frac{1}{2}(p_1 + p)$ .

The values given to the coefficient  $b_1$  vary considerably, because, as stated above, it varies with the diameter, and also with the nature of the material of the pipe. It is generally admitted that it is independent of the pressure, and it is probable that within certain limits of pressure this hypothesis is in accordance with the truth.

D'Aubuisson gives for this case, in his "Traité d'Hydraulique," a rather complicated formula, containing a constant deduced from experiment, whose value, according to a calculation made by the Author, corresponds approximately to  $b_1 = 0.0003$ . This constant was determined by taking the mean of experiments made with tin tubes of 0.0235 m. ( $\frac{15}{16}$  inch), 0.05 m. (2 inches), and 0.10 m. (4 inches) diameter; and it was erroneously assumed that it was correct for all diameters and all materials.

M. Arson, engineer to the Paris Gas Company, published in 1867, in the "Mémoires de la Société des Ingénieurs Civils de

France," the results of some experiments on the loss of pressure in gas when passing through pipes. He employed cast-iron pipes of the ordinary kind. He has represented the results of his experiments by the binomial formula  $au + bu^2$ , and gives values for the coefficients  $a$  and  $b$ , which diminish with an increase in diameter, but would indicate greater losses of pressure than D'Aubuisson's formula.

M. Devillez, in his "Rapport sur les travaux de percement du tunnel sous les Alpes," states that the losses of pressure observed in the air-main at the Mont Cenis tunnel confirm the correctness of D'Aubuisson's formula; but his reasoning applies to too complex an air-main to be absolutely convincing.

Quite recently M. E. Stockalper, engineer-in-chief at the northern end of the St. Gothard tunnel, has made some experiments on the air-main of this tunnel, the results of which he has kindly furnished to the Author. These lead to values for the coefficient  $b_1$  appreciably less than that which is contained implicitly in D'Aubuisson's formula. As he experimented on a rising pipe, it is necessary to introduce into the formula the difference of level  $h$  between the two ends; it then becomes—

$$\frac{p_1 - p}{\Delta} = \frac{64 b_1}{\pi^2 D^5} L Q^2 + h.$$

The following are the details of these experiments:—

*First series of Experiments.*—Air-main consisting of cast-iron pipes, joined by means of flanges, bolts, and india-rubber rings.  $D = 0.20$  m. (8 in.);  $L = 4600$  m. (15,100 ft.);  $h = 26.77$  m. (87 ft. 10 in.).

*1st Experiment.*— $Q = 0.1860$  cub. m. (6.57 cub. ft.), at a pressure of  $\frac{1}{2}(p_1 + p)$ , and a temperature of  $22^\circ$  Centigrade ( $72^\circ$  Fahrenheit);  $p_1 = 5.60$  atm.,  $p = 5.24$  atm. Hence  $p_1 - p = 0.36$  atm.  $= 0.36 \times 10334$  kilogrammes per sq. metre (2116 lbs. per sq. ft.); whence we obtain  $b_1 = 0.0001697$ .

D'Aubuisson's formula would have given  $p_1 - p = 0.626$  atm.; and M. Arson's would have given  $p_1 - p = 0.92$  atm.

*2nd Experiment.*— $Q = 0.1566$  cub. m. (5.53 cub. ft.), at a pressure of  $\frac{1}{2}(p_1 + p)$ , and a temperature of  $22^\circ$  Cent. ( $72^\circ$  Fahr.);  $p_1 = 4.35$  atm.,  $p = 4.13$  atm. Hence  $p_1 - p = 0.22$  atm.  $= 0.22 \times 10334$

kg. per sq. m. (2116 lbs. per sq. ft.); whence we obtain  $b_1 = 0.0001816$ .

D'Aubuisson's formula would have given  $p_1 - p = 0.347$  atm.; and M. Arson's would have given  $p_1 - p = 0.53$  atm.

*3rd Experiment.*— $Q = 0.1495$  cub. m. (5.28 cub. ft.), at a pressure of  $\frac{1}{2}(p_1 + p)$  and a temperature of  $22^\circ$  Cent. ( $72^\circ$  Fahr.);  $p_1 = 3.84$  atm.,  $p = 3.65$  atm. Hence  $p_1 - p = 0.19$  atm.  $= 0.19 \times 10334$  kg. per sq. m. (2116 lbs. per sq. ft.); whence we obtain  $b_1 = 0.0001966$ .

D'Aubuisson's formula would have given  $p_1 - p = 0.284$  atm., and M. Arson's would have given  $p_1 - p = 0.43$  atm.

*Second series of Experiments.*—Air-main composed of wrought-iron pipes, with joints as in the first experiments.  $D = 0.15$  m. (6 inches),  $L = 522$  m. (1712 feet),  $h = 3.04$  m. (10 feet).

*1st Experiment.*— $Q = 0.2005$  cub. m. (7.08 cub. ft.), at a pressure of  $\frac{1}{2}(p_1 + p)$ , and a temperature of  $26^\circ.5$  Cent. ( $80^\circ$  Fahr.);  $p_1 = 5.24$  atm.,  $p = 5.00$  atm. Hence  $p_1 - p = 0.24$  atm.  $= 0.24 \times 10334$  kg. per sq. m. (2116 lbs. per sq. ft.); whence we obtain  $b_1 = 0.0002275$ .

*2nd Experiment.*— $Q = 0.1586$  cub. m. (5.6 cub. ft.), at a pressure of  $\frac{1}{2}(p_1 + p)$ , and a temperature of  $26^\circ.5$  Cent. ( $80^\circ$  Fahr.);  $p_1 = 3.650$  atm.,  $p = 3.545$  atm. Hence  $p_1 - p = 0.105$  atm.  $= 0.105 \times 10334$  kg. per sq. m. (2116 lbs. per sq. ft.); whence we obtain  $b_1 = 0.0002255$ .

It is clear that these experiments give very small values for the coefficient. The divergence from the results which D'Aubuisson's formula would give is due to the fact that his formula was determined with very small pipes. It is probable that the coefficients corresponding to diameters of 0.15 m. (6 in.) and 0.20 m. (8 in.) for a substance as smooth as tin would be still smaller respectively than the figures obtained above. The divergence from the results obtained by M. Arson's formula does not arise from a difference in size of pipes, as this is here taken into account. The Author considers that it may be attributed to the fact that the pipes for the St. Gothard tunnel were cast with much greater care than ordinary pipes, which rendered their surface smoother; and also to the fact that flanged joints produce



much less irregularity in the internal surface than the ordinary spigot and faucet joints. Lastly, the difference in the methods of observation, and the errors appertaining to these, must be taken into account. M. Stockalper, who experimented on high pressures, used metallic gauges, which are instruments on whose sensibility and correctness complete reliance cannot be placed; and the standard gauge with which they were compared was also one of the same kind. The Author is not of opinion that the divergence is owing to the fact that M. Stockalper made his observations on an air-main in which the pressure was much higher than in gas pipes. Indeed it may be assumed that gases and liquids act in the same manner; and, as will be explained later on, there is reason to believe that with the latter a rise of pressure increases the losses of pressure instead of diminishing them.

All the pipes for supplying compressed air in tunnels and in headings of mines are left uncovered, and have flanged joints; which are advantages not merely as regards prevention of leakage, but also for facility of laying and of inspection. If a compressed-air pipe had to be buried in the ground, the flanged joint would lose a part of its advantages; but nevertheless the Author considers that it would still be preferable to the ordinary joint.

It only remains to refer to the motors supplied by the compressed air. This subject is still in its infancy from a practical point of view. In proportion as the air becomes hot by compression, so it cools by expansion, if the vessel containing it is impermeable to heat. Under these conditions it gives out in expanding a power appreciably less than if it retained its original temperature; besides which the fall of temperature may impede the working of the machine, by freezing the vapour of water contained in the air. If it is desired to utilise to the utmost the force stored up in the compressed air, it is necessary to endeavour to supply heat to the air during expansion, so as to keep its temperature constant. It would be possible to attain this object by the same means which prevent heating in compression, namely, by the circulation and injection of water. It would perhaps be necessary to employ a rather larger quantity of water for injection,

as the water, instead of acting by virtue both of its heat of vaporisation and of its specific heat, can in this case act only by virtue of the latter.

These methods might be employed without difficulty for air machines of some size. It would be more difficult to apply them to small household machines, in which simplicity is an essential element; and we must rest satisfied with imperfect methods, such as proximity to a stove, or the immersion of the cylinder in a tank of water. Consequently loss of power by cooling and by incomplete expansion cannot be avoided. The only way to diminish the relative amount of this loss is to employ compressed air at a pressure not exceeding 3 or 4 atmospheres.

The only real practical advance made in this matter is in Mékarski's compressed-air engine for tramways. In this engine the air is made to pass through a small boiler, containing water at a temperature of about  $120^{\circ}$  Cent. ( $248^{\circ}$  Fahr.), before entering the cylinder of the engine. It must be observed that in order to reduce the size of the reservoirs, which are carried on the locomotive, the air inside them must be very highly compressed; and that in going from the reservoir into the cylinder it passes through a reducing valve, or expander, which keeps the pressure of admission at a definite figure; so that the locomotive can continue working so long as the supply of air contained in the reservoir has not come down to this limiting pressure. The air does not pass the expander until after it has gone through the boiler already mentioned. Therefore, if the temperature which it assumes in the boiler is  $100^{\circ}$  Cent. ( $212^{\circ}$  Fahr.), and if the limiting pressure is 5 atm., the gas which enters the cylinder will be a mixture of air and water-vapour at  $100^{\circ}$  Cent.; and of its total pressure the vapour of water will contribute 1 atm. and the air 4 atm. Thus this contrivance, by a small expenditure of fuel, enables the air to act expansively without injurious cooling, and even reduces the consumption of compressed air to an extent which compensates for part of the loss of power, arising from the preliminary expansion which the air experiences before its admission into the cylinder.

It is clear that this same contrivance, or, what amounts to the same thing, a direct injection of steam, at a sufficient pressure, for the purpose of maintaining the expanding air at a constant temperature, might be tried in a stationary engine worked by compressed air with some chance of success. Whatever method is adopted, it would be advantageous that the losses of pressure, in the pipes connecting the compressors with the motors, should be reduced as much as possible, for in this case that loss would represent a loss of efficiency. If, on the other hand, owing to defective means of reheating, it is necessary to remain satisfied with a small amount of expansion, the loss of pressure in the pipe is unimportant, and has only the effect of transferring the limited expansion to a point a little lower on the scale of pressures.

If  $W$  is the net available power from the shaft of the engine which works the compressor,  $v_1$  the volume of air supplied by the compressor at the pressure  $p_1$  and at the temperature of the surrounding air, and  $p_0$  the atmospheric pressure; then the efficiency of the compressor, assuming the air to expand according to Boyle's law, is given by the well-known formula—

$$\frac{p_1 v_1 \log \frac{p_1}{p_0}}{W}.$$

Let  $p_2$  be the value to which the pressure is reduced by the loss of pressure at the end of the pipe, and  $v_2$  the volume which the air occupies at this pressure and at the same temperature: then the force stored up in the air at the end of its course through the pipe is  $p_2 v_2 \log \frac{p_2}{p_0}$ . Consequently the efficiency of the pipe is

$$\frac{p_2 v_2 \log \frac{p_2}{p_0}}{p_1 v_1 \log \frac{p_1}{p_0}};$$

a fraction which may be reduced to the simple form  $\frac{\log \frac{p_2}{p_0}}{\log \frac{p_1}{p_0}}$  if there is no leakage during the passage of the air, because in that case  $p_2 v_2 = p_1 v_1$ .

Lastly, if  $W_1$  is the net available power from the shaft of the compressed-air motor, the efficiency of this engine will be—

$$\frac{W_1}{p_2 v_2 \log \frac{p}{p_0}} ;$$

and the product of these three partial efficiencies is equal to  $\frac{W_1}{W}$ , the general efficiency of the transmission.

### III.—TRANSMISSION BY PRESSURE-WATER.

As transmission of power by compressed air has been specially applied to the driving of tunnels, so transmission by pressure-water has been specially resorted to for lifting heavy loads, or for work of a similar nature, such as the operations connected with the manufacture of Bessemer steel, or of cast-iron pipes. The Author does not propose to treat of transmissions established for this special purpose, and depending on the use of accumulators at high pressure, as he has no fresh matter to impart on this subject, and as he believes that the remarkable invention of Sir William Armstrong was described, for the first time, in the Proceedings of the Institution of Mechanical Engineers. His object is to refer to transmissions applicable to general purposes.

The transmission of power by water may occur in another form. The motive force to be transmitted may be employed for working pumps which raise the water, not to a fictitious height in an accumulator, but to a real height in a reservoir, with a channel from this reservoir to distribute the water so raised amongst several motors arranged for utilising the pressure. The Author is not aware that works have been carried out for this purpose. In many towns however a part of the water from the public mains serves to supply small motors: consequently if the water, instead of being brought by a natural fall, has been previously lifted artificially, it might be said that a transmission of power is here grafted on to the ordinary distribution of water.

Unless a positive or negative force of gravity is introduced into the problem, independently of the force to be transmitted, it must be

assumed that the motors supplied with the pressure-water are at the same level as the forcing pumps; or more correctly that the exhaust from those motors is at the same level as the surface of the water from which the pumps draw their supply. In this case the general efficiency of transmission is the product of three partial efficiencies, which correspond exactly to those mentioned with regard to compressed air.

The height of lift, contained in the numerator of the fraction which expresses the efficiency of the pumps, is not to be taken as the difference in level between the surface of the water in the reservoir and the surface of the water whence the pumps draw their supply; but as this difference in level, *plus* the loss of pressure in the suction pipe, which is usually very short, and *plus* the loss in the channel up to the reservoir, which may be very long. A similar loss of initial pressure affects the efficiency of the discharge channel from the reservoir. Such a reservoir, if of sufficient capacity, may become an important store of power; whilst the compressed-air reservoir can only be so to a very limited extent.

Omitting the subject of the pumps, and passing on at once to the water mains, the Author may first point out that the distinction between the ascending and the descending mains of the system is of no importance, for two reasons: firstly, that nothing prevents the motors being supplied direct from the first alone; and secondly, that the one is not always distinct from the other. In fact the reservoir may be connected by a single branch pipe with the system which extends from the pumps to the motors: it may even be placed at the extreme end of this system beyond the motors, provided always that the supply-pipe is taken into it at the bottom.

The same formula may be adopted for the loss of initial pressure in water pipes as for compressed-air pipes, viz.

$$\frac{p_1 - p}{\delta} = \frac{64}{\pi^2} \frac{b_1}{D^5} L Q^2 \pm h;$$

$h$  being the difference of level between the two ends of the portion of pipe of length  $L$ , and the sign  $+$  or  $-$  being used according as the pipe rises or falls. The specific weight  $\delta$  is constant, and the quotients  $\frac{p_1}{\delta}$  and  $\frac{p}{\delta}$  represent the heights  $z_1$  and  $z$  to which the water

could rise above the pipe, in vertical tubes branching from it, at the beginning and end of the length  $L$ .

The values assigned to the coefficient  $b_1$  in France are those determined by D'Arcy. For new cast-iron pipes he gives—

$$b_1 = 0.0002535 + \frac{1}{D} 0.00000647;$$

and recommends that this value should be doubled, to allow for the rust and incrustation which more or less form inside the pipes during use. The determination of this coefficient was made from experiments in which the pressure did not exceed 4 atmospheres; within these limits the value of the coefficient, as is generally admitted, is independent of the pressure. The experiments made by M. Barret, on the pressure pipe of the accumulator at the Marseilles docks, seem to indicate that the loss of pressure would be greater for high pressures, everything else being equal. This pipe, having a diameter of 0.127 m. (5 in.), was subjected to an initial pressure of 52 atmospheres. The Author gives below the results obtained for a straight length of 320 m. (1050 ft.); and has placed beside them the results which D'Arcy's formula would give.

Velocity of Flow. Per second.		Loss of Head, in metres or feet respectively per 100 metres or feet run of pipes.		
		Actual Loss observed.	Calculated Loss.	
			Old pipes.	New pipes.
Metres.	Feet.	Met. or Ft.	Met. or Ft.	Met. or Ft.
0.25	0.82	1.5	0.12	0.06
0.50	1.64	2.5	0.48	0.24
0.75	2.46	3.7	1.08	0.54
1.00	3.28	5.5	1.92	0.96
1.25	4.10	6.1	3.00	1.50
1.50	4.92	7.3	4.32	2.16
1.75	5.74	8.0	5.88	2.94
2.00	6.56	10.2	7.68	3.84
2.25	7.38	11.7	9.72	4.86
2.50	8.20	14.0	12.00	6.00

Moreover, these observed results would appear to indicate a different law from that which is expressed by the formula  $b_1 u^2$ , as is easy to see by representing them graphically. It would be very

desirable that fresh experiments should be made on water pipes under high pressure, and of various diameters.

Of machines worked by water pressure, the Author proposes to refer only to two, which appear to him in every respect the most practical and advantageous.

One is the piston machine of M. Albert Schmid, engineer at Zurich. The cylinder is oscillating, and the distribution is effected without an eccentric, by the relative motion of two cylindrical surfaces fitted one against the other, and having the axis of oscillation for a common axis. The convex surface, which is movable and forms part of the cylinder, serves as a port-face, and has two ports in it communicating with the two ends of the cylinder. The concave surface, which is fixed and plays the part of a slide-valve, contains three openings, the two outer ones serving to admit the pressure-water, and the middle one to discharge the water after it has exerted its pressure. The piston has no packing. It has grooves turned in its circumference, which produce a sort of water packing, maintained by adhesion. A small air-chamber is connected with the inlet pipe, and serves to deaden the shocks. This engine is often made with two cylinders, having their cranks at right angles.

The other engine, which is much less used, is a turbine on Girard's system, with a horizontal axis and partial admission, exactly resembling in miniature those employed in raising water at the waterworks of St. Maur, near Paris. The water is introduced by means of a distributor, which is fitted inside the turbine casing, and occupies a certain portion of its circumference. This turbine has a lower efficiency than Schmid's machine, and is less suitable for high pressures; but it possesses this advantage over it, that by regulating the amount of opening of the distributor, and consequently the quantity of water admitted, the power can be altered without altering the velocity of rotation. As it admits of high speeds, it could be usefully employed direct, without the interposition of spur-wheels or belts, for driving magneto-electric machines employed for the production of light, for electrotyping, &c.

In compressed-air machines the losses of pressure due to incomplete expansion, cooling, and waste spaces, play an important part. In water-pressure machines loss does not occur from these causes, on account of the incompressibility of the liquid; but the frictions of the parts are the principal causes of loss of power. It would be advisable to ascertain whether, as regards this point, high or low pressures are the most advantageous. Theoretical considerations would lead the Author to imagine that for a piston machine low pressures are preferable.

In conclusion, the following Table gives the efficiencies, as measured in 1871 by Professor Fliegner, of a Girard turbine, constructed by Messrs. Escher Wyss and Co. of Zurich, and of a Schmid machine :—

Escher Wyss and Co.'s Girard Turbine.				Schmid Motor.			
Effective Head of Water.		Revolutions per minute.	Efficiency.	Effective Head of Water.		Revolutions per minute.	Efficiency.
Metres.	Feet.	Revs.	Per cent.	Metres.	Feet.	Revs.	Per cent.
..	..	..	..	8·3	27·2	226	37·4
..	..	..	..	11·4	37·4	182	67·4
..	..	..	..	14·5	47·6	255	53·4
..	..	..	..	17·9	58·7	157	86·2
20·7	67·9	628	68·5	20·7	67·9	166	89·6
20·7	67·9	847	47·4	20·7	67·9	225	74·6
..	..	..	..	24·1	79·0	238	76·7
24·1	79·0	645	68·5	24·1	79·0	389	64·0
27·6	90·5	612	65·7	27·6	90·5	207	83·9
27·6	90·5	756	68·0	..	..	..	..
31·0	101·7	935	56·9	..	..	..	..
31·0	101·7	1130	35·1	..	..	..	..

It will be observed that these experiments relate to low pressures; it would be desirable to extend them to higher pressures.

#### IV.—TRANSMISSION BY ELECTRICITY.

However high the efficiency of an electric motor may be, in relation to the chemical work of the electric battery which feeds it, force generated by an electric battery is too expensive, on account of



the nature of the materials consumed, for a machine of this kind ever to be employed for industrial purposes. If however the electric current, instead of being developed by chemical work in a battery, is produced by ordinary mechanical power in a magneto-electric or dynamo-electric machine, the case is different; and the double transformation, first of the mechanical power into an electric current, and then of that current into mechanical power, furnishes a means for effecting the conveyance of the power to a distance.

It is this last method of transmission which remains to be discussed. The Author however feels obliged to restrict himself in this matter to a mere summary; and indeed it is English physicists and engineers who have taken the technology of electricity out of the region of empiricism, and have placed it on a scientific and rational basis. Moreover they are also taking the lead in the progress which is being effected in this branch of knowledge, and are best qualified to determine its true bearings.

When an electric current, with an intensity  $i$ , is produced, either by chemical or mechanical work, in a circuit having a total resistance  $R$ , a quantity of heat is developed in the circuit; and this heat is the exact equivalent of the power expended, so long as the current is not made use of for doing any external work. The expression for this quantity of heat, per unit of time, is  $Ai^2R$ ;  $A$  being the thermal equivalent of the unit of power corresponding to the units of current and resistance, in which  $i$  and  $R$  are respectively expressed.

The product  $i^2R$  is a certain quantity of power, which the Author proposes to call *power transformed into electricity*. When mechanical power is employed for producing a current by means of a magneto-electric or dynamo-electric machine,—or, to use a better expression, by means of a *mechanical generator of electricity*,—it is necessary in reality to expend a greater quantity of power than  $i^2R$ , in order to make up for losses which result either from ordinary friction or from certain electro-magnetic reactions which occur. The ratio of the quantity  $i^2R$  to the power  $W$  actually expended per unit of time is called the efficiency of the generator. Designating it by  $K$ , we have

$$W = \frac{i^2R}{K}.$$

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It is very important to ascertain the value of this efficiency, considering that it necessarily enters as a factor into the evaluation of all the effects to be produced by means of the generator in question.

The following Table\* gives the results of certain experiments made early in 1879, with a Gramme machine, by an able physicist, M. Hagenbach, Professor at the University at Basle, and kindly furnished by him to the Author:—

No. of Experiment.	1	2	3	4
Revolutions per minute	893	900.5	919.5	935
Total Resistance in Siemens units .....	6.06	4.94	3.82	2.55
Total Resistance in absolute units .....	$5.787 \times 10^9$	$4.718 \times 10^9$	$3.648 \times 10^9$	$2.435 \times 10^9$
Intensity in chemical units .....	6.28	8.09	10.99	17.67
Intensity in absolute units .....	1.005	1.295	1.759	2.828
Work Done $i^2R$ in absolute units .....	$584.9 \times 10^7$	$791.3 \times 10^7$	$1129.2 \times 10^7$	$1948.6 \times 10^7$
Work Done $i^2R$ in kilogrammetres .....	59.62	80.66	115.1	198.6
Power Expended in kilogrammetres .....	83.25	86.25	141.0	301.5
Efficiency .....per cent.	71.6	93.5	81.6	65.9

M. Hagenbach's dynamometric measurements were made with a brake. After each experiment on the electric machine, he applied the brake to the engine which he employed, taking care to make it run at precisely the same speed, with the same pressure of steam, and with the same expansion, as during the experiment. It would certainly be better to measure the force expended during, and not after, the experiment, by means of a registering dynamometer. Moreover M. Hagenbach writes that his measurements with the brake were very much prejudiced by external circumstances: doubtless this is the reason of the divergences among the results obtained.

About the same time Dr. Hopkinson communicated to this Institution the results of some very careful experiments made on a Siemens machine. He measured the force expended by means of a

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\* See Mr. Shoolbred's conversion of these results into English nomenclature, p. 88 *infra*.

registering dynamometer, and obtained very high coefficients of efficiency, amounting to nearly 90 per cent. M. Hagenbach also obtained from one machine a result only  $6\frac{1}{2}$  per cent. less than unity.

Mechanical generators of electricity are certainly capable of being improved in several respects, especially as regards their adaptation to certain definite classes of work. But there remains hardly any margin for further progress as regards efficiency.

Power transformed into electricity in a generator may be expressed by  $i\omega MC$ ;  $\omega$  being the angular velocity of rotation,  $M$  the magnetism of one of the intervening poles, either inducing or induced, and  $C$  a constant specially belonging to each apparatus, and independent of the units adopted. This constant could not be determined except by an integration practically impossible; and the product  $M C$  must be considered indivisible. Even in a magneto-electric machine (with permanent inducing magnets), and much more in a dynamo-electric machine (inducing by means of electro-magnets excited by the very current produced), the product  $M C$  is a function of the intensity. From the identity of the expressions  $i^2R$  and  $i\omega M C$  we obtain the relation  $M C = \frac{iR}{\omega}$ , which indicates the course to be pursued to determine experimentally the law connecting the variations of  $M C$  with those of  $i$ . Some experiments made in 1876 by M. Hagenbach on a Gramme dynamo-electric machine appear to indicate that the magnetism  $M C$  does not increase indefinitely with the intensity, but that there is some maximum value for this quantity.

If, instead of working a generator by an external motive force, a current is passed through its circuit in a certain given direction, the movable part of the machine will begin to turn in the opposite direction to that in which it would have been necessary to turn it in order to obtain from it a current in the given direction. In virtue of this motion, the electro-magnetic forces which are generated may be used to overcome a resisting force. The machine will then work as a motor or receiver.

Let  $i$  be the intensity of the external current which works the motor, when the motor is kept at rest. If it is now allowed to move,

its motion produces, in virtue of the laws of induction, a current in the circuit, of intensity  $i_1$ , in the opposite direction to the external current: the effective intensity of the current traversing the circuit is thus reduced to  $i - i_1$ . The intensity of the counter current is given, like that of the generating current, by the equation  $i_1^2 R = i_1 \omega_1 M_1 C_1$ , or  $i_1 R = \omega_1 M_1 C_1$ ; the suffix  $_1$  denoting the quantities relating to the motor. Here  $M_1 C_1$  is a function of  $i - i_1$ , not of  $i$ .

As in a generator the power transformed into electricity has a value  $i \omega M C$ , so in a motor the power developed by electricity is  $(i - i_1) \omega_1 M_1 C_1$ . On account however of the losses which occur, the effective power  $W_1$ , that is the power available from the shaft of the motor, will have a smaller value; and in order to arrive at it a coefficient of efficiency  $K_1$  must be added. We shall then have  $W_1 = K_1 (i - i_1) \omega_1 M_1 C_1$ . The Author has no knowledge of any experiments having been made for obtaining this efficiency  $K_1$ .

Next let us suppose that the current feeding the motor is furnished by a generator, so that actual transmission by electricity is taking place. The circuit, whose resistance is  $R$ , comprises then the coils, both fixed and movable, of the generator and motor, and the conductors which connect them. The intensity of the current which traverses the circuit had the value  $i$  when the motor was at rest; by the working of the motor it is reduced to  $i - i_1$ . The power applied to the generator is itself reduced to  $W = \frac{(i - i_1) \omega M C}{K}$ .

The prime mover is relieved by the action of the counter current, precisely as the consumption of zinc in the battery would be reduced by the same cause, if the battery were the source of the current.

The efficiency of the transmission is  $\frac{W_1}{W}$ . Calculation shows that it is expressed by the following equations:—

$$\frac{W_1}{W} = K K_1 \frac{\omega_1 M_1 C_1}{\omega M C}, \text{ or } = K K_1 \frac{\omega_1 M_1 C_1}{\omega_1 M_1 C_1 + (i - i_1) R};$$

expressions in which it must be remembered  $M C$  and  $M_1 C_1$  are really functions of  $(i - i_1)$ .

This efficiency is then the product of three distinct factors, each evidently less than unity, namely the efficiency belonging to the generator, the efficiency belonging to the motor, and a third factor

depending on the rate of rotation of the motor and the resistance of the circuit. The influence which these elements exert on the value of the third factor cannot be estimated, unless the law is first known according to which the magnetisms  $MC$  and  $M_1 C_1$  vary with the intensity of the current.

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Casting a retrospective glance at the four methods of transmission of power which have been examined, it would appear that transmission by ropes forms a class by itself, whilst the three other methods combine into a natural group, because they possess a character in common of the greatest importance. It may be said that all three involve a temporary transformation of the mechanical power to be utilised into potential energy. Also in each of these methods the efficiency of transmission is the product of three corresponding factors or partial efficiencies:—namely, 1st, the efficiency of the instrument which converts the actual energy of the prime mover into potential energy; 2nd, the efficiency of the instrument which reconverts this potential energy into actual energy, that is into motion, and delivers it up in this shape for the final motors which perform useful work; 3rd, the efficiency of the intermediate agency which serves for the conveyance of potential energy from the first instrument to the second. This third factor has just been given for transmission by electricity. It is to a certain extent the correlative of the efficiency of the pipe, in the case of compressed air, or of pressure water.

It is as useful in the case of electric transmission, as of any other method, to be able, in designing a system, to estimate beforehand what results it will be capable of furnishing; and for this purpose it is necessary to calculate exactly the factors which compose the efficiency. In order to obtain this desirable knowledge, the Author considers that the three following points should form the aim of experimentalists:—

- 1st. The determination of the efficiency  $K$  of the principal kinds of magneto-electric, or dynamo-electric, machines working as generators.
- 2nd. The determination of the efficiency  $K_1$  of the same machines working as motors.

3rd. The determination of the law according to which the magnetism of the cores of these machines varies with the intensity of the current.

The Author is of opinion that experiments made with these objects in view would be more useful than those conducted for determining the general efficiency of transmission; for the latter give results only available under precisely similar conditions. However it is clear that these have their value, and must not be neglected.

There are moreover many other questions requiring to be elucidated by experiment, especially as regards the nature of the conducting wires; but it is needless to dwell further upon this subject, which has been ably treated by many English men of science, for instance Dr. Siemens and Professor Ayrton. Nevertheless for further information the Author would refer to the able articles published in Paris by M. Mascart, in the "*Journal de Physique*," in 1877 and 1878.

The Author would gladly have concluded this paper with a comparison of the efficiencies of the four systems which have been examined, or, what amounts to the same thing, with a comparison of the losses of power which they occasion. Unfortunately such a comparison has never been made experimentally, because hitherto the opportunity of doing it in a demonstrative manner has been wanting; for the transmission of power to a distance belongs rather to the future than to the present time.

Transmission by electricity is still in its infancy; it has only been applied on a small scale, and experimentally. Of the three other systems, transmission by means of ropes is the only one that has been employed for general industrial purposes; whilst compressed air and water under pressure have been applied only to special purposes, and their use has been due much more to their special suitability for these purposes than to any considerations relative to loss of power. Thus the useful effect of the compressed air used in driving the tunnels through the Alps, assuming its determination to be possible, was undoubtedly very low; nevertheless, in the present state of our

appliances, this is the only process by which such operations can be accomplished.

The Author believes that transmission by ropes furnishes the highest proportion of useful effect; but that, as regards a wide distribution of the transmitted power, the other two methods, by air and water, might merit the preference.

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### *Discussion.*

The SECRETARY said he had received a letter from M. Achard expressing his regret that it was quite impossible for him to be present on that occasion, owing to a recent severe family loss.

Mr. J. N. SHOOLBRED observed that on p. 82 the author had given a Table of the results of M. Hagenbach's experiments, in a form that differed somewhat from that in which experiments of a similar character were tabulated in Dr. Hopkinson's papers (Proc. 1879, p. 249, and 1880, p. 268), and also as carried out by Mr. Gray of Silvertown (Proc. 1880, p. 276) on a Gramme machine of the same size as that referred to by M. Achard. He had thought it might be interesting if the experiments in the paper were tabulated in a form similar to that previously adopted, so that the data might be readily compared with those of Dr. Hopkinson and Mr. Gray: and he had done this in the Table on the next page.

# HAGENBACH'S EXPERIMENTS WITH GRAMME MACHINE OF "A" SIZE.

(See *M. Achard's Table*, p. 82 ante.)

Number of Experiment.	Total Resist- ance.  Ohms.	Current.		Quantity.	Work Done.			Power Expended.			Efficiency per cent.	Revolutions of Armature per Minute.
		Intensity.										
		Milli- grammes of Water decom- posed per sec.	Volts.		Webers.	Erg-tens.	Horse Power.	Kilogram- metres.	Erg-tens.	Horse Power		
1	5·79	0·94	58·19	10·05	0·59	0·79	59·62	0·82	1·10	83·25	71·6	893
2	4·72	1·21	61·12	12·95	0·79	1·07	80·63	0·85	1·14	86·25	93·5	900·5
3	3·65	1·65	64·20	17·59	1·13	1·52	115·06	1·38	1·86	141·60	81·6	919·5
4	2·44	2·65	79·00	28·28	1·95	2·62	198·69	2·96	3·97	301·50	65·9	935



These experiments presented some rather peculiar results, and certain of the figures might be doubtful. In M. Hagenbach's original communication to M. Achard (which by M. Achard's kindness he had been allowed to inspect), a note was appended by M. Hagenbach himself to the experiment No. 4 in the accompanying Table, saying that the figures were somewhat uncertain; and he himself could not help thinking that in these experiments there had not been the same scrupulous attention to details, as had been given by Dr. Hopkinson and Mr. Gray. Still they were extremely valuable, and they bore out in a great measure the results of Mr. Gray's experiments upon a similar machine.

It should be borne in mind that M. Hagenbach's experiments, as well as those of Dr. Hopkinson and Mr. Gray, simply bore upon the question of the efficiency of magneto-electric machines, not upon the transmission of power. With regard to the question of transmission of power, some experiments, carried out under the direction of Dr. Siemens, and mentioned in a paper by Messrs. Higgs and Brittle (*Proc. Inst. C.E.*, vol. lii., p. 53), showed, as Dr. Siemens had repeatedly stated, that there was practically a loss of about 50 per cent. in efficiency between the power imparted in the original motor, and that taken out from the second machine. This loss was caused by a counter current generated by the second machine, and subtractive from the efficiency of the first one. He had recently had the opportunity of making some experiments himself in reference to transmitted power. Though not complete, they were sufficient to enable him to suggest whether it might not be possible, by a certain arrangement between the proportions of the machines themselves and the speed at which they were driven, to reduce somewhat that percentage of loss. It was a very important question, whether a large loss like that could not be reduced in practice. Even with that loss there were certain applications in the industrial arts in which transmitted motion might be useful. There were in the first place large natural sources of power, which at present were useless, but which might be made use of in this way. The power cost nothing at the original site, and if it could be transmitted at a comparatively economical rate for use, it would prove exceedingly

valuable. For instance, a letter from Sir William Armstrong had appeared in *The Engineer* (21 Jan. 1881, page 49), with reference to some Swan electric lights which he had put up at his house at Rothbury. The power for those lights was taken from a brook at a distance of about three-quarters of a mile, and occasionally during the day the power transmitted was made use of for working a saw-bench, &c. In the next place, in the case of large works, the central source of power might be made use of in out-of-the-way parts, where it would be difficult and perhaps expensive to locate a separate engine. Again, in cases where running power existed, such as overhead travelling cranes, the moving parts and the connections might be considerably simplified and more economically constructed, where electricity was supplied. Electric motors were found to be more compact and economical than either steam or hydraulic motors.

With regard to locomotion caused by power transmitted by electricity, Dr. Siemens (Proc. Society of Telegraph Engineers, 1880, p. 301), when speaking of the electric railway at Berlin, had referred to the peculiar effect at the ascending or descending inclines. Now when the driven machine was either under-weighted or over-weighted, the effect was very similar to that at a descending or ascending incline, although the motor was stationary. He believed that this form of transmission by electricity might, under certain circumstances, receive very considerable extension. M. Achard had clearly pointed out the experiments that were required in order to give more information on this subject; and to these should be added the study of the best arrangement of machines, by which the present very large loss might be materially reduced.

Questions were so often asked as to any examples existing of the transmission of power by electricity, that it might be interesting to describe briefly what at present were probably the two most important examples of such transmission. One was the electric railway, first shown at the Exhibition at Berlin in 1879, by Dr. Werner Siemens, and afterwards at those in 1880 at Düsseldorf and Brussels. The machines for the Siemens railway were simply two equal machines, of their "medium" size. One was stationary and the other was driven by it, and was mounted on wheels. The stationary

machine transmitted the current in the first instance along a central rail laid on the railway, and from thence to the travelling machine. The motion of this machine was communicated to a pair of wheels which acted as driving wheels, and the return current took place through the ordinary rails. The arrangement was found, he believed, to develop in the motor about 4 or 5 HP., and the power given off in the travelling machine was estimated at 2 HP., or a little over. As to the power of the engine which worked the motor, he had no information. There were three or four cars drawn at Berlin, and he understood that the speed was from 15 to 20 miles an hour.

The other example was at M. Menier's chocolate works at Noisiel, which were visited by the members in 1878 on the occasion of the Paris meeting of the Institution. Since then M. Menier had been making use of the turbines, which gave him power from the river Marne for his works, to drive a pair of Gramme machines of a peculiar construction, and had applied the reproduction of the power for the purposes of ploughing. He had made use of two of Fowler's ploughs, at a distance in some cases of nearly three miles; placing a similar machine to the generators on each of two carriages, which took the place of the steam engines for working the plough. M. Gramme himself had constructed a machine especially for the purpose. It was practically a quadruple machine; there were four pairs of poles and four brushes. The arrangement was very compact, and he understood that as much as 16 or 18 HP. was given off by the initial machine. M. Henri Menier had had charge of the experiments on transmission of power by that machine at Noisiel, and probably they would shortly have the benefit of them. In the United Kingdom there were, he believed, but two minor examples: one at Messrs. Poynter's chemical works, Greenock, where a turbine was used to drive the first machine; and the second at Sir William Armstrong's private house, to which he had previously made reference. That was likewise driven by a turbine, taking water from a brook. In both cases the machines were by Siemens.

Mr. ALEXANDER SIEMENS thought that the author of the paper and Mr. Shoolbred attached far too much value to the question of

efficiency, both in the electric transmissions and in compressed-air transmission. It would be practicable in this way to use the great forces of nature, such as water-falls: to establish a sort of central station, and to distribute the power from thence to small motors at different points, either by hydraulic power, or by compressed air, or by electricity. In such cases the distribution of power would be useful, even with a loss of 50 per cent. or more, because at the central station the power could be obtained so cheaply. The transmission of power by electricity had a great advantage over the other two methods mentioned, because the leading wires were so much more manageable than either water pipes or air pipes. Sir William Armstrong had employed a Siemens medium sized machine in his works, and at his house he had been employing a small sized machine for several years and for several purposes; both these worked well. Dr. Siemens had also lately introduced, at his house at Tunbridge Wells, a small Tangye engine, working two electric-light machines, which were utilised at night for horticultural purposes, and in the daytime for cutting hay or turnips by transmitting their current to a dynamo-machine at the farm. There was also another dynamo-machine for pumping water to the house. Such applications were perfectly feasible, and they ought to be better known. It would be a great thing to establish in populous districts a central station, where an economical steam engine could be put up, from whence to distribute the power. He had no doubt that very soon this would be put into practice.

With regard to the experiments suggested by M. Achard (p. 85) to determine "the efficiency  $K$  of the principal kinds of generators," that work had already been done partly by M. Hagenbach and partly by Dr. Hopkinson. As to "the determination of the efficiency  $K_1$  of the same machines working as motors," that had also been done by different experimentalists. The author was of opinion "that experiments made with these objects in view would be more useful than those conducted for determining the general efficiency of transmission; for the latter give results only available under precisely similar conditions." But those "precisely similar conditions" were easily obtained, because in the case of electric

transmission the leading wire between the machines could be given the same resistance, whether the distance was a mile or three-quarters. If the proper speed for the two machines was once determined, the same results could always be obtained by inserting the same amount of resistance between them. He thought therefore that the application of the transmission of power by electricity was at the present time hampered more by prejudice than by a want of knowledge on the part of its promoters.

Mr. J. FERNIE, having lived a short time in Geneva, might be permitted to say that it was a great misfortune the writer of the paper was not present, because he might have given them some information as to the practical application of water-power at Geneva for the purposes described. It was a very extraordinary thing that with the immense resources running to waste at Bellegarde, and with the machinery erected to take advantage of them, people would not go and settle down there. It had been suggested to him that the reason lay in the fact that there were no amusements for the workpeople at Bellegarde, and so nothing to induce them to settle there. Turbines had been erected, and everything made ready for a large population and for great manufactures to be established, but the people were slow in going there, and the money seemed to be wasted. In some large towns in Switzerland however, great advantage was being taken of water power, such as Englishmen had no idea of. Those who saw how conveniently and economically small machines were worked in that way would be surprised that something of the kind had not been done in England. In Geneva a company was formed which took advantage of the great fall of water in the Rhone. They had the water at high pressure, and let it out on hire; and all the little manufactories, such as watch manufactories, in Geneva, were supplied with power from that source. It was uncommonly cheap, and very regular, and there was no trouble about steam engines, boilers, &c. The man who came to cut wood for the house used in old times to bring a saw and trestles with him; but now he brought only a little hydraulic machine, which he connected to a pipe in the street, and sawed the wood in that way.

The resources in the way of water-power in Switzerland were immense, if they could only be used. During the time he resided in Geneva another company was formed to take the water of the Rhone as it left the Lake of Geneva, and carry it to a series of turbines, and so utilise the fall from the point where the river left the lake, to where it joined the Arve, a distance of three-quarters of a mile with a fall of 25 or 30 feet. Considering the enormous volume of the Rhone, it was easy to see what an immense power might be thus obtained; but the Genevese people were in great fear that the beauty of their city would be destroyed; they therefore protested against the scheme, and it came to an end.

He wished to ask whether steel had not been employed for the wire ropes, which were common all over Switzerland, as the author mentioned iron only; and it would be interesting to know the difference in the wear and tear between iron and steel. In connection with the transmission of power by means of wire ropes, he might mention that the Institution of Civil Engineers possessed an excellent set of photographs illustrating all the work of that kind which had been done in Switzerland: so that those who had not had the opportunity of examining that mode of conveying power might here see it well illustrated.

Mr. W. SCHÖNHEYDER said the author had alluded (page 60) to the great advantage which leather belts possessed if they were made very wide—say three or four or five feet—because a partial vacuum was said to be formed under them, so that the adhesion was much greater than would be expected according to theory. He should like to know how the author had ascertained that: whether it had been tried, or whether it was only an assumption. It appeared to him more likely that the air would have a difficulty in getting away from between the pulley and belt on the in-going side. The wider the belt, the more difficult it appeared to him to be for the air to get out sideways: so that the air might rather be expected to accumulate, than to get away altogether in the way stated by the author. There was one point which the author had omitted to mention—the centrifugal force of the belt at very high velocities. He could not now say whether, with

the velocities mentioned of 4000 to 6000 feet per minute, the centrifugal force was enough to lessen the adhesion materially; but with very high velocities the belt tended to leave the pulley, and so made the adhesion less. At page 62 the author, speaking of wire-rope transmission, stated that the intermediate pulleys ran faster than the rope. That meant that slipping took place; and he supposed it was partly on account of that slipping (which ought not to take place) that wire ropes wore out so fast. It seemed monstrous to think that wire ropes should only be in use twelve months, or at most two years. He should like to know whether that was due to too high a working strain being allowed. The author mentioned 11 tons per sq. in., but did not say why he had adopted that figure. It appeared to him that if the ropes only lasted twelve months something must be wrong: either they were too tight, or too high a tension was allowed per square inch of section. Possibly heavier ropes would last much longer. The expense of renewing them every twelve months must be very serious.

At page 67, speaking of the transmission of power by the Seraing air-compressor, the author stated, "The great defect of this apparatus is the loss of power resulting from the alternating movement imparted to a large body of water." That seemed to him an error. Power was not lost by imparting reciprocating motion to water. Great force was required to start it or stop it, which however might be of advantage if driving by steam worked expansively; for it helped to take off the excessive pressure of steam at the beginning of the stroke, and gave a higher pressure at the end of the stroke, so that it acted as a kind of fly-wheel. Of course that class of air-compressors could not be worked as fast as one of the simple piston compressors. If it were, the water got into a state of agitation, and did not drive away all air through the ports; but he thought it was an error to say that power was lost by reciprocating water.

At page 78 a Table was given with regard to the friction in pipes at very high pressures. That was a new subject, which had not yet been investigated to anything like the proper extent. If this Table could be relied upon, it appeared that the friction due to high pressures was something like three or five times as great as might

be expected. From calculations he had recently made, when consulted about some heavy presses for pressing cotton by other means than hydraulic pressure, he was inclined to believe that was not so. He had indeed been told by a gentleman who had worked with hydraulic presses very largely in India, that the loss of pressure in hydraulic pipes was enormous. He could not believe the statement in the Table, p. 78, that the friction increased so much at a pressure of only 52 atmospheres, say 800 lbs. per sq. in.; but if so, how much must the friction have increased in the case to which he referred, where the pressure was perhaps two or three tons per square inch? He thought it would be well if some experiments could be made upon friction in hydraulic pipes, so that the question might be solved.

A friend had called his attention to the absence of any mention in the paper of another mode of transmitting power, namely by steam. It was used in this country,\* but not for transmission to any distance. He understood however that it had been used to a large extent in Hartford, Connecticut, where steam had been carried as far as a mile with good results. He was sorry that he could not give the particulars.†

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\* At Kippax Colliery, near Leeds, steam was conveyed 1030 feet from a boiler at surface to work an elevator in the pit. (See Proceedings Inst. M. E. 1861, p. 220.)

† On this head the following information has been supplied to the Secretary by Mr. H. Olrick:—"In the United States great interest is taken in the subject of the transmission of heat and power to the inhabitants of cities, by means of steam and highly heated water carried through pipes in the streets, and supplied to the houses and buildings in much the same way as water and gas are ordinarily supplied. Mr. Holley, the inventor of the high-pressure pumping system, was the first to make the experiment with steam in his native town of Lockport, New York, and he has laid down plant in several cities, supplying steam for heating purposes and for machines of small power. The most successful steam system however was put down at Hartford, Connecticut, by Mr. Burdett Loomis. This system occupies a mile and a half of piping, and supplies sufficient steam to heat 6,000,000 cubic feet of room space, or to supply about 150 HP. nominal. He informs me that with 70 lbs. boiler pressure, the pressure is reduced only 2 lbs. at a mile from the boilers; which at all events shows that his system of covering the pipes is very successful. This



Mr. J. G. MAIR said it was stated, p. 60, that the vacuum between the belt and the pulley was produced "by the aid of an adequate velocity." He should be obliged if the author would state precisely what was meant by that term, since at whatever speed the belt ran he could not see how a vacuum could exist. In reference to Mr. Schönheyder's remarks about belting, the calculations in the paper as to the running ropes were based on their being stationary. The centrifugal force, which had such an important influence when they were running, was not taken into account. The author had stated

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is done simply by means of creosoted logs, bored out so as to allow a 2 in. air-space to be maintained all round the wrought-iron pipes carrying the steam. These logs are driven one within the other at the ends, so that a perfectly tight joint is made and no air allowed to circulate in them; and it appears that this mode of covering is superior to any asbestos, hair, or felt covering which has been used up to the present time. At distances of about 100 feet are placed expansion joints, contained in man-holes which are also kept air-tight, but which can be opened for examining or tightening up the joints. All the condensed water is taken back to the boilers through a return pipe, laid alongside the steam pipe and covered in a similar manner, the water being trapped into this pipe from each building. This is a very important improvement, since it saves not only the heat of the return water but also the water itself, which, in towns remote from natural water supply, means a very important item in the running expenses.

"The *hot water* system alluded to is the invention of Mr. W. E. Prall of New York, and consists in employing water heated to a high temperature, say about 400° Fahr., which is not allowed to evaporate into steam until it enters the building where it is to be used. At times when very little is being used, but that little still at a high temperature, as for cooking purposes, the flow of water is kept up by means of specially designed pumps, which maintain a continual circulation. This system is now being laid down in New York city. The late Mr. Max Hjortsberg of Chicago, chief engineer to the Chicago Burlington and Quincy Railway, also put down about a mile of 2½ in. pipe on this plan, with a result so satisfactory to himself that he declared in favour of water as against steam. The temperature of the water at the end of the mile was only 2 degrees less than at the boiler, working at about 160 lbs. pressure. The water was conveyed to a factory, where, after the pressure had been reduced, the steam evolved was used for driving an engine, and the unevaporated water for heating the rooms, returning afterwards to the boiler for further use."

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on p. 80, "In compressed-air machines the losses of pressure due to incomplete expansion, cooling, and waste spaces, play an important part. In water-pressure machines loss does not occur from these causes." He disagreed with this as to the waste spaces; if these could be done away with in engines worked by water-power, they would have more efficient machines than at present.

Mr. W. E. RICH said he observed no remark in the paper upon the best pressure to use, in machinery for the transmission of power by compressed air. He believed he was right in saying that the experience of most engineers who had used compressed air, and had looked into the question carefully, was that, if the size of the pipes and air engines was not a serious hindrance, low pressures were most efficient. It was natural that it should be so. If they used dry air compressors, and did not attempt to cool the air as it was compressed, about 30 lbs. per sq. in. was a good pressure to use for works on the surface of the ground. The efficiency of air-compressing machinery working continuously, so far as he had tested it, was low: and it was much more applicable to intermittent action than to continuous action. The ports of air engines were very liable to become choked by ice if they were kept running constantly. He had removed the inconvenience in one instance by putting a small fire under the ports; but had heard recently that glycerine used as a cylinder lubricant was an antidote, as it prevented the adhesion of ice to the metal surfaces. The author had given some experiments in reference to the loss by friction in air pipes, which were very welcome to engineers, for there was very little information in the way of practical experiment upon the subject.

With reference to the question of water engines, he thought it was pertinent to remark upon the great inconvenience and difficulty in working with slide-valves in water engines. The slide-valve was the part of a water engine that usually gave the most trouble. In the first place, if they expected an engine to work occasionally and to stand occasionally, it was necessary to make both the valve-face and the valve of gun-metal; and a gun-metal valve working on a gun-metal face in water was one of the most likely combinations for setting up

abnormal friction. They had better content themselves with a cast-iron face and a gun-metal valve, and balance the pressure on the face of the valve. In many cases it was better to have a cylindrical valve, and to put up with some waste. A water engine to give the best results should be designed with a long stroke, large cylinder capacity, and low speed in revolutions or strokes per minute. A large air-vessel should always be provided close to the engine on the supply pipe, and the cylinder should have a small air-vessel in connection with each end.

Mr. A. PAGET said that, as M. Achard had been prevented from being present owing to family affliction, no doubt the members would excuse a departure from the usual procedure, to allow M. Achard to give an answer in the Proceedings on this and other points. He fully shared in Mr. Schönheyder's and Mr. Mair's difficulty as to the vacuum under the belt; the real effect of great speed appeared to him to be the exact contrary of what had been stated.

Mr. E. B. ELLINGTON said a remark had been made by a previous speaker that it was a wonder there were no systems of transmitting power for public use in England. He wished to say that such a system had been in operation in Hull for the last three or four years, on the principle of using hydraulic power, transmitted through mains laid along the streets, and distributed by branch pipes as required (*see a paper by Mr. Henry Robinson, Proc. Inst. C.E., vol. xlix. p. 1, and also the Transactions of the Liverpool Engineering Society, vol. i.*).

The PRESIDENT was sorry that the author was not present to reply to the several questions that had been asked, and also to defend some of the statements he had made; but the report should be sent to him, and he would be able to insert his reply in the Proceedings. On some points the paper was perhaps not as full as it might have been. There were omissions, for instance, in reference to the application of hydraulic power at Hull, and also in reference to the conveyance of power through long distances for pumping, by means of flat-rods, as

in Cornwall.\* Something also might be said as to the use of steel ropes. The author had spoken of nothing but iron wire, whereas light hard-drawn steel wire was no doubt much better. He proposed a vote of thanks to M. Achard for his paper, which was carried unanimously.

M. ACHARD, replying by letter to the remarks made in the discussion upon the paper, explained that the failure of the attempts to supply motive power at Bellegarde and Fribourg was due to their lacking the most important conditions of successful working: the mere fact of having cheap power available not being enough to make up for the deficiency of those conditions. The suggestion referred to by Mr. Fernie by no means met the case. Wherever a working population congregated, amusements suitable for their entertainment would be sure to follow fast enough of their own accord; their absence was the effect, not the cause, of dearth of workpeople.

The doubt he had expressed at the outset of the paper (p. 57), as to the attainment of practical success in large undertakings for distributing power to a number of factories, was confirmed by the experience gained at Schaffhausen; notwithstanding that there the circumstances were much more favourable than at either Fribourg

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\* This method was adopted on a very large scale, in the case of the old Wheal Friendship Mine at Marytavy in Devonshire, for the transmission of power from large overshot water-wheels to pumps fixed in the shaft of the mine, at a considerable distance higher up the valley. The largest water-wheel was 52 feet diameter and 12 feet breast, and its ordinary speed of working was 5 revolutions per minute. The length of stroke given by the crank to the horizontal or "flat" rods was 8 feet; the rods were round wrought-iron,  $3\frac{1}{2}$  inches diameter, and were carried on cast-iron pulleys. These particulars have been furnished by the kindness of Mr. Richard Taylor, who states that in the instances he has known of the use of flat-rods in Cornwall the amount of power conveyed was much smaller, the rods being of 2-inch round iron.

At Devon Great Consols, near Tavistock, there are altogether very nearly 3 miles of 3-inch wrought-iron rods, carried on bobs, pulleys, and stands, whereby power for pumping and winding is conveyed along the surface to different parts of these extensive mines, from eleven large water-wheels ranging up to 50 feet diameter, to which water is brought along  $8\frac{1}{2}$  miles of leats of 18 feet width.

or Bellegarde. Schaffhausen possessed an industrious population accustomed to labour, and the power supplied from the Rhine by the works erected for that purpose was readily taken up. Moreover the founder of the enterprise, the late M. Henri Moser, had presented a large part of the requisite capital as a free gift, so that the amount paying dividend was only about £32,000. In spite of these advantages, and of excellent management, the concern had never paid more than 2 or 3 per cent. on its share capital; and in some years, owing mainly to heavy repairs, there had been no dividend at all. At Zurich, which again was essentially a manufacturing town, the municipality had for some years past distributed, by means of ropes, power obtained from the river Limmat as it flowed out of the lake; but he was informed on good authority that this undertaking had been a very costly one, and was bringing in very small profits. These two examples therefore were not very encouraging.

Turning to Geneva, the conditions were far from being so favourable as they were at either Zurich or Schaffhausen. Manufacturers were less enterprising there; wages were high; and the workpeople were used to light handicrafts requiring taste and accuracy, and were not of the class needed for heavy trades. At the present time there were many owners of water-wheels along the banks of the Rhone who could find no one to rent the power they had to let.

The water-pressure at present let out in Geneva for working small machines in houses and shops was not supplied by any private company, as Mr. Fernie had stated, but by the town itself through the ordinary water mains; the pressure was only  $4\frac{1}{2}$  atm. (67 lbs. per sq. in.) at the outside. It would be advantageous if this department of the water supply to the town could be extended; since at Geneva almost the only way of effecting a useful distribution of power was by multiplying small ramifications or subdivisions.

With reference to the project mooted some years ago for utilising on an extensive scale the current of the Rhone, where it flowed out of the lake of Geneva, the fall available from that point down to the confluence of the Arve was nothing like so much as 25 or 30 ft. In the interest of properties bordering on the lake, the outflow of the Rhone ought to be so regulated as to keep the flood waters down to a

proper level; and the result would then be an available fall ranging from 5 to 7 ft. only. Owing to the small difference of level even as at present existing, the high floods that occurred in the Arve had the effect of more or less drowning the water-wheels along the banks of the Rhone above the confluence. Had the project been carried into effect, it would have proved no eye-sore to Geneva; and the reason of its falling through had nothing to do with the beauty of the city or neighbourhood, but was due to a difference as to terms. A further attempt in the same direction was in contemplation; but he did not know whether circumstances were now more favourable for its realisation, and it would be hard to predict the result.

The statements given in pages 60 and 61 of the paper, respecting the use of wide driving belts for transmitting large amounts of power, were derived entirely from a report drawn up by Herr Max Radinger for the Austrian Commission at the Philadelphia Exhibition in 1876. He must refer Mr. Schönheyder and Mr. Mair to that report as his authority, not having himself had any opportunity of becoming acquainted with that branch of the subject.\*

In reference to the most advantageous pressure to employ in machines worked by compressed air, it had been mentioned on page 74 of the paper that, in the absence of satisfactory means for reheating the expanding air, it was from a low pressure, not exceeding 4 atmospheres, that the highest useful effect was obtained. The reasons, which would readily be understood, had been fully entered into in his original articles in the "*Annales des Mines*," seventh series, vol. vi., pp. 335-8.

He was surprised it should have been thought by Mr. A. Siemens that too much importance had been attached to the question of efficiency. In any general examination of the transmission of power, without reference to any individual application, it seemed to him the very first consideration was that of efficiency; but he had not failed to point out how this consideration might itself be outweighed by others, as soon as particular instances came to be dealt with.

As to the absence of loss from waste spaces in water-pressure

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\* See also Cooper on the Use of Belting, p. 53.

machines, as commented on by Mr. Mair, of course there would necessarily be a loss if the water filling the waste spaces were allowed to escape at each stroke of the piston; but if this water were prevented from escaping, there would be no loss of power, because as soon as ever the communication with the pressure pipe was opened again, the full pressure would be restored to the water left in the waste spaces.

Notwithstanding Mr. Schönheyder's remarks about water-piston air-compressors, which however had now almost fallen into disuse, he adhered to the opinion that the alternating movement imparted to the water at each stroke of the piston was attended with a loss of power. There was a distinction between power expended in imparting velocity to the water, and power expended in producing the rise and fall of the water-level in the two upright chambers at the ends of the horizontal cylinder. The rise and fall no doubt counterbalanced each other without any loss of power. But the velocity imparted to the water in one direction in the forward stroke was evidently incapable of serving to produce the velocity in the contrary direction in the return stroke; it could only become transformed into eddies, and ultimately into heat, so that the equivalent work was totally lost. What took place in such compressors might be compared with what would occur in the case of a single-acting pump delivering direct into a water main without the intervention of an air-vessel: the inertia of the column of water in the main would then have to be overcome at every stroke.

In reference to the use of steel wire-ropes for the transmission of power, he would remark that steel was by no means a material of uniform quality. Whilst soft wrought-iron approached very closely to chemically pure iron, steel contained more or less of carbon, and sometimes of phosphorus, and varied greatly both in its chemical composition and in its molecular structure. On this account care had to be exercised with regard to many of the applications that might be made of it; this was the case with respect to its use for the construction of boilers, and the same would be true for wire-ropes. At the time of his first taking up this subject, steel was altogether out of favour in Switzerland for wire-ropes, as used for transmitting

power; but progress had been made since then, and steel wire-ropes were now coming more and more into use. The result of experiments made at Zurich, as he understood from Mr. G. Naville, of Messrs. Escher Wyss and Co., was that steel wire-ropes should be of the same diameter as those of iron, and would then last rather longer; a rope running continuously night and day would last from 200 to 250 days if of iron, and from 250 to 300 if of steel, thus about compensating for the difference in cost. Moreover steel ropes stretched less in working than iron, so that a steel rope running continuously would have to be shortened up only once in 120 days, against twice in the same time for an iron rope. A letter from Mr. D. H. Ziegler, of Messrs. T. T. Rieter and Co., Winterthur, expressed a more decided preference for steel ropes, from the experience of recent years; and recommended particularly the Creusot mild steel, made especially for the manufacture of wire. It added that the pulleys for steel wire-ropes need be no larger in diameter than those for iron ropes.

With respect to transmission of power by water pressure, as at Hull, and by flat-rods, as in Cornwall, these were methods peculiar to England; and he had therefore not thought it necessary to enter into them in a paper presented to English engineers, who had so much better opportunities than himself of becoming acquainted with the particulars.

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