On the Mechanical Ventilation of the Liverpool Passenger Tunnel on the London and North Western Railway

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ON THE MECHANICAL VENTILATION OF THE LIVERPOOL PASSENGER TUNNEL ON THE LONDON AND NORTH WESTERN RAILWAY.

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(*Supplementary Paper.*)

Since the last meeting of the Institution, at which a description was given of the large Ventilating Fan employed for clearing this tunnel of smoke and steam after the passage of locomotives (see Proceedings Inst. M. E. January 1871 page 22), further experiments have been made with a view to ascertain the vacuum produced by the fan at various positions in the central opening of the fan case; and the results of these experiments are given in the accompanying Table.

TABLE OF EXPERIMENTS.

Vacuum shown by Water-Gauge at different positions in entrance of Fan Case.

Speed of Fan, 45 revolutions per minute. Diam. 29 ft. 4 ins. Width 7 ft. 6 ins.

1 Position of Orifice of Gauge-Pipe. See Fig. 8, Plate 17.	2 Orifice pointing OUTWARDS.	3 Orifice pointing INWARDS.	4 Orifice *muffled*, pointing OUTWARDS.	5 Orifice *muffled*, pointing INWARDS.	6 Revolutions of Anemometer per minute.
	Inch.	Inch.	Inch.	Inch.	No.
A	0·70	0·70	—	—	170
B	0·30	0·50	—	—	—
C	0·60	—	—	—	Irregular
D	0·30	0·90	1·05	0·95	400
E	1·30	1·20	1·10	1·20	190
F	0·50	1·70	1·25	1·65	250
G	0·80	1·10	0·75	1·05	330
H	0·80	1·20	1·00	—	320
I	0·35	1·10	0·80	1·05	350

The mouth of a lead gauge-pipe of $\frac{1}{2}$ inch bore was placed in the nine positions shown by the black dots A to I in Fig. 8, Plate 17, in the central opening O O of the fan case, on the side nearest to the tunnel, Fig. 7. The other end of the pipe communicated with a water-gauge placed in the engine house, and the readings of this gauge are given by the figures in the table. The atmospheric pressure in the engine house during the working of the fan was previously compared with that of the air outside, and was found not to differ appreciably from it. The whole of these experiments were made while the fan was running at the regular working speed of 45 revolutions per minute.

The figures in the second column are the readings of the water-gauge when the mouth of the pipe was pointed directly outwards, from the fan, so as to face the current; those in the third column, when it was pointed directly inwards, towards the fan. The fourth column gives the readings when the pipe was muffled by a coarse cloth tied over its mouth, and was pointed directly outwards, from the fan; and the fifth column, when the muffled pipe was turned directly inwards, towards the fan.

The sixth column shows the number of revolutions made per minute by an anemometer placed in the positions shown by the black lines at A to I in Fig. 8. This instrument was of the kind recommended by Dr. Robinson, and consists of four hemispherical cups, attached to the extremities of two arms at right angles to each other, and revolving in a horizontal plane upon a vertical spindle, by the excess of pressure of the current of air upon their concave surfaces over that on their convex surfaces. The diameter of each of the cups is 2 inches, and they revolve in a circle of 12 inches diameter; on the vertical spindle is a tangent screw actuating the wheelwork of a small counter. No opportunity having occurred for testing this instrument on a perfectly calm day, or for comparing its readings with those of a known standard, the figures given in the table are simply the number of revolutions made by the anemometer in the different positions, and are considered only as indicating the relative velocities in the different parts of the current, with the fan running at 45 revolutions per minute.

The indicated horse power of the engine, whilst exhausting the tunnel, amounts to

126·0 horse power with the fan running at 43 revolutions per minute.
133·3 ,, ,, ,, 44 ,, ,,
133·9 ,, ,, ,, 45 ,, ,,

When the outlet at the top of the fan case was closed, and therefore no useful work was being done, the indicated horse power expended in driving the engine and fan was as follows, the work done by the fan being then confined to fluid friction, skin friction, and probably the flux and reflux of air through the central openings of the fan case:—

32·0 horse power with the fan running at 43 revolutions per minute.
33·8 ,, ,, ,, 44 ,, ,,

The PRESIDENT observed that the further experiments now described, which had been suggested by the remarks in the discussion at the previous meeting, had had to be made in a place that was necessarily dark, and the regular working of the train service had been carried on all the time as usual, which caused the fan case and its approaches to be filled continually with black smoke; so that considerable difficulties had presented themselves in the way of getting at scientifically accurate results. Practically however he believed the results arrived at were sufficiently near the truth; and the conclusion he drew from the further facts thus elicited was that no material improvement could be made in this ventilating fan, except in regard to the concentric half of the fan case. From the figures given in the Table it was evident that the discharge from the fan was exceedingly small round the concentric half, and it was only on approaching the spiral portion that any large quantities of air were delivered, thus showing that it would have been better if the spiral casing had been continued round the concentric half also, as had been originally intended, so as to allow

of a free discharge round that portion of the circumference. It should be borne in mind that ventilating fans might be divided into two broad classes, which might be termed "intensity" fans and "quantity" fans; and the present tunnel fan was emphatically one of the latter class, delivering a large quantity of air with a very slight degree of vacuum. With regard indeed to the actual amount of the vacuum, repeated experiments as to the degree of resistance due to the tunnel itself had fully confirmed the amount stated in the former paper (0·14 inch of water) as the vacuum caused by the tunnel resistance; which showed that if the tunnel itself were removed, and the fan were left to draw in the air direct from the atmosphere through the cross drift alone, there would be but little difference in the result as regarded either the quantity or tension of the air entering the fan case. He thought accordingly that a delivery round the entire circumference of the fan would be preferable for discharging the large quantity of air required, and therefore that the spiral form of case would be the best under such circumstances. This conclusion was not inconsistent with the results which had been arrived at in other experiments upon ventilating fans constructed on the Guibal principle for ventilating mines, where the degree of vacuum was much greater on account of the greater resistance of the mine passages, but where the quantity of air to be delivered was much less. In the case of the large Guibal fan of the same diameter employed for ventilating the Staveley collieries, which he had seen in operation, having the concentric casing and adjustable sliding shutter which were among the distinguishing features of that construction of ventilator, the quantity of air to be discharged at each revolution of the fan did not exceed about 1,700 cubic feet, and the concentric case was therefore not incompatible with that low delivery; but in the tunnel fan the quantity to be discharged at each revolution amounted to nearly 10,000 cubic feet. The apparently low duty of the latter fan, when considered in relation to its actual effect in ventilating the tunnel, was mainly to be accounted for by the great loss of power consequent upon the amount of obstruction offered to the air current after it had left the tunnel, the current being four times diverted at right angles

before it was discharged from the fan: once on entering the cross drift from the tunnel, a second time on turning up from the drift into the uptake to the fan, again on entering the fan case, and lastly on quitting the circumference of the fan. It was evident that by further increasing the resistance offered to the current, the tension of the air would be increased and the quantity discharged would be diminished in any given fan, until the extreme limit was reached when the resistance would be so great that there would be no discharge at all, and the fan case might then be made concentric all round. The results of the present experiments therefore, showing as they did the differences in the tension of the current at different parts of the central inlet of the fan case, had led him to the general conclusion that the spiral case was the proper form for at least a certain portion of the circumference; and that where the quantity to be delivered was large, the spiral should extend further round the fan, while for a smaller delivery the proportion of the concentric part of the case might be increased.

Mr. F. J. BRAMWELL enquired whether any explanation could be given of the circumstance that in the fan experiments now described the number of revolutions made by the anemometer in the different positions in which it was placed did not appear to bear any relation whatever to the amount of vacuum noted by the water-gauge in the same positions. For instance, with the highest vacuum of 1·30 inch (in column 2 of the Table) the number of revolutions of the anemometer was only 190 per minute; whilst in another position, with a vacuum as low as 0·30 inch, the anemometer made as many as 400 revolutions per minute.

The PRESIDENT replied that the apparent anomaly pointed out in the results of the experiments had taken him much by surprise, and he was at a loss to account for it, unless it arose from some local disturbance occasioned by the cross girder which carried the fan shaft. An anemometer of the construction employed in these experiments was of course open to the action of currents in any direction; and it had been found that there was a cross current passing along the horizontal girder, right across the opening of the fan case, as was shown in the Table of results by the greater degree

of vacuum at the point marked H on the expanding side of the fan case, than at the opposite point marked C on the concentric side. This was the only cause he could think of for the remarkable irregularities shown by the anemometer; and he could only give the results as facts which had been ascertained as carefully as was possible.

Mr. E. A. COWPER thought the principles deduced from the results of the fan experiments now described would be followed out in the most complete manner by making the fan case of a spiral form all round; for it was shown that with this large fan, delivering a large quantity of air with a very moderate degree of vacuum, the concentric half was inoperative as regarded any discharge of air, and the spiral half alone was effective. The more correct mode, he considered, of meeting variations in the quantities to be delivered, would be to adhere in all cases to a complete spiral round the entire circumference, and simply to vary the pitch or degree of opening of the spiral according to the delivery required in each particular instance. For an infinitesimal delivery this plan would give a spiral of infinitesimal opening, which would thus coincide with the concentric casing arrived at under the same condition by the other mode of viewing the subject. If a large quantity of air had to be delivered with a small degree of vacuum, the spiral would be made to open out rapidly; while on the other hand a small delivery with a great amount of vacuum would require a spiral of more gradual opening. The great advantage of the complete spiral casing was that all the vanes were then always equally effective throughout the entire revolution, and always doing their full share of the work, and the air was treated in the same way all round the fan, an equally free delivery being provided for it at every portion of the circumference. With that form of casing therefore, he considered, the greatest possible effect would be obtained from any size of fan, with the least amount of loss by eddies or regurgitations of the air.

Mr. A. ALEXANDER concurred in thinking the spiral form was the right one for the fan case, and believed this had generally proved the best for all kinds of fans. The extreme instance however of a fan

working under a great pressure or vacuum but with an infinitesimal delivery could hardly be considered to bear upon the question of the spiral form of the casing, because the degree of opening of the spiral would then be so minute that the casing would practically be identical with a concentric one. A suggestion that occurred to him with regard to the construction of the fan itself was to curve the blades backwards, instead of making them radial as in the tunnel fan; the backward curving of the blades he believed had been found very advantageous in other cases, particularly where a large quantity of air was required to be delivered. He thought also it would be an improvement to make both the fan and the casing of a taper form, narrowing in width from the centre to the circumference, in order to preserve the same area of passage for the current at all distances from the centre of the fan, so that the velocity of the air should continue uniform throughout.

The PRESIDENT said that when the tunnel fan was first set to work, the tips of the blades were curved backwards, but were not found to be so effective as when straight; and it was in consequence of the decided opinions expressed in connection with the Guibal fan, in favour of making the blades radial at the tips, that he came to the conclusion they should be so, at least in the outer portion, whatever might be the form of the inner portion of their length; the blades had accordingly been altered so as to be radial throughout, and he believed the alteration had been for the better. It had to be borne in mind that, under the particular circumstances of the tunnel fan, a special object kept in view in making it in its present form had been to have as much ventilating power as possible when the fan was at rest, by taking advantage of the heated air produced by the passage of locomotives, and the heat from the fan engine, so as to get up a considerable amount of natural ventilation; the fan had therefore been made of as open a construction as possible, with wide spaces between the blades, that it might present the least obstruction to the passage of the air through it when standing; and it was found that the expectations upon this point had been realised in practice. Some modification might doubtless be made with advantage for mine ventilation, where the

fan would always be in motion; but this was not the case in the present instance of the tunnel, as the fan was not at work during the night and part of the day; and it was found that with the wide passages through the fan the natural ventilation alone was sufficient during a considerable portion of each day.

Mr. J. W. BARRY suggested that if the width of the tunnel were divided throughout its entire length, by a brattice down the middle, it would only be necessary in this instance to ventilate half the tunnel, as the descending trains made no smoke. He did not know whether such a plan would be applicable in the present case, where the tunnel was a long one, but the question was one that had arisen in his own experience in dealing with a number of short tunnels; and it appeared to him that by dividing them each into two tunnels the interference of opposing currents would be avoided, and the current created in each half by the passage of trains would be always in one direction, whereby the ventilation would be materially assisted. In tunnels of about half a mile length, with only a single line of rails through them, he had found a considerable velocity of current was obtained by the passage of successive trains going always in the same direction, and producing therefore somewhat the effect of a plunger in a pump. In the Liverpool tunnel, though the descending trains did not foul the air, they must produce a cross current interfering with the ventilation, which would be avoided if the tunnel were divided; the expense of the division would not add much he thought to the cost of an ordinary tunnel with double line of way through it, as a tunnel 27 feet wide would well admit of a brattice down the centre.

Mr. C. COCHRANE observed that with a partition down the centre of the tunnel, although one side of the tunnel would continue clear on account of the descending trains making no smoke, the ascending trains would have double the effect in fouling the air in the other half of the tunnel; and therefore as much ventilating power would probably still be required for clearing that half as was at present needed for the whole. It was also to be borne in mind that, owing to the tunnel being on an incline, the speed of the ascending trains was lower and would have less effect in aiding the current of ventilation.

The PRESIDENT concurred in the view that the addition of a brattice in the tunnel would increase the degree of fouling occasioned by the passage of the trains on the ascending side. His own experience had been that the effect which the motion of the train produced upon the movement of the air in a tunnel was very slight indeed, and could scarcely be looked upon as of any considerable importance in the ventilation even of a short tunnel.

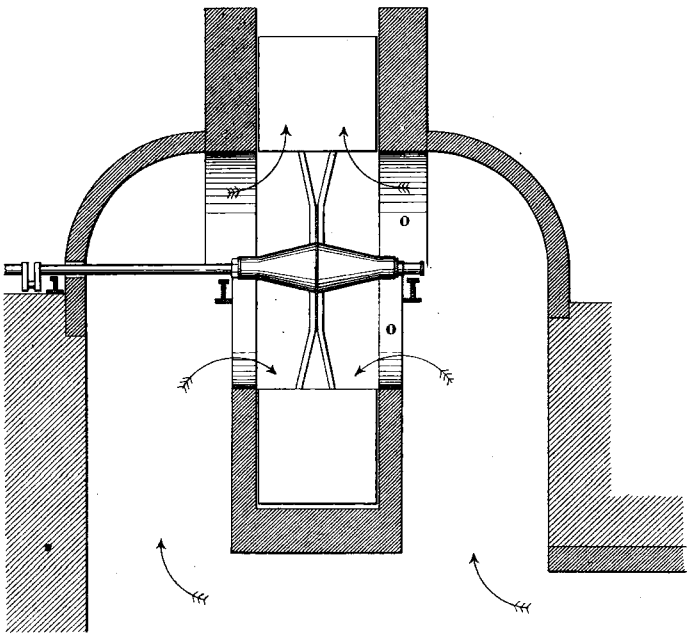
The following paper was then read:—

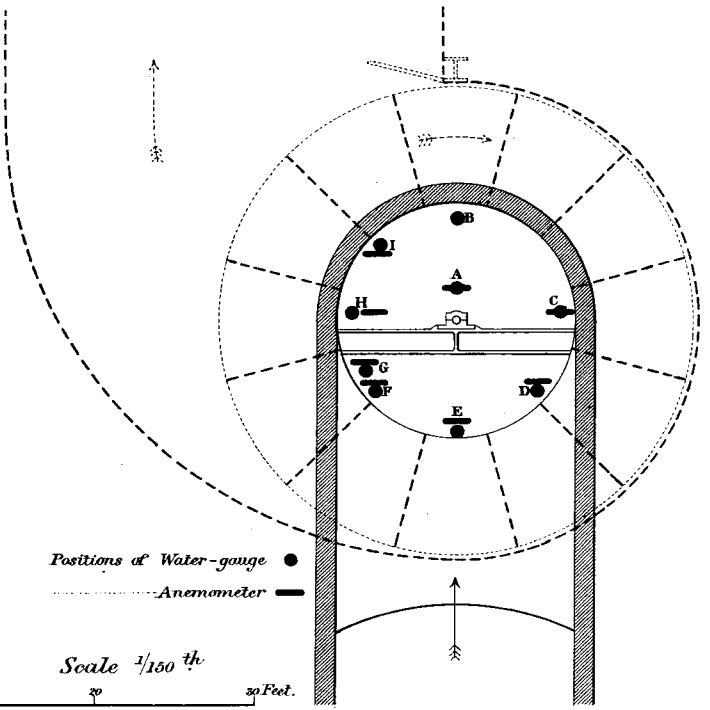
TUNNEL VENTILATING FAN.

Plate 17.

Fig. 8. *Elevation of Side of Fan-Case, showing positions of Water-gauge and Anemometer in the experiments.*

Fig. 7.
Longitudinal Section.





Scale 1/150 th

10 5 0 10 20 30 Feet.

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