RESEARCH COMMITTEE
ON THE VALUE OF THE STEAM-JACKET.

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No. 66.—EXPERIMENT ON A LOCOMOTIVE ENGINE,
BY PROFESSOR T. HUDSON BEARE AND MR. BRYAN DONKIN.

Object of Experiment.—The object of this experiment was to ascertain the advantage gained by jacketing the cylinders of a locomotive engine. The trials were undertaken, and carried out on the Lancashire and Yorkshire Railway, at the suggestion of Mr. John A. F. Aspinall, Chief Mechanical Engineer, who gave every assistance to the experimenters. The latter were on the locomotive during the trials, as well as several assistants who were taking indicator diagrams and other data.

Owing to the fact that these trials were carried out on a locomotive doing its ordinary train service, it was impossible to obtain results as complete and thorough as would have been aimed at, had the experimenters been able to make the trials on a special train, the working of which could have been arranged to meet the necessities of the experiment. The trials were of short duration, and the condition of the fires at the start and the finish of each had to be determined by the necessities of the traffic requirements, and could not therefore be varied to suit the wishes of the experimenters. The consumption of steam was obtained with a close approach to absolute accuracy; but the same cannot be said respecting the fuel consumption, owing to the above circumstance with regard to the condition of the fires. The results obtained are therefore not such as will enable any definite conclusions to be drawn as to the value of the steam-jacket in locomotives. They are nevertheless interesting and valuable; and having involved considerable trouble

on the part both of the experimenters during the trials and of Mr. Aspinall in the preparation of the engine for the experiment, it has been thought advisable to publish them for the use of the Members.

Description of Engine.—The experiment was made on a passenger locomotive, No. 1093, during its regular work of taking the 7.30 a.m. express train from Manchester to York, a distance of $76\frac{1}{2}$ miles, and returning with the 3.0 p.m. express from York to Manchester. Both engine and tender are the ordinary standard pattern of this railway. As illustrated in Plates 107 to 110, the engine is a four-wheel coupled with bogie truck, the driving wheels being 7 ft. 1 in. diameter and the bogie wheels 3 ft. $0\frac{1}{2}$ in. The cylinders are inside and horizontal, with their valve-chests on the top. The engine wheel-base is 21 ft. $6\frac{1}{2}$ ins., and the total wheel-base of engine and tender 41 ft. $1\frac{1}{2}$ ins. The weight of engine and tender when empty is 56.287 tons, and when in working order 70.925 tons, the tender carrying 1,800 gallons of water. The boiler is of steel, 4 ft. 2 ins. diameter and 10 ft. $7\frac{3}{8}$ ins. long; the fire-box shell of steel, and the fire-box of copper, 6 ft. long, 4 ft. 1 in. wide, and 5 ft. 10 ins. high. There are 220 tubes of $1\frac{3}{4}$ inch outside diameter. The heating surface in the tubes is 1,108.73 sq. ft., and in the fire-box 107.68 sq. ft.; total 1,216.41 sq. ft. The fire-grate area is 18.75 sq. ft., the ratio of heating surface to grate area being 65 to 1. The fire-brick arch in the combustion chamber is about $2\frac{1}{2}$ ft. long. The height of the chimney above the fire-grate level is 10 ft.

The cylinders were originally of the normal pattern, 19 inches diameter and 26 inches stroke. For this experiment they had been bored out and fitted with cast-iron liners, which reduced the internal diameter to $17\frac{1}{2}$ inches, thus providing a body jacket of 3–8ths inch space. The front cylinder covers were fitted with external covers, the space between the two forming a steam-jacket. The back covers however were imperfectly jacketed by fitting over them, as close to the actual covers as possible, an annular wrought-iron ring with an inner and an outer cover, the space between the two latter forming a jacket space. The external surfaces of the end jackets were much exposed,

and not well covered. In the diagrams Figs. 7 to 9, Plates 111 and 112, are shown sectional views of the cylinders as thus fitted with their jackets.

In Table 1 (page 473) are shown the clearance volumes of the cylinders, and the jacketed and unjacketed internal surfaces exposed to steam in the clearances alone, and also in the clearances and cylinders at 90 per cent. of the stroke. It will be seen that the proportion of the clearance surface jacketed is only about a quarter of the whole, and this is mainly due to the cover jackets; of the back ends therefore a large part is hardly jacketed at all, in the true sense of the word.

Description of Trials.—Four trials were made, lettered A B C D, on 18th and 19th September 1894: A unjacketed and B jacketed on the 18th; C jacketed and D unjacketed on the 19th. A and C were made on the runs from Manchester to York, and B and D on the return runs from York to Manchester. See Tables 2 and 3, pages 474–7.

Observations.—In each trial the weights of coal and feed-water consumed were measured, and readings of the various gauges were taken, and the position of the reversing gear was noted. Indicator diagrams were obtained, and in trials C and D samples of the furnace gases were collected from the smoke-box below the exhaust pipe.

Coal.—The coal used in the trials was from the Mitchell Main Colliery, Wombwell, near Barnsley. Samples were taken from each sack used, and were submitted to Mr. Charles J. Wilson for determining the calorific value in a calorimeter. The mean value from his tests was 14,200 thermal units per pound of dry coal, equivalent to an evaporation of 14·7 lbs. of water from and at 212° Fahr. The coal was placed on the tender in sacks holding 200 lbs. each; and the time of emptying each sack upon the footplate was noted, as well as the total weights. An attempt was made to have the fire in the same condition at the end of each run as at the

start ; but it was difficult to carry out this arrangement, since the trials were made during ordinary runs, and could not be allowed to interfere in any way with the regular working of the traffic. The gradients at the two ends of the journey are different, as seen in the profile of the line, Fig. 16, Plate 115 ; and different fires were therefore needed to ensure adequate steam at the beginning and end of each run.

The ashes and clinkers from the smoke-box and fire-box were weighed off at the end of each run, but those in the ashpan were weighed only at the end of each double journey. As each trial lasted only about two hours, errors introduced by variation in the condition of the fire might be thought to bear rather a large proportion to the total coal consumption ; but, bearing in mind the rapidity of consumption, amounting to about 50 or 60 lbs. per square foot of grate per hour, this was probably not the case.

The actual coal consumption per indicated horse-power per hour of steaming time in the four journeys was respectively 2·87, 3·07, 2·73, and 2·79 lbs. In Fig. 10, Plate 112, is plotted the coal consumption in each of the four trials.

Furnace Gases and Temperatures.—On the first day no attempt was made to collect the gases ; and as the thermometer for taking their temperature had been fixed above the blast-pipe orifice, Plates 109 and 110, it was not thought worth while to note its readings. On the second day the gases were collected continuously ; but the thermometer, placed in a better position, unfortunately broke almost immediately after leaving Manchester, so that the temperatures could not be ascertained.

The difficult operation of collecting the gases while going at express speed was carried out by Mr. Michael Longridge. They were drawn off through a $\frac{1}{4}$ -inch copper pipe, and then through a rubber pipe into a gasometer containing water, whilst a branch pipe led to a collecting bottle filled with mercury. After drawing off all the air in the pipe connections, the cock on the branch was opened, so that part of the current of waste gases passing to the gasometer could be diverted and collected by displacement over mercury in the collecting bottle. During the outward journey C much trouble

was experienced, owing to the heavy chimney-blast; but in the return journey D everything worked quite satisfactorily.

The mean results of the three analyses made from the sample collected on each journey are the following volumetric percentages:— trial C, carbonic acid 12·85 per cent., oxygen 4·15, carbonic oxide 0·80, nitrogen 82·20; trial D, carbonic acid 15·10, oxygen 1·97, carbonic oxide 0·85, nitrogen 82·08 per cent.

Feed Water.—As arranged by Mr. Aspinall, the feed-water was measured by means of a Siemens water meter M on the pipe between the tender and the injector, Figs. 2 and 4, Plates 107 and 108. It was originally intended to have a means of making direct measurement of the feed-water; but he had not been able to carry out the necessary arrangements. The meter was read at the time of starting from each station, and thus a fair approximation to the rate of consumption was obtained, as well as the total quantity. The overflow from the injector was caught and allowed for.

After the trials were over, the meter was sent to University College, London, and tested there by Professor Beare at rates of flow similar to those in the trials. The error was somewhat variable, but the meter was found to be registering on the average 2·6 per cent. too low. In order to be able to correct for differences of level in the boiler, the quantity passing through the meter to raise the level in the gauge glasses one inch, for each inch in their height with the engine standing under full steam, was determined by Mr. Donkin after the trials.

Steam-Jacket Water.—The jackets were drained into three small tanks T, Figs. 1 and 5, Plates 107 and 109, carried upon a temporary staging on the front of the engine; one measurement was made for the two body jackets together, another for the two front covers, and a third for the two back covers. While standing at York on each day radiation tests were made, by measuring the quantity of steam condensed in each pair of jackets with the engine standing, all hot; these lasted $2\frac{1}{2}$ hours on the first day, and $1\frac{1}{2}$ hours on the second. The following were the results obtained:—

Condensation of Steam in Jackets, lbs. per hour.

	While running.		While standing.	
	Sep. 18, B.	Sep. 19, C.	Sep. 18.	Sep. 19.
Two Body Jackets .	267	241	35·0	26·7
Two Front Covers .	123	103	16·0	13·7
Two Back Covers .	65	55	12·0	15·8

Times, Pressures, &c.—The times of passing all the stations were noted; and also the times during which the steam was shut off, in order to determine the actual running time and the actual steaming time in each trial. Whenever a set of indicator diagrams was taken, a note was made of the boiler pressure, of the pressure in the jackets, of the position of the reversing gear, and also of the gradient and mileage.

Indicator Diagrams.—These were taken simultaneously from both ends of each cylinder; those nearest the mean in each of the four trials are shown in Figs. 11 to 14, Plates 113 and 114. The springs of the indicators used were not tested for errors, since these would not affect the comparative results of the four trials. In Tables 4 to 7 (pages 478–481) are given the times of taking the diagrams, and also the speed of train and other particulars. Unfortunately no counter was fixed for the trials, as had been intended. The speed in miles per hour was continuously registered by a Boyer speed recorder R, Figs. 2 and 6, Plates 107 and 110, kindly lent by Mr. Aspinall, upon a paper wound on a drum which was driven from the rear bogie axle. A diagram of the curves obtained is shown in Fig. 15, Plate 115. If this instrument recorded correctly, the circumference of the driving wheels being known and all slip neglected, the revolutions per minute of the driving wheels can be calculated. An attempt was made to count the revolutions at the time the diagrams were being taken; but it was found impossible to do this correctly at the high speeds. After much deliberation, it was decided to make a series of tests of the Boyer recorder, by driving it at known speeds, in order that any errors in the diagram it recorded might be ascertained. This was afterwards done by Mr. Donkin, and details of the method

of testing are given in the appendix, page 482; the errors being plotted on a speed base, the error at any speed can easily be ascertained. In Tables 4 to 7 the revolutions per minute are the corrected values, while the miles per hour are the speeds actually registered by the recorder, and are therefore on the average some 2 or 3 per cent. too low. The indicated horse-power given in the tables is calculated from the revolutions obtained from the recorder, after correction for the error ascertained by the testing. Had a counter been fixed, it would have saved much trouble, and would have been much more satisfactory.

General Results.—Tables 2 and 3 (pages 474–477) give the mean results of all the important observations. Comparing trials A and C, both from Manchester to York, the jacketed trial C shows a consumption of 24·49 lbs. of steam per I.H.P. per hour, Table 3, line 16, against 26·70 lbs. for the non-jacketed run A, or a saving of 8·3 per cent. by jacketing. Comparing trials B and D, both from York to Manchester, the figures are 24·48 and 24·87 lbs. respectively, or a saving of 1·5 per cent. by jacketing. Comparing the figures for coal consumption in trials A and C, Table 2, line 17, the jacketed trial C shows an economy of 0·14 lb. per horse-power per hour, or practically 5 per cent., the increased consumption per train-mile in this run being accounted for by the greater load hauled; the load was 8 per cent. greater in C than in A, the average speed being nearly the same in both runs. Comparing trials B and D however, the jacketed trial B is distinctly less economical, the coal consumption being 0·28 lb. greater per horse-power per hour than in the non-jacketed trial, or 10 per cent. more; and the consumption is also greater per train-mile. In these two trials, while the weight of train hauled was the same, the speed was nearly 3 miles an hour greater in the non-jacketed run D, with a correspondingly much increased horse-power.

TABLE 1.—*Engine Dimensions.*

Diameters of Cylinders, { right inches	17·543
taken hot. { left inches	17·559
Diameter of Piston-rods inches	2·95
Mean Areas of Pistons { right . . . square inches	238·31
{ left . . . square inches	238·76
Stroke of Pistons inches	26
Diameter of Driving Wheels on tread . . . inches	85
Cylinder constants for indicated horse- power per lb. of mean effective pressure at 1 revolution per minute { right . I.H.P.	0·031293
{ left . I.H.P.	0·031352
Clearance Volumes* { front cubic foot	0·293
{ back cubic foot	0·247
{ mean cubic foot	0·270
Mean Clearance Volume in inches of stroke . . inches	1·96
” ” ” in percentage of piston displacement } . per cent.	7·52
Volume of Steam at 90 per cent of stroke, mean of both cylinders, including clearance } . cubic feet	3·500

<i>Internal Surfaces exposed to Steam.</i>			
Mean of both cylinders and of front and back	Jacketed	Non-Jacketed	Total.
Clearance { square feet	2·56	6·78	9·34
{ per cent.	27·4	72·6	100·0
Clearance plus Cylinder { square feet	10·46	8·18	18·64
at 90 per cent. of stroke . { per cent.	56·1	43·9	100·0

* Mean of both cylinders, obtained by filling with water the calculated volumes came 2 per cent. higher.

TABLE 2.--Boiler Results.

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1	Trial	A	B	C	D
2	Date of trial, 1894 September	18	18	19	19
3	Journey {	Manchester to York	York to Manchester	Manchester to York	York to Manchester
4	WITH or WITHOUT all Steam-Jackets	WITHOUT	WITH	WITH	WITHOUT
5	Duration of trial, station to station minutes	134½	108	134	99½
6	Total running time, excluding stops minutes	111	97½	113	92
7	Total time steam was on minutes	95	83	93	78
8	Total Load, including engine and tender tons	173	171	187	171
9	Average Speed while running miles per hour	41·3	47·1	40·6	49·9
	<i>Mean Steam Pressure per square inch above atmosphere.</i>				
10	In boiler lbs.	156	162	158	160
11	In barrel jackets lbs.	—	149	147	—
12	In front-cover jackets lbs.	—	149	147	—
13	In back-cover „ lbs.	—	149	147	—

TABLE 2 (*continued*).

	<i>Coal Consumption.</i>	trial	A	B	C	D
14	Total during trial (see Fig. 10, Plate 112)	lbs.	2,211	2,160	2,400	2,050
15	Per hour of total time	lbs.	986	1,200	1,075	1,236
16	Per square foot of fire-grate per hour	lbs.	52·6	64·0	57·3	65·9
17	Per I.H.P. per hour of steaming time	lbs.	2·87	3·07	2·73	2·79
18	Per train-mile	lbs.	28·9	28·2	31·4	26·8
19	Ashes and clinker, total	lbs.	389	494	320	454
20	„ „ „ percentage of coal	per cent.	17·6	22·9	13·3	22·1
	<i>Feed-water Consumption.</i>					
21	Temperature	Fahr.	55°	56½°	57°	58°
22	Total, corrected for boiler level and meter	lbs.	20,580	17,190	21,500	18,260
23	Per hour of total time	lbs.	9,180	9,550	9,625	11,010
24	Per square foot of heating surface per hour	lbs.	7·55	7·85	7·91	9·05
25	Per pound of coal	lbs.	9·31	7·96	8·96	8·91
26	„ „ „ from and at 212° F.	lbs.	11·28	9·64	10·85	10·78
27	Calorific Value of Coal, water evaporated per pound from and at 212° F.	lbs.	14·7	14·7	14·7	14·7
28	Thermal Efficiency of boiler, $100 \times \text{line 26} \div \text{line 27}$	per cent.	76·7	65·6	73·8	73·3

TABLE 3.—*Engine Results.*

1	Trial letter	A	B	C	D
2	Date of trial, 1894 September	18	18	19	19
3	Journey	Manchester to York	York to Manchester	Manchester to York	York to Manchester
4	WITH or WITHOUT all Steam-Jackets	WITHOUT	WITH	WITH	WITHOUT
5	Condition of Rails, dry or wet	dry	dry	wet	dry
6	Wind	moderate	moderate	strong	moderate
7	Air Temperature, average Fahr.	58°	58°	57°	57°
8	Mean Revolutions per minute, at time of taking indicator diagrams } revs.	187·8	188·2	198·7	224·3
9	Mean Effective Pressure per square inch, } right lbs. from indicator diagrams, } left lbs.	44·87 40·24	47·78 44·11	51·20 43·86	44·57 38·38
10	Mean Indicated Horse-power, right I.H.P.	255·9	263·9	305·6	301·5
11	„ „ „ left I.H.P.	230·9	243·4	260·8	263·2
12	„ „ „ total I.H.P.	486·8	507·3	566·4	564·7

TABLE 3 (*continued*).

	<i>Steam Consumption.</i>	trial	A	B	C	D
13	Total, including jackets	lbs.	20,580	17,190	21,500	18,260
14	Total time of steam in cylinders	hour	1·583	1·383	1·550	1·300
15	Steam per hour of steaming time	lbs.	13,000	12,430	13,870	14,050
16	„ „ „ „ „ per I.H.P.	lbs.	26·70	24·48	24·49	24·87
17	Economy due to Jackets, percentage less steam	per cent.		1·5	8·3	
	<i>Jacket Water.</i>					
18	Two barrel jackets, total	lbs.		370	357	
19	Two front covers „	lbs.		170	160	
20	Two back covers „	lbs.		90	85	
21	Jacket Water, total	lbs.		630	602	
22	„ „ per hour of steaming time	lbs.		455	388	
23	„ „ „ „ „ „ „ per I.H.P.	lbs.		0·897	0·686	
24	Percentage of feed-water, $100 \times \text{line 21} \div \text{line 13}$	per cent.		3·7	2·8	

TABLE 4.—*Trial A. Manchester to York. Tuesday 18 September 1894.*WITHOUT *Steam in Jackets.*

No. of Diagram.	Time.	Gradient.	Speed.		Steam cut off.	Mean Effective Pressure per sq. inch.		Indicated Horse-power.	
			Revolutions per minute.	Miles per hour.		Right.	Left.	Right.	Left.
			Revs.	Miles.	Per cent.	Lbs.	Lbs.	I.H.P.	I.H.P.
1		1 in 150 rising	119·0	32	45	71·8	58·0	267·4	216·4
2		1 „ 1,056 „	140·2	37	40	51·7	47·0	226·8	206·6
3		1 „ 161 „	161·2	42	35	53·8	49·9	271·4	252·2
4		level	161·2	42	25	34·5	30·7	174·0	155·2
5		1 in 183 falling	182·6	47	17	24·3	20·6	138·8	118·0
6		1 „ 183 „	230·0	58	20	30·0	29·4	216·0	212·0
7		1 „ 377 „	131·6	35	25	45·1	40·0	185·7	165·0
8		1 „ 528 „	212·7	54	25	37·6	33·5	250·3	223·4
9		1 „ 440 „	212·7	54	35	59·0	52·2	392·7	348·1
10		1 „ 440 „	238·6	60	25	35·1	31·5	262·1	235·6
11		1 „ 528 „	281·3	70	25	37·4	32·9	329·2	290·1
12		1 „ 330 „	161·2	42	35	60·0	51·5	302·7	260·3
13		1 „ 330 rising	187·0	48	25	40·4	38·7	236·4	226·9
14		1 „ 3,153 „	191·4	49	30	45·0	41·0	269·5	246·0
15		1 „ 3,162 falling	174·0	45	30	47·2	44·0	257·0	240·0
16		1 „ 1,175 rising	178·3	46	30	47·3	43·9	263·9	245·4
17		level	230·0	58	30	42·5	39·3	305·9	283·4
Means			187·8	48·2		44·87	40·24	255·9	230·9
Total								486·8	

Moderate wind ; rails dry.

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TABLE 5.—*Trial B. York to Manchester. Tuesday 18 September 1894.*

With Steam in Jackets.

No. of Diagram.	Time.	Gradient.	Speed.		Steam cut off.	Mean Effective Pressure per sq. inch.		Indicated Horse-power.	
			Revolutions per minute.	Miles per hour.		Right.	Left.	Right.	Left.
1	p.m.		Revs.	Miles.	Per cent.	Lbs.	Lbs.	I.H.P.	I.H.P.
2	—	level	156·9	41	35	62·1	56·1	304·9	276·0
3	3-12	1 in 1,175 falling	182·6	47	30	53·0	48·1	302·9	275·4
4	3-17	1 „ 10,560 rising	225·6	57	30	40·9	36·6	288·7	258·9
5	3-20	1 „ 631 „	242·8	61	30	43·0	39·0	326·7	297·0
6	3-29	1 „ 3,153 falling	52·1	15	35	78·4	72·4	127·8	118·3
7	3-38½	1 „ 330 rising	187·0	48	30	45·7	44·9	267·5	263·2
8	3-46	level	110·7	30	40	74·5	71·4	258·1	247·8
9	3-49	1 in 660 rising	221·3	56	30	43·0	38·7	297·8	268·5
10	3-54	1 „ 440 „	208·5	53	25	41·2	35·3	268·8	230·8
11	3-59	1 „ 440 „	208·5	53	25	41·0	36·6	267·5	239·3
12	4- 3½	1 „ 528 „	204·2	52	30	44·1	40·6	281·8	260·0
13	4- 9	1 „ 377 „	230·0	58	30	41·5	39·2	298·7	282·7
14	4-14	1 „ 183 „	204·2	52	30	41·7	40·9	266·5	261·9
15	4-25	level	178·3	46	25	37·0	35·0	206·5	195·7
16	4-31	1 in 330 falling	208·5	53	20	29·7	26·8	193·8	175·2
Means			188·1	48·1		47·78	44·11	263·9	243·4
Total								507·3	

Moderate wind; rails dry.

TABLE 6.—*Trial C. Manchester to York. Wednesday 19 September 1894.**WITH Steam in Jackets.*

No. of Diagram.	Time.	Gradient.	Speed.		Steam cut off.	Mean Effective Pressure per sq. inch.		Indicated Horse-power.	
			Revolutions per minute.	Miles per hour.		Right.	Left.	Right.	Left.
	a.m.		Revs.	Miles.	Per cent.	Lbs.	Lbs.	I.H.P.	I.H.P.
1	7-52	1 in 150 rising	119·0	32	35	86·4	76·6	321·7	285·8
2	8- 4	1 „ 161 „	178·3	46	35	63·4	58·6	353·7	327·6
3	8- 8	level	204·2	52	25	48·3	40·2	308·7	257·4
4	8-18	1 in 183 falling	208·5	53	17	26·0	20·4	169·6	133·4
5	8-24	1 „ 183 „	225·6	57	17	22·3	14·9	157·4	105·4
6	8-36	1 „ 377 „	200·0	51	25	48·0	41·3	300·5	259·0
7	8-50	1 „ 440 „	230·0	58	30	49·3	42·4	354·9	305·8
8	8-57	1 „ 660 „	242·8	61	25	35·5	27·9	269·7	212·4
9	9-12	1 „ 330 „	169·7	44	35	68·8	63·2	365·4	336·3
10	9-21	1 „ 484 „	217·0	55	30	51·5	43·1	349·7	293·2
11	9-27	1 „ 3,153 rising	165·4	43	25	59·5	51·0	308·0	264·5
12	9-38½	1 „ 3,162 falling	204·2	52	35	60·4	52·2	386·0	334·2
13	9-47	1 „ 1,175 rising	195·8	50	25	51·7	42·7	316·8	262·1
14	9-51	level	221·3	56	25	45·7	39·5	316·5	274·1
Means . .			198·7	50·7		51·20	43·86	305·6	260·8
Total								566·4	

Strong head-wind; rails wet.

TABLE 7.—Trial D. *York to Manchester. Wednesday 19 September 1894.*

WITHOUT Steam in Jackets.

No. of Diagram.	Time.	Gradient.	Speed.		Steam cut off.	Mean Effective Pressure per sq. inch.		Indicated Horse-power.	
			Revolutions per minute.	Miles per hour.		Right.	Left.	Right.	Left.
1	p.m. 2-58½	level	174·0	45	35	71·1	52·5	387·2	286·4
2	3- 1½	1 in 1,320 falling	221·3	56	25	45·5	41·3	315·1	286·6
3	3- 5	1 „ 1,320 „	247·1	62	25	42·5	36·4	328·6	282·0
4	3- 8	1 „ 3,078 „	255·6	64	25	39·4	35·8	315·1	286·9
5	3-12	1 „ 3,162 rising	255·6	64	25	39·5	35·8	316·0	286·9
6	3-16	1 „ 631 „	242·8	61			33·7		256·5
7					0	Steam off			
8	3-28	1 in 484 rising	182·6	47	25	48·0	41·5	274·3	237·6
9	3-33½	1 „ 330 „	161·2	42	35	66·3	53·3	334·5	269·4
10					0	Steam off			
11	3-43	level	182·6	47	25	46·9	39·6	268·0	226·7
12	3-46	1 in 660 rising	225·6	57	25	42·5	37·3	300·0	263·8
13	3-49½	1 „ 660 „	234·3	59	25	44·2	39·8	324·1	292·4
14	3-53½	1 „ 440 „	247·1	62	30		39·4		305·2
15	3-57	1 „ 440 „	238·6	60	25	41·8		312·1	
16	4- ½	1 „ 377 „	234·3	59	25	42·7		313·1	
17	4- 5	1 „ 377 „	225·6	57	25	43·9		310·0	
18	4- 8	1 „ 183 „	221·3	56	25	43·5		301·2	
19	4-12	1 „ 183 „	204·2	52	30	46·3		295·9	
20	4-20	1 „ 330 falling	208·5	53	25	39·4	36·0	257·1	235·3
21	4-23½	1 „ 330 „	251·3	63	25	37·5	34·5	294·9	271·8
22	4-28	1 „ 161 „	272·7	68	17	21·2	18·8	180·9	160·7
Means			224·3	56·7		44·57	38·88	301·5	263·2
							Total	564·7	

Moderate wind; rails dry.

APPENDIX.

Testing of Boyer Speed Recorder.

The instrument used in the trials was afterwards tested at Bermondsey by Mr. Donkin in October 1894. It was driven by a small vertical engine, on the crank-shaft of which was a counter. The instrument is so constructed that when it is driven at 600 revolutions per minute the pencil should record a speed of 60 miles per hour on the paper. The circumference of the driving pulley on the instrument was 17·75 ins., and that of the engine pulley 44·75 ins., or a ratio of 1·000 to 2·521. The recorder being driven by a steel wire without slip, the revolutions per minute of the engine multiplied by 2·521 give the revolutions per minute of the recorder; and these divided by 10 give the calculated speed in miles per hour which the recorder should register. The difference between this calculated speed and the speed actually registered by the recorder is the error of the instrument. Altogether some fifteen tests were made, each of five minutes duration, during which the mean speed of the engine was taken by the counter, and compared with the mean speed registered by the recorder. The results of the tests showed that at about 15 miles per hour the instrument recorded about 10 per cent. too high, at 40 miles it recorded correctly, and at 60 to 80 miles per hour 4 per cent. too low. The errors when plotted on a base of speed form a regular curve, from which the following corrections have been taken :—

Speed, miles per hour . . .	15	20	25	30	35	40	45	50	55	60	65
Error of Recorder, per cent.	{ 10	7½	5½	3½	1½ }	0	{	<i>too low</i>			}
		<i>too high</i>					{ 1½	2½	3½	4	4½ }

Discussion.

Mr. JOHN A. F. ASPINALL, Member of Council, drew attention to the fact that the experiments described in the paper were tried as far back as September 1894. On the whole they were of value, he thought, rather because they served to show what ought to be done in any future experiments, than as having any immediate practical results. Before the experiments were tried by Professor Beare and Mr. Donkin, a number of runs had been made with the engine, and the figures then obtained agreed generally with those given in the paper. But the trials were a matter of great difficulty. The engine had to have three sets of measuring tanks in front of it, connected with the different steam-jackets; and all three had to be carefully watched, together with the indicators, the different pressure-gauges, the water-gauge registering the vacuum in the smoke-box, the water-meter between the engine and tender, and various other instruments; and at least half a dozen observers had to hang on as carefully as they could, while the engine was going at a considerable speed. It would thus be seen what real difficulty there was in conducting experiments of this kind, such as was not experienced with an ordinary stationary engine. Such experiments ought indeed to be tried upon a line going through a district where there were not many signals and not much to trouble the driver; and not upon such a line as that on which the present trials had been made, where on 500 miles of railway there were no less than 800 signal boxes.

With the remark in page 466, about the condition of the fires not suiting the wishes of the experimenters, he did not altogether agree. The conditions of the experiments he held ought not to be varied to suit the wishes of the experimenters, but the latter should accept the ordinary conditions of locomotive running; because the object was to see whether putting steam-jackets upon an engine was of any advantage or not, and the commercial advantage would be proved by the engine doing well under ordinary conditions of running.

Again, the figures given in page 469 for the coal consumption per indicated horse-power per hour of steaming time in the four several journeys, he thought could not be taken as reliable. This opinion

(Mr. John A. F. Aspinall.)

he held without thereby casting any reflection upon the observers, to whom his thanks were due for the way in which they had conducted the experiments: but simply because it had been found immediately after the trials that the indicator diagrams exhibited—and bad diagrams indeed it would be agreed they were—had been made of the shape shown on account of the presence of water in the indicator pipes. That had been a source of endless trouble. Recently he had been trying some experiments with indicators put right on the ends of the cylinders, with the shortest possible steam-pipes. The area of the diagrams so taken was thereby increased largely, and the initial pressure approached almost exactly to the steam-chest pressure or the boiler pressure. The result of the inaccuracy of the indicator diagrams which accompanied the paper was that the figures deduced from them in the paper were perforce inaccurate also.

In page 470 it was mentioned that it had originally been intended to have a means of making direct measurement of the feed-water, but that he himself had not been able to carry out the necessary arrangements. The original idea of the experimenters, so far as he remembered, had been that the tender should be marked off with horizontal lines to show the number of gallons it contained for each inch of depth; and that the consumption of water should be read off in that way. But a meter he thought was a much better and a much more positive way of ascertaining it than by trying to measure the water in the tender, because of the surging backwards and forwards which took place when the engine was running. Moreover the latter method was rendered more difficult, because water had to be picked up from track troughs more than once on each journey.

From page 471 it appeared that the experimenters would have preferred a counter, instead of a Boyer speed recorder. The latter however, enabling the speed to be seen at the instant of taking the indicator diagrams, he thought was a better instrument than a counter, which counted the revolutions not only during the short time of taking the diagrams, but also for a long time before and after they were taken, and from which therefore only a mean result could be obtained. If the Boyer recorder had been used in the way in

which he thought it could have been, it would have been easy for one of the observers to mark at once upon it the times at which the diagrams were taken, and thereby the speed would have been exactly recorded.

The remarks he had already made with regard to the figures of coal consumption in page 469 applied also to those in page 472, which were vitiated by the inaccuracy of the indicator diagrams; and he was reminded of a saying that, next to an ammeter, no instrument could give such false results as a steam-engine indicator.

The engine had continued running with the steam-jackets since the experiments had been tried, and on the whole it had shown economy; but he was not yet prepared to say what the actual economy was, because all such matters required to be tried with the greatest possible care. It was so difficult to be certain as to the results obtained from a single locomotive, that in experiments of this kind, when the figures seemed to point to success, he was always tempted to doubt them more than ever, because it was necessary to take into consideration questions of load, of wind and weather, and of other matters, which never arose with a stationary engine. While he thought there had been an economy in the use of the steam-jackets, he might mention that in some other experiments, in which he had tried drawing the hot smoke-box gases round the cylinders, whereby the temperature in the jackets rose as high as about 470° Fahr., he had met with contrary results, and had not got the economy he had expected. He therefore looked upon all the experiments tried up to the present time as only indicating how much more care ought still to be taken, before it could be stated positively that the results were good.

Mr. DAVID JOY mentioned that from experiments made on the *Aberdeen* steamship, which had been carefully carried out and reported to the Institution of Naval Architects (Transactions 1882, vol. xxiii, page 33), no definite conclusion could be arrived at; they had been much like the present experiments in not showing which way the result was—whether there was any advantage or not in steam-jacketing.

Mr. SAMUEL W. JOHNSON, Vice-President, enquired whether, notwithstanding the admitted unreliability of the trials recorded, the use of steam-jackets had so far commended itself to Mr. Aspinall that he contemplated altering all his engines to it. No doubt the difficulties of making such experiments were great; and it seemed to him that the results of those recorded in the paper must necessarily be unreliable. The statement of steam and coal consumption in page 472 he thought was rather misleading, because the differences in load and speed and other conditions would themselves be sufficient to make all the difference in consumption. In trials of this kind on a railway the great difficulty lay in getting the engine making the experiments to take a train under precisely the same conditions in the successive trials. The value of the steam-jacket on a locomotive engine he thought was perhaps small, compared with the ordinary method of keeping the cylinders warm either by the hot-air of the smoke-box or by a wood lagging, or by simply a lagging of sheet-iron with a space of air between.

Mr. MICHAEL LONGRIDGE, while agreeing that the paper was certainly to some extent a record of failure to ascertain facts, thought there were great excuses to be made for the failure; for no one who had not made a locomotive trial could have any conception of what the difficulties really were. Nevertheless he considered the paper valuable, because he thought it taught an important lesson. With regard to the value of the steam-jacket, he was afraid it told absolutely nothing. It was quite true that in the first pair of trials compared in page 472, A and C, there was a difference of 8·3 per cent. in the steam consumption, in favour of jacketing; but he was afraid that this was rather due to errors of observation than an absolute fact, for in trials B and D the saving was only 1·5 per cent. If it was considered that the engine was running almost in the same way, and at nearly the same load, and over the same line, there was no apparent reason why the steam consumption should be 7 per cent. greater in the one case than in the other. Then going a step further, and looking at the quantity of steam used in comparison with the coal burnt, it would be noticed that on the first day the rate of

evaporation must have been such as could hardly be credited. From line 26 in Table 2 it would seem as though in trial A there had been an evaporation of 11.28 lbs. of water per pound of coal; but this did not at all represent the real fact, because from line 20 it would be seen that in the two trials on that day the weight of the ashes and clinkers taken out of the ashpan and fire-box and smoke-box amounted to 17.6 per cent. in trial A and 22.9 per cent. in trial B. These figures however did not represent exactly the facts, because, as stated in page 469, the ashes from the ashpan were weighed only at the end of each double journey: so that on the whole it might be said that the ash made was about 20 per cent. in each trial, or about one-fifth of the entire weight of coal was taken out in ashes. If this were deducted, it would be found that there was an evaporation of 14.1 lbs. of water per pound of coal, which according to page 468 would be equivalent altogether to only 600 thermal units less than the total value of the coal, thus leaving only 600 units for the losses by imperfect combustion, radiation, and coal blown out of the chimney: which last he was sure was no inconsiderable quantity, for he had watched the chimney carefully himself, being in front of the engine all the time. It seemed therefore doubtful whether the reported water consumption of 26.7 lbs. per I.H.P. per hour in trial A was at all reliable; he was inclined to think it was over-estimated, and that the consumption was probably much the same in all the trials. With regard to the boiler moreover, it was difficult to rely upon the results exactly, because the quantity of coal in the fire-box at the beginning and at the end of the trial might easily have differed by an appreciable quantity without its being perceived. In a locomotive fire-box it was difficult, he thought, to estimate the thickness of the fire to within six inches; and if that were the case, the fire-box of the engine tried would hold some 270 lbs. of incandescent fuel in a thickness of six inches, which was about 12 per cent. of the total consumption of coal in each trial. But whether the results were reliable or not, their general tendency was to show a rate of evaporation far higher than was generally obtained in stationary boilers. On working out the figures he had found that the heat put

(Mr. Michael Longridge.)

into the water per pound of coal was 10,400 units. The heat equivalent of the unburnt carbon in the ashes he estimated at 1,400 units; for he was sure from what he knew of the coal used that it did not contain more than 7 per cent. of ash, and he had accordingly taken as unburnt carbon the difference between this 7 per cent. and the 17 per cent. mentioned in the paper. The imperfect combustion shown by the production of carbonic oxide, which he presumed was taking place while the engine was running without steam and with a thick fire, would cause a loss of about 400 units; and the mean quantity of heat taken up the chimney—assuming the temperature to be 800° F., which he thought it probably was, since it burst the thermometer, notwithstanding Mr. Aspinall's statement (page 485) of only 470°—would account for 2,500 units more. Altogether therefore 14,700 units would seem to have been got out of coal containing only 14,200. All this seemed to him to point indubitably to one fact, namely a considerable amount of priming. The lesson therefore which the trials taught was that, instead of putting steam-jackets on locomotive cylinders, a superheater ought to be put in the smoke-box. If this were done, and the priming water were turned into steam, he thought there would be a considerable economy, with little more weight to be carried than by steam-jacketing the cylinders.

Mr. ASPINALL explained that the 470° F., which he had mentioned having obtained in the jackets from the hot smoke-box gases, had no relation to these particular experiments; it was only the result of some temperature measurements in another instance. No doubt Mr. Longridge's estimate of 800° was much nearer the mark for the temperature of the smoke-box in the experiments reported.

Mr. JOHNSON quite agreed with Mr. Longridge that it would be well if a locomotive could be tried with steam superheated. That there was some economy in steam-jacketed cylinders he did not in any way deny; but in a locomotive he was satisfied that it must be only a small percentage. A great deal of the difference in water

consumption recorded in the tables arose he thought from saturated steam or from priming. The amounts of water per pound of coal burnt were in his opinion rather excessive ; and superheating would tend greatly to do away with that source of loss.

Mr. DRUITT HALPIN considered the locomotive evaporation, commented upon by Mr. Longridge as so high, involved the question not only of the economy but also of the rate of evaporation. In a paper by his father, the late Mr. J. A. Longridge, eighteen years ago (*Proceedings Inst. C.E.*, 1878, vol. lii, page 101), it had been shown conclusively that locomotive evaporations, both as to economy and as to speed of evaporation, were unsurpassed in any other boilers ; the heat transmission was about 11 units per hour per square foot of heating surface per degree of difference in temperature, whereas in ordinary stationary boilers it was only about 5 or 6 units. It had always seemed to him that this was to be accounted for to a great extent by the fact that a locomotive boiler was in a condition which no other boiler was in, except perhaps that of a torpedo boat. The chatter that went on was exceedingly favourable to rapidity of heat transmission, from the fact that each nascent bubble of steam, no matter how small, was jarred off immediately it was formed ; and the economy of evaporation was probably produced by the fact that from the same cause the fire was kept in such a lively state that each particle of carbon got its own proper particle of oxygen direct.

In these trials it would be noticed that there were water-traps as well as tanks on the platform on the front of the engine ; but he did not know whether it could be hoped that water-traps placed above the level of the steam-jackets and exposed to such jolting would give any reliable results ; of course if they had the effect of water-jacketing the cylinders, the difference from steam-jacketing would be great. The conflicting results reported were practically worthless in respect of economy, as he thought might be expected, because in order to derive any good from steam-jackets there must be a combination of two factors : namely difference of temperature between the cylinder and the jacket during the stroke, and time. There must be a difference of temperature, and necessarily therefore a difference

(Mr. Druitt Halpin.)

of pressure between the cylinder and the jacket during part at least of the stroke; and to some extent this condition seemed to have been realised in the experiments; the indicator diagrams might be right or wrong in other respects, but they showed at any rate a difference of pressure, and therefore a difference of temperature, for a good part of the stroke. But the other important factor—time—had been wanting; the pistons were running at 800 to 900 feet per minute, and at those high speeds it did not matter what the expansion and the consequent difference of temperature might be; there was not time for the transference of heat from the jacket to the cylinder to take place. From all the experiments made it appeared to him that the indicator diagrams were not of much use.

The consumption of $26\frac{3}{4}$ lbs. of steam per I.H.P. per hour he thought was too good a performance under the circumstances, and that it must point to a great deal of priming. In the complete and careful locomotive experiments made by Bauschinger for the Bavarian government thirty years ago, working up hill and down dale, with heavy load and light load, and with goods and passenger trains, the average consumption of steam per I.H.P. per hour came to 27 lbs. In the present experiments the engine had been working under favourable conditions, with a good load and over a good road, and had been carefully looked after in all respects; but of course if the indicator diagrams were wrong, the whole of the conclusions were wrong. That the diagrams were wrong he was quite prepared to believe, from what had been said by Mr. Aspinall (page 484), and from what he had himself seen and known to be the consequence of using small and long pipes to the indicators. On a former occasion (Proceedings 1886, page 364) he had shown some diagrams which proved that, when the indicator was placed direct upon the cylinder, the change had resulted in an increase of no less than 38 per cent. in the area of the indicator diagram obtained. No doubt the same result would have followed in the diagrams now exhibited, if the same change had been made in the way of using the indicators.

Mr. WILLIAM SCHÖNHEYDER thought it could hardly have been expected, even before the experiments were made, that any great

economy would result from using steam-jackets on locomotive cylinders, because the jacketed surface was far too small for heating the large quantity of steam which passed through the cylinders in so short a time. The measurement of the feed-water he observed had been attempted by means of a water-meter of the inferential kind, which he thought was hardly good enough for such purposes; for many uses it was an excellent meter and sufficiently accurate, but he thought not so for boiler experiments. The tests which had been made of it afterwards were mentioned in page 470 as having given varying results, with a mean error of 2.6 per cent. too low; it would be interesting to know what was the maximum error. Moreover in arranging a water-meter for accurately measuring boiler evaporation, he considered it should never be placed on the suction side of the feed-pump or injector, as had been done in these trials, though it appeared there was a pressure upon the suction side from the tank; but according to the speed of water through the pipe leading from the tender tank to the meter, and the size of the pipe, it was quite possible that, if any leak existed in the pipe or the joints, more or less air might be drawn in, and in that way the registration of the meter might be vitiated. In these experiments it was possible the pipe joints might have been made sound, and might have kept sound; but that was always an untrustworthy way of using a meter. It should always be placed on the pressure or delivery side of the injector or feed-pump: though of course there might not be much room in the locomotive for placing it in that position.

Mr. HENRY M. ROUNTHWAITE noticed the absence of any record of the temperature of the external air, or (except in Table 6) of the force or direction of the wind, or whether there was rain falling, or how the weather was in other respects at the time of the trials; these were points which he thought had an important bearing upon the result in the trial of a locomotive. Then again the cylinder with the liner in it, when working without any steam in the space between the liner and the cylinder, was not in the same condition as an ordinary unjacketed cylinder. Including the liner there was thicker metal, not quite twice as thick; and there was the

(Mr. Henry M. Rounthwaite.)

air-jacket between. Even if the air were taken to be of no value as a non-conductor, there were two extra surfaces of metal; and in the passage of heat through metals by radiation the great resistance was at the surfaces, in passing from metal to air and again from air to metal. The experiments he therefore thought could not be expected to show the same difference between jacketing and non-jacketing as if in the latter case an ordinary cylinder had been tried without the liner. The arrangement actually tried showed a gain of say 6 or 8 per cent. by jacketing; but, had the liner been absent on the non-jacketed trial, he felt certain this gain would have been nearly double; in that case the comparison would have been between a partly steam-jacketed cylinder and an entirely unjacketed cylinder.

Mr. C. FREWEN JENKIN called attention to the feed-water consumption per pound of coal (Table 2, line 25), which varied from 9.31 lbs. to 7.96 lbs., or a variation of 14 per cent., of which no explanation appeared to be offered in the paper. It had been pointed out by Mr. Longridge (page 487) that 12 per cent. might be accounted for by a difference of six inches in estimating the thickness of fuel in the fire-box.

Mr. W. WORBY BEAUMONT asked why the results of the trials were disparaged in page 466 on account of the coal consumption not having been ascertained so accurately as the steam consumption. If the statement in page 466 was correct, that the consumption of steam was obtained with a close approach to absolute accuracy, surely this was the most important point of all in making such experiments. The coal consumption, if it also could have been satisfactorily ascertained, would of course have formed a check upon the results; but surely the steam consumption, if correctly known, ought to be sufficient. With regard to Mr. Aspinall's remark (page 484) as to the errors of indicators, he asked whether it might be supposed that the indicators persisted in the same errors throughout the whole of their indications in these experiments; because it would appear to him that, if they did so, the comparative results would be the same: in other words, if the diagrams were all to the same extent smaller than

they ought to be, then the difference between the behaviour of the steam in the cylinders, when the jackets were in use and when they were not, could be just as well ascertained from the indicator diagrams actually obtained as if these had all been as much larger as they ought to have been. This argument of course depended entirely upon whether the same true or false tale was told by the indicators right through the experiments. Doubt had been thrown upon the steam consumption of 26·7 lbs. per I.H.P. per hour; and it would appear that such a doubt would be even greater, if the indicator diagrams were increased in size, as they would be expected to be if connecting pipes of such length as were seen in the drawing were done away with. If the indicator diagrams ought properly to be so much larger, the steam consumption would be reduced to something considerably below the 26·7 lbs. per I.H.P. per hour, affording thereby another illustration of the great economy with which locomotives worked, in contrast with the statements often put forward to prove how much more economical it would be to work locomotives by electricity than by steam. If under its actual conditions of working the engine tried in these experiments would run with a steam consumption of something less than 26·7 lbs. per I.H.P. per hour, it was obvious that electric locomotives would have a great deal to beat. The apparent smallness of the gain due to the jacketing of the cylinders, and also the variation in that small gain, were doubtless explained by the consideration advanced by Mr. Halpin (page 490), namely the high piston-speed. It appeared to himself impossible to expect any gain whatever from the use of a steam-jacket, especially of a jacket having such a thin steam-space, with a piston-speed so high as that in locomotive engines and with the conditions of running so varying. The conditions that obtained in any of the engines which did gain something by jacketing were here entirely absent.

Mr. E. C. DE SEGUNDO remarked that, although unfortunately the results of the trials were so indecisive, experience showed how difficult it was to obtain accurate results in experiments of so arduous a nature as these. Even if the trials appeared to some a

(Mr. E. C. de Segundo.)

failure, it would be remembered that the greatest results had often sprung from apparent failures. Having had occasion some time ago to look through the results of a somewhat similar trial, he fully concurred with Mr. Longridge how difficult it was to take accurate indicator diagrams off a locomotive engine. Unless the indicators were placed close to each end of the cylinder, as had been done by Mr. Aspinall (page 484), the diagrams taken could not help being inaccurate. In the diagrams which he had had occasion to examine, taken by the same indicator from both ends of the cylinder, it had been found that those from the back end were three-eighths of an inch longer than those from the front end. The pipe leading to the indicator from the front end was comparatively straight, while that from the back end was brought round a bend to the indicator; and it was discovered that, when the pressure came on the back pipe, the pipe straightened itself on the principle of the Bourdon pressure-gauge, and consequently lengthened the stroke of the indicator, and thereby vitiated the diagram.

Professor T. HUDSON BEARE had endeavoured to a certain extent to disarm criticism by the statement at the outset of the paper (page 466) that the results were not such as would enable any definite conclusions to be drawn respecting the value of the steam-jacket in locomotives. The great difficulty of carrying out experiments of this kind with an express locomotive had been remarked on by Mr. Aspinall (page 483). It was hard enough to carry out accurate scientific observations on a locomotive going at a low speed; but harder still on an express locomotive travelling at a speed of occasionally sixty miles an hour over a line with large numbers of points and crossings, when the observers had to cling on pretty firmly, in order to avoid being jerked off the foot-plate or the buffer plank. Moreover the apparatus available for these experiments was not everything that could be desired, as had been pointed out in the paper. Although measurement of the feed-water by meter was considered by Mr. Aspinall (page 484) to be on the whole more satisfactory than would have been measurement of the depth of water in the tender, he himself differed

entirely from that opinion. All meters had errors; and the worst of a meter was that it could never be known whether the error was the same today as yesterday, and whether it would be the same tomorrow. The meter might be taken off and tested carefully after the trial was over, as had been done in this instance; but there was no certainty that the error so determined was the error which the meter had during the time of the trial. The measurement of the depth of water in the tender he believed was much more reliable than measurement by meter, and it was much more simple. Naturally it could not be expected that the depth in the tender could be measured accurately while the engine was running; but there were certain stoppages in the runs between Manchester and York, which afforded sufficient opportunity for measuring carefully the level of the water in the tender, and so determining the consumption of water during known periods.

In the testing of the meter, the error found was not constant (page 491), but varied between 4 and 1.3 per cent.; the maximum was therefore not much greater than the mean of 2.6 per cent. given in the paper, which was the average of a number of tests.

On the question of the condition of the fires at the beginning and end of each trial, the point intended to be emphasized in the paper was that the real coal consumption could not be known accurately if there were much difference between the amount of incandescent coal on the fire at the end of a run and at the beginning. As pointed out by Mr. Longridge (page 487), it was practically impossible by mere inspection to see how much incandescent fuel there was upon the fire-bars of a locomotive. On a journey of less than two hours, where the total consumption of coal was not more than about one ton, an error in estimating the allowance to be made for such variation in the fuel on the fire-bars would make a serious difference in the result. If there was a thick fire at the end and only a thin fire at the start, or conversely, the proportionate error would be great. It was on this account that he thought it would have been more satisfactory in such a trial if the fire could have been worked down to the same thickness at the end as it had at the beginning. Although it had not been

(Professor T. Hudson Beare.)

practicable in this instance, that was what should be aimed at in boiler trials, so as to eliminate error arising from estimating the condition of the fire.

With regard to a counter, he was still disposed to reiterate what had been said in the paper, that a counter would have been much more satisfactory than any speed recorder. Counters gave positive direct results; but any recorder had errors, which had to be allowed for and corrected. It was objectionable he considered in any experiments to have observations which had afterwards to be corrected for errors of instruments. Some degree of error attached of course to every instrument; but if an instrument could be used with an error which might be neglected, so much the better.

Possibly the difficulty of estimating the condition of the fire at the beginning and end of a run, and therefore of determining accurately the coal measurement, affected considerably the evaporation per pound of coal as given in the tables; and therefore, although the latter appeared so high, it might not be due mainly to priming, as had been suggested by Mr. Longridge (page 488), though there might perhaps be some priming; but it might be due in part to the above causes. There had been a great deal of trouble with the indicators, owing, as had been pointed out by Mr. Aspinall (page 484), to the water in the pipes; of this it had been endeavoured to get rid as much as possible by blowing through just before taking each diagram. The consequent errors in the indicators he imagined had not been large, and had probably been about the same in each trial, so that it was considered comparative figures would not be vitiated thereby; for this reason no attempt had been made to calibrate their errors. The trials, after all, were comparative; and any errors in the indicators would hardly be likely to vary much during the two 'days' consecutive trials.

With regard to the high evaporation of locomotive boilers, he thought Mr. Halpin's remarks (page 489) undoubtedly furnished a good explanation: namely that a locomotive boiler was in a continual state of vibration, which must greatly facilitate the liberation of the globules of steam as fast as they were formed, and their escape to the surface of the water, thereby greatly helping

the transmission of heat through the tubes and the plates. Every one who had experimented on heat transmission through plates knew that, if the steam globules were got rid of as fast as they were formed, the heat went through with great rapidity indeed.

The only explanation he could offer of the variation in the feed-water evaporation per pound of coal (page 492) was that given in page 466, namely the difficulty of determining the quantity of fuel on the fire at the beginning and at the end of each experiment. None of the observations of the consumption of water were incorrect beyond the extent of the meter error; and undoubtedly, after correction for that error, the quantities of water recorded in Table 2 did really go into the boiler. Whether all came out as steam, or whether it came out partly as steam and partly as priming water, there were no means of saying; but in the total consumption he believed there was no error. With regard to the fuel, while he was certain that the actual quantity which was put upon the fires was weighed and recorded carefully, the admitted error arose from the doubt about the condition of the fire at the beginning and at the end. If these several points were taken into account, he thought it would still be found that these results were of some use, even though they did not throw any definite light upon the important question whether the steam-jacket was or was not of advantage in a locomotive engine.

The information asked for about the weather at the time of the trials (page 491) had now been inserted in lines 5-7 of Table 3. It might be of interest to add that the amount of coal burnt in lighting up in the running shed at Horwich was 400 lbs. on 18th September, and 600 lbs. was used in getting up steam to 160 lbs. pressure and coming to Manchester; and 289 lbs. was burnt while standing in the station yard at York. On 19th September 800 lbs. was used in getting up steam and coming to Manchester from the running shed; the amount burnt while standing in the yard at York was not noted.

Mr. BRYAN DONKIN, Member of Council, recalled that the whole of the special arrangements connected with the locomotive, and also

(Mr. Bryan Donkin.)

the whole of the experimental appliances, had been provided by the kindness of Mr. Aspinall ; and all that the observers had to do was to take the utmost possible advantage of them for making the trials. Their thanks therefore ought to be particularly accorded to Mr. Aspinall for the kind way in which he had put this express locomotive at their disposal, and fitted it so extensively with testing apparatus. If he ever adopted a compound locomotive, he hoped he would give them an opportunity of making another trial. Here it had been a single-cylinder engine ; but in a compound engine, having an efficient steam-jacket on the low-pressure cylinder and covers, a much greater head of heat would be obtained, and the advantages of steam-jacketing he considered would tell much more in the low-pressure cylinder than in the high, as had been proved by many experiments on stationary engines. As shown in Table 1, the proportion of internal surface exposed to the steam-jackets in the clearance space was here only a little more than one quarter of the total internal clearance surface ; and at 90 per cent. of the stroke the internal jacketed surface was only a little more than half of the total internal clearance and cylinder surface. This was in his opinion the key to the whole question. Some interesting experiments, bearing upon steam-jackets for locomotives, had lately been made in France on the Paris and Orleans Railway. There were two locomotives, exactly similar in every other respect including boilers, and twenty-four experiments were made with each : one engine had four Corliss valves to each cylinder, and in the other there were the usual slide-valves. There was a gain of about 12 per cent. economy in water consumption in favour of the locomotive with Corliss valves. This he considered was partly due to the ends of the cylinders being practically jacketed with live steam on the boiler side of the Corliss valves ; and partly to diminished initial condensation, because with four Corliss valves to each cylinder the steam had not to go through the same ports : the live steam entered through two ports, and the exhaust steam passed out through two other ports ; and thereby the condensation in the cylinder and passages was considerably reduced. Actually there were not any steam-jackets ; but the mere fact of the two Corliss valves being put

on the top at each end was equivalent to jacketing the cylinder ends, which were the most important surfaces.

That there must have been priming, he agreed with Professor Beare and Mr. Longridge; but to what extent it was difficult to say. In some experiments made on the Great Eastern Railway nine years ago by Professor Kennedy and himself* they had been troubled in the same way with priming, and the heat account had overbalanced.

The large amount of evaporation by a locomotive boiler had been confirmed by those Great Eastern Railway experiments, in which the water had been actually measured in the tender. Though the locomotive boiler was so excellent an evaporator, it primed; and it primed in the shops just as badly as on the road, because it had been found that the evaporation was about the same in the locomotive on the Great Eastern Railway, both in the shop and on the road, causing the heat account to overbalance in each instance. As in many stationary boilers, the priming was not got rid of, even when the locomotive was standing still.

To measure the water in the tender he agreed with Professor Beare would have been the best plan, and to trust to no meter, however accurate it might be. It would have been easy with a float to read off the depth of water when the locomotive was standing on the level; the tender might either be filled by gauge cans, or might be weighed. It had actually been weighed at the beginning and at the end of each run in the Great Eastern Railway tests.

Jacketing locomotive cylinders by drawing the hot smoke-box gases round them, as had been tried by Mr. Aspinall (page 485), had been tested also in Italy, he believed with considerable success. Some experiments had been published by Mr. Kossuth, who seemed to have proved that there was some economy.

The indicator pipes had been well covered, and it seemed to him that if there were any errors in the indicator diagrams, arising from water in the pipes, they would be the same throughout the trials, and would not affect the comparison of jacketing and non-jacketing. The high piston-speed was a much more important point.

* See "Engineering," 21 October 1892, pages 501-4.

The PRESIDENT thought it must be a gratification to the authors that the paper had elicited such a discussion, because it showed how interesting it had been, and how valuable in one way or another were the results. Not that much economy had as yet been shown, because the experiments had been conducted under unfavourable conditions, upon a run much too short to prove the value of the steam-jacket. No doubt what a locomotive superintendent looked to was the saving of coal. On the Midland Railway Mr. Johnson had a long run of about 200 miles, he believed, with few stoppages; and if he would fit up a locomotive either with steam-jacketed cylinders or with a superheater, he was sure that, as the present paper had been received by the members with so much satisfaction, the same observers would be induced again to venture to carry out some further experiments. With the experience they had already obtained, they would probably be able to bring results before the Institution which would be highly valuable and interesting. The present experiments had been conducted under most difficult conditions; and he had great pleasure in proposing a hearty vote of thanks to Professor Beare and Mr. Donkin for their interesting communication, and to Mr. Longridge for his co-operation in the trials; and also to Mr. Aspinall, by whom they were originally suggested, for his kindness in fitting up the locomotive and making all the necessary arrangements for carrying out the experiments.

VALUE OF STEAM-JACKET.

Plate 107.

Express Passenger Locomotive, L. and Y. Railway.

Fig. 1.
Sectional Plan.

Fig. 2.
Elevation.

Scale 1/64th

Plate 107.

VALUE OF STEAM-JACKET.

Plate 108.

*Express Passenger Locomotive,
Lancashire and Yorkshire Railway.*

Fig. 3.
*Front view
of Steam Traps.*

Scale $\frac{1}{32}$ nd

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

Fig. 4.
Front view of Water Meters.

Mechanical Engineers 1896.

Plate 108.

VALUE OF STEAM-JACKET.

Thermometer

Fig. 5.

Longitudinal Section.

Express Passenger Locomotive,
Lancashire and Yorkshire Railway.

Jacket Pressure Gauges

Front Body Back

Steam
Trap

T

Scale $\frac{1}{24}^{th}$

Inches 12 6 0 1 2 3 4 Feet 5

Mechanical
Engineers 1896.

Express Passenger Locomotive, L. and Y. Railway.

Fig 6.

Transverse Section.

Cylinders.

Fig. 7. *Sectional Plan.*

Fig. 8. *Transverse Section.*

VALUE OF STEAM-JACKET. *Plate 113.*

Express Passenger Locomotive Engine, L. and Y. Ry.

Indicator Diagrams nearest mean.

VALUE OF STEAM-JACKET.

Plate II4.

Express Passenger Locomotive Engine, L. and Y. Ry.

Indicator Diagrams nearest mean.

Boiler Pressure 166 lbs.

Fig. 13. Trial B WITH steam in Jackets.
Right cylinder, set 10.

Boiler Pressure 162 lbs.

Fig. 14. Trial C WITH steam in Jackets.
Right cylinder, set 6.

Plate 115.

The image contains two line graphs showing the performance of a steam locomotive during various trials between Manchester and York. The vertical axis for both graphs represents speed in miles per hour, ranging from 0 to 80. The horizontal axis represents distance, with vertical lines marking key stations: Manchester, Signal, Bridge, Wakefield, and York. Other stations like Signal, Church, and Castleford are also marked on the top graph.

Top Graph: This graph displays four trials: A, B, C, and D. Trials A and D are represented by dotted lines, while Trials B and C are represented by solid lines. Trial A shows a speed of approximately 40 mph for most of the journey, with a slight increase to 50 mph near Wakefield. Trial B shows a speed of approximately 40 mph, with a slight increase to 50 mph near Wakefield. Trial C shows a speed of approximately 40 mph, with a slight increase to 50 mph near Wakefield. Trial D shows a speed of approximately 40 mph, with a slight increase to 50 mph near Wakefield. The graph also includes a legend: "Trials B and C WITH steam in jackets, full lines" and "Trials A and D WITHOUT steam in jackets, dotted lines".

Bottom Graph: This graph displays two trials: B and C. Trial B is represented by a solid line, and Trial C is represented by a dotted line. Both trials show a speed of approximately 40 mph for most of the journey, with a slight increase to 50 mph near Wakefield. The graph also includes a legend: "Trials B and C WITH steam in jackets, full lines" and "Trials A and D WITHOUT steam in jackets, dotted lines".

Fig. 16. Profile of Line between Manchester and York.

Station	Gradient
Manchester (Victoria)	1 in 150
Newton Heath	1 in 161
Castleton	Level
Rochdale	1 in 330
Smithy Bridge	Level
Littleborough	1 in 330
Todmorden	1 in 160
Walsden	1 in 183
Hebden Bridge	1 in 330
Mytholmroyd	1 in 317
Sowerby Bridge	1 in 258
Ilkden Road	1 in 440
Brighouse	1 in 440
Cooper Bridge	1 in 440
Metfield	Level
Thornhill	Level
Horbury	Level
Wakefield	Level
Normanton	1 in 350
Altofts	1 in 484
Castleford	1 in 553
Burton Salmon	1 in 637
Melford Junction	1 in 637
Shearburn	1 in 637
Church Fenton	1 in 637
Ullselt	1 in 637
Bottom Percy	1 in 637
Copmanthorpe	1 in 637
York	1 in 637