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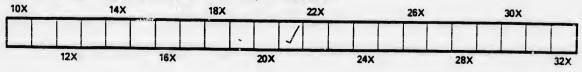


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RESULTS OF EXPERIMENTS WITH A FIFTY HORSE-POWER SINGLE NON-CONDENSING BALL AND WOOD ENGINE TO DETERMINE THE INFLUENCE OF COMPRESSION ON THE WATER CONSUMPTION.

BY D. S. JACOBUS, HOBOKEN, N. J. (Member of the Society.)

In a paper presented to this Society at the recent Chicago meeting by Mr. F. H. Ball,[†] a theory was advanced in regard to the probable effect of compression on the economy of the steam engine, and a law was suggested for determining the most economical compression curve. Since that meeting, an opportunity has been afforded, at the Stevens Institute of Technology, for investigating this subject by experiment, and the following pages are a record of the facts thus obtained.

The engine used for this purpose, which will be more fully described further on, was provided with two valves for alternate use, one of them being a special valve arranged for obtaining full compression to initial pressure, as shown in Fig. 1. Owing to the rather large clearance of this engine, it was found impracticable to obtain the compression curve sought, if any later cutoff was used than the one shown, giving only about 20 lbs. M.E.P., and thus limiting the M.E.P. of Fig. 3 to about 30 lbs., which is considerably below the rated capacity of the engine at which it is supposed to give its highest economy. It was also found necessary to reduce the pressure to about 71 lbs. to obtain the desired compression, and the temporary foundation made it

^{*} Presented at the Montreal meeting (June, 1894) of the American Society of Mechanical Engineers, and forming part of Volume XV. of the *Transactions*.

⁺ Transactions American Society of Mechanical Engineers, Volume XIV., p. 1067, No. 545.

necessary to run the engine about 50 revolutions per minute below its normal speed; so that, because of this reduced speed, the low boiler pressure, and the small load, the consumption of steam per indicated horse-power per hour was considerably above what might have been expected from an engine of this class under more favorable conditions. These unfavorable conditions, however, did not present any obstacles to the investigation that was sought regarding the relative economy of varying amounts of compression.

The experiments prove that for either equal amounts of work produced, or for equal points of cut off, the cushion steam in an engine should not be compressed as high as the initial pressure but to some lower pressure in order to obtain the best economy, thus verifying conclusions arrived at by theory in the paper referred to.

The results obtained are as follows :

With a special valve in the engine, so arranged as to compress the cushion steam to the initial pressure, and cut-off a^t onequarter stroke, the steam consumption was 37.9 lbs. per hour per horse-power.

For the same work as with the special valve, and compression to two-thirds the initial pressure, the steam consumption was 36.8 lbs. per hour horse-power.

For the same cut-off as the special valve, and compression to about five-eights the initial pressure, the steam consumption was 31.8 lbs. per hour per horse-power.

The cylinder dimensions were: bore, 10 inches; stroke, 11 inches. The stear pressure averaged about 72 lbs. above the atmosphere, and the revolutions 250 per minute.

The average indicator cards for the three sets of conditions are given in Figs. 1, 2, and 3.

The special valve released the steam at a later point in the stroke than the regular valve, so that small corrections have been made in the above figures to eliminate variations from this cause, by extending the expansion line in each case to the end of the card, as represented in Figs. 1, 2, and 3. A Barrus calorimeter was employed to determine the amount of moisture present in the steam, and the moisture was deducted to obtain the steam used. In making the tests, the work developed by the engine was absorbed by means of a Prony brake. The exhaust steam was condensed in a surface condenser, and

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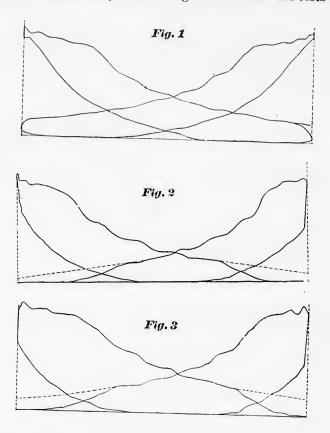
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weighed. Indicator cards were taken every five minutes, the indicator being cleaned and oiled between each three cards. Readings of the revolutions, temperatures, pressure, etc., were also made every five minutes. The water was collected in barrels, and weighed each fifteen or twenty minutes. The weighings agreed very well among themselves. All tests were



an hour or longer in duration. In order to make certain that the tests were long enough to insure the proper accuracy, the steam per hour per horse-power was calculated for the first half of five of the runs, and the maximum discrepancy between the results for the first half of the runs and the entire runs was found to be one-tenth of a pound of steam per hour per horsepower, or about one-fourth of one per cent. this is less than the

possible error, and thus proves that the tests were of ample length.

The results of the separate tests are given in Tables I. and II. The tests made under similar conditions are seen to agree very well among themselves, the greatest discrepancy being one per cent.

TABLE I.

FINAL RESULTS OF TESTS, CORRECTED FOR DIFFERENCES IN POINTS OF RELEASE BY EXTENDING THE EXPANSION LINES TO THE ENDS OF INDICATOR CARDS, AS IS INDICATED IN FIGURES 1, 2, AND 3.

Average Duration Steam mean Indicated No. of Test. of test effective per honr horsepressure in lbs. per sq. inch. CONDITIONS. per horsepower. minutes. power. $20.81 \\ 20.90 \\ 20.90 \\ 20.90$ Special valve so arranged as to compress the cushion steam to the initial pressure. 60 $22.76 \\ 22.80 \\ 22.79 \\$ 37.8 38.1 37.9 5 6 100 120 Average..... 20.87 22.78 37.9 Ordinary vaive. Nearly the same mean ef-fective pressure as for the special vaive. Cushion steam compressed to about two-thirds the initial pressure. 80 60 $20.37 \\ 20 \ 20 \\ 20.02 \\ 20.02$ $22.65 \\ 22.00 \\ 21.62$ 36.8 36.8 27-8 60 36,6 Average..... 20.20 22.09 36.8 Ordinary valve. Same point of cut-off as for the special' valve. Cushlon steam compressed to five-eighths the initial $\frac{1}{3}$ 105 75 $28.14 \\ 27.30$ $30.29 \\ 30.46$ $35.0 \\ 84.7$ pressure. Average 27.72 30.33 34.8

Steam pressure at engine = 72 ibs. above atmosphere. Revolutions per minute, about 250.

For results in detail see Tables III., IV., and V.

TABLE II.

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FUNAL RESULTS NOT CORRECTED FOR DIFFERENCES IN THE POINTS OF RELEASE SO THAT THE STEAM USED PER HOUR PER HORSE-POWER GIVEN IN THIS TABLE IS THAT ACTUALLY CONSUMED BY THE ENGINE.

Conditions.	No. of Test.	Duration of test in mins.	Average mean effec- tive pres- sure in ibs., per square iuch.	Indicated horse- power.	eam per hour per horse- power.
Special valve so arranged as to compress the cushion steam to the initial pressure.	4 5 5a 6 6a	60 100 40 120 60	20 69 20.78 20.89 20.78 20.78 20.72	22.63 22.68 22.78 22.71 22.62	38.1 38.8 38.2 38.1 38.2
Average, not including partlai runs mar	ked <i>a</i>		20.75	22.67	38.2
Ordinary valve. Nearly the same mean ef- fective pressure as for the special valve when allowance is made for differences in the points of release. Cushion steam compressed to about two-thirds the initial pressure.	2 2a 7 8	80 40 60 60	18.66 18.71 18.48 18.31	20.75 20.89 20.13 19.77	40.2 40.2 40.2 40.2 40.0
Average, not including partial runs mark	18.48	20.22	40.1		
Ordinary valve. Same point of cut-off as for the special valve. Cushion steam compressed to five-cighths the initial pressure.	1 1a 8 3a	105 60 75 45	25.\$9 25.99 25.23 25.08	27.98 28.01 28.15 27.99	37.9 87.9 87.5 37.6
Average, not including partial runs mark	ed a		25.61	28.06	87.7

The averages marked a are for the first portions of the corresponding tests. These averages are used in calculating the performances for the first portions of the runs, which are shown not to vary over one-fourth of one per cent. from the results deduced for the entire runs. This indicates that the runs were of sufficient length. For comparative figures see Table V.

The Barrus calorimeter was attached in the main steam pipe about three feet from the steam chest. The waste steam was carried off a short distance through a three-quarter-inch pipe, which produced a slight back-pressure, so that the lower thermometer read 213° when the exit steam was saturated. The various percents of priming are given along with the average data for the tests in Table III.

Table IV. gives the average heights of the indicator cards, and Table V. the mean effective pressures and calculations of horsepower. Table VI. gives the data observed, and Table VII. the measurements of the indicator cards for one of the tests.

The indicator spring was tested over the entire range of the indicator cards, and all variations in the scale were corrected for

by employing the scale corresponding to each ordinate of the forward and back pressure lines, as explained at the last meeting of this Society in a paper on the Comparison of Indicators. Cards for each set of conditions were taken, and it was found that the differences in the equivalent scales corrected for all variation between the cards under the several sets of conditions, and between the largest and smallest cards of a set, were within the limits of practical errors. The average of the scales, or 58.2 lbs. per inch, was, therefore, used in computing the horse-power-The calculation of the equivalent scales for one of the cards is given in Table VIII.

TABLE III.

AVERAGE DATA OF TESTS AND WEIGHT OF STEAM LESS ENTRAINED WATER.

NUMBER OF TEST.	Datë,	Conditions,	Duration of test in mins.	Total number of revolutions by counter.	Average pressure of steam at engine in pcunds per square inch above atmos- phere.	Total weight of steam and entrained water in pounds.	Average temperature of exit steam at calorimeter.	Percentage of moisture in steam.	Steam per hour less en- trained moisture.
1	March 10	Equal cut-off	105	26,188	70.8	1,8811	253 253	1.4	1,060.2
1a	·· 10 ·· 12	Equal M.E.P.	60 80	14,978 20,608	70.8 72.1	1.076	200	9.4	1,060.9
2a	" 12	in main	40	10,342	72.1	5761	224	2.9	838.8
3	" 15	Equal cut-off	75	19,377	71.2	1,3221	276	0,1	1,056.7
3a	** 15		45	11,629	71.0	7931	271	0,4	1,053.8
4	" 1ð	Special valve	60	15,205	71.8 71.7	870	259	1.0	861.3
5 5a	April 3		100	25,280 15,148	71.7	1,4754	244	1.8	869.4
5a	3		60	15,148	71.8 72.2	5881	242	2.0	870.5
6 1	. 4		120	30,383	72.2	1,7411	268	0.6	865.5
	" 4	Equal M.E.P.	60 60	15,175 15,186	71.7 72,1	868) 824)	268 248	$ \begin{array}{c} 0.6 \\ 1.7 \end{array} $	363.0 810.2
6a 7 8	4								

A small variation in the amount of work done will cause a greater discrepancy in the results than the difference between the economy at full and for partial compression; so that unless the greatest care be exercised in performing the experiments, the comparative results may be misleading. ; e...

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TABLE IV.

INDICATOR CARD MEASUREMENTS.

MEAN			DR CARDS	MEAN EFFECTIVE PRESSURES IN LBA. PER SQUARE INCH. SCALE = 58.2.					
Ifead	d Eud.	Cran	k End.	Ifea	d End.	Crank End.			
Actual.	Corrected for release.	Actual.	Corrected for release,	Actual.	Corrected for r ase.	Actual.	Corrected for release.		
0.468	0.505	0,425	0,462	27.24 27.24	29,89	91.74 24.74	26.89		
0,340 0,466	0.501	$0.303 \\ 0.401$	0.437	$ \begin{array}{r} 19.79 \\ 27.12 \end{array} $	29,16	$17.63 \\ 23.34$	19,26 25,43		
$ \begin{array}{c} 0.370 \\ 0.369 \end{array} $	0.313 0.372	$0.341 \\ 0.345$	$\begin{array}{c} 0.842 \\ 0.346 \end{array}$	$21.53 \\ 21.48$	21.71 21.65	$19.85 \\ 20.08$	19,90 20,14		
0.368 0.367 0.332	0.871	$0.346 \\ 0.345 \\ 0.303$	0.347	21.42 21.36 19.52	21,59 91,67	$ \begin{array}{r} 20.14 \\ 20.08 \\ 17.63 \end{array} $	20.20 19.32 19.15		
	Пеал Асtual. 0,468 0,468 0,468 0,464 0,464 0,369 0,871 0,368 0,369	IN IN Head End. Actual. Corrected for release. 0,468 0.505 0,468 0.505 0,468 0.505 0,468 0.505 0,468 0.501 0,464 0,309 0.372 0,371 0,367 0.371 0,332 0.307	IN INCRES. Head Eud. Cran Actual. for release. Actual. 0,468 0.505 0.425 0,368 0,425 0,340 0,303 0,464 0.505 0.425 0,340 0,303 0,464 0.309 0.302 0,340 0.332 0.341 0,369 0.372 0.345 0,309 0.372 0.345 0.309 0.372 0.345 0.307 0.336 0.337 0.335 0.347	Head End. Crank End. Actual. for release. Corrected for release. Corrected for release. 0.468 0.505 0.425 0.462 0.389 0.369 0.303 0.331 0.464 0.425 0.389 0.369 0.303 0.464 0.398 0.370 0.837 0.341 0.432 0.370 0.353 0.341 0.432 0.370 0.353 0.341 0.342 0.370 0.353 0.341 0.342 0.371 0.335 0.345 0.346 0.371 0.345 0.345 0.346 0.372 0.345 0.345 0.346 0.372 0.345 0.346 0.347 0.332 0.345 0.345 0.345	IN INCRES. PER 5 Head End. Crank End. Head Actual. Corrected for release. Corrected for release. Actual. Corrected for release. Actual. 0,463 0.505 0.425 0.462 27.24 0,468 0.505 0.425 0.462 27.24 0,468 0.501 0.425 0.462 27.24 0,468 0.501 0.402 0.331 19.79 0,464 0.303 19.79 24 303 19.79 0,464 0.398 0.371 0.345 0.346 21.48 0.371 0.347 0.346 21.48 0.337 21.50 0.367 0.385 0.385 21.36 0.385 21.36 0.387 0.385 0.385 21.36 0.385 21.36	IN INCHES. PER SQUARE INC. Head End. Crank End. Head End. Actual. Corrected for release. Corected for release. Corrected for rele	IN INCRES. PER SQUARE INCR. SCALE Head End. Crank End. Head End. Cran Actual. for release. Corrected for release. Corrected for release. Corrected for release. Corrected for release. Corrected for release. Actual. Corrected for release. Corrected for release. Corrected for release. Actual. Actual.		

TABLE V.

CALCULATIONS OF INDICATED HORSE-POWER AND STEAM PER HOUR PER HORSE-POWER.

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NUM- BER OF TEST.	DUR-	REVS.		INDICATED HORS W. WET						STFAM PER Hour per Honse-power.	
	ATION IN MIN-	1'ER MIN- UTE.	Actual.					г	per hour less en- trained		Correct
	UTES.		Head end,	Crank end,	Total.	ί.		ત્રી.	molsture.	Actua ¹ .	
1	105	249.4	14.82	13,16	27.98	15.99	14,30	30.29	1,060.2	37.9	35.0
10	60	249.6	14.84	13.17	28.01				1.060.9	37.9	
2	80	257.6	11.09	9.66	20.75	12.07	10.58	22,65	184.6	40.2	36.8
21	40	258.6	11.17	9.72	20,89				838.8	40.2	
3	75	258.4	15.29	12.86	24.15	16.44	14.02	30.46	1,056.7	37.5	34.7
3a	45	254.4	15.22	12.77	27.99				1,053.7	37.6	
4	60	253.4	11.90	10.73	22.63	12.00	10.76	22,76	861.3	38.1	37.8
5	100	252.8	11.85	10,83	22.68	11,94	10.86	22.80	869.4	38.3	38.1
59	-40	252.5	11.90	10.88	22.78				870.5	38.2	
5	120	253.2	11.83	10.88	22.71	11.93	10,91	22.84	865.5	38.1	37.9
6a	60	252.9	11.79	10.53	22.62				\$63.0	38.3	
7	60	252.3	10.64	9.49	20,13	11.60	10,40	22,00	810.2	40.2	36.8
8	60	250.2	10.45	9.32	19.77	11.40	10.22	21,62	790.7	10.0	36.6

TABLE VI.

Steam preseure at engine in lbe. per sq. inch above atmoe. Thermometer in Barrus calorimeter. Degrees Fahr. REVOLUTION COUNTER. WEIGHT OF WATER BATBELS IN LBS. PRONT TIME. TACHO. BRAKE METER. P. M. SCALES. Total reading. Differ-Net Initial. Final. ence. 291 1922 226 233 221 $\begin{array}{c} 48,428\\ 49,723\\ 51,030\\ 52,320\\ 53,609\\ 56,187\\ 57,471\\ 58,770\\ 60,056\\ 91,336\\ 62,609\\ 63,002\\ 65,100\\ 66,476\\ 67,752\\ 69,034\end{array}$ 190 190 285588021508085321 1,297 1,297 1,300 1,290 1,289 1,289 1,288 1,284 1,280 1,273 1,286 1,280 1,273 1,286 1,276 1,276 1,276 • • • • • • • • 190 190 791 3691 2801 190 190 190 190 190 190 220 224 •••• • • • • •••• 9:1)..... 223 2861 9:13. 9:20. 9:25. 9:30. 941 3814 222 222 190 193 190 190 190 190 190 190 238 238 535 285 80 9:85. 9:40. 224 232 222 •••• 9:45. 9:50. 239 237 95 9:55.... 379 284 190 Averages and Totals. 72.1 257.6* 1,288 1,146 190 157 227

DATA OBSERVED IN TEST NO. 2.

* Revolutions per mluute.

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TABLE VII.

DEFAILS OF MEASUREMENTS OF MEAN HEIGHTS OF INDICATOR CARDS FOR TEST NO. 2.

	МЕЛ	N HEIGH	TS IN INC	CHES.		MEAN HEIGHTS IN INCHES.					
TIME CARD WAS	Head	end.	Crank end.		TIME CARD WAS	Head	end.	Crank end.			
TAKEN.	Actual.	Cor- vected for release.	Actual.	Cor- rected for release.	TAKEN.	Actual.	Cor- rected for release.	Actual.	Cor- rected for release.		
8:83 8:40 8:45 8:50 8:55 9:00 9:05	0.344 0.349 0.348 0.835 0.833 0.343 0.348 0.344	0.372 0.374 0.376 0.366 0.366 0.375 0.375	$\begin{array}{c} 0.293 \\ 0.303 \\ 0.313 \\ 0.300 \\ 0.300 \\ 0.304 \\ 0.307 \end{array}$	0.322 0.335 0.341 0.329 0.334 0.332 0.335	9:20 9:25 9:30 9:35 9:40 9:45 9:50	$\begin{array}{c} 0.335\\ 0.335\\ 0.341\\ 0.341\\ 0.333\\ 0.347\\ 0.347\\ 0.347\\ \end{array}$	0.366 0.360 0.369 0.349 0.349 0.347 0.375 0.375	$\begin{array}{c} 0,295\\ 0,294\\ 0,303\\ 0,303\\ 0,303\\ 0,301\\ 0,304\\ 0,305\end{array}$	$\begin{array}{c} 0.325\\ 0.323\\ 0.331\\ 0.334\\ 0.323\\ 0.333\\ 0.333\\ 0.356\end{array}$		
9:10 9:15 Averag	0.333 0.331 ge	0.365 0.362	0.207 0.299	0.334 0 326	9:55	0.337	0.368	0.306	0.338		

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TABLE VIII.

CALCULATION OF EQUIVALENT SCALE OF INDICATOR SPRING CORRECTED FOR ALL VARIATIONS IN THE FOT SCALE OF THE SPRING. OK. (NARY VALVE, SAME WORK AS FOR SPECIAL VALVE,

Division of card.	Атен.	Mean Height,	Corre- spoud'g scale,	Area reale,	Division of card.	Area.	Mean Height,	Corre- spond'g scale.	Area scale,
A1	0.85	1,10	59.6	20.51	B1	0.20	0.62	58.3	11.66
A2	0,31	0.97	58.7	18,20	B2	0.10	0.81	56.8	5.68
A3	0.21	0.65	58.8	12.35	B8	0.05	0.15	56.8	2.84
A4	0,16	0,50	57.3	9.17	B4	0.005	0.02	56.8	0.28
A5	0.12	0.87	56.8	6.82	B5	0.00	0.00	56.8	9.00
A6	0.09	0.28	56.8	5.H1	B6	0.00	0.00	56.8	0.00
A7	0.07	0.21	56.8	3.98	B7	0.00	0.00	56.8	0.00
A9	0.04	0.12	56.8	2.27	B8	0.00	0.00	56.8	0.00
A9	0.004	0.01	56.8	0.23	B9	0.00	0.00	56.8	0.00
10	0,00	0,00	00,0	0,00	B10	0.00	0.00	56.8	0.00
Totals	1,354			78.64	Totals	0,855			20,46

Equivalent scale = (78.64 - 20.46) + (1.354 - 0.255) = 58.2

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