A TEST OF AN OTTO GAS ENGINE.

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[Contributed by the Mechanical Engineering Department of the University of Pennsylvania.]

The following article is an abstract of a test made by Messrs. Kidwell and Keller for a graduating thesis in the Department of Mechanical Engineering.

The engine had been in use for a long time without overhauling by the makers, but was in fair average condition. The admirable set of experiments, conducted under the auspices of the Society of Arts, the results of which were published after these experiments were made, seemed to make it unnecessary to publish the entire record and work of the test, but as some of the results are worked out in a somewhat different way, a short account of the test and its results may be of interest.

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METHODS.

The engine experimented on was a seven horse-power (nominal) Otto type engine. The volume of the cylinder and clearance space was determined by filling with water and found to be .439 cubic feet for the total volume, and .1796 cubic feet for the clearance space, leaving .2594 cubic feet for the volume swept through by the piston each stroke.

The gas used during the test was passed through a large meter, and thence through rubber bags to the cylinder, a portion passing through a second meter, being taken from the same supply for the jet.

The pressure of the gas used was taken by a manometer, attached to the supply pipe, and the absolute pressure of the gas was found by adding to this reading that of the standard signal service barometer. The temperature of the

gas was taken as that of the room, the meter, bags and pipes being practically entirely within the room. Samples of the gas were taken for analysis. The amount of cooling water used was weighed, by allowing it to discharge in a vessel for periods of ten minutes during the test, the water running at practically the same quantity per minute throughout the entire test. The temperature of the water before and after leaving the cylinder jacket was taken by thermometers placed as shown in *Fig. 1*, which also shows the position of a Brown's pyrometer placed in the exhaust pipe of the engine. The length of pipe between the cylinder and pyrometer was carefully covered with asbestos board, preventing radiation to a great extent.

The power developed in the cylinder during each explosion was determined from a mean indicator card constructed as described below, the power given off by the engine being absorbed by a friction brake on the fly-wheel.

The speed was taken every five minutes by a revolution counter and stop-watch.

It was found necessary to limit the duration of the tests to one hour at a time because of the heating of the fly-wheel. The engine was started and allowed to run an hour; the brake was then put on, and after the engine had settled down to steady condition the test began. It was continued for an hour, the brake was removed, and the engine kept running until the wheel cooled down, when the brake was replaced and another set of observations made. The total duration of the tests, that is, the actual time during which the observations were made, was three hours, ten minutes.

APPARATUS.

The thermometers used were made by Henry J. Green, of New York, and read to degrees Fahrenheit. The pyrometer used was made by Edw. Brown, of Philadelphia, and was graduated at intervals of 10° to $1,200^{\circ}$ F. The revolution counter used was of the endless-screw and wheel type, reading to single revolution. The stop-watch read to one-fifth second. The meters used were a large one, made by the Goodwin Meter Company, for gas-engine tests, and

an ordinary seven-light meter made by the same company. The scales for weighing the water read to $\frac{1}{100}$ pound.

The apparatus used for analyzing the gas was an Elliott apparatus, similar to that used at the International Electrical Exhibition in 1884.

A Crosby indicator, with a 100-pound spring, was used throughout the test.

The bulbs of the thermometers used for measuring the temperature of the jacket water were inserted in thin metal cups screwed into the pipe connections, as shown in *Fig. 1*, the lower one being kept full of water, and the upper one of oil.

The following are some of the results of the test:

Date, January 19, 1889,	
Time of test,	3 hrs. 10 m.
Temperature gas,	62° 2
Temperature of exhaust,	774° 28
Temperature of entering water,	50° 43
Temperature of exit water,	89° 19
Manometer, inches water,	3° 06
Barometer (reduced to pounds),	14° 85
Total gas used, cubic feet,	344° 4
Gas for ignition,	9° 625
Average revolutions per minute,	161° 6
Explosions missed per minute,	6° 83

COMPUTATION.

As the test was rather for determining the distribution of the head developed by burning the gas, or for getting data for determining its efficiency as a heat engine rather than as a machine, and as the observing force was limited, the brake horse-power was not taken.

The indicator cards were worked up in the following way. *Fig. 2* is a mean card obtained as follows: On each of the forty-two cards taken, twenty-eight lines were drawn at right angles to the atmospheric line as shown, and the pressure of the bottom and top of each card was read and tabulated. From the mean of these tabulated values, the card shown in the figure was drawn. From this card the horse-power was calculated as follows:

Mean pressure for card = 59 pounds.

Mean pressure per foot = 59×144 pounds.

Value of stroke in feet = .2594.

Work per explosion = $59 \times 144 \times .2594$ ft. pounds.

Explosion per minute = $\frac{161.6}{2} - 6.83 = 73.97$.

Horse-power = $\frac{73.97 \times 59 \times 144 \times .2594}{33,000} = 4.939$.

It will be noticed that the exhaust and admission parts of the diagram are omitted as they practically coincided with the atmospheric line.

In addition to finding the work done, the mean card was used to determine the general equation of the expansion, compression and explosion part of the diagram.

In determining these curves the part between ordinates (8) and (28) was taken for the compression curve in the calculation; the explosion curve was taken to embrace all the upper curve between (23) and (28); and the expansion curve was taken to cover all the upper curves between (5) and (18).

The expansion and compression curves were assumed to vary according to a law $p v^n = c$, in which p is the pressure in pounds per square inch, and v = the volume in cubic feet of the mixture, while c and n are constants. By taking the values of p and v , as given on the mean indicator card by the method of Least Squares, the most probable values of n and c were determined.

The equation to the curve of expansion was found to be

$$p v^{1.4385} = 15.901$$

and for the compression curve was found to be—

$$p v^{1.5313} = 3.7557.$$

The explosion curve was found to be practically a parabola, whose equation is—

$$y = -1.788 x + 32.833 \pm \sqrt{89.423 x - 1588.61}$$

in which

$$y = \frac{p}{10}, x = 100 v.$$

The broken lines on *Fig. 2* show the curves corresponding

to the equation, and the following table gives the errors by calculation.

EXPANSION CURVE.

v	p from equation.	p from card.	v	p from equation.	p from card.
'23855	124'97	123'20	'32109	81'52	81'39
'25034	116'60	117'18	'33288	77'41	77'63
'26213	109'11	110'34	'34467	73'62	73'89
'27392	102'47	103'49	'35646	70'14	70'15
'28571	96'44	97'03	'36825	66'97	66'89
'29750	90'98	91'25	'38004	63'98	63'56
'30929	86'02	86'25	'39183	61'23	59'99

COMPRESSION CURVE.

v	p from equation.	p from card.	v	p from equation.	p from card.
'17960	52'06	52'25	'25034	31'32	31'41
'18550	49'55	49'13	'26213	29'19	29'25
'19139	47'24	47'08	'27392	27'29	27'30
'19729	45'09	44'87	'28571	25'58	25'53
'20318	43'10	42'91	'29750	24'04	23'91
'20908	41'26	41'27	'30929	22'65	22'72
'21497	39'54	39'60	'32109	21'39	21'46
'22089	37'93	38'32	'33288	20'24	20'34
'22676	36'43	36'94	'34467	19'19	19'15
'23266	35'03	35'39	'35646	18'22	18'34
'23855	33'70	33'94			

EXPLOSION CURVE.

v	p from equation.	p from card.	v	p from equation.	p from card.
'1796	48'90	51'25	'19729	108'70	108'70
'1855	80'59	81'01	'20318	116'55	116'99
'19139	97'10	97'01	'20908	121'91	122'49

HEAT.

From the mean indicator card it was found that the mean pressure was fifty-nine pounds per square inch, and the work performed per explosion was $59 \times 144 \times .2594$ (volume passed through by the piston) = 2203.8 foot pounds. This is equivalent to—

$$\frac{2203.8}{772} = 2.854$$

heat units transformed into work at each explosion.

From the amount and temperature of the jacket water it was found that 461.92 heat units were carried away per

minute by the cooling water. Or as there were 73.97 explosions per minute—

$$\frac{461.92}{73.97} = 6.24$$

heat units removed per explosion by the cooling water.

The following gives the results of the tests of the gas used as determined by the Elliott apparatus:

	<i>By Volume, Per Cent.</i>	<i>By Weight, Per Cent.</i>
CO ₂ ,	15.0	11.923
C ₂ H ₄ ,	41.32	10.520
O ₂ ,	1.00	2.797
CO,	6.33	15.419
CH ₄ ,	27.18	38.042
H ₂ ,	51.57	9.021
N ₂ ,	9.06	22.273

The following are the calculated results from these values:

	<i>Weight per Explosion.</i>	<i>Heat Developed per Explosion.</i>	<i>Oxygen Required.</i>	<i>Products of Combustion. H₂O</i>	<i>CO₂</i>
CO ₂ ,	.00001210	—	—	—	—
C ₂ H ₄ ,	.00013903	1.6785	.000045697	.00017832	.00001210
O ₂ ,	.00002420	—	.00002420	.00017832	.000043682
CO,	.00011313	.5322	.00000464	.000062396	.00017776
CH ₄ ,	.00027730	6.4927	.00110920	.00039216	.00076269
H ₂ ,	.00006580	3.7364	.00052640	.00039216	—
N ₂ ,	.00016190	—	—	—	—
	.00079346	12.4398	.00213271	.00139464	.00138923
Nitrogen,			.007101		
Air required,			.00023373		
Gas,			.00079346		
Total water gas and air entering cylinder per explosion,			.01003319		
H ₂ O,				.00139464	
N added,				.00710110	
N ₂ ,				.00016190	
					.01005594

The heat carried off in the products of combustion is—

	<i>Heat Units.</i>		<i>Per Cent.</i>
In H ₂ O (steam),	1.9291		
CO ₂ ,	.2149		
N ₂ ,	.2438		
Heat carried off in exhaust,	3.4049	12.44	27.93
Heat converted into work,	2.85		22.91
Heat taken by jacket water,	6.24		50.16
Total heat accounted for,	12.49		100.4
Total heat received,	12.44

These calculations are made on the supposition that the amount of air supplied to the cylinder is just enough to cause complete combustion, and are given for what they are worth. That they are, at least to a certain extent, justifiable can be seen from the following:

·00079346 pounds of gas occupying

$$\frac{334.78 \text{ (cubic feet, total)}}{14054 \text{ (no. explosion)}} \text{ cubic feet}$$

at 62°·2 F. and a pressure of 14·96 pounds per square inch, requires ·00923373 pounds of air to completely burn it.

It is fair to suppose that just before the mixture of gas and air is compressed it has the temperature of the cylinder, which must be about that of the jacket water or 89°·19 F. The gas occupies a volume of

$$\frac{334.78}{14054} \times \frac{548.59}{521.6} \times \frac{14.96}{14.85} = .02523 \text{ cubic feet.}$$

·00923373 pounds of air at 14·85 pounds per square inch and a temperature of 89·19 occupies ·22985 cubic feet. The total volume occupied by the gas and air is therefore ·25508 cubic feet. The clearance volume was filled with the products of combustion at this same pressure and temperature before the mixture of gas and air was drawn in. The incoming gas and air should therefore fill a volume equal to the stroke displacement, or ·2594 cubic feet, and we have therefore a volume of air = ·2594 — ·25508 = ·00432 cubic feet of air drawn in, but not used, a quantity that we can omit in our calculations.