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On the Distribution and Variation of Temperature in the Cylinder and Piston of an Aircraft Engine.

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(with 12 plates)

1. Object and scope of investigation.

In the petrol engine a certain percentage of heat of combustion in the cylinder flows through the piston body into the water jacket or the cooling fins and there may exist very often a considerable gradient of temperature in the piston head and barrel resulting in various unfavorable effects such as excessive internal stresses due to unequal expansion of the material; it is of the utmost importance from the designer's point of view to know the actual distribution of temperature in these parts of an engine. As to ordinary automobile engines much interesting and valuable information on this subject has been published from time to time, but the results are of less importance in relation to recent aircraft engines.

The present investigation was carried out with the object of obtaining reasonably conclusive data which might be utilized in the practice of aircraft engine design.

The distribution of temperature in the cylinder and piston may vary, of course, according to the type and construction of the engine, to the mode of operation, etc. But, at present, our investigations are limited to the case of aluminium piston and steel cylinder of a water cooled engine running under perfect conditions. The results obtained, however, detail some of the important characteristics of heat flow in the cylinder and piston. The paper deals only with the experimental results and does not push far into questions of theory of heat which, at present, are deferred until more deta are available.

The interesting experiment on aluminium pistons made by F. Jardine and F. Jehle* seems to be the only recent research published on this subject. They measured the temperature of the piston of a single cylinder Liberty engine at four different portions and showed how variation in the piston design affects its working temperature. Their experiments were confined chiefly to the case of steady state of temperature and did not cover that of varying conditions which might deserve more attention.

2. Engine employed in the experiments.

In our experiment a Hall-Scott L–6 Engine of Liberty type was utilized. The general characteristics of the engine are as follows :

No. of cylinders..	6 in line,	Rated HP....	200,
Bore............	5 in.,	Carburetors ...	Miller,
Stroke..........	7 in.,	Ignition......	Delco,
Normal R.P.M...	1650-1700,	Cooling......	Water.

The cylinder is of steel about 3 mm. in thickness with steel jacket welded on. The piston is of aluminium alloy with three cast iron rings at the head and with seven oil grooves turned round the barrel, as shown in Fig. 1. The sectional views of the cylinder and piston are shown in Fig. 5.

In order to absorb the engine power a fan-brake dynamometer of

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known coefficient was directly coupled and the brake horse power of the engine was calculated from the speed of the fan shaft together with atmospheric pressure and temperature.

The cooling water was kept in two tanks, each of one ton capacity, and was circulated by means of a centrifugal pump attached to the engine ; no radiator was employed in the cooling system.

The petrol used in this experiment was N.S.K.'s Kômori whose specific gravity was 0.69, and the lubricating oil was Gargoyl Mobiloil A. Throughout the experiments, the oil supply was regulated at the relief valve to a pressure from 2.5 to 2.8 kg. per sq.cm.

The ignition was timed at either 13.7° or 30° before top dead center according to the speed of engine. This has been entered in attached Tables for each experiment.

The starting of engine was effected by means of an electric motor and the time of operation was measured always from the instant at which continuous explosions occurred in the cylinders.

3. Apparatus employed in the temperature measurement.

In order to measure the cylinder and piston temperature copper and constantan couples in conjunction with sensitive galvanometers of short period were used ; the diameter of copper wire was 0.30 mm. and that of constantan wire 0.28 mm. For measurement of gas temperature within the cylinder platinum and platinum-rhodium couples of 0.13 mm. in diameter were employed. All these thermocouples were attached to the sixth cylinder and piston, that is, those at the propeller end of the engine. Among them 6 couples were inserted in the cylinder wall, 9 in the piston body and 2 in piston rings ; their locations are shown in Fig. 5, where each couple is numbered by I1, I2, I3, II, III, etc. In Tables and Diagrams attached to the end of this paper the positions of couples are all specified by these numbers. Couple I1 is located at the piston head 5 mm. deep from its top surface ; couples I2 and I3 are nearly at the center of piston head about 1.5 and 9.0 mm. deep from the top surface, respectively ; couples II and III in the piston head, each 5 mm. deep from the surface and 25 and 49 mm. from the center of piston head, respectively ; couples VI and VI in the top and second rings, each at its center of cross-section ; couples V and VII in the piston collars between the rings at 3 mm. from the outer surface ; and couples IX and XI in the piston barrel, also 3 mm. from the outer surface, and 80 and 41.5 mm. from the bottom of skirt, respectively. All these piston thermocouples are on the intake side and in one plane at right angles to the plane of the gudgeon pin. The holes for the thermocouples, about 0.6 mm. in diameter, are drilled in the piston body at the gudgeon pin side. The junctions, properly insulated, are inserted in these holes and are calked firmly in position.

Through the water jacket, couples XII, XIII, XIV, XV, and XVI are inserted in the cylinder wall and XVII in the lower part of cylinder, each being at a depth of 1.5 mm. from the inner surface of the cylinder, as shown in Fig. 5.

A couple, denoted by CC, was located on the gudgeon pin boss and made to respond to the air temperature inside the crank case. Through the water jacket and cylinder head a platinum and platinum-rhodium couple g was projected into the combustion chamber at the side of the exhaust valve. Thus the number of the couples was 19 in total.

The temperature of circulating water was measured by means of 2 sensitive mercury thermometers, one set across the water inlet WI to the cylinder and the other at its exit WO as shown in Fig. 1. These mercury thermometers were previously checked and were found sufficiently sensitive to take up the variation of water temperature even in case of its quickest change in these experiments.

10 thermocouples out of 19, at the same time, were connected to the 10 galvanometers, which were all that were available in the present experiment, and simultaneous observations of temperature were made every 20 or 15 seconds on these 10 galvanometers and 2 direct reading mercury thermometers.

It was not easy work to provide means for conducting the leads of the piston thermocouples out of the engine when running at high speed, to the galvanometers, without subjecting them to undue stress caused by vibration. After some trials quite satisfactory results were obtained by a method devised by the authors, the general layout of which is shown in Figs. 2, 3 and 4.

Fig. 2 shows the piston *p* taken out of the cylinder with connecting rod and the links, and Fig. 3 is the same mechanism seen from a different side. One arm *u* of a U-shaped piece *uu'*, which is of special steel, is rigidly fixed to the inside of the piston barrel, and the other *u'*, carrying a link at its end, is led to move along a vertical guide. Its bigger arm *u* is of I-section and the smaller *u'* of square with grooves at the sides for leading the thermocouple wires *c*, the weight of the piece including the aluminium cross-head being about 500 grammes.

Fortunately there is, in the crank chamber, a space left between the connecting rod, crank arm and main bearing, just sufficient to permit this U-piece moving up and down with the piston body. The curved part of the U-piece passes round the skirt end of the cylinder and the arm *u'* projects out through an opening cut in the upper crank case. A cross-head *h* at the end of *u'* slides along a cross-head guide g, Fig. 4. A long link *l* and short one *m*, both of duralumin, connect the cross-head *h* with the fixed hinge *o*. Thus along the U-piece and two links *l* and *m* the leads of piston thermocouples *c* are conducted safely to the galvanometers.

4. Gas temperature within the cylinder.

It was desirable to observe the temperature existing within the cylinder, but in case of the high speed engine the exact measurement of this temperature is not an easy process on account of the exceedingly wide and rapid variation in temperature of the charge.

In order to measure the mean temperature of gas it was necessary to prepare a couple with sufficiently thick wire, so that it should be more or less insensitive to rapid fluctuation of temperature. But an unavoidable objection to thick wire couples is that the charge is very liable to make surface combustion on the highly heated wire projected into the cylinder during a part of the suction and compression strokes, and consequently that the mean temperature indicated by the galvanometer would be much higher than the actual mean temperature of gas within the cylinder.

The authors made some preliminary experiments on the effect of suface combustion with thermocouples of platinum and platinum-rhodium wires of different sizes, and found that when the engine was running at high speed, the wire of about 0.13 mm. in diameter gave almost satisfactory results.

The figures given under the column " the mean temperature of gas " in the annexed Tables are the values obtained by inserting this thermocouple in the explosion chamber at the point specified before; and these values are not considered exact, at present, but may be sufficiently relied upon to the order of approximation. The mean temperature of gas also varies considerably according to the position of couple attached.

5. Variation of temperature in the piston and cylinder when the engine is starting.

Experiments were made to investigate how the piston and cylinder were warmed up when the engine was started. Nos. 3, 4, 5, 9 and 11 are some of the various cases of these experiments.

Experiment No. 3. Previously, the main throttle of the engine was opened a little way and the throttle lever was fixed at the position, and the timing lever was also fixed. Then the engine was set to revolve by means of a starting electric motor. As soon as explosions occurred in the cylinder the engine accelerated quickly to a certain constant speed which was predetermined by adjusting the positions of throttle and timing levers. The speed attained was 1110 R.P.M. and the power 55.6 HP. In this experiment temperature readings were taken simultaneously every 20 seconds on 8 thermocouples, that is, I3, I1, III, V, VII and XI in the piston, XIV and XVI in the cylinder wall and on 2 mercury thermometers WI and WO in the circulating water inlet and outlet, respectively. The results of experiment are shown in Table 1 and plotted in Diagram 1. In the Diagram time is measured from the instant at which the regular explosions were heard in the cylinders. In this experiment the initial temperature readings of the piston and cylinder and of the jacket water were not all coincident, owing to the fact that the engine was run for some length of time and was still warm at the time of new starting for the present test. When the engine was set to start the temperatures of piston rose very quickly in the first minute, then rather slowly in the second minute, very slowly arriving at a steady state in the third minute. The couples XIV and XVI indicate that the temperatures of the cylinder wall are very near those WO and WI of the circulating water and vary closely with them. The mean temperature of gas within the cylinder was estimated to be 620° C.

Experiment No. 4. The temperatures were measured by the same couples and in the same way as above except that the throttle was opened previously a little wider. The speed of the engine after starting was 1170, the power 65.2 HP., and the mean temperature of gas 660° C. The results of the experiment are shown in Table 2 and plotted in Diagram 2. The shapes of the temperature curves are the same as in the previous experiment except that they run, as a whole, a little higher than those observed before.

Experiment No. 5. In this experiment temperatures of the piston and cylinder were measured mostly at different positions, that is, by couples I1, II, VII and IX in the piston, IV and VI in the piston rings, XII in the cylinder wall, CC in the crank chamber and 2 mercury thermometers for the circulating water temperatures. As was expected, the general feature of the temperature curves is just the same as that in the cases stated above, and it may deserve some attention that the temperatures of the piston rings are a little lower than those of the piston collars between rings. In this experiment the speed of engine was 900 R.P.M., the power 28.9 HP. and the mean temperature of gas 490° C.

Experiment No. 9 and No. 11. Temperature observations were made with the same couples and in the some way as in Experiment No. 5 except that the position of the throttle lever was different. In No. 9 the speed was 1020 R.P.M., the power 42.5 HP. and the mean temperature of gas 550° C. and in No. 11 these were 1155 R.P.M., 61.1 HP. and 650° C., respectively.

Summing up the results of the above experiments we may state that, when the engine is starting the temperature of the piston attains to a certain steady state corresponding to its speed and power in about 3 minutes ; the temperature of the cylinder wall always changes closely with that of circulating water.

6. Change of temperature in the piston and cylinder with change of speed and power of the engine.

It was one of the objects of this investigation to determine the temperature distribution in the piston and cylinder when the engine is operating under full load. Before attaining the full power condition, the engine was tested at different speeds, increased step dy step, and the simultaneous observations of temperatures were made every 15 seconds throughout the time the engine was running.

Experiment No. 15. In this experiment and in what follows hereafter the temperature and speed readings were taken simultaneously every 15 seconds.

After starting, the engine was kept running at a speed of 900 R.P.M. for about 3 minutes, then the throttle lever was quickly advanced permitting the engine to run at 980 R.P.M. ; next, the speed was increased to 1070 R.P.M. and then to 1160 R.P.M. ; the engine being kept running always for 3 minutes at each stage of speed. The results are tabulated in Table 6 and are plotted in Diagram 6. During the experiment a constant quantity of cooling water which was kept in the tank was made to circulate by the centrifugal pump attached to the engine. No radiator being employed in the system, the temperature of water rose gradually as the engine continued to operate. The rate of rise of temperature was about 1.3° C. per minute. The temperature curve of couple XVI, running almost straight between those of circulating water, indicates that the temperature of the lower part of the cylinder does not much depend upon the temperature change of gas within the cylinder. But the temperature in the cylinder head XII and the middle part of the cylinder barrel XIV are affected more or less by the gas temperature. The fact can be seen more distinctly in Diagrams 7 and 8.

The temperature curves I3, III, V, IX and XI show that the gas temperature has fairly strong influence upon the temperature of the piston, the effect being most remarkable at the center of piston crown and decreasing gradually towards its shoulder and down to the skirt, where the effect of the circulating water becomes more predominant.

Experiment No. 16. In this experiment the observations were made with the same couples as before, under four different speeds of engine, that is, 1200, 1300, 1420 and 1480 R.P.M. The results are tabulated in Table 7 and plotted in Diagram 7. After the engine was started the throttle was opened very gradually until the engine attained to a predetermined speed of 1200 R.P.M.; accordingly the shapes of the temperature curves plotted between 1 to 3 minutes became quite unlike those obtained in case of starting. At the instant $6\frac{1}{4}$ minutes after starting a little unexpected trouble in the ignition system stopped the spark of the sixth cylinder for a few moments. The result was an interesting small wave on each temperature curve between 6 and 7 minutes.

Experiment No. 17. The observations were made also at four different speeds, that is, 1380, 1480, 1560 and 1670 R.P.M., the last-mentioned figure being nearly full speed of the engine. The results of the experiment are given in Table 8 and plotted in Diagram 8. At the instant 15 minutes after starting, the engine was suddenly throttled down to 1180 R.P.M., and accordingly the piston temperature fell very quickly in the first one minute, and rather moderately in the second minute, and then very slowly down to a steady state in the third minute.

From the results of experiments Nos. 15, 16 and 17 the relation of B.H.P. to the steady temperature in the various parts of the piston was deduced; values are shown in Table 12 and Diagram 12, in which the piston temperatures are measured above that at the outlet of the circulating water.

From these experiments it may be stated that when the engine operates normally, there exists no great difference between the temperatures of the cylinder wall and that of the circulating water; it is 40° C. or so at the top and less than 10° C. at the lower part of the cylinder.

The temperature of gas within the cylinder has strong effects upon that of the piston. The effect is biggest at the center of piston crown and there the temperature change may be something of the order of 1/6 that of the gas, and diminishes gradually towards the bottom of piston skirt. The highest temperature of the piston crown, when the engine is running under good condition, is 200° C, or so, measured above the temperature of circulating water at the exit of cylinder jacket. In ordinary cases the temperature of the circulating water at its outlet may be below 80° C. and we can conclude that the maximum working temperature of the aluminium piston of this engine is below 300° C. The temperature at the shoulder is about 50° C. lower than that at the center, and that of skirt about 40°C. higher than that of water outlet. This temperature may vary, of course, according to the type of engine, kind of fuel, mixture strength, or other various factors, but within the scope of this experiment the results are considered to be fairly conclusive.

7. Change of temperature in the piston and cylinder when the spark is switched off for a few minutes.

Experiment No. 12. Initially the engine was kept running at a speed of 1200 R.P.M. and at the point of 8 minutes after starting the spark at the sixth cylinder alone was suddenly switched off, the throttle being left untouched and the other five cylinders firing normally; consequently the speed of the engine was reduced to 1120 R.P.M. At 12 minutes the spark was again switched on, and the engine regained its initial speed. At 18 minutes the engine was switched off and the main throttle was shut at the same time; the engine stopped in a few seconds and was, left to cool freely. The couples utilized in this experiment were I1, II, VII, IX in the piston, IV, VI in the piston rings, XII in the cylinder, CC of crank chamber and WO and WI of the circulating water. The results are shown in Table 9 and Diagram 9.

When the spark is switched off all the temperatures in the piston and cylinder begin to fall very quickly at first, and then gradually flatten out towards the steady state in about 3 minutes. The temperature at the top of cylinder falls down to that of circulating water, but the piston temperatures, being affected by the temperature of gas within the cylinder which is working on idle cycles without explosion, are kept about 20° C. higher than that of the cooling water.

When the spark is switched on again all temperatures go up to the initial state in the same way as that at the time of starting.

When the engine stops all temperatures in the piston and cylinder fall, while the temperature of the exit water rises distinctly, showing that the water is warmed by the residual heat of the working part of the engine as it ceases to circulate through the jacket. In this case it takes at least 5 minutes before the engine is cooled down to the temperature of the circulating water.

Experiment No. 13. This is a similar experiment to the previous one but with couples at different position, that is I1, I3, III, VII and XI in the piston, VI in the ring, and XIV and XVI in the cylinder wall. The results are shown in Table 10 and Diagram 10.

8. Temperature change in the piston and cylinder with that of the circulating water.

The change of temperatures in the piston and cylinder due to sudden change of temperature of cooling water has been investigated ; the temperature of the circulating water at the inlet was about 60° C. initially and about 20° C. after the change.

The speed of engine, which was 1180 R.P.M., was not affected practically by this change. At an instant $22\frac{3}{4}$ minutes after starting the water connection was changed again and the warmer water was made to circulate. A few moments after this change the throttle was opened a little wider and the engine speeded up to 1300 R.P.M. Again at $28\frac{3}{4}$ minutes the connection was changed and cooler water was supplied to the circulating system.

The results of this experiment are shown in Table 11 and Diagram 11. In this experiment the temperature of the circulating water is varied through 40° C. and the temperature change of piston induced thereby was from 20° to 25° C., the effect being less toward the center of the piston head, with a time lag of about 3 minutes.

The temperature of the cylinder wall follows sensitively that of the circulating water, as was confirmed also through previous experiments.

9. Effect of friction on the temperatures of the piston and cylinder.

The effect of friction between the cylinder and piston on their temperatures may be by no means small according to the running condition of engine. It is an important subject of general interest, but so far as these researches are concerned where the engine is perfectly lubricated this effect is considered not to be serious. For in Diagram 9 the mean temperature of gas within the cylinder is observed to be 85°C. (Table 9) while that of the water is a little below 40° C. and all temperatures of the cylinder and piston settle between 50° to 60° C., showing that there exists but little frictional effect between them.

10. Summary and conclusion.

The results of this investigation may be summarized as follows :

1. The temperatures in the piston and cylinder attain a steady state in about 3 minutes after starting, the change being very rapid in the first minute.

2. When the speed and power of the engine vary the temperatures of piston and cylinder also vary with them and attain the stationary condition in about 3 minutes.

3. The temperature of the lower part of the cylinder is only a little higher than that of inlet water and is not materially influenced by the temperature change of gas within the cylinder. When the engine is running at normal speed under good conditions the difference between the temperatures of the top of cylinder barrel and of the cooling water outlet is less than about 50°C.

4. The change of temperature at the center of the piston crown is of the order of 1/5 to 1/7 that of the gas and of 1/2 of the circulating water.

5. The highest temperature of piston exists, of course, at the crown center and is about 200°C. above the outlet temperature of circulating water. The temperature of piston shoulder is about 130°C. and that at the skirt about 30°C. higher than that of circulating water.

6. The temperatures of the piston rings are considerably lower than that of the piston collar which holds the rings.

7. There exists a considerable temperature gradient near the edge of piston head and also along the piston barrel down to the bottom of

skirt, although not so steep as in the case of ordinary exhaust valves.

8. When the spark is switched off, the temperatures of the piston and cylinder fall rapidly and attain a steady state in 3 minutes. In case of full stop at least 5 minutes are required for free cooling of the piston and cylinder down to the temperature of circulating water at its outlet.

As stated above all these experiments were made only on the engine running under perfect conditions, yet the results seem highly suggestive for other particular cases arising often in practice. Further researches on an engine running under abnormal condition such as the case of overheating due to insufficient cooling, poor lubrication, excessive carbon deposit on the piston head or the like, even up to the very moment of break-down of the engine will be of very much importance. The authors are preparing for these investigations and the results will be published in a near issue of the Report of the Institute.

In conclusion the authors desire to express their special appreciation to Mr. K. Tomizuka, Assistant Professor of the Tôkyô Imperial University, who is now in Paris, and with whom they were in close collaboration for years, for his valuable advice and assistance during the earlier time of this investigation. The authors also express their acknowledgment to Messrs Y. Gotô and A. Hasimoto, Assistant Engineers of the Institute, for their faithful assistance throughout the investigation.

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Table 1. Rise of temperature in the piston and cylinder when the engine is starting.

Experiment No. 3.
R. P. M. of Engine 1110
B. H. P. of Engine 55.6
Ignition 13.7°

May 14, 1921
Atmos. pressure 761
Room temperature 18.7° C.

Time		Mean Temp. of Gas	Temperature of Piston						Temp. of Cylinder		Temp. of Circulating Water	
Min.	Sec.		I_3	I_1	III	V	VII	XI	XIV	XVI	Inlet WI	Outlet WO
	0	620	60	64	59	56	57	58	56	56	45	62
	20	„	66	65	62	56	57	58	56	52	49	54
	40	„	111	108	93	75	75	62	53	48	47	52
1	0	„	128	122	105	85	82	66	54	49	47	52
	20	„	135	130	109	91	87	69	56	49	48	52.5
	40	„	140	133	114	95	90	72	56	50	49	53
2	0	„	142	135	115	96	91	73	56	50	49	54
	20	„	142	136	115	96	92	74	57	51	50	54
	40	„	141	136	115	96	92	75	57	51	50	55
3	0	„	142	136	115	96	93	76	58	52	50.5	55
	20	„	142	136	116	97	93	75	58	52	51	56

Table 2. Rise of temperature in the piston and cylinder when the engine is starting.

Experiment No. 4
R. P. M. of Engine 1170
B. H. P. of Engine 65.2
Ignition 13.7°

May 14, 1921
Atmos. pressure 761
Room temperature 18.6° C.

Time		Mean Temp. of Gas	Temperature of Piston						Temp. of Cylinder		Temp. of Circulating Water	
Min.	Sec.		I_3	I_1	III	V	VII	XI	XIV	XVI	Inlet WI	Outlet WO
	0	660	67	66	66	65	65	62	64	58	51	68
	20	„	78	78	74	66	67	62	62	57		64
	40	„	123	121	105	86	83	65	61	56	55	59
1	0	„	142	138	116	96	93	72	62	57	55	59

Table 2. (Continued)

Time Min.	Sec.	Mean Temp. of Gas	Temperature of Piston I_3	I_1	III	V	VII	XI	Temp. of Cylinder XIV	XVI	Temp. of Circulating Water Inlet WI	Outlet WO
	20	660	153	149	124	103	98	76	64	58	57	61.5
	40	,,	158	153	126	106	101	79	65	59	57.5	62
2	0	,,	159	154	128	107	103	80	65	59	58	63
	20	,,	160	156	130	109	103	81	65	60	58.5	63
	40	,,	162	157	131	109	104	83	66	60	59	63.5
3	0	,,	162	159	131	110	105	84	66	60	59	64
	20	,,	162	159	131	110	105	84	67	60	59.5	64.5
	40	,,	163	160	132	111	105	85	68	61	60	65
4	0	,,	163	161	133	111	106	86	68	61	60.5	65

Table 3. Rise of temperature in the piston and cylinder when the engine is starting.

Experiment No. 5
R. P. M. of Engine 900
B. H. P. of Engine 28.9
Ignition 13.7°

May 20, 1921
Atmos. pressure 755.5
Room temperature 23.8° C.

Time Min.	Sec.	Mean Temp. of Gag	Temperature of Piston I_1	II	VII	IX	Temp. of Piston Ring IV	VI	Temp. of Cylinder XII	Temp. in Crank chamber CC	Temp. of Circulating Water Inlet WI	Outlet WO
	0	490	20	20	20			19	20	21		
	15	,,	38	44	30	27	27		26	25	19	24.5
	30	,,	56	59	38	33	36	36	30	28	19.5	25
	45	,,	72	73	45	39	41	42	32	32	20	26
1	0	,,	80	80	50	43	44	45	33	35	20	26
	15	,,	85	84	54	47	48	48	33	38	20.5	26.5
	30	,,	87	86	55	49	49	50	33	41	21	27
	45	,,	88	89	57	50	52	51	33	43	21.5	27
2	0	,,	90	90	58	51	52	52	33	45	22	28
	15	,,	90	92	59	52	52	53	33	46	22	28
	30	,,	90	91	59	53	53	54	33		22	28.5
	45	,,	90	92	60	54	53	54	34	47	23	27.5
3	0	,,	90	91	60	54	53	54	34		23	27
	15	,,	90	91	60	54	53	55	33	49	23	27

Table 4. Rise of temperature in the piston and cylinder when the engine is starting.

Experiment No. 9 — May 21, 1921
R. P. M. of Engine 1020 — Atmos. pressure 759.3
B. H. P. of Engine 42.5 — Room temperature 23° C.
Ignition 13.7°

Time Min.	Time Sec.	Mean Temp. of Gas	Temperature of Piston I_1	II	VII	IX	Temp. of Piston Ring IV	VI	Temp. of Cylinder XII	Temp. in Crank Chamber CC	Temp. of Circulating Water Inlet WI	Outlet WO
	0	550	42	41	38	40	39	38	44	43	34.5	49.5
	15	„	65	66	49	46	44	45	47	43	37	41
	30	„	85	85	58	53	52	55	50	47	38	42
	45	„	96	95	64	58	60	60	51	51	38	43
1	0	„	102	101	68	62	65	62	50	54	38.5	43.5
	15	„	106	106	72	65	68	65	51	56	39	44
	30	„	108	108	74	68	68	68	51	58	39	44.5
	45	„	110	110	75	68	71	69	51	60	39	45
2	0	„	112	111	76	70	75	69	51	61	39.5	45
	15	„	112	111	77	70	75	70	50	62	40	45.5
	30	„	113	111	78	70	77	71	51	63	40	46
	45	„	113	112	78	71	80	71	51	63	40	46
3	0	„	113	113	79	72	80	71	51	64	40.5	46
	15	„	114	113	79	72	77	71	51	64	41	46.5
	30	„	114	113	79	73	80	72	51	65	41	47
	45	„	114	113	79	73	80	72	52	65	41.5	47

Table 5. Rise of temperature in the piston and cylinder when the engine is starting.

Experiment No. 11
R.P.M. of Engine 1155
B.H.P. of Engine 61.1
Ignition 13.7°

May 21, 1921
Atmos. pressure 759.3
Room temperature 25.5° C.

Time Min.	Time Sec.	Mean Temp. of Gas	Temperature of Piston I1	II	VII	IX	Temp. of Piston Ring IV	VI	Temp. of Cylinder XII	Temp. in Crank Chamber CC	Temp. of Circulating Water Inlet WI	Outlet WO
	0	650	56	60	57	59	55	55	59	58	51.5	65.5
	15	,,	70	70	60	60	57	57	60	60	57	57.5
	30	,,	94	93	71	65	68	66	68	61	58	61.5
	45	,,	115	114	81	72	78	76	71	65	58	63
1	0	,,	124	125	88	78	84	82	72	68	59	63.5
	15	,,	132	133	93	82	87	85	72	71	59	64
	30	,,	138	137	95	85	92	89	73	73	59	64.5
	45	,,	141	140	98	87	95	91	73	75	59.5	65
2	0	,,	144	142	99	89	96	92	74	76	60	65
	15	,,	145	143	100	90	98	93	74	77	60	65.5
	30	,,	146	144	100	91	100	93	74	78	60	66
	45	,,	146	145	101	91	100	94	74	80	60.5	66
3	0	,,	146	146	102	92	100	95	74	81	61	66.5
	15	,,	147	147	103	93	101	96	74	82	61	67
	30	,,	148	147	103	93	101	96	74	83	61.5	67
	45	,,	148	148	103	94	101	96	74	83	62	67.5
4	0	,,	150	148	104	95	101	96	74	83	62	67

Table 6. Change of temperature in the piston and cylinder with the change of engine speed and power.

Experiment No. 15 July 22, 1921
Atmos. pressure 762.5 Room temperature 26.8° C.
Ignition 13.7°

Time		Mean Temp. of Gas	Temperature of Piston					Temperature of Cylinder			Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
Min.	Sec.		I3	III	V	IX	XI	XII	XIV	XVI	Inlet WI	Outlet WO		
1	0	490	67	55	52	45	36	38	40	32	27	33.5	900	28.8
	15	,,	78	62	60	47	40	40.5	40.5	32	28	34.5	,,	,,
	30	,,	85	68	65	51	41	43	41.5	32.5	28	35	,,	,,
	45	,,	92	72	69	55	46	43	41.5	33	28	35	,,	,,
2	0	,,	94	74	72	56	49	43.5	41.5	33.5	28.5	35.5	,,	,,
	15	,,	95	75	74	58	50	43.5	42	33.5	29	36	,,	,,
	30	,,	97	76	74	58	50	44.5	42	34	29	36.5	,,	,,
	45	,,	97	77	75	60	51	44.5	42.5	34	29.5	36.5	,,	,,
3	0	,,	97	78	77	60	52	45	42.5	34.5	30	37	,,	,,
	15	530	98	77	77	60		45	43	34.5	30	37	980	37.3
	30	,,	102	79	79	61		46.5	43	34.5	30.5	37.5	,,	,,
	45	,,		82	81	61		47.5	45	36	31	38	,,	,,
4	0	,,	106	83	82	64		48	45	36	31	38	,,	,,
	15	,,	108	84	82	64	61	48	44	36	31.5	38.5	,,	,,
	30	,,	108	85	83	64	65	48.5	45	36	32	39	,,	,,
	45	,,	108	84	84	65	65	49	45.5	36.5	32	39	,,	,,
5	0	,,	108	85	85	65	65	49	45	36.5	32	39.5	,,	,,
	15	,,	108	85	85	65	65	49	45.5	37	33	39.5	,,	,,
	30	,,	108	86	85	67	65	48.5	46	37	33	40	,,	,,
	45	,,	107	85	85	67	65	48.5	46	37.5	33	40	,,	,,
6	0	,,	106	85	84	67	65	48.5	46	37.5	33.5	40.5	,,	,,
	15	580	111	86	85	67	65	50.5	47	37.5	34	41	1070	48.5
	30	,,	115	89	87	67	65	51	47	38	34	41	,,	,,
	45	,,	118	92	90	69	65	52	47.5	38.5	34	41.5	,,	,,
7	0	,,	120	93	91	70	65	52.5	48	38.5	34.5	42	,,	,,
	15	,,	122	97	92	73	66	53	48	39	35	42	,,	,,
	30	,,	122	97	92	73	67	53	48.5	39	35	42.5	,,	,,
	45	,,	122	96	93	75	67	53.5	48.5	39.5	35.5	43	,,	,,

Table 6. (Continued)

Time Min.	Time Sec.	Mean Temp. of Gas	Temperature of Piston I3	III	V	IX	XI	Temperature of Cylinder XII	XIV	XVI	Temp. of Circulating Water Inlet WI	Outlet WO	R.P.M. of Engine	B.H.P. of Engine
8	0	580	122	97	93	75	70	53.5	49	39.5	35.5	43	1070	48.5
	15	"	122	98	93	75	70	53.5	49.5	40	36	43.5	"	"
	30	"	122	98	93	75	70	53.5	49.5	40.5	36	43.5	"	"
	45	"	122	98	93	75	70	53.5	49.5	41	36.5	44	"	"
9	0	"	122	98	93	75	71	54	50.5	41	37	44	"	"
	15	650	127	99	95	75	71	55	51	41	37	44.5	1160	61.9
	30	"	132	103	98	76	71	56.5	52.5	41.5	37.5	45	"	"
	45	"	134	105	99	76	72	57	53	41.5	38	45.5	"	"
10	0	"	135	107	100	76	72	57.5	53.5	42	38	46	"	"
	15	"	136	107	100	76	73	57.5	53.5	42.5	38.5	46	"	"
	30	"	136	108	101	78	73	57.5	53.5	43	39	46.5	"	"
	45	"	136	108	101	80	74	57.5	54	44	39.5	47	"	"
11	0	"	136	109	101	80	74	57.5	54.5	44	39.5	47	"	"
	15	"	135	109	101	80	74	56	55.5	44.5	40	47.5	"	"
	30	"	136	110	101	80	74	57	55.5	44.5	40	48	"	"

Table 7. Change of temperature in the piston and cylinder with change of engine speed and power.

Experiment No. 16 July 22, 1921
Atmos. pressure 762.5 Room temperature 26.8° C.
Ignition 30°

Time Min.	Time Sec.	Mean Temp. of Gas	Temperature of Piston I3	III	V	VII	IX	XI	Temperature of Cylinder XII	XIV	XVI	Temp. of Circulating Water Inlet WI	Outlet WO	R.P.M. of Engine	B.H.P. of Engine
1	30		111	94	87	80	76	65	64	59	50.5	46	52		
	45		118	100	91	83	76	65	65	59.5	51	46.5	52.5		
2	0		127	106	96	86	78	66	66.5	60.5	51.5	47	53.5		
	15		134	111	100	89	79	69	67	61.5	52	47	54		
	30	670	142	117	105	92	84	73	69	61.5	52.5	48	54.5	1200	68.5
	45	"	148	121	108	94	87	74	71	61.5	52.5	48	55	"	"

Table 7. (Continued)

Time		Mean Temp, of Gas	Temperature of Piston						Temperature of Cylinder			Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
Min.	Sec.		I3	III	V	VII	IX	XI	XII	XIV	XVI	Inlet WI	Outlet WO		
3	0	670	152	124	110	96	89	75	72	62	53	48.5	55.5	1200	68.5
	15	,,	153	125	111	97	90	75	72	62.5	53.5	49	56	,,	,,
	30	,,	153	126	113	98	90	76	72	63	54	49	56.5	,,	,,
	45	,,	154	126	113	98	91	77	72	63.5	54.5	49.5	56.5	,,	,,
4	0	,,	155	126	113	99	91	78	72	63.5	54.5	49.5	57	,,	,,
	15	,,	155	127	114	99	91	80	72.5	63.5	55	50	57	,,	,,
	30	,,	155	127	114	99	91	80	72.5	64	55	50.5	57.5	,,	,,
	45	,,	156	127	115	100	91	81	72.5	64	55	51	58	,,	,,
5	0	,,	156	128	115	100	91	81	72.5	64.5	56	51	58	,,	,,
	15	,,	156	128	115	100	91	81	73	64.5	56	51.5	58.5	,,	,,
	30	,,	156	128	115	101	91	82	73	65	56.5	52	59	,,	,,
	45	,,	156	128	115	101	93	82	74	65	57	52	59	,,	,,
6	0	,,	158	129	115	101	93	83	73	65.5	57	52	59.5	,,	,,
	15	800	166	133	117	103	93	83	73	66.5	57.5	53	60	1300	87.0
	30	,,	163	135	121	108	93	84	74.5	64	57.5	53.5	60.5	,,	,,
	45	,,	167	134	119	104	94	84	77.5	67	58	53.5	60.5	,,	,,
7	0	,,	179	141	123	107	96	84	79.5	67.5	59	54	61.5	,,	,,
	15	,,	183	144	127	108	99	86	80	68.5	59.5	54	62	,,	,,
	30	,,	186	147	128	110	103	88	79.5	69	60	55	62.5	,,	,,
	45	,,	189	149	129	111	104	88	81.5	69	60	55	63	,,	,,
8	0	,,	191	151	131	113	104	89	82	69.5	60.5	55.5	63.5	,,	,,
	15	,,	191	151	132	113	106	90	83	69.5	61	56	64	,,	,,
	30	,,	193	152	132	113	106	90	83.5	70	61.5	56.5	64	,,	,,
	45	,,	194	153	133	114	106	91	84	70	62	57	64.5	,,	,,
9	0	,,	194	153	134	114	106	91	84	70	62	57	64.5	,,	,,
	15	950	198	155	134	115	105	91	85	70.5	62.5	57.5	65	1420	113.3
	30	,,	202	159	136	117	107	92	86	72	62.5	58	66	,,	,,
	45	,,	207	162	139	119	108		86.5	72.5	63	58	66.5	,,	,,
10	0	,,	210	165	141	121	108	95	88	73.5	63.5	58.5	67	,,	,,
	15	,,	213	167	142	121	111	96	90	74	64	59	67.5	,,	,,
	30	,,	215	167	143	122	112	97	92	74.5	64.5	59.5	68	,,	,,
	45	,,	217	168	144	123	114	97	91	75	65	60	68.5	,,	,,
11	0	,,	217	169	144	123	115	98	92	75	65	60.5	69	,,	,,

Table 7. (Continued)

Time Min. Sec.		Mean Temp. of Gas	Temperature of Piston						Temperature of Cylinder			Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
			I3	III	V	VII	IX	XI	XII	XIV	XVI	Inlet WI	Outlet WO		
	15	950	217	170	145	125	116	98	92	75	65	61	69.5	1420	113.3
	30	"	219	170	145	126	116	99	93.5	75.5	65.5	61.5	70	"	"
	45	"	219	171	147	126	116	99	94	76.5	65.5	62	70	"	"
12	0	"	219	171	147	126	118	100	94.5	76.5	66	62	70.5	"	"
	15	1020	220	171	148	128	118	100	95	77	66.5	62.5	71	1480	128.6
	30	"	221	171	148	128	119	100	97.5	77.5	67	63	71.5	"	"
	45	"	223	172	149		119	101	97.5	78	67.5	63.5	72	"	"
13	0	"	225	174	150		119	102	97.5	78.5	67.5	64	72.5	"	"
	15	"	226	174	151		119	104	97	79	68	64.5	73	"	"
	30	"	226	175	151		119	102	96	79.5	68.5	65	73.5	"	"
	45	"	226	175	151		119	102	97	79.5	69	65	74	"	"
14	0	"	226	175	151		119	103	96.5	80	69.5	65	74.5	"	"

Table 8. Change of temperature in the piston and cylinder with change of engine speed and power.

Experiment No. 17 July 28, 1921
Atmos. pressure 759.7 Room temperature 27.5°C.
Ignition 30°

Time Min. Sec.		Mean Temp. of Gas	Temperature of Piston						Temperature of Cylinder		Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
			I3	III	V	VII	IX	XI	XII	XIV	Inlet WI	Outlet WO		
3	0	900	163	127	108	92	81	73	61	53	30.5	39	1380	103.5
	15	"	168	130	110	94	84	74	62.5	54.5	31	39	"	"
	30	"	172	133	112	96	87	74	63.5	54.5	31.5	40	"	"
	45	"	176	136	114	97	89	75	64.5	54.5	32	40.5	"	"
4	0	"	178	138	115	98	90	75	65	55	32.5	41.5	"	"
	15	"	179	139	116	99	91	78	65.5	56	33	42	"	"
	30	"	180	140	117	100	91	80	66.5	56.5	33.5	42	"	"
	45	"	181	140	118	100	91	81	67	57	34	43	"	"
5	0	"	181	140	118	100	91	82	67	57.5	34	43.5	"	"

Table 8. (Continued)

Time Min.	Time Sec.	Mean Temp. of Gas	Temperature of Piston I3	III	V	VII	IX	XI	Temperature of Cylinder XII	XIV	Temp. of Circulating Water Inlet WI	Outlet WO	R.P.M. of Engine	B.H.P. of Engine
	15	900	181	140	118	100	91	82	67	57.5	35	44	1380	103.5
	30	”	181	141	119	101	91	82	68	58	35	44.5	”	”
	45	”	181	141	119	101	93	82	68	58.5	36	45	”	”
6	0	”	181	141	119	102	93	82	69	58.5	36	45	”	”
	15	1020	183	142	120	102	93	82	69.5	59.5	37	45.5	1480	127.8
	30	”	188	147	122	103	93	82	71.5	58.5	37	46	”	”
	45	”	198	153	126	106	94	82	74	59	38	46.5	”	”
7	0	”	205	158	129	109	96	82	75	59.5	38	47	”	”
	15	”	208	160	132	110	99	86	75.5	60.5	39	48	”	”
	30	”	211	161	133	111	100	87	76	60.5	39	48.5	”	”
	45	”	212	163	134	113	–	–	77	61.5	40	49.5	”	”
8	0	”	212	163	135	113	103	89	77.5	61.5	40.5	50	”	”
	15	”	213	164	136	113	104	89	77.5	62	41	51	”	”
	30	”	214	165	137	114	104	90	78	63	41	51.5	”	”
	45	”	214	165	137	115	105	90	78.5	63	42	51.5	”	”
9	0	”	215	165	137	115	105	91	79	63.5	42.5	52	”	”
	15	1060	217	166	138	115	105	91	80	64	43	52.5	1560	149.5
	30	”	223	170	140	118	107	92	81	64	43	53	”	”
	45	”	226	172	141	119	107	92	82.5	65	44	54	”	”
10	0	”	229	174	144	120	108	94	83	65	44.5	54.5	”	”
	15	”	230	176	144	121	108	94	84.5	66	45	55	”	”
	30	”	232	177	145	121	108	95	84.5	66.5	45.5	55.5	”	”
	45	”	232	177	146	122	110	96	85.5	67	46	56	”	”
11	0	”	233	177	146	122	111	96	86	67	46.5	56 5	”	”
	15	”	233	178	146	122	111	97	86	67.5	47	57	”	”
	30	”	233	178	146	123	111	98	87.5	67.5	47.5	58	”	”
	45	”	233	178	147	123	112	98	88	68.5	48	58	”	”
12	0	”	234	178	147	124	112	98	88.5	69	48.5	58.5	”	”
	15	1080	236	179	148	125	114	98	89	69.5	49.5	59	1670	183.3
	30	”	243	184	152	125	118	98	91	70.5	50	59.5	”	”
	45	”	245	187	153	127	118	98	93	71.5	51	60	”	”
13	0	”	246	188	154	128	119	99	94	71.5	51.5	61	”	”
	15	”	246	188	155	128	119	99	94	72	52	62	”	”

Table 8. (Continued)

Time		Mean Temp. of Gas	Temperature of Piston						Temperature of Cylinder		Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
Min.	Sec		I_3	III	V	VII	IX	XI	XII	XIV	Inlet WI	Outlet WO		
	30	1080	246	188	155	129	119	100	95	72.5	53	62.5	1670	183.3
	45	,,	246	188	155	129	119	100	94.5	73	53	63	,,	,,
14	0	,,	246	188	155	130	119	101	96	73.5	54	63.5	,,	,,
	15	,,	244	187	155	130	119	102	96	74	54.5	64.5	,,	,,
	30	,,	244	187	155	130	119	102	96	73	55	64.5	,,	,,
	45	,,	244	187	155	130	120	102	95.5	73.5	55.5	65	,,	,,
15	0	,,	243	187	155	131	120	103	95.5	73.5	56	66	,,	,,
	15	650	205	169	146	122		102	86.5	71.5	57	65.5	1180	64.8
	30	,,	187	155	136	116		101	84	70.5	57	65	,,	,,
	45	,,	178	149	130	112		100	84	70.5	57	64.5	,,	,,
16	0	,,	172	143	127	110		99	83.5	70	57	64.5	,,	,,
	15	,,	170	141	125	108		98	83.5	70.5	57	65	,,	,,
	30	,,	168	140	123	107		98	83.5	70.5	58	65	,,	,,
	45	,,	168	139	123	107		98	84	70.5	58	65	,,	,,
17	0	,,	168	139	122	107		97	84	70.5	58	65	,,	,,
	15	,,	166	139	122	107		97		71.5	58.5	66	,,	,,
	30	,,	166	139	122	107		97	83.5	71.5	59	66	,,	,,
	45	,,	166	139	122	107		97	83.5	71.5	59	66.5	,,	,,
18	0	,,	166	139	122	107		97	83.5	72	59.5	66.5	,,	,,

Table 9. Change of temperature in the piston and cylinder when the spark is switched off for a few minutes, and after the engine is stopped.

Experiment No. 12 May 28, 1921

Atmos. pressure 756.2 Room temperature 20.5° C.

Ignition 13.7°

Time		Mean Temp. of Gas	Temperature of Piston				Temp. of Piston Ring		Temp. of Cylinder	Temp. of Crank Chamber	Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
Min.	Sec.		I_1	II	VII	IX	IV	VI	XII	CC	Inlet WI	Outlet WO		
6	0	690	143	138	89	76	80	79	50	65	30	36.5	1200	69.4
	15	,,	143	139	89	76	80	79	50	66	30	37	,,	,,

Table 9. (Continued)

Time Min.	Time Sec.	Mean Temp. of Gas	Temperature of Piston I1	II	VII	IX	Temp. of Piston Ring IV	VI	Temp. of Cylinder XII	Temp. of Crank Chamber CC	Temp. of Circulating Water Inlet WI	Outlet WO	R.P.M. of Engine	B.H.P. of Engine
	30	690	144	139	90	77	82	80	50	66	30.5	37.5	1200	69.4
	45	,,	144	140	90	77	82	80	50	67	31	38	,,	,,
7	0	,,	144	140	90	78	82	80	50	67	31	38	,,	,,
	15	,,	144	140	91	78	84	81	52	68		38.5	,,	,,
	30	,,	144	140	91	79	84	81	53	69	32	39	,,	,,
	45	,,	144	140	91	79	84	82	53	69	32.5	39	,,	,,
8	0	,,	144	140	90	79	84	82	53	69	33	39.5	,,	,,
	15	85*	120	115	84	76	84	77	44	69	33	38	1120	56.4
	30	,,	100	91	72	70	79	68	38	67	33.5	36.5	,,	,,
	45	,,	86	81	67	65	70	60	38	66	34	36	,,	,,
9	0	,,	77	73	63	62	68	58	37	63	34	36	,,	,,
	15	,,	73	67	60	60	65	55	37	62	34.5	36.5	,,	,,
	30	,,	69	63	58	59	63	54	37	60	35	36.5	,,	,,
	45	,,	66	61	57	58	63	54	38	60	35	37	,,	,,
10	0	,,	65	60	56	57	60	53	38	59	35	37	,,	,,
	15	,,	64	59	55	57	60	53	38	57	35.5	37	,,	,,
	30	,,	64	58	55	56	58	52	38	57	36	37.5	,,	,,
	45	,,	64	58	55	56	56	52	38	57	36	38	,,	,,
11	0	,,	64	57	55	55	56	52	38	56	36.5	38	,,	,,
	15	,,	64	57	54	55	56	52	38	55	37	38.5	,,	,,
	30	,,	63	57	54	55	56	52	38	55	37	38.5	,,	,,
	45	,,	63	57	54	55	56	50	39	55	37	39	,,	,,
12	0	,,	63	57	54	55	56	52	39	55	37.5	39	,,	,,
	15	690†	86	83	63	58	63	58	51	57	38	42.5	1200	69.4
	30	,,	106	103	72	64	63	66	56	60	38.5	44	,,	,,
	45	,,	122	118	81	70	73	73	56	62	39	44.5	,,	,,
13	0	,,	130	128	85	74	77	78	57	65	39	45	,,	,,
	15	,,	136	133	89	77	84	80	58	67	39.5	46	,,	,,
	30	,,	140	137	91	79	84	82	59	69	40	46	,,	,,
	45	,,	144	140	93	81	84	84	59	72	40	46.5	,,	,,
14	0	,,	146	142	95	82	85	85	59	72	40.5	47	,,	,,
	15	,,	147	144	96	83	87	86	60	73	41	47	,,	,,
	30	,,	147	144	97	84	87	88	59	74	41	48	,,	,,

Table 9. (Continued)

Time		Mean Temp. of Gas	Temperature of Piston				Temp. of Piston Ring		Temp. of Cylinder	Temp. of Crank Chamber	Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
Min.	Sec.		I_1	II	VII	IX	IV	VI	XII	CC	Inlet WI	Outlet WO		
	45	690	147	145	98	84	88	88	60	74	41.5	48	1200	69.4
15	0	”	148	145	98	85	90	89	60	75	42	48.5	”	”
	15	”	150	145	98	85	90	89	61	76	42	49	”	”
	30	”	151	146	98	86	90	90	61	77	42.5	49	”	”
	45	”	151	144	99	86	90	90	62	77	43	49.5	”	”
16	0	”	151		99	87	90	90	62	77	43	50	”	”
	15	”	151		99	87	92	90	62	77	43	50	”	”
	30	”	151		100	88	92	91	62	77	44	50.5	”	”
	45	”	153		100	88	92	91	63	78	44	51	”	”
17	0	”	153	145	100	88	95	92	63	78	44.5	51	”	”
	15	— §	131	118					60	78	44	54	0	0
	30		108	99	93	89			56	78	44	57	”	”
	45		98	91	87	86			55	79	44	59	”	”
18	0		90	83	81	82			55	79	44	60	”	”
	15		86	78	77	79			56	79	44	62	”	”
	30		81	75	75	76			56	78	43.5	63	”	”
	45		79	73	72	74			57	77	43.5	64	”	”
19	0		75	70	70	72			57	77	43.5	65	”	”
	15		73	67	70	70			57	75	43.5	65.5	”	”
	30		72	66	66	69			57	74	43.5	66	”	”
	45		70	65	65	68			57	72	43.5	66	”	”
20	0		69	63	63	67			57	71	43	66	”	”
	15		66	62	63	65			57	70	43	66	”	”
	30		65	61	62	65			57	69	43	66	”	”
	45		64	60	62	64			57	68	43	66	”	”
21	0		64	60	60	62			57	67	43	66	”	”
	15		63	59	59	62			57	66	43	65.5	”	”
	30		63	58	59	61			57	66	43	65.5	”	”

* Sparks switched off.
† Sparks switched on again.
§ Engine stopped.

Table 10. Change of temperature in the piston and cylinder when the spark is switched off for a few minutes, and after the engine is stopped.

Experiment No. 13 — May 30, 1921
Atmos. pressure 762.6 — Room temperature 22.2° C.
Ignition 13.7°

Time Min.	Time Sec.	Mean Temp. of Gas	Temperature of Piston I3	I1	III	VII	XI	Temp. of Piston Ring VI	Temp. of Cylinder XIV	XVI	Temp. of Circulating Water Inlet WI	Outlet WO	R.P.M. of Engine	B.H.P. of Engine
7	0	690	153	147	110	88	68	79	44	30	28	35	1200	69.5
	15	”	154	146	110	88	68	80	45	31	29	35.5	”	”
	30	”	154	147	112	88	68	80	45	31	29.5	36	”	”
	45	”	154	148	112	89	69	80	45	31	29.5	35.5	”	”
8	0	”	155	148	112	89	69	80	45	32	30	37	”	”
	15	84*	122	120	104	80	68		38	31	30	35	1120	56.6
	30	”	96	98	87	69	66	65	36	30	30	32.5	”	”
	45	”	81	85	76	62	63	59	36	31	31	32.5	”	”
9	0	”	73	77	70	58	62	55	36	31	31	32.5	”	”
	15	”	67	72	65	55	60	52	36		31.5	32.5	”	”
	30	”	63	68	63	53	59	50	36		32	33	”	”
	45	”	61	65	60	52	57	49	36		32	34	”	”
10	0	”	60	64	58	51	57	48	36		32.5	34	”	”
	15	”	59	64	56	51	57	48	36		32.5	34.5	”	”
	30	”	57	64	55	50	56	48	36		33	35	”	”
	45	”	57	63	55	50	55	48	37		33	35	”	”
11	0	”	57	62	56	50	55	48	37		33.5	35	”	”
	15	”	57	62	56	50	55	48	37		34	35.5	”	”
	30	”	57	62	56	50	55	48	38		34	36	”	”
	45	”	57	62	56	50	54	48	38		34.5	36	”	”
12	0	”	57	60	56	50	54	48	38		35	36.5	”	”
	15	690†	86	83	66	59	56	55	47		35	40	1200	69.5
	30	”	112	108	70	70	58	65	48	36	35.5	41.5	”	”
	45	”	127	122	96	77	62	72	49	37	36	42	”	”
13	0	”	139	132	101	82	65	76	50	38	36.5	42.5	”	”
	15	”	144	138	104	86	68	79	50	38	37	43	”	”

Table 10. (Continued)

Time	Mean Temp. of Gas	Temperature of Piston					Temp. of Piston Ring	Temp. of Cylinder		Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
Min. Sec		I_3	I_1	III	VII	XI	VI	XIV	XVI	Inlet WI	Outlet WO		
30	690†	149	142	109	89	69	80	51	38	37	43.5	1200	69.5
45	”	152	145	112	91	70	82	51	39	37.5	44	”	”
14 0	”	155	147	115	93	72	83	52	39	38	44.5	”	”
15	”	155	143	115	93	73	85	53	40	38	45	”	”
30	”	155	148	115	94	73	85	53	40	38.5	45	”	”
45	”	156	140	115	94	74	86	53	40	39	45.5	”	”
15 0	”	155	148	114	94	75	86	53	41	39	46	”	”
15	”	155	149	114	94	75	86	54	41	39.5	46	”	”
30	”	156	150	115	95	76	86	54	42	40	47	”	”
45	”	155	143	115	95	76	87	54	42	40	47	”	”
16 0	”	155	150	114	95	76	83	56	42	40.5	47	”	”
15	”	153	143		95	76	88	54	42	41	47.5	”	”
30	”	154	148		95	76	87	56	43	41	48	”	”
45	”	155	150		95	77	88	56	43	42	48	”	”
17 0	”	156	151		96	77	88	56	43	42	49	”	”
15	—§	123	128		91	71	85	40	43	41.5	51	0	0
30		103	110	104	85	70	82	50	44	41.5	53.5	”	”
45		96	98	96	79		78	51	45	41.5	56.5	”	”
18 0		87	90	85	75		72	51	45	41	58	”	”
15		81	84		70		69	53	45	41	60	”	”
30		75	81		67		66	53	45	41	61.5	”	”
45		72	77		64		63	56	45	41	62	”	”
19 0		70	73		63		62	56	45	41	63	”	”
15		67	72		61		60	56	44	41	63.5	”	”
30		65	70		59		59	56	44	41	64	”	”
45		64	69		58		57	56	43	41	64	”	”
20 0		62	66		57		56	56	43	41	64	”	”
15		60	65		56		55	56	43	41	64	”	”
30		60	64		54		54	54	43	41	64	”	”
45		59	64		54		53	53	43	41	64	”	”
21 0		57	63		53		52	53	42	41	64	”	”
15		57	62		53		51	53	42	41	63.5	”	”
30		56	61		52		51	51	42	41	63.5	”	”

Table 10 (Continued)

Time	Mean Temp. of Gas	Temperature of Piston					Temp. of Piston Ring	Temp. of Cylinder		Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
Min. Sec.		I_3	I_1	III	VII	XI	VI	XIV	XVI	Inlet WI	Outlet WO		
45		55	60		52		50	51	42	41	63	0	0
22 0		54	59		51		50	51	42	41	63	,,	,,
15		54	57		50		49	50	42	40.5	63	,,	,,
30		53	57		50		49	50	42	40.5	63	,,	,,
45		52	56		49		49	49	42	40.5	62.5	,,	,,
23 0		52	56		49		48	49	43	40.5	62.5	,,	,,

* Sparks switched off.
† Sparks switched on again.
§ Engine stopped.

Table 11. Change of temperature in the piston and cylinder with that of cooling water.

Experiment No. 17a — July 28, 1921
Atmos. pressure 759.7 — Room temperature 27.5° C.
Ignition 30°

Time	Mean Temp. of Gas	Temperature of Piston					Temperature of Cylinder		Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
Min. Sec.		I_3	III	V	VII	XI	XII	XIV	Inlet WI	Outlet WO		
19 0	660	165	138	122	107	97	83.5	73	61	67.5	1180	64.8
15	,,	165	139	122	107	97	84	73.5	61	68	,,	,,
30	,,	165	138	122	108	97	84	73.5	61	68	,,	,,
45	,,	165	139	122	108	97	84.5	74	62	68.5	,,	,,
20 0	,,	165	139	122	107	96	77.5	64			,,	,,
15	,,	162	133	116	98	90	55	42	22	32	,,	,,
30	,,	156	127	111	94	88	51	39.5	22	31	,,	,,
45	,,	152	122	106	90	84	49.5	39	22	30.5	,,	,,
21 0	,,	147	118	103	88	82	49.5	39	22	30.5	,,	,,
15	,,	145	116	101	86	81	49.5	39.5	22.5	30.5	,,	,,
30	,,	143	115	100	85	80	49.5	39.5	23	30.5	,,	,,
45	,,	143	115	99	85	78	49.5	40	23	31	,,	,,
22 0	,,	142	114	99	85	78	49.5	40	23	31.5	,,	,,

Table 11. (Continued)

Time Min. Sec.	Mean Temp. of Gas	Temperature of Piston I3	III	V	VII	XI	Temperature of Cylinder XII	XIV	Temp. of Circulating Water Inlet WI	Outlet WO	R.P.M. of Engine	B.H.P. of Engine
15	660	141	113	98	84	78	50	40	24	31.5	1180	64.8
30	"	141	113	97	84	78	50	40	24	32	"	"
45	"	141	112	97	84	78	50.5	40.5	24.5	32.5	"	"
23 0	"	141	112	99	86	77	63.5	53.5	56	50	"	"
15	"	143	118	105	87	78	77.5	68	59	62	"	"
30	"	150	124	110	97	81	82	70.5	60	66	"	"
45	800	154	128	114	101	82	83	71.5	60.5	67	1300	86.5
24 0	"	163	134	116	103	83	85.5	72.5	61	68	"	"
15	"	176	143	123	108	84	87.5	73	62	68.5	"	"
30	"	183	149	127	111	87	87.5	74	62	69.5	"	"
45	"	186	151	130	113	89	88.5	74.5	63	70	"	"
25 0	"	189	154	132	115	90	89	75	63	70.5	"	"
15	"	191	155	134	116	90	89.5	76	63.5	71	"	"
30	"	191	156	134	116	92	90	76	64	71.5	"	"
45	"	192	157	135	117	94	90	77	64	72	"	"
26 0	"	194	158	136	117	94	91	77	64.5	72	"	"
15	"	194	158	136	118	95	90.5	77	65	72.5	"	"
30	"	194	158	136	118	96	91	77.5	65	72.5	"	"
45	"	194	159	137	118	97	91	78	65.5	73	"	"
27 0	"	195	159	137	119	97	91.5	78.5	66	73	"	"
15	"	194	159	137	119	98	91.5	79	66	73.5	"	"
30	"	195	159	137	119	98	91.5	79	66.5	74	"	"
45	"	194	159	138	119	98	91.5	79	67	74	"	"
28 0	"	195	160	138	119	98	92	79.5	67	74.5	"	"
15	"	195	159	138	119	99	92.5	80	67.5	75	"	"
30	"	194	160	138	120	99	92.5	80	68	75	"	"
45	"	195	160	139	120	100	93	80	68	75.5	"	"
29 0	"	195	160	139	119	100	80	64.5	30.5	55	"	"
15	"	192	155	132	109	98	65	48	27	38	"	"
30	"	186	149	126	105	94	61	45.4	27.5	37	"	"
45	"	182	145	122	102	92	60.5	46	28	37	"	"
30 0	"	179	142	120	101	90	60.5	46	28.5	37.5	"	"
15	"	176	140	118	100	89	60.5	46.5	29	37.5	"	"

Table 11. (Continued)

Time Min. Sec.	Mean Temp. of Gas	Temperature of Piston					Temperature of Cylinder		Temp. of Circulating Water		R.P.M. of Engine	B.H.P. of Engine
		I3	III	V	VII	XI	XII	XIV	Inlet WI	Outlet WO		
30	800	174	140	117	99	88	60.5	47	30	38	1300	86.5
45	”	174	139	117	99	88	61	47.5	30	38.5	”	”
31 0	”	174	139	117	99	88	61.5	47.5	31	39	”	”
15	”	174	139	117	99	87	61.5	48	31	39.5	”	”
30	”	174	139	117	99	87	61.5	48	31.5	39.5	”	”
45	”	174	139	117	99	86	61.5	48	32	40	”	”
32 0	”	174	139	117	99	86	62	48	32	40.5	”	”

Table 12. Relation between temperature in the piston and the engine power. (Piston temperature is measured above that at the exit of cooling water.)

Experiment No.	B. H. P. of Engine	Mean Temperature of Gas	Temperature of Piston					
			I3	III	V	VII	IX	XI
15	28.8	490	60	40	39		24	16
”	37.3	530	69	46	45		26	24
”	48.5	580	79	54	50		31	26
”	61.9	650	89	62	54		34	26
16	68.5	670	98	69	56	42	34	23
”	87.0	800	130	88	68	49	41	26
”	113.3	950	149	100	76	56	46	29
”	128.6	1020	153	102	78		45	29
17	103.5	900	137	96	75	55	48	37
”	127.8	1020	162	113	84	62	52	37
”	149.5	1060	175	120	88	64	54	39
”	183.3	1080	186	127	92	66	56	38

第五號

大正十一年十二月發行

抄録

航空發動機の氣筩及「ピストン」に於ける溫度の分布と其變化

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航空發動機に於ては極めて輕く且つ小さい氣筩から比較的甚だ大なる動力を發生せしめるので,氣筩や「ピストン」は強く熱せられる傾向を有して居り,且つ溫度の不同のために大なる內力を受ける場合が多い．從て氣筩や「ピストン」を設計するに當り先づ溫度の分布を基として內力の狀況を研究し,又各種の遊隙を算定することが最も必要なる事項である．即ち發動機設計の基礎として上記溫度の分布及其變化を實驗的に見出すことが本研究の目的である．

氣筩及び「ピストン」に於ける溫度の分布は發動機の種類構造等の如何により異なるのであらう．又同一發動機に於ては其運轉狀況の如何によりて異なるのであらう．是等種々の場合を一々研究することは到底不可能であるが,本研究は Liberty 型 Hall-Scott 200 馬力の水冷却式發動機に就き其鋼製氣筩と「アルミニウム」製「ピストン」に關する實驗であつて,且つ其發動機の通常運轉狀態の場合に限りたるものである．發動機の過熱されたる場合とか或は廻轉速度の過大なる場合とかの如きは本研究の範圍外である．

第一圖は此の氣筩及「ピストン」の寫眞であつて其寸法及び斷面は第五圖に示した．

動力測定には係數既知の「ファンブレーキダイナモメーター」を使用し,發動機の廻轉速度と大氣の溫度及壓力とで馬力を決定した．

本實驗に於て氣筩及「ピストン」等比較的低溫度の部分の測定には何れも銅線と「コンスタンタン」線の「カップル」を使用し,又氣筩內の瓦斯の溫度を測定するには白金及白金「ロヂウム」線の「カップル」を使用した．冷却水の溫度の測定には鋭敏なる水銀溫度計を使用した．

本實驗は發動機の始動する場合,廻轉速度及馬力の增減する場合,氣

筩內爆發中絕の場合,冷却水の溫度が變る場合等に就て氣筩及「ピストン」に於ける溫度の分布と其變化を硏究し同時に全力運轉の際の溫度分布を決定したものである.

其の溫度分布の實況は多樣であつて本文中の表或は曲線により之を知るの外はないが結果の概略を記すと次の通りである.

1. 發動機の運轉狀況が良好である場合各部分の溫度は一定の速度及荷重に對し略々一定の定常値を有して居り發動機始動後約三分間でこの狀態に達する.

2. 運轉中馬力及速度を變化した場合にも同樣に約三分間で各部の溫度は定常狀態に落付く.

3. 氣筩壁の溫度は冷却水の溫度に平行する. 氣筩下部の溫度は主として冷却水の溫度に影響され瓦斯の溫度に殆んど無關係である. 全力運轉に於て氣筩頭部の溫度は冷却水の出口より高きこと約50度以內である.

4.「ピストン」の溫度は瓦斯の溫度の影響を蒙ること勿論であるが冷却水の影響もかなり受ける. 其頭部中央に於ける溫度の變化は瓦斯溫度の變化の約1/5乃至1/7であり同時に冷却水溫度の變化の約1/2である.

5.「ピストン」最高溫度は冷却水の出口より高きこと約200度で頭部周圍では同じく約130度,又裾では約30度である. 此等の溫度は氣筩壁の摩擦の影響によりて大に變ずる樣である.

6.「ピストンリング」の溫度は其の接せる「ピストン」體の部分の溫度より數十度低い.

7. 爆發中絕の場合の各部の溫度は一齊に降下し互に接近して約三分間で平衡する. 發動機止轉の場合には約五分間で冷却される.

8.「ピストン」頭の周圍に近き部分及側壁には大なる溫度の傾度が生ずる.

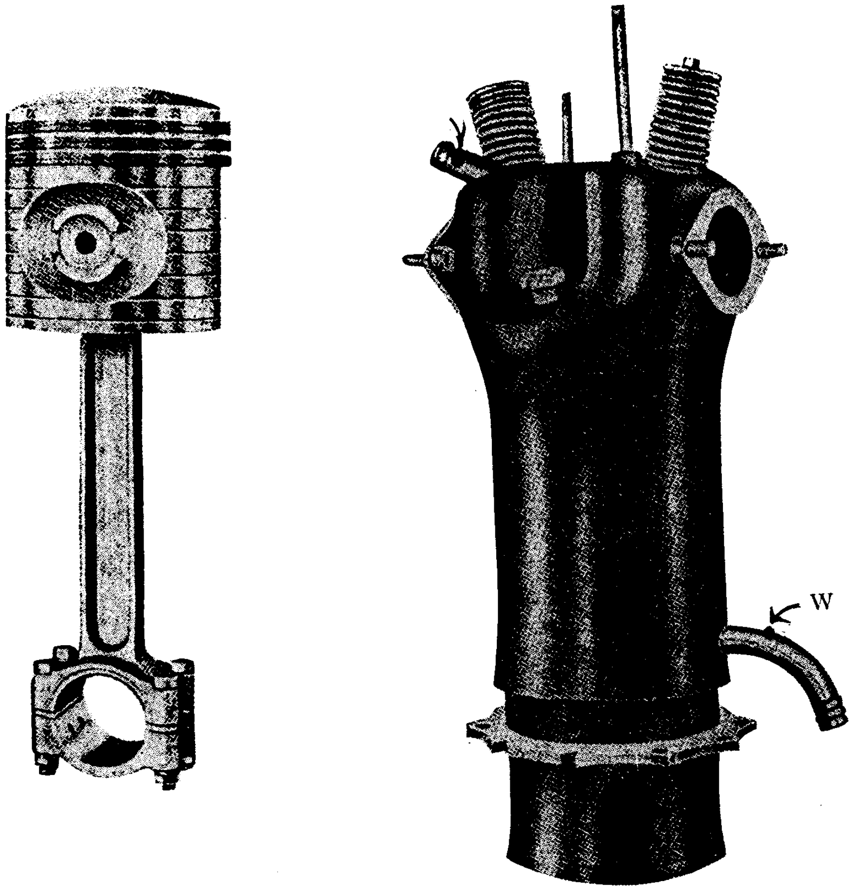


Fig. 1. Piston and Cylinder

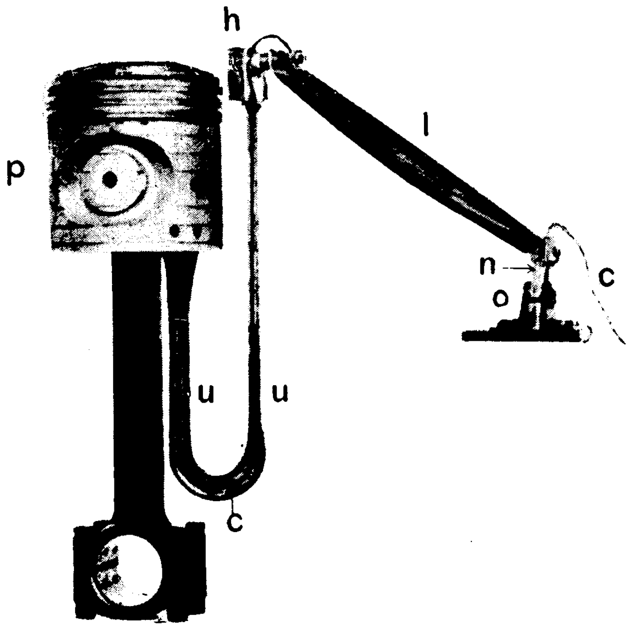


Fig. 2.

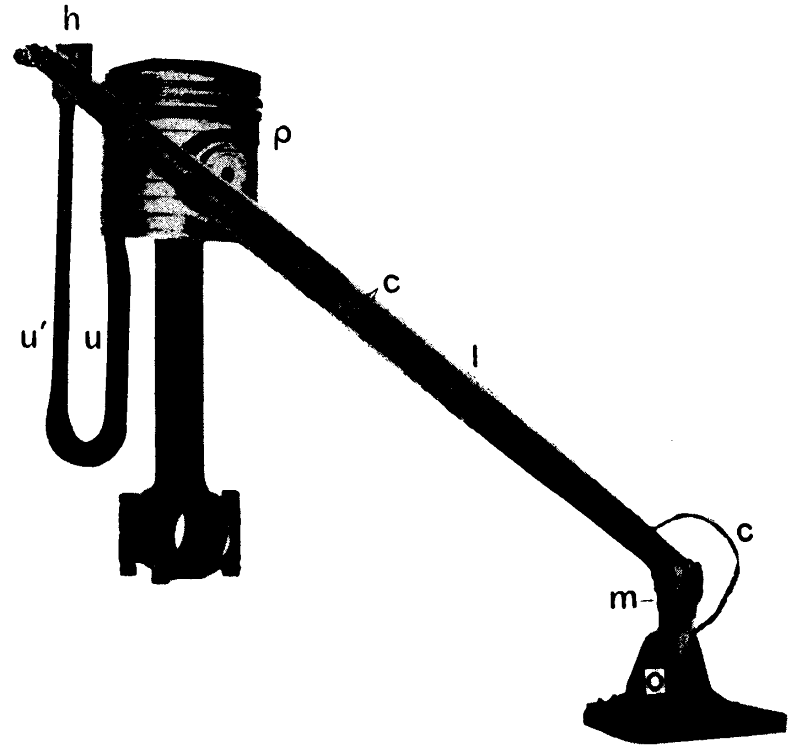


Fig. 3.

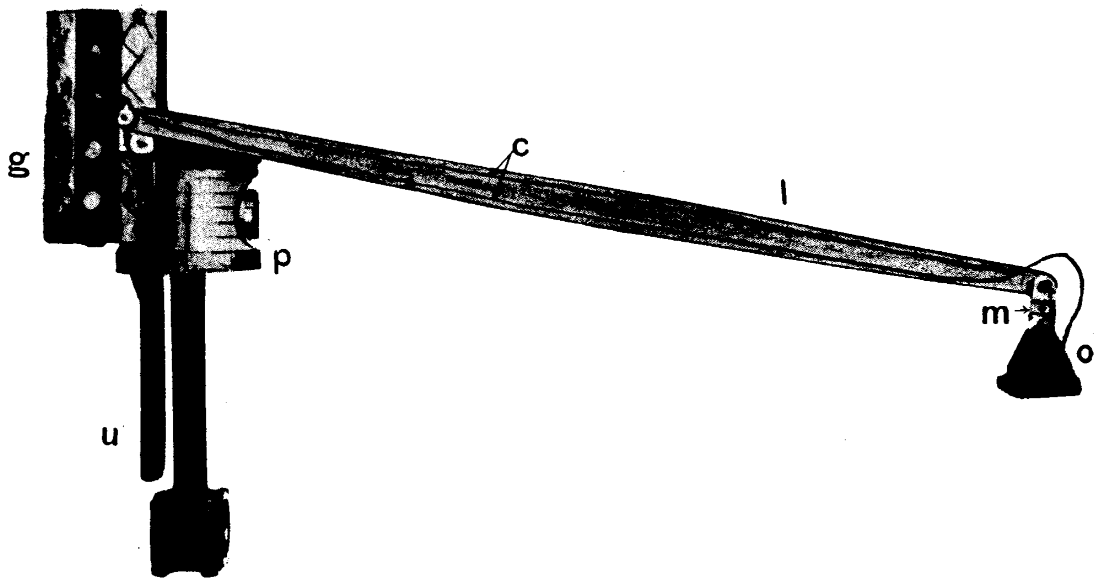


Fig. 4.

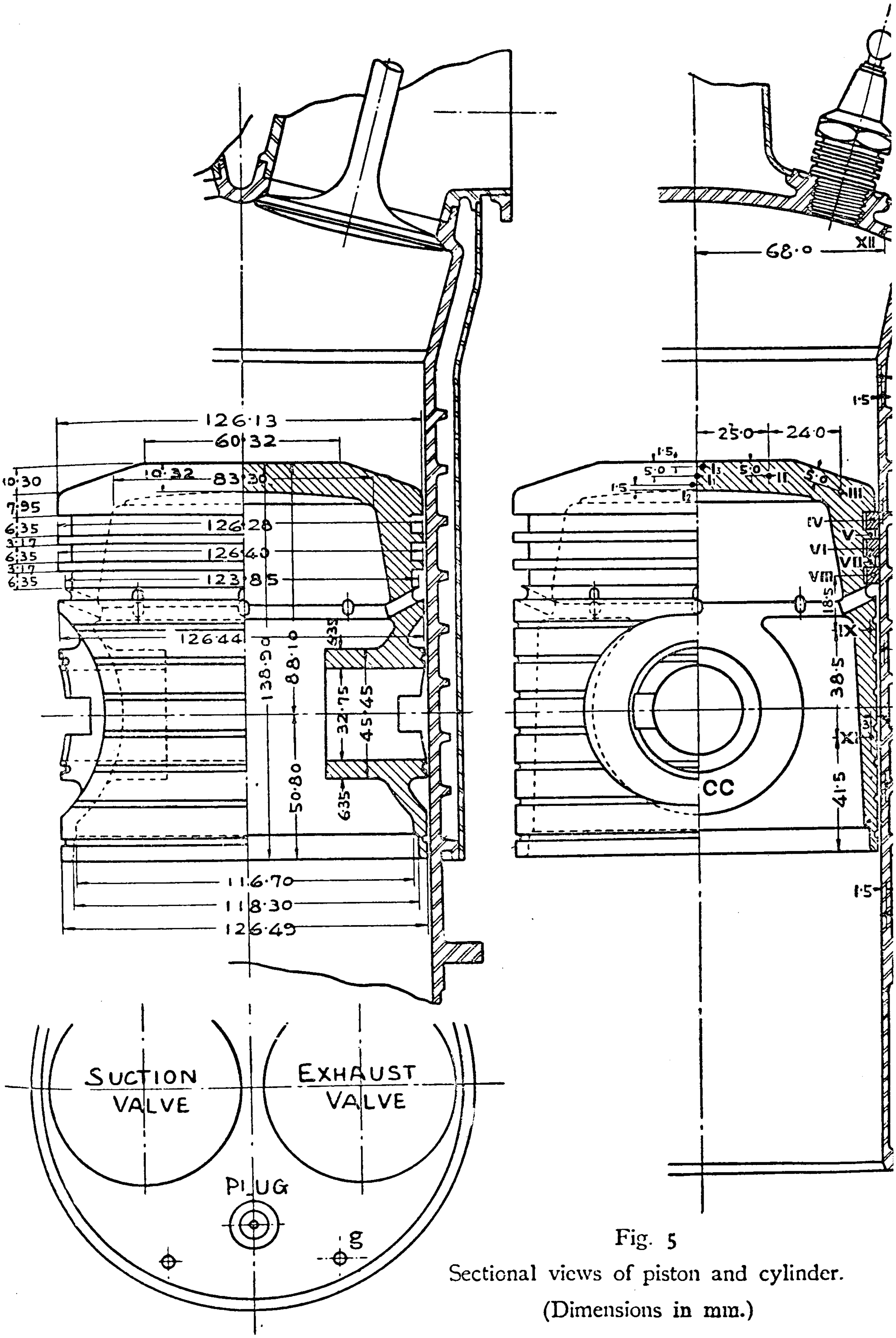


Fig. 5
Sectional views of piston and cylinder.
(Dimensions in mm.)

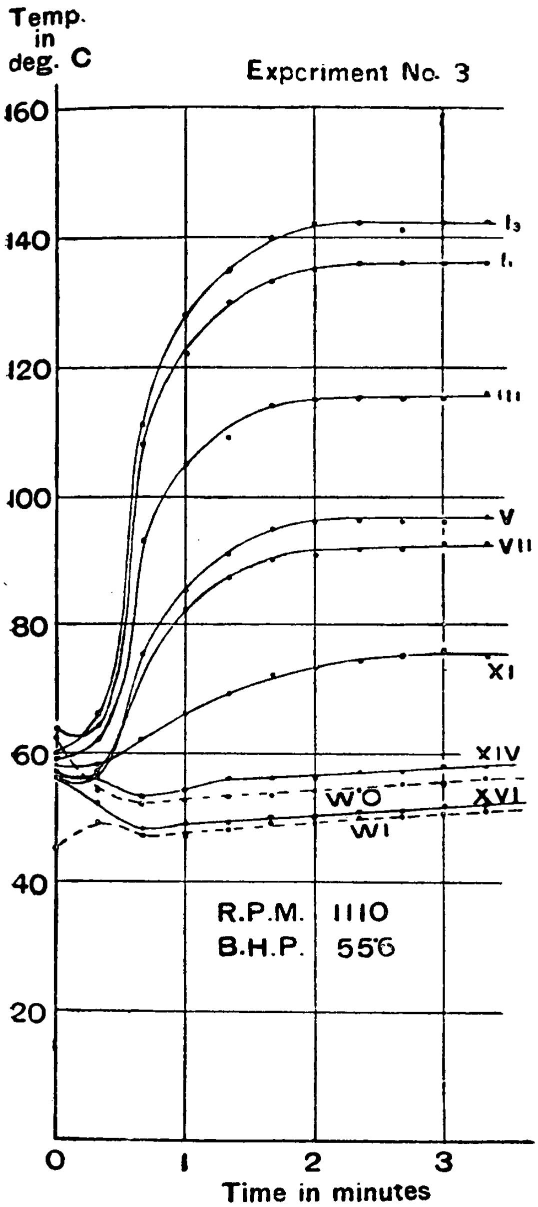


Diagram 1. Rise of temperature in the piston and cylinder when the engine is starting.

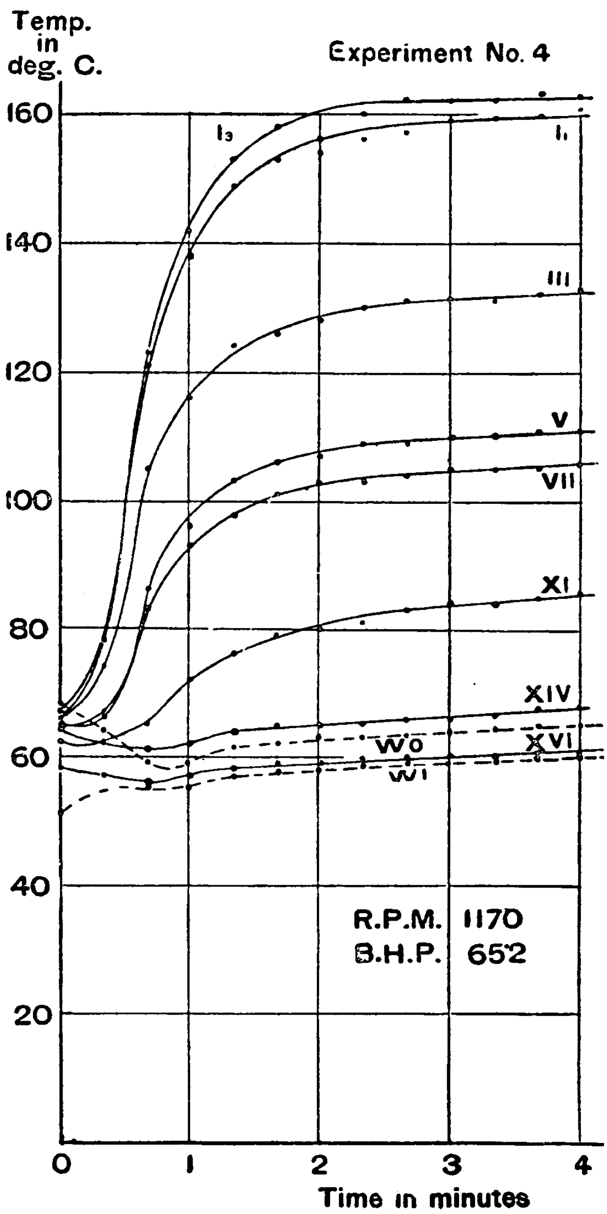


Diagram 2 Rise of temperature in the piston and cylinder when the engine is starting.

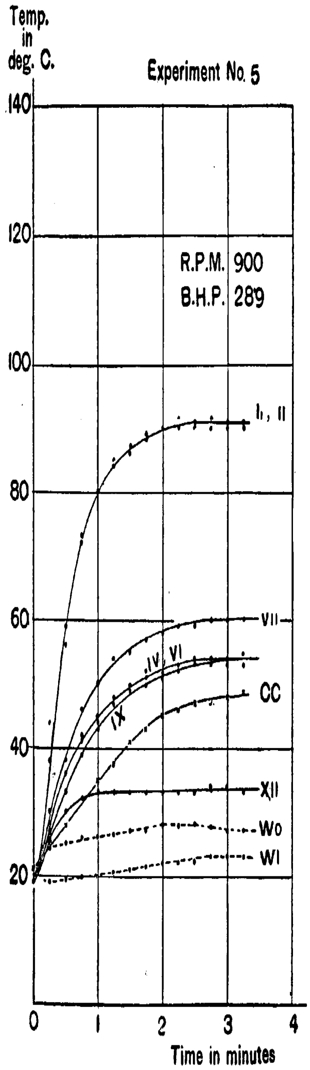


Diagram 3. Rise of temperature in the piston and cylinder when the engine is starting.

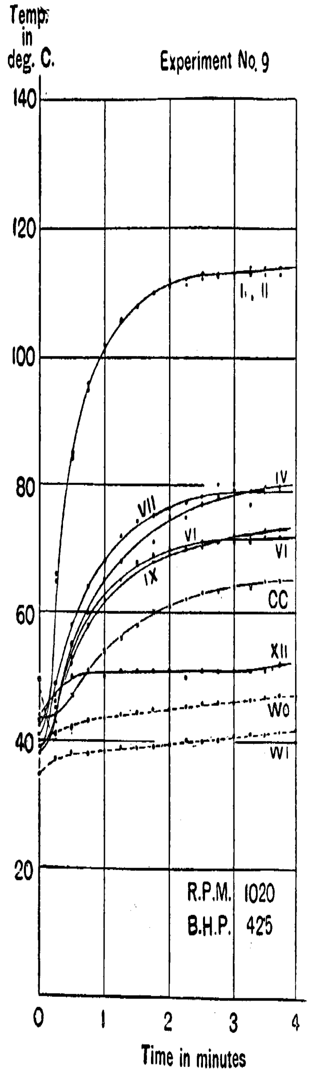


Diagram 4. Rise of temperature in the piston and cylinder when the engine is starting.

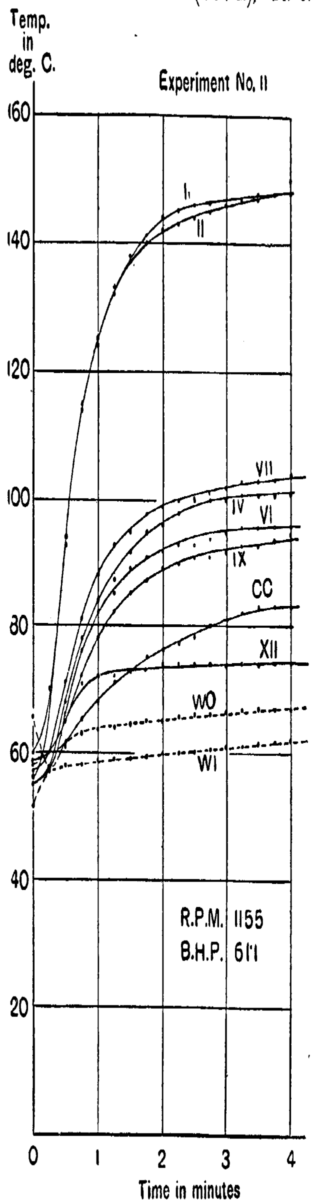


Diagram 5. Rise of temperature in the piston and cylinder when the engine is starting.

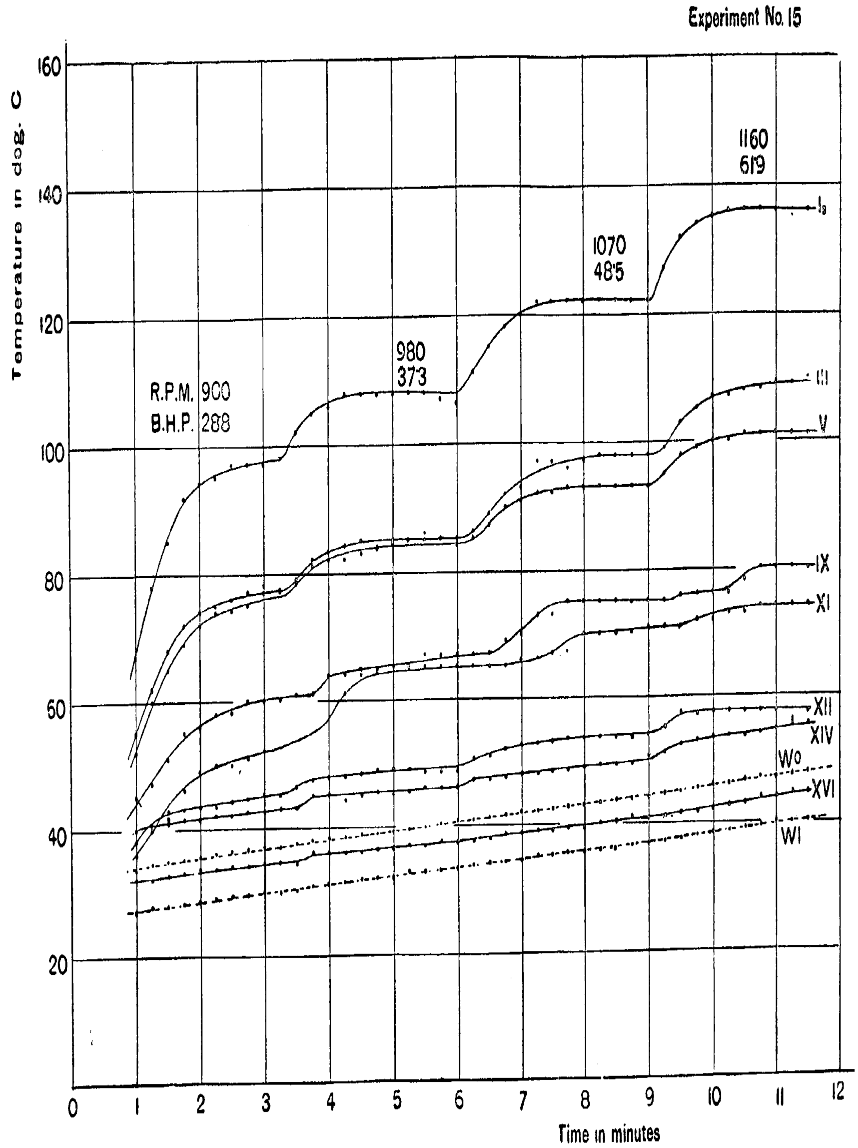


Diagram 6. Change of temperature in the piston and cylinder with change of engine speed and power.

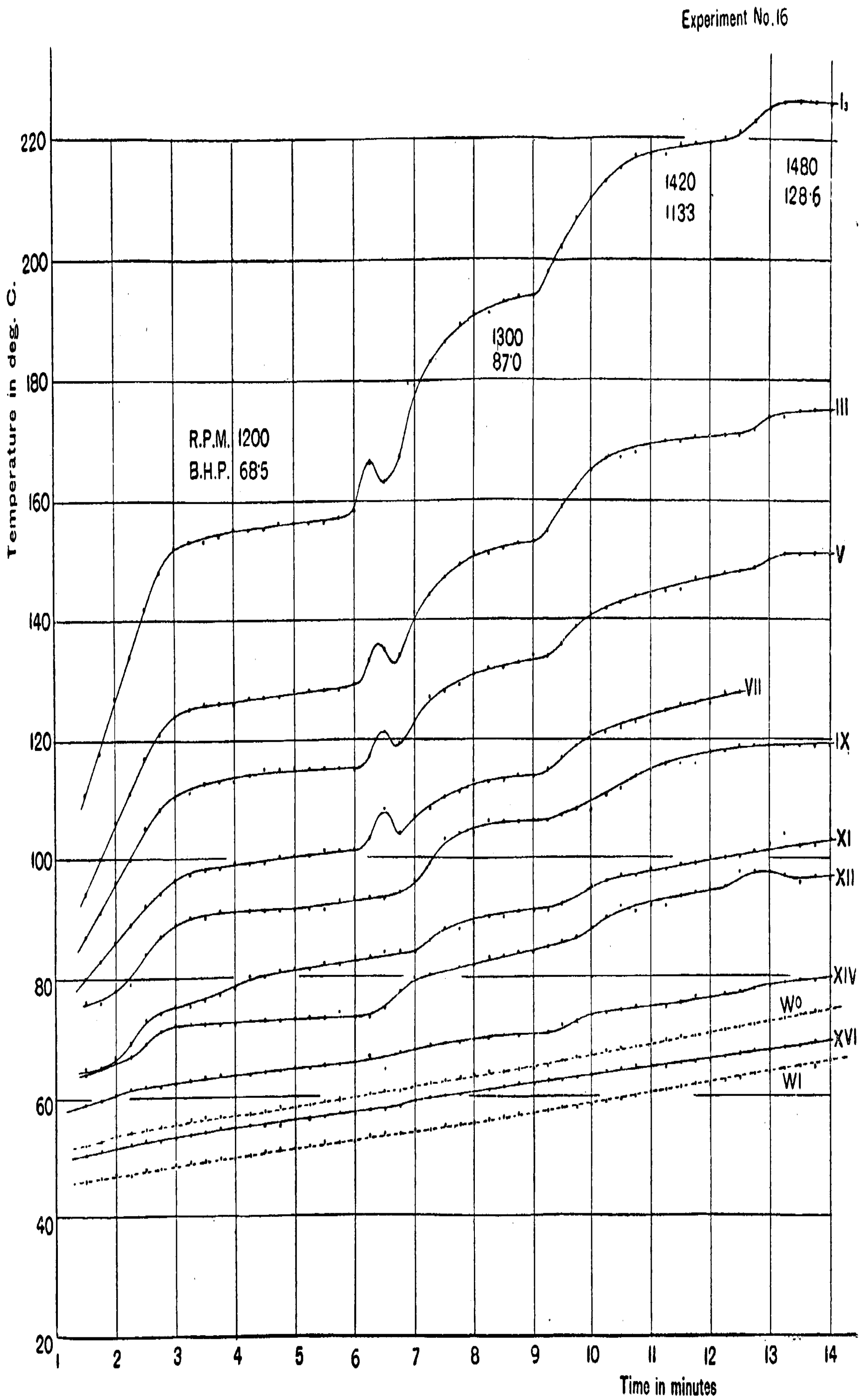


Diagram 7. Change of temperature in the piston and cylinder with change of engine speed and power

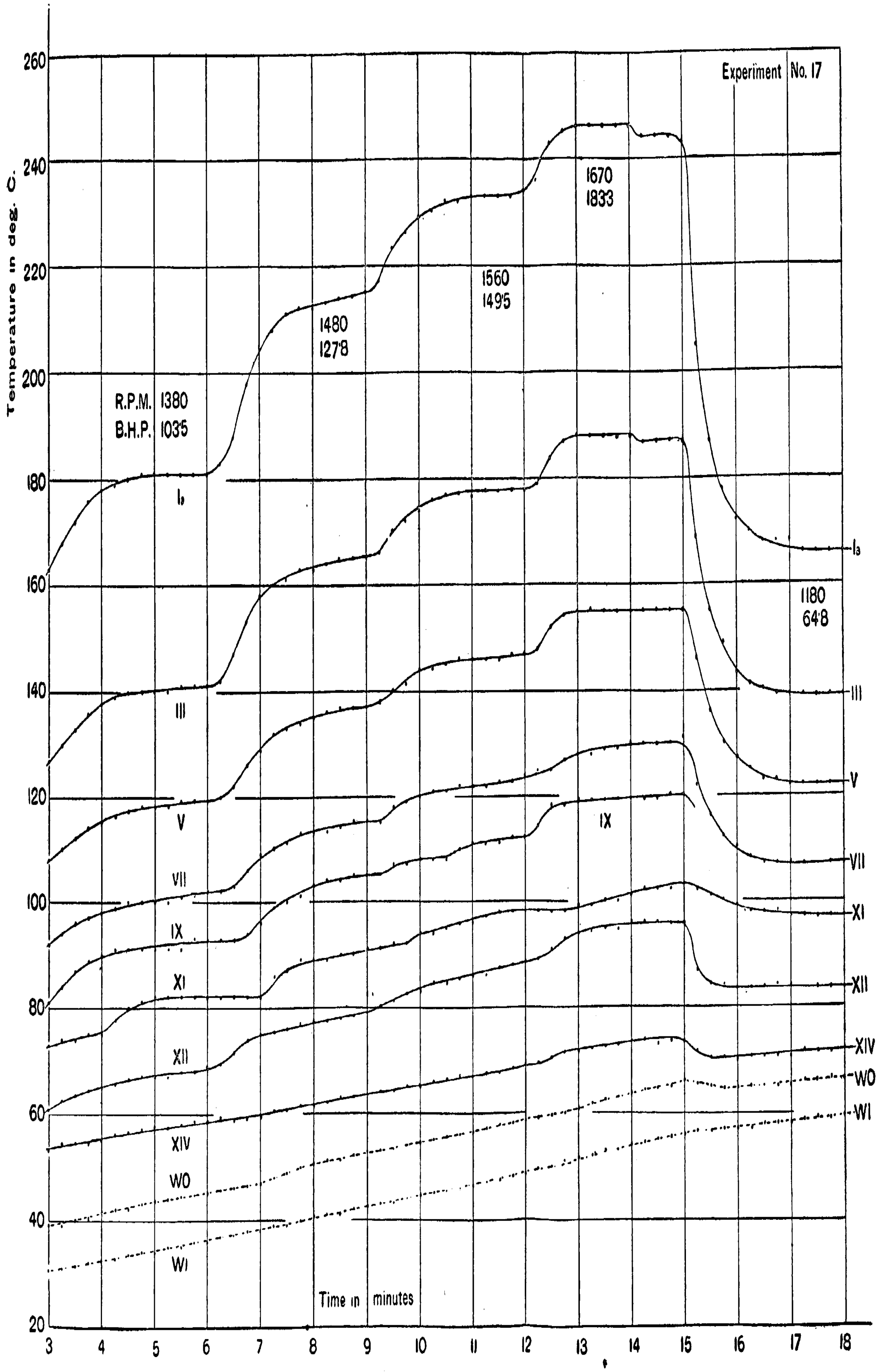
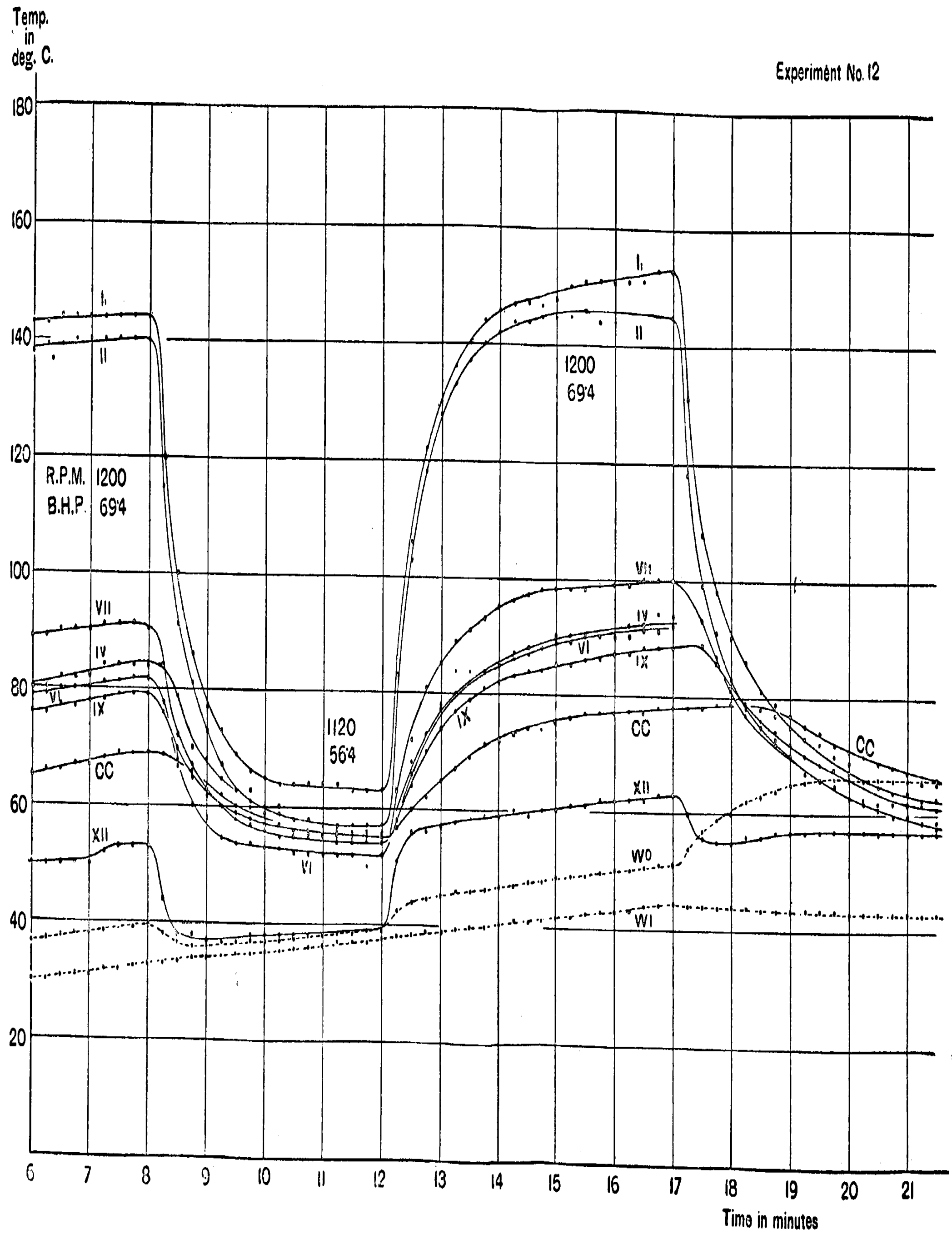


Diagram 8. Change of temperature in the piston and cylinder with change of engine speed and power.



Diagram, 9. Change of temperature in the piston and cylinder when the spark is switched off for a few minutes, and after the engine is stopped.

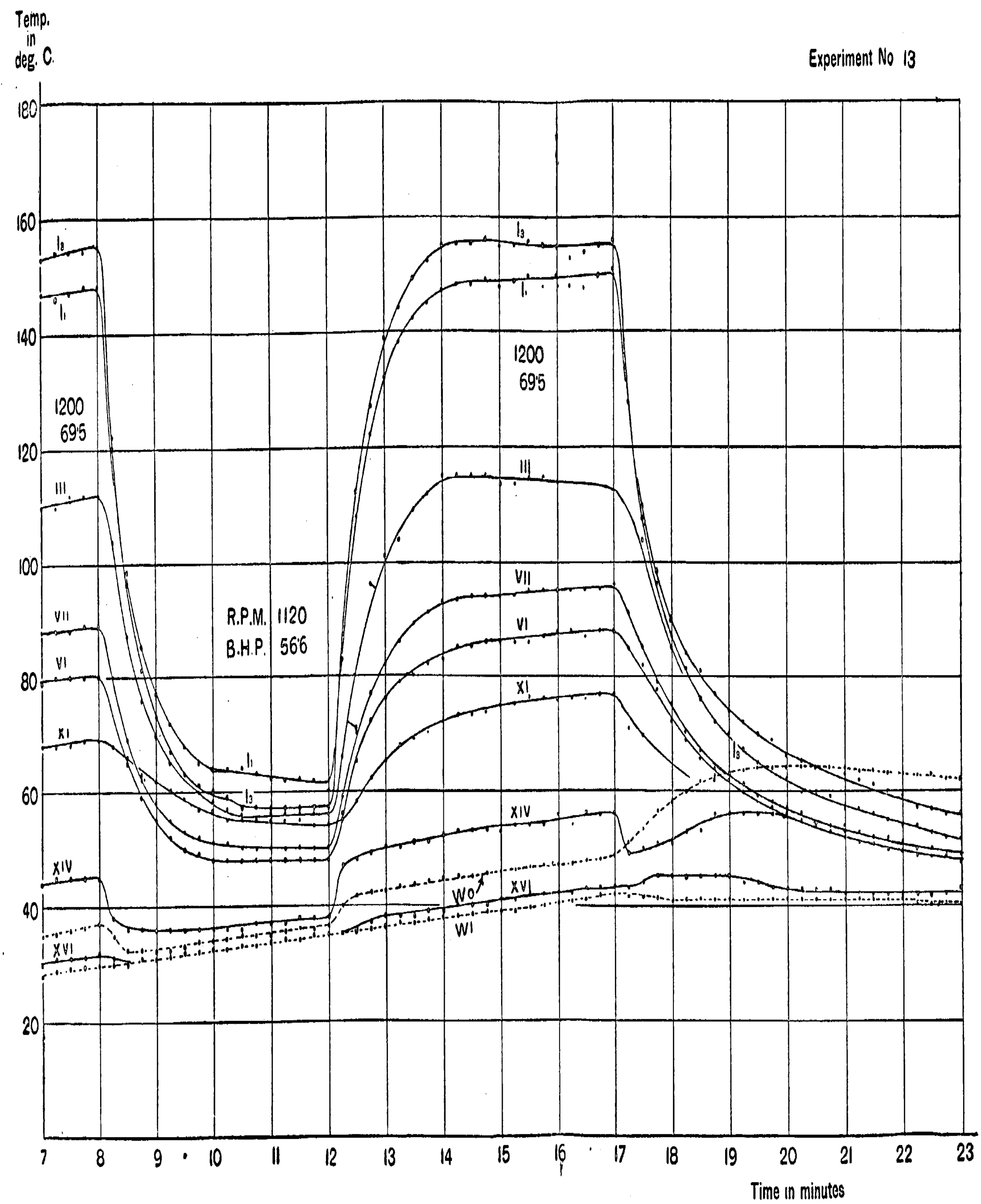


Diagram 10. Change of temperature in the piston and cylinder when the spark is switched off for a few minutes, and after the engine is stopped.

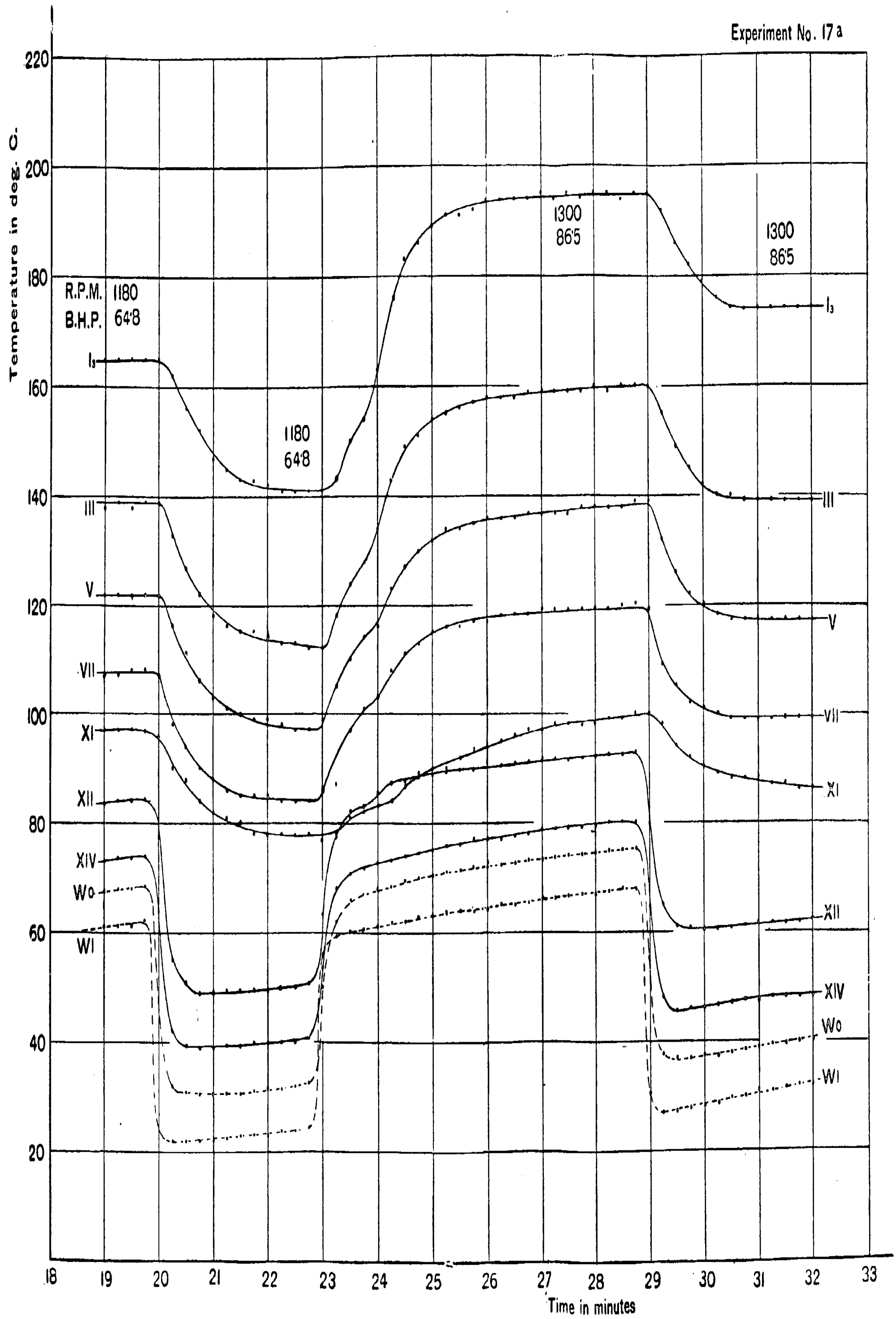


Diagram 11. Change of temperature in the piston and cylinder with that of cooling water.

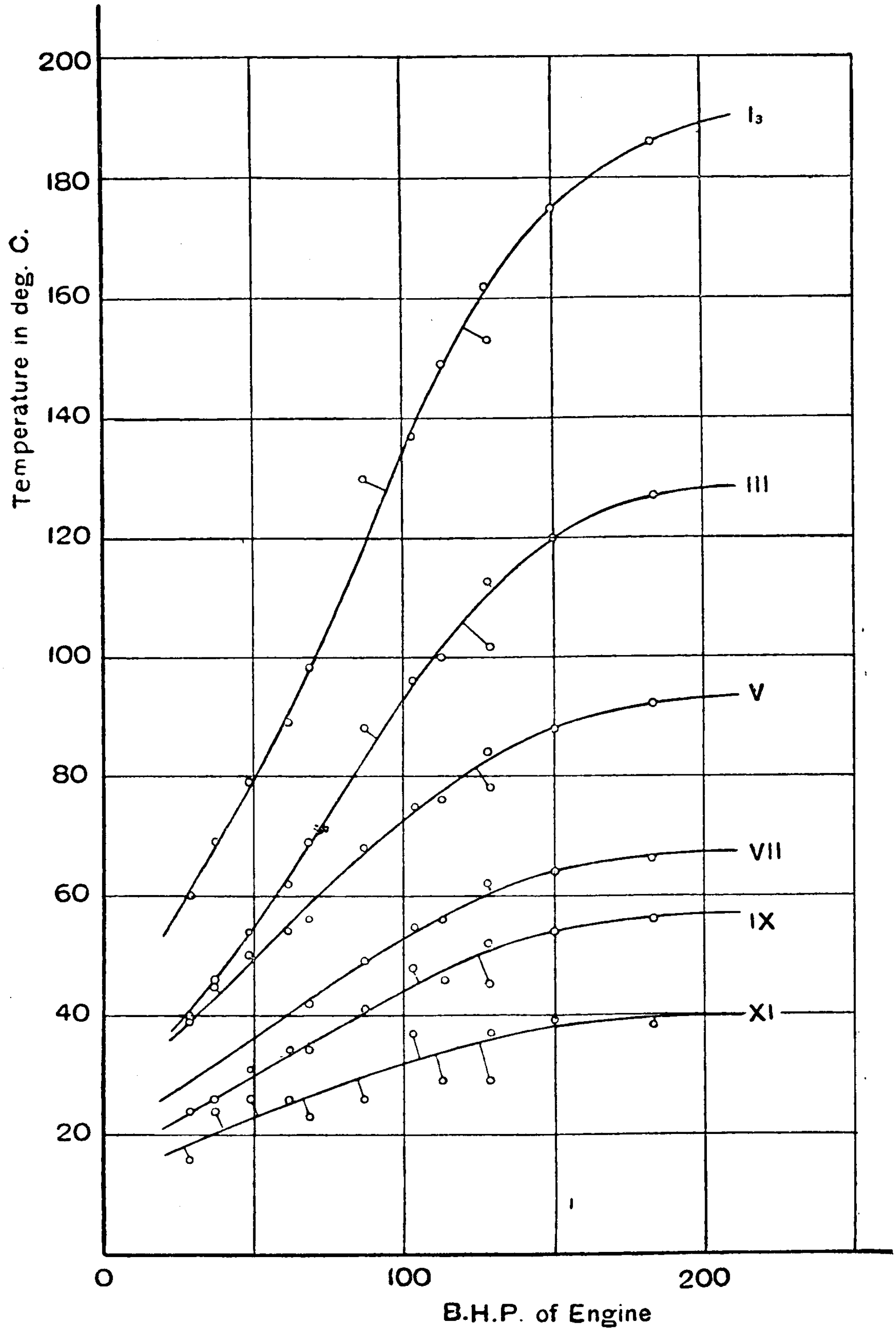


Diagram 12. Relation between temperature in the piston and the engine power. (Piston temperature is measured above that at the exit of cooling water.)