CARBURETTER ACTION.

BY EVAN P. TAYLOR, B.E., HALL FELLOW.

(Paper read before the Sydney University Engineering Society, on August 11th, 1915.)

LIST OF SYMBOLS USED THROUGHOUT THE PAPER.

Q = Quantity of air in cubic feet per second.
q = Quantity of fuel in gallons per hour.
A^1 = Area of cylinder in square inches.
A = Area of choke tube in square inches.
a = Area of jet orifice in square inches.
d = Diameter of jet orifice in inches.
L = Length of stroke in inches.
n = Number of cylinders.
N = Number of R.P.M.
V = Velocity of air through choke in feet per second.
v = Velocity of fuel through jet in feet per second.
h = Suction head in inches, water.
c = Co-efficient of efflux through choke.
α, β and γ Are constants.
K = Ratio of density of charge actually drawn in to density of charge at atmospheric pressure.

CARBURETTER ACTION.

1. INTRODUCTORY.—Of all the parts that together make up the complete automobile or motor cycle, none is so delicate in its action as the carburetter.

The magneto is decidedly a more delicate piece of construction, but the conditions under which it works are not nearly so variable and severe as those which the modern carburetter has to meet.

The primary function of a carburetter is to convert the liquid fuel into a vapour, mixed with a correct amount of air, in order to produce under all circumstances the most suitable explosive charge in the cylinder of the engine.

This paper proposes to deal only with light-spirit carburetters of the ordinary jet-spray type. A brief discussion of the processes which take place in the simplest of this type of carburetter exposes its defects; and an outline of the various methods employed by carburetter-makers to minimise them, leads to the principle that was adopted in producing still another design of carburetter. In order to collect sufficient data for this purpose, a series of experiments were conducted in the Mechanical Laboratory of this Engineering School during 1912. An experimental carburetter was built, having a brass framework, but using glass where possible, to enable observation of the mechanical action of the carburetter to be made.

The necessary suction, in the first set of experiments was produced by a motor-driven fan. Later, a four-cylinder 15-h.p. motor-car engine was used.

One valuable result of testing the same carburetter on an engine, after the fan suction experiments, was to show that there was no appreciable difference in the action on the carburetter.

The general scheme of the experiments was to measure the fuel, benzine of s.p. g.r. ·70, supplied to the carburetter, and the volume of air drawn through to mix with it. The latter quantity was varied by altering the speed of the fan in the first series of experiments, and by altering the brake on the engine when the latter was being used. The resulting quantities of air and fuel were plotted as a curve, showing the relation between them for any particular size of jet, choke-tube, or throttle opening. These results were further reduced to a general equation, which holds for the particular brand of benzine, used at the temperature at which the experiments were conducted.

Simple Carburetter.—The simplest construction of a jet-spray carburetter (Figure 1), entails three parts. A choke-tube attached to the end of the induction pipe, a jet, and a float, whereby the level of the fuel is kept just below the top of the jet when suction ceases.

A partial vacuum is produced in the induction or suction pipe of the engine. Atmospheric pressure causes a flow of air into the pipe through the choke-tube, and at the same time, atmospheric pressure on the fuel in the float chamber forces a stream of fuel through the jet. This stream, mingling with the rapidly-moving air, forms a spray, and the liquid partially vaporises in the pipe. Observation leads to the conclusion that, if complete vaporisation takes place in an engine, it mostly occurs while the mixture is passing the hot valves, and while in the still hotter cylinder. Until the engine warms up the vaporisation is by no means complete; and it is for this reason that a richer proportion of fuel to air is necessary when starting up a cold engine, in order that what liquid does vaporise may be sufficient to produce a correct mixture with the air.

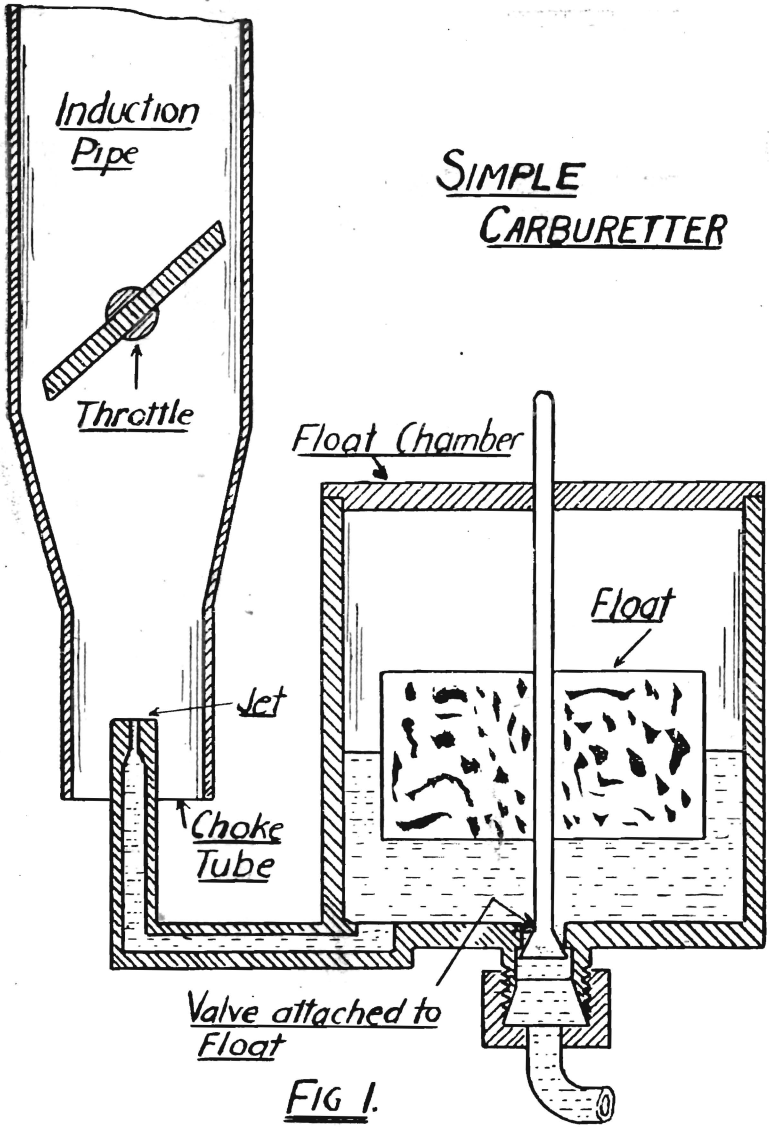
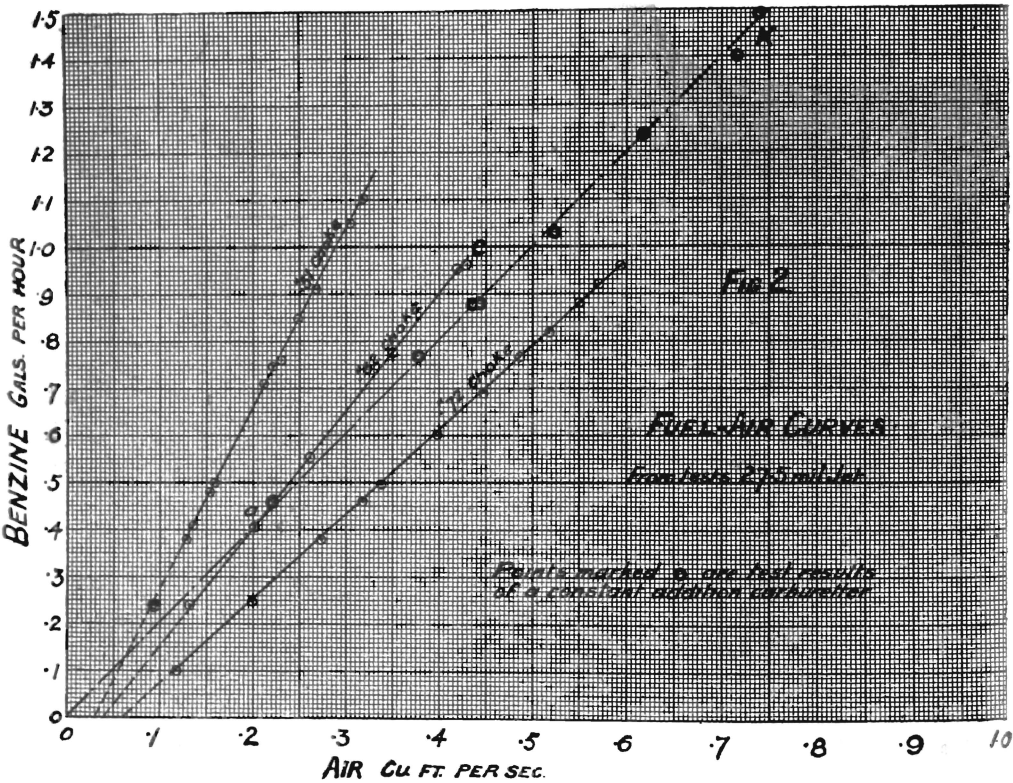


FIG I.

The action of a carburetter can best be described by referring to its "characteristic curve." Such a curve shows the relation between the fuel in gallons per hour passing through the jet, and the air, measured in cubic feet per second. These units have been chosen in order that a simple comparison may be made at any time with actual performances by motor-car engines on the road or bench.



A curve representing a mixture of constant and correct proportion is shown by OK, Figure 2.

Whereas a simple carburetter would produce a curve c, as shown in Figure 2, at only one point, a, on the curve c is the proportion of fuel and air correct. If the engine be running so as to draw 0·2 cubic feet per second of air through the choke, and the jet were of a suitable bore, to pass 0·4 gallons of benzine an hour, a satisfactory condition would exist. But now, suppose the load on the engine to be increased, and its speed to fall, so that only 0·1 cubic feet of air is flowing through the choke, the corresponding amount of fuel will be 0·15 gallons per hour. This, by comparison with the correct mixture curve, is seen to be too weak a mixture: "popping back" would occur in the carburetter, and the engine would stop. It would be difficult to start the engine, since it will not run below a speed corresponding to a suction of ·2 cubic feet of air per second. The popular method of flooding the carburetter, or injecting benzine into the engine, makes starting possible under these circumstances; but the engine is not able to run at slow speeds. Incidently, this is why an engine cannot be made to run slowly if there are air leaks in the induction pipe, etc. On the other hand, with this size of choke and jet (actually ·62in. choke diam. and 27·5—1,000in. jet), an increase in the suction causes too rich a mixture. The effect of this is not, up to a certain point, so manifest as in the case of the weak mixture, for the engine continues to run. But "choking" occurs since the mixture is not of the best proportion for complete and consequently rapid combustion. Waste of fuel, a sooted engine and spark plugs, and loss of power are the chief disadvantages.

It follows that this carburetter would not be satisfactory where a variable speed engine was required. It is eminently suitable for stationary engines, working under fairly uniform loads and speeds, and consequently is usually fitted to such engines; but for road vehicles it has to be considerably modified.

The effect of fitting a smaller choke or larger jet, is roughly to swing the characteristic curve into a steeper position, about some imaginary point P (approximately — ·1 galls. per hour), on the zero air ordinate. If a smaller choke of say ·51in. diameter be fitted, then the "characteristic" curve will cut the correct mixture curve at a consumption of .06 cubic feet of air per second, enabling the engine to run at a corresponding slower speed than with the ·62in. choke. Starting up will be very much easier, too, but at anything above slow speeds the mixture will be much too rich.

3. Modifications to Simple Carburetter.—There are obviously three directions in which improvements may be made in these defects:—

a.—By supplying extra air.
b.—By varying the choke area.
c.—By varying the jet opening.

a. Extra Air.—An extra air opening, governed by a valve of the sliding piston type, and controlled by hand, is almost a universal fitting, even on carburetters that rely for their automatic action on other methods. It is useful to correct the influence of changes in the weather. For, whatever means are adopted to improve the action of a simple carburetter, it will be upset by a change in the temperature of the benzine; the warmer the liquid the less viscous it becomes, and consequently, for the same suction, a greater quantity passes through the jet. This richer mixture requires that the extra air port should be opened more.

Most motor-cycle carburetters are forms of the simple type, with a hand-controlled extra air inlet. This necessitates a control lever for the extra air, as well as one for the throttle.

On the other hand, car-designers prefer to have only the throttle lever to manipulate, and most car carburetters are of the automatic form.

The most prevalent automatic design favours an extra air inlet, operated by the suction pressure in the carburetter. The tendency of the mixture to become too rich with increasing suction (i.e., decreasing absolute pressure) is neutralised by a valve, which opens wider the greater the suction, letting in more air to mix with the fuel. The valve is controlled either by a spring or by gravity. In general, the former is liable to derangement, due to weakening of the spring and injudicious adjustment; whereas the latter is more susceptible to jolts and vibrations. Both may be upset by friction, grit, and wear, and both are incapable of correct adjustment for all conditions. For it does not necessarily follow that, in every position of equilibrium under suction and spring, the air valve is passing the correct quantity of air.

Some carburetters have been designed with the extra air valve inter-connected with the throttle. This cannot give a correct mixture under all ordinary conditions, as one simple case will show. Imagine the engine at full-speed and throttle full open. A hill is encountered and the speed falls. Leaving the throttle as it is, the carburetter behaves just like a simple one; and, if the mixture were about correct at first, it will soon become too weak, just when full-power is required. It is well known that, with a carburetter of this pattern, closing the throttle has the paradoxical effect of increasing the "pull" of the engine when forced to go slower, due to the extra air opening being reduced.

b. Varying Choke.—The second device consists in enlarging the size of the choke-tube as the suction increases. The necessary apparatus may be inter-connected with the throttle or operated by suction; in either case, the same objections hold as for the extra air port, and being mechanically more difficult to arrange than an extra air valve, it is very seldom adopted.

Both devices, a and b, have the advantage of keeping the velocity of the air through the choke-tube more uniform than would otherwise be the case. This is important, as the following consideration will show. It is necessary to attain a certain initial suction before any benzine issues from the jet, for until this point is reached, the surface tension of the liquid prevents its outlet. A greater suction still is advisable, in order to produce a good spraying action, by giving the fluid and air a fair velocity. These considerations require that, at slow engine speeds, the choke-tube should be relatively small. On the other hand, at high speeds, the velocity of air through this choke would be high enough to produce a serious throttling effect on the engine, if there were no extra air opening or expandable choke.

Still, a considerable increase in the suction, from lowest to highest speeds, is necessary, even with these modifications, in order to draw an increased supply of fuel through the jet.

It is in connection with this that the third method is employed—variable jet.

c. VARIABLE JET.—It might be possible, by varying the size of the jet opening, to regulate the characteristic curve of a carburetter, in order to bring it into line with the correct mixture curve; but the limits of low and high velocity in the choke would be too far apart if this method alone were relied upon.

Combined with a variable extra air or choke, it serves a very useful purpose, for in this way it is possible to keep the velocity in the choke within as reasonable limits as desired.

A well-known carburetter is fitted with a jet whose orifice is controlled by a tapered needle in it, inter-connected with the throttle. Opening the throttle withdraws the needle a little, and so enlarges the jet. Also, the carburetter is supplied with an extra air valve, controlled by an adjustable spring, and operated by the suction in the carburetter.

In any one position of the throttle the extra air valve has to accommodate the varying suction. Opening the throttle to obtain more power from the engine also enlarges the jet, and so it is not necessary that proportionately greater suction should occur in the carburetter in order to draw in the requisite increased supply of fuel. In this way, the suction may remain almost the same by using a large enough extra air valve and suitable spring.

In another example of what is usually termed a "constant vacuum" carburetter, the jet needle is inter-connected with a suction-operated variable choke. By this means it is possible to keep the suction approximately constant, and the choke and jet areas can be designed to give very nearly a correct mixture in all positions.

But the jet being such a fine part, there are difficulties, when manufacturing it and the jet needle, in keeping exactly to the dimensions required by the design.

The foregoing carburetters have to rely, in general, on mechanical arrangements that are the more delicately and intricately controlled in those designs which achieve the best results, and are the more liable on that account to get out of adjustment.

d. CONSTANT ADDITION.—There is another principle on which to base the design of a correct mixture carburetter, which Figure 2 will help to explain. In describing Figure 2, it was stated that increasing the jet, or decreasing the choke, tended to swing the characteristic about the Point P into a steeper slope. Conversely, increasing the size of the choke would make the curve become less steep, until a suitable one was chosen to make the characteristic come parallel to the correct mixture curve. A simple carburetter with this choke and jet would produce a mixture at all times too weak, but such, that, if by suitable means a constant small addition of fuel (·1 gallons per hour) were added, the characteristic would be made to coincide with the correct mixture curve. This would be so irrespective of suction, position of throttle, or speed of engine.

Several carburetters have been designed on this principle, but have fallen short of the ideal in the unsuccessful attempt to supply a constant addition of fuel. Constructional difficulties have resulted in this quantity being more or less varying.

The author designed and constructed a carburetter which, on testing, gave a constant mixture under all conditions of engine speed and throttle opening. The results of these tests will be given later.

4. Description of Apparatus.—In order to collect data sufficient for designing a carburetter of the "constant addition" type, numerous tests were made on a simple type of carburetter.

Carburetter.—In Figure 3 is seen the general shape of the experimental carburetter. A brass cylindrical throttle chamber was connected above to the induction pipe by a glass tube 8ins. long, and below was provided with a glass choke-tube, fitted in by means of a tight leather ring. One side of the throttle chamber was made also of glass, so that the whole passage of the fuel stream could be watched for a distance of about one foot. The jet was screwed into a projection from the float chamber, in order that the fuel level could be adjusted to any height in it. The float chamber was made separately from the throttle chamber, in order that the height of the jet in the choke could be varied at will.

Jets varying from 27.5 to 39.5 mils or thousandths of an inch diameter, and choke tubes of ·51in. to 1·15in. diameter, were provided.

The temperature of the liquid in the float chamber was observed by placing a thermometer through a cork in the cover.

Fuel Measurement.—Benzine from a supply tank was led through a burette to the carburetter. The burette was specially made, and found very convenient. It consisted of three glass bulbs, the bottom one being 110 cc., and the two upper 50 cc. each, terminating in a long tube extending to above the height of the petrol in the tank. Below the bottom bulb were

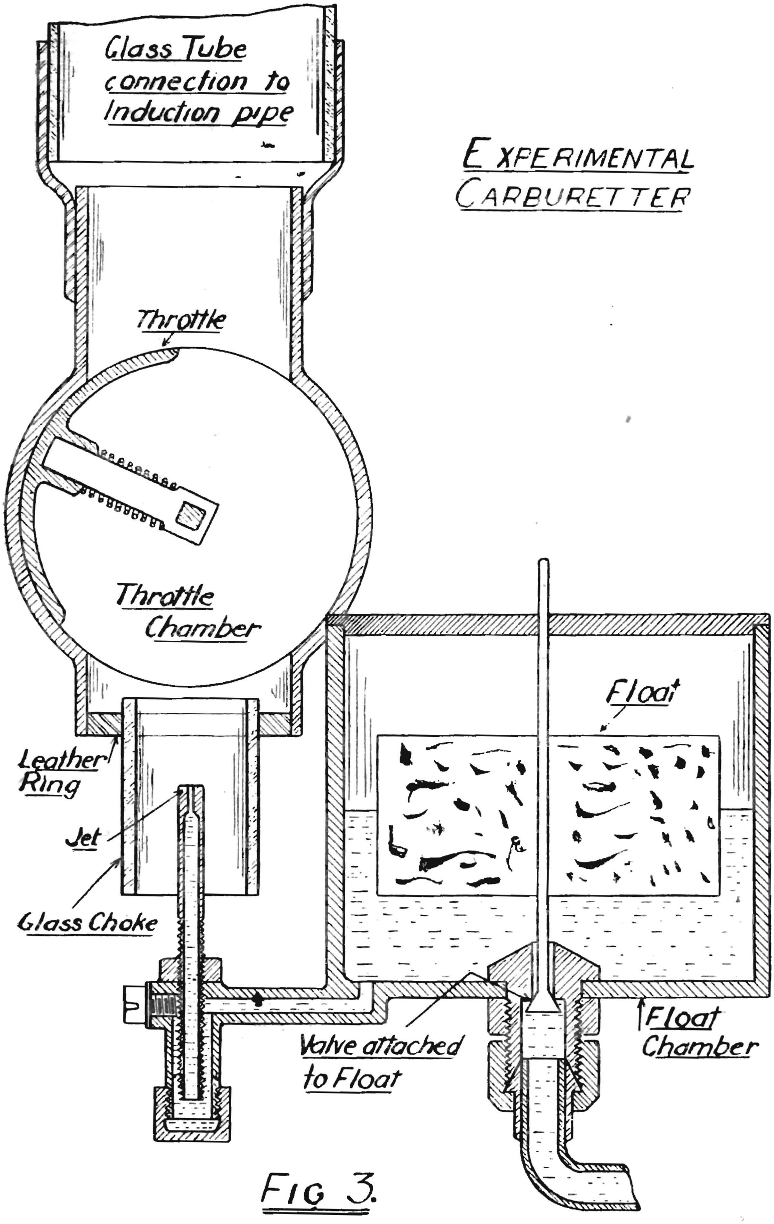


Fig 3.

two cocks; by keeping both open a free supply of fuel was allowed to the carburetter and engine until suitable running conditions had been arranged. The inlet cock was then closed, and the instant the fuel passed the zero mark on the long stem of the burette, a stop-watch for timing the consumption was started. At the end of 50 cc. the liquid passes a mark on the construction between the two bulbs, and the time for the consumption cf 50 cc. may be taken. Longer runs, using 100, 160, or 210 cc. of fuel, are possible with this burette.

Air Measurement.—The volume of air immediately after passing through the carburetter was measured by an orifice type of air meter. This piece of apparatus was used only in the fan-suction experiments. When the carburetter was connected to the engine a calibrated manometer in the choke-tube was used, as will be described later. The air-meter was of the thin-plate orifice type. It was found necessary to considerably enlarge the section of the meter on each side of the orifice, and to place the latter at a suitable distance from the carburetter, in order that the change in the size of the choke-tube might not affect the calibration of the air-meter.

Different sized orifices were cut in a plate—¼ sq. in., ½ sq. in., and 1 sq. in. area—anyone of which could be slid into operation. By this means a suitable reading on a water-manometer was obtained over the whole range through which the air volume varied. This manometer measured the difference of air pressure on either side of the orifice, and, to give a magnified scale, was inclined at a slope of 1 to 3.

The air-meter was calibrated by means of a gasometer of known dimensions. The bell of the gasometer was raised by counterweights, and, being connected by a length of piping to the air-meter and carburetter, drew air through the latter at a steady rate. The time taken for a 45in. rise enabled the quantity of air in cubic feet per second to be calculated. Calibration curves, in which these values were plotted against the corresponding manometer readings, were drawn for the three sizes of orifices.

When experimenting with the carburetter on the engine, the air-meter could not be used; and, to measure the quantity of air under these conditions, a fine tube was inserted in the choke-tube of the carburetter, and connected to another water manometer. With any one choke-tube, the greater the quantity of air flowing through the choke the greater is the velocity of the air, and consequently the greater is the head producing this velocity. It is this head that the manometer measures. Calibration tests were carried out on the carburetter when connected to the air-meter, and curves of suction head and quantity of air were drawn from the results. Having these new curves, one for each choke-tube, the air-meter could be dispensed with when testing the carburetter on the engine.

Electric-Driven Fan.—In the preliminary set of experiments, air was drawn through the carburetter by means of a centrifugal fan. A 1-h.p. D.C. motor placed outside the carburetter room, about 30 feet away, drove the fan, which was connected, on the suction side, to the carburetter by 3in. down-piping, well soldered, and painted at joints.

The fan motor was controlled by water rheostats placed conveniently in the carburetter room.

Car-Engine.—In later experiments, the carburetter was fitted to a four-cylinder Clement-Bayard car-engine. The engine was mounted on a special bench, and arranged to be driven, through a clutch, by a 5-h.p. electric motor. This arrangement was convenient, when it was not possible or desirable to drive the engine under its own power. At the same time, it formed a ready means of starting up the engine when it could be run by fuel.

The dimensions of the engine were as follows:—

Number of Cylinders	4, water-cooled.	
Bore	85 m.m., or	3·35in.
Stroke	120 m.m. ,,	4·72in.
Area of Cylinder ..	56·8 sq. c. ,,	8·8 sq. in.
Valve Diameter ..	34 m.m. ,,	1·34in
Valve Lift..	8 m.m. ,,	·315in.

Valve Setting.—

Inlet opened 20° past top dead-centre.

Inlet closed 20° past bottom dead-centre.

Exhaust opened 125° past top dead-centre.

Exhaust closed 15° past top dead-centre.

The cylinders were of the T-headed pattern, i.e., exhaust valves on one side of the engine and inlet valves on the other.

Fan Brake.—For loading the engine and running brake-tests a fan brake, calibrated by the makers, was used. The brake was supplied with three sets of vanes: 1 sq. ft., ½ sq. ft., and ¼ sq. ft. area. A pair of these could be attached to the arms at any of 15 holes. When in the outermost holes the centres of the vanes were approximately 2ft. 6in. apart.

A series of curves were drawn from the maker's co-efficients, showing the relation between H.P. and R.P.M. for the various vanes and holes. A glance at the tachometer and the curves showed at once the B.H.P. being developed.

Speed Measurement.—A hand tachometer was attached to the frame of the machine, and was driven by a spring belt from a small pulley on the engine shaft to one of the same size on the tachometer.