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Technique of Measuring Gas Stream Velocity by means of Electric Discharge*

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A new measuring technique of gas stream velocity, based on the phenomena that the path of electric discharge moves downstream under influence of gas stream, has been developed. A probe, a thin conductive wire grounded by a resistor, is placed at a distance l downstream from electrodes. When the discharge path arrives at the probe, the probe voltage rises rapidly. By means of measuring the time interval τ , elapsing between the beginning of spark and the rising of probe voltage, the stream velocity w can be determined by the formula, $w=kl/\tau$, where k is a constant, independent of distance l , intensity of turbulence, temperature and pressure of flowing gases. The value of k depends only on electrode spacing. Digital measurement of τ can be made easily. This technique can be applied to not only steady but pulsating flow such as suction flow of internal combustion engines.

1. Introduction

Up to the present, various techniques of measuring gas stream velocity using electric discharge have been developed. Stankewitsch⁽¹⁾ measured successfully the gas velocity in the exhaust tube of a two-stroke diesel engine, using an ion cloud generated by electric spark. Saheki⁽²⁾ measured velocity profiles of boundary layers by means of double sparks. Bomelburg, Herzog, and Weske⁽³⁾ developed a method of making air flow visible by means of high frequency series of electric sparks, which was applied to various aerodynamic investigations. Harada and Sekiyama⁽⁴⁾ developed an "ion wave" velocity meter of gases.

The new technique of measuring gas stream velocity described in this paper differs from the above methods and it is based on the phenomena that the path of electric arc discharge current moves downstream continuously under influence of gas stream. By means of this technique, the digital measurement of gas stream velocity can be made easily.

When arc or glow discharge occurs in flowing gas, it is observed that the positive column i.e. brilliant zone is blown downstream from electrodes owing to gas stream⁽⁵⁾, and the distance from the

electrodes to the most advanced point of brilliant zone increases with gas stream velocity⁽⁶⁾. These phenomena are explained as follows: the ion cloud produced by electric discharge moves downstream, and the discharge occurs continuously in the space of high density of ions, and consequently, the path of electric discharge current moves downstream with gas flow. When the arc discharge occurs perpendicularly to gas stream, if the moving path of the discharge can be detected, the gas stream velocity may be determined by means of measuring the time during which the discharge path moves over a definite distance. In order to detect this moving path of discharge, the probe was placed at a distance downstream from electrodes. When the discharge path arrives at the probe, a part of discharge current flows through the probe and the probe voltage rises rapidly. By means of measuring the time interval, elapsing between the beginning of spark breakdown and the rising of probe voltage, the stream velocity can be determined.

The influences of electrode spacing, the distance from the electrodes to the probe, the temperature and pressure of flowing gases, and the turbulence intensity of the stream on the measured values were investigated in steady flow by applying this technique. As an application of this measuring technique, suction air velocities in a crankcase scavenged two-stroke cycle engine were measured successfully.

2. Measuring method

The shifts of the path of electric discharge

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influenced by air stream perpendicular to the direction of electrodes are shown in Figs. 1 and 2. Fig. 1 shows high speed motion pictures (8000 frames per second) of the electric discharge, when the air flows through electrodes having a spacing of 9 mm, at a velocity of 3.2 m/sec. The shifts of discharge path due to air flow are observed clearly. As a power supply equipment for electric discharge, an ordinary transistorized igniter (type JSN-A, manufactured by Mitsubishi Electric Corporation) for gasoline engine is used. The electric discharge by the transistorized igniter consists of two components i. e. capacitive and inductive components. After very short duration of capacitive discharge, inductive discharge follows for a relatively long period. For instance, when the discharge takes place at needle type electrodes of a spacing of 4 mm in atmosphere, the duration of capacitive discharge is about $0.3 \mu\text{sec}$ and the duration of inductive discharge is about 2.5 msec. The

discharge voltage of inductive component is about -900 volts. It is shown in Fig. 1 that the path of inductive discharge is affected evidently by the gas stream; the path of capacitive discharge, however, is hardly affected. Fig. 2 shows that the moved distance of discharge path x from the electrodes to the most advanced point of discharge path, is proportional to the elapsing time t from the beginning of spark. It can be understood that the path of discharge moves with gas stream. Consequently, if the moving of discharge path can be detected, the gas stream velocity can be determined. In order to detect the discharge path, a probe, that is a thin conductive wire grounded through a resistor, is placed at a distance l downstream from electrodes as shown in Fig. 3. When the discharge path arrives at the probe, a part of discharge current flows through the probe and the probe voltage rises rapidly and the arriving of discharge path at the probe is

detected. The stream velocity can be determined by measuring the time interval τ , elapsing between the beginning of spark and the rising of probe voltage. τ is the time required for the discharge path to move over a distance l . In order to avoid disturbing the state of stream, the discharge electrodes are made of steel needles of 0.6 mm. and the probe is a copper wire of 0.1 mm in diameter. The wave forms of the electric discharge voltage and the probe voltage in flowing gases are displayed on a cathode ray oscilloscope as shown in Fig. 4. The absolute value of inductive dis-

Fig. 1 High speed motion pictures of electric discharge (8000 frames per second)

Fig. 2 Shifts of discharge path

Electrodes: Steel needles of 0.6 mm in diameter
Probe: Copper wire of 0.1 mm in diameter
Measuring pipe: Transparent pipe of 45 mm in inside diameter
Fig. 3 Schematic diagram of measuring method

charge voltage in flowing gases increases with the elapsing time from spark beginning. When the current begins to flow through the probe, the inductive discharge voltage changes suddenly, because a part of the discharge current flows to the probe. The digital measurement of τ can be made easily. Because the measured values of τ fluctuate due to turbulence of flow, it is desirable to obtain numerous measuring values. For this purpose, the digital analyser for fluctuating phenomena⁽⁷⁾ was applied conveniently to measurement of τ .

The relations between air flow velocity and τ were investigated for various values of l and d , where l was a distance from the center of the electrodes spacing to the surface of the probe, and d was electrode spacing. The air flow velocity w was measured by the hot wire anemometer having a diameter of 0.005 mm. The experimental results are shown in Fig. 5. If d was constant, l/τ was proportional to w , and the following relation was obtained experimentally,

$$w = k \frac{l}{\tau} \quad (1)$$

The constant k is independent of l . It depends on d as shown in Fig. 6. The result that $k < 1$ in Fig. 6 shows that $\tau < l/w$, that is, the time interval τ elapsing between the beginning of spark and the rising of probe voltage is shorter than the time

Fig. 4 Wave forms of electric discharge voltage and probe voltage ($w=9$ m/sec)

Fig. 5 Relation between w and τ

required for the air to be moved over a distance l at flowing velocity w . Although the reason for this result is not quite clear, it seems that the diffusions of ions produced by electric discharge and the effects of electric field intensity affect these phenomena.

3. Influences of temperature, pressure and turbulence intensity of flowing gases on the value of k

In order to apply this technique to measuring the velocities of non-steady flows, it is necessary that the constant k in Eq. (1) is independent of temperature, pressure and turbulence intensity of flowing gases.

Figs. 7 and 8 show the results of testing the influence of temperature and pressure of flowing gases respectively, where d and l are constant*. It may be clear that k is independent of temperature and pressure of gases in the ranges of 20~260 °C and 680~1860 mm Hg abs. In the experiments made on the effects of temperature of gas, the flow velocity was measured by the Pittot tube, and the temperature of gas was measured by a chromel-alumel thermo-couple of 0.1 mm in diameter. In the experiments made on the effects of pressure of gas, the flow velocity was calculated from mass-flow

Fig. 6 Influence of d on k

Fig. 7 Influence of Temperature of gas

Fig. 8 Influence of pressure of gas

* The value of l could not be determined exactly in the measuring duct made of steel, therefore $w\tau = kl$ was used instead of k in Figs. 7 and 8.

velocity measured by the orifice flow meter.

In order to produce the turbulences of various intensities, perforated plates were placed at about 400 mm upward from the discharge electrodes. Fig. 9 shows the value of k versus the turbulence intensity $\Delta w/\bar{w}$, where $\bar{w}$ is mean flow velocity, and Δw is root mean square of variation of flow velocity. It seems that k is independent of turbulence intensity in the range of $\Delta w/\bar{w}=0.015 \sim 0.095$.

It is expected as a matter of course that the fluctuation of τ i.e. $\Delta\tau/\bar{\tau}$ increases with $\Delta w/\bar{w}$, where $\bar{\tau}$ is mean value of τ and $\Delta\tau$ is root mean square of variation of τ . The measurement of τ was repeated about 1000 times for one condition of experiment. $\Delta w/\bar{w}$ was determined by a hot wire anemometer placed upstream of 8 mm from discharge electrodes. Although the hot wire is removed when τ is measured, it is presumed that there are added turbulences produced by electrodes. Consequently, it is expected that turbulence intensities at the point of the hot wire mounted and of the electrodes are not equal always. The relations between $\Delta w/\bar{w}$ and $\Delta\tau/\bar{\tau}$ are shown in Fig. 10, neglecting the

Fig. 9 Influence of $\Delta w/\bar{w}$

Fig. 10 Relation between $\Delta w/\bar{w}$ and $\Delta\tau/\bar{\tau}$

differences mentioned above. If $\bar{w}$ is constant, $\Delta\tau/\bar{\tau}$ increases linearly with $\Delta w/\bar{w}$, being independent of the electrode spacing d . When the mean velocity $\bar{w}$ is changed, however, it seems that the gradients of increasing of $\Delta\tau/\bar{\tau}$ with $\Delta w/\bar{w}$ are not equal always. The measured value by the electric discharge method represents a mean velocity of gases moving over a definite distance l , but in exact meaning, it is not an instantaneous velocity. The fluctuation of the measured value τ includes the fluctuation of mean velocity in τ and l , and the fluctuation of electric discharge itself. Though $\Delta\tau/\bar{\tau}$ may not be able to represent exactly the turbulence intensity, it will give an estimate of turbulence intensity.

4. Measurement of suction air velocity in a crankcase scavenged two-stroke cycle engine

Although the value measured by this technique represents a mean velocity of stream during the time interval τ , this technique can be applied to determine the velocity of pulsating flow, because τ can be made very short. For instance, when d and l are made 4 mm and 6 mm respectively, τ is about 0.11 msec at w of 40 m/sec. If τ is made short enough compared with the period of varying velocity, the velocity of the pulsating flow can be determined by means of this measuring technique.

As an example of application of this measuring technique to the studies of internal combustion engine, the suction air velocity in a crankcase scavenged two-stroke cycle engine driven by electric motor was determined. The main specifications of the test engine are shown in Table 1. Fig. 11 is a schematic diagram of an inlet pipe where the suction air velocity is measured. In order to determine both velocities of forward and backward flow during suction period, the probes were placed on both sides of

Table 1 Engine specifications

Number of cylinder		1
Stroke volume		133 cm ³
Cylinder bore / stroke		56/54 mm
Volume of crankcase (Piston at T.D.C.)		295 cm ³
Port timing	Inlet port opening and closing	59.5° before and after T.D.C.
	Scavenging port opening and closing	62.0° before and after B.D.C.
	Exhaust port opening and closing	70.0° before and after B.D.C.
Length of exhaust pipe (without exhaust silencer)		44 mm

the electrodes.

The discharge timing was changed stepwise from inlet port opening to closing, and then the air velocity in the inlet pipe during suction period was investigated in the inlet pipes having various lengths. Fig. 12 shows the experimental results, and the negative velocity in the diagram shows a backward flow. The changes of the suction air velocity can be explained well in this diagram. The period of the velocity change is mainly due to the natural frequency in the oscillating system consisting of an inlet pipe and a crankcase. The experimental results coincide with the values calculated by the following equations⁽⁸⁾, as shown in Table 2.

$$\nu_0 = \frac{c}{2\pi} \sqrt{\frac{1}{aV_m}}, \quad a = \frac{L}{f} + \frac{1}{2r}, \quad T = \frac{1}{\nu_0},$$

where

T = period of varying velocity [sec]

ν_0 = natural frequency of the system [sec⁻¹]

c = mean sound velocity [m/sec]

V_m = mean volume of crankcase during suction period [cm³]

L = length of inlet pipe [cm]

f = cross sectional area of inlet pipe [cm²]

$2r$ = diameter of inlet port [cm]

In order to estimate the turbulence intensity of

Fig. 11 Schematic diagram of measuring method of suction air velocity

Fig. 12 Suction air velocity

suction air flow, $\Delta\tau/\bar{\tau}$ was investigated. The results are shown in Fig. 13. In the early stage of suction period, the turbulence intensity is not very strong, and at the moment of changing the flow direction, a very strong turbulence occurs. From this test it was confirmed that this measuring technique could be applied to the measurement of pulsating flow velocity such as suction air velocity of internal combustion engine.

5. Conclusion

A new measuring technique of gas stream velocity, based on the phenomena that the path of electric arc discharge moves downstream under influence of gas stream, has been developed. As an example of application of this technique, the suction air velocity in a crankcase scavenged two-stroke cycle engine has been determined successfully.

The results of investigation are as follows;

(1) By means of measuring the time interval τ , elapsing between the beginning of spark and the rising of probe voltage, the stream velocity can be determined by Eq. (1).

(2) The constant k in Eq. (1) is independent of distance l from the electrodes to the probe, intensity of turbulence $\Delta w/\bar{w}$, temperature and pressure of flowing gases.

This technique has the following merits.

(1) The measuring method is very simple, and the digital measurement of gas stream velocity can be made easily.

(2) This technique needs no optical method such as photography. The measurement of velocity is possible even in the place where optical observation is impossible.

Table 2 Periods of air velocity wave in suction pipe

Length of inlet pipe L mm	426	326	226	126
Measured value msec	10.7	9.4	8.0	6.2
Calculated value msec	10.59	9.32	7.85	6.03

Fig. 13 Turbulence of suction air flow

(3) This technique can be applied to not only a steady but also a pulsating flow such as the suction flow of internal combustion engine, because τ can be made short.

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Errata (Vol. 11, No. 47, October, 1968)

Author	Page	Column	Line	For	Read
H. OHUCHIDA et al.	747	under Table 2			(add) * H_v 650
K. ENDO et al.	795	right	2~3	cy cl ewhich	cy-cle which
K. ONO et al.	815		6 from bottom	P_o	p_o
	816	left	8	F_o	F_θ
H. TAMURA et al.	827	right	2	limi ed	limited
	"	Eq. (12·b)		$F_{pm} = F_{rm} \sum_{j=1}^N \dots$	$F_{pm} = F_{rm}^{1.5} \sum_{j=1}^N \dots$
	"	Eq. (13)		$F_{pm} = (F_{rm}/2\pi) \int_0^{2\pi} [\cos\theta]^{1.5} d\theta$ $= (F_{rm}/2\pi) \Gamma(1.25)/\Gamma(1.75)$ $= 1.215$	$F_{pm} = (F_{rm}^{1.5}/2\pi) \int_0^{2\pi} [\cos\theta]^{1.5} d\theta$ $= 1.25[\Gamma(1.25)/\Gamma(1.75)]^2$ $= 1.215$
	828	Eq. (17·a)		$\bar{P}_z = N\bar{z}(-\bar{r}_n)^{1.5}F_{r\infty}$	$\bar{P}_z = N\bar{z}(-\bar{r}_n)^{1.5}F_{p\infty}$
	829	Eq. (25·b)		$\dots \left \frac{r}{\bar{r}_n} \right ^{1.5} \dots$	$\dots \left \frac{\bar{r}}{\bar{r}_n} \right ^{1.5} \dots$
	"	"		$0 < \mu \equiv (1 - \bar{r}_n/\bar{r})/2 < 1$	$0 < \mu \equiv (1 - \bar{r}_n/\bar{r})/2 < 1$
	831	Fig.7 (b)			(add to lower abscissa) Y
	832	Eq. (28·c)		$P_r > NP_n \dots$ $P_r \text{ (kg)} = 0.29 \dots$	$P_r \geq NP_n \dots$ $P_r \text{ (kg)} \geq 0.29 \dots$
	834	"	1	an expression	an expression
	"	"	2	$+ \bar{z}(\bar{z}_1^c \cos + \bar{z}_1^s \sin\theta)_{(3)}$	$+ \bar{z}(\bar{z}_1^c \cos\theta + \bar{z}_1^s \sin\theta)_{(3)}$
	"	Eq. (35·b)		$\begin{bmatrix} \bar{p}_0 \\ \bar{p}_2 \\ q_2 \end{bmatrix} = \dots$	$\begin{bmatrix} \bar{p}_0 \\ \bar{p}_2 \\ \bar{q}_2 \end{bmatrix} = \dots$
	836	left	1	s made	is made
T. NAGAO	866	foot note	1	1697	1967
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