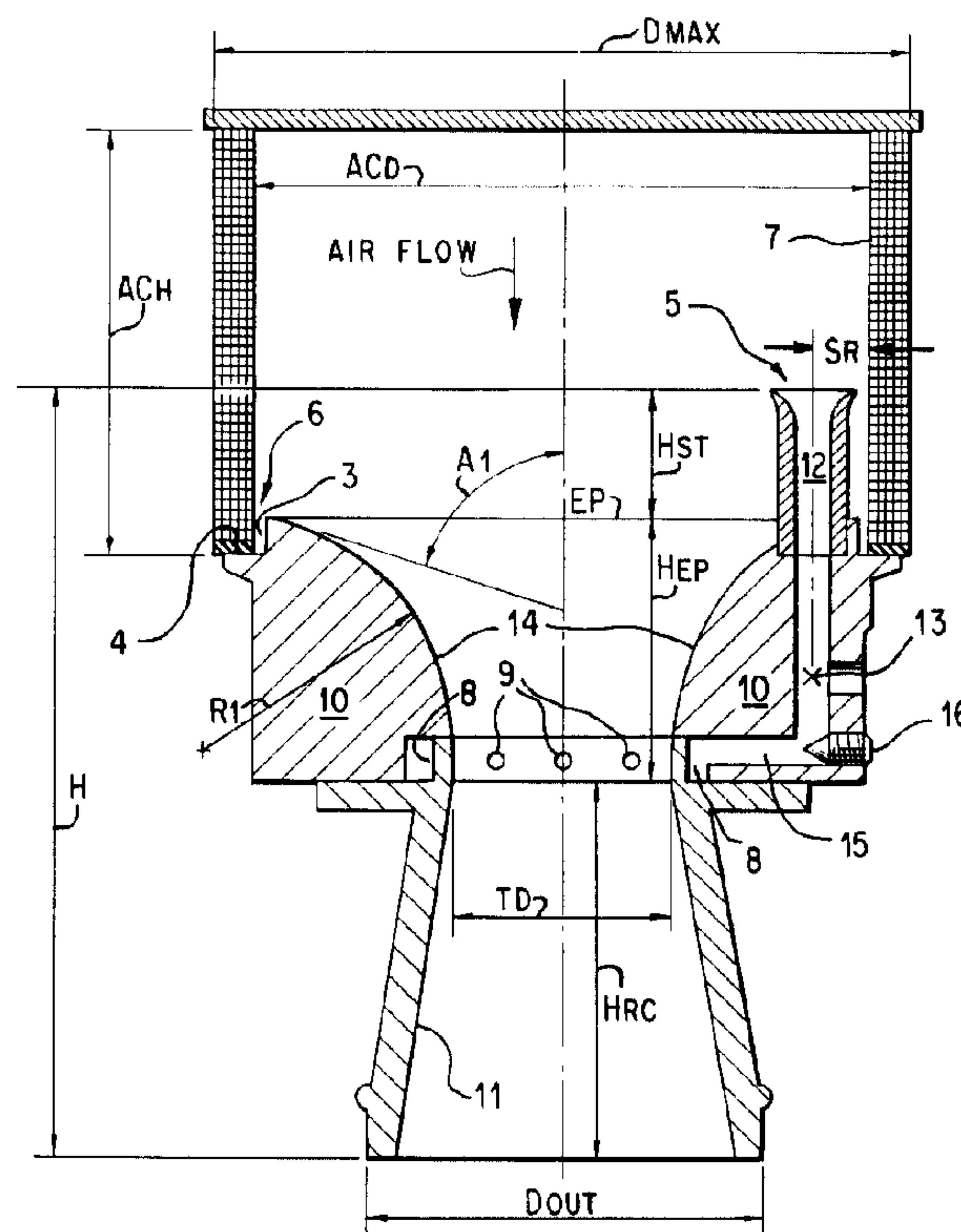




(86) Date de dépôt PCT/PCT Filing Date: 1991/05/16
(87) Date publication PCT/PCT Publication Date: 1991/11/28
(45) Date de délivrance/Issue Date: 2001/07/24
(85) Entrée phase nationale/National Entry: 1992/11/16
(86) N° demande PCT/PCT Application No.: US 91/03438
(87) N° publication PCT/PCT Publication No.: WO 91/18272
(30) Priorité/Priority: 1990/05/17 (524,581) US

(51) Cl.Int.⁵/Int.Cl.⁵ G01F 1/76
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(54) Titre : DEBITMETRE POUR MESURER LE DEBIT MASSIQUE DE L'AIR
(54) Title: MASS AIR FLOW METER



(57) Abrégé/Abstract:

Improvements in a mass air flow meter for internal combustion engines are disclosed which comprise structure for improving the flow dynamics of the air flow through the sampling path including expansion of the dynamic range and increase of the signal to noise ratio resulting in improved engine performance, fuel efficiency, and emission control. Such structure includes a sample tube (12) being tapered in decreasing area in the direction of air flow therethrough and a pneumatic equivalent of a low pass RC filter which decouples the high turbulence in the main flow through the venturi (10), averages same and provides a scaled down profiled flow through the sample tube for measurement by a transducer (13) in the sample tube, the measurements having an accuracy of $\pm 2\%$ of reading.





INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification⁵ :

G01M 19/00

A1

(11) International Publication Number:

WO 91/18272

(43) International Publication Date:

28 November 1991 (28.11.91)

2083047

(21) International Application Number: PCT/US91/03438

(22) International Filing Date: 16 May 1991 (16.05.91)

(30) Priority data:

524,581

17 May 1990 (17.05.90)

US

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US]; 3450 John R. Road, Rochester, MI 48307 (US).(74) Agent: HARRINGTON, Donald, J.; 1000 Town Center,
22nd Floor, Southfield, MI 48075 (US).(81) Designated States: AT (European patent), AU, BE (Euro-
pean patent), BR, CA, CH (European patent), DE (Euro-
pean patent), DK (European patent), ES (European pa-
tent), FI, FR (European patent), GB (European patent),
GR (European patent), IT (European patent), JP, KR,
LU (European patent), NL (European patent), NO, SE
(European patent).

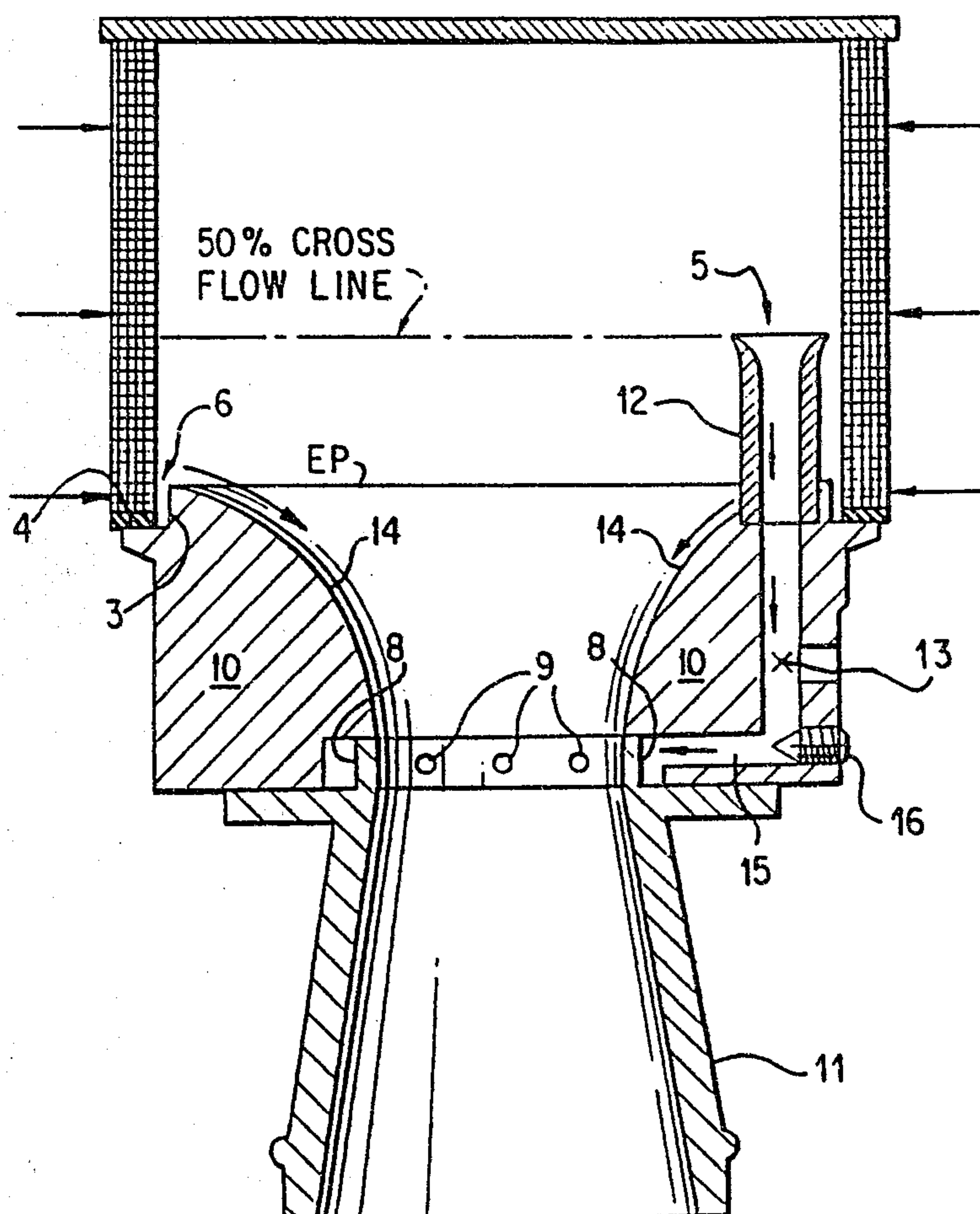
Published

With international search report.

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(57) Abstract

Improvements in a mass air flow meter for internal combustion engines are disclosed which comprise structure for improving the flow dynamics of the air flow through the sampling path including expansion of the dynamic range and increase of the signal to noise ratio resulting in improved engine performance, fuel efficiency, and emission control. Such structure includes a sample tube (12) being tapered in decreasing area in the direction of air flow therethrough and a pneumatic equivalent of a low pass RC filter which decouples the high turbulence in the main flow through the venturi (10), averages same and provides a scaled down profiled flow through the sample tube for measurement by a transducer (13) in the sample tube, the measurements having an accuracy of $\pm 2\%$ of reading.



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MASS AIR FLOW METERTECHNICAL FIELD

This invention relates to mass air flow meters for internal combustion engines.

5

BACKGROUND ART

The need for this invention is to fill anticipated needs of the 1994 emission requirements for better and more accurate control of air/fuel ratio in internal combustion engines.

10

The major problems with the present meters available are:

15

1. Present meters always have a high pressure drop across the meter that causes the horsepower to be reduced (at sea level 8 to 14% at 5000 feet this loss goes to 11 to 20%). My meter has a very low pressure drop because of pressure recovery system designed in (13 in. H₂O drop vs. 3 in. H₂O).

20

2. Low dynamic range of the present meter will read from 13 to 850 Kg./Hr. with 4% accuracy and 12% noise. My meter has a range of 17 to 2000 Kg./Hr. with 3% accuracy and less than 3% noise.

25

3. High noise above idle to mid throttle makes the present meter unsure of the actual air intake. System as measured have as high as 12% noise from 30 to 90 Kg./Hr. My meter the same area has less than 1% noise making open loop air fuel calculations in the emission control system at least 8 to 12 times better. Increasing accuracy in air fuel ratio makes the emissions better and reduces air pollution.

30

4. The present intake system introduces further restriction by an air cleaner that has a very

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high pressure drop and routes the incoming air through a tortuous path which restricts the maximum horsepower by another 5 to 12% and increases the work that the engine has to do without any benefit. My system close
5 couples a very low restriction air cleaner that reduces the work the engine has to do to breathe.

5. The present air meters are such that changes in throttle angle (demand for power) and upstream and downstream tubes and components have a
10 large effect on the transducer calibration curve. Simple moving of tubes or changing to another type of air cleaner may change air meter transduction characteristics by 4 to 7%. My system is not affected by these conditions because of my design of the intake
15 for the main flow and the sample system including the tapered sample tube and distribution ring.

6. Present air meters have fast transduction response times and the output (electrical transduced signal) is averaged over the input cycle to
20 allow the computer to find the intake air mass. This practice generally runs the engine rich because the flow curve is a function of the volts plus a constant raised to the 3.3 power. When this is done the average volts calculated through the function is always less
25 than the average of flow. This can be fixed if the engine control computer is able to calculate many times over the intake stroke, sum the flows and then divide by the number of observations. This takes large amounts of computer time and is not possible without a
30 very fast and sophisticated computer. My system has a filtering network built into the sample system that filters the pulsating main flow to provide a sample flow that is representative of the average flow through the main venturi. The flow through the sample system
35 is at a very low differential pressure and is in the

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laminar flow regime. The flow signal is the representative of the averaged flow through the main venturi over 24 to 65 ms.

DISCLOSURE OF THE INVENTION

5 By way of a tradename or trademark for my mass air flow meter I prefer to describe it as the "Pro (M)" meter (or "Pro-M-Dot" meter).

My mass air flow meter has size specifications as follows (see Fig. 5):

10 Overall Height (H) of meter is 2.5 times the throat diameter (TD);

The Height (Hep) of the bell entrance plane (EP) upstream from the throat dia. (TD) shall be 1.3 times the throat diameter (TD);

15 The height of the recovery system Hrc shall be a minimum of 1.25 times the throat dia (TD);

Overall diameter at upstream end (Dmax) is 2 times throat diameter (TD);

20 Diameter at the downstream end (Dout) is 1.3 times throat diameter (TD);

The height (ACh) and diameter (ACd) of the air cleaner shall be each a minimum of 1.9 throat diameters (TD).

25 For the family of flow meters sizes 0.5" to 5" throat diameter of venturi (TD), both the flow through the sample path and the main flow through the venturi throat are variable with engine requirement (see Fig. 6). The flow through the sample path will vary from zero to maximum value of about 0.7 poundals
30 (W/g) per minute.

My mass air flow meter has a fluidically correct shaping of venturi (10) and tapered sample tube (12) for the most correct reading of air flow rates.

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a. The bell inlet (14) of the venturi (10) has a minimum radius (R1) equal to at least 1/2 of the throat diameter (TD) of said venturi and the form thereof is determined by a cubic equation. A tangent line from the outermost edge of the bell inlet forms a minimum angle (A1) of at least 70 degrees to the axis of the venturi. (see Fig. 5.)

b. The Recovery system (11) is tapered to increasing diameter preferably about 14 degrees included angle for best possible air flow pressure recovery. 96.6% of pressure is recovered at the exit plane of said exit cone. (see Fig. 5.)

In tests performed on a stock 1990 Mustang engine (5.0 liter High Output) an increase of at least 25 horse power was achieved by simply removing the production mass air flow meter and replacing same with my mass air flow meter.

My mass air flow meter has a unique air cleaner mount which (see Fig. 8) consists of means radially outward of the bell inlet (4) for receiving an end of the air cleaner (7) and disposing it below the entrance plane (EP) of said bell mouth (14). Such means include a stagnation surface or circumferential shoulder (3) and a radial shoulder (4) which provide a static pressure gap (6) disposed between the inside circumference of the air cleaner and the circumferential shoulder (3). The static pressure gap (6) allows the air to change direction. The incoming air is forced to step up. Said filter mount forces incoming air to attach to the bell mouth surface so as to increase the intake efficiency. The closely attached air cleaner provides both air filtration and radial direction to the intake flow. This isolates the intake of the meter from under-hood air currents that are induced by rotating accessories, engine fan, and

vehicular movement that otherwise would increase transduction noise. (See Fig. 5)

5 The main inlet is stepped up to capture the air flow over the approaching inlet lip to allow for the inlet air to attach to the inlet immediately after crossing the air filter. This keeps the air attached to the inlet horn and allows for much better intake efficiency. (See Fig. 8)

10 In my mass air flow meter the height of the tapered sample tube (Hst) above the bell entrance plane (EP) shall be a minimum of .5 times the throat diameter (TD) (see Fig. 5). In any case at least above the 50% cross flow line (50% C.F.L.; see Fig. 6). By 50% cross C.F.L. I mean that 50% of the cross flow of air through
15 the air cleaner is below this line.

The inlet of the tapered sample tube (12) shall have a trumpet bell (5) shape, be unguarded and be disposed radially inside the air cleaner a predetermined minimum distance (Sr) and a predetermined
20 minimum distance (Hst) axially upstream from the entrance plane (EP) of the bell inlet equal to at least .5 of the throat diameter (TD).

Sr is the radial distance inward from said circumferential shoulder (3) to the axis of the sample
25 tube (12). Hst is the height of the sample tube above the entrance plane (EP).

In my mass air flow meter the bypass tapered sample tube (12) is tapered to decreasing diameter (preferably about .7 to 2.0 degrees) in the direction
30 of air flow to eliminate cyclonic effects of the flow which otherwise would become high noise. (see Fig. 12)

In my mass air flow meter the air sensing element (13) is positioned at the end of the tapered sample tube (12) such that the tube is still tapering
35 for at least 1 diameter beyond the element. (see Fig.

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5)

In my mass air flow meter a transverse conduit (15) with a flow trimming device (16) receives the flow from the sample tube (12) and delivers same to the sample collection chamber (8).

In my mass air flow meter the sample collecting chamber (8) (downstream from the tapered sample tube at the minimum throat diameter of the venturi) receives the flow from the transverse conduit (15) and collects same and has a flow restriction outlet (9) to the main air flow flowing through the minimum diameter (TD) of the venturi. The ratio of volume of the collecting chamber to the volume of sample tube being between 3 to 1 and 14 to 1 depending upon the filter time constant (see Figs. 9, 10A and 10B). The filter time constant varies depending upon the intake characteristics of the target engine.

	<u>Engine Cylinders</u>	<u>RC Time Constant</u>	<u>Ratios of Volume</u>
		<u>ms.(milliseconds)</u>	
20	8 and 6	12 to 44	4:1 to 9:1
	5 and less	44 to 90	8:1 to 14:1

Further reference is made to Fig. 9 wherein is shown the sampling tube (12) which has a given pneumatic resistance to flow R. The collecting chamber or ring (8) has a given volume which, together with the volume of the sample tube (12) below the transducer (13), is the pneumatic counterpart of capacitance C of an RC filter. The volume of the transverse conduit (15), when used, adds to the combined volume of the ring (8) and the lower part of the sample tube below the transducer (13).

In my mass air flow meter the maximum flow through the tapered sample tube (12) is made to be a constant at maximum flow for a given family of flow meter sizes.

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The actual flow through the tapered sample tube is close to 0.7 poundals/Min at design flow rate. This flow rate limits the flow regime that the sample tube will see.

5 The following are two typical mass air flow meters from my family of mass air flow meters:

10 a. The ATZ-1000 3.0 in. dia. venturi is 1000 C.F.M. (S.T.P.) The flow rate through the tapered sample tube is approximately 8.7 C.F.M. (S.T.P.) while through the venturi is 991.3 C.F.M. (S.T.P.) The pressure signal at the minimum venturi diameter is approximately 28.0 inches of H₂O.

15 b. The PFT-1 2.75 in. dia. venturi is 800 C.F.M. (S.T.P.) The flow rate through the tapered sample tube is approximately 8.7 C.F.M. (S.T.P.) while through the venturi is 791.3 C.F.M. (S.T.P.).

20 Further reference is made to Figure 6 wherein the air flow split can be seen. The sample is drawn back into the main flow at the minimum throat diameter through flow restrictions. In Figure 7 for maximum design flow when the barometric pressure is 29.5 inches Hg, for example, the pressure drop from atmosphere to the flow restriction means (9) is approximately 28 inches H₂O. At the exit plane, the flow pressure is recovered to about 96.6% of the atmospheric pressure.

25

BRIEF DESCRIPTION OF THE DRAWINGS

30 My invention relates to a mass air flow meter with Air Cleaner for measuring the flow of air mass inducted into an internal combustion engine for controlling the air/fuel ratio thereof. The principal object of my invention is to provide an improved mass air flow meter which is characterized by very low

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pressure drop, improved transduction accuracy, low transduction noise, and high efficiency (reducing the work the engine must do to breathe).

5 The foregoing object of my invention and the advantages thereof will become apparent during the course of the following description, taken in conjunction with the accompanying drawings in which:

10 Figure 1 is a vertical sectional view of a prior art mass airflow meter (as disclosed in U.S. patent 4,393,697);

Figure 2 is a perspective view of my air flow meter (with filter) viewed so that the mounting surface thereof (for a sensing element shown detached in this Fig.) can be seen;

15 Figures 3 and 4 are respectively, top plan of my air flow meter (with the air cleaner detached) and bottom plan view of my air flow meter;

20 Figure 5 is a vertical sectional view of my air flow meter showing some of the construction details thereof;

Figure 6 is a view similar to Figure 5 showing the split of air flow through the sample system and the main venturi;

25 Figure 7 is a schematic view showing the expected pressure drops for my family of mass air flow meters from 1" to 5" throat diameters;

Figure 8 is a fragmentary vertical sectional showing the interface construction with the air cleaner;

30 Figure 9 is a schematic view with parts in section of the sampling system;

35 Figures 10A and 10B are schematic views illustrating respectively the pneumatic circuit and the electrical equivalent of the sampling system used in my air flow meter;

Figures 11A through 11D are a series of graphs illustrating averaging effect of my sampling system on the pulsating flow through the main venturi;

5 Figure 12 is visualized flow diagrams showing air flow through my sampling system;

Figure 13 is a view similar to Figure 12, but showing such air flow in the sample system of a prior art mass air flow meter;

10 Figure 14 is a vertical sectional view of another embodiment (than that shown in Figs. 1 to 8) of my mass air flow meter;

Figure 15 is a top plan view of the structure of Fig. 14;

15 Figure 16 is a bottom plan view thereof; and

Figures 17 and 18 are respective horizontal views thereof through the lines 17-17 and 18-18, respectively, in Fig. 14.

BEST MODE FOR CARRYING OUT THE INVENTION

20 Description of advantages of my mass air flow meter.

All internal combustion engines operate in at least 3 specific phases of air intake into the engine.

I. Air Intake Condition Idle To 40% Throttle.

25 Characterized by near constant flow through the intake system. High intake manifold vacuum and throttling valve being at low angles.

II. Air Intake Condition Rapid Change In Throttle Demand.

30 Changing throttle angle means the operator is demanding the engine to either accelerate or decelerate and the engine must respond very quickly.

III. Air Intake Condition Above 40% To Wide Open Throttle.

Characterized by high pulsations of flow and

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even flow reversals. Intake manifold is pulsating from 2 in. Hg. gage vacuum to 1 in. Hg. gage pressure.

My invention handles all of the above three operating phases (I, II, and III).

5 In respect to Phase I air intake condition (Idle to 40% throttle):

A. Prior art bypass units have always had high noise (3 to 20% of signal). As shown in Figure 13, the noise in the bypass system is mainly due to
10 cyclonic type flow in the non-tapered tube which rambles about the sample tube, produces eddies, random wall attachment and results in inaccurate sensing. High noise adversely affects the measuring accuracy of the prior art unit, which in turn adversely affects
15 emissions control, engine efficiency, and fuel economy. In a current production sampling tube, air flow is coming from the tube attached to the front of the meter and is somewhat parallel to the axis of the main venturi. Air is now induced into the sampling tube but
20 is confused by sharp edges and surfaces perpendicular to the established flow. As air flow is drawn down the tube, the flow is not attached at the sides and begins to meander through the tube. The flow attaches at random to various points and resembles a cyclone in the
25 tube. As the flow hits the element in a random fashion, the element is not sure of the flow and the output becomes very noisy.

B. In my air flow meter the tapered sample tube is continuously tapered to focus the center flow
30 on the sensing device. As a consequence of the profiled velocity front through the sampling tube, my air flow meter has low noise (0.5 to 3% of signal).

(i) Cross flows, perpendicular surfaces, or close objects have no effect upon capture of sample
35 air.

(ii) The taper constantly accelerates the flow to insure attachment thereof to the tapered wall while maximizing the acceleration at the center of the flow stream to produce a parabolic velocity front (P.V.F.) as shown in Figure 12, whereby eddies cannot form and the sensing element always sees a non-fluctuating maximum accelerated center flow stream. Therefore, because the element always sees the same P.V.F., flow transduction noise is minimized while accuracy and repeatability are maximized. The result is that the control computer has a stronger more accurate signal, engine emissions are minimized, while engine efficiency and fuel economy are both maximized.

In respect to Phase II and III air intake conditions: transient acceleration/deceleration and wide open throttle operating areas.

A. Prior art systems do not have a flow averaging system for air intake conditions II and III. Instead, they follow the air flow response poorly and give false readings of flow in the high pulsation flow areas. This makes the control system even more confused and makes poor performance and even worse emissions.

B. My air flow meter uses the sample flow system as an air flow equivalent to an electrical low pass filter having an RC time constant. The mechanical sampling system is illustrated in Figure 10A while the analogous electronic circuit is shown in Figure 10B where the collecting chamber providing the equivalent electrical capacitance (C_{cc}), said flow restriction means providing the equivalent electrical resistance $R_{flow\ means}$ in series circuit with said capacitance, and said sample tube, hot wire transducer, flow trimmer and transverse conduit providing the equivalent electrical coupling resistance whereby the flow through the sample

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path read by the hotwire transducer represents the average value of the main flow through the venturi throat. The time constant of the flow meter is the product of the $R_{\text{flow means}}$ and C_{cc} .

5 The graphs in Figures 11A and 11B illustrate the flow response to a quiet signal such as idle to 1/3 to 40% total throttle opening when the flow is stable. The average flow is identical to the actual flow and no differences are seen. Figure 11A shows main venturi
10 flow and Figure 11B shows sample tube flow (scaled). These are time base graphs showing flow response. In each case, the idle flow is stable at about 80kg/hr. The cruise flow (level ground at 50 mph) is also stable at about 220 kg/hr. Up to 40% of wide open throttle
15 the flow of air is choked at the throttle plate. There are no fluctuations in air flow. Flow through the sample tube is scaled but quiet. Scaled flow and actual flow are equal.

 The graphs in Figures 11C and 11D illustrate
20 what the element sees when the flow is pulsing. The main venturi sees the entire pulsing flow and the flow restriction means lets the flow in the collection chamber lag slightly behind the main flow. This lag allows the sample flow to only vary slightly from the
25 air flow average and becomes a filter that will block fluctuations that are cyclic and above a frequency of 15 to 30 hertz. Large throttle angle changes are averaged and the flow output lags the actual transient by .03 to .09 seconds. However, the transfer function
30 of the intake manifold is closer to the flow outputted by the device and the engine is less prone to over react to these changes and produce air fuel spiking.

 Figures 11C and 11D are time based graphs showing flow response for a 4 cylinder engine. Figure
35 11C is a worst case - 1200 rpm with wide open throttle

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and one's foot on the brake. Wide open throttle actual flow varies from 0 to 160% of flow average. Figure 11D shows the RC of the chamber. This averages the sample flow and the transducer sees the scaled flow. Average flow is 35 kg/hr. The value of the scaled flow runs from 291 to 330 kg/hr.

The volume of the collection chamber changes for various applications. The ratio of volume of the collecting chamber to the volume of sample tube being between 3 to 1 and 14 to 1 depending upon the filter time constant. The filter time constant varies depending upon the intake characteristics of the target engine:

15	<u>Engine Cylinders</u>	<u>Time Delay ms (milliseconds)</u>	<u>Ratio Of Volume</u>
	8 and 6	12 to 44	4:1 to 8:1
	5 and less	44 to 90	8:1 to 14:1

The following is a description of how a typical one of my mass air flow meters functions.

A 3 inch device divides the air flow in the approximate ratio of 114 to 1 (air through the throat to air through the tapered sample tube).

The tapered sample tube is brought above the entrance plane (EP) of the device to allow for better capture of the sample air. The sample air resembles an infinite source because

a. The tapered sample tube entrance is disposed above the 50% air flow line not allowing cross currents to affect the sample air stream.

b. The incoming air velocity is at a maximum of 40 degrees from the axis of the sample tube assuring a clean capture

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of the air.

- c. A sharp edged trumpet cone is used for better capture efficiency of the sample air.

5 The sample flow is drawn through the sample path and is collected at the minor diameter by a specially made distribution ring and collection chamber which has a volume of 4 to 14 times that of the tapered sample tube in front of the sensing element. The flow
10 is formed into a parabolic velocity front by the tapered sample tube and is focused on the element (see Figure 12). In my sampling tube, air is induced and attached to the walls of the tube by the trumpet shaped bell inlet. As the flow is drawn down the sample tube,
15 the tapered sides force the flow to be accelerated and attach to the walls. The flow is forced into a parabolic velocity front and is focused in the center of the tube. When it passes the flow sensing element, the flow is in a well developed parabolic flow profile
20 and focused on the element.

 This flow measured is the average main venturi flow and enables the engine controller to read the average air charge much more accurately without synchronous sampling techniques from the engine
25 computer.

Advantages of the tapered sample tube:

- a. Maximize the signal to noise ratio at the hotwire because of tapering of sample tube and disposition of inlet
30 mouth thereof;
- b. The pressure drop is controlled across the sample tube making the flow always stay in the laminar regime; and

- 5 c. Profiled flow means that the element that is used to sense the flow may be of any size or shape because the flow profile does not have any random movements in it.

Advantages of sample collection system and flow restriction ring:

- 10 a. Minimize the downstream effects of the air flow through the meter. In prior art meters the signal from the meter was affected by downstream bends and devices in the air flow, i.e. throttle plate angle affects transduction curve and different air cleaner elements affect
- 15 the transducer curve.
- b. Venturi flow is averaged by the restriction and the volume of the ring design, which is unique in obtaining an averaged flow signal.
- 20 c. Minimize the effect of reverse flow when the engine is pulsing during wide open throttle operation.

Referring to Figures 14 to 18, there is shown therein another embodiment of my mass air flow meter

25 which is generally designated 200. In my mass air flow meter shown in Figures 1 to 8, the venturi for the main airflow is provided by the body being formed to neck down to a minimum cross sectional area at the level where the flow restriction apertures 9 are located.

30 Also the sample tube is disposed laterally of the path of flow for the main air flow through the meter body. The meter body has a bell shaped entrance and means for directly connecting to an air filter. In my mass air

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flow meter 200 shown in figures 14-18, the venturi is "inside-out" in that the I.D. of the body 210 is relatively straight while a collecting chamber 208 is used to provide a minimum cross sectional area 216 at the level where flow restriction apertures 209 are located. The mass air flow meter 200 is used in conjunction with a remote air filter and saves space within the engine compartment. It also saves in manufacturing cost while retaining other benefits of my mass air flow meter including low noise and R.C. time averaging. My mass air flow meter in Figures 1 to 8 will always have a lower pressure drop because of the better job it does in capturing entrance air (its bell shaped entrance and means for joining to its own air filter) and because of the unimpeded path it has with the air flow. The body 210 is generally cylindrical, but has a slight internal taper 215 therein. The taper 215 decreases in the direction of air flow and aids in columnating or profiling the main air flow through the mass air meter. The tapered sample tube 212 and the collecting chamber 208 are disposed coaxially (with the longitudinal axis of the body 210) and arranged in a substantially straight line, as shown. The sample tube 212 and collecting chamber 208 are supported by a multi-leg spider (3 legs, in this instance) which, in turn, is supported by the inside wall of the body 210. One leg of the spider is hollowed out, as shown, to receive and hold therein an air flow sensing element 213. A prior art signal amplifying and conditioning device 217 is affixed to the outside wall of the body 210 and electrically coupled to the flow transducer 213, as is well known in the art. Where the collecting chamber 208 joins the lower end of the sample tube 212, it provides a steep air foil shape which expands rapidly in diameter to a maximum at the level where

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flow restriction apertures 209 are located. Downstream from the flow restriction apertures 209, the collecting chamber gradually decreases in diameter (about 25 degrees included angle) to provide an "inside-out" recovery cone. The volume of the collecting chamber 208 to that of the sample tube 212 and to the area of the flow restriction means 209 is the same as in the prior embodiment of Figures 1 to 8. The maximum pressure drop is created at the flow restriction means (in the form of equally circumferentially spaced apertures) 209 formed through the wall of the collecting chamber 208 to produce maximum draw of the air flowing through the sample path. The tapered wall of the sample tube 212 is extended downwardly (internally of the collecting chamber 208) below the level of the flow restriction means 209. In this instance, the ambient temperature reference wire 214 for the flow transducer 213 is disposed above the spider on the tapered wall 215 because of the space limitation of the hollow spider leg.

The shape of the collecting chamber below the flow restriction means is tapered in decreasing diameter (in the direction of the air flow) to provide an "inside out" recovery cone to reduce pressure drop across the mass air flow meter 200. It is preferred that the body 210 extend below the end of the collecting chamber by at least 1 diameter of the collecting chamber 208, (maximum diameter at the level of the flow restriction apertures 209) of the collecting chamber 208. It is preferred that the upper end of the sample tube extend above the upper end of the body 210 to isolate same from any turbulence at the mechanical interface for the upper end of the body 210.

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What I claim is:

1. Improvements in a mass air flow meter for internal combustion engines having a hollow elongated body having a venturi formed therein, a
5 sample tube associated with said body for receiving a flow of sample air therethrough, said venturi having a bell shaped entrance at the upstream end thereof, the entire air source for an engine being split into a main flow path through the venturi and into a sampling path
10 through the sample tube, an air flow transducer disposed in said sample tube, the flow through the sample tube downstream from said transducer being recombined with the main flow of air through said venturi, said improvement comprising the following
15 structure for improving the flow dynamics of the air flow through the sampling path including expansion of the dynamic range and increase of the signal to noise ratio resulting in improved engine performance, fuel efficiency, and emission control:

20 (a) said sample tube being tapered in decreasing area in the direction of air flow through the sample tube;

(b) the transducer being disposed near the minimum area of said sample tube;

25 (c) said sample tube having a length equal to more than 6 times the maximum cross sectional dimension thereof near the transducer;

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(d) a collecting chamber downstream from the sample tube for receiving the output flow therefrom;

(e) flow restriction means opening to the minimum throat diameter of said venturi and serving as the outlet of said collecting chamber;

(f) said collecting chamber serving as an accumulator for the outlet flow from said sample tube and having a volume more than twice the volume of the sample tube above said transducer;

(g) the total cross sectional area of said flow restriction means being about half that of the minimum cross sectional area of said sample tube near the transducer so that the pressure drop across said flow restriction means is at least 1.5 times that across the length of the sample tube above said transducer; and

(h) said collecting chamber and said flow restriction means providing a pneumatic equivalent of a low pass R C filter which decouples the high turbulence in the main flow through the venturi, averages same and provides a scaled down profiled flow through the sample tube for measurement by said transducer, said measurements having an accuracy of $\pm 2\%$ of reading error.

2. Improvement in a mass air flow meter for

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internal combustion engines as claimed in claim 1 in which the taper of the sample tube is uniform over the length thereof.

3. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which the ratio of the length of said sample tube to the minimum diameter thereof near the transducer is between 8 to 1 and 12 to 1.

4. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which the taper of the sample tube is within a range of 0.5 to 2.0 degrees included angle.

5. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 5 in which said taper of the sample tube is .9 degrees included angle.

6. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which said collecting chamber is an annular chamber disposed about the minimum throat diameter of the venturi and in which said flow restriction means comprises equally circumferentially spaced-apart

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apertures through the venturi wall at the minimum diameter of the venturi.

7. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 further comprising a transverse conduit disposed downstream of the sample tube and upstream from the collection chamber, the volume of said transverse conduit being added to that of said collecting chamber in providing the C equivalent of said R C filter.

8. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which the inlet to the sample tube has a trumpet shaped mouth inlet to enhance the capture of sample air and to enhance the signal to noise ratio.

9. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which said body has an entrance plane coincident with the upstream end of said venturi and the sample tube has such length that it extends above said entrance plane such a distance that the inlet end thereof is disposed above a 50% cross-flow line in respect to the total cross flow of air

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entering the venturi from said air source.

10. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which the sample tube has such length that the inlet end thereof extends above the transducer by a distance of between 6 and 12 diameters (minimum diameter of the sample tube near the transducer).

11. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 7 further comprising a manually adjustable air flow trimmer at the intersection of the downstream end of the sample tube and the inlet end of the transverse conduit, said flow trimmer being used to fine tune the R of the low pass R C filter.

12. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which said transducer is located above the outlet end of the sample tube by a distance of at least 1 diameter (minimum diameter of sample tube near the transducer).

13. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 further comprising means at the outer circumferential

wall of said body below said entrance plane for holding an air filter in place thereon, said holding means including a radial wall and a cylindrical wall for forming, with the air cleaner, a static pressure gap whereby to enhance attachment of the incoming air to said bell shaped entrance.

14. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 further comprising a recovery cone downstream from said venturi expanding in diameter in the direction of flow by an amount so as to provide an included conical angle of between 8 and 20 degrees.

15. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 14 in which said expanding diameter has an included conical angle of 14 degrees.

16. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 14 in which the minimum throat diameter of the venturi is sized to give at maximum expected airflow a maximum of 28 in. H₂O pressure drop (from atmosphere to the minimum throat diameter) and a maximum pressure drop of 13 in. H₂O throat (from atmosphere to the outlet end of the

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recovery cone).

17. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which the pressure drop over the length of the sample tube above said transducer is less than 10 inches of H₂O, whereby, the flow of sample air in said sample tube remains profiled in the laminar regime.

18. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1 in which the volume of said sample path downstream of the flow transducer including that of the collecting chamber in relation to the volume of the sample tube upstream of the transducer is in the ratio of 2.5 to 1 and 15 to 1 depending upon the time delay required for the intake characteristics of the target engine, said time delay being between 12 and 90 milliseconds.

19. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 1, said improvement comprising:

(a) the collecting chamber being formed at the lower end of the sample tube so as to receive direct in-line flow therefrom;

(b) both the sample tube and the collecting chamber being supported within the interior of said elongated body centrally coaxially thereof;

(c) the exterior surface of said collecting chamber having

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a maximum external dimension so as to form, with the inside cross-sectional area of said elongated body, an inside-out venturi having a minimum annular cross-sectional throat area;

(d) the principal internal volume of said collecting chamber (for accumulation of sample air exiting from said sample duct) being disposed downstream from the location of the minimum throat area; and

(e) flow restriction means through the wall thickness of the collecting chamber body at the location of said minimum throat area, said flow restriction means serving as the outlet for the air accumulated in said collecting chamber.

20. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 19 in which the downstream end of the sample tube is extended downstream of the upstream end of the collecting chamber and internally thereof to a level below that of the flow restriction means so as to isolate the flow of air exiting from the sample tube from that which exits through the flow restriction means.

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main air flow;

(f) the collecting chamber having a maximum diameter to form, with said body, a minimum annular area (cross sectional) serving as a venturi;

(g) flow restriction means through the wall of the collecting chamber body at the level of said minimum annular area and serving as the outlet for the flow of sample air; and

(h) said collecting chamber and said flow restriction means providing a pneumatic equivalent of a low pass R C filter which decouples the high turbulence in the main flow through the venturi, averages same and provides a scaled down profiled flow through the sample tube for measurement by said transducer, said measurements having an accuracy of +/- 2% of reading error.

20. Improvement in a mass air flow meter for internal combustion engines as claimed in claim 19 further comprising structure affixed to the inside wall of the flow meter body for supporting both the sample duct and the collecting chamber, part of said structure being hollow and opening to the interior of the sample duct for carrying the flow transducer.

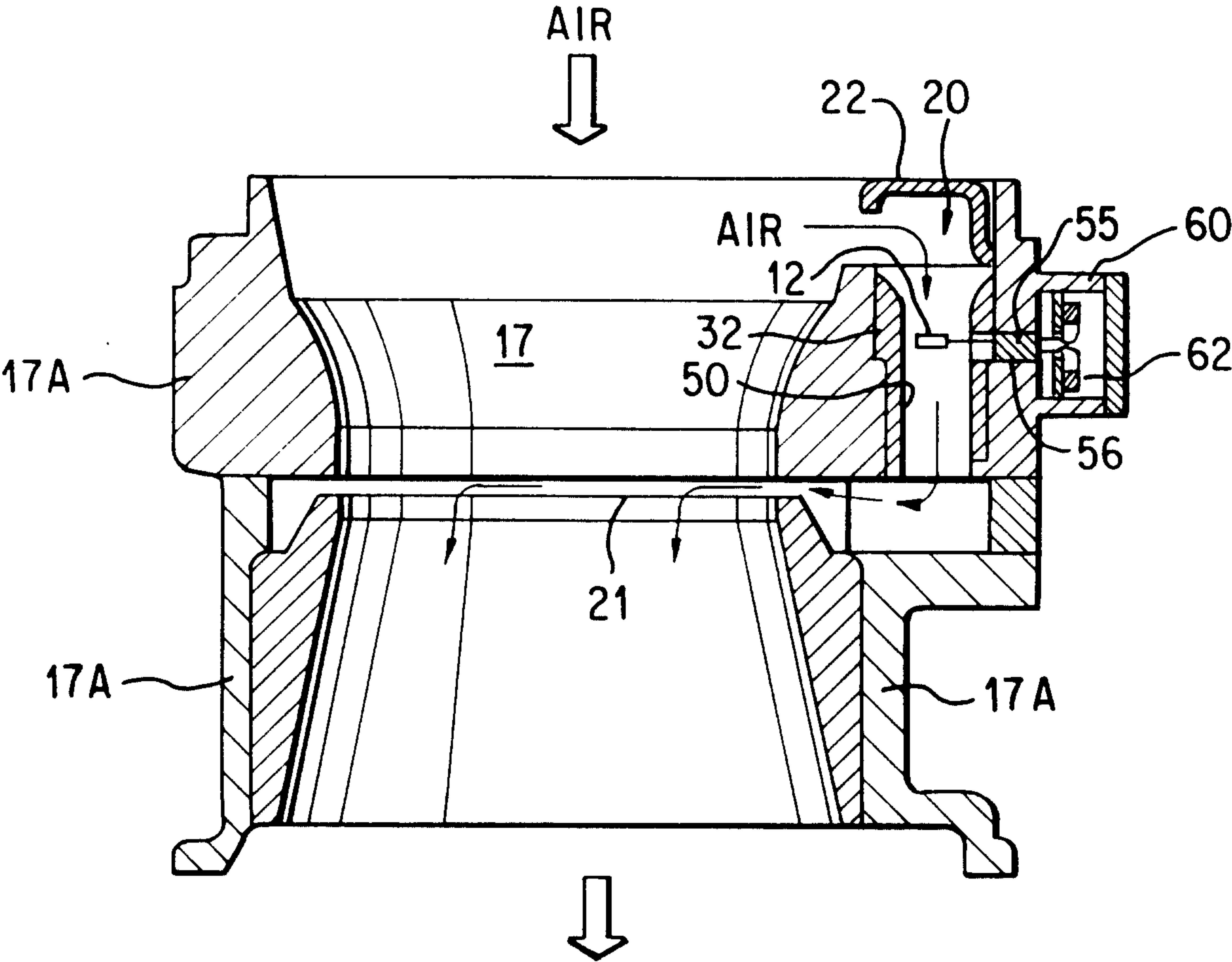


FIG. 1 PRIOR ART

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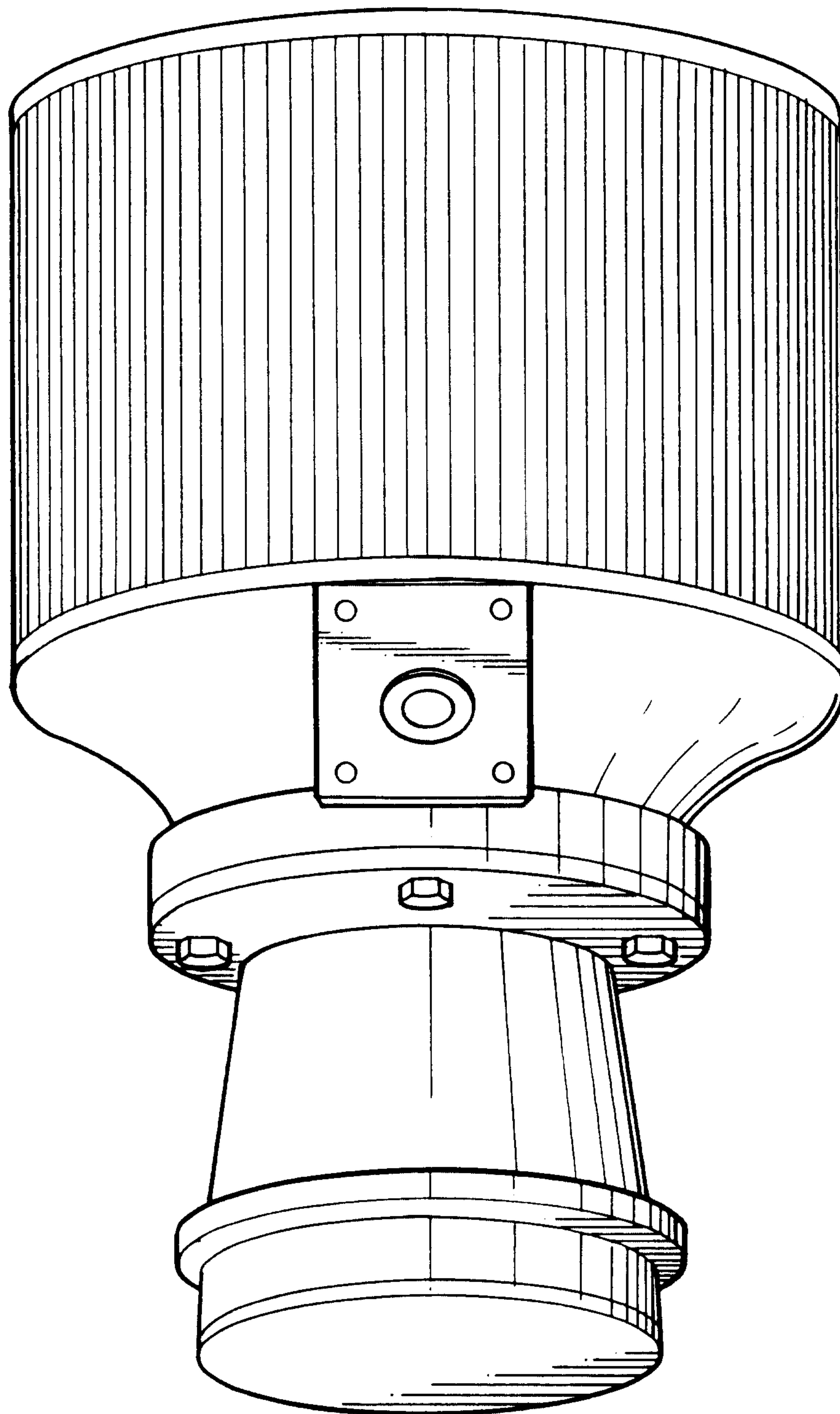
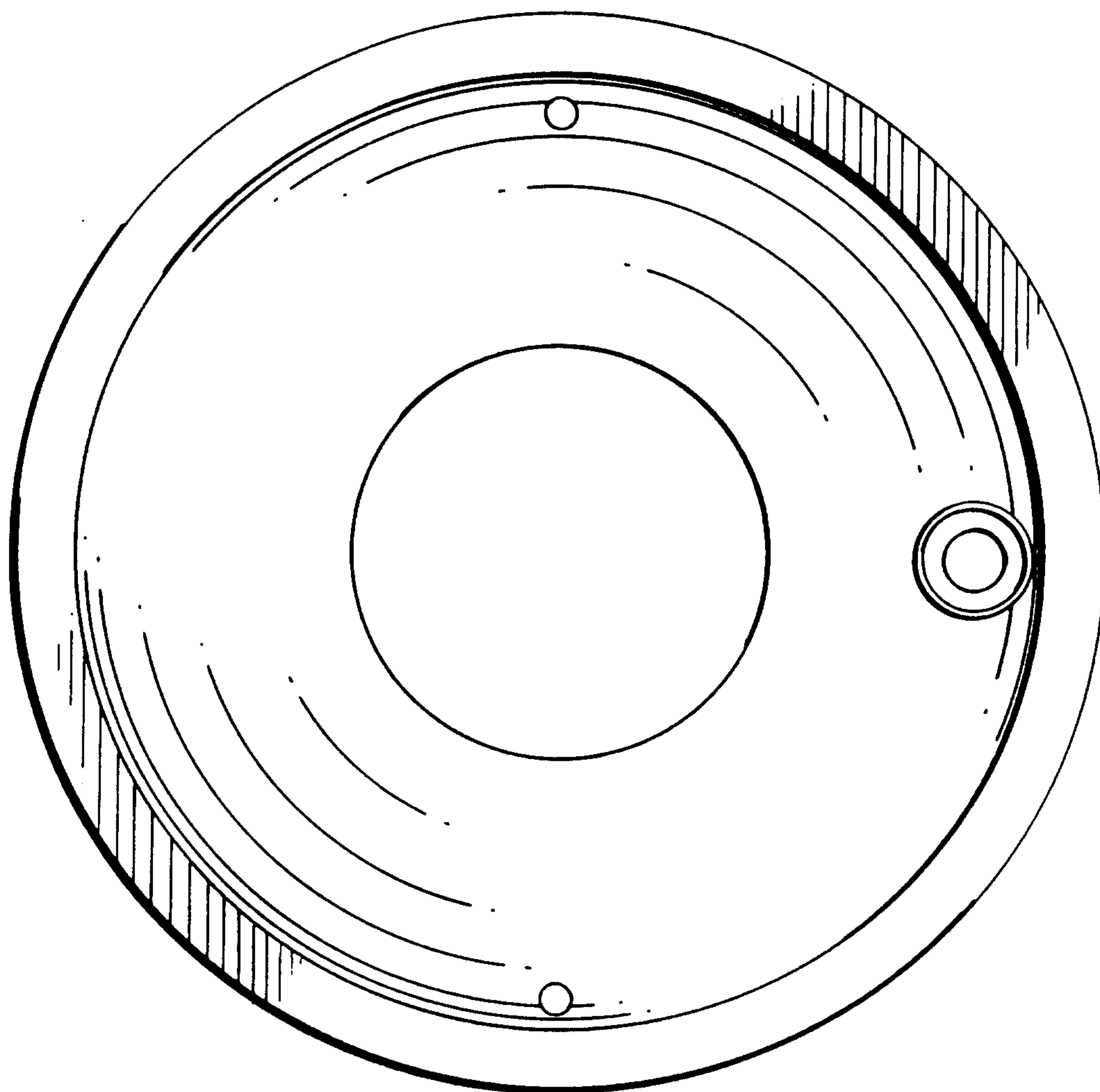


FIG. 2

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FIG. 3



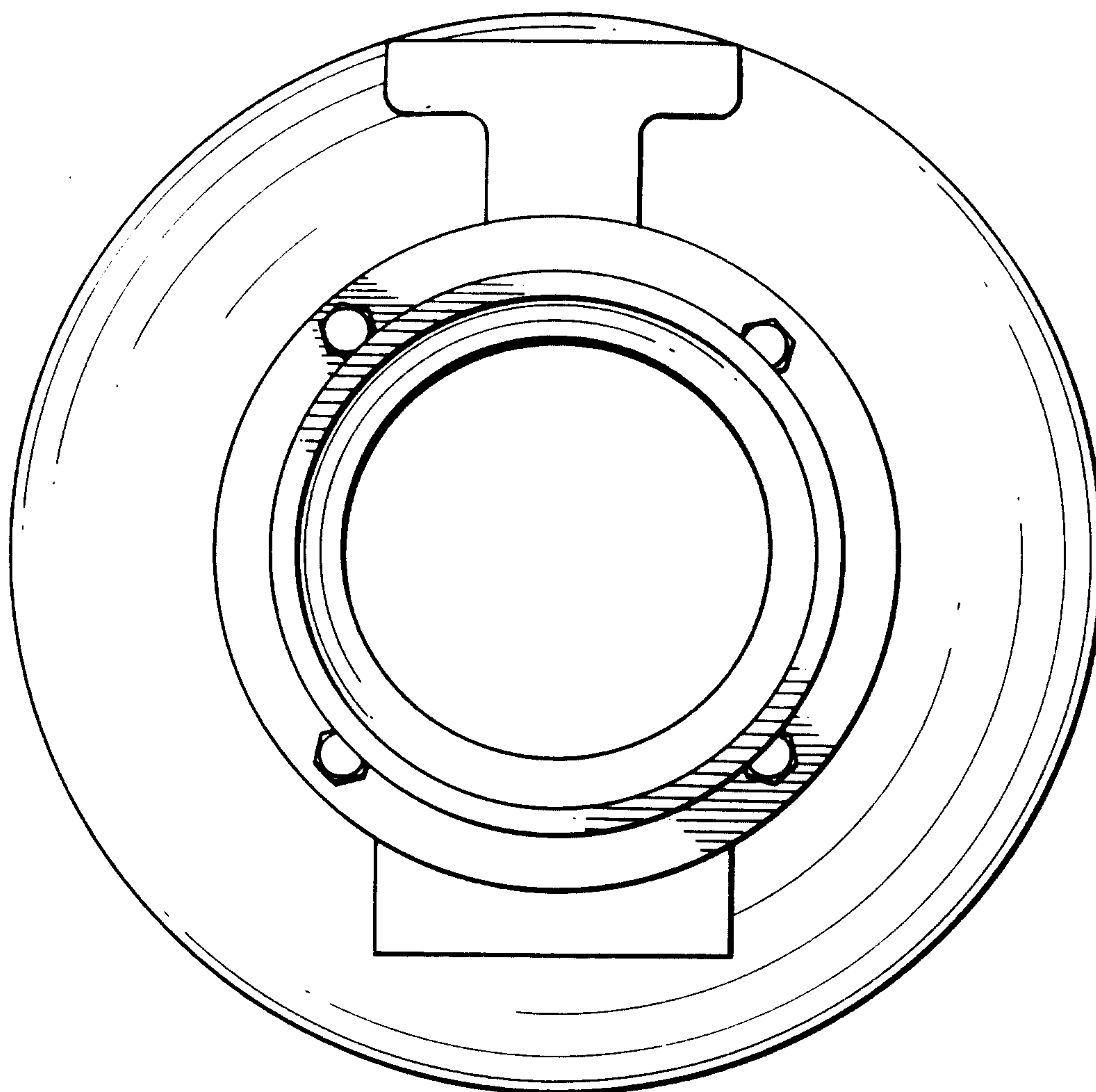


FIG. 4

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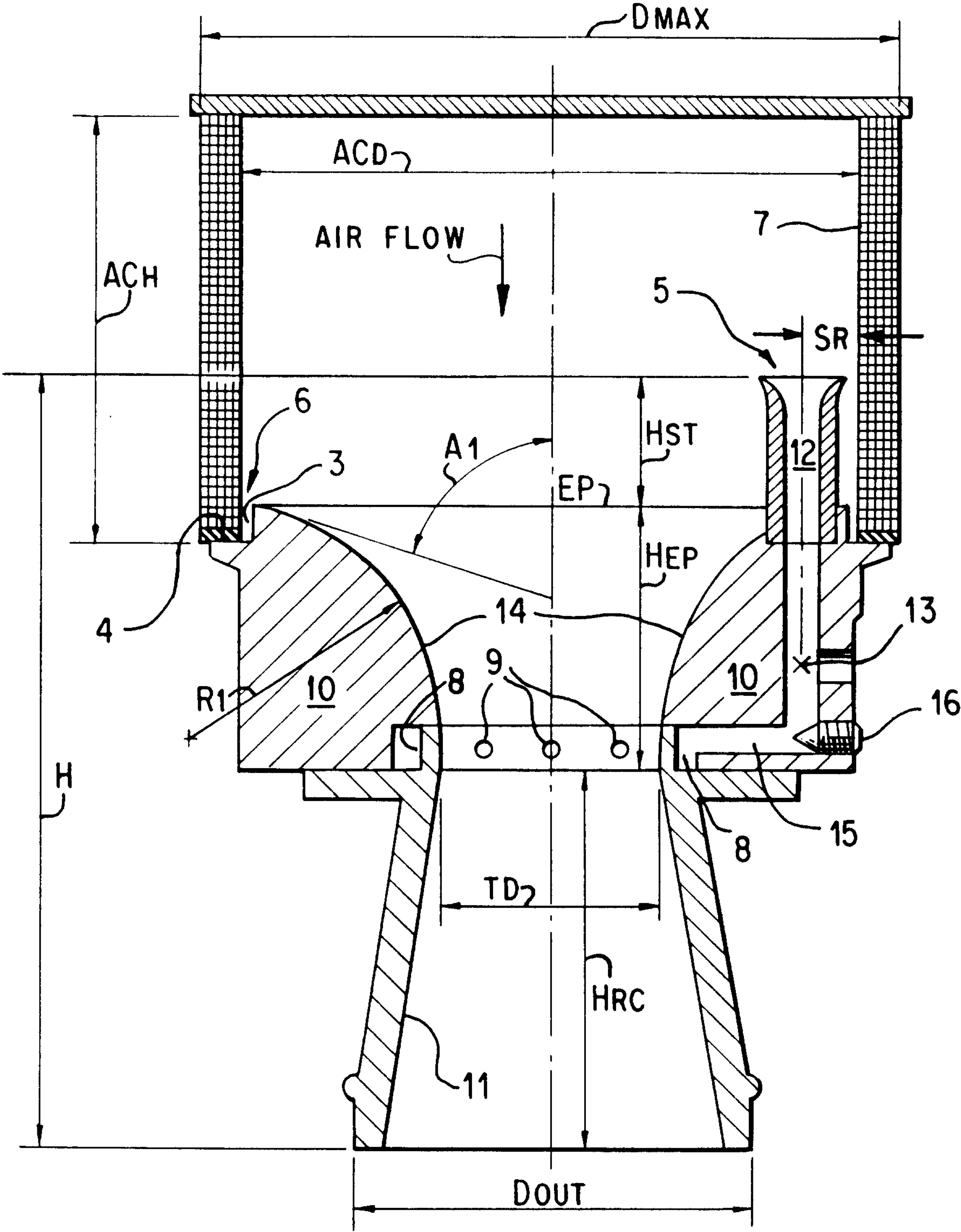


FIG. 5

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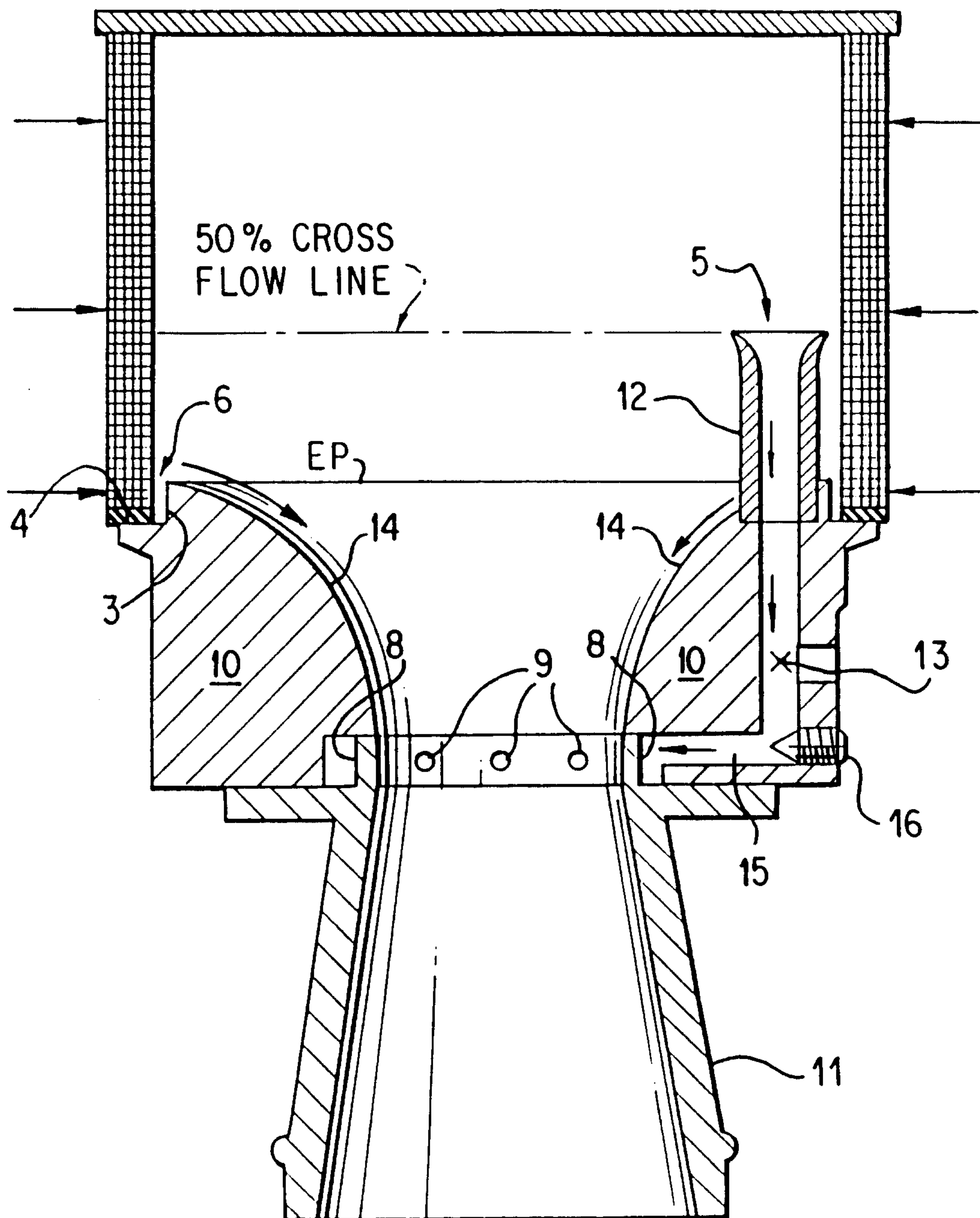


FIG. 6

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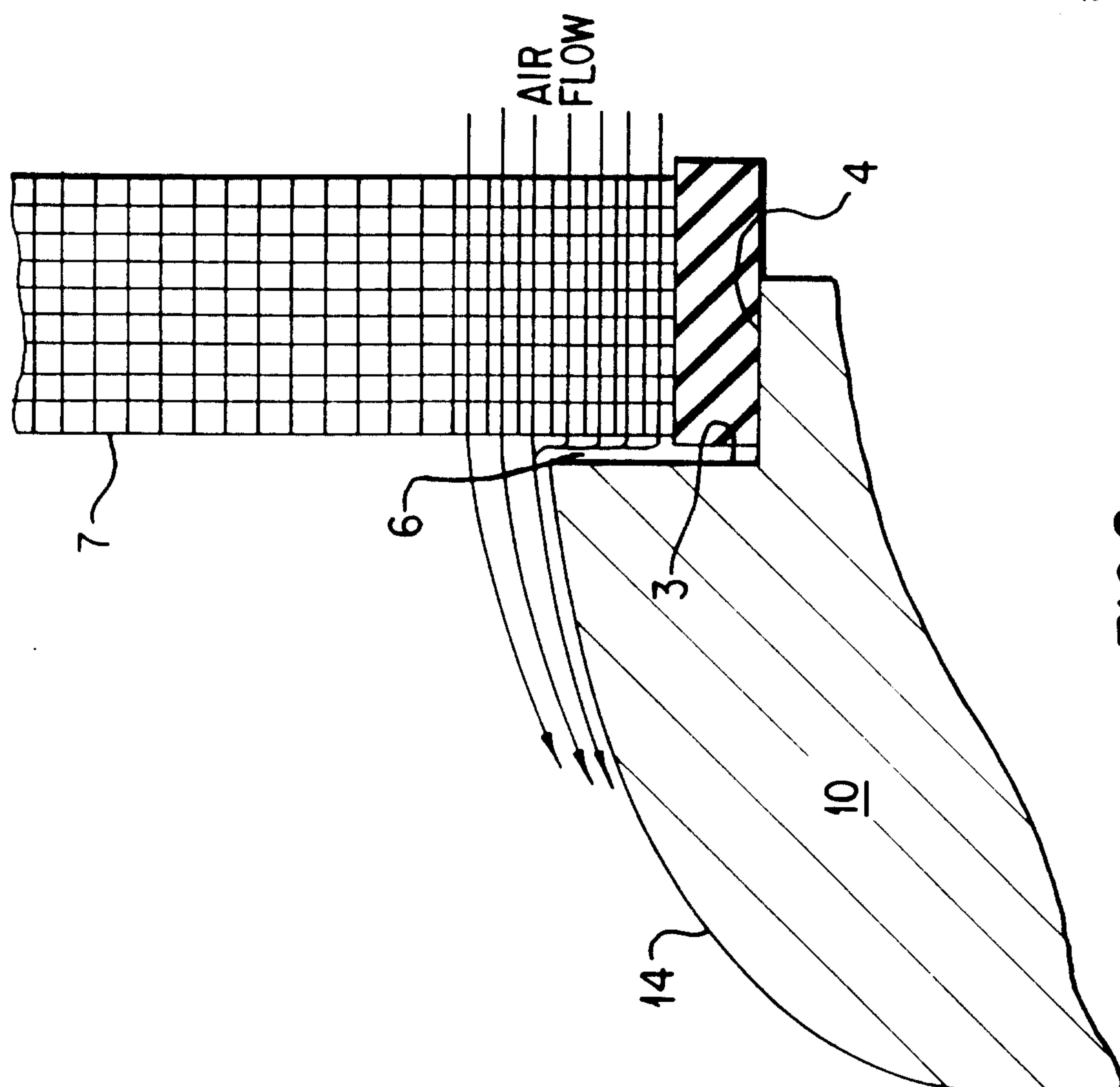


FIG. 8

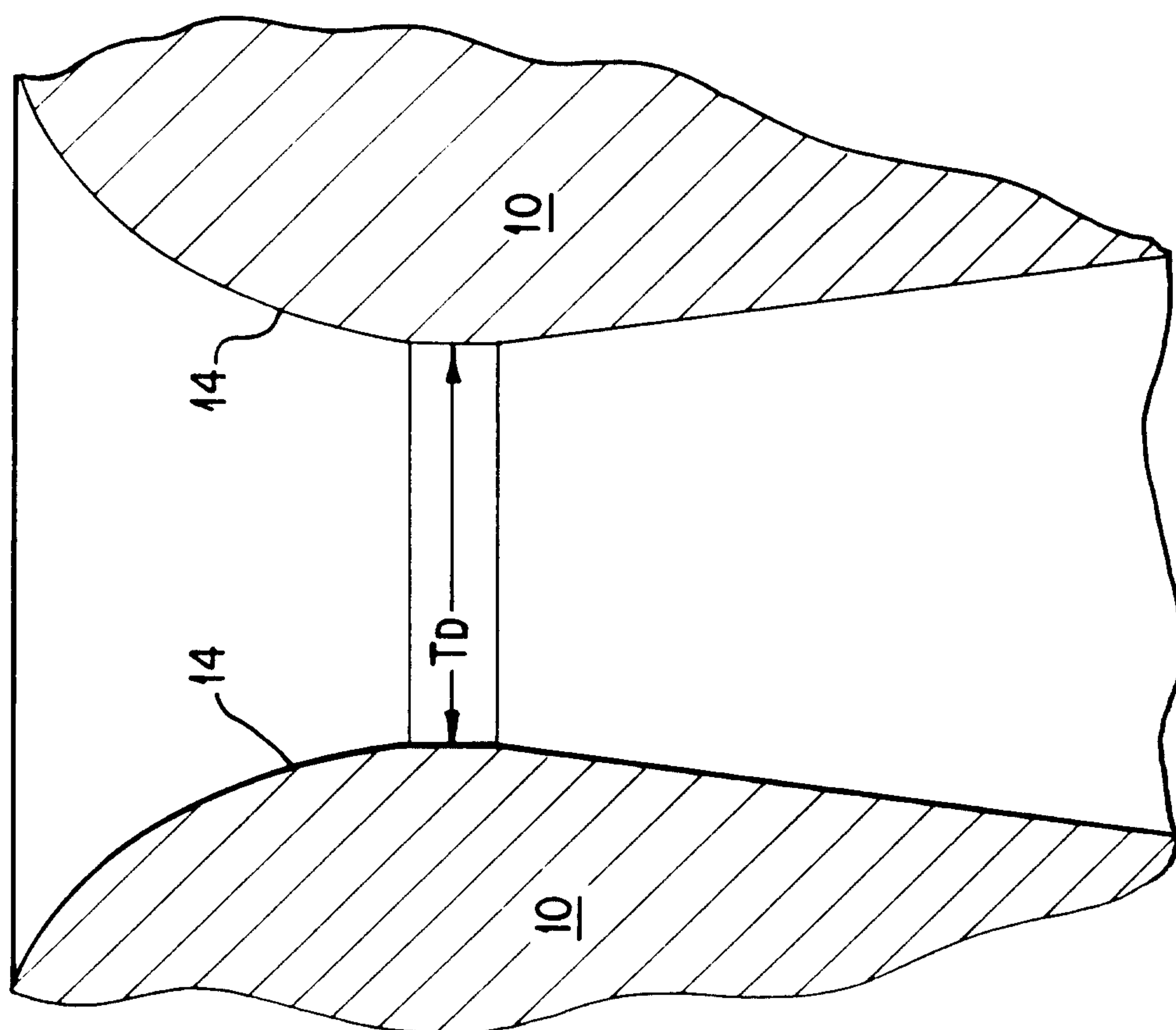


FIG. 7

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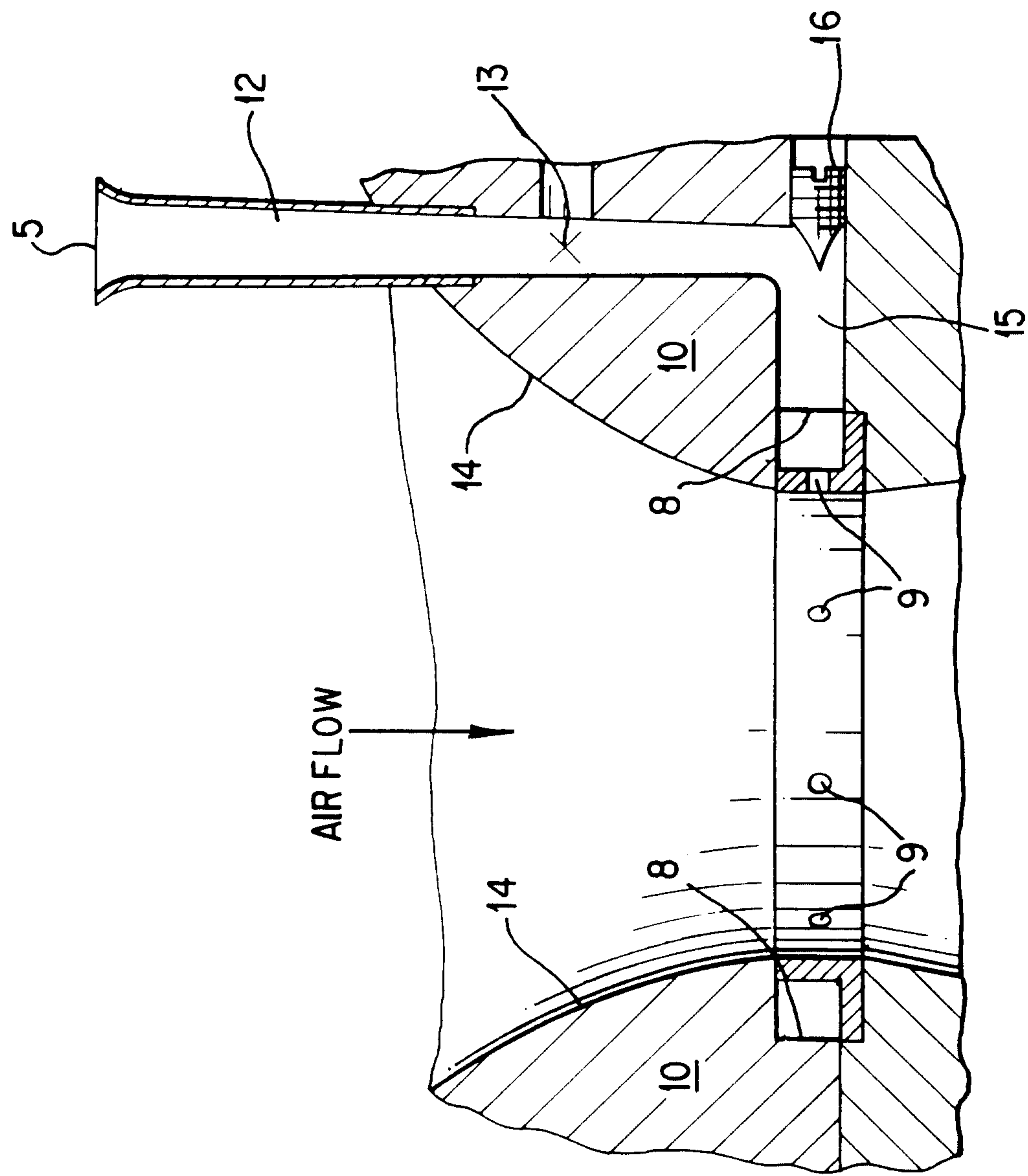


FIG. 9

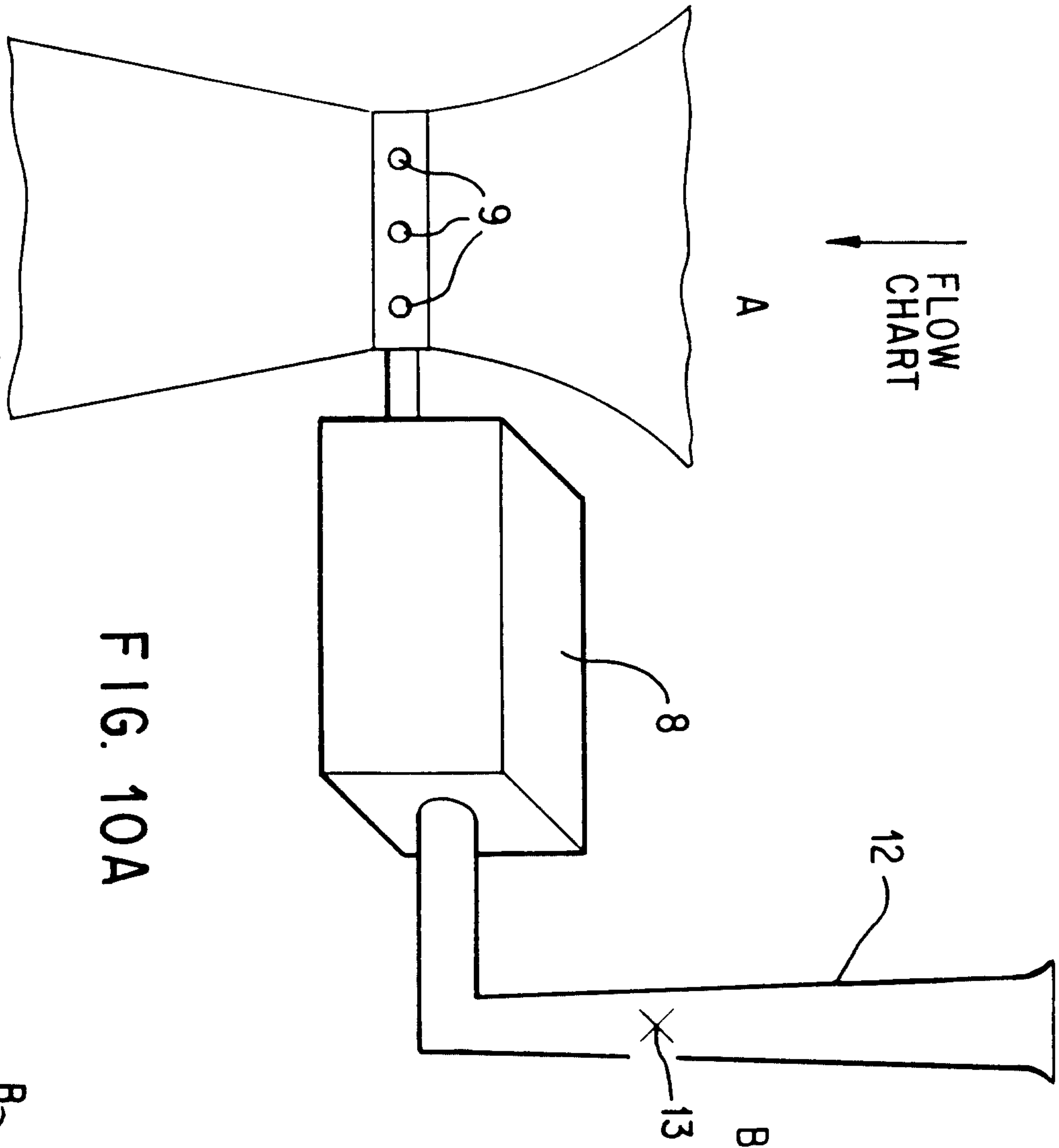


FIG. 10A

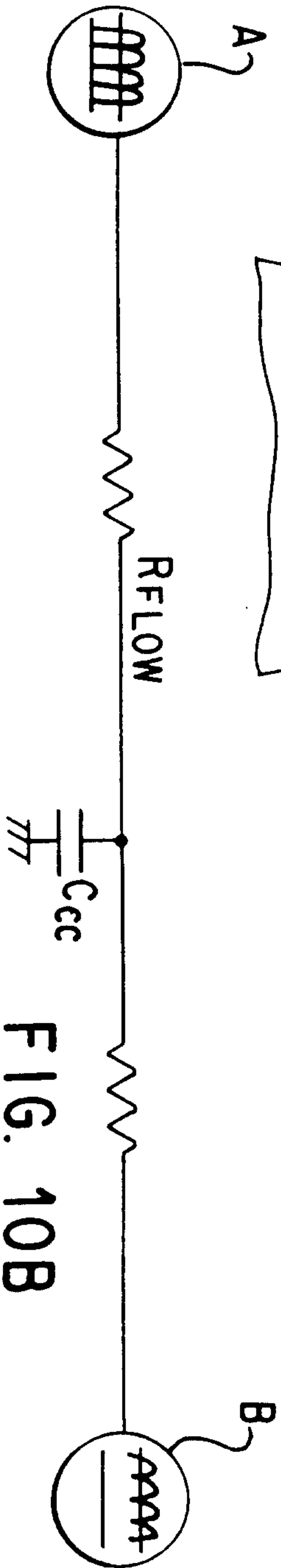


FIG. 10B

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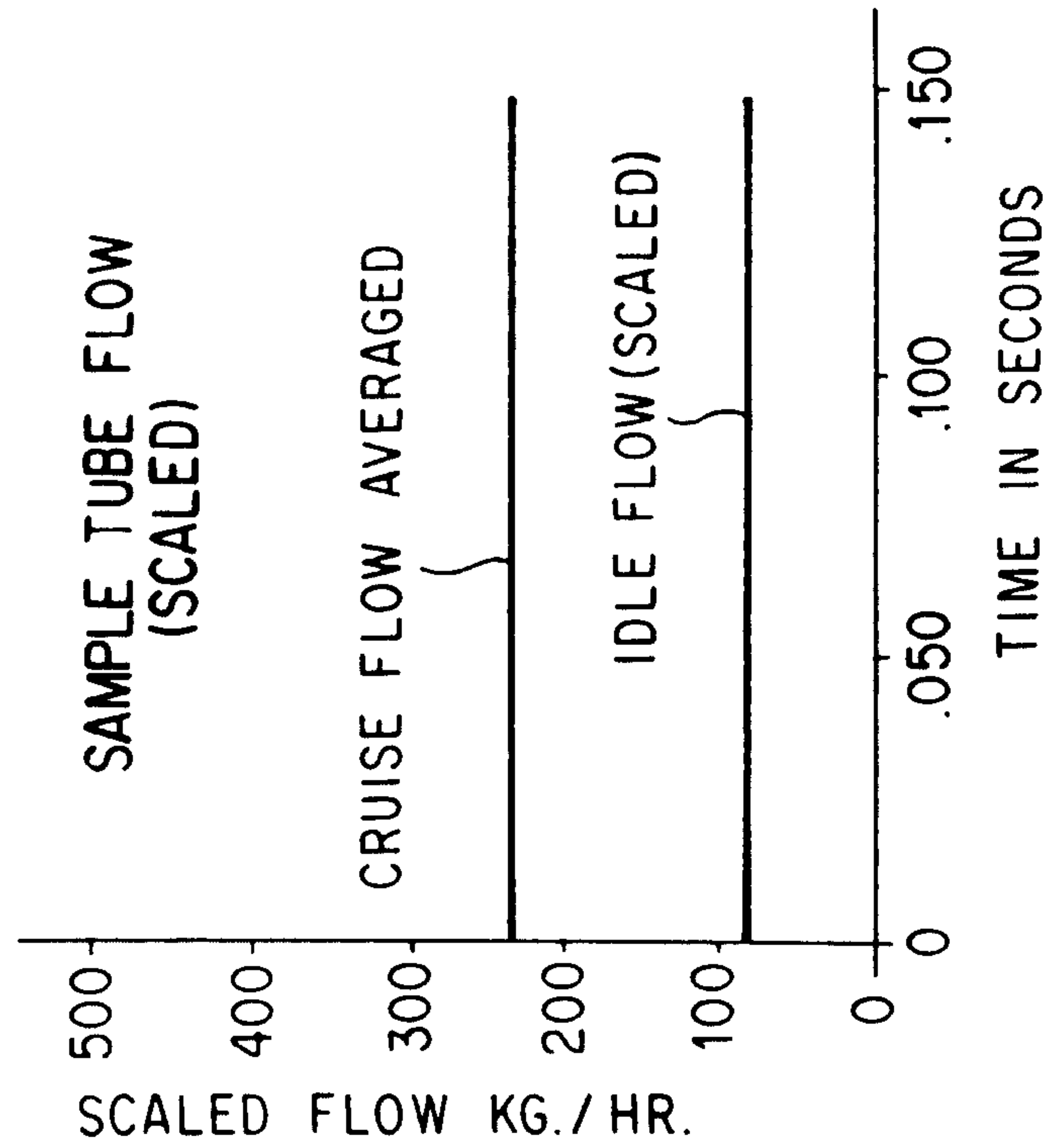


FIG. 11B

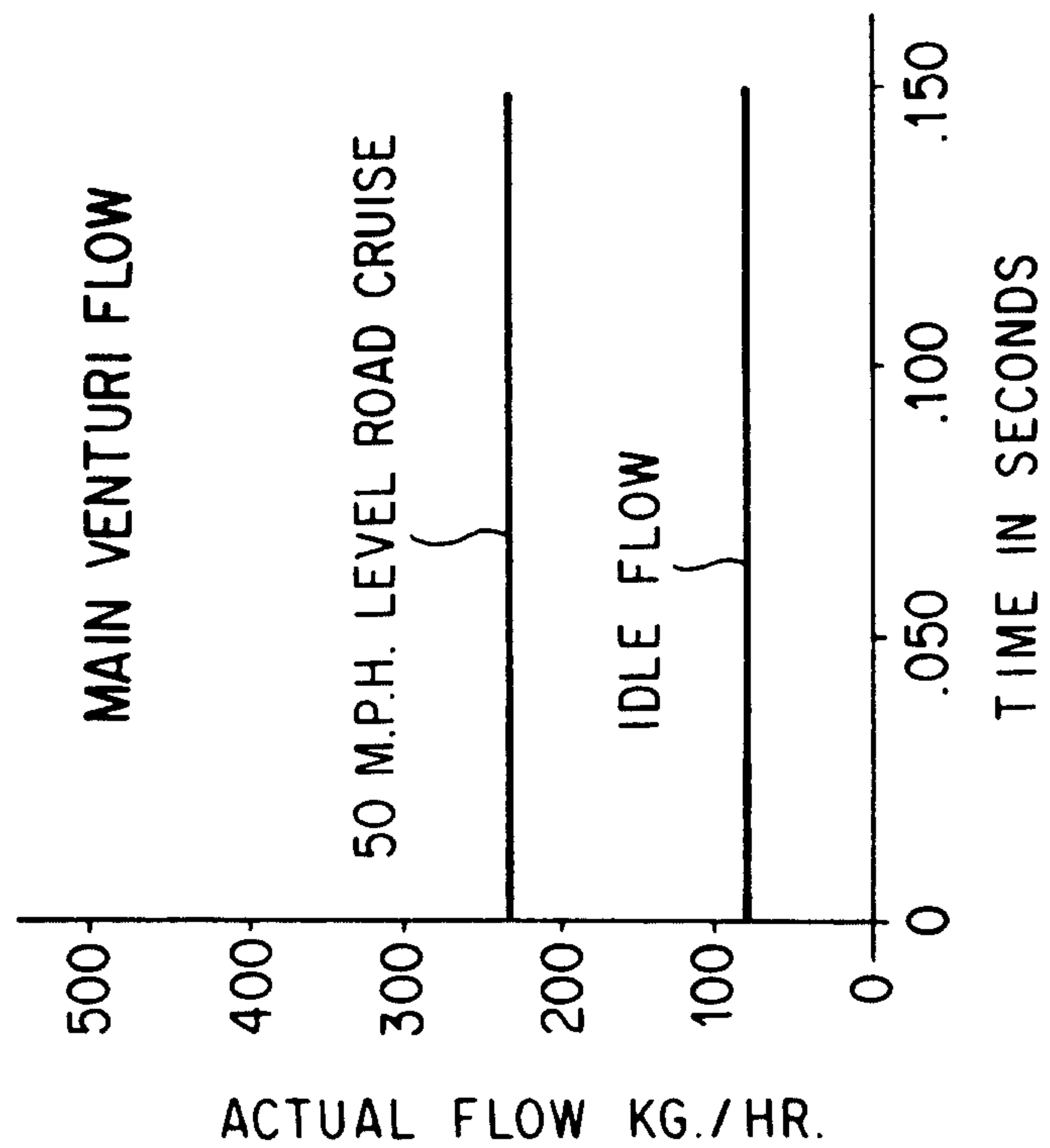


FIG. 11A

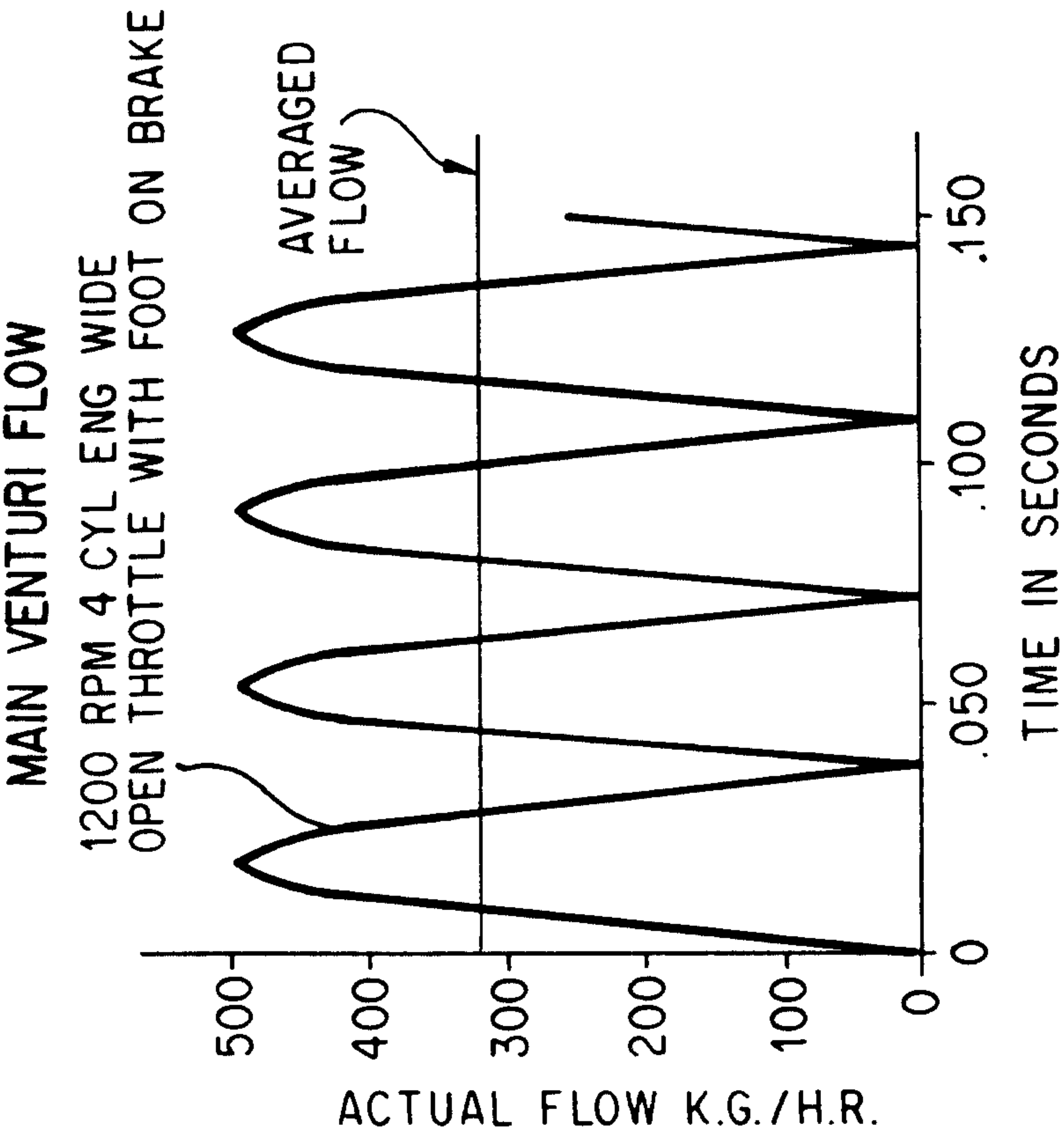


FIG. 11C

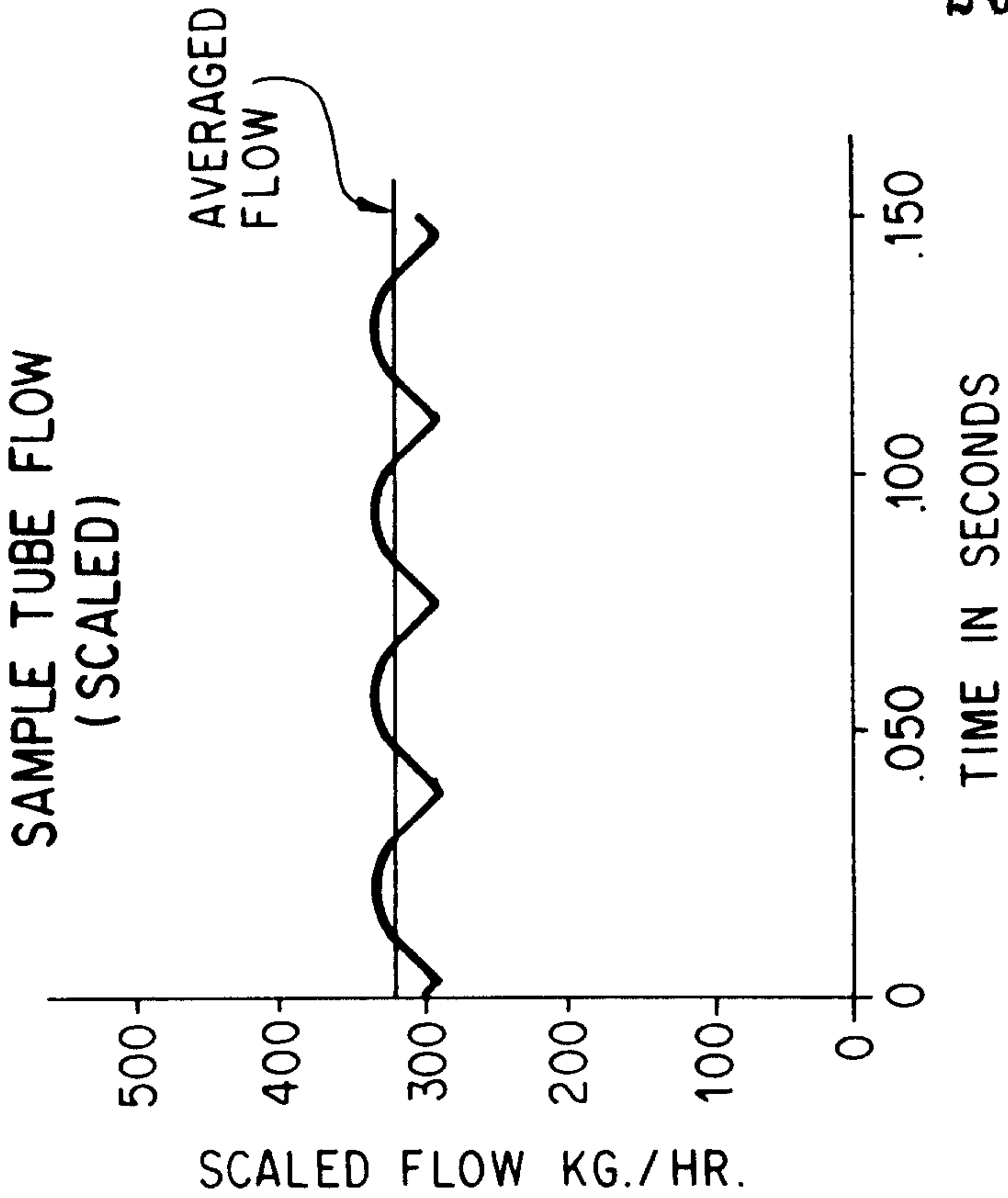
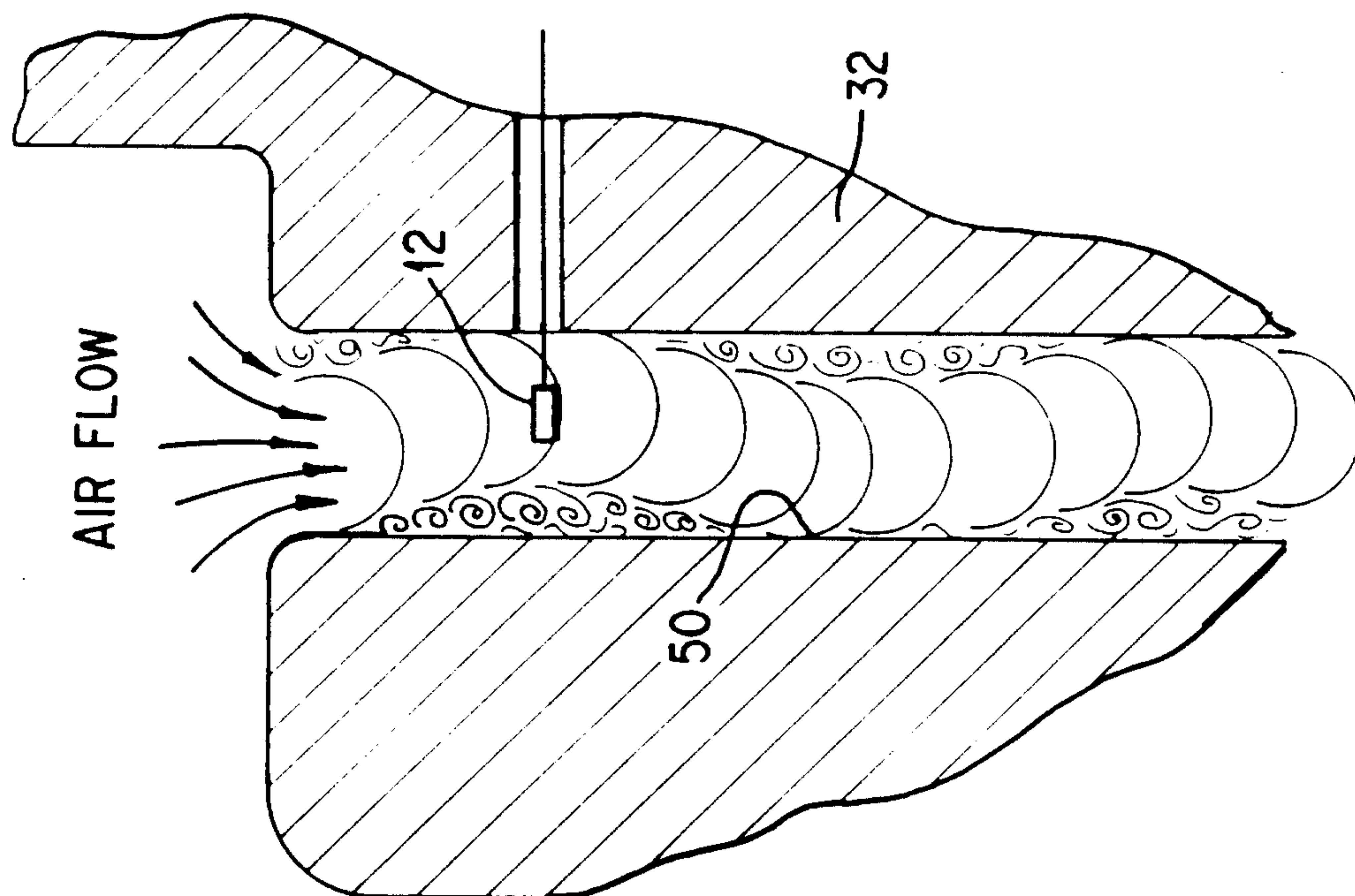
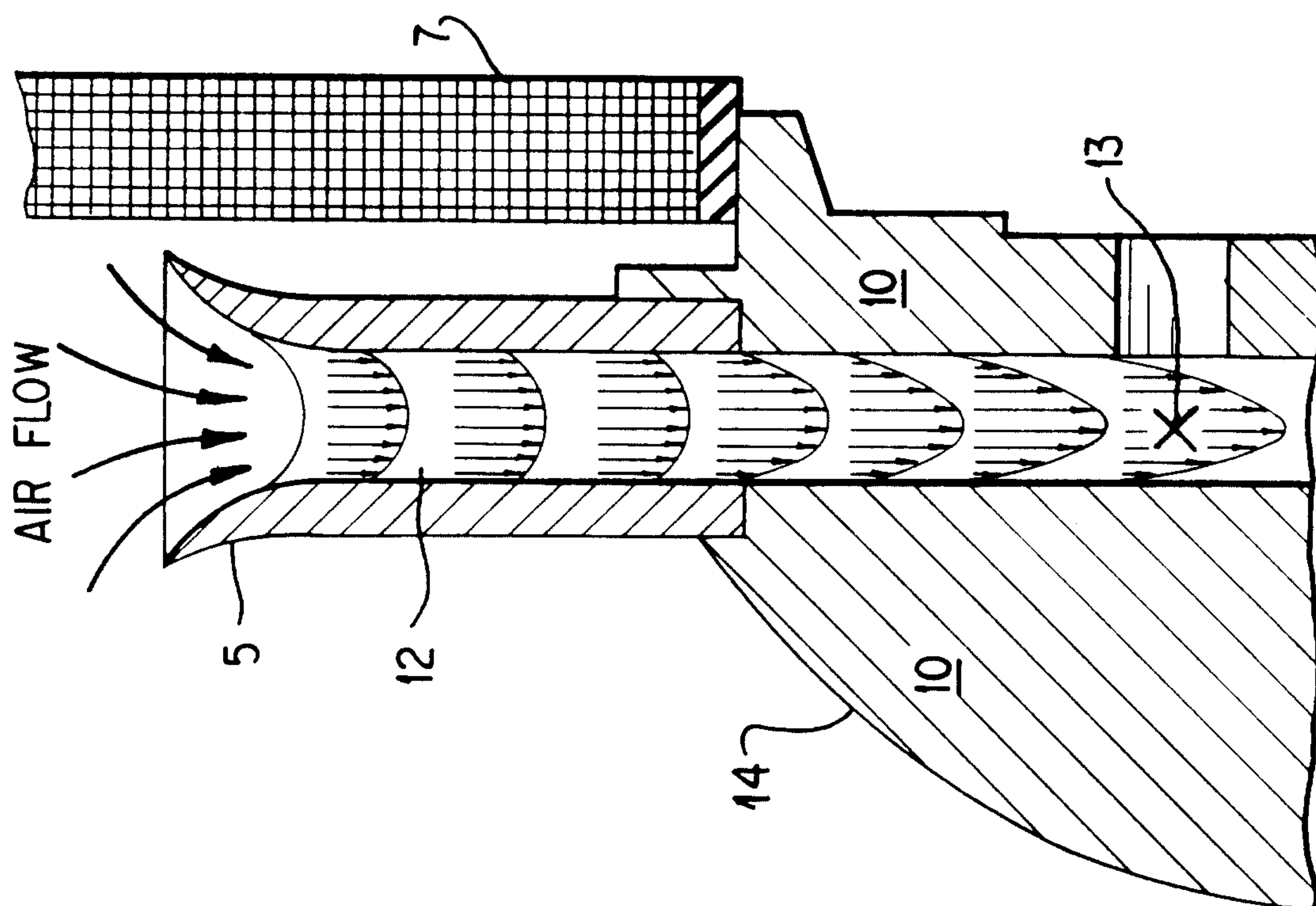


FIG. 11D

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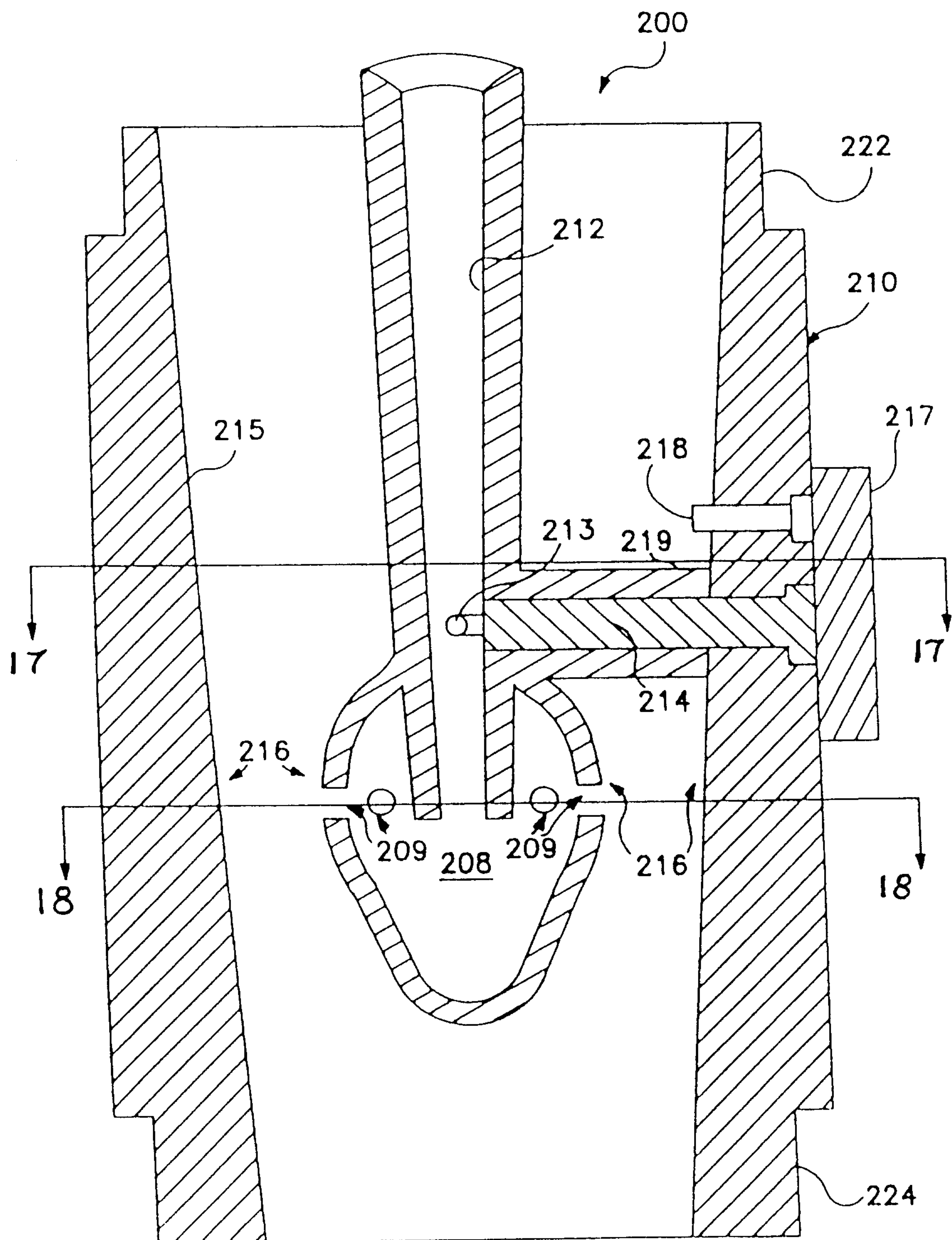


FIG. 14

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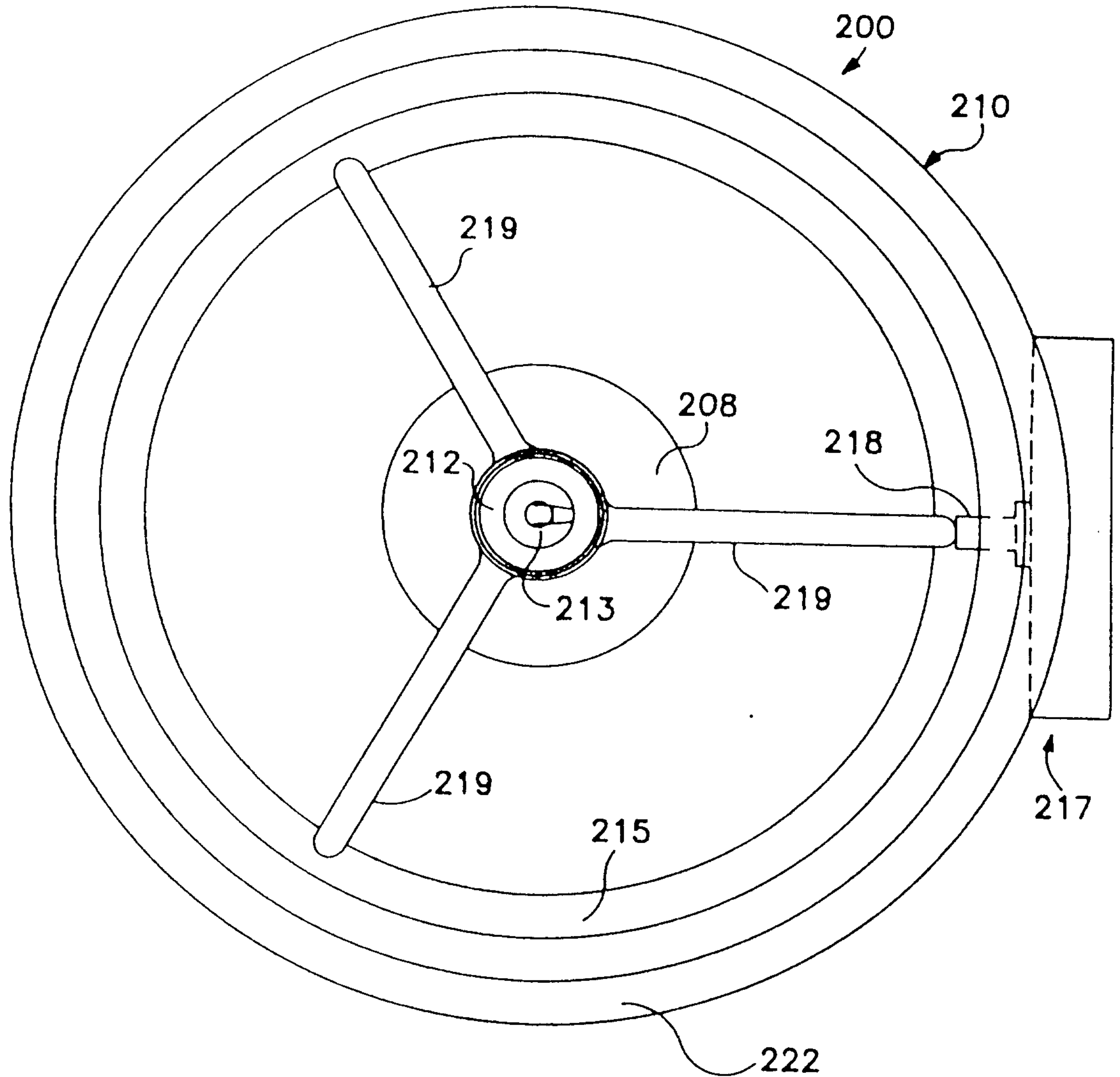


FIG. 15

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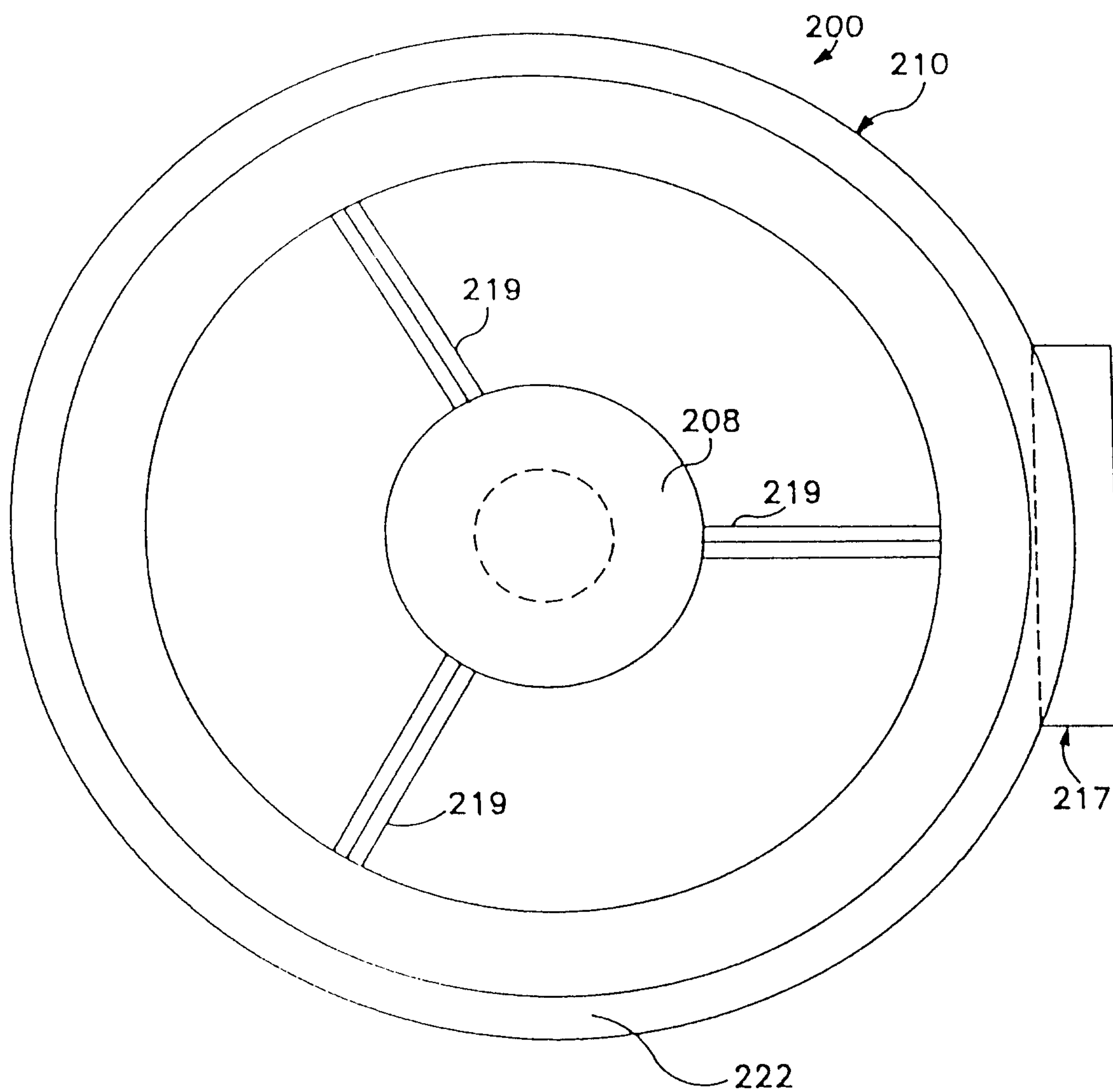


FIG. 16

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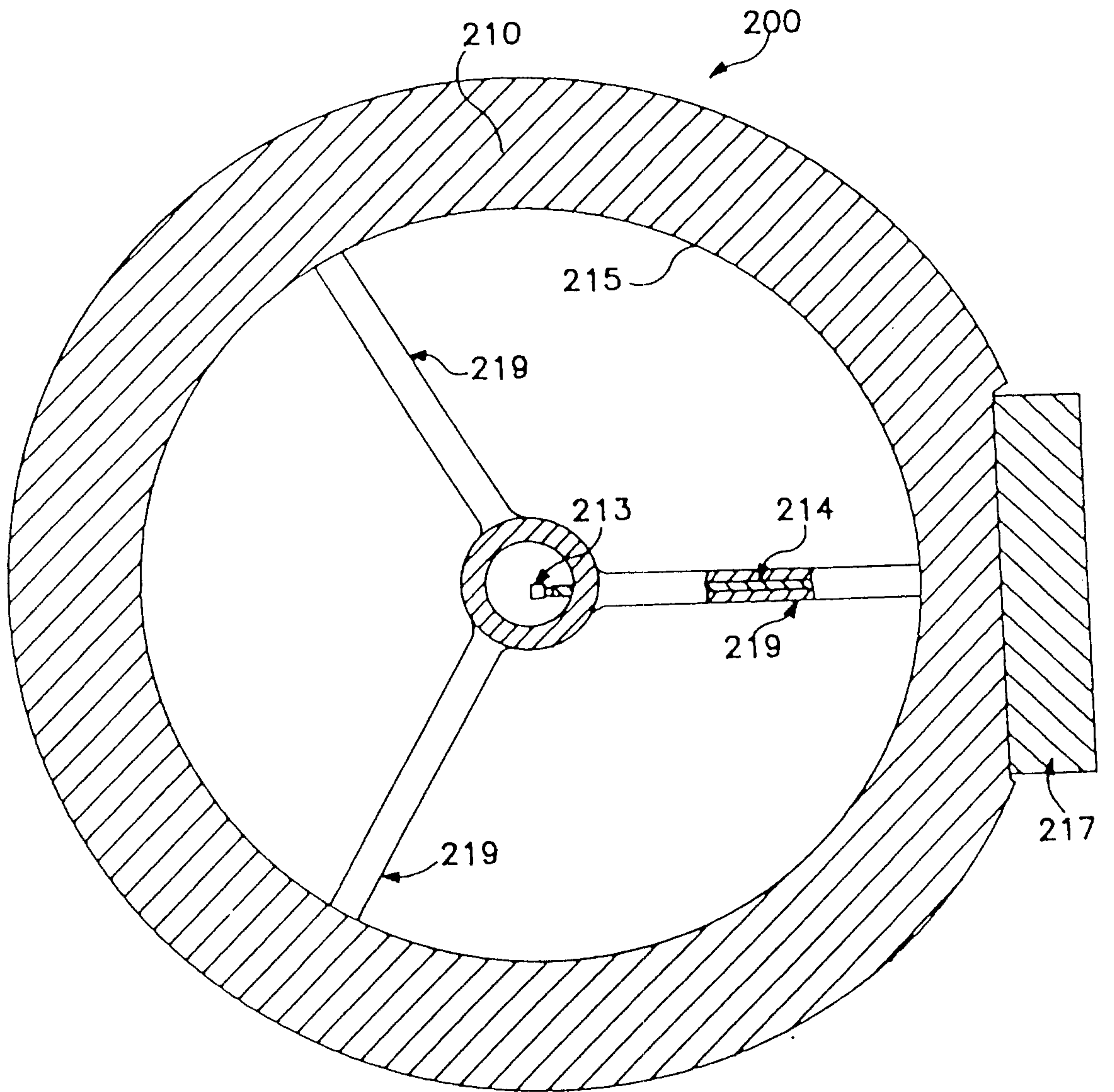


FIG. 17

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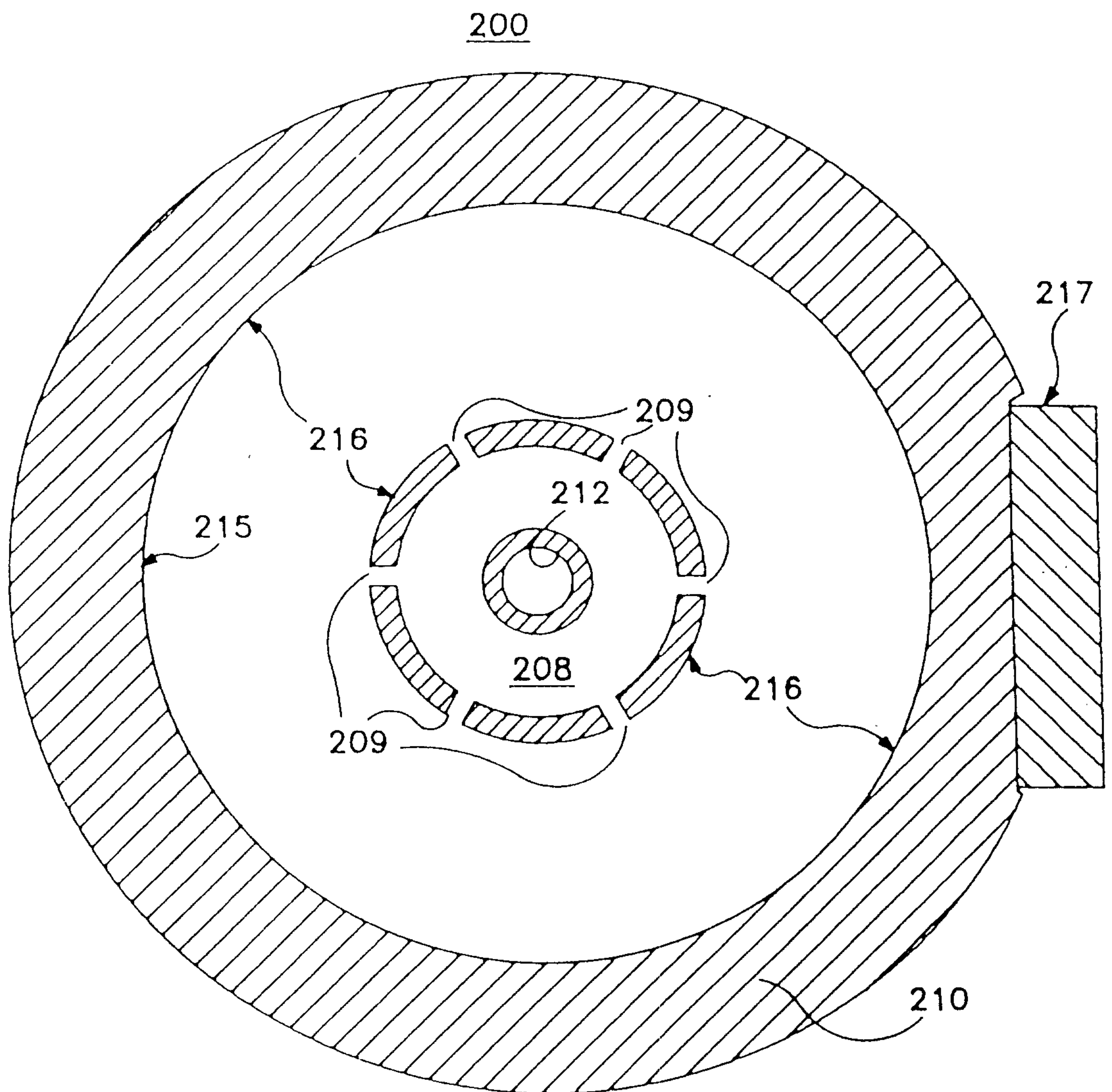


FIG. 18

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