# United States Patent

**Olin**

[15] **3,653,253**

[45] **Apr. 4, 1972**


## [54] AEROSOL MASS CONCENTRATION SPECTROMETER


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[21] Appl. No.: **1,068**

[52] **U.S. Cl.** ................................**73/28,** 73/61 R, 73/432 PS

[51] **Int. Cl.** ........................................................**G01n 15/02**

[58] **Field of Search** .............................73/432 PS, 61, 23, 28



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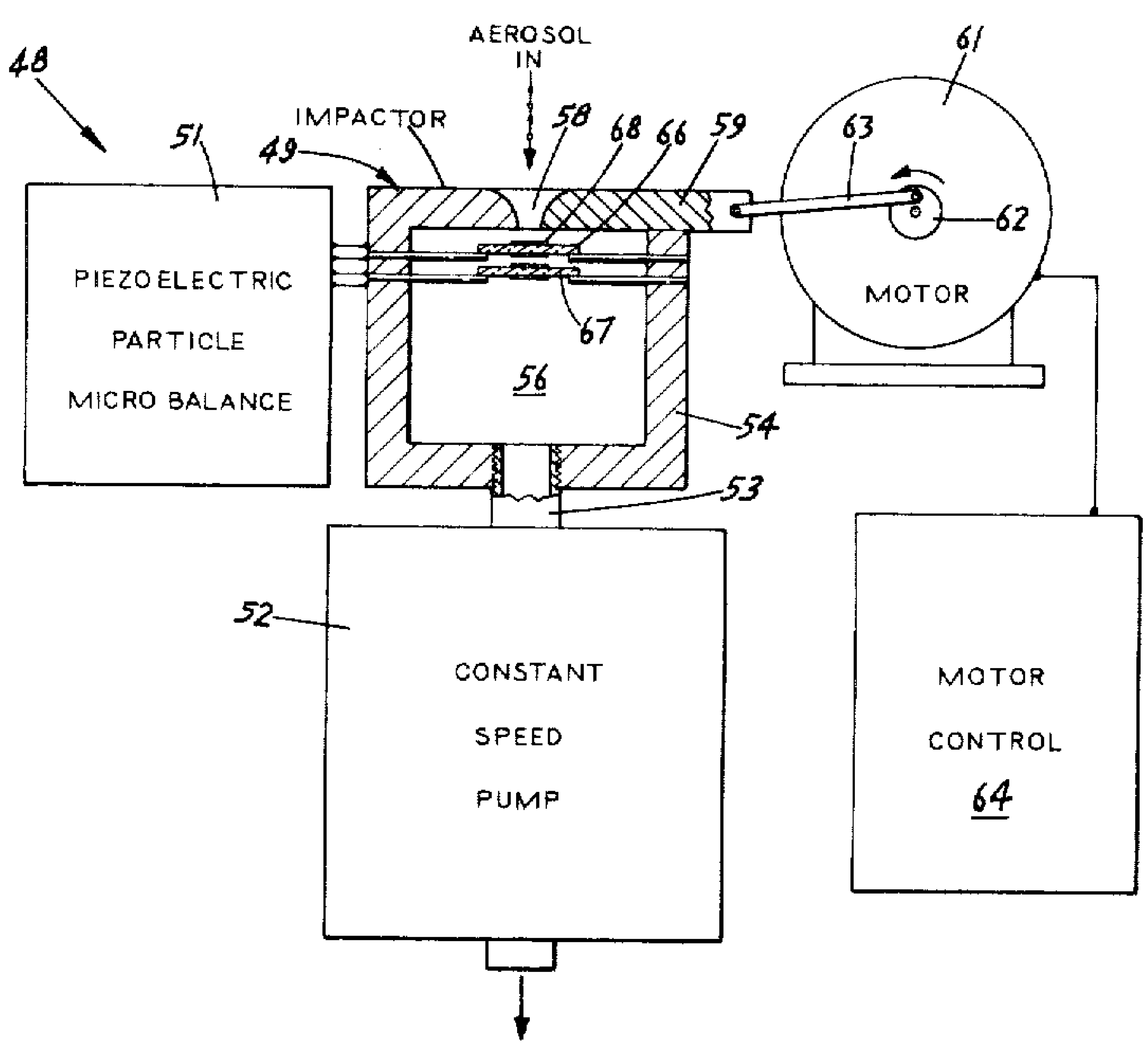
[57] **ABSTRACT**

An apparatus and method for determining particle or aerosol mass concentration distribution using a particle sensing element, as a piezoelectric crystal, for collecting particles to increase the mass of the element. The particles are force deposited on the sensing element. The amount of force is sequentially changed to alter the critical particle size deposited on the sensing element. The mass of the particles accumulated on the sensing element during each force period provides information of the particle mass concentration. The difference between particle mass concentration, at two successive values of critical particle sizes, provides data relative to particle mass concentration distribution.


**31 Claims, 11 Drawing Figures**



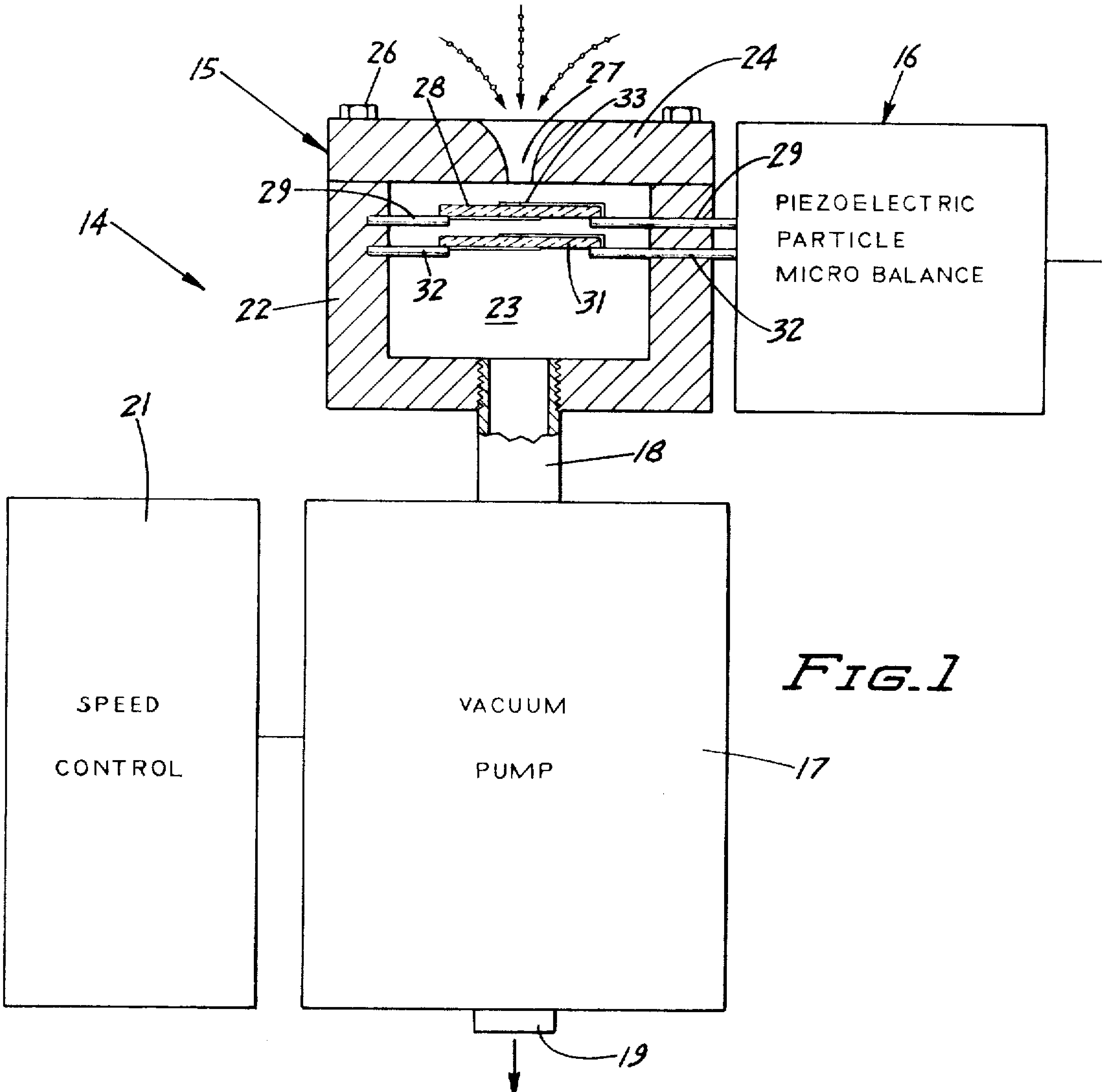



FIG. 1

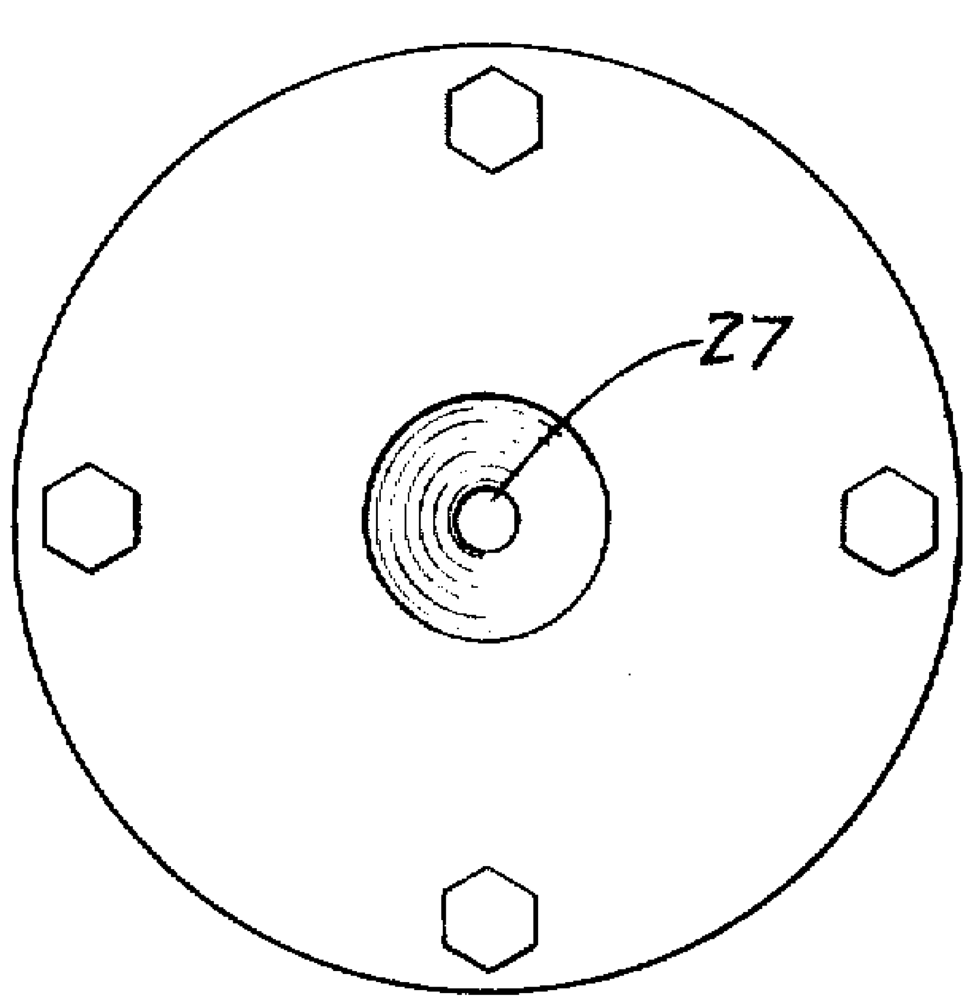



FIG. 2

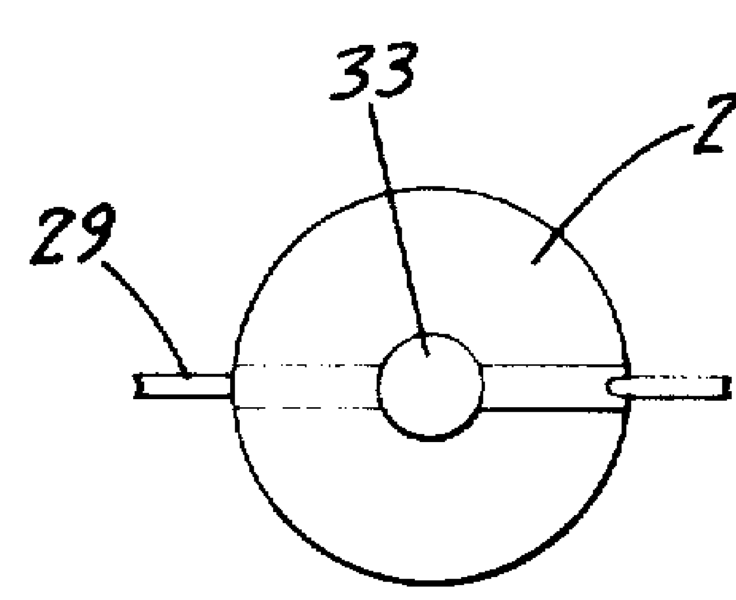



FIG. 3

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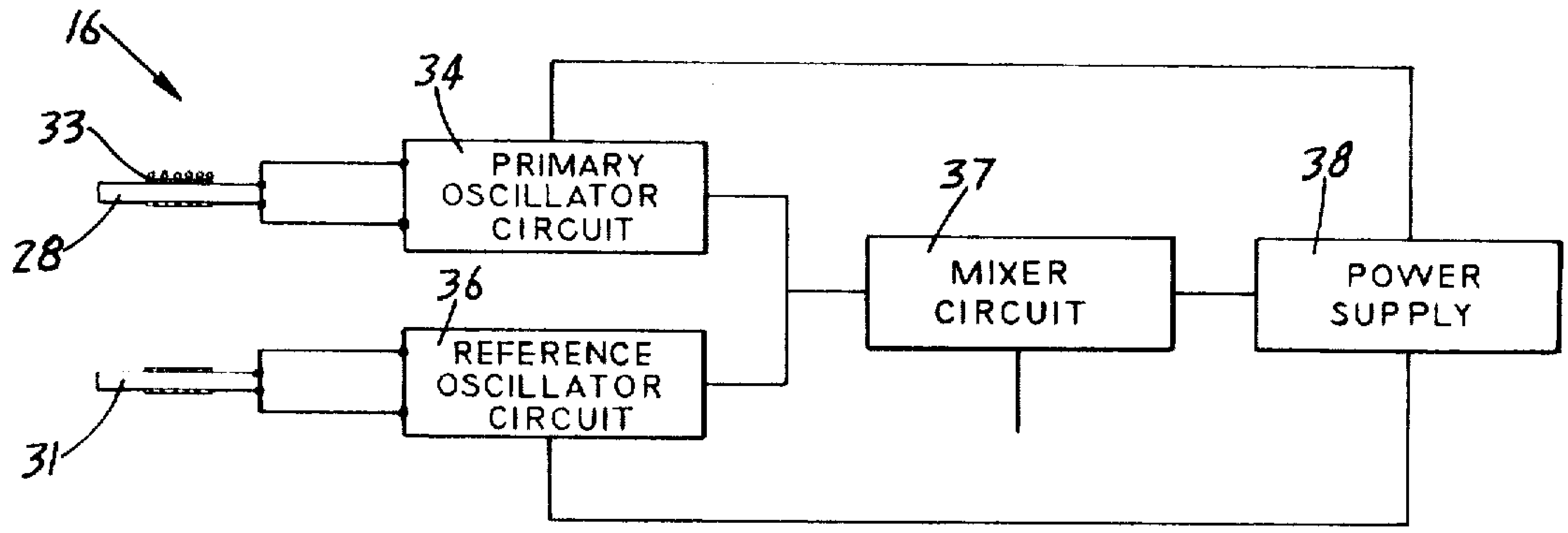


FIG. 4

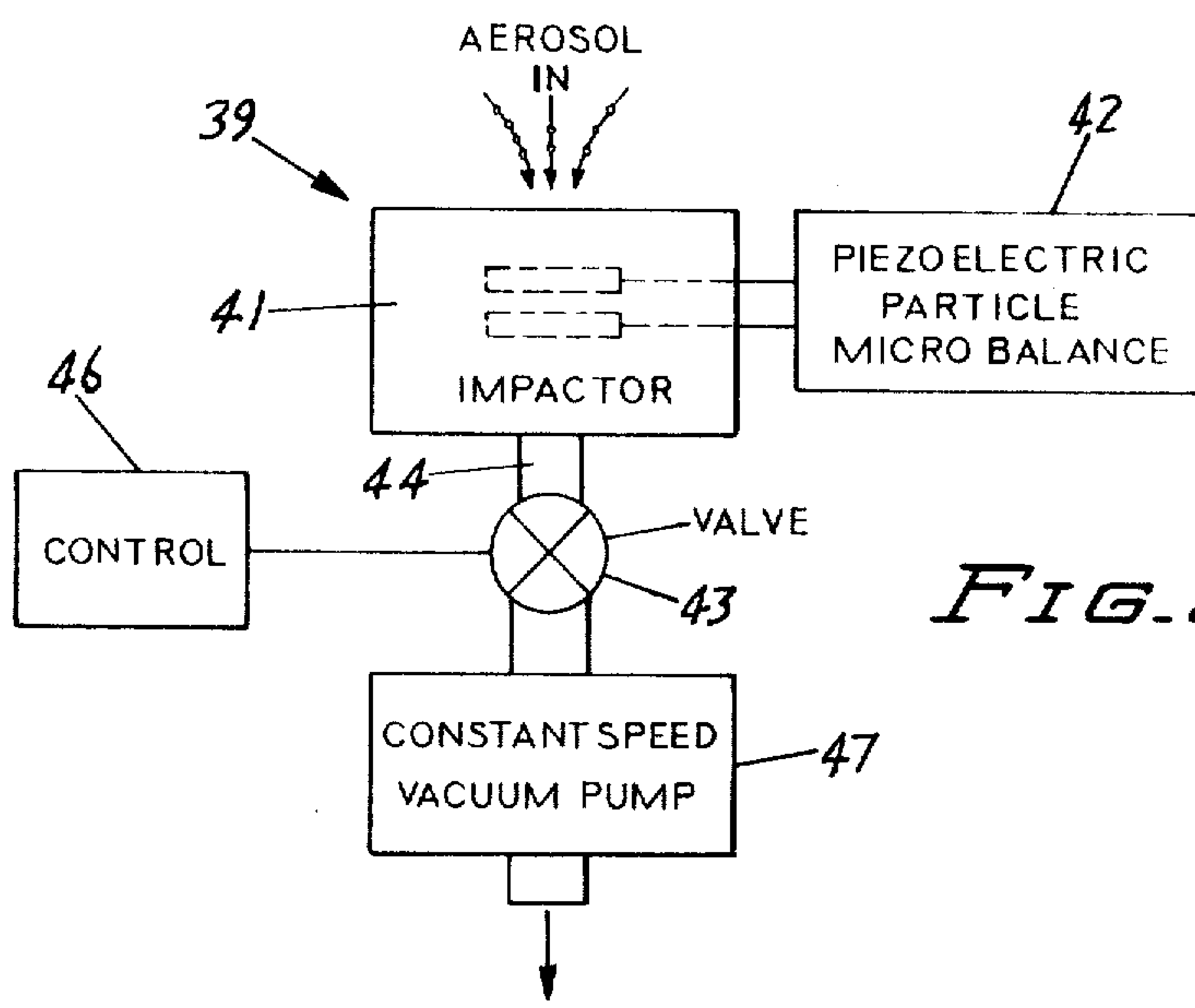


FIG. 5

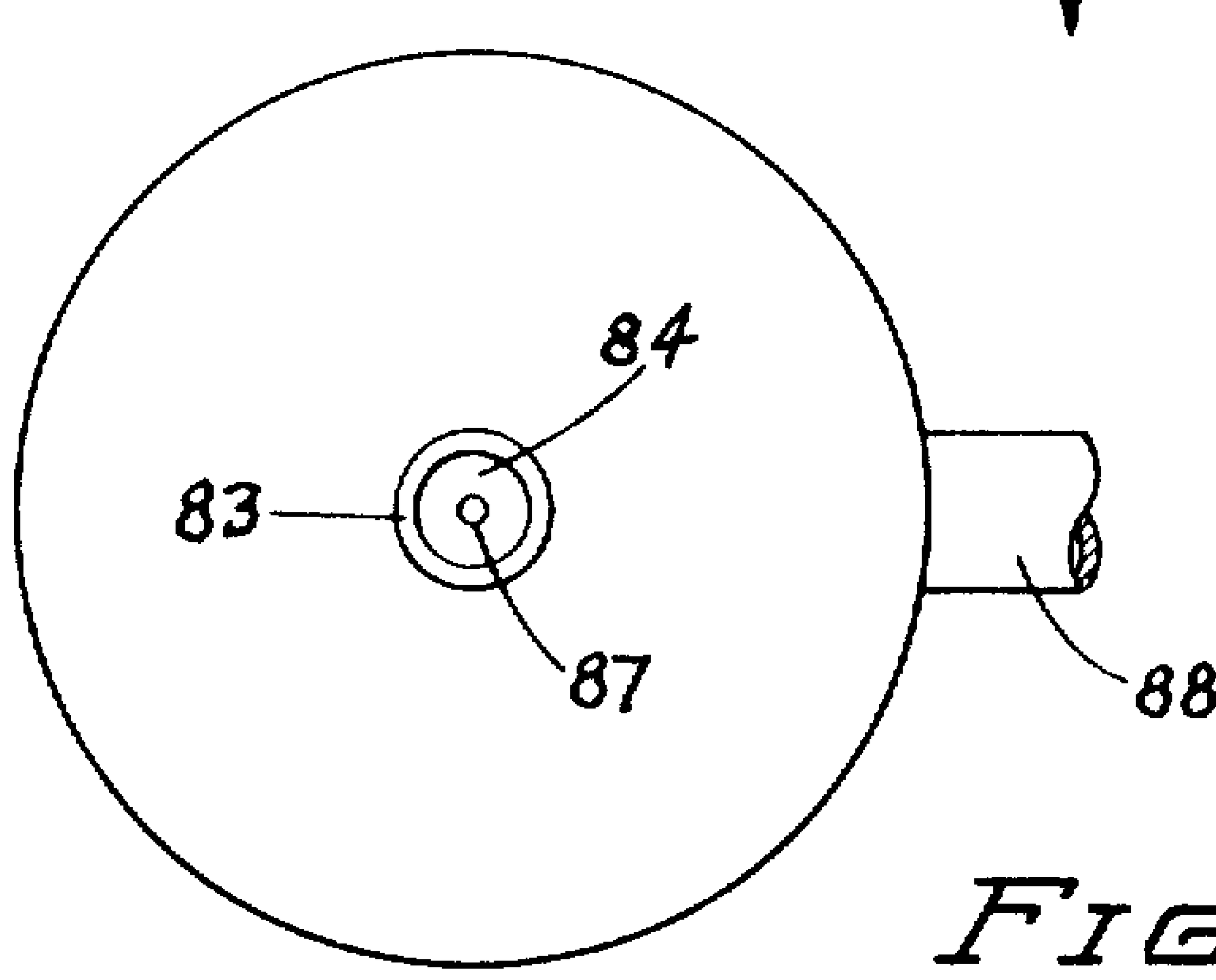


FIG. 9

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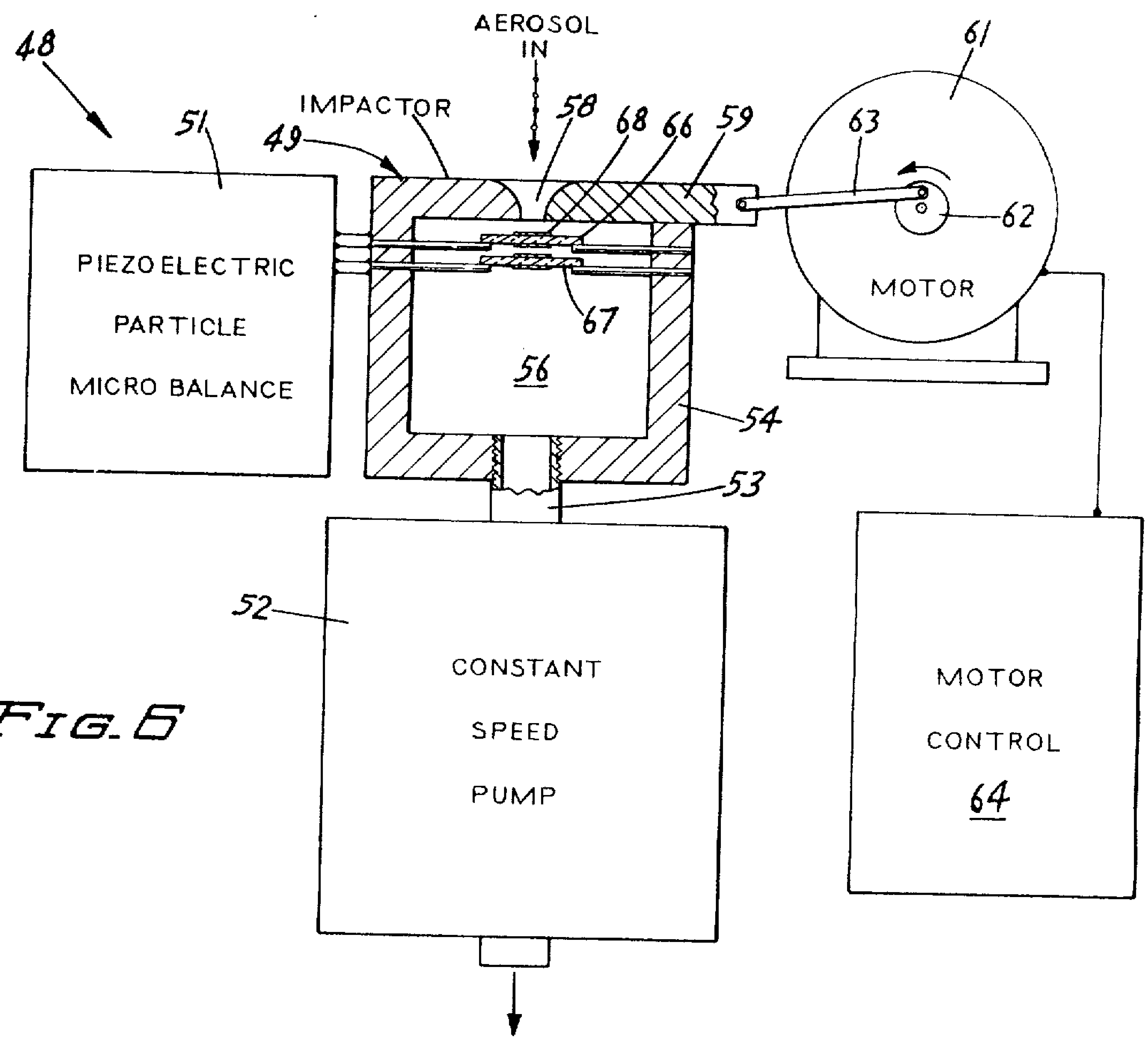


FIG. 6

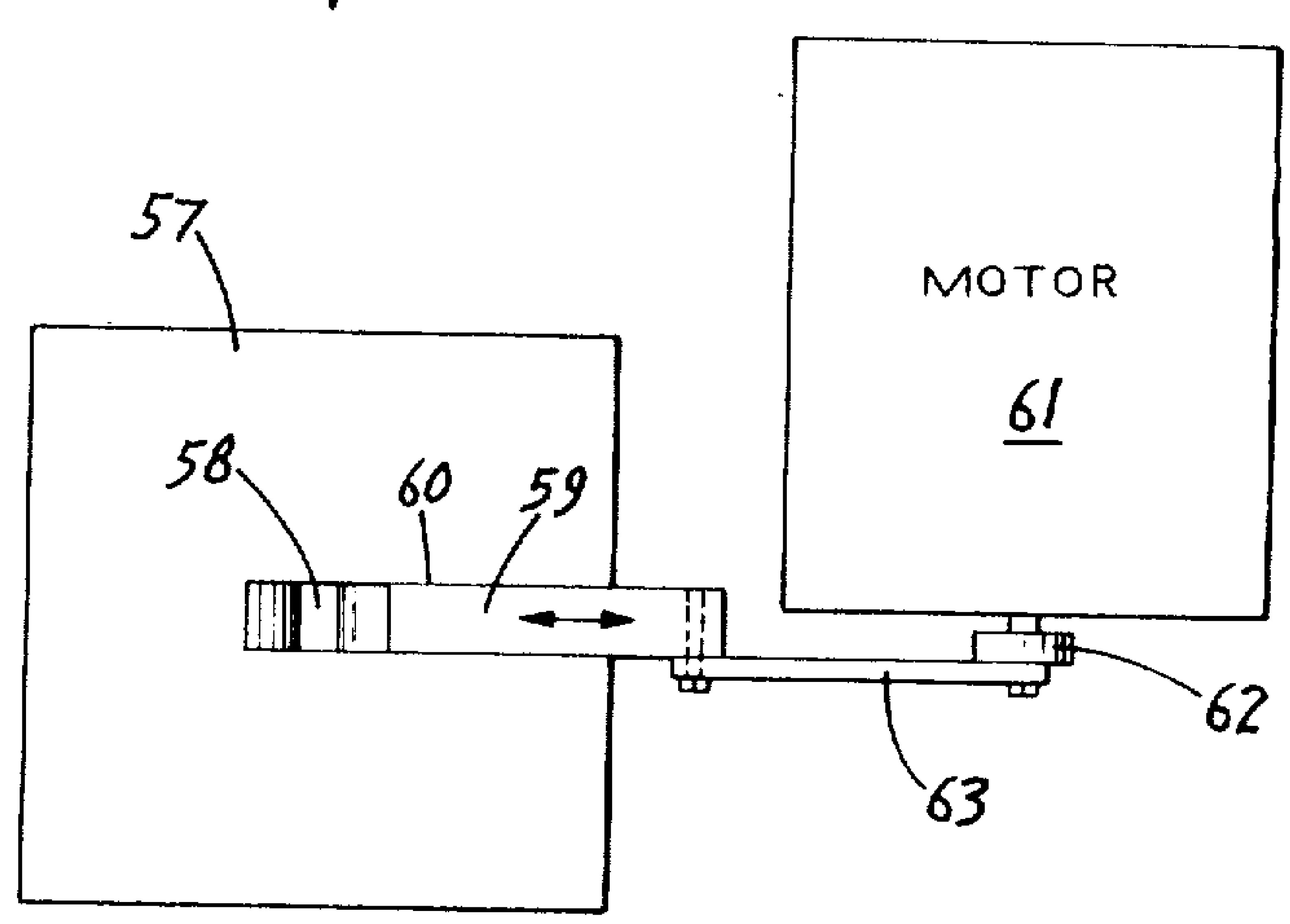


FIG. 7

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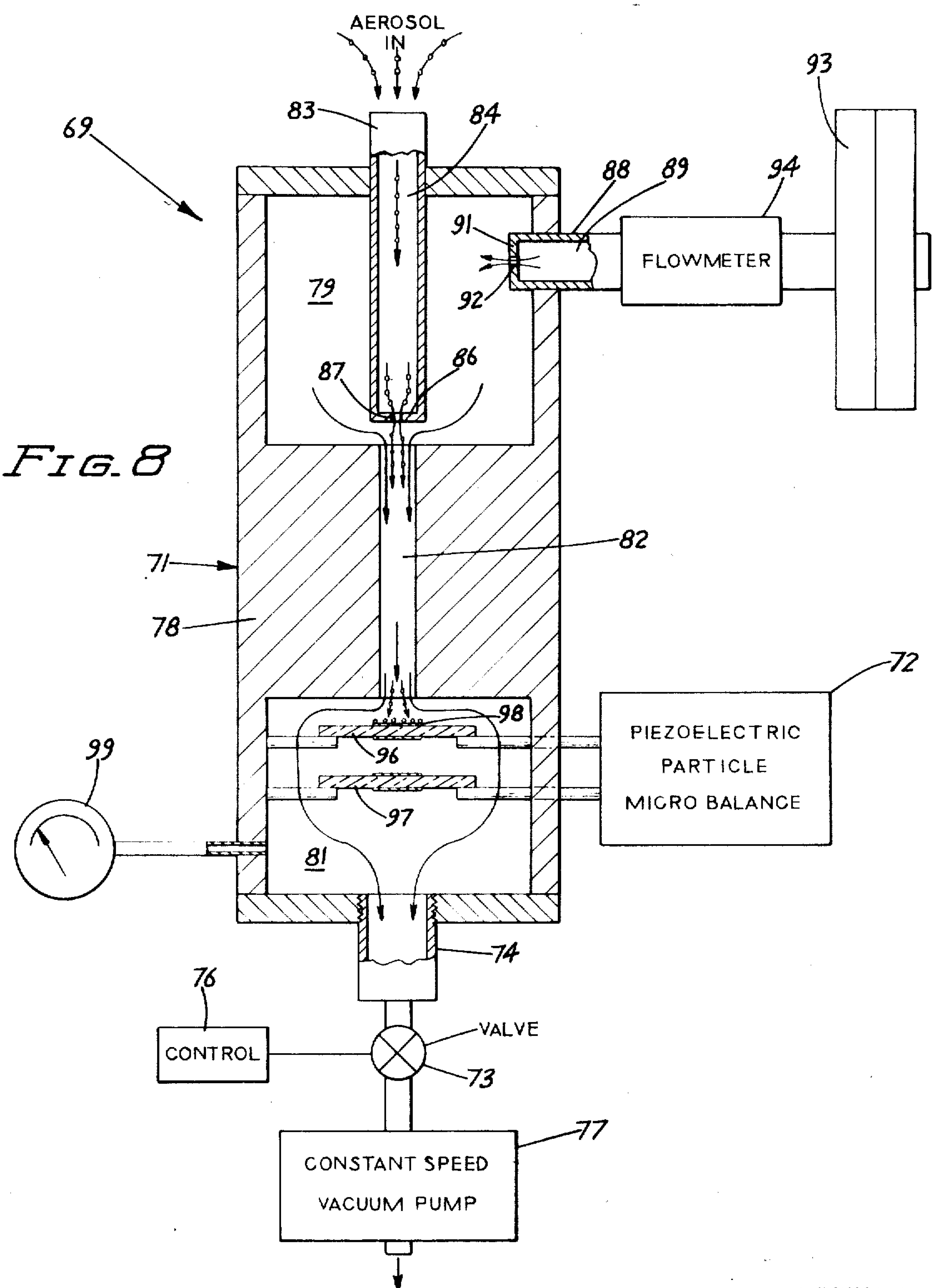


FIG. 8

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FIG. 10

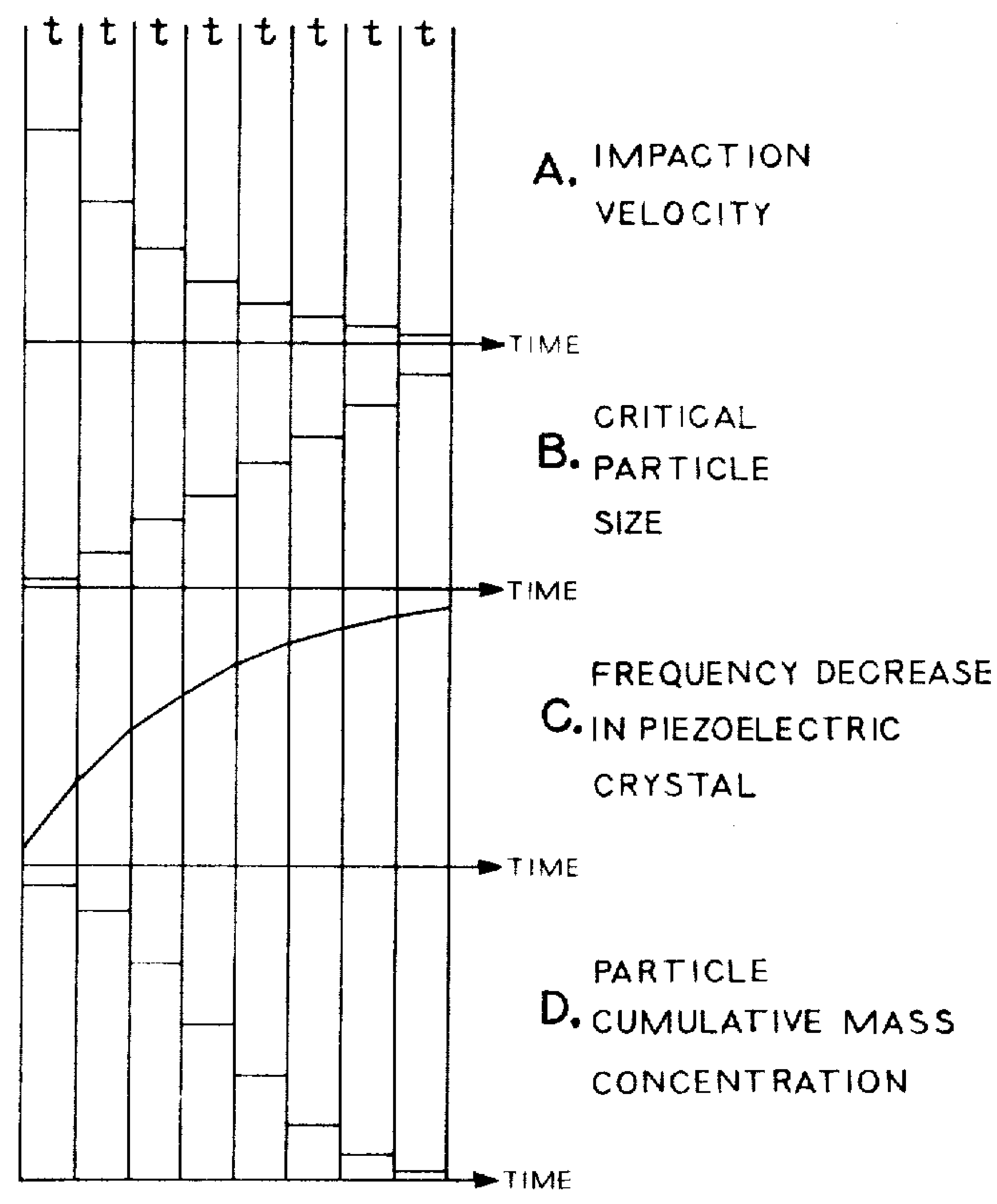
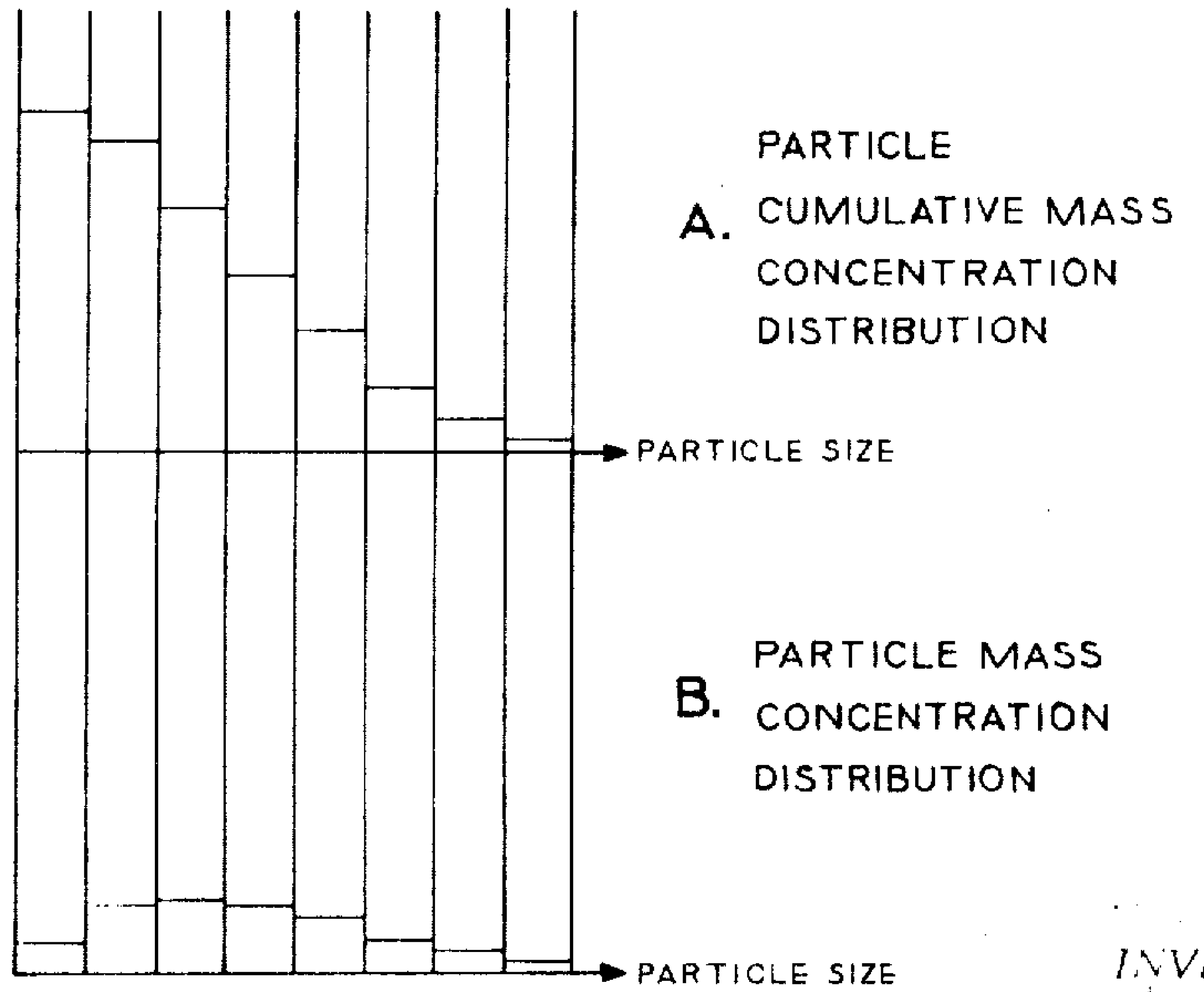



FIG. 11

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## AEROSOL MASS CONCENTRATION SPECTROMETER

### BACKGROUND OF INVENTION

The mass concentration of particles in air is a difficult parameter to measure. The traditional method of measurement is the high-volume filtration technique. A large volume of particles is sucked through a filter until enough particles are collected so that they can be detected by weighing the loaded and unloaded filter on a balance. This method is subject to numerous errors, takes a relatively long period of time, requires manual handling and weighing, and cannot be automated easily. The filtering method does not provide a means for obtaining information as to the mass concentration distribution of the aerosol.

The standard method of obtaining particle mass concentration distribution is to use a cascade impactor with several single-stage impactors operating in series. Each successive impactor has a smaller jet size to achieve particle classification. The particle samples from each of the impactors are weighed separately to determine aerosol mass concentration distribution.

An apparatus for measurement of particulate mass force deposited on a surface of a sensing means is described in U.S. Pat. No. 3,561,253. A force field in this apparatus is used to impinge the particles on the sensitive surface of the sensing means. The particles which contact the surface of the sensing means strongly adhere to that surface and hence add to the mass of the sensing means. A frequency sensing circuit is used to determine the change in the resonant frequency of the sensing means caused by the mass of the particles on the surface of the sensing means. The signal, representative of the change in frequency, is related to the mass of particles collected on the sensing surface. This apparatus can obtain an in situ, transduced measurement of the mass concentration of the particles with very high time resolution. The invention in the present application utilizes the force collecting principle disclosed in copending application Ser. No. 810,659 to obtain particle mass concentration distribution.

### SUMMARY OF INVENTION

The invention relates to an apparatus and method for determining in situ the particle mass concentration distribution in a relatively short period of time. The apparatus has a particle sensing means with a sensitive particle collection surface. The particles forced into engagement with the collection surface are deposited on the surface to increase the mass of the sensing means. The apparatus includes means to alter the force and thereby change the critical particle size deposited on the surface. The mass of deposited particles is monitored for each change in the force to provide information usable to determine the particle mass concentration distribution.

In terms of a method of measurement of particle mass concentration distribution, the invention consists of force depositing particles onto a sensitive particle collection surface, as an electrode on a piezoelectric crystal. This force is sequentially varied, in a step-by-step procedure, to change the critical particle size deposited on the surface. The mass of the particles deposited at each force level is sensed to provide information of the particle mass concentration, whereby the difference in the particle mass concentration between two successive values of critical particle size provides data relative to particle mass concentration distribution.

In the Drawings

FIG. 1 is a diagrammatic view, partly sectioned, of the apparatus for measurement of particle mass concentration distribution;

FIG. 2 is a top plan view of the impactor in the apparatus of FIG. 1;

FIG. 3 is a plan view of a piezoelectric crystal used in the microbalance shown in FIG. 1;

FIG. 4 is a block diagram of a piezoelectric particle microbalance;

FIG. 5 is a block diagram of a modified apparatus for measurement of particle mass concentration distribution;

FIG. 6 is a diagrammatic view, partly sectioned, of another modification of the apparatus for measurement of particle mass concentration distribution.

FIG. 7 is a top plan view of the impactor and motor used to move the orifice slide to vary the size of the orifice;

FIG. 8 is a longitudinal view, partly sectioned, of the apparatus of the invention having a low pressure impactor;

FIG. 9 is a top plan view of the impactor of FIG. 8;

FIG. 10 is a schematic graph showing the operation of the apparatus with stepped velocity in separate time intervals; and

FIG. 11 is a schematic graph showing particle mass concentration as a function of particle size with stepped velocity.

Referring to the drawings, there is shown in FIG. 1 a schematic view of an apparatus for determining a particle mass concentration distribution for particles in the size range of approximately 0.5 to 10 microns. The term particles includes aerosols, particulates, mists, fogs, dusts and the like. Apparatus 14 comprises an ambient pressure impactor, indicated generally at 15, having a variable particle impaction parameter. Impactor 15 operates in conjunction with a piezoelectric particle microbalance 16 to measure particle mass at each impaction parameter and thus directly measure particle mass concentration at each parameter. The change in the particle mass concentration between the parameters provides data directly related to the particle mass concentration distribution. A vacuum pump 17 is connected through an outlet tube 18 with the impactor 15. The pump 17 is operable to continuously draw air and particles through the impactor and discharge the air and free particles through the outlet 19. A speed control 21, connected to the pump 17, operates to vary the speed of the pump which will change the vacuum force established by the pump. The speed control 21 can be an adjustable automatic speed unit which will program the operation of the pump for predetermined periods of time so that the flow rate of the particles through the impactor 15 is changed in a step-by-step fashion.

The impactor 15 has a cylindrical housing 22 with a central upright chamber 23. The chamber 23 is closed with a cover 24 attached to the housing 22 with fasteners 26, as bolts or the like. The center of the cover has a general funnel-shaped circular orifice 27 for directing a jet of air and particles into the chamber 23.

The piezoelectric particle microbalance 16 has a first primary quartz crystal 28 supported in the chamber 23 directly below the outlet end of orifice 27. A pair of supports 29 mount the crystal 28 on the housing 22. Located below crystal 28 is a second reference quartz crystal 31. Supports 32 mount the reference crystal 31 on the housing 22. As shown in FIG. 3, crystal 28 has an electrode 33 in the center portion of the crystal. The electrode 33 is a thin, metallic film which is an electrically driven portion of the surface of the crystal. The electrode can be a metal, such as silver, gold, nickel, aluminum or platinum. The electrode can be evaporated or sputtered on the surfaces of the crystal. Electrode 33 can be any suitable shape, as circular, rectangular, and the like with a flat, convex or irregular outer surface. The edges of the electrode 33 may be beveled. The lower side of crystal 28 has a similar electrode. Also, reference crystal 31 has similar electrodes on its opposite sides.

Referring to FIG. 4, piezoelectric particle microbalance 16 has a primary oscillator circuit 34 electrically coupled to the electrodes on crystal 28. In a similar manner, a reference oscillator circuit 36 is electrically coupled to the electrodes on the crystal 31. The oscillator circuits 34 and 36 are identical and are connected to a mixer circuit 37 operable to subtract the signals from the two oscillator circuits producing an information signal indicative of the particle mass concentration collected on the electrode 33 of the primary crystal 28. A power supply 38 is connected to the oscillator circuits 34 and 36 and the mixer circuit 37.

The piezoelectric particle microbalance 16 detects, with high sensitivity, the mass of aerosol particles which are force field deposited on the electrode 33 on the primary quartz crystal 28. The fundamental property of the quartz crystal is that the crystal forces the electronic oscillator circuit to oscillate at one of the resonant mechanical frequencies of the quartz crystal. The resonant frequency of the oscillating quartz crystal decreases with an increase in the foreign mass deposited on the electrically driven electrode 33. When particles are deposited on the electrode of the quartz crystal, the resonant frequency of the crystal decreases in response to the incremental mass of particle deposition. Type AT quartz crystals can be used in the piezoelectric particle microbalance. Type AT crystals vibrate in the thickness-shear mode, whereby the frequency of vibration is independent of the elastic properties of thin layers of particles on the crystal surface. The quartz crystal microbalance is an effective transducer for obtaining in situ measurements of the particle mass concentration of air pollution aerosols with a very high time resolution. The time resolution depends on the ambient particle mass concentration. If high, then the time resolution is high.

The impactor, through the orifice 27, directs the air and particles toward the sensitive electrode 33 on the crystal surface. The particles must adhere to the electrode surface with enough force to counteract the inertia forces which tend to dislodge the particles from the surface. The balance of attractive forces and inertial forces results in a maximum size particle that can be accurately sensed by the piezoelectric particle microbalance. The attractive force acting on the particle is a combination of forces, as Van der Waals molecular forces, electrostatic forces, and surface-tension forces. These forces vary with the size and type of particle, the type of surface, and humidity. The attractive force is related to the size of the particle. Coatings, as glycerin, vacuum grease, and the like, can be applied to the electrode 33 to enhance the adhesion of the particles. Particles greater than the maximum particle size have inertial forces greater than adhesion forces. These particles slip past the electrode 33 and their mass is not measured with 100 percent efficiency.

The piezoelectric microbalance measures the total mass of all particles with a size greater than a so-called "critical" particle size and less than the maximum particle size. The "maximum" particle size is determined by the slippage past the electrode 33. The "critical" particle size is determined by impaction physics. Impaction theory shows that this critical particle size decreases as the aerosol impactor velocity increases or as the more general parameter, the impaction parameter, increases. The flow rate through the impactor orifice 27 can be changed to alter the impactor jet velocity. By starting at a high velocity and decreasing it monotonically and step-wise to zero, the microbalance will successively measure the total mass of all particles with a size above successively increasing values of the critical particle size. The difference in the particle mass concentration between two successive values of critical particle sizes provides data relative to particle mass concentration distribution. The apparatus in FIG. 1 varies the flow rate of the air and particles through the impactor by varying the rpm of of the pump 17.

FIG. 5 shows another means of varying the flow rate of the air and particles through the impactor. The instrument shown in FIG. 5, and indicated generally at 39, has an impactor 41 joined with a piezoelectric particle microbalance 42. Impactor 41 and microbalance 42 can be identical to the impactor 15 and microbalance 16 shown in FIGS. 1 and 4. A valve 43 is connected in the outlet 44 of the impactor for varying the flow rate of air and particles through the impactor. A control 46 is operatively connected to the valve to change the position of the valve. The control can be an automatic control which operates in sequential time intervals to program or index the valve to different locations to change the flow rate of air and particles through the impactor. A change in the flow rate of air and particles changes the velocity of the particles impinging on the primary crystal of the microbalance. This change in velocity changes the critical particle size that adheres to the electrode surface. A constant speed vacuum pump 47, coupled to valve 43, operates to provide a continuous vacuum force on the valve.

Another method of programming the flow rate through the impactor consists of several valves of choked orifices in parallel, each operated with a separate solenoid valve. This battery of parallel choked orifices replaces the single valve 43 in FIG. 5. The control 46 of FIG. 5 can be designed to sequentially operate the solenoids, either individually or in combination to yield the desired programmed flow rate.

Referring to FIGS. 6 and 7, there is shown another modification of the apparatus for measurement of particle mass concentration distribution, indicated generally at 48. The apparatus has an impactor 49 operatively joined with a piezoelectric particle microbalance 51. A constant speed pump 52 is connected to an outlet 53 of the impactor 49 to provide for a flow of air and particles through the impactor 49.

Impactor 49 has a housing 54 having a chamber 56. The top of the chamber is closed with a cover 57 having a central V-shaped orifice 58. The size of the orifice is varied with a movable slide 59 positioned in a slot 60 in the cover 57. The slide 59 is controlled by a motor 61 having a rotatable drive member 62. A rod 63 connects the slide 59 with the member 62 so that upon operation of the motor, it will control the position of the slide 59 and thereby regulate the size of the orifice 58. The motor 61 is programmed or sequentially controlled with a motor control 64. The motor control 64 can be an automatic device which will sequentially operate the motor for predetermined periods of time so that the size of the orifice 58 will be changed in predetermined steps. Motor 61 can be a programmed precision stepping motor.

Located within chamber 56 is primary quartz crystal 66 and reference quartz crystal 67 of the piezoelectric particle microbalance 51. Primary quartz crystal 66 has a sensitive electrode 68 on the top surface thereof in axial alignment with the orifice 58. In sue, as the slide 59 is moved to vary the size of the orifice 58, the exposure area of the electrode 68 is changed so that the particles are distributed over the surface of the electrode 68. The distribution of particle mass on the crystal electrode surface is important. If large amounts of mass are placed on a small portion of the electrode, several secondary modes of vibration are induced, causing instability in the fundamental thickness-shear mode of vibration used to transduce particle mass. Also, particles many layers away from the vibrating electrode surface may not be measured since they may not stick together firmly enough.

The constant speed pump 52 operates to impart a constant vacuum force in chamber 56. By varying the size of the orifice 58, the impact velocity of the particles on the piezoelectric crystal is changed. This change in velocity changes the critical particle size of particles deposited on the electrode surface.

Referring to FIG. 8, there is shown a low-pressure impaction instrument, indicated generally at 69, for determining particle size concentration of particles of from approximately 0.05 to 5 microns. Most important air-pollution particles have little mass below 0.05 microns making the instrument 69 effective in obtaining particle mass concentration distribution over the lower end of the total size range of air-pollution particles.

The instrument 69 has an impactor, indicated generally at 71, operatively coupled to a piezoelectric particle microbalance 72. A flow control valve 73, as a precision micrometer valve, is connected to an outlet tube 74 of the impactor to vary the flow rate of air and particles through the impactor. A control 76 sequentially operates the valve 73. Control 76 can be programmed to sequentially step the valve over a period of time. A constant speed vacuum pump 77, connected to the valve 73, operates to establish a constant vacuum force on the valve 73. Other means of varying the impactor parameter can be used, as in the impactor of FIG. 1.

The impactor 71 has a housing 78 with a first upper chamber 79 and a second lower chamber 81. A longitudinal axial bore 82, through the midportion of the housing 78, provides a passageway between the chamber 79 and the chamber 81.

Extended longitudinally into the chamber 79 is a first tube 83 having a central passageway and an end 86 spaced a short distance from the open end of the bore **82**. The end **86** has a small sonic orifice **87** for directing air and particles into the bore **82**. As shown in FIGS. **8** and **9**, the opposite end of the tube **83** projects through the top housing wall and is open to the outside environment.

A second tube **88**, mounted on the housing **78**, extends into the chamber **79** to introduce clean air into the chamber. The second tube has a passage **89** and an end **91**. A small sonic orifice **92**, in end **91**, limits the amount of air flow into the chamber **79**. Mounted on the outer end of tube **88** is an absolute filter **93**. Filter **93** can have a removable filter element which can be replaced to insure clean air flow into the chamber **79**. Located adjacent the filter **73** is a flow meter **94** operable to calibrate the sonic orifice **92**. The same flow meter can be connected to first tube **83** to calibrate sonic orifice **87**.

The piezoelectric particle microbalance **72** has a primary quartz crystal **96** and a reference quartz crystal **97** positioned in chamber **81**. Primary quartz crystal **96** has a sensitive electrode **98** located below the open end of the bore **82**. The static pressure in chamber **81** is monitored with a static pressure gauge **99**.

In use, the constant speed vacuum pump **77** is operable to withdraw air through the impactor **71** and control valve **73**. The air and particles flow through the passage **84** in the tube **83** and through the sonic orifice into the accelerating passage **82**. The clean air in the chamber **79** forms an annular sheet or cylinder of air around the particle jet issuing from the sonic orifice **86**. The clean air sheet pinches the particle jet into the core or center portion of the accelerating passage **82**, thus keeping the particles away from the walls of the passage **82**. Furthermore, since the clean air sheet pinches the particles inwardly, the particles have a velocity which is very close to the center line velocity of the developing air velocity profile. This uniformity of particle impaction velocity greatly improves the sharpness of the particle size cutoff.

Both the impaction velocity and Cunningham slip coefficient are varied simultaneously by varying the pressure in impaction chamber **81**. This pressure is varied with the valve **73**. The critical particle size decreases as pressure decreases because as the pressure decreases both velocity and Cunningham slip coefficient increase.

By starting at a high value of velocity and decreasing it monotonically and step-wise to zero, both the ambient pressure impactors and the low-pressure impactor will successively measure the total mass of all particles with a size above the successively increasing value of critical particle size. The difference in particle mass concentration between the successive values of critical particle size provides data relative to particle mass concentration distribution.

The operation of the piezoelectric particle mass concentration spectrometer is schematically shown in the graphs of FIGS. **10** and **11**. The impactor velocity, graph **10A**, is decreased in equal time steps over the sampling period. Any variable in the impaction parameter, as impaction velocity, jet size, or Cunningham slip coefficient, can be varied. Graph **10B** shows the stepped increase in critical particle size as the impaction velocity decreases. The change in the frequency of the primary piezoelectric crystal is shown in graph **10C**. The cause of the frequency change, particle cumulative mass concentration, is shown in graph **10D**. the oscillating frequency of the primary piezoelectric crystal decreases linearly with the particle mass addition to the crystal.

FIG. **11** shows the particle distribution at each stepped velocity as a function of particle size. Graph **11A** illustrates particle cumulative mass concentration distribution of all particles with sizes greater than the critical particle size at each velocity. The difference in the particle mass concentration distribution between the successive values of critical particle size provides the particle mass concentration distribution, as shown in graph **11B**.

Automation of the impactors to maximize the long-term unattended operating time requires an automatic means for crystal cleaning, indexing, or movement relative to the impactor jet. Crystal cleaning is necessary because an excessively heavy particle deposition on the crystal surface will cause the crystal to cease oscillating stably. The crystal can be cleaned by driving it at a very high current causing the particles to dislodge from the surface. The loosened particles are then blown away with a jet of clean air from a pressurized reservoir, pump, or other clean air source. The crystal can alternatively be cleaned with cleaning liquid, as alcohol, or a clean gas, as air, directed at the surface of the crystal to wash or blast away the deposited particles. After cleaning, the crystal is left to dry before being used again.

An electric heater can be incorporated into the impactors to raise the temperature of the crystals from the ambient conditions. By observing the loss of particle mass as the crystal is being heated, information concerning the volatility of the collected particles can be obtained. For example, if the particles are observed to evaporate quickly near the sublimation point of dry ice or the boiling point of water, it can be inferred that $CO_2$ or water is present in particulate form.

While there have been shown and described preferred embodiments of the invention, it is to be understood that various changes, omissions and substitutions can be made by those skilled in the art without departing from the scope of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An apparatus for measurement of particle mass concentration distribution of an aerosol comprising: particle sensing means having a resonant frequency and a particle collection surface for collecting particles of an aerosol, means to drive and sense the resonant frequency of the sensing means, means imparting a force field on the particles for forcing particles into engagement with the particle collection surface, means for varying the amount of said force, whereby the variation in the critical size of particles accumulated on the particle collection surface is related to the variance of the force, and monitor means to read the sensed resonant frequency providing information as to the changes in resonant frequency of the sensing means at each force variation to determine the particle mass concentration distribution.

2. The apparatus of claim 1 wherein: the means for forcing the particles into engagement with the particle collection surface is an impactor having an inlet orifice to direct particles toward the surface and vacuum pump means connected to the impactor operable to draw air and particles through the impactor.

3. The apparatus of claim 2 wherein: the means to vary the amount of force is a valve means located between the impactor and pump, means to control the flow rate of air and particles, for the valve means to regulate the flow rate of air and particles through the orifice.

4. The apparatus of claim 2 wherein: the means to vary the amount of force is a control means to vary the speed of operation of the pump means to change the flow rate of air and particles through the orifice.

5. The apparatus of claim 2 wherein: the means to vary the amount of force comprise means to change the size of the orifice to alter the velocity of air and particles moving through the orifice.

6. The apparatus of claim 5 wherein: the means to change the size of the orifice comprises a slide, and motor means to move the slide to change the size of the orifice.

7. An apparatus for measurement of particle mass concentration distribution of an aerosol comprising: particle sensing means including a piezoelectric crystal having a sensitive particle collecting surface for collecting particles of an aerosol, means for forcing particles into engagement with the particle collection surface, means for varying the amount of said force whereby variation in the critical size of particles accumulated on the surface is related to the variance of the force, said means to sense the mass of particles deposited on the surface including means to sense the resonant frequency of the

crystal, and monitor means operable to read the changes in the resonant frequency of the crystal due to changes in the total mass of particles added to said surface in response to changes in the amount of force used to deposit particles onto said surface at each force variation providing information to determine the particle mass concentration distribution.

**8.** The apparatus of claim **7** wherein: the means for forcing the particles into engagement with the particle collection surface is an impactor having an inlet orifice to direct particles toward the surface and vacuum pump means connected to the impactor operable to draw air and particles through the impactor.

**9.** The apparatus of claim **8** wherein: the means to vary the amount of force is a valve means located between the impactor and pump means to control the flow of air and particles, and control means for the valve means to regulate the flow rate of air and particles through the orifice.

**10.** The apparatus of claim **8** wherein: the means to vary the amount of force is a control means to vary the speed of operation of the pump means to change the flow rate of air and particles through the orifice.

**11.** The apparatus of claim **8** wherein: the means to vary the amount of force comprise means to change the size of the orifice to alter the velocity of air and particles moving through the orifice.

**12.** The apparatus of claim **11** wherein: the means to change the size of the orifice comprises a slide, and motor means to move the slide to change the size of the orifice.

**13.** The apparatus of claim **7** wherein: the means for forcing the particles into engagement with the particle collection surface is an impactor having a first chamber and a second chamber spaced from the first chamber, passage means connecting the first chamber with the second chamber, first means for introducing particles and air into the first chamber, second means for introducing clean air into the first chamber, said particle collection surface located in axial alignment with the discharge end of the passage means, and means to withdraw air from the second chamber, whereby the particles introduced into the first chamber are drawn through the passage means and an annular sheath of clean air surrounds the particles in the passage means, said particles as they move in the passage means being surrounded with a moving annular sheath of clean air.

**14.** The apparatus of claim **13** wherein: the first means is a tubular member extended into the first chamber in axial alignment with the passage means, said tubular member having a sonic orifice for the particles and ambient air.

**15.** The apparatus of claim **13** wherein: the means to vary the amount of force is a valve located between the second chamber and means to withdraw air from the second chamber, and control means for the valve to regulate the flow rate of ambient air and particles and clean air through the passage means.

**16.** An apparatus for measurement of particle mass concentration distribution comprising: particle sensing means having a particle collection surface for collecting particles, means to sense the mass of particles deposited on the particle collection surface, means for forcing particles into engagement with the particle collection surface, means for varying the amount of said force, whereby a variation in the critical size of particles accumulated on the surface is related to the variance of the force, and monitor means to read the sensed mass of particles at each force variation providing information to determine the particle mass concentration distribution, said means for forcing the particle into engagement with the particle collection surface is an impactor having a first chamber and a second chamber spaced from the first chamber, passage means connecting the first chamber with the second chamber, first means for introducing particles and air into the first chamber, second means for introducing clean air into the first chamber, said particle collection surface located in the second chamber in axial alignment with the discharge end of the passage means, and means to withdrawn air from the second chamber, whereby the particles introduced into the first chamber are drawn through the passage means and an annular sheath of clean air surrounds the particles in the passage means, said particles as they move in the passage means being surrounded with a moving sheath of clean air.

**17.** The apparatus of claim **16** wherein: the first means is a tubular member extended into the first chamber in axial alignment with the passage means, said tubular member having a sonic orifice for the particles and ambient air.

**18.** The apparatus of claim **16** wherein: the means to vary the amount of force is a valve located between the second chamber and means to withdraw air from the second chamber, and control means for the valve to regulate the flow rate of ambient air and particles and clean air through the passage means.

**19.** A method of measurement of particle mass concentration distribution of an aerosol comprising: force depositing particles of an aerosol directly onto a sensitive particle collection surface of a particle sensing means having a resonant frequency with a force sufficient to place the particles in contact with the particle collection surface, driving the particle sensing means at its resonant frequency, sequentially varying the force acting on the particles to change the critical particle size deposited on the surface, and monitoring the resonant frequency change of the particle sensing means during the depositing of particles on the particle collection surface of each force variation to provide information to determine the particle mass concentration distribution.

**20.** The method of claim **19** wherein: the force is sequentially increased to decrease the critical particle size deposited on the surface.

**21.** The method of claim **19** wherein: the particles are force deposited with a jet of air directed toward the sensitive particle collection surface and varying the velocity of the jet of air to change the critical particle size deposited on the particle collection surface.

**22.** The method of claim **19** wherein: the particles are enclosed in a sheath of clean air during the time they are directed toward the particle collection surface.

**23.** The method of claim **19** wherein: the particles are force deposited with a jet of air directed toward the particle collection surface, and surrounding said jet of air with a sheath of clean air to confine and accelerate the particles, and varying said velocity of the jet of air to change the critical particle size deposited on the particle collection surface.

**24.** The method of claim **19** wherein: the force is sequentially decreased to increase the critical particle size deposited on the surface.

**25.** A method of measurement of particle mass concentration distribution of an aerosol comprising: force depositing particles of an aerosol directly onto a sensitive electrode of a piezoelectric crystal, sequentially varying the force acting on the particles to change the critical particle size deposited on the electrode, driving the crystal and sensing the resonant frequency of the crystal at each force to provide information on the particle mass concentration at each force, whereby the difference in the particle mass concentration between two successive values of critical particle sizes provides data relative to particle mass concentration distribution.

**26.** The method of claim **25** wherein: the force is sequentially increased to decrease the critical particle size deposited on the electrode.

**27.** The method of claim **25** wherein: the particles are force deposited on the electrode with a jet of air directed toward the electrode and varying the velocity of the jet of air to change the critical particle size deposited on the electrode.

**28.** The method of claim **25** wherein: the particles are enclosed in a sheath of clean air during the time they are directed toward the electrode.

**29.** The method of claim **25** wherein: the particles are force deposited with a jet of air directed toward the electrode, and surrounding said jet of air with a sheath of clean air to confine and accelerate the particles, and varying said velocity of the jet of air to change the critical particle size deposited on the particle collection surface.

30. The method of claim 25 wherein: the force is sequentially decreased to increase the particle size deposited on the electrode.

31. An apparatus for measurement of particle mass concentration distribution of an aerosol comprising: particle sensing means having at least a first sensing device and a second sensing device, each of said sensing devices having a resonant frequency and a particle collection surface for collecting particles of an aerosol, means to drive and sense the resonant frequency of the sensing devices, means imparting a force field on the particles for forcing particles into contact with at least one of the particle collection surfaces, means for varying the amount of said force, whereby variation in the critical size of particles accumulated on the particle collection surface is related to the variance of the force, and monitor means to read the sensed resonant frequency providing information as to changes in resonant frequency of the sensing devices at each force variation to determine the particle mass concentration distribution.

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# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,653,253 Dated April 4, 1972

Inventor(s) John G. Olin

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 2, "of" (second occurrence) should be --or--.

Column 4, line 33, "sue" should be --use--.

Column 5, line 62, "the" should be --The--.

Column 6, line 52, after "particles" insert --and control means--.

Column 8, line 26 "of" (second occurrence) should be --at--.

Signed and sealed this 19th day of September 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents