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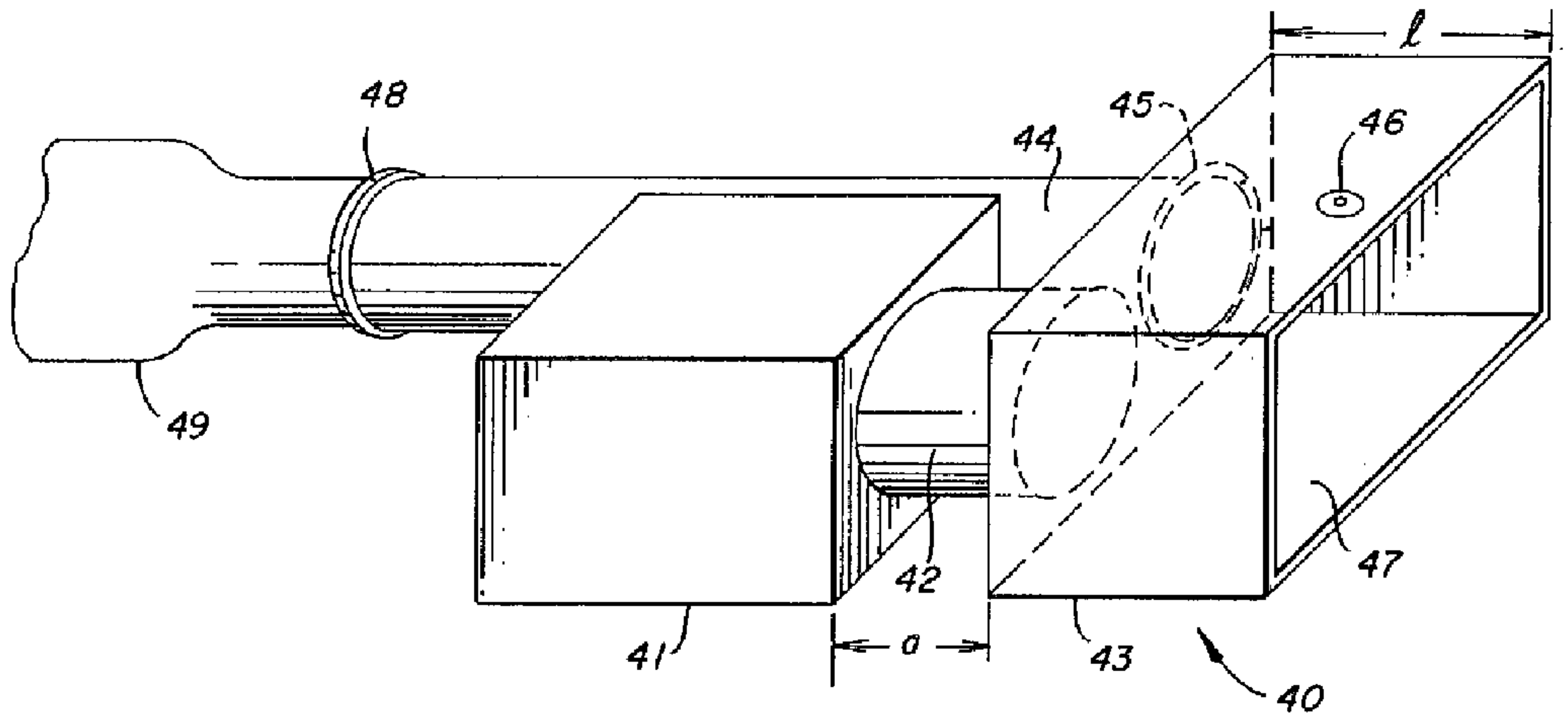
(54) **ATTENUATEUR ACOUSTIQUE ACTIF**
(54) **ACTIVE NOISE CANCELLING MUFFLER**



(57) Cette invention se rapporte à un système d'insonorisation à atténuateur acoustique actif, qui comprend une unité de commande active (60), une enceinte de haut-parleur (41) contenant des espaces de capacité acoustique, des moyens de prolongement de conduit (42, 43) placés en communication avec ladite enceinte de haut-parleur et servant à conférer à un diagramme de rayonnement dipôle la forme d'une onde plane qui peut être mesurée par un microphone (46).

(57) An active muffle noise cancellation system having an active controller (60), a speaker housing (41) with acoustic compliance spaces, a duct extension means (42, 43) in communication with said speaker housing and adapted to conform a dipole radiation pattern into a plane wave which can be measured by a microphone means (46).

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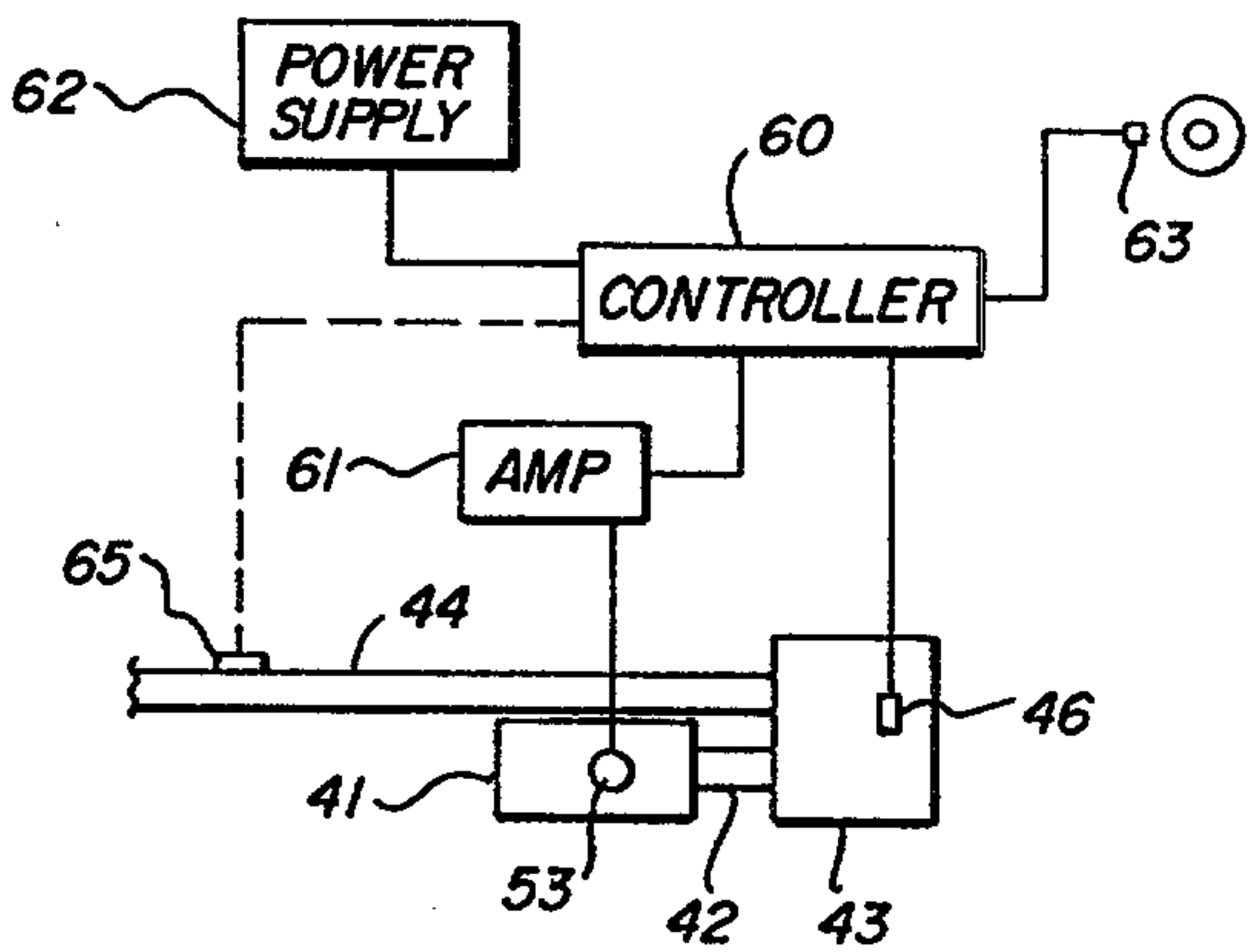
(57) Abstract

An active muffle noise cancellation system having an active controller (60), a speaker housing (41) with acoustic compliance spaces, a duct extension means (42, 43) in communication with said speaker housing and adapted to conform a dipole radiation pattern into a plane wave which can be measured by a microphone means (46).



ACTIVE NOISE CANCELLING MUFFLER

Introduction

In implementing a muffler system which relies on active cancellation of the offensive noise source, problems of packaging and durability are critical. Other authors have described arrangements which permit high acoustical outputs over a predetermined frequency range in a relatively small package, for example, U.S. 5,097,923 and PCT/US91/02731, "Improvements In and Relating to Transmission Line Loudspeakers" to Hoge et al. The descriptions below utilize the transducers described by the above mentioned documents. The current invention seeks to add enhancements which improve the packagability and durability of these active muffler devices. The importance of durability and low cost in such systems cannot be overstated. Passive devices which represent the current state of the art are inexpensive and very durable, sometimes performing for decades without attention of any kind. Therefore, it is essential to utilize the lowest cost, most durable system to enhance the operation of active systems.

Background and Background Art

Several authors have described devices which cancel noise propagating through a pipe or duct. For example, Chaplin in U.S. 4,122,303 and Kato in U.S. 4,805,733 propose the use of undefined noise sources placed within the duct to cause a reflection of the propagated sound. Other authors, for example, Eriksson in U.S. 4,665,549 and Angelini et al in U.S. 4,177,874 and Bremigan in U.S. 5,044,464 define the device being inserted into the duct. A refinement in these systems is represented by the devices described by Ziegler et al. in U.S. 5,097,923 and Hoge et al in PCT/US91/02731. These patents and application describe piping systems in which the active control anti-source is placed concentric to the duct and in the plane of the duct outlet. The active source described in both cases is a tuned acoustic enclosure which emits high power sound throughout a limited frequency band. The sound output per unit volume is maximized through the use of this type of source. Using this type of outlet configuration, the highest possible frequency can be cancelled with the anti-noise source and many of the environmental problems associated with placing a transducer in a corrosive gas flow are avoided almost entirely.

The use of noise sources which are placed in close proximity to the outlet of a pipe has been cited extensively in the technical literature. For example, Chaplin in U.S. 4,489,441 and Nelson and Elliott in their book Active Control of Sound, 1992, pages 233-244 describe this arrangement. Kido et al. in "A New Arrangement of Additional Sound Source in an Active Noise Control System" from Proceedings of Internoise '89, December 1989, pages 483-488, and Hall et al. in "Active Control of Radiated Sound from Ducts" from ASME Transactions Journal of Vibration and Acoustics, July 1992, pages 338-346 describe several different pipe outlet configurations. However, these authors propose the use of a very simple acoustic source or make no mention of the type of active transducer to be used.

Attempts to use active sources on mufflers include the work of Cain, U.S. Patent No. 5,272,286 which shows an active noise cancelling device surrounding an exhaust pipe in a generally concentric configuration. The problem with such an arrangement is the tremendous expense involved in building something in direct contact with a hot exhaust pipe, the lack of being able to retrofit the system to existing tailpipes and its enormous bulk as well as other problems in its operation. A similar device is shown in Japanese Application, 60-22010, entitled "Exhaust Noise Reducing Device" by Toshiyuki Kaminaga, published on February 4, 1985. Scherrer, in French Patent No. 1,190,317, published October 12, 1959 shows a system very much like Cain, supra, where concentric pipes empty into a mixing chamber. Finally, U.S. Patent No. 4,487,289, December 11, 1984, entitled "Exhaust Muffler with Protective Shield", shows an extension fitting over a tailpipe, again like Cain.

Summary of the Invention

The invention relates to the enhancement of active acoustical attenuation by coupling an engine exhaust pipe with the acoustic exhaust of an active enclosure.

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When active noise control is applied to an offending noise source, a secondary source is placed in close proximity to the offensive noise source. The secondary source can be placed either around the offensive noise source, concentrically, or beside the noise source, in a dipole configuration, as long as the separation between the two source centers is much smaller than the wavelength of the highest frequency of cancellation. The secondary source creates an acoustic wave form equal in amplitude and 180 degrees out of phase from the offensive source. The secondary source is driven by an adaptive controller system that requires a feedback microphone. The feedback microphone measures the effectiveness of the destructive interference and is used to adjust the signal of the secondary source and optimize cancellation.

In general the invention provides improved coupling between a dipole oriented engine exhaust and an active enclosure acoustic port. It increases the amount of attenuation achievable with a dipole oriented engine exhaust and an active enclosure acoustic port and decreases the amount of power required to achieve a certain amount of attenuation for a given active noise cancellation system.

It also allows for the acoustic port of the active enclosure to be shorter thereby increasing the acoustic output of the active enclosure and allows for surface mounting of an error sensor. The arrangement provides protection to the error sensor from road debris, provides a way to integrate the error sensor cable into the active enclosure to minimize cables and protects the cable by encasing it in a conduit. The arrangement has a flared port to reduce turbulence and an internal heat shield to protect the error sensor or sensing microphone. The duct extension can be styled in a variety of shapes.

Accordingly, it is an object of this invention to provide improved coupling between a dipole oriented engine exhaust and an active enclosure acoustic port.

Another object of this invention is to increase the amount of attenuation achievable with a dipole oriented engine exhaust and active enclosure acoustic port.

A further object of this invention is to decrease the amount of power required to achieve a certain amount of attenuation for a given active noise cancellation system in a dipole orientation.

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A still further object of this invention is to allow the active enclosure to be mounted further behind the automobile muffler and further from the road surface.

Yet another object of this invention is to provide a channel which will allow harmful engine exhaust gases to exit out from underneath the vehicle at the regulatory distance.

Additional objects of the invention include:

(i) allowing the acoustic port of the active enclosure to be shorter thereby increasing the acoustic output of the active enclosure;

(ii) allowing a surface for mounting the error sensor;

(iii) providing protection to the error sensor from road debris and foreign matter;

(iv) providing a way to integrate the error sensor cable into the active enclosure so that the active enclosure and the error sensor may be powered from one input cable;

(v) providing protection to the error sensor cable by enclosing the cable in a built in conduit which mates with the active enclosure; and

(vi) providing an internal heat shield to protect the error sensor from extreme exhaust gas temperatures.

In accordance with one aspect of the present invention there is provided an active muffler noise cancellation system for use on stationary or vehicle applications which involve an exhaust pipe, said system comprising: an active noise enclosure; an active noise attenuator in said active enclosure adapted to produce a counter noise wave to cause destructive interference with a noise wave emanating from said exhaust pipe; an adaptive controller connected to said active noise attenuator; a counter noise wave and outlet pipe, said outlet pipe adapted to terminate immediately adjacent said tailpipe at an acute angle thereto, so that exhaust gas pulses emitted from said outlet pipe form an acoustic dipole to thereby attenuate noise coming from said tailpipe; and a transducer listening means associated with said outlet pipe and counter noise source and adapted to be located in a plane generally perpendicular to a plane equidistant from the acoustic centers of the exhaust outlet and outlet pipe.

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In accordance with another aspect of the present invention there is provided an active noise cancelling muffler system for use on stationary or vehicle applications which involve an exhaust pipe, said system comprising: an active noise enclosure; an active noise attenuator in said active enclosure adapted to produce a counter noise wave to cause destructive interference with a noise wave emanating from said exhaust pipe; an adaptive controller connected to said active noise attenuator; an extension duct connected to said active enclosure through a port and adapted to receive a terminus of said exhaust pipe so as to receive both said exhaust pipe gases, said noise and said counter noise at one end of said extension duct, said noise and counter noise combining to form a single plane wave at an opposite end of said extension duct; and a transducer listening device on said extension duct and adapted to provide a residual signal to said adaptive controller to allow it to adjust said active noise attenuator to provide the necessary counter noise; wherein a dipole is created where the noise and counter noise enter said duct extension, the shape of said duct extension, the shape of said duct extension forcing said dipole pattern into a plane wave adjacent said transducer listening device.These and other aspects will become apparent when reference is had to the accompanying drawings and the detailed description below.

Brief Description of the Drawings

Figure 1 is a plan view of one embodiment of this invention.

Figure 2 is a perspective view of the embodiment of Figure 1.

Figure 3 is a diagrammatic view of the speaker enclosure.

Figure 4 is an end view of the speaker enclosure of Figure 3 showing its relationship to a tailpipe.

Figure 5 shows an alternative embodiment of the speaker enclosure.

Figure 6 is a perspective view of a third embodiment of the invention.

Figure 7 is a cross-sectional view of the port connection of Figure 6.

Figure 8 is a cross-sectional view of the speaker enclosure of Figure 6.

Figure 9 is a block diagram of the control system.

Figure 10 is a partial perspective view of a heat shield/air vent/cable conduit.

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Description of the Invention

The proposed invention utilizes basic configurations similar to those described by Ziegler et al. and Hoge et al. in the above mentioned patent and patent application. The instant device, however, instead of being arranged concentric with the pipe is non-integral with the pipe as shown in Figure 1. Anti-source, 2, is placed such that the outlet, 3, is placed near the outlet of pipe, 1, connected to passive muffler, 15, which contains a flow of gas containing pressure pulsations. Passive muffler, 15, is used to reduce noise at frequencies above the capability of the active anti-source. Active transducer means, 2, consists of outlet acoustic mass, 4, acoustic compliances 5 and 6, speaker driver, 7, and, optionally, an acoustic mass, 8. Figure 2 shows a variation. Figure 2 shows the two outlets from the end. If a microphone, 9, is placed on the plane, 10, between the pipe, 1, outlet and the active source outlet, 3, the electronic controller will cause the two sources to form an acoustic dipole. A dipole has a directional radiation pattern, but if the acoustic centers of the two sources are within approximately one tenth of a wavelength the minimum cancellation will be approximately 10 decibels. This minimum will occur along the line through the centers of the source and anti-source. For this reason, it is sometimes advantageous to orient the two sources above and below each other, as shown in Figures 3 and 4, since microphones or listeners are less likely to be located above or below the sources if the device is mounted on a vehicle. However, 10 decibels is generally sufficient to result in what is perceived to be a significant reduction in the noise and is sufficient to reduce the offensive tone to the level of the other system noise sources. Since a passive element, 15, is generally used with this type of active source to eliminate the high frequency sound, the one-tenth wavelength rule will rarely be violated in practice.

There are several advantages to this orientation of active sources and the use of this type of source. First, the active source can be located remotely from the hot exhaust pipe. This increases the potential that packaging solutions can be found, particularly on automobiles, in which the space limitations are severe. More importantly, though, the remote location of the active source allows different materials to be used in the construction of the active source to save weight, reduce cost and improve durability. For example, whereas the challenges of using plastic

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to construct the anti-noise source were severe when the source was in direct contact with the exhaust pipe, the use of plastic is a simple matter with the new outlet arrangement.

The active source now can be disguised as a traditional "dual" exhaust package, which reduces the possibility consumers will react negatively to its appearance. The non-integral active muffler can now be placed within the vehicle's trunk if necessary and its use in what were near-impossible applications is now easier. For example, marine mufflers, in which a flow of water is mixed with the hot gases are now possible without exposing the active transducer to water. The transducer can be mounted above the waterline.

One alternative arrangement is shown in Figure 3 in which the non-integral active muffler outlet is pointed 90 degrees away from the pipe outlet. In this manner, the acoustic centers of the two noise sources can be moved closer together to extend the upper frequency limit of the system. Other outlet arrangements and shapes are similarly possible and will be obvious to those skilled in the art.

Figure 6 shows the perspective of a third preferred embodiment of the invention. The apparatus, generally denoted as 40 has a speaker enclosure 41 with a connecting port 42 to duct extension 43. An opening in extension 43 is adapted to receive the end of tail or exhaust pipe 44 and be secured thereto by an annular clamping means 45 which is similar to a pipe clamp. Port 42 and pipe 44 enter duct extension 43 side by side so as to create dipole radiation of noise. Duct 43 alters and compresses this radiation into a plane wave which is sensed by microphone 46 as it exits the open end 47 of duct extension 43. Tailpipe 44 is connected via clamp 48 to straight through muffler 49. The diameter of port 42 is at least as large as the diameter of tailpipe 44. The cross-sectional area of duct extension 43 is such that the cut-on frequency of non-plane wave behavior or propagation is above the operating frequency of the controller and its length 1 is 2 to 3 times its reduced circular cross section. Dimension "a" should be as short as possible to reduce acoustic mass.

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An extension duct 43 is fitted over the end of both the engine exhaust pipe 44 and the acoustic port 42. The extension duct 43 allows for better coupling between the exhaust noise and the anti-noise emitted from the active enclosure acoustic port 42. The results of this improved coupling is increased acoustical attenuation using less electrical power. These improvements are very important for active noise cancellation systems on automobiles since the enclosures are small and less powerful for packaging purposes and the available electrical power for the system is limited.

The extension duct 43 also channels the harmful exhaust fumes and allows the fumes to exit out from underneath the car at the regulatory distance. This feature allows the active enclosure to be positioned further underneath the car, from the bumper and from the road surface.

Since the extension duct 43 channels the exhaust fumes from under the car, both the engine exhaust pipe 1 and the acoustic port 42 can be much shorter. Shortening the acoustic port 42 reduces the acoustic mass of the port 42 which increases the acoustic output of the active enclosure 41. An increase in output power is always desirable.

The instant invention further contemplates the use of a duct extension 43 into which both the anti-noise and exhaust pipe noise enter, are mixed and conformed to a plane wave and a sensing microphone samples the resulting plane wave noise to cause adjustments to be made, if needed, to the control means. The duct extension 43 is connected via a port 42, usually the same size or larger than the exhaust pipe 44, to an enclosure containing the active noise cancelling speaker 53 with accompanying front 52 and back cavities 57. A port 42 connecting the cavities may be provided. The dimensions and relationship between the cavities and the speaker are generally dictated by the theory and desired response curves as discussed by A.N. Thiele, "Loudspeakers in Vented Boxes; Part 1", <u>Journal of the Audio Engineering Society</u>, March 1961, pages 181-191 and "Closed-Box Loudspeaker Systems Part II: Synthesis", <u>Journal of the Audio Engineering Society</u>, pages 282-289, by Richard H. Small.

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Generally, the size of the duct extension 43 must be such that its cross-sectional area is large enough so that the cut-on frequency of non-plane wave (or higher order) is above the operating frequency of the active noise controller. Once this criteria is established and met the actual shape of the duct extension 43 is not that important even though it determines what the cut-on frequency will be. The end of the duct extension 43 can be beveled or styled in any number of ways to conform to, e.g., an automotive style.

The length of the duct extension 43 is preferably greater and from two to three times its reduced circular cross-section diameter. The extension changes the dipole radiation into a plane wave which is then sensed by a residual microphone which inputs to the controller how well the device is working and causes it to rapidly adapt to achieve full attenuation.

The diameter of the port 42 connecting the enclosure with the duct extension 43 should be at a minimum as large as the exhaust pipe 44 diameter and should be relatively short to reduce acoustic mass.

The control system for the invention may use the sync control described in U.S. Patent No. 4,490,841 to Chaplin, the control described in U.S. Patent No. 5,105,377 to Ziegler or that described in co-pending PCT Application Serial No. PCT/US92/05228, entitled, "Control System Using Harmonic Filters". All these control systems use a residual microphone and a sync to an engine or motor. The control system also may use the digital virtual earth/adaptive feedforward system described in U.S. Patent No. 5,475,761, entitled "Adaptive Feedforward and Feedback Control System". In such a case, no sync is required but a second microphone is used to sense the exhaust noise upstream.

Figure 7 shows the inside of port 42 to be flared as at 50 to reduce flow turbulence.

Figure 8 shows a cross-sectional view of speaker enclosure 41 with rear cavity 57, front cavity 52 and speaker 53. If required, a second speaker 54 may be added. A port 55 may also be provided to make the arrangement behave as a 6th order speaker as described in PCT/US91/02731.

The control system is shown generally in Figure 9 with controller 60 and amplifier 61 driving speaker 53 in enclosure 41. Power supply 62 is connected to controller 60 as is residual microphone 46. If the system is using only a residual

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microphone a sync connection 63 to an engine flywheel 64 or the like is necessary. If no sync is used a digital virtual earth or an adaptive feedforward system with an upstream sensing microphone 65 can be used.

Figure 10 shows a combination hollow heat shield and conduit unit 70 mounted atop duct extension 43 and containing a cable 71 to microphone 46, enclosed by conduit unit 70 which also has vent holes 72, 73 to allow outside air to ingress and egress to cool microphone 46. The unit also protects microphone 46 from road debris and the like. The conduit unit 70 is generally mounted on heat shield 74 which is held in a spaced relationship to duct extension 43 by spacers 75. This allows for further heat relief of microphone 46. Conduit 70 has two passageways, one for the cooling air and one for the cable 71.

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Claims:

1. An active muffler noise cancellation system for use on stationary or vehicle applications which involve an exhaust pipe, said system comprising:

an active noise enclosure;

an active noise attenuator in said active enclosure adapted to produce a counter noise wave to cause destructive interference with a noise wave emanating from said exhaust pipe;

an adaptive controller connected to said active noise attenuator;

a counter noise wave and outlet pipe, said outlet pipe adapted to terminate immediately adjacent said tailpipe at an acute angle thereto, so that exhaust gas pulses emitted from said outlet pipe form an acoustic dipole to thereby attenuate noise coming from said tailpipe; and

a transducer listening means associated with said outlet pipe and counter noise source and adapted to be located in a plane generally perpendicular to a plane equidistant from the acoustic centers of the exhaust outlet and outlet pipe.

2. An active muffler system as in claim 1 wherein said outlet and exhaust pipe cross-sections are circular and tangentially immediately adjacent one another and said transducer listening means is in the plane containing said tangential adjacently.

3. An active noise cancelling muffler system for use on stationary or vehicle applications which involve an exhaust pipe, said system comprising:

an active noise enclosure;

an active noise attenuator in said active enclosure adapted to produce a counter noise wave to cause destructive interference with a noise wave emanating from said exhaust pipe;

an adaptive controller connected to said active noise attenuator;

an extension duct connected to said active enclosure through a port and adapted to receive a terminus of said exhaust pipe so as to receive both said exhaust pipe gases, said noise and said counter noise at one end of said extension

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duct, said noise and counter noise combining to form a single plane wave at an opposite end of said extension duct; and

a transducer listening device on said extension duct and adapted to provide a residual signal to said adaptive controller to allow it to adjust said active noise attenuator to provide the necessary counter noise;

wherein a dipole is created where the noise and counter noise enter said duct extension, the shape of said duct extension, the shape of said duct extension forcing said dipole pattern into a plane wave adjacent said transducer listening device.

4. A system as in claim 3 wherein said port has generally the same cross-sectional area or larger than said exhaust pipe.

5. A system as in claim 3 wherein said port has inner surfaces that flare adjacent its junction with said active noise enclosure and said extension duct so as to reduce flow turbulence of said counter noise.

6. A system as in claim 3 wherein said extension duct has an opening the same size as said exhaust pipe cross-section to receive the latter and includes securing means to hold said exhaust pipe in place.

7. A system as in claim 3 wherein said port is relatively short in length so as to reduce the acoustic mass.

8. A system as in claim 3 and including a heat shield means to keep said transducer listening device from the hot exhaust gases flowing through said extension duct.

9. A system as in claim 8 wherein said heat shield means includes an outside air flow means.

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10. A system as in claim 3 wherein said active noise attenuator includes a closed back cavity, a front cavity in communication with said extension duct and a speaker means between said front and back cavities and adapted to produce counter noise into said front cavity.

11. A system as in claim 3 wherein said adaptive controller includes a synchronization means adapted to sync the control cycle to the cycle of the unit producing the exhaust gases and noise.

12. A system as in claim 3 and including a second transducing listening device adapted to be placed upstream on said exhaust pipe so as to provide a first signal to said adaptive controller.

13. A system as in claim 12 wherein both of said transducer listening devices are microphones.

14. A system as in claim 3 wherein said active noise enclosure is constructed of plastic.

15. A system as in claim 3 wherein said adaptive controller has an operating frequency, the cross-sectional area of said duct extension means is such that the cut-on frequency of non-plane wave is above said operating frequency.

16. A system as in claim 3 wherein the length of the extension duct is preferably 2 to 3 times its reduced circular cross-sectional diameter.

17. A system as in claim 3 where said extension duct is styled and has a beveled cut-off end.

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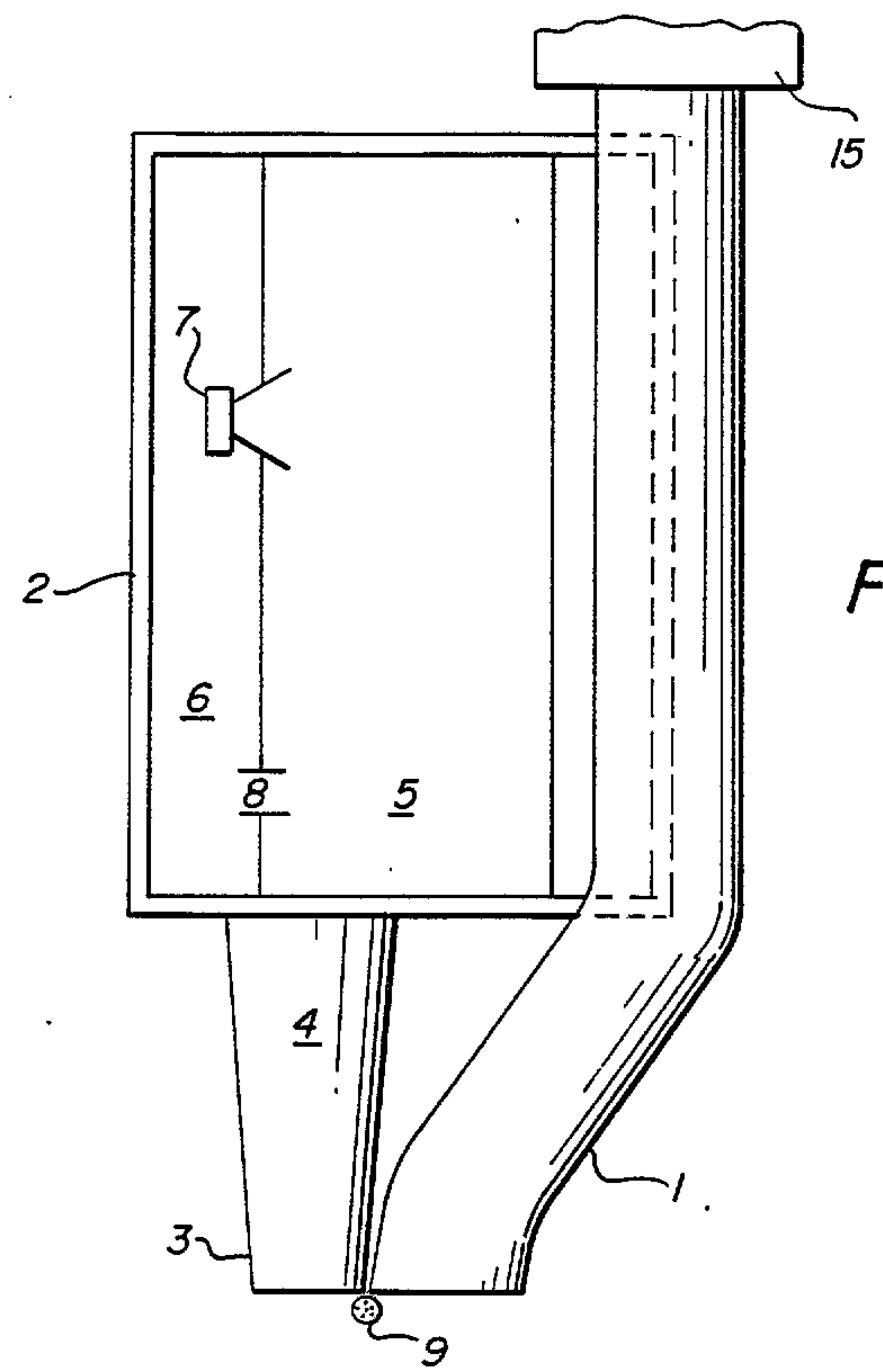

FIG. 1

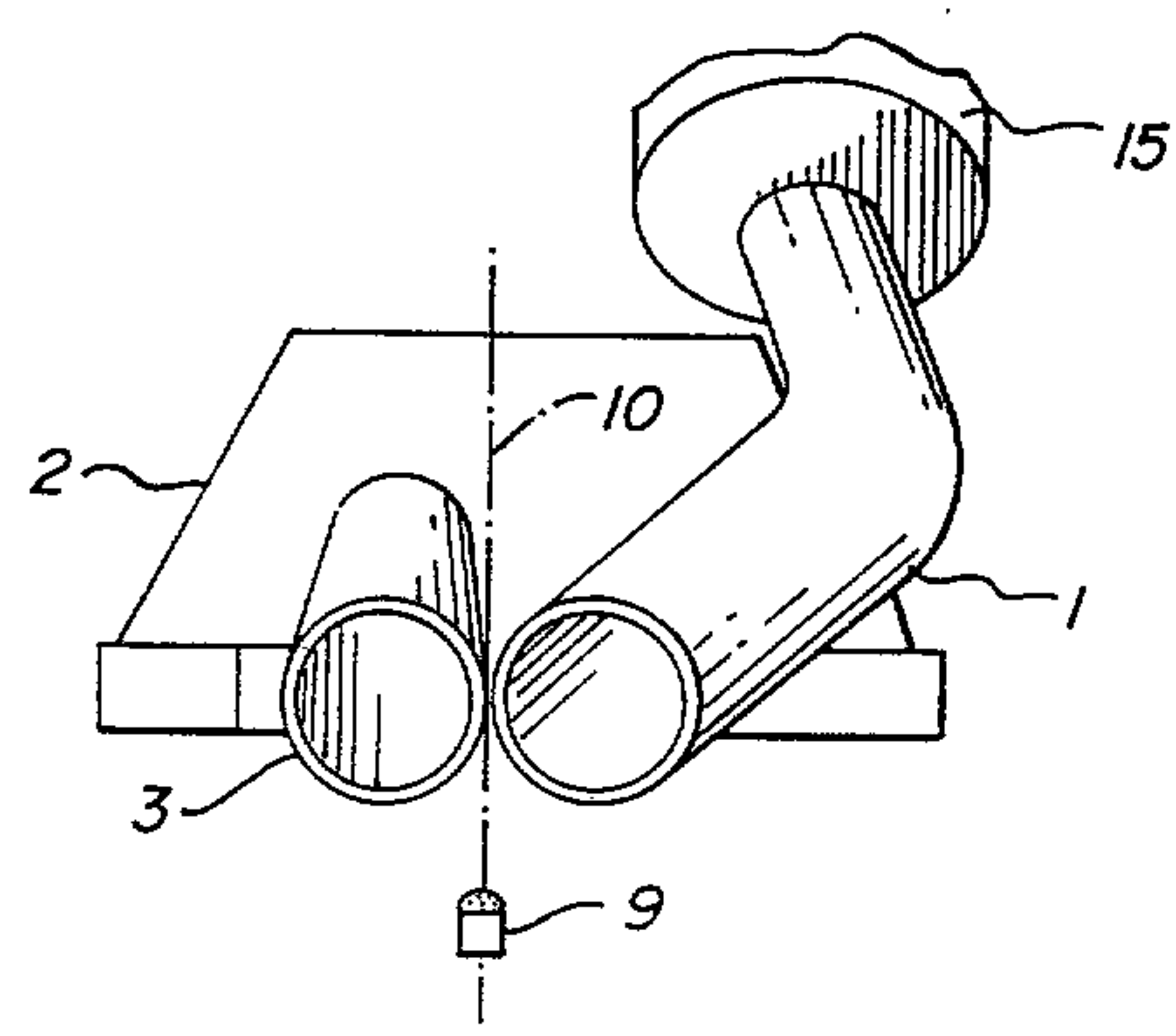

FIG. 2

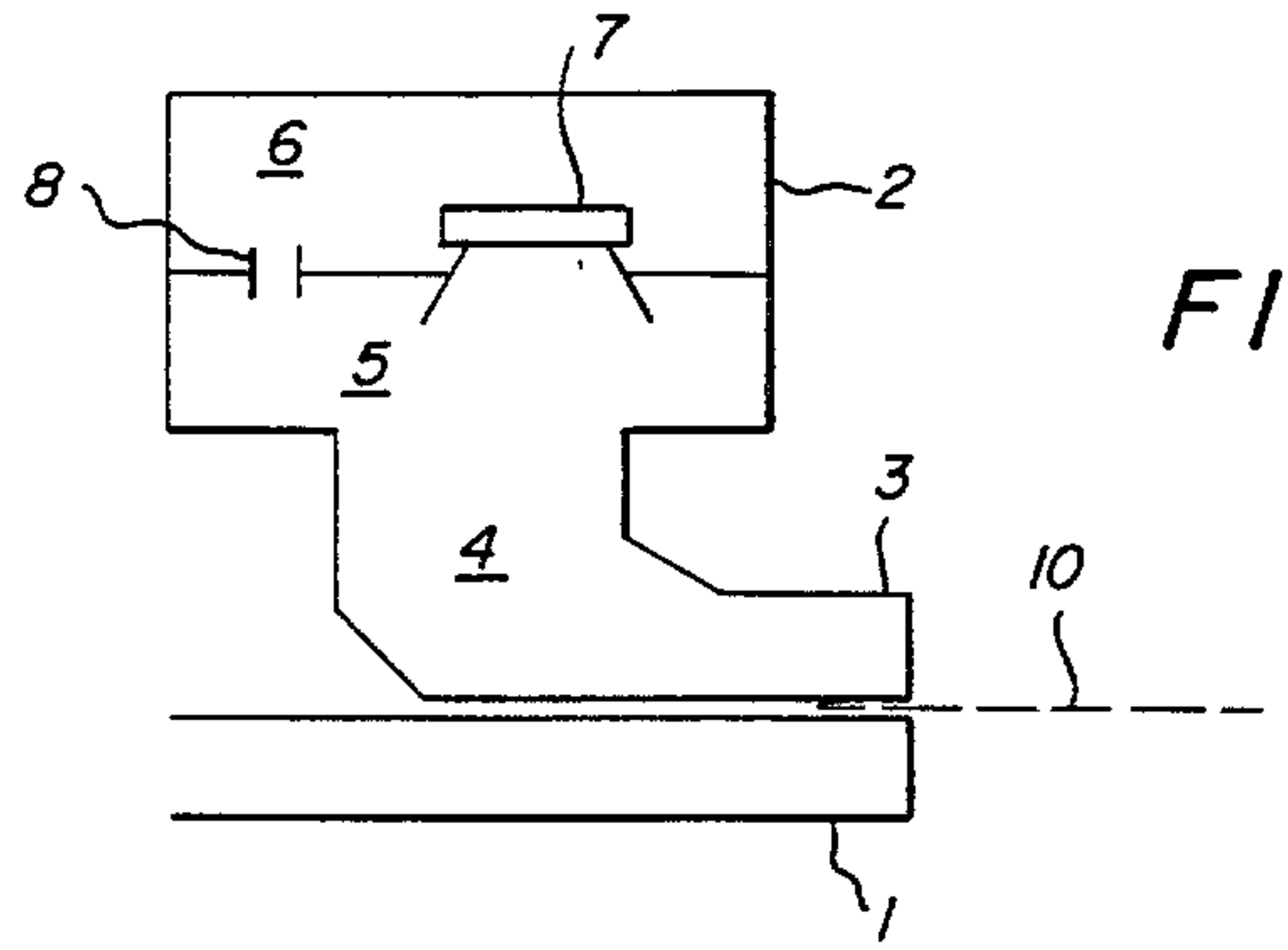

FIG. 3

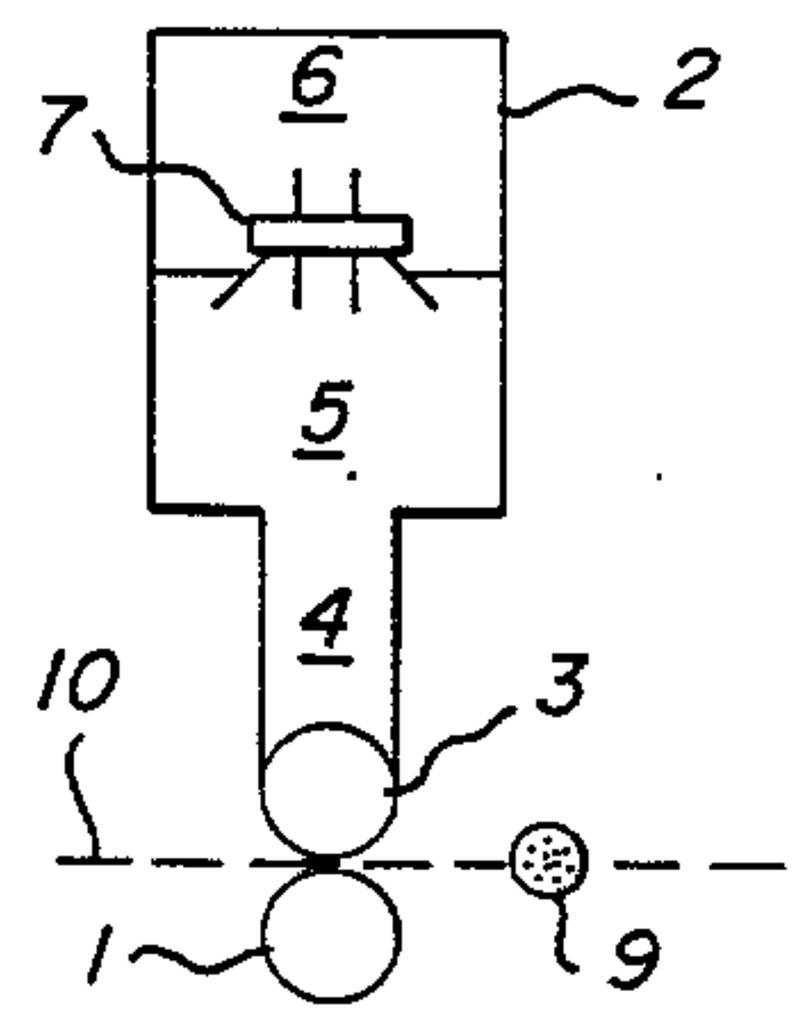

FIG. 4

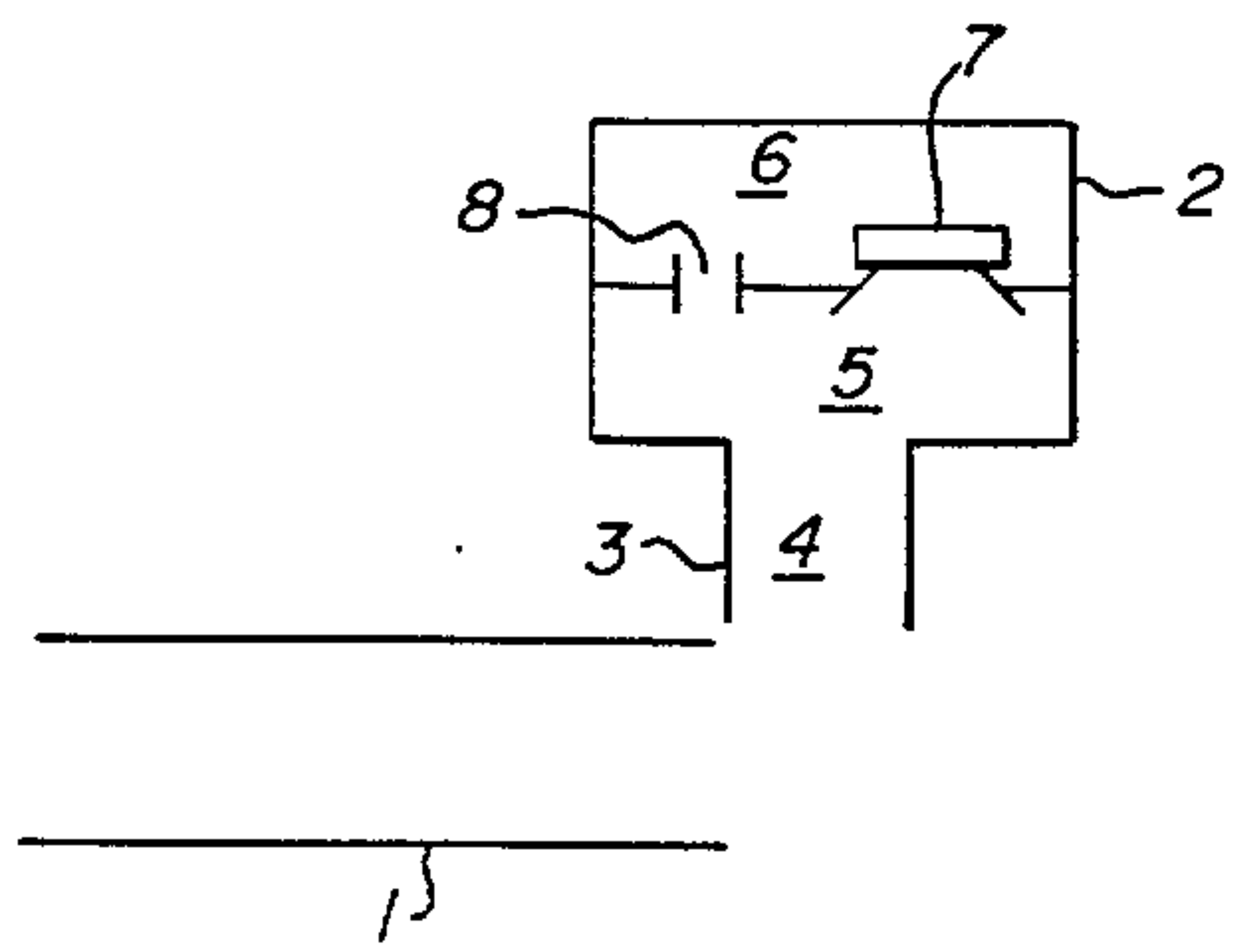

FIG. 5

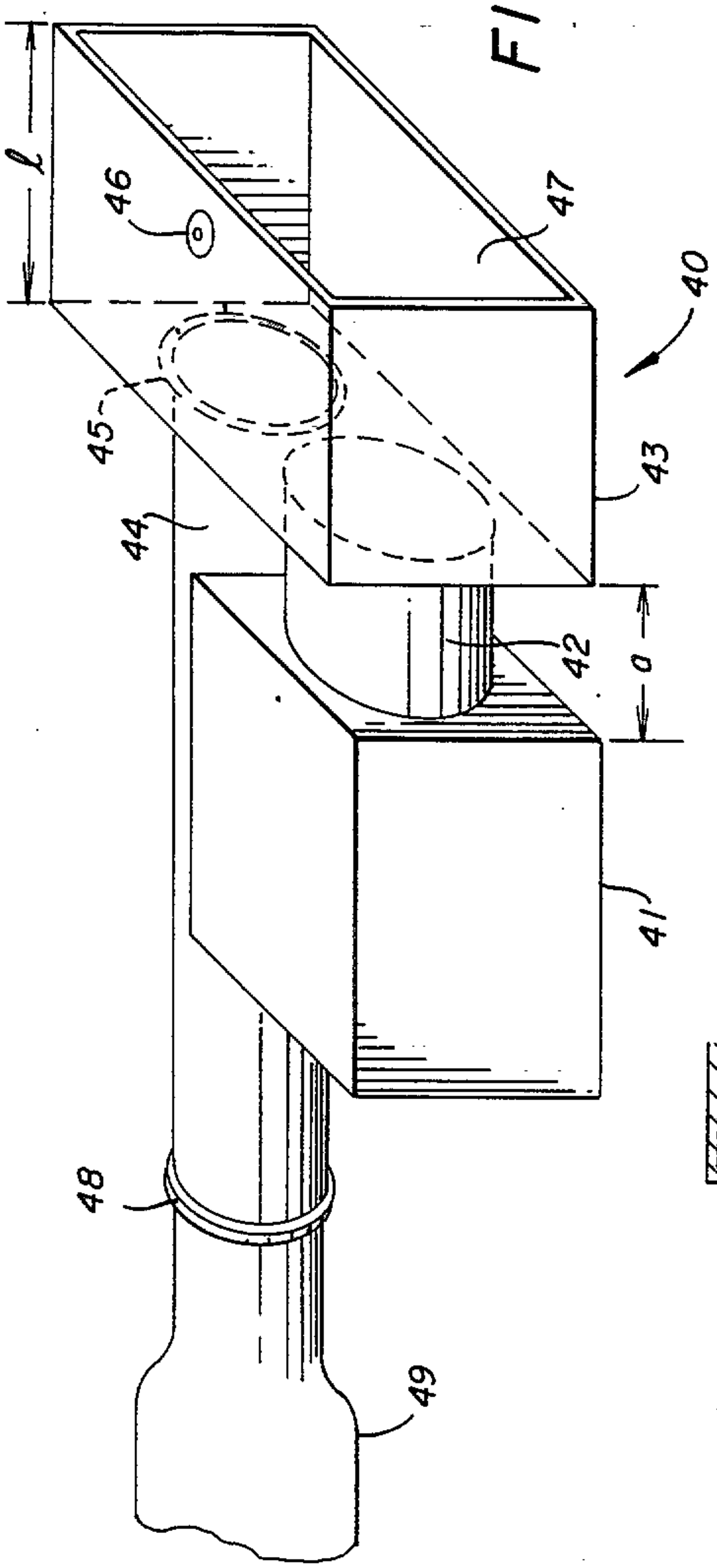

FIG. 6

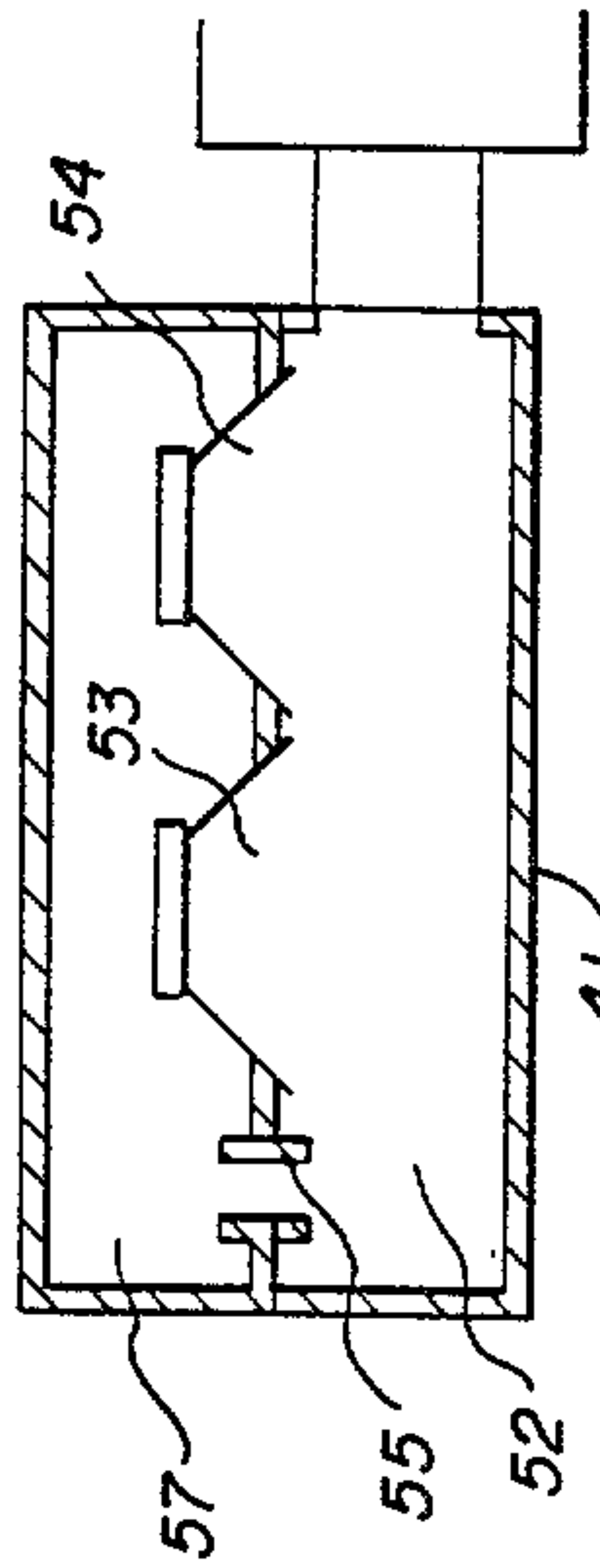

FIG. 8

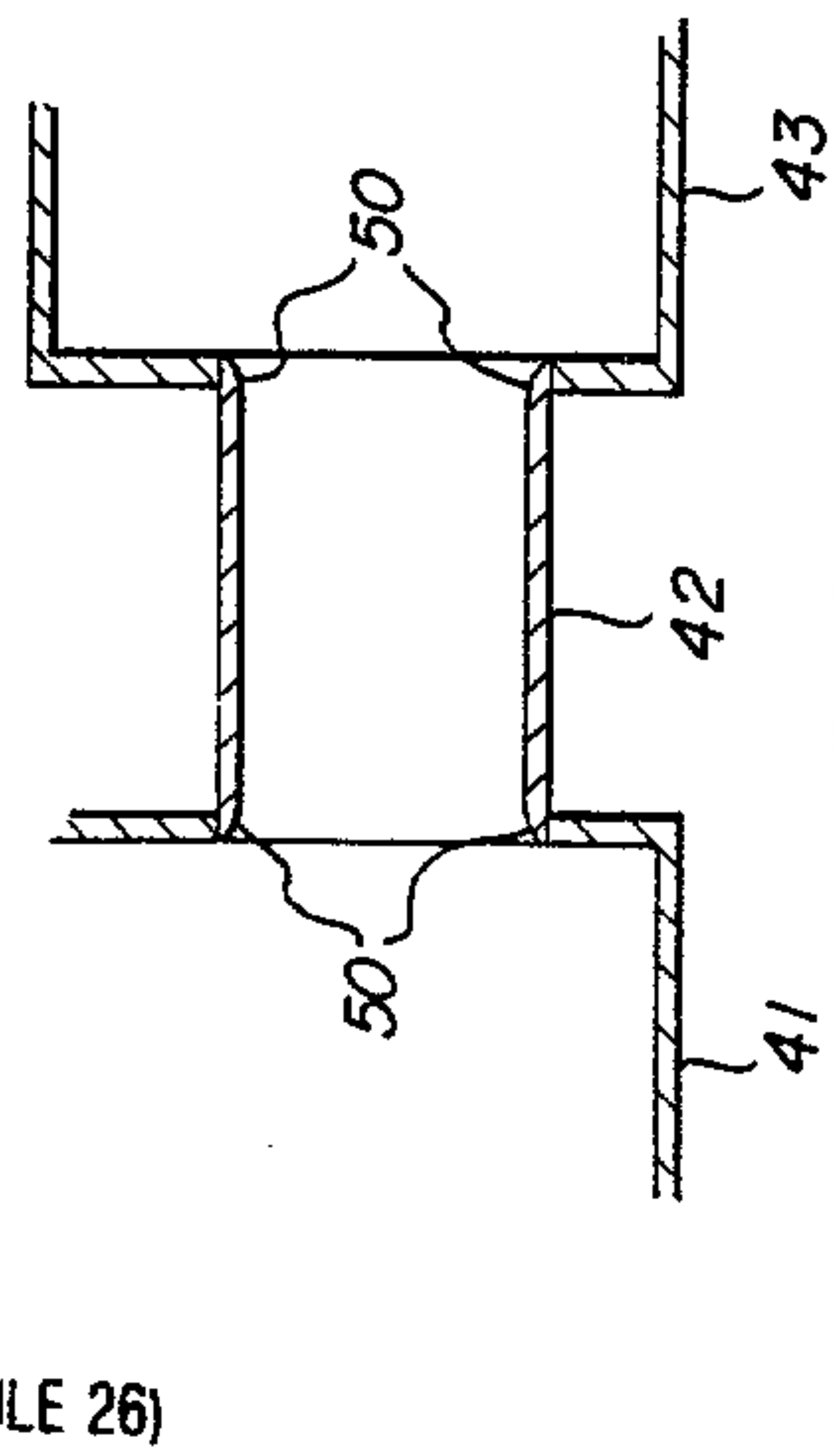

FIG. 7

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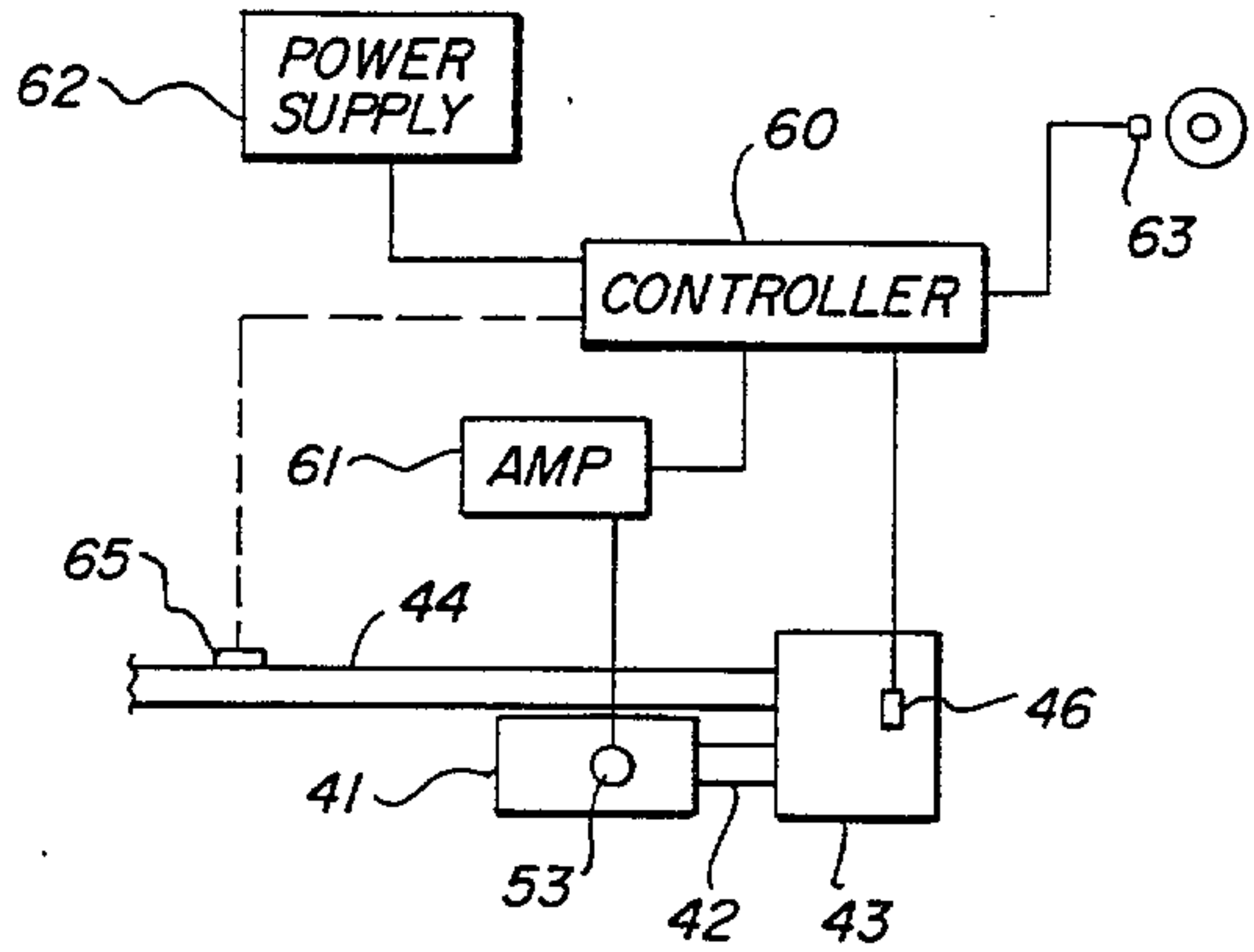

FIG. 9

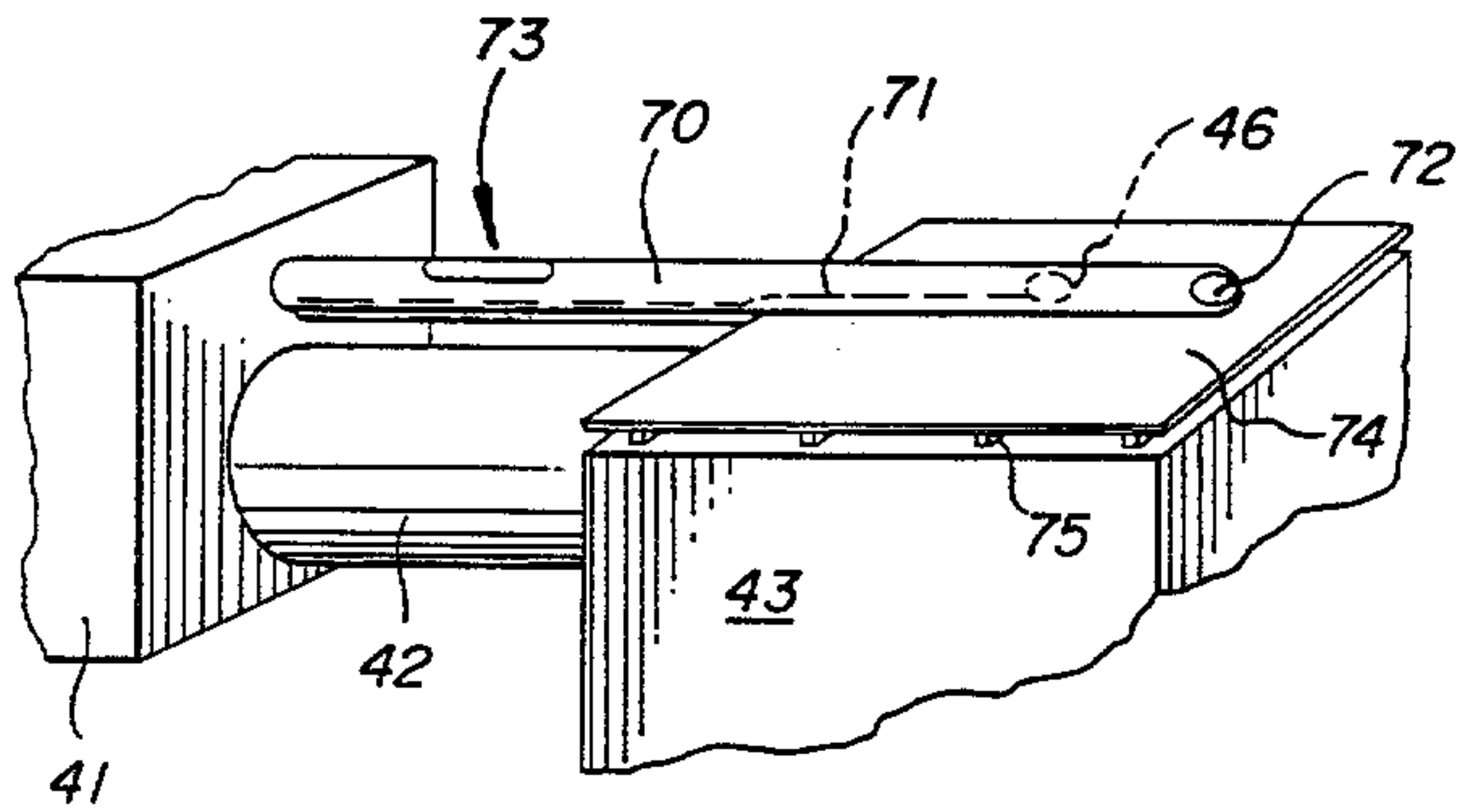

FIG. 10