March 14, 1961 L. J. BRUEGGEMAN ET AL 2,974,529

ACCELERATION INTEGRATOR

Filed June 27, 1958

FIG. 1.

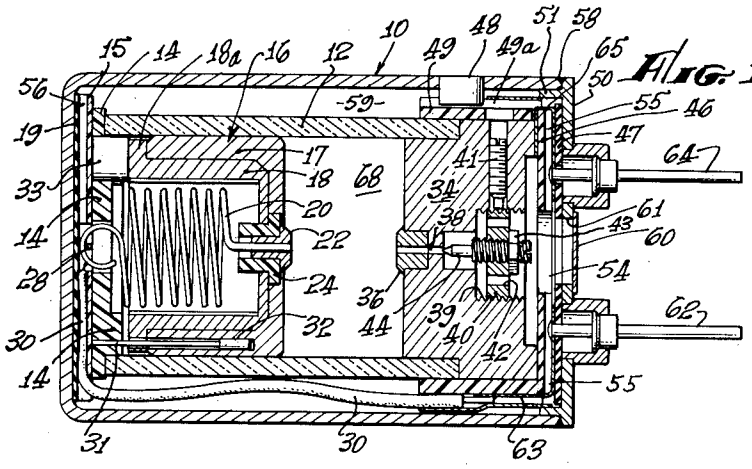


FIG. 2.

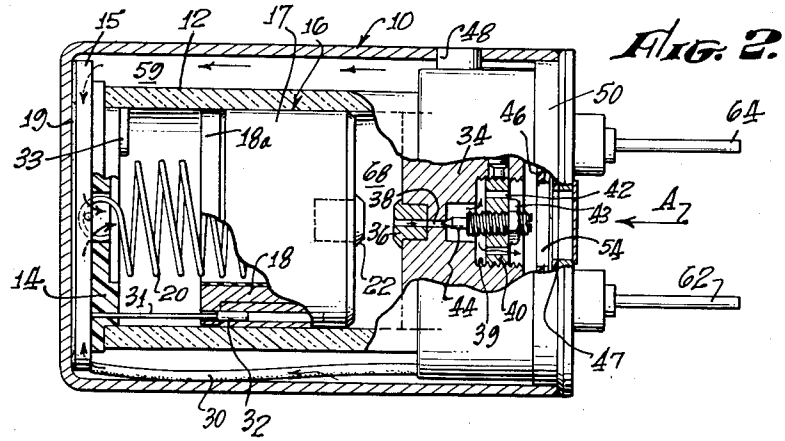
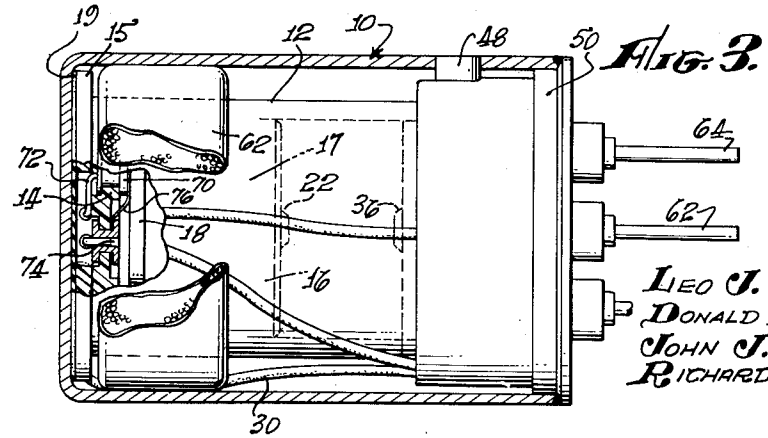


FIG. 3.



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ACCELERATION INTEGRATOR

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This invention relates to an acceleration integrator which is useful in missiles and the like as a burning time and acceleration control, and in other similar applications.

The invention utilizes a fluid confined within a cylinder between a substantially free piston and a fixed end of the cylinder, with an orifice in one of the surfaces bounding the confined fluid. When the device is bodily accelerated axially the piston tends to move toward the closed end of the cylinder, exerting a pressure on the confined fluid and forcing the confined fluid out of the orifice. The rate of flow through the orifice depends upon the pressure applied by the piston and the obstruction offered by the orifice. Signal means responsive to the total amount of fluid forced through the orifice provides an indication of the value of the time integral of the acceleration.

The invention is characterized by certain novel aspects and advantages which are best described with reference to a specific embodiment thereof in connection with the attached drawings in which:

Fig. 1 is an axial section of one embodiment of the invention at rest;

Fig. 2 is an axial section of the same embodiment during axial acceleration; and

Fig. 3 is a section of a second embodiment at rest.

Broadly described, these embodiments comprise a hermetically sealed container filled with an inert gas, a cylinder assembly inside the container having one closed end, a movable piston within the cylinder, an adjustable orifice in the closed end of the cylinder, and an abutment near the open end of the cylinder. With the piston in rest position engaging the abutment, a fixed volume of gas is contained between the piston and the closed cylinder end. The piston is substantially free to move when the device is accelerated axially in the forward direction, thereby exerting a pressure on the gas and forcing it out the orifice. Signal mechanism, typically comprising a pair of electrical contacts is arranged to be actuated when a predetermined total amount of gas has been forced through the orifice, providing an illustrative type of electrical signal which indicates a predetermined value of the time integral of the acceleration.

When the acceleration of the device ceases, the piston is typically returned to its rest position against the abutment by spring means. In accordance with one aspect of the invention, restraining means for holding the piston in its rest position are provided to supplement the action of such spring means. The piston may contain magnetically permeable material, and the cylinder wall be made of non-magnetic material, for example, and a solenoid may be mounted within the container around the rest position of the piston to provide a magnetic restraining force, as illustrated in Fig. 3. Alternatively, a permanent magnet of suitable strength may be attached to the abutment, as illustrated in Figs. 1 and 2.

Referring to Figs. 1 and 2, a hermetically sealed cylindrical container **10** forms the outer casing of the device. Within the container is coaxially mounted a cylinder structure comprising a cylinder wall **12** of non-magnetic material, and end pieces **14** and **34** rigidly attached to the cylinder wall. End piece **14**, which forms the abutment at the open end of the cylinder, rests on a spacing assembly comprising the spacing disc **15** and the resilient washer **19**. Spacing disc **15** has one or more radial channels **56** which permits unobstructed passage of gas therethrough. Within the cylinder is a movable piston **16** comprising a graphite sleeve **17** forming a bearing surface and an inner magnetic core structure **18** of magnetic material such as soft iron, steel or invar. In preferred form of the invention, cylinder **12** is of glass, with an inner wall that is effectively polished and that fits closely the outer graphite surface of piston **16**, forming a substantially gas-tight seal while permitting effectively free axial movement of the piston.

The piston carries an electrical contact **22** seated in an insulating plug **24**, which is in turn fixedly mounted in a coaxial bore in magnetic core structure **18**. A spring **20** is soldered to electrical contact **22** at one end and at its other end is fixedly secured to cylinder end piece **14** by a cross member **28**. The fixed end of spring **20** is soldered to an electrical conductor **30**, which is connected to an external terminal, to be described. A guide rod **31** having an enlarged generally cylindrical head **32** is rigidly mounted on end piece **14** with its head slidably bearing in an axial bore in the graphite bearing structure **17**. Rod head **32** prevents rotation of the piston while causing virtually no restraint upon its axial movement.

An abutment member **33**, comprising a permanent magnet, is fixedly mounted on cylinder end piece **14** in position to engage the radially flanged portion **18***a* of piston core **18** and to positively limit piston movement to the left as shown in the drawings. When so engaged, the magnet exerts a restraining force upon the piston, tending to prevent its movement to the right. The magnitude of that force may readily be determined in known manner by suitable selection of the dimensions and nature of the magnet and of piston core member **18**, which acts as armature for the magnet.

Cylinder end piece **34**, at the right hand end of cylinder **12** as shown, is gas-impervious except for an orifice of predetermined size to be described. End piece **34** is typically formed of electrically conductive material and carries an electrical contact **36** in position to be engaged by piston contact **22** in response to piston movement to the right as shown. A gas channel **38** is drilled coaxially through both contact **36** and end piece **34**, and is counterbored at **39** at the outer side of the latter. An adjustable support **40** is coaxially threaded in the bore **39**, and is provided with locking means shown as the set screw **41** in a radial bore in end piece **34**. Support **40** is drilled at **42** to permit unobstructed flow of gas therethrough and to receive a tool for adjusting the axial position of the support. A needle valve member **44** is coaxially threaded in support **40**, forming with the restricted portion of channel **38** an adjustable needle valve assembly. A lock nut **43** is provided to fix the needle in any desired position with respect to its support.

The cylinder assembly is mounted within container **10** between the spacing discs **15** and **46** and the insulating resilient mounting pads **19** and **47** at the respective left and right ends of the assembly. Spacing disc **46** is provided with an axially extending peripheral flange **49** which fittingly encloses cylinder **12** and centers it. The outer face of flange **49** is axially slotted at **49***a* to receive the keying pin **48**, which is fixedly mounted on the cylindrical wall of container **10** and defines a definite angular position of the entire assembly. The container cover **50** is provided with a spacing flange **51**, which fits between the periphery of disc **46** and the inner cylindrical wall of

the container and maintains their coaxial relation. When cover **50** is sealed in place, as by solder at **58**, resilient pads **19** and **47** are compressed sufficiently to hold the entire cylinder mechanism firmly yet yieldingly in position.

A passageway for substantially free gas flow is provided within container **10** from the outer side of valve **44** around the exterior of cylinder **12** to the left hand face of piston **16**. That passage structure, as illustratively shown, includes the holes **42** in valve support **40**, already mentioned, the axial bore **54** and the radial channels **55** in spacing disc **46**, and channel **49***a*, leading to the annular chamber **59** between cylinder **12** and the container wall. From that chamber, the passage structure includes the radial channels **56** in spacer disc **15** and axial bores in that disc and in end piece **14**. The described radial channels may also accommodate electrical wires such as **30**. Electrical terminals **62** and **64** are mounted in insulated and hermetically sealed relation on cover **50**. Terminal **62** is connected via the conductive strip **63** to conductor **30** and thence to piston contact **22**. Terminal **64** is connected via the strip **65** to cylinder end piece **34** and through the conductive material of that member to fixed contact **36**. Pad **47** and end plate **50** are axially bored at **61** to provide access to the screw adjustments for needle **44** and needle support **40**. The opening in end plate **50** is normally closed by a seal **60** which may be soldered in place.

Fig. 2 shows the response of the embodiment disclosed in Fig. 1 to bodily acceleration of the device in the forward direction, which is to the left on the drawing as indicated by the arrow A, which represents acceleration. When that acceleration exceeds a predetermined initial value, the acceleration force tending to produce relative movement of the piston to the right overcomes the combined holding force of spring **20** and magnet **33**. The piston then moves to the right, compressing the gas confined in the chamber **68** between the piston and end piece **34**, until the pressure differential across the piston balances the other forces acting on the piston, including the acceleration force. The compressed gas escapes from chamber **68** at a limited rate through the channel **38** past needle **44**, through openings **42** in plate **40** and through the described passage system back to the other side of the piston, the light arrows indicating such gas flow. The gas is substantially unobstructed in its passage except at the needle valve orifice, which may be adjusted to set the amount of obstruction in the gas passageway. The total mass of gas forced through the orifice is substantially proportional to the pressure differential across the orifice multiplied by the time duration of that pressure differential, i.e., to the integral of pressure differential with respect to time. And since the pressure differential depends on the magnitude of acceleration, the total mass of gas forced through the orifice provides a measure of the integral of acceleration with respect to time. When a pre-set mass of gas has been forced through the orifice, electrical contacts **22** and **36** close and provide an output signal, which may be utilized in known manner for any desired indicating or control function.

Following such operation, when the force on the piston due to acceleration drops below the force exerted by spring **20**, the spring moves the piston back toward its rest position against abutment **33**. When the piston reaches its rest position, the permanent magnet of that abutment contacts the magnetic core **18**, holding the piston securely at its rest position.

The use of the magnetic holding device in combination with the restoring spring, in accordance with this invention, provides important advantages. It is desirable to keep the force of spring **20** as low as possible, since it introduces non-linearity into the response of the device. During normal operation, the force actually exerted by the piston on the gas is substantially equal to the difference between the force of the spring and the force due to acceleration. But for theoretically perfect linearity the force exerted on the gas should depend only on the acceleration. Therefore the spring force introduces a non-linearity which tends to increase with increasing spring force. In previously available mechanisms it has been necessary that the spring **20** or its equivalent be strong enough not only to return the piston to its rest position within a reasonable time but also to hold it reliably in that position ready for use under widely varying conditions of orientation, vibration and the like.

In accordance with the present invention such additional holding force is provided by means which do not increase non-linearity of response. The combination of magnet **33** and the magnetically permeable piston core **18** provides such a holding force. When the magnetic materials are in direct contact an appreciable attractive force is exerted between the magnet **33** and the piston core **18**, typically equal to at least about one-half the weight of the piston. This force adds to the force of spring **20** to effectively lock the piston in its rest position against normal vibration and jolts. But, when the device is accelerated beyond a predetermined threshold value, the piston moves away from the magnet **33**. Even very slight piston movement forms an air gap between the magnet and the magnetic core **18** which reduces the attractive force of the magnet on the piston very sharply, leaving only the relatively uniform retarding force of the spring. Hence the magnetic holding action is effectively released in response to an acceleration that exceeds a predetermined threshold value. Thus by a combination of spring means just strong enough to return the piston under normal conditions toward its rest position and magnetic means providing the additional force required to secure the piston in its rest position against abnormal conditions such as vibration, the non-linearity of the device is reduced relative to that inherent in prior art devices.

An additional feature of the invention resides in the use of a confined gas as fluid medium. Any change in viscosity or density of the fluid medium will change the volume rate of flow through the orifice for any given pressure differential, and thus render the device inaccurate. Although viscosity of a gas normally changes very little with variation in its temperature, the gas density ordinarily decreases relatively rapidly with increasing temperature, and the specific volume decreases correspondingly. We have found, however, that if the gas is confined in a constant volume, preventing such variation of the specific volume, the direct effects of temperature upon the flow characteristics of the gas are practically eliminated. Thus, through the use of a confined gas, inaccuracy due to change in properties of the gas with temperature is kept to a minimum.

Another potential inaccuracy introduced by a varying temperature is a change in the clearance between the piston and cylinder wall, and hence in the amount of gas leaking around the piston. The bearing surface of the piston preferably fits extremely closely against the inner surface of the cylinder wall, but it is never possible to get a perfect fit and there is always some leakage of gas round the piston. Although the piston material and the cylinder wall material are preferably chosen to have coefficients of temperature expansion as nearly alike as possible, it is seldom feasible to get them perferably matched. Therefore, in practical usage there is some leakage around the piston, the amount of which varies with temperature in accordance with the difference in expansion coefficients of the piston and wall materials. In accordance with the invention, that variable leakage is counteracted by the use of different materials in the needle valve assembly, with the needle having a different coefficient of temperature expansion from the member in which the channel is cut, which is end piece **34** in the present embodiment. The obstruction offered by the

needle valve orifice will then also vary with a change in temperature, and by suitably selecting the materials and other factors such as the angle of the needle point this variation can be made to compensate for other temperature effects, including the variation in leakage around the piston. If the temperature coefficient of expansion of the piston is larger than that of the cylinder, the needle material is chosen to have a temperature coefficient smaller than the channel; and if the cylinder wall coefficient is the larger the arrangement is reversed. The magnitude of the variation of valve orifice with temperature may be controlled by suitable selection of the angle of taper of the tip of the needle. That angle may be separately selected for each general embodiment of the device, but cannot conveniently be varied from one instrument to another to provide optimum temperature compensation.

In accordance with a further aspect of the invention, such final adjustment of each instrument is made possible by mounting the valve needle, as already typically described, in a support that is axially movable with respect to the valve seat. Axial adjustment of support **40** in the present embodiment provides continuous variation of the effective length of the valve stem. By increasing that length, for example, the rate of change of the orifice size with temperature is increased. It is thus possible, by axial adjustment of carrier **40**, to produce accurate temperature compensation of each instrument for any selected pair of temperatures.

Another feature of the invention resides in the fact that the electrical contacts do not close until substantially all of the confined gas is driven through the orifice. It will be understood that even if the orifice were closed the piston would undergo some movement as a result of an applied acceleration due to the compressibility of the gas. If the contacts were to be closed by movement associated with compression of the gas, then the closing of the contacts would be a function of the magitude of the applied acceleration rather than the applied acceleration multiplied by time. But if the confined gas must be substantially all forced past the orifice before the contacts are closed, the effect of compressive movement will be minimized, and the contacts will close at a time depending on the time integral of acceleration, and substantially independent of the magnitude of acceleration. In practice, of course, it is not practicable to have the confined volume reduced absolutely to zero when the contacts close, but by making the closing volume small compared to the rest volume of chamber **68**, that is from one to five percent of the rest volume, for example, the potential inaccuracy can be lowered to a negligible level.

Another feature of the invention is the combination of the guide pin **31** with the guide bore formed in the graphite bearing surface of the piston. It will be understood that it is never possible to construct a cylinder having perfectly circular inner walls. As a practical means of assuring a uniform fit between the piston bearing surface and the cylinder walls the piston bearing surface is made slightly oversize and then honed into close fitting relationship with the cylinder walls in a definite angular orientation. To preserve this close fit it is important that the piston be restrained from any rotation relative to the cylinder, since rotation will destroy the honed fit between the irregularities of the cylinder wall and the piston. Guide pin **31** preserves the close fit by securing the angular orientation of the piston. Pin **31** does not appreciably affect the sliding movement of the piston, since the working friction between the metal pin head **32** and the graphite guide surface is negligible.

Fig. 3 shows a second embodiment of the invention, comprising a solenoid winding **62** which is fitted over the outside of the cylinder wall **12** near the rest position of the piston and is energized via an electrical switch which opens in response to a predetermined value of acceleration. Solenoid **62** can be utilized to provide an adjustable magnetic force acting to hold the piston in its rest position. The acceleration responsive switch is shown illustratively as comprising the contact **70** and the spring member **76** attached to the fitting **74** which are mounted on end piece **14**. Spring member **76** is deflected into engagement with contact **70** by the end of the piston when in its rest position. The switch is connected in series with the solenoid winding, and with an external source of power which may be applied to the series combination from two external terminals. When the piston is in its rest position against the abutment, the switch is closed and current flows through the solenoid winding, creating a magnetic field which attracts the magnetic core of the piston and holds it against the abutment. When the piston is moved from its rest position by a threshold acceleration great enough to overcome the spring force and magnetic force, switch member **76** springs away from contact **70**, thereby breaking the circuit and removing the magnetic field. The solenoid **62** may either supplement or replace a permanent magnet, such as permanent magnet **33** in the first mentioned embodiment. It may, however, be desirable to provide a suitably formed member of magnetically permeable material in the place of the permanent magnet to act as a pole-piece for the solenoid winding. In this case it may be desirable to use material such as soft iron which has a very low degree of magnetic remanence, such that the magnetic forces will substantially disappear when the current is interrupted through the solenoid. Thus the solenoid serves substantially the same functions as the permanent magnet disclosed in Fig. 1, with the additional advantage of being adjustable by variation of the solenoid current, and therefore adaptable to some additional functions. Except for the solenoid and its associated switch, the structure and functions of this embodiment are substantially identical to the structure and functioning of the first mentioned embodiment.

Additional aspects of the invention facilitate the process of calibrating the instrument. The device is ordinarily calibrated so that the contacts **22** and **36** close when the integral of acceleration with respect to time reaches some particular value. That may be done, for example, by putting the device under the influence of an accurately known uniform acceleration, as on a centrifugal table, and observing the length of time required for the contacts to close. The needle valve orifice **44** may then be adjusted so that the contacts close in the required length of time. Since an appreciable time is required to bring a centrifugal table up to standard speed, it is desirable to prevent operation of the device until the table reaches standard speed, and then to release the device at a known time so that an accurate measurement may be had of the amount of time required to close the contacts under the influence of the known acceleration. In this invention the magnetic core of the piston in combination with the non-magnetic walls of the cylinder provide such a means for retarding the operation of the piston and releasing it at an accurately known time.

In the case of the embodiment disclosed in Fig. 1 a solenoid may be externally mounted over the container, the container walls in that case being also of non-magnetic material such as aluminum or stainless steel. The solenoid is energized with a current large enough to hold the piston at rest against an acceleration greater than the calibration acceleration. After the centrifugal table reaches the desired speed the current in the solenoid may be interrupted manually or automatically, freeing the piston to respond to the calibration acceleration. The interruption of solenoid current also marks the starting time of the integrating action. The use of magnetic core material in the piston in combination with a non-magnetic cylinder thus serves an additional important function in making possible an easy and accurate method of calibration. It is not, of course, necessary that the solenoid used for calibration purposes be mounted external to

the container. In the embodiment disclosed in Fig. 3, which has a solenoid **62** mounted internal to the container, the solenoid may also be used for calibration in the manner described above. In that case the solenoid **62** has a double utility. In normal operation it provides a means for securing the piston in its rest position under the influence of normal vibrations and jolts; and during calibration it provides a means of securing the piston in its rest position during table acceleration, as described above. The use of an internal solenoid has the additional advantage of making it possible to use a magnetic material for the container **10** without sacrificing the advantages of a solenoid in calibration of the device. It will be understood that in some applications it may be desirable to have magnetic shielding around the device in order to isolate the magnetic core of the piston from any external magnetic fields, such as are commonly encountered around electrical machinery.

An additional aspect of the invention is the use of nitrogen under atmospheric pressure hermetically sealed within the container. In addition to being an inert gas, nitrogen has a viscosity which is very close to the viscosity of air, so that the device may be calibrated by the use of air at atmospheric pressure, and may then be evacuated of air and filled with dry nitrogen at the same pressure without essentially changing the operating characteristics of the device. Therefore the use of nitrogen combines the convenience and structural simplicity obtained by calibrating the device with air and the advantages obtained by use of a dry inert gas. The nitrogen is introduced through the hole **61** in cover **50** after the device has been calibrated and evacuated of air and moisture. Seal **60** is then permanently secured over the hole, hermetically sealing the device and confining the nitrogen within the container. It will be understood, of course, that the terminal structures attached to the cover **50** are also hermetically sealed, as is the joint **58** between the cover and the container **10**.

The particular embodiments of the invention described in this document and illustrated in the drawings are intended for illustration only, and should not be construed as constituting any limitation on the invention. Many variations in the specific structures disclosed are possible within the spirit of this invention, which includes all such variations that fall within the limits of the following claims.

We claim:

1. An acceleration integrator actuable in response to a critical value of initial acceleration that is controllably variable, said integrator comprising the combination of structure forming a cylinder closed at one end, piston means including magnetically permeable armature means and movable inwardly in the cylinder in response to axial acceleration thereof, fluid means for limiting the rate of piston movement, abutment means engageable by the piston means and defining a normal position thereof adjacent the other end of the cylinder, solenoid means variably energizable to hold the piston and armature means in engagement with said abutment means with a variable force corresponding to said critical value of initial acceleration, a switch connected in series with the solenoid, and means acting to close the switch only when the piston means is in said normal position.

2. An acceleration integrator comprising structure forming a cylinder closed at one end, piston means movable within the cylinder in response to axial acceleration thereof, and fluid means limiting the rate of piston movement and comprising a fluid contained within the cylinder, structure forming a fluid passageway between the portions of the cylinder on opposite sides of the piston, and temperature responsive valve means forming a flow limiting orifice in said passageway, said valve means comprising elongated throat structure having a valve seat at one end, a support member mounted at the other end of the throat structure and adjustably movable axially thereof to vary its distance from the valve seat, and a needle axially threaded in the mounting member for adjustable cooperation with the valve seat, the needle and the throat structure having different coefficients of temperature expansion, the effective length of the needle being adjustable by said movement of the mounting member to vary the degree of temperature response of the valve means.

3. An acceleration integrator comprising structure forming a cylinder closed at one end, piston means movable within the cylinder in response to axial acceleration thereof, and fluid means limiting the rate of piston movement and comprising a fluid contained within the cylinder, structure forming a fluid passageway between the portions of the cylinder on opposite sides of the piston, means forming in said passageway a flow limiting orifice of temperature dependent size, first adjusting means actuable to vary continuously the size of the orifice, and second adjusting means actuable to vary continuously the rate at which the size of the orifice changes with temperature.

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