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(54) A METHOD AND A SYSTEM FOR CONTROLLING A MODULATING VALVE UNIT INCLUDING AN ELECTROMAGNET

VERFAHREN UND SYSTEM ZUR STEUERUNG EINER MODULATIONSVENTILEINHEIT MIT
EINEM ELEKTROMAGNETEN

PROCÉDÉ ET SYSTÈME POUR COMMANDER UNE UNITÉ DE SOUPAPE DE MODULATION
COMPRENANT UN ÉLECTROAIMANT

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Description

Technical field

[0001] The invention is applied in particular in the field of systems for controlling the gas feed to burners of heating appliances in general, whose flame is intended directly to heat the environment or to heat an intermediate fluid circulating in a boiler installation.

Technological background

[0002] These appliances, like all installations using a gas burner, are normally provided with a valve unit designed to control the supply of the flow of gas to the burner, so that the feed pressure and/or the flow of gas fed thereto can be regulated in a controlled manner. These valve units are typically intended to provide a multifunctional control of the flow of gas fed to the burner, having simultaneously to ensure the function of safe interception of the gas path as well as the feed pressure regulation/modulation function.

[0003] One of the main components of these valve units is formed by a pressure regulator device disposed in the main gas feed duct and typically including a valve having a plug with diaphragm control, the diaphragm being subjected on one side to the pressure regulated by the device and on the other side to a pressure generated by a resilient load, possibly subject to calibration. By means of such a regulator device, the feed pressure is kept substantially constant and equal, less a factor of proportionality, to the ratio between the resilient force and the surface of the diaphragm subject to the resilient load. These pressure regulators may also be provided in order to carry out amplitude-modulated pressure regulation. In such a configuration, an operating means (for instance of linear type), which term is understood as any actuation means having a control member, whose movement is controlled, acting on the spring to vary the resilient force generated thereby, acts on the spring (which generates the resilient load). These operators are formed, for instance, by electromagnets or by controlled-axis motors or other like motor-driven means.

[0004] In the solution using pressure regulators provided with an electromagnet, the operating means comprises an electromagnet and therefore a coil supplied with a predetermined current, by means of which the force with which the plug means acts on the above-mentioned diaphragm is changed. Typically, at least in a predetermined working range, as a current supplying the coil of the electromagnet increases, the outlet pressure increases since the force with which the operating means acts on the spring increases.

[0005] Irrespective, however, of the relationship between the current flowing in the coil and the outlet pressure of the gas, which is known once the valve unit in question has been calibrated, the known modulating valve units also comprise means for controlling the cur-

rent with which the electromagnet is supplied in order to determine the outlet pressure from the valve unit according to need, i.e. it is desirable for selection means to be provided such that - once a pressure needed for the correct operation of the burner according to need has been established - the value of the corresponding current to be supplied to the electromagnet is known. These control means may, for instance, comprise a microprocessor in which the relationship "current supplied to the coil / pressure supplied" is stored for instance in the form of a curve or a table (or a plurality of curves or tables, or both); therefore, once the desired pressure has been established, the current needed to ensure that the electromagnet acts on the plug with the appropriate force is set using appropriate signal selection means and this table/curve.

[0006] However, these valves are commonly subject to the phenomenon of hysteresis, i.e. separate current values are very often needed in these valves for the force exerted by the operating means to be the same, depending on other operating conditions, in other words two outlet pressure values of the gas correspond to an identical current supplied to the coil depending on whether a falling or a rising pressure regime is involved. The "current magnitude versus outlet pressure" curve has the characteristic shape of a closed curve similar to a parallelogram typical of hysteresis.

[0007] This phenomenon is, however, undesirable as it does not enable a correct selection of the outlet pressure: as two outlet pressures may be associated with the same current, it is not known to which outlet pressure the predetermined magnitude of the current supplied to the electromagnet by the control means described above may correspond.

[0008] In the prior art, in order to remedy this drawback, the so-called "dithering" signal has been introduced, i.e. the operating means of the electromagnet which acts on the plug is not kept stable in a predetermined position, but is caused to oscillate about a median position, which median position is the position corresponding to the desired outlet pressure. This oscillation prevents the formation of hysteresis and enables a substantially unequivocal relationship between the magnitude of the current supplied to the coil and the outlet pressure of the gas, obviously with a minimal degree of uncertainty due to the dithering signal which causes the oscillation. The frequency and amplitude of the oscillations due to dithering must be appropriately determined such that the mean value of the magnitude of the current is the value desired to obtain the necessary outlet pressure without any mechanical noise, excessive wear, pressure pulses or other drawbacks being created, moreover, within the valve unit.

[0009] According to the prior art, a first option for obtaining the dithering is, for instance, to superimpose an alternating current oscillating at high frequency, i.e. the dither signal as this current oscillation generates the mechanical dither, on a direct current signal, i.e. a current signal which has the desired constant magnitude. This

type of option is disclosed for instance in DE 3320110.

[0010] Alternatively, according to a second option, the valves of the type described above are supplied with a pulse-width modulation (PWM) voltage signal having an appropriate frequency such that it is the ripple of the current deriving from this PWM signal that ensures the necessary vibration, as will be described in detail below. Signals of PWM type are often used to control solenoids as they minimize the loss of energy in the form of heat, which loss is very high when they are supplied with a constant voltage/current.

[0011] The PWM voltage signal may then be supplied at a frequency high enough for the resulting current to be substantially constant and the dither signal described above in the first option is superimposed on that signal at a much higher frequency than the frequency of the PWM signal. This type of option is disclosed for instance in US Patent Application 2009/0005913.

[0012] All these options nevertheless have drawbacks: the first and the third options in practice require two separate signal generators, a first voltage or constant or PWM signal generator and a second dither signal generator, making the valve control circuit relatively complex and therefore relatively costly.

[0013] As regards the second option, as the dither signal depends on the PWM voltage signal, the amplitude and the frequency of the dither signal depend on the frequency and the duty cycle of the PWM signal, quantities which are not constant given that the duty cycle of the PWM voltage signal is varied whenever it is wished to vary the gas outlet pressure, this dither is not constant. The fact that the dither is not constant is undesirable as oscillations outside of a predetermined range considered to be optimum in accordance with the characteristics of the valve unit in question may entail mechanical noise or resonance, wear or pressure pulses.

[0014] Document US 5020771 A discloses in combination all the features in the preamble of claims 1, 4.

[0015] Document JP4039721 B discloses the combination two PMW signals, one main and one for dithering, wherein the frequency of the dither signal is automatically varied. This variation is automatically performed by making the dither frequency dependent on the main signal duty cycle.

[0016] Document US2009005913 discloses the combination of two PMW signals, wherein the dither signal is always active.

Specification of the invention

[0017] The purpose and main object of the invention is to provide a valve unit which is structurally and functionally designed to remedy the drawbacks discussed with respect to the cited prior art.

[0018] The present invention therefore relates to a valve unit and to a method of controlling this valve unit including a control circuit comprising a PWM signal generator with a duty cycle and frequency which may be

varied in the manner described below. This valve unit is designed to supply combustible gas in a modulating manner, i.e. the unit may assume a plurality of positions so as to supply as output a plurality of different pressures/rates of flow of the combustible gas. In the following description, P therefore indicates both the pressure and the rate of flow unless only one of the two is explicitly specified. The valve unit in particular comprises a plug whose position depends - *inter alia* - on the force exerted by an electromagnet included in the valve unit and supplied by the PWM signal generator.

[0019] The PWM signal generator in particular supplies this signal to the electromagnet which generates a force proportional to the current circulating in the coil. This force, depending on its magnitude, keeps the plug of the valve unit open to a greater or lesser degree, thereby generating a gas outlet pressure/rate of flow P_u : the gas outlet pressure is therefore proportional to the magnitude of the current supplied to the electromagnet. The proportionality between the current and the gas outlet pressure (or rate of flow) is considered to be known and is for instance controlled by a sensor disposed in feedback or is stored, in the form of a curve or tables, in a memory in the control circuit of the valve unit.

[0020] According to a preferred embodiment of the invention, the valve unit modulates the rate of flow of the gas output, not the pressure, simply by varying the dimension of the gas outlet hole by means of a plug which engages to a greater or lesser degree in the valve seat.

[0021] A signal of PWM type is defined in particular by a frequency of the PWM signal known as $\nu = 1/T$, in which T is the period of the signal, and by the duty cycle d, i.e. the ratio, in the presence of a signal having a rectangular wave shape, between the duration of the "high" signal and the total period of the signal, and shows for what proportion of the period the signal is "active".

[0022] With reference to Fig. 3a, the duty cycle is:

$$d = \tau / T$$

where τ is the portion of the period at high level and T is the total period. The result of the ratio is always a number between 0 and 1.

[0023] With reference to Figs. 4a and 4b, a PWM signal of the type illustrated in Fig. 4a having a frequency within a predetermined range generates a current signal in the electromagnet illustrated in Fig. 4b. As can be seen, as a result of the inductance of the electromagnet, when a predetermined potential difference is applied thereto, the current does not follow the same stepped course as the PWM signal, but has a time period during which it increases until reaching a maximum and similarly when the supply voltage is brought to zero, the current does not immediately drop to zero. The resulting magnitude of the current is not therefore continuous but shows an oscillation ("ripple") which may be compared with a dither

signal as this current variation generates an oscillation of the coil of the electromagnet which is therefore associated with an oscillation of an actuator means acting on the plug of the valve unit.

[0024] A PWM voltage signal is supplied to the electromagnet such that the mean value of the magnitude of the current generated is the desired value, i.e. the value that generates the desired outlet gas pressure according to the known curve. According to the prior art, the PWM voltage signal is supplied at constant frequency and with a duty cycle d such that the magnitude of the current supplied to the electromagnet is that desired to obtain a predetermined P_u . If a new P_u is desired, the frequency of the PWM signal is kept constant and only the duty cycle of the signal is varied. As the signal increases, so does the mean magnitude of the current acting on the electromagnet. The amplitude of the dithering signal due to the ripple in the current signal changes as the duty cycle changes.

[0025] The range of frequencies of the PWM voltage signal supplied to the electromagnet such that mechanical dithering is obtained is well defined and depends on various characteristics of the system, for instance the mechanical frequency that is defined by masses and springs, the time constants of the diaphragm, static and dynamic friction, the inductance of the magnetic circuit, etc. An optimum range of frequencies for domestic appliances preferably varies between 200 Hz and 1000 Hz depending on the mean value of the magnitude of the current. The range of frequencies is described below as the "range of dither frequencies of the PWM signal". Below the minimum frequency of this range, the current signal generated by a PWM signal at such a low frequency is similar to that shown in Fig. 3a (PWM signal) and Fig. 3b (current signal): the magnitude of the current does not reach the potential maximum as there is not enough time to reach it: the voltage is already cancelled out prior to the maximum and the current starts to decrease again. Alternatively, above the maximum frequency of the dither frequency range, the PWM signal is at such a high frequency that the magnitude of the current does not drop further between one step and the next of the voltage signal and the current always maintains the mean value desired to obtain a particular P_u . This situation is illustrated in Figs. 5a and 5b. In this high-frequency regime of the PWM signal, and again according to the prior art, the PWM signal has superimposed on it a dither signal which is constant in frequency and amplitude and does not therefore depend on the mean value of the signal of the magnitude of the current as it is completely unconnected therefrom.

[0026] As mentioned above, both a signal such as that of Fig. 4b and that of Fig. 5b in which a dither signal is superimposed have some drawbacks. The Applicants have observed that in the first case the "ripple" generated by the mechanical dither has an amplitude which may vary depending on the duty cycle of the PWM signal, and in the second case two signal generators are needed,

one for the PWM signal and one for the dither signal.

[0027] According to a feature of the present invention, the control circuit of the valve unit includes a PWM signal generator which has a variable duty cycle, i.e. the duty cycle of the signal is varied so as to obtain a value of the magnitude of the current needed to obtain the desired outlet pressure, but also has a variable frequency.

[0028] In particular, having selected a duty cycle by means of which the desired outlet pressure is obtained, the frequency of the signal is selected such that it is within the dither frequency range of the PWM signal, i.e. not a frequency which is too high or too low within the meaning given above to those terms. In further detail, the frequency is set such that the ripple signal which is transformed into the dither of the current also generates a mechanical dither, in other words a mechanical oscillation, which has a predetermined amplitude and which is independent from the duty cycle variations of that signal such that the amplitude of the mechanical dither is always the same irrespective of the P_u . In particular, this amplitude of the mechanical dither has to be such as not to create mechanical noise, and must not be excessively wide so as not to cause damage by wear or oscillations of the outlet pressure which in turn entail combustion which is not optimum. This means that, having established the amplitude of the desired ripple from which the mechanical dither is obtained, if a different gas outlet pressure is desired, the duty cycle of the PWM signal is varied so as to obtain the desired magnitude of the current; according to the invention, the frequency of the signal is varied at the same time so as to keep the amplitude of the mechanical dither equal to the value which is desired and in particular kept constant irrespective of the predetermined duty cycle of the PWM signal.

[0029] The proportionality between the frequency of the PWM signal and the mean magnitude of the current may be any and depends on the type of appliance in question. The present invention applies to any existing proportionality which is established at the time of calibration of the appliance.

[0030] The Applicants have observed, however, that a continuous oscillation of the electromagnet during the whole operation of the valve unit is not desirable as it entails mechanical wear after a relatively short time. However, as mentioned above, this mechanical oscillation has the advantage of substantially cancelling out undesirable hysteresis effects which would greatly reduce the precision of the valve unit when determining the correct supply of a desired outlet gas pressure.

[0031] The Applicants have therefore developed a method and a device for regulating the PWM signal in which the phenomenon of dithering is present solely when the mean magnitude of the current is changed.

[0032] In a first embodiment not belonging to the invention, once a desired first feed pressure or first rate of flow has been predetermined, the electromagnet is supplied with a PWM voltage signal at high frequency, i.e. such that the resulting magnitude of the current is sub-

stantially constant and such as to obtain the desired Pu of the gas. In this case there is no mechanical dithering. When a change to the outlet pressure is requested by the control circuit, i.e. a different gas supply, the duty cycle of the PWM signal is modified to obtain a different mean magnitude of the current and therefore a different Pu. According to the invention, in a predetermined time interval, preferably both before and after the modification of the duty cycle of the PWM signal, the frequency of the PWM signal is modified such that it is no longer in the high frequency regime, but enters the dither frequency range of the PWM signal, i.e. for a certain time interval the frequency of the PWM signal is such as to generate a ripple in the corresponding current signal and therefore a mechanical dither. The above-mentioned teaching of the present invention obviously applies to the duty cycle/frequency parameters of this PWM signal, i.e. irrespective of the duty cycle required to generate a predetermined mean current, the amplitude of the dither is always the same and this is obtained by appropriately calibrating the frequency of the PWM signal.

[0033] Therefore, in a first time interval, the PWM signal has a high frequency and a duty cycle such as to obtain a first outlet pressure by generating a substantially constant current signal, then for a transient time interval prior the change of duty cycle, the frequency of the signal is lowered so as to create a certain ripple in the current signal while keeping the duty cycle constant, the duty cycle of the signal is then changed to obtain the new desired pressure and the frequency is kept "low" in order to continue to generate the ripple signal which creates the dithering for a second transient time interval. Following this second transient time interval, the frequency of the signal is returned to "high" while keeping the duty cycle constant. The frequency of the signal before and after the change of duty cycle is adapted such that the amplitude of the mechanical dither remains substantially constant.

[0034] According to an embodiment, the ripple of the signal has an amplitude of approximately 20 milliamperes in comparison with 130-150 milliamperes in the case of the overall signal.

Brief description of the drawings

[0035] Other advantages and features of the present invention will become clear from the following detailed description of preferred embodiments, given with reference to the appended drawings which are provided purely by way of non-limiting example and in which:

- Fig. 1 is a diagrammatic view in longitudinal section of a first embodiment of a valve unit not belonging to the invention;
- Figs. 2a and 2b are diagrammatic views in longitudinal section of a second and a third preferred embodiment of a valve unit of the invention;
- Figs. 3a and 3b are graphs representing a first PWM

voltage signal and the corresponding current signal supplying a coil of an electromagnet of the valve unit of Figs. 1 or 2;

- Figs. 4a and 4b are graphs representing a second PWM voltage signal and the corresponding current signal supplying a coil of an electromagnet of the valve unit of Figs. 1 or 2;
- Figs. 5a and 5b are graphs representing a third PWM voltage signal and the corresponding current signal supplying a coil of an electromagnet of the valve unit of Figs. 1 or 2;
- Fig. 6 is a curve representative of the gas outlet pressure signal as a function of the magnitude of the current circulating in the electromagnet;
- Fig. 7 is a diagrammatic view of the control circuit of the valve unit of Figs. 1 or 2;
- Figs. 8a to 8c are curves representative, respectively, of the current, frequency of the PWM signal and duty cycle of the PWM signal supplied to the electromagnet of the valve unit of Figs. 1 or 2 according to a preferred embodiment of the invention;
- Fig. 9 is a block diagram of the method of operation of the valve unit of the invention;
- Fig. 10 is an experimental graph of the correlation between the frequency of the signal and the corresponding mean magnitude of the current in the electromagnet.

Description of the embodiments

[0036] With reference, first, to Fig. 1, a multifunctional valve unit device for controlling the supply of combustible gas (referred to hereafter simply as gas) not belonging to the present invention, is shown overall by 1.

[0037] The valve unit 1 comprises a feed duct 2 for transferring the gas from a feed member (not shown) to a burner appliance (not shown) which extends between a gas inlet opening 3 and a gas outlet opening 4 to the burner. The duct has a smaller section at the outlet 4 and is for instance shaped as a nozzle 4a.

[0038] The duct 2 is preferably provided with an electrovalve 5 designed safely to enable or intercept the passage of the gas through the duct 1 with an on/off control of its plug in the corresponding valve seat. It is for instance of the type which is normally closed and comprises an electromagnetic actuator, known per se, with a resilient return means disposed so as to move the plug so that it closes the valve seat when the electromagnet is not supplied. More preferably, in an embodiment which is not shown, the duct 2 comprises two safety electrovalves in series.

[0039] Downstream of the electrovalve 5, the valve unit 1 comprises a pressure regulator device, shown overall by 6, including a valve seat 7, obtained in the duct 2, cooperating with a plug 8 whose control stem 9 is rigidly connected to a control diaphragm 10 for its control.

[0040] The diaphragm 10 is subject on one side to the feed pressure regulated by the regulator device 6, shown

by P_u , and on the other side to a resilient load generated by a spring 11 whose axial ends 11a, 11b are connected respectively to the diaphragm 10 and to a wall 12 of a stationary structure 12 of the valve unit. The face of the diaphragm 10 urged by the spring 11 is also subject to atmospheric pressure through the provision of an orifice 13 through which the chamber housing the spring 11, bounded in part by the diaphragm 10 and the wall 12, communicates with atmosphere.

[0041] The precise embodiment of the valve unit as regards the various elements described above has no impact, however, on the teaching of the present invention: it is enough for there to be a pressure regulator including a valve seat and a plug which may be displaced and by means of which an outlet pressure P_u is determined.

[0042] The pressure regulator device 6 further comprises an operating means, shown overall by 14, associated directly with the plug 8 in order to control the latter to move in a controlled manner relatively to the valve seat 7, as will be explained in further detail below.

[0043] The operating means 14 comprises a rod-like member 15 which may be displaced in translation, coaxially to the stem 9 of the plug 8, in a direction shown by X in the drawings. The member 15 comprises, at a free end thereof, a plate 16 extending transversely to the axis X and disposed in a position facing the plug 8 on the side opposite the stem 9. A spring active between the plate 16 and the plug 8 is shown by 17.

[0044] The operating means 14 is of proportional or stepped type, such that the control member 15 may assume, in the direction X, a plurality of positions during a controlled movement in translation. This member 15 is formed as a mobile fitting of a proportional electromagnet, in which the spatial positions thereof along the axis X are proportionally correlated with the magnitude of the electrical signal (for instance the magnitude of the current) supplied to the control electromagnet.

[0045] The rod-like member 15 is preferably recalled into a predetermined safety position when there is no control signal to the operating means. This safety device may be formed by decoupling means of electromagnetic type or by resilient return means depending on the embodiment chosen. In any case, the safety device is such as to recall the member 15 into a predetermined position irrespective of the operating condition reached by the operating means, when the control signal to the latter is discontinued or is, for instance, below a predetermined set threshold value.

[0046] With particular reference to Fig. 1, if there is no control signal to the operating means 14, the valve seat 7 is intercepted by the resilient action of the spring 17 which, opposing the resilient load of the spring 11, urges the plug 8 to close the seat 7. The springs 11, 17 are therefore dimensioned such that, in this condition, the resilient action of the spring 17 predominates over the resilient action of the spring 11 so as to ensure the closure of the plug 8.

[0047] From this condition (not shown), following the supply of a control signal to the operating means 14, the member 15 is moved away from the plug 8 such that the resilient load thereon generated by the spring 17 (Fig. 1) is gradually reduced and the pressure is therefore modulated in a proportional manner correlated to the ratio between the resultant of the resilient forces (springs 11, 17) and the surface of the diaphragm on which this resultant force acts.

[0048] Fig. 2a, in which similar components bear the same reference numerals as in Fig. 1, shows a variant of the valve unit 1 including the pressure regulator device 6 in which the resilient force acts on a second diaphragm in fluid communication with the first diaphragm.

[0049] Fig. 2b shows a further valve unit 1" for regulating the flow of gas, in which the flow regulator device 6' includes a plug 8 designed to close the valve seat 7 in a controlled manner. The movement of the plug is similar to that described with respect to the plug 8 of the unit 1 or 1' by means of the electromagnet 15.

[0050] As mentioned above, the operating means 14 is of proportional type and includes an electromagnet (not shown) to which a signal generated by a control circuit 100 (see Fig. 7) is supplied to determine the position of the rod-like member 15 and therefore the gas outlet pressure. The control circuit 100 for instance includes a microprocessor 101 which transmits a PWM voltage signal on the basis of data stored in a memory 102 internal or external to the microprocessor. The stored data in question comprise the proportionality relationship existing between the current I in the electromagnet and the outlet pressure P_u (or the outlet gas flow) and the relationship between the current in the electromagnet and the duty cycle of the PWM signal. Examples of these relationships are shown in the graphs of Figs. 6 to 9. Given the request for a predetermined pressure/rate of flow P_u by a burner supplied by the flow of gas output from the duct 2, the microprocessor 101 uses the graph of Fig. 6 (or a similar graph or tables which establish a relationship between P_u and I) to calculate the "mean" current which needs to be supplied to the electromagnet of the pressure regulator 6 so that the rod-like member 15 is in the necessary position to supply this pressure (as a result of the force developed by the magnetic field of the coil to which this current is supplied). When this current value is given, again by means of appropriate data stored in a memory 103 (which may also be the memory 102), the microprocessor calculates the duty cycle of a PWM voltage signal by means of which this current is obtained. Fig. 9 shows an example of this correlation.

[0051] It will be appreciated that Fig. 6 and Fig. 9 are no more than possible examples of the correlation between the current and the outlet pressure and between the duty cycle of a PWM signal and the current that it generates in a solenoid. There may be other curves or correlations depending on the type of pressure regulator 6 used and on its particular construction parameters.

[0052] The microprocessor for transmitting this signal

includes a PWM signal generator 105 which is controlled to transmit a PWM voltage signal having the duty cycle determined by means of the data stored in the memory 102 and in the memory 103 as described above.

[0053] This signal is supplied to the base of a transistor 107 connected to the solenoid of the electromagnet. The transistor is activated and de-activated by the voltage signal transmitted by the PWM signal generator 105 and therefore applies a current to the solenoid.

[0054] The operation of this pressure regulator device 6 is detailed below. In a first embodiment not belonging to the present invention, once a specific gas outlet pressure has been requested, the duty cycle of the signal transmitted by the PWM generator is such that the current generated has a magnitude such as to obtain that pressure. Moreover, the frequency of the PWM signal transmitted by the PWM signal generator 105 is within the "dither frequency range of the PWM signal" (signal of the type shown in Fig. 4a), i.e. it is such that the current signal to the solenoid from the transistor is not constant but has a ripple, as is illustrated in Fig. 4b. The rod-like member 15 is therefore subject to a mechanical dither. The ripple is selected (by appropriately selecting the frequency of the PWM signal) such that it generates an optimum mechanical dither.

[0055] When the required outlet pressure P_u changes, for instance because hot water from the domestic water circuit or a greater/lower ambient temperature has been requested, a different current signal is needed. The microprocessor 101, using the data shown by way of example in Fig. 6, calculates the new value of this current and, from the data shown in Fig. 9, the corresponding new duty cycle of the PWM signal which has to be transmitted by the generator 105, such that the amplitude of the mechanical dither is kept constant, and at the same time the frequency of the PWM signal is also modified for that purpose. The second PWM signal transmitted by the generator 105 to the base of the transistor 107 therefore has a new duty cycle corresponding to the required duty cycle - and obtained from the stored data - in order to obtain a specified mean magnitude of the current and also has a frequency such that the amplitude of the dither signal caused by this new signal with the new duty cycle is equal to the amplitude of the dither signal which was obtained previously by the first PWM signal before the change of duty cycle, i.e. in order to keep the mechanical dither constant.

[0056] This modification of the duty cycle and frequency, obtained by appropriate means for regulating the duty cycle 108 and means for regulating the frequency 109 of the PWM signal included in the control circuit 100 (for instance directly within the PWM signal generator 105), is carried out each time that a variation (upwards or downwards) of the outlet gas pressure is requested. The amplitude of the dither signal thus remains unchanged irrespective of the duty cycle of the PWM signal.

[0057] According to a second embodiment belonging to the invention, the control circuit 100 further includes a

timer 110 which serves the following purpose. During the normal operation of the pressure regulator 6, when a specified pressure/rate of flow of the gas has been selected, as in the preceding embodiment, the microprocessor 101 of the regulation circuit 100, using the data stored in the memories 102, 103, selects the corresponding current in the electromagnet to obtain this P_u . This is followed by the selection of the duty cycle of the PWM signal, now called the first PWM signal, which determines this current, but - in contrast to the preceding embodiment - the frequency of this signal is "high", i.e. such that no ripple is formed in the current signal and therefore no mechanical dithering phenomenon is obtained. An example of this signal is illustrated in Figs. 5a and 5b, i.e. a substantially constant current signal.

[0058] When, however, a change of gas outlet pressure is required, the timer 110, in which a predetermined time interval T_1 is stored (this value T_1 may also be stored at another location accessible to the timer), starts to measure the passage of time from the request for the change of P_u and the microprocessor 101 also transmits a control signal to the PWM signal generator such that it generates a separate PWM signal with the same duty cycle as before, i.e. keeping substantially the same current in the electromagnet, but with a lower frequency, such that there is a return to the "dither frequency range of the PWM signal" as a result of which a ripple is formed in the current signal as shown in Fig. 4b. This new "transient" signal is supplied to the electromagnet for a predetermined time T_1 as measured by the timer 110, at the end of which the generator 105 generates a new second transient PWM signal having the duty cycle required to obtain the second outlet pressure. However, the frequency of this second transient PWM signal is still within the "dither frequency range of the PWM signal" and, moreover, this frequency is such that the amplitude of the mechanical dither is substantially identical to the amplitude of the dither obtained by the first transient signal prior to modification of the duty cycle. This second transient signal is supplied to the electromagnet for a time T_2 , preferably where $T_2 = T_1$, at the end of which the generator 105 generates a second PWM signal which maintains the same duty cycle of the second transient signal, but at different frequency: the frequency variation means change the frequency of the second transient signal until it is brought to a high frequency regime such that the ripple in the current signal, and therefore the mechanical dither, disappears.

[0059] Figs. 8a, 8b and 8c show an example of these transients. Fig. 8a shows the current signal as generated by a PWM voltage signal whose duty cycle and whose frequency are shown by the graphs of Figs. 8c and 8b. The current signal includes a stepped course. At each step, the value of the current is substantially constant; however, at the time ends of each step, i.e. at the beginning and end of each substantially constant current magnitude interval, for a brief section, of time T_1 and T_2 at the end and the beginning respectively, a ripple signal

which generates the mechanical dither is present. This type of course of the current signal is obtained, with reference now to the course of the signal 8b, by maintaining the duty cycle of the PWM signal generating this voltage signal constant for the entire length of each individual step, and varying the duty cycle from one step to the next. This duty cycle variation generates the jump from one step to the next. In the transient periods, i.e. around the "jump" from one step to the next, corresponding to the times T1 and T2, the frequency is varied as shown in Fig. 8c. The frequency in the periods of constant current magnitude also remains constant, but is varied at the transient moments, and in particular lowered, in order to enter the ripple formation regime.

[0060] In this way, the advantages of the presence of the mechanical dither are exploited in order to minimize problems of hysteresis, but its presence is limited to the outlet pressure changes required in order also to minimize mechanical wear. In addition, in this case as well, the amplitude of the dither is fixed and constant irrespective of the duty cycle of the PWM signal and optimized for the particular type of device involved.

[0061] This method is also shown in the block diagram of Fig. 9.

[0062] The control signal supplied to the electromagnet of the device 6 is generated as follows: it is initially ascertained whether the actual current differs from the desired value and whether the difference in absolute values is greater than a predetermined threshold. If so, the frequency by means of which the desired mean current is obtained in the electromagnet is calculated (block B2). The values of the curves are stored, as mentioned above, in the memories 102, 103. This frequency is calculated by means, for instance, of the experimental curve shown in Fig. 10. Any other curve may be used, however, and the curve varies in practice depending on the valve unit in question.

[0063] Once the frequency is calculated in the block B3, the corresponding duty cycle is calculated, for instance by means of a PID controller. This PWM signal S2 is then generated and supplied to the electromagnet by appropriate means. The current circulating in the electromagnet is also measured - as a function of feedback - in block B4, and the value is supplied to the block B2 in order possibly to modify the frequency; the valve is therefore appropriately modulated at B5. As feedback to check whether the desired correct operation is taking place, a possible sensor measures, for instance, the actual gas outlet pressure in order to detect any anomalies (block B6).

[0064] If, however, the current difference is below the threshold, a predetermined time interval, T1 or T2 or both (block B7) starts to be calculated, in which the second PWM signal is included at a maximum frequency (block B8), again by means of a PID controller (block B9), for instance, and the two signals are therefore superimposed in order to actuate the valve.

Claims

1. A valve unit (1) for controlling the feed of a combustible gas to a burner apparatus, comprising:
 - a device (6) for regulating the pressure of the gas at the outlet of the unit (1), including a valve seat (7) associated with a plug (8), and an operating means (14) for causing the plug (8) to move relatively to the corresponding valve seat (7), to regulate the outlet feed pressure (Pu) by modulation, wherein the operating means (14) is of the type comprising at least one electromagnet of the proportional type;
 - a control circuit (100) of the pressure regulating device (6) including a PWM signal generator (105) generating a PWM voltage signal adapted to generate a current signal in the electromagnet in order to move the plug (8) as a function of the magnitude of the current signal and thus determine the outlet pressure (Pu), the magnitude of the current being a function of the duty cycle of the PWM signal; the PWM signal having a frequency such that the operating means (14) is subjected to a mechanical dither having a specified amplitude at least for a specified time interval (T1, T2);
 - **characterized in that** the PWM signal generator (105) includes means of controlling the duty cycle and means of controlling the frequency of the PWM signal, the duty cycle control means varying the duty cycle of the PWM signal with the variation of the desired outlet pressure (Pu), and the frequency control means being adapted to vary the frequency of the PWM signal as a function of the variation of the duty cycle so as to keep the amplitude of the dither substantially constant, independently from the variations of the duty cycle of the PWM signal;
 - and **in that** the control circuit (100) includes a timer (110) which can access the value of a first and/or a second time interval (T1; T2) stored in the circuit (100), this timer being active in the first and/or second time interval before and/or after a request to change the outlet gas feed pressure, the frequency variation means being adapted to set the frequency of the first and/or second PWM signal within a range of frequencies capable of generating the dither only when the timer is active, and being adapted to set the frequency of the PWM signal above a frequency level at which the current signal in the electromagnet is substantially constant when the timer is inactive.
2. A valve unit according to claim 1, wherein the plug is a plug (8) controlled by a diaphragm (10), the diaphragm being subjected on one side to the pressure

regulated by the regulating device (6) and on the other side to a predetermined load, and including, in association with the plug (8) of the pressure regulating device (6), a means (17; 24) for returning the plug (8) towards a position in which it closes the corresponding valve seat (7), the operating means (14) causing the plug (8) to move relative to the corresponding valve seat (7) in opposition to these return means.

3. A valve unit according to claim 1 or 2, including a microprocessor (101) comprising the means of generating a PWM signal (105).

4. A method for controlling the supply of a combustible gas to a burner by a valve unit (1) including a device (6) for regulating the outlet gas pressure, including a valve seat (7) associated with a plug (8), and an operating means (14) for causing the plug (8) to move relative to the corresponding valve seat (7), in order to regulate the outlet feed pressure (Pu) by modulation, wherein the operating means (14) is of the type comprising at least one electromagnet of the proportional type, the method including the following steps:

- o determining a first outlet gas feed pressure (Pu);
- o generating a first PWM voltage signal in such a way as to generate a current signal in the electromagnet in order to move the plug (8) as a function of the magnitude of the current signal and thus obtain the first outlet pressure (Pu), the following steps being required for the generation of this signal:

- setting the duty cycle of the first PWM signal on the basis of stored data in order to provide the required magnitude of the current signal to obtain the first outlet pressure (Pu);
- setting the frequency of the first PWM signal in a range of frequencies such that the operating means (14) is subjected to a mechanical dither having a specified amplitude for at least a specified time interval (T1, T2);

- o determining a second outlet gas pressure (Pu);
- o modifying the duty cycle of the first PWM signal in order to vary the magnitude of the current signal sent to the electromagnet to obtain the second outlet pressure;
- o **characterized in that** it further comprises the step of modifying the frequency of the first PWM signal as a function of the variation of the duty cycle in order to keep the amplitude of the dither substantially constant independently from the

variations of the duty cycle of the PWM signal, thus generating a second PWM signal with the modified frequency and duty cycle;

- o and **in that** it further comprises the step of sending the first PWM signal to the electromagnet for a time interval T1 preceding the modification of the duty cycle and/or sending the second PWM signal to the electromagnet for a time interval T2 following the modification of the duty cycle.

5. A method according to claim 4, including the step of:

- generating a third PWM signal in a time interval outside the time interval T1, with a duty cycle substantially equal to the duty cycle of the first PWM signal, and at a frequency above the frequency of the first PWM signal, in order to generate a substantially constant current signal in the electromagnet.

6. A method according to claim 5, including the step of:

- generating a fourth PWM signal in a time interval outside the time interval T2, with a duty cycle substantially equal to the duty cycle of the second PWM signal, and at a frequency above the frequency of the second PWM signal, in order to generate a substantially constant current signal in the electromagnet.

7. A method according to any one of claims 4 to 6, wherein $T1 = T2$.

Patentansprüche

1. Ventileinheit (1) zum Steuern der Zufuhr eines Brenngases zu einer Brennvorrichtung, umfassend:

- eine Vorrichtung (6) zum Regulieren des Drucks des Gases am Auslass der Einheit (1) mit einem Ventilsitz (7), der mit einem Stecker (8) in Verbindung ist, und eine Betätigungseinrichtung (14), die bewirkt, dass sich der Stecker (8) relativ zum entsprechenden Ventilsitz (7) bewegt, um den Auslass-Zufuhrdruck (Pu) durch eine Modulation zu regulieren, wobei die Betätigungseinrichtung (14) ein Typ ist, der zumindest einen Proportionaltyp-Elektromagneten aufweist;
- einen Regelkreis (100) der Druckregulierungsvorrichtung (6) mit einem PWM-SignalGenerator (105), der ein PWM-Spannungssignal erzeugt, das angepasst ist, um ein Stromsignal im Elektromagneten zu erzeugen, um den Stecker (8) als Funktion der Größenordnung des Stromsig-

nals zu bewegen und so den Auslassdruck (P_u) zu bestimmen, wobei die Größenordnung des Stroms eine Funktion der Einschaltdauer des PWM-Signals ist; wobei das PWM-Signal eine Frequenz aufweist, so dass die Betätigungseinrichtung (14) einer mechanischen Schwankung mit einer bestimmten Amplitude, zumindest für ein bestimmtes Zeitintervall (T_1 , T_2), unterzogen wird;

- **dadurch gekennzeichnet, dass**

- der PWM-Signalgenerator (105) eine Einrichtung zum Steuern der Einschaltdauer und eine Einrichtung zum Steuern der Frequenz des PWM-Signals umfasst, wobei die Einschaltdauer-Steuereinrichtung die Einschaltdauer des PWM-Signals mit der Änderung des gewünschten Auslassdrucks (P_u) verändert, und die Frequenz-Steuereinrichtung angepasst wird, um die Frequenz des PWM-Signals als Funktion der Änderung der Einschaltdauer zu verändern, um so die Amplitude der Schwankung im Wesentlichen, unabhängig von den Änderungen der Einschaltdauer des PWM-Signals, konstant zu halten;

- und dadurch, dass der Regelkreis (100) einen Timer (110) umfasst, der auf den Wert eines ersten und/oder eines zweiten Zeitintervalls (T_1 ; T_2), die im Regelkreis (100) gespeichert sind, zugreifen kann, wobei dieser Timer im ersten und/oder zweiten Zeitintervall vor und/oder nach einer Anforderung zum Ändern des Auslass-Gaszufuhrdrucks aktiv ist, wobei die Frequenz-Änderungseinrichtung angepasst ist, um die Frequenz des ersten und/oder des zweiten PWM-Signals innerhalb eines Bereichs von Frequenzen festzulegen, die die Schwankung nur erzeugen können, wenn der Timer aktiv ist, und angepasst ist, um die Frequenz des PWM-Signals oberhalb eines Frequenzniveaus festzulegen, bei dem das Stromsignal im Elektromagneten im Wesentlichen konstant ist, wenn der Timer nicht aktiv ist.

2. Ventileinheit gemäß Anspruch 1, wobei der Stecker ein Stecker (8) ist, der durch eine Membran (10) gesteuert wird, wobei die Membran auf einer Seite dem Druck, der durch die Reguliervorrichtung (6) reguliert wird, und auf der anderen Seite einer vorbestimmten Last unterzogen wird, und in Verbindung mit dem Stecker (8) der Druckreguliervorrichtung (6) eine Einrichtung (17; 24) zur Rückkehr des Steckers (8) an eine Position, an der sie den entsprechenden Ventilsitz (7) schließt, umfasst, wobei die Betätigungseinrichtung (14) bewirkt, dass sich der Stecker (8) relativ zum entsprechenden Ventilsitz (7) entgegen diesen Rückkehreinrichtungen bewegt.

3. Ventileinheit gemäß Anspruch 1 oder 2 mit einem

Mikroprozessor (101), der die Einrichtung zum Erzeugen eines PWM-Signals (105) aufweist.

4. Verfahren zum Steuern der Zufuhr eines brennbaren Gases zu einem Brenner durch eine Ventileinheit (1) mit einer Vorrichtung (6) zum Regulieren des Auslass-Gasdrucks, mit einem Ventilsitz (7), der mit einem Stecker (8) in Verbindung ist, und mit einer Betätigungseinrichtung (14) zum Bewirken, dass sich der Stecker (8) relativ zum entsprechenden Ventilsitz (7) bewegt, um den Auslass-Zufuhrdruck (P_u) durch eine Modulation zu regulieren, wobei die Betätigungseinrichtung (14) der Typ ist, der zumindest einen Proportionaltyp-Elektromagneten aufweist, wobei das Verfahren die folgenden Schritte umfasst:

- Bestimmen eines ersten Auslass-Gaszufuhrdrucks (P_u);

- Erzeugen eines ersten PWM-Spannungssignals in der Weise, um ein Stromsignal im Elektromagneten zu erzeugen, um den Stecker (8) als Funktion der Größenordnung des Stromsignals zu bewegen und um damit den ersten Auslassdruck (P_u) zu erhalten, wobei die folgenden Schritte zur Erzeugung dieses Signals erforderlich sind:

- Festlegen der Einschaltdauer des ersten PWM-Signals auf der Basis der gespeicherten Daten, um die erforderliche Größenordnung des Stromsignals vorzusehen, um den ersten Auslassdruck (P_u) zu erhalten;

- Festlegen der Frequenz des ersten PWM-Signal in einem Bereich von Frequenzen, so dass die Betätigungseinrichtung einer mechanischen Schwankung mit einer bestimmten Amplitude für zumindest ein bestimmtes Zeitintervall (T_1 , T_2) unterzogen wird;

- Bestimmen eines zweiten Auslass-Gasdrucks (P_u);

- Modifizieren der Einschaltdauer des ersten PWM-Signals, um die Größenordnung des Stromsignals zu verändern, das zum Elektromagneten gesandt wird, um den zweiten Auslassdruck zu erhalten;

- **dadurch gekennzeichnet, dass** es ferner den Schritt zum Modifizieren der Frequenz des ersten PWM-Signals als Funktion der Änderung der Einschaltdauer aufweist, um die Amplitude der Schwankung im Wesentlichen, unabhängig von den Änderungen der Einschaltdauer des PWM-Signals, konstant zu halten, wodurch ein zweites PWM-Signal mit der modifizierten Frequenz und Einschaltdauer erzeugt wird;

- und dadurch, dass es ferner den Schritt zum Senden des ersten PWM-Signals zum Elektromagneten für ein Zeitintervall (T_1), dass der Modifikation der Einschaltdauer vorausgegangen ist, und/oder Senden des zweiten PWM-Signals

zum Elektromagneten für ein Zeitintervall (T2), das der Modifikation der Einschaltdauer folgt, aufweist.

5. Verfahren gemäß Anspruch 4, das den Schritt umfasst zum:

- Erzeugen eines dritten PWM-Signals in einem Zeitintervall, das außerhalb des Zeitintervalls T1 liegt, mit einer Einschaltdauer, die im Wesentlichen gleich der Einschaltdauer des ersten PWM-Signals ist, und mit einer Frequenz oberhalb der Frequenz des ersten PWM-Signals, um ein im Wesentlichen konstantes Stromsignal im Elektromagneten zu erzeugen.

6. Verfahren gemäß Anspruch 5, das den Schritt umfasst zum:

- Erzeugen eines vierten PWM-Signals in einem Zeitintervall, das außerhalb des Zeitintervalls T2 liegt, mit einer Einschaltdauer, die im Wesentlichen gleich der Einschaltdauer des zweiten PWM-Signals ist, und mit einer Frequenz oberhalb der Frequenz des zweiten PWM-Signals, um ein im Wesentlichen konstantes Stromsignal im Elektromagneten zu erzeugen.

7. Verfahren gemäß einem der Ansprüche 4 bis 6, wobei T1 = T2 ist.

Revendications

1. Unité de vanne (1) pour commander l'alimentation en gaz combustible d'un appareil brûleur, comprenant :

◦ un dispositif (6) de régulation de pression de gaz à la sortie de l'unité (1), comprenant un siège de vanne (7) associé à un bouchon (8), et un moyen de fonctionnement (14) pour provoquer un déplacement du bouchon (8) relatif au siège de vanne (7) correspondant, de manière à réguler la pression d'alimentation de sortie (Pu) par modulation, dans lequel le moyen de fonctionnement (14) est du type comprenant au moins un électroaimant de type proportionnel ;
 ◦ un circuit de commande (100) du dispositif de régulation de pression (6) comportant un générateur de signal PWM (modulation d'impulsions en largeur, en anglais « Pulse Width Modulation ») (105) générant un signal de tension PWM adapté pour générer un signal de courant dans l'électroaimant afin de déplacer le bouchon (8) en fonction de la magnitude du signal de courant et déterminer ainsi la pression de sortie (Pu), la magnitude du courant étant

une fonction du rapport cyclique du signal PWM ; le signal PWM possédant une fréquence de sorte que le moyen de fonctionnement (14) soit soumis à une vacillation mécanique possédant une amplitude spécifiée au moins pour un intervalle de temps spécifié (T1, T2) ;

◦ **caractérisé en ce que** le générateur de signal PWM (105) comporte des moyens de commande du rapport cyclique et des moyens de commande de la fréquence du signal PWM, les moyens de commande du rapport cyclique faisant varier le rapport cyclique du signal PWM avec la variation de la pression de sortie (Pu) souhaitée, et les moyens de commande de la fréquence étant adaptés pour faire varier la fréquence du signal en fonction de la variation du rapport cyclique pour maintenir l'amplitude de vacillation sensiblement constante, indépendamment des variations du rapport cyclique du signal PWM ;

◦ et **en ce que** le circuit de commande (100) comporte un chronomètre (110) pouvant accéder à la valeur d'un premier et/ou un deuxième intervalle de temps (T1 ; T2) enregistré(s) dans le circuit (100), ce chronomètre étant actif dans le premier et/ou deuxième intervalle de temps avant et/ou après une demande de modification de la pression d'alimentation en gaz de sortie, les moyens de variation de fréquence étant adaptés pour régler la fréquence du premier et/ou deuxième signal PWM au sein d'une gamme de fréquences pouvant générer la vacillation seulement lorsque le chronomètre est actif, et étant adaptés pour régler la fréquence du signal PWM pour qu'elle soit supérieure à un niveau de fréquence auquel le signal de courant dans l'électroaimant est sensiblement constant lorsque le chronomètre est inactif.

2. Unité de vanne selon la revendication 1, dans lequel le bouchon est un bouchon (8) commandé par un diaphragme (110), le diaphragme étant soumis sur un côté à la pression régulée par ledit dispositif de régulation (6) et sur l'autre côté à une charge prédéterminée, et comportant, en association avec le bouchon (8) du dispositif de régulation de pression (6), un moyen (17 ; 24) de retour du bouchon (8) vers une position dans laquelle il ferme le siège (7) correspondant, le moyen de fonctionnement (14) provoquant un déplacement du bouchon relatif au siège (7) correspondant dans le sens contraire de ces moyens de retour.

3. Unité de vanne selon la revendication 1, comportant un microprocesseur (101) comprenant les moyens de génération d'un signal PWM (105).

4. Procédé de commande de l'alimentation d'un brû-

leur en gaz combustible par une unité de vanne (1) comportant un dispositif (6) de régulation de pression de gaz de sortie, comportant un siège de vanne (7) associé à un bouchon (8), et un moyen de fonctionnement (14) pour provoquer un déplacement du bouchon (8) relatif au siège de vanne (7) correspondant, de manière à réguler la pression d'alimentation de sortie (Pu) par modulation, dans lequel le moyen de fonctionnement (14) est du type comprenant au moins un électroaimant de type proportionnel, le procédé comportant les étapes suivantes :

- la détermination d'une première pression d'alimentation en gaz de sortie (Pu) ;
- la génération d'un premier signal de tension PWM de sorte à générer un signal de courant dans l'électroaimant de manière à déplacer le bouchon (8) en fonction de la magnitude du signal de courant et obtenir ainsi la première pression de sortie (Pu), les étapes suivantes étant nécessaires pour générer ce signal :

- le réglage du rapport cyclique du premier signal PWM à partir de données enregistrées de manière à fournir la magnitude du signal de courant nécessaire pour obtenir la première pression de sortie (Pu) ;
- le réglage de la fréquence du premier signal PWM dans une gamme de fréquences de sorte que le moyen de fonctionnement (14) soit soumis à une vacillation mécanique possédant une amplitude spécifiée pour au moins un intervalle de temps spécifié (T1, T2) ;

- la détermination d'une deuxième pression de gaz de sortie (Pu) ;
- la modification du rapport cyclique du premier signal PWM de manière à faire varier la magnitude du signal de courant transmis à l'électroaimant pour obtenir la deuxième pression de sortie ;

- **caractérisé en ce qu'il** comprend en outre l'étape de modification de la fréquence du premier signal PWM en fonction de la variation du rapport cyclique de manière à garder l'amplitude de vacillation sensiblement constante indépendamment des variations du rapport cyclique du signal PWM, générant ainsi un deuxième signal PWM avec la fréquence et le rapport cyclique modifiés ;

- **et en ce qu'il** comprend en outre une étape de transmission du premier signal PWM à l'électroaimant pour un intervalle de temps T1 précédant la modification du rapport cyclique et/ou la transmission du deuxième signal PWM à l'électroaimant pour un intervalle de temps T2 à la suite de la modification du rapport cyclique.

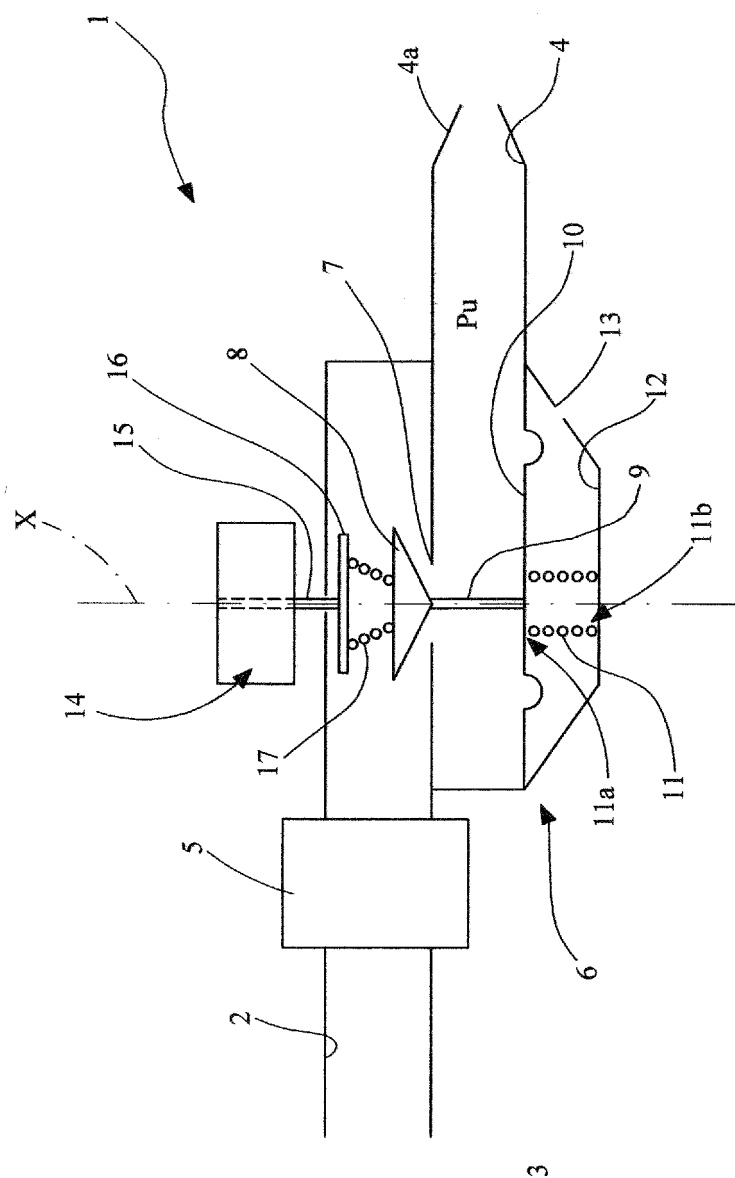
5. Procédé selon la revendication 4, comportant l'étape consistant à :

- générer un troisième signal PWM dans un intervalle de temps hors de l'intervalle de temps T1, avec un rapport cyclique sensiblement égal au rapport cyclique du premier signal PWM, et à une fréquence supérieure à la fréquence du premier signal PWM, de manière à générer un signal de courant sensiblement constant dans l'électroaimant.

6. Procédé selon la revendication 5, comportant l'étape consistant à :

- générer un quatrième signal PWM dans un intervalle de temps hors de l'intervalle de temps T2, avec un rapport cyclique sensiblement égal au rapport cyclique du deuxième signal PWM, et à une fréquence supérieure à la fréquence du deuxième signal PWM, de manière à générer un signal de courant sensiblement constant dans l'électroaimant.

7. Procédé selon l'une quelconque des revendications 4 à 6, dans lequel T1 = T2.



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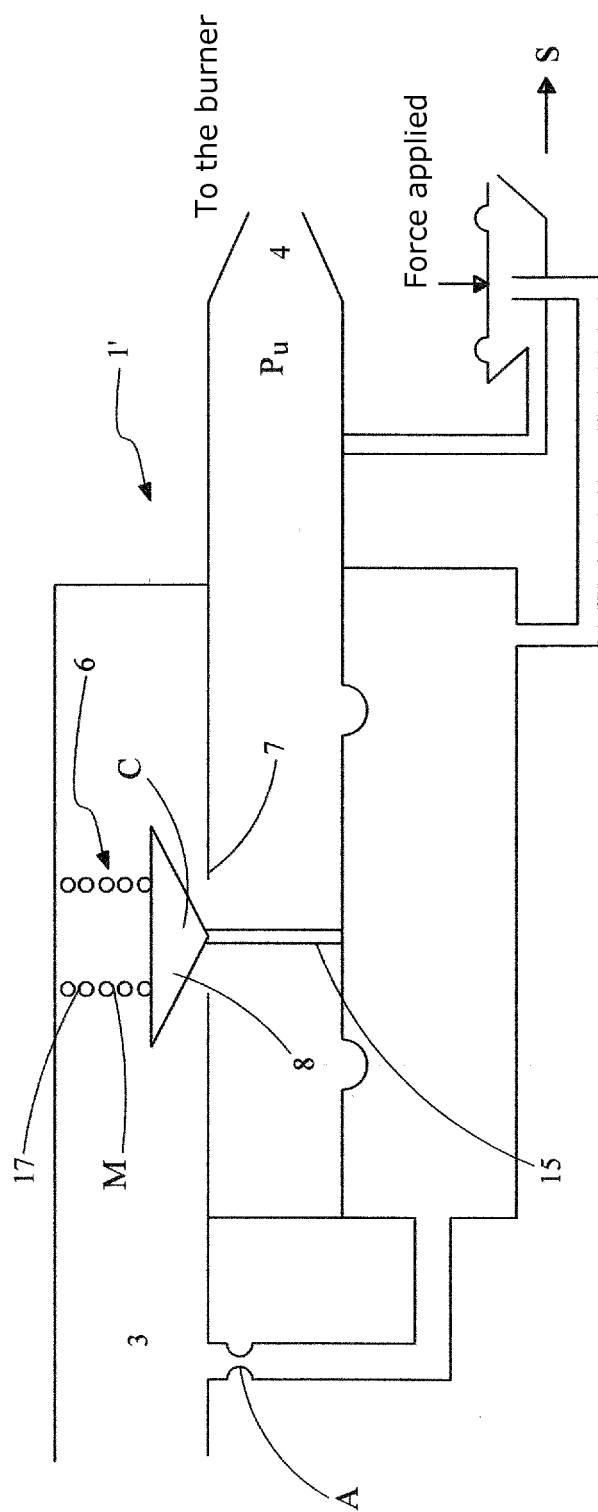


Fig. 2a

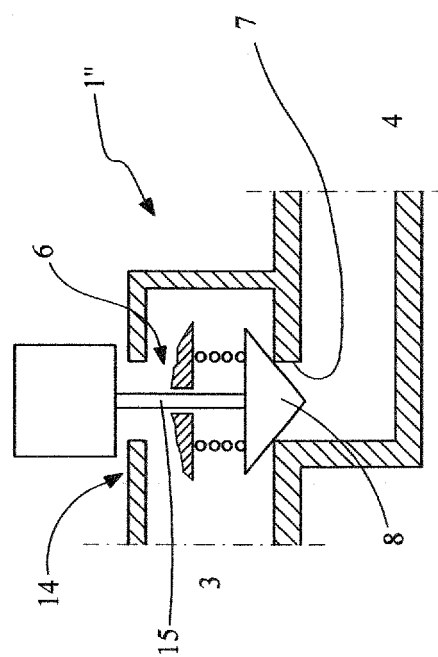


Fig. 2b

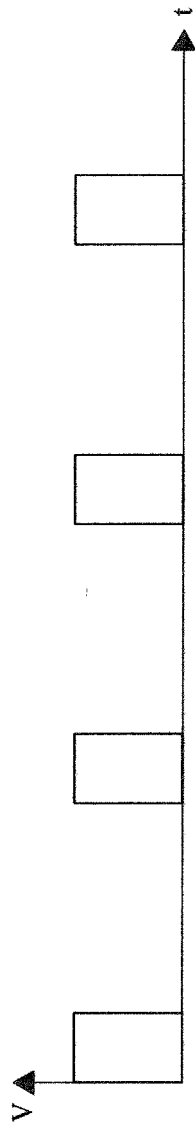


Fig. 3a

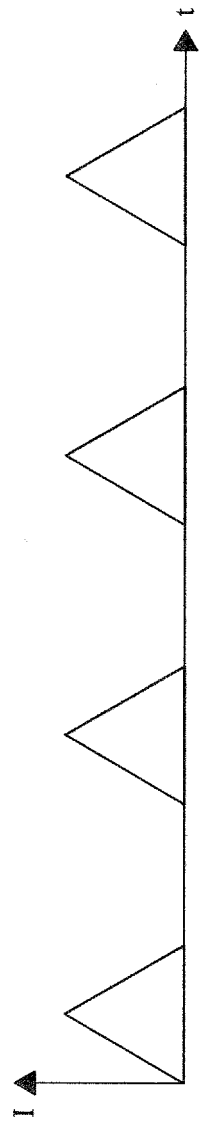


Fig. 3b

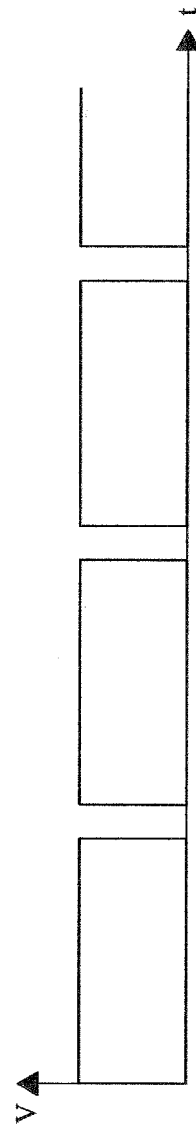


Fig. 4a

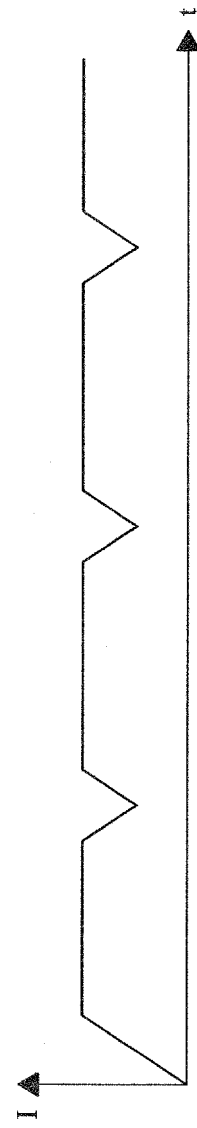
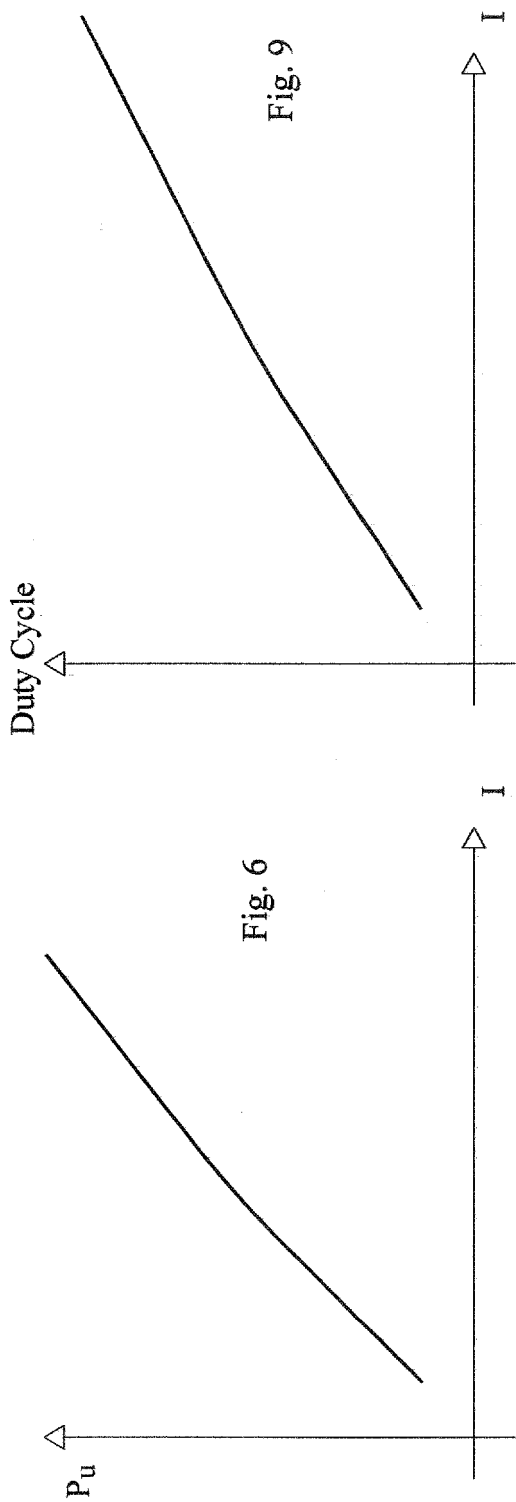
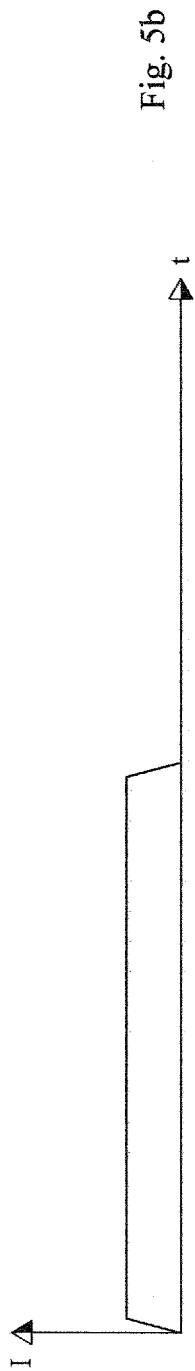
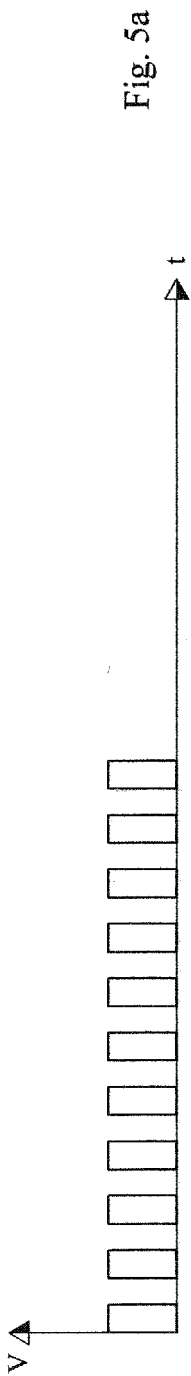


Fig. 4b



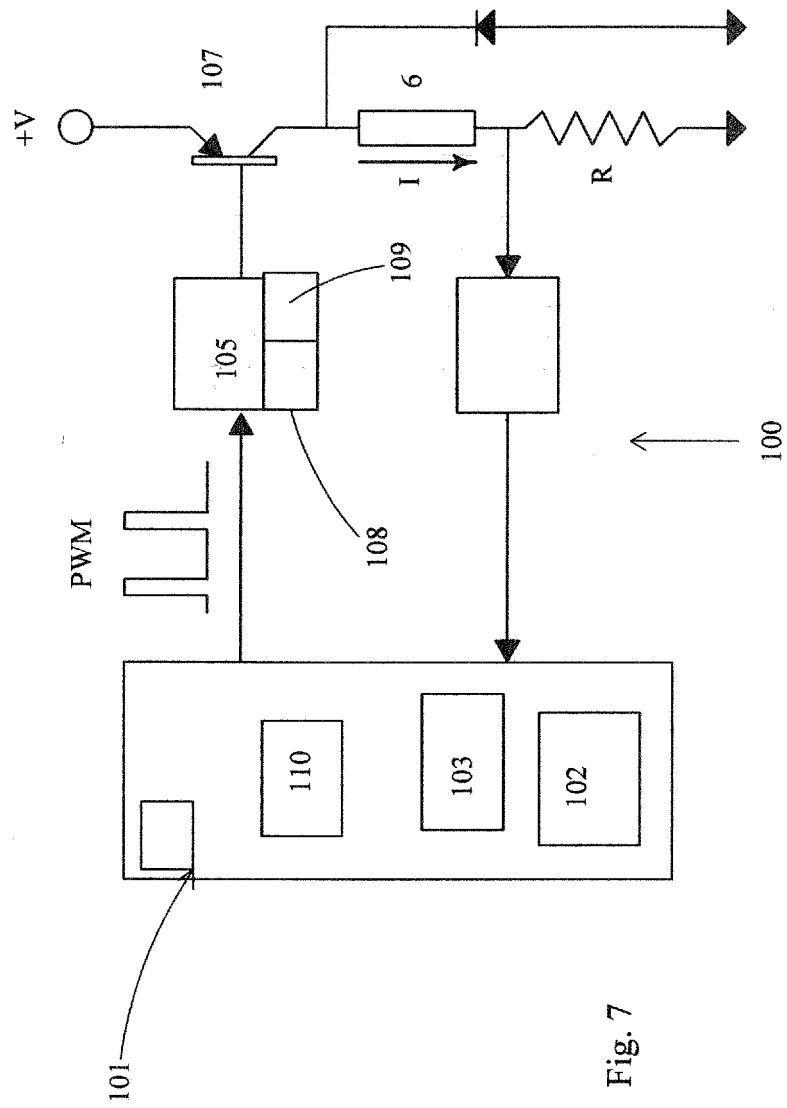


Fig. 7

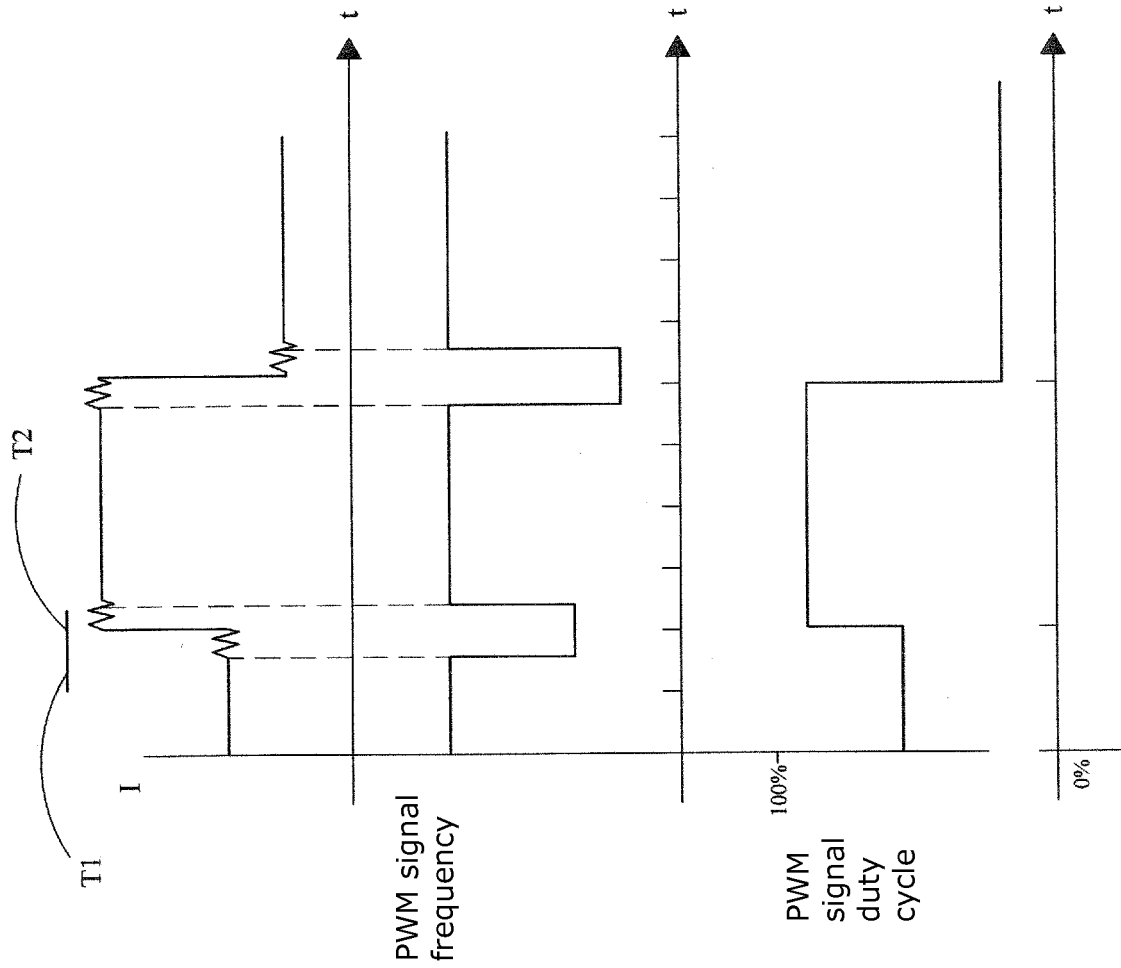


Fig. 8a

Fig. 8b

Fig. 8c

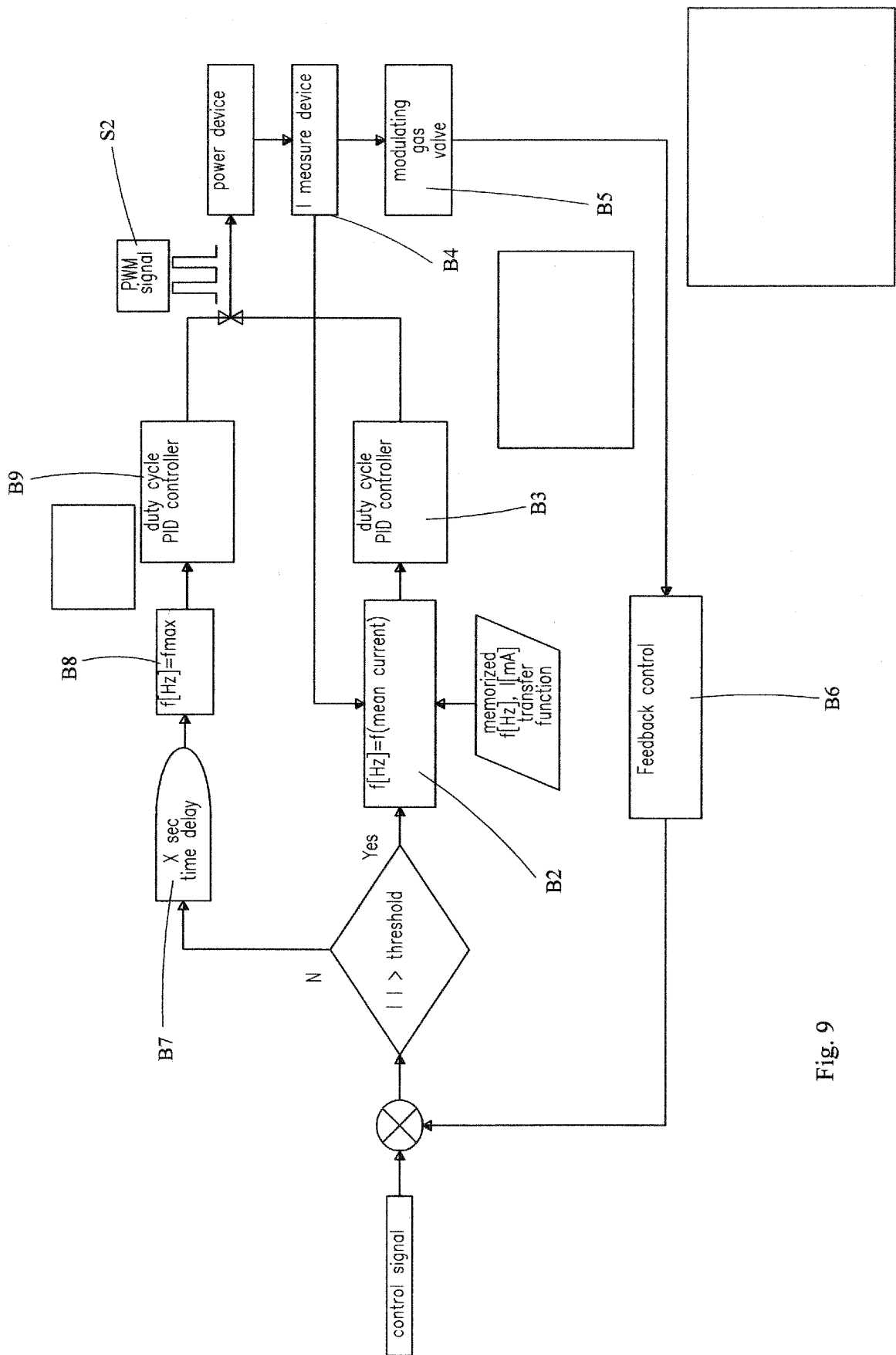


Fig. 9

845 modulator with return spring
PWM frequency as a function of current

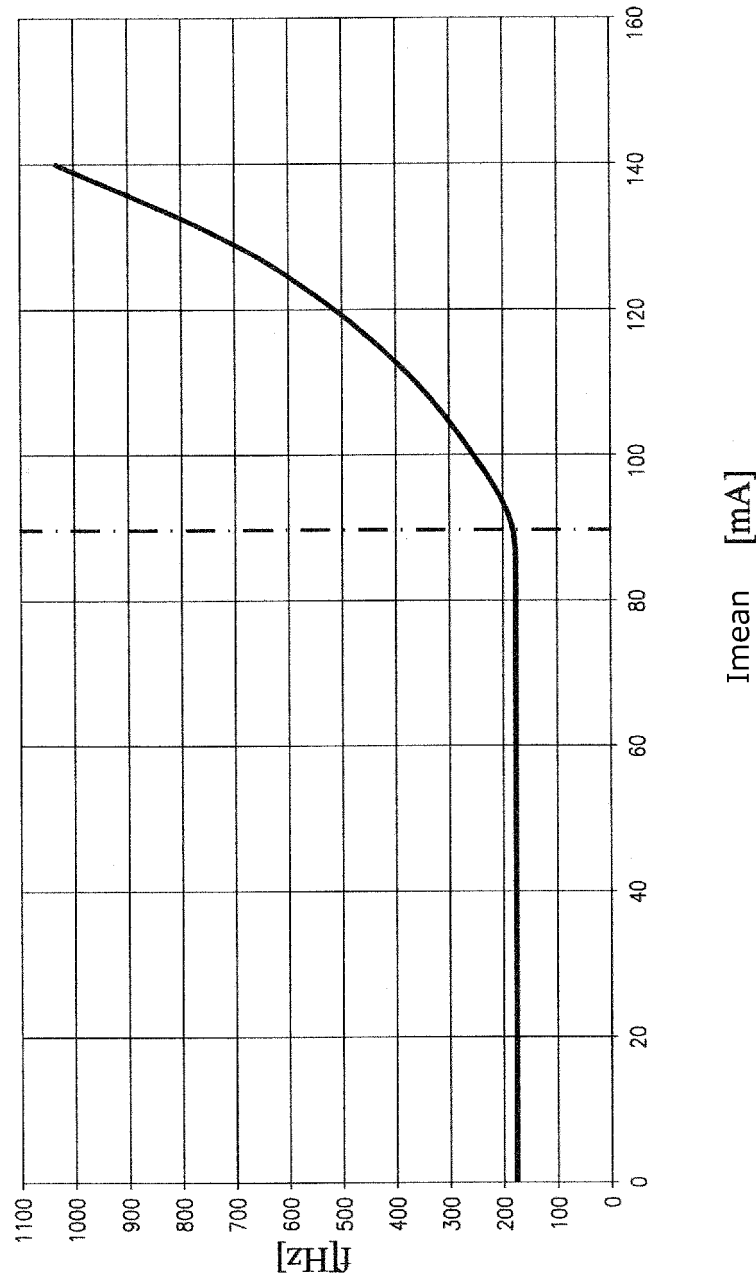


Fig. 10

REFERENCES CITED IN THE DESCRIPTION

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