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(54) **METHOD FOR IGNITING THE AIR-FUEL MIXTURE IN AN INTERNAL COMBUSTION ENGINE**

(57) A process for the ignition of the fuel-air mixture in an internal combustion engine is described, which includes stages of raising the intensity of the electrical field in the spark plug electrode gap until a spark passes across it, and, repeatedly, the stepped reduction of the electrical field intensity to a set level, maintaining this level of intensity for 2.5-25 µsec, inverting the direction of the electrical field, and raising the intensity of the electrical field in the spark plug electrode gap until a spark passes across it.

Also described is an ignition system using piezo-elements to implement the new process. The invention makes it possible to raise the degree of completeness of the fuel combustion and to improve the economy and ecological characteristics of the engine.

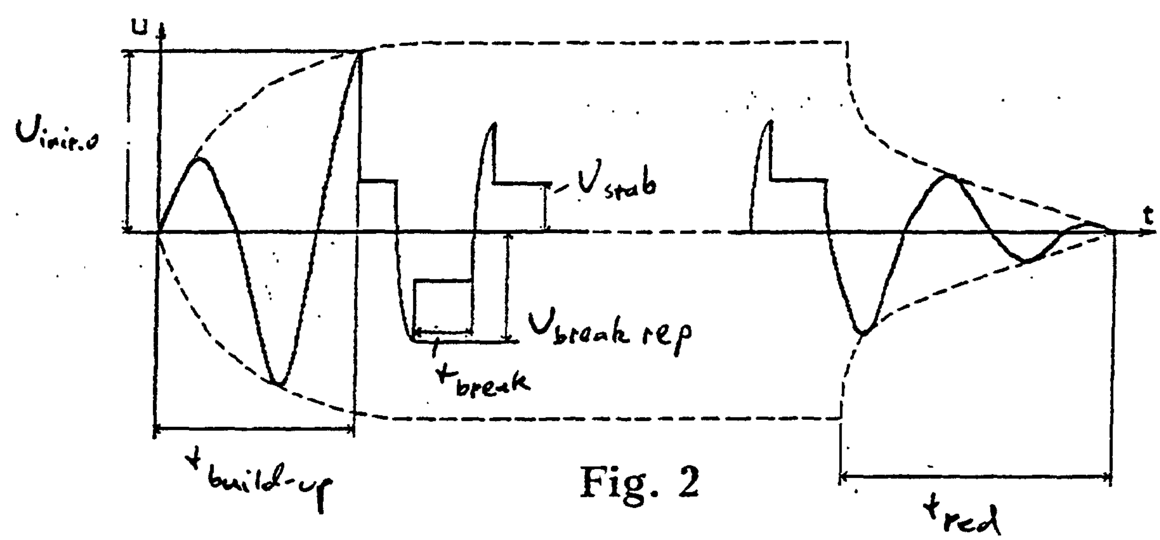

Fig. 2

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Description

Technology field

[0001] This invention relates to the technology of igniting fuel mixtures, more specifically to processes for ion-plasma combustion (ignition), providing an increase in volume in the initial combustion region (space ignition).

Prior art

[0002] There is a known process for the ignition of fuel-air mixture in an internal combustion engine (USSR Authorship Certificate No. 1464274), consisting of the preliminary combustion of a small quantity of fuel in a limited-volume cavity around the spark plug electrodes and the subsequent ejection of a plasma-flame jet through a small aperture in the plug into the combustion chamber.

[0003] This ignition process is energy-consuming. The design of the plug is complex and fuel consumption is increased.

[0004] There is a known process for the ignition of fuel-air mixture in an internal combustion engine, consisting of the action of an electric pulse on the fuel-air mixture in the plug electrode zone to decrease electric strength, after which the amplitude of the electric pulse is decreased and the mixture is ignited under the effect of the energy produced by the pulse. Fig. 1 shows the dependence of voltage at the spark plug electrodes obtained in implementing this process (Ross Tveg, Ignition systems for cars. - Moscow: "Za rulyom" Publishing House, 1998, fig. 2, page 5).

[0005] The problem with this process is the relatively low volume of ignition of the mixture and the presence of parasitic detonations, impairing the reliability of the ignition.

[0006] There is a known process for the ignition of fuel-air mixture in an internal combustion engine (USSR Authorship Certificate No. 1368936), consisting of creating a current-conducting medium containing charged particles between the spark plug electrodes, imparting directed motion to the charged particles to create a spark discharge and then igniting the fuel-air mixture. Space ignition in this process is created by increasing the number of charged particles in the combustion chamber by using an electron source with auto-electronic emission, containing a piezo-ceramic resonator and an Austin emitter.

[0007] This ignition process is ecologically cleaner, since the introduction of an additional quantity of charged particles into the combustion chamber improves the ignition process and the subsequent combustion of the mixture in the engine cylinder is more complete. The presence of additional charged particles improves conditions for the combustion of the mixture in the cylinder, which reduces the quantity of toxic substances and decreases the amount of energy consumed by the process.

[0008] The problem with this process is the relatively low volume of initial combustion, which increases toxicity and reduces ignition efficiency.

Substance of the invention

[0009] The main problem to be solved by this invention is the creation of a process and system for the ignition of fuel-air mixture which provide improved economy and reduced toxicity by a more uniform ignition process and more complete combustion of the fuel-air mixture.

[0010] In accordance with this invention, the fuel-air mixture ignition process comprises the following successively implemented stages:

(a) increasing the intensity of the electrical field in the spark plug electrode gap until an electric spark passes across it;
(b) decreasing the intensity of the electrical field in steps to a set level;
(c) fixing (maintaining) this level of intensity for 2.5-25 μsec until high-frequency radiation appears in the plug electrode gap;
(d) inverting the direction of the electrical field;
(e) increasing the intensity of the electrical field in the plug electrode gap until an electric spark passes across it;
(f) decreasing the intensity of the electrical field in steps to a set level;
(g) fixing (maintaining) this level of intensity for 2.5-25 μsec until high-frequency radiation appears in the plug electrode gap;
(h) taking the electrical field away from the spark plug.

[0011] It is advisable to repeat stages (d) to (g) several times until the fuel-air mixture ignition cycle is complete.

[0012] Stage (a) is implemented in an alternating electrical field, using a harmonic alternating field with the duration of each half-wave in turn greater than the preceding one.

[0013] The electrical field is taken away gradually, using an alternating electrical field.

[0014] The solution of the problem is also achieved by the fact that the current in the spark plug electrode gap is fixed at stages (b) and (f).

[0015] The gradual increase in the intensity of the electrical field at stage (a) over several hundred microseconds enables a sufficient concentration of free radicals to form in the spark plug electrode gap, which makes it easier for a discharge to take place between the spark plug electrodes and makes it more stable.

[0016] The stepped (by nanosecond units) reduction in the intensity of the electrical field to a set level determined by the minimum current magnitude in the electrode gap, and the subsequent fixing of this level, enable the current in the spark plug electrode gap to be maintained at not less than a certain magnitude, and the fuel-air mixture to flow into the region bounded by the spark plug electrode gap from the peripheral regions of the combustion chamber to support the discharge for 2.5-25 μsec.

[0017] The stepped inversion of the electrical field, with the subsequent stepped rise (in steps of the order of one microsecond) in the intensity of the electrical field to spark-over level and the stepped reduction in intensity to the set level at which it was fixed, alters the gradient of concentration of free radicals in the spark plug electrode gap, improving conditions for the combustion of the fuel-air mixture between the spark plug electrodes and making the combustion process virtually continuous.

[0018] The multiple repetition of stages (d) to (g) (a hundred times or more) over the whole ignition cycle makes it possible to burn the fuel-air mixture more efficiently and to raise the efficiency of the engine and its ecological characteristics by increasing the duration of the continuous discharge by a factor of two or more.

[0019] The use of an alternating electrical field at stage (a) generates free radicals in the spark plug electrode gap. Due to the alternation of the electrical field, the radicals are injected into the combustion chamber, thus ensuring more efficient ignition of the fuel-air mixture due to a reduction in the activation energy. Increasing the duration of each of the half-waves of the harmonic electrical field in succession at stage (a) makes it possible to generate the free radicals and inject them into the combustion chamber with greater efficiency.

[0020] The gradual reduction in the intensity of the electrical field at the end of the ignition cycle (combustion completion stage) makes it possible to prolong the period of existence of the free radicals in the spark plug electrode gap and to ensure the more complete combustion of the fuel-air mixture. The alternating nature of the electrical field at this stage enables more free radicals to be injected into the combustion chamber and provides more efficient completion of the combustion of the fuel-air mixture.

[0021] The fixing of the current in the spark plug electrode gap enables the process of combustion of the fuel air mixture to be stabilised if its parameters and combustion conditions change.

[0022] The high-frequency radiation occurring in the spark plug electrode gap at stages (c) and (g) is due to the thermodynamic instability caused by the presence of a gradient of concentration of positively and negatively charged free radicals, creating screened regions close to the spark plug electrodes, thus preventing the combustion process. The fixing of the set level of intensity before the moment when high-frequency radiation occurs with subsequent stepped inversion of the electrical field alters the gradient of concentration of the free radicals and thus stops the high-frequency radiation, so that the screened regions created by the, three-dimensional discharge close to the spark plug electrodes can be eliminated.

[0023] The fuel-air mixture ignition system in accordance with this invention includes a generator with switching-on and switching-off input and a piezo-transformer, with its input connected to the output of the said generator. Unlike known ignition systems, it contains a reorientation resonator, combined in the design with a piezo-transformer, and forming with it a single piezo-element, the output of which is connected to the spark plug electrode. In accordance with the invention, the generator of the ignition system may also contain a synchronisation input and a discharge current control input, in which case the system has two feedbacks from the piezo-element to the generator, one of which is connected to the said synchronisation input and the other to the said discharge current control input.

[0024] The inclusion in the ignition system of a reorientation resonator combined in the design with the piezo-transformer and forming with it a single piezo-element enables an internal feedback to be created in the piezo-element to bring about the inversion of its output signal when high-frequency radiation occurs in the spark plug ignition gap.

[0025] The introduction of two feedbacks from the piezo-element to the generator, one of which is connected to the synchronisation input and the other to the discharge current control input, makes it possible to synchronise the frequency of the generator with the moments of inversion of the output signal of the piezo-element and to fix the current in the spark plug electrode gap.

Description of drawings

[0026] Fig, 1 shows the dependence of the voltage at the spark plug electrodes in the known process.

[0027] Fig. 2 is a time diagram, illustrating the proposed process in accordance with the invention.

[0028] Fig. 3 is a block diagram of the ignition system in accordance with this invention.

[0029] Fig. 4 shows graphs of the controlling pulse voltages and the excitation voltage.

[0030] Fig. 5 shows another variant of block diagram of the ignition system in accordance with this invention.

Examples of the implementation of the invention

[0031] Let us consider Fig. 2, showing: U - axis of voltage between spark plug electrodes; t - time; $U_{init.o}$ - initial spark-over voltage; $U_{break\ rep}$ - repeat spark-over voltage; U_{stab} - stabilisation voltage; $t_{build\text{-}up}$ - duration of gradual build-up of intensity of electrical field; t_{red} - duration of gradual reduction in intensity of electrical field.

[0032] Up to the moment when spark-over occurs, for time $t_{build\text{-}up,}$ the intensity of the field in the spark plug electrode gap steadily increases to $U_{init.o,}$ this being an alternating electrical field. The intensity of the electrical field is then reduced in steps to the set level U_{stab} and this level is fixed. After the occurrence of high-frequency radiation in the spark plug electrode gap, the direction of the electrical field is inverted and the intensity of the electrical field is again raised to the level at which spark-over occurs in the spark plug electrode gap ($U_{break\ rep}$), $U_{break\ rep}$ being less than $U_{init.o,}$ and the intensity of the electrical field is again reduced in steps to the set level U_{stab}, and this level is fixed. The process is then repeated many times until the end of the ignition cycle. The electrical field is then gradually reduced over time t_{red}.

[0033] The block-diagram shown in Fig. 3 of an ignition system implementing the fuel-air ignition process in an internal combustion engine in accordance with the invention includes spark plug 5, piezo-transformer 2 and generator 1 with switching-on and switching-off input 7, the output of which is connected to the input of piezo-transformer 2, and also re-orientation resonator 3, combined in the design with piezo-transformer 2 and forming with it a single piezo-element 4, as a result of which an internal feedback 6 is formed. The input of piezo-element 4 is connected to the electrode of spark plug 5.

[0034] The circuit operates as follows. Control pulses (Fig. 4a) of duration t_{cont} 2-5 msec with period T_{cont} = 20-200 msec, depending on the rate of rotation of the engine crankshaft, determining the initial moment and the duration of the fuel-air mixture ignition cycle, are sent to the switching-on and switching-off input 7 of the generator 1 and permit it to operate. The sine curve signal (Fig. 4b), for the duration t_{cont} of the control pulse from the output of the generator 1, goes to the signal input of the piezo-electric transformer 2 and on through the series-wired reorientation resonator 3 forming the single piezo-element with the piezo-transformer 2, to the electrode of the spark plug 5.

[0035] In connection with the high quality factor of the piezo-element 4, the amplitude of the sine curve signal at its output will build up gradually in accordance with the law [1 - exp(-t/$_2$)] for time $t_{build\text{-}up}$ ~ 0.5 msec (see Fig. 2) to magnitude $U_{init.o}$ ~ 10 kV, i.e. up to the moment that discharge formation begins. This ensures a gradual rise in the intensity of the electrical field in the spark plug electrode gap (stage a).

[0036] At the moment of commencement of the discharge, step reduction of voltage occurs down to the set level U_{stab} ~ 650 V, at which it is maintained virtually up to the end of the current half-period of the excitation voltage in stages (b) and (c) of the process. The set level is achieved by selecting the amplitude of the build-up sine curve sent to the input of the piezo-element 4.

[0037] When high-frequency radiation occurs in the electrode gap, the internal feedback in the piezo-element operates, causing the inversion of its output signal.

[0038] The presence of internal feed back is due to the fact that when high-frequency radiation occurs in the in the electrode gap, there is a sharp change in the output impedance of the spark plug 5. This causes reorientation of the polarisation vector of the surface layers in the reorientation resonator (3), leading to a step change in the phase ratios when acoustic waves are propagated in the piezo-transformer 2 (thus implementing internal feedback 6 in the piezo-element 4), as a result of which inversion of the output voltage of the piezo-element (in stage d of the process) takes place.

[0039] In the next half-period, the voltage builds up to spark-over level $U_{break\ rep}$ ~ 2 kV, which is only about a fifth of the initial spark-over level $U_{init.o,}$ due to the presence of residual ionisation (free radicals) in the electrode gap of the spark plug 5 (stage e of the process). After the formation of the discharge in this half-period, the voltage again falls to the set level U_{stab}, at which it is maintained virtually up to the end of the current half-period of the excitation voltage (stages c and g of the process).

[0040] This process is repeated in each half-period up to the end of the action of the excitation voltage at the input of the piezo-element 4.

[0041] At the end of the excitation action on the input of the piezo-element 4, the amplitude of the sine curve signal at its output begins to diminish gradually in accordance with the exponential law for time t_{red} ~ 0.5 msec, which ensures a gradual reduction in the intensity of the alternating electrical field.

[0042] When the next controlling pulse arrives, the process is repeated.

[0043] The block diagram of the ignition system shown in Fig. 5 differs from that shown in Fig. 3 in that the generator 1 also contains a synchronisation input 8 and a discharge current control input 9. There are two feedbacks from the piezo-element, one of which is connected to the synchronisation input 8 and the other to the discharge current control input 9 of the generator 1.

[0044] The introduction of a feedback via the generator synchronisation input 8 makes it possible to synchronise the inversion of the output signal of the piezo-element 4 with the change of phase of the output signal of the generator 1, and the connecting of the feedback to the discharge current control input 9 of the generator 1 makes it possible automatically to maintain a fixed current level in the electrode gap of the spark plug 5, e.g. by altering the output power of the generator 1.

[0045] Experiments carried out have shown that the characteristic values for the process applied for are as follows: $U_{init.o}$ - 8-14 kV; $t_{build\text{-}up}$ - 0.4-0.6 msec; time for step reduction of intensity of electrical field after spark-over - 3-10 nsec; step raising of intensity of electrical field during inversion - 0.5-1 μsec; $U_{break\ rep}$ - 1-2 kV; U_{stab} - 400-800 V; duration of t_{break} - 10-14 μsec; t_{red} - 0.4-0.6 msec. The process achieved a fuel saving of 15-30% due to more complete combustion, and a reduction in toxicity of 20-30%.

Claims

1. Ignition process for fuel-air mixture in an internal

combustion engine, *characterised* in that it includes the following sequence of stages being carried out:

(a) increasing the intensity of the electrical field in the spark plug electrode gap until an electric spark passes across it;
(b) decreasing the intensity of the electrical field in steps to a set level;
(c) maintaining this level of intensity for 2.5-25 μsec until high-frequency radiation appears in the plug electrode gap;
(d) inverting the direction of the electrical field;
(e) increasing the intensity of the electrical field in the plug electrode gap until an electric spark passes across it;
(f) decreasing the intensity of the electrical field in steps to a set level;
(g) maintaining this level of intensity for 2.5-25 μsec until high-frequency radiation appears in the plug electrode gap;
(h) taking the electrical field away from the spark plug.

2. Process in accordance with claim 1, *characterised* in that stages (d) to (g) are repeated several times up to the end of the fuel-air mixture ignition cycle.

3. Process in accordance with claims 1-2, *characterised* in that stage (a) is carried out with an alternating electrical field.

4. Process in accordance with claim 3, *characterised* in that at stage (a), a harmonic alternating electrical field is used, the length of each successive half-wave of which exceeds that of the previous one.

5. Process in accordance with claims 1-4, *characterised* in that the removal of the electrical field is implemented only with repeated change of its sign.

6. Process in accordance with claims 1-2, *characterised* in that at stages (b) and (f), the current in the spark plug electrode gap is fixed.

7. Process in accordance with claims 1-2, *characterised* in that at stages (c) and (g), the maintenance of the set level of intensity proceeds until high-frequency radiation occurs in the spark plug electrode gap.

8. Ignition system for fuel-air mixture in an internal combustion engine containing a spark plug, a piezo-transformer and a generator with switching-on and switching-off input with its output connected to the input of the piezo-transformer, *characterised* in that it includes a reorientation resonator, combined in the design with the piezo-transformer and forming with it a single piezo-element, the output of which is connected to the spark plug electrode.

9. Ignition system in accordance with claim 8, *characterised* in that the generator also includes a synchronisation input and a current discharge control input, and in which two feedbacks from the piezo-element to the generator are introduced, one of which is connected to the said synchronisation input, and the other to the said generator discharge current control input.

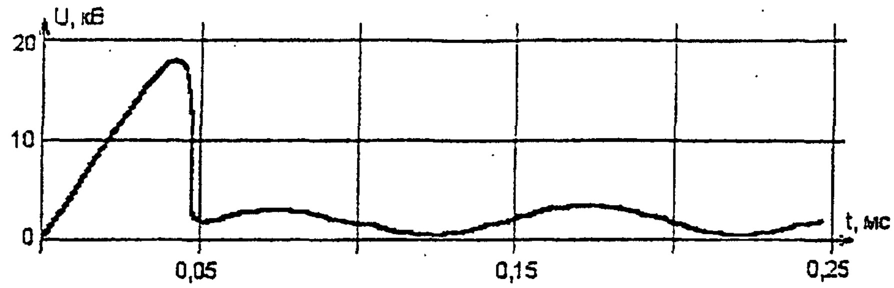

Fig. 1

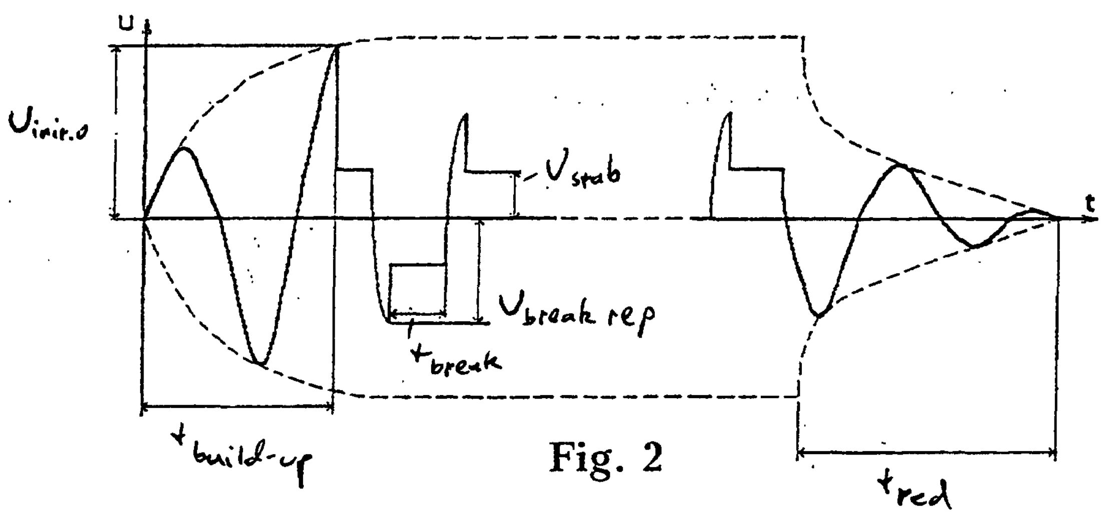

Fig. 2

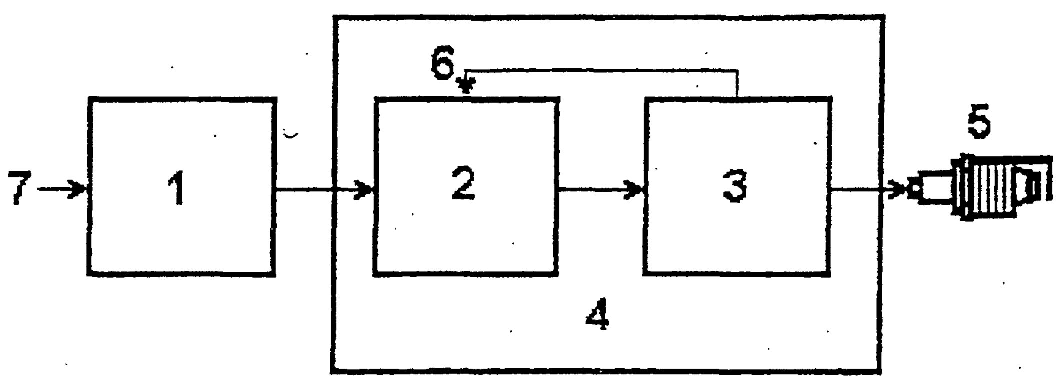

Fig. 3

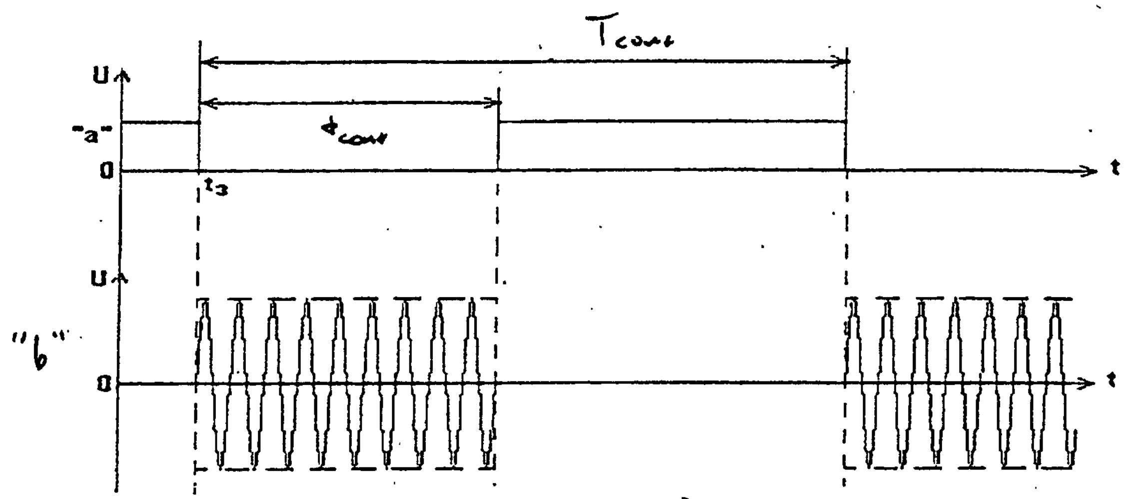

Fig. 4

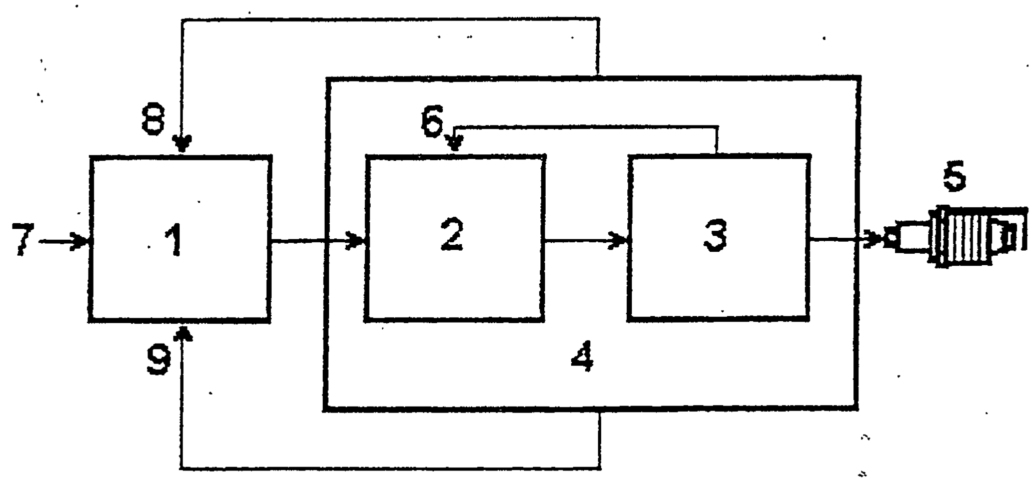

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT /RU 98/00373

A. CLASSIFICATION OF SUBJECT MATTER [6]:

IPC6 : F02P 3/12, 3/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC6 : F02P 3/00, 3/02, 3/04, 3/06, 3/08, 3/12, 15/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5715801 A (HONDA GIKEN KOGYO KABUSHIKI KAISHA) 10 February 1998 (10.02.98)	1-9
A	US 4455989A (NISSAN MOTOR COMPANY, LIMITED) 26 June 1984 (26.06.84)	1-7
A	RU 205621 C1 (SCERBATJUK VLADIMIR ANDREEVICH et al) 20 March 1996 (20.03.96)	1-7
A	US 4562822 A (NISSAN MOTOR COMPANY, LIMITED) 07 January 1986 (07.01.86)	1-7
A	SU 907290 A (UFIMSKY A VIATSIONNY INSTITUT IM. ORDZHONIKIDZE) 25 February 1982 (25.02.82)	8-9
A	GB 1537008 A (ROBERT BOSCH G.m.b.H) 29 December 1978 (29.12.78)	1-7

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☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 June 1999 (29.06.99)	08 July 1999 (08.07.99)
Name and mailing address of the ISA/ Facsimile No. R U	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)