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(11) **EP 0 931 929 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
28.07.1999 Bulletin 1999/30

(51) Int. Cl.⁶: **F02P 3/04**, F02P 3/02

(21) Application number: **98830021.6**

(22) Date of filing: **21.01.1998**

(84) Designated Contracting States:
**AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC
NL PT SE**
Designated Extension States:
AL LT LV MK RO SI
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(54) **A system for driving a coil with counter current for inverse pre-polarization of the core**

(57) An ignition system for internal combustion engines, comprising:

- a coil (14) with a magnetic core and a primary electric winding (14b) run through by a nominal primary current (I_n) and provided for generating a main magnetic flux; and
- a control circuit (10) adapted to drive said nominal primary current (I_n) so as to cyclically produce a charge phase and a discharge phase. The control circuit (10) produces an auxiliary primary current (I_p) adapted to maintain a pre-polarization magnetic flux superimposed to the main magnetic flux.

Fig. 4a

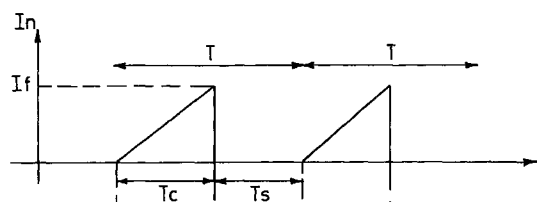


Fig. 4b

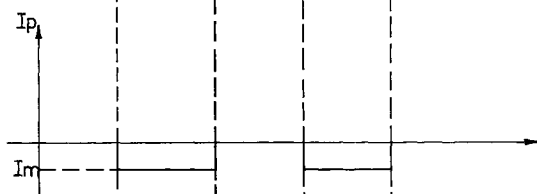
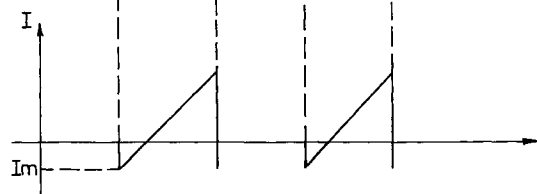


Fig. 4c



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Description

[0001] The present invention relates to an ignition system for internal combustion engines with spark ignition, according to the preamble of claim 1.

State of the art

[0002] It is known that the efficiency of an ignition system depends essentially by the quantity of energy which can be stored by an ignition coil. This energy depends in its turn on the type of core and on its magnetic properties. The enclosed figure 1a shows the magnetization curve associated to a generic magnetic core of an ignition coil of the most common type, that is without inverse pre-polarization of the core, which at the present state of the art means without any permanent magnet.

[0003] In this more typical case, the operating cycle of the coil begins in a condition wherein both the magnetic field K and the magnetic induction B are zero (point 1). During the charge phase, the primary current I circulating in the primary winding increases progressively from the initial value $I_i=0$ to the final maximum value I_f . The magnetic induction B which is also the density of flux (per turn) f , and therefore the total magnetic flux linked with all the n turn F , increase substantially linearly and with high gradient until the final value B_f is reached (point 2) if the coil remains in the high permeability zone, that is before the saturation. Beyond a saturation threshold indicated by B_s , even a substantial increase of the current I in the primary winding produces only a small increase, still about linear with low gradient, of the magnetic flux (saturation zone with low permeability) and therefore also a low increase of the stored energy.

[0004] In the state of the art it is also known a solution for providing a more efficient coil, which employs a permanent magnet associated with the core, so as to generate a pre-polarization magnetic flux with a direction opposite to the final main flux F induced by the final charge current.

[0005] The operating cycle when the core is inversely pre-polarized, is described in the following with reference to the diagram of enclosed figure 1b, which shows the magnetization curve of a generic magnetic core in the presence of a pre-polarization flux. At the beginning of the charge phase, the coil is in a condition wherein the initial magnetic field and magnetic induction, respectively indicated by H_i and B_i , are due to the pre-polarization condition (point 1). During the charge phase, by increasing the primary current I , the magnetic induction B increases until it reaches a final value B_f (point 2). The operating point moves along the magnetization curve on the whole zone wherein such curve maintains an high gradient (substantially linear high permeability zone).

[0006] With a given magnetomotive force $FM=N \times I$ (product of the number of turns of the primary winding N

and of the total difference of the charge current I), and with a predetermined material of the magnetic core (having a certain level of induction of saturation B_s), with a suitable design of the pre-polarization level and of the air gap of the core, it is possible to double the stored magnetic energy as well as the performances of the coil with respect to an analogous coil without pre-polarization. In fact, with the pre-polarization, the coil has a zone with high permeability with a difference of induction $B=B_f-B_i=2 \times B_s$, which is double with respect to the normal case.

[0007] Conversely, if the air-gap is maintained constant as assumed in the two figures 1a and 1b which have the same high gradient in the central zone, it is possible to stress the same material up to a double charge F (that is, with the same number of turns N , it is possible to double the difference of charging current I on the winding).

[0008] Therefore, the sectioned area in figure 1b which indicates the stored energy is four time as great as the one of figure 1a, because both the value of B and the current I double.

[0009] On the other hand, the indisputable advantage of a doubling (approximately) of the rate performances/dimensions, which can be obtained with inversely pre-polarized coils, involves some disadvantages of the solution which utilizes permanent magnets to achieve this object. The main disadvantages of this solution are the following. The first disadvantage of the solution according to the prior art is represented by the fact that the intensity of the pre-polarizing flux produced by the permanent magnet is constant and is predetermined when the disposition of the magnet with respect to the core is selected.

[0010] The second disadvantage consists in that it is necessary to use materials for the permanent magnets having a temperature of Curie T_c (temperature beyond which the ferro-magnetic property of the material disappear) sufficiently higher than the maximum temperature of operation typical of this application, which is about 150-200°C.

[0011] This limit is well respected, in general, by the material more commonly used for the permanent magnets. Anyway, the action of the temperature even if lower than T_c , but combined with mechanical vibrations, in view of the specific application, it is possible that the magnetic characteristics of the permanent magnet deteriorate in the time.

[0012] This may bring to a drift of the value of some operating parameters of the device. This drift cannot be recovered in any way since it is not possible to vary the intensity of the pre-polarizing flux.

[0013] Then there is the problem of the encumbrance of the magnet. In order to reduce such encumbrance in axial dimension it is necessary to employ materials with high coercitive force H_c .

[0014] Further, with the assumption that the magnet has the same transversal area of the core, it is neces-

sary to ensure that the induction of saturation of the magnet B_{sn} is not less than the one of the core B_s , in order to avoid a limit on the sought energetic advantage.

[0015] On the front of the energy loss, the additional material of the magnet will cause an increase thereof, proportional to the mass of the magnet.

[0016] Anyway, being in general the permanent magnets constituted by "hard magnetic materials" (i.e. with high magnetic hysteresis) of sintered type, the contribution to this passive losses will be mainly due to the losses for magnetical hysteresis as opposed to the losses for eddy currents. It must also be taken in consideration the greater difficulty of the design and the increase of the final tolerances on the performances of the coil, for the addition of the magnet.

[0017] This involves finally the worst inconvenience: the increase of the final cost of the coil, on which even the direct cost of the magnet has substantial influence, in view of the necessity to look for materials with competitive characteristics in order to overcome the various critical aspects explained above.

Summary of the invention

[0018] In order to eliminate all the various disadvantages connected to the use of the magnets, used for obtaining the pre-polarization of the core, the present invention has the object to obtain the same effect, that is the prepolarized core, and therefore to maintain the great energetic advantage shown above, by eliminating completely the magnets.

[0019] The present invention provides a specific magnetizing system with a circuit which determines the circulation of a suitable current, separated or superimposed to the usual charge current and circulating in a winding assigned also or only to this purpose.

[0020] It is necessary the addition and/or the integration in the present driving unit of the ignition system of a specific control system for controlling the direction and/or for regulating the pre-polarizing current.

[0021] By virtue of the circulation of this polarizing current in the respective winding, which may be either a third winding inserted in the coil (first embodiment of the present invention) or may be coincident with the already existing winding of the traditional coils, in particular with the primary winding (second embodiment of the present invention), it is possible to obtain the same pre-polarization of the core which was obtained with the permanent magnets.

[0022] Since the energetic advantage can be obtained when the core is pre-polarized in a direction opposite to the magnetic flux induced by the normal charge current (which circulates in the primary winding), which in the traditional driving system for inductive discharge coils begins always from an initial value equal to zero, such polarizing current must have a direction, "contrary" to the one of the usual charging current, wherein the direction is indicated by the direction of the flux induced in

the core. Therefore, this polarizing current can be defined "magnetizing counter-current".

[0023] Thus, the new driving system according to the present invention can be defined "driving system with counter-current for the inverse pre-polarization of the core".

[0024] In fact, in the embodiment which carries out the invention without the need to add a third winding and which use the same primary winding already present for the normal charging current I_c , variable between the initial value $I_i=0$ to the final value $I_f=I_{pk}$, the new polarizing current I_p is actually a current contrary to the charge current I_c .

[0025] Thus, for this configuration, the assigned difference of the charge current $I=I_f-I_i=I_{pk}$, which is available in the primary winding will not anymore vary between $I_i=0$ and $I_f=I_{pk}$, as usual, but between $I_i=-I_p$ and $I_f=I_{pk}-I_p$, being I_p the absolute value of the polarization "counter-current", which is superimposed to the usual charge current I_c .

[0026] If, as can be understood from figure 1b, the maximum energetic advantage is sought, the best rate between the two currents I_p and I_c , components of the single resulting total current I_p+I_c circulating in the primary winding, is, in general $I_p=I_{pk}/2$.

[0027] It comes out that, with respect to the usual systems with or without magnets, instead of a single current peak $I_f=I_{pk}$, now there will be two current peak, in general equal and contrary to each other: $I_i=-I_{pk}/2$ and $I_f=+I_{pk}/2$ but having a minor absolute value, in general halved.

[0028] This specific embodiment of the invention which does not require the magnet and which obtain the inverse pre-polarization of the core without an additional winding and without any other variation within the coil has a further competitive advantage which consists in a substantial reduction of the peak values and of the effective current circulating in the primary winding during the charging phase.

[0029] This reduction of the current, in general equal to half with respect to the systems with the same current difference $I=I_{pk}$, will result in a minor energy request of the ignition system with respect to the battery supply system.

[0030] Now with maximum peak current reduced to half, with the same electrical resistance of the charging circuit, the maximum reduction admissible for the battery voltage V_p which is still in condition to guarantee the complete charge of the system may double with respect to the previous situation.

[0031] Conversely, remaining the same the minimum battery voltage V_{bmin} , which is present in the most critical situation, it is possible to operate with double primary resistance: the primary winding, as well as the relative supply system, may have their useful section and therefore their encumbrance reduced to half.

[0032] The energy dissipated for Joule effect, proportional to the time and to the square of the effective cur-

rent, will be subjected, only for the charge phase, to a substantial reduction.

[0033] If the total difference of current $DI=I_{pk}$ and the material of the core remain the same, if 100 is the total loss of energy E_j in the case without pre-polarization, by using the magnets it is possible to double the magnetic energy but the total Joule loss will become 200.

[0034] On the contrary, according to the invention, since the effective charge current is halved, if the same charge time is maintained as in the case with the magnet, the above loss will be reduced to $200/4=50$.

[0035] Therefore, the relative loss of efficiency of the charge phase, E_g/E_m , which in practices remains the same either with or without the magnet, will now be reduced of about four times.

Advantages of the invention

[0036] In general, with any particular embodiment of the present invention, with respect to the present systems there will be the following advantages.

1. Complete removal of the permanent magnet and of all the problems connected thereto, maintaining in any case the energetic advantage of (approximately) doubling the rate performances/encumbrance with respect to the conventional systems.

2. Possibility to control the system in view of the integration in the present coil driving system of a specific unit which carries out the function of determining the desired level of pre-polarization of the magnetic core.

A new variable is thus available, that is the pre-polarization current I_p , on which, depending on the demand of the internal combustion engine and of the responses of the ignition system, it is possible to intervene with the most suitable feedback system, in order to vary the performances of the coil in order to increase the effectiveness and the efficiency of the system.

3. Only for the version which uses the same primary winding as prepolarizing circuit, there is a reduction (up to approximately half) both of the peak value and of the effective value of the current circulating in the primary winding during the charging phase. This involves lower request in terms of minimum voltage and energy to be supplied by the battery supply system to the ignition system.

[0037] In addition, the system according the invention can be used as a useful laboratory instrument for developing and designing coils with a core pre-polarized by means of permanent magnets, which can be easily simulated.

Detailed description of the invention

[0038] The main characteristics of two particular

embodiments of the ignition system according to the invention will be described in the following.

[0039] The description is given purely by way of non limiting example, in order to show concretely the basic concepts of the idea.

[0040] In the drawings:

- figures 1a and 1b which have already been described above, are diagrams which show a generic magnetization curve of a ferro-magnetic core, respectively without and in the presence of a pre-polarization flux;
- figure 2 is a simplified scheme of a generic ignition system for internal combustion engines;
- figure 3 is a simplified scheme of an ignition system according to a first embodiment of the invention; and
- figures 4a, 4b and 4c are a group of diagrams which show the variation in the time of the primary current and of its components in a second embodiment of the present invention.

[0041] In figure 2 it is shown a simplified scheme of a conventional ignition system which, except for the possible insertion of permanent magnets in the magnetic circuit of the coil, remains for all the rest equally valid both for the case of non polarized core and in the case wherein it is polarized by means of magnets.

[0042] In this figure, the circuital control means are summarily identified by a single block 10 which receives the supply from a battery 12. A primary electric winding 14p of a coil 14 is run through by a primary current I and is associated to the control means 10. During a whole cycle of the coil 12, the control means drive a primary current I which progressively increases from an initial value zero to a final value I_{pk} , during a charge phase of the coil and which returns instantly to the initial value zero in the moment of switching. The current is maintained to the value zero during all the subsequent discharging phase which takes place on the secondary winding for all the rest time before the beginning of a subsequent charge cycle.

[0043] In figure 3 it is shown a first embodiment of the invention according to a scheme analogous to the one of figure 2. The circuital means 10 are provided for driving a nominal primary current I_n circulating in the primary winding 14p and an auxiliary magnetizing current I_p circulating in an auxiliary winding 14a of the same coil 14. The winding 14a is run through by the current I_p so as to generate a magnetic pre-polarizing flux having a direction opposite to the direction of the main magnetic flux. The intensity of the current I_p is determined so as to establish the initial condition on the magnetizing curve of the core, at the beginning of the charge phase of the coil, in correspondence with the beginning point of the charge indicated with 1 in figure 1b.

[0044] The control means 10 are adapted to detect according to known modality, for example by means of

an electronic control unit (ECU), some operating parameters of the engine to which the coil is associated. Depending on such parameters, the control means 10 regulate the intensity of the current I_p and adapt the behaviour of each coil to the type of operation required. In addition, with the purpose to reduce the energy losses, by controlling the phases of the operating cycle of the ignition system, the same means can activate the auxiliary current I_p only during the strictly necessary phases, i.e. during the charge phase (with the necessary advance required by the time necessary to establish the current I_p by the inductance L_p), the switching and the discharge, switching off the current I_p during the remaining rest time. This will always be convenient when the rest time in the auxiliary magnetizing circuit exceeds its characteristic time constant L_p/R_p , ratio between the induction L_p and the resistance R_p of the same circuit.

[0045] In this connection it must be specified that, being the magnetic energy a state function of the magnetic field linked with the core and its air-gap, if it is desired to transfer and to obtain on the secondary winding all the energy accumulated during the charging phase (except the losses due to commutation and discharge) it is necessary to maintain the counter-polarization also for the switching and discharge phases.

[0046] In fact, it must be permitted to the "magnetic field system" which was moved from point 1 to point 2 of figure 1b during the charging phase, to return from point 2 to the same starting point 1, so that it can return all the magnetic energy previously stored.

[0047] On the other hand, when the permanent magnets are used, they are always present with all their effects and act permanently. Therefore, the magnetic effect which they induce acts, during the whole active cycle of the coil, composed by charge, switching and discharge, and also for the inactive rest time between successive active cycles.

[0048] In a second embodiment, it is possible to obtain the same global effects on the flux F induced in the core, produced separately by a part of the normal nominal charge current I_n circulating in the primary winding, and by the auxiliary polarizing current I_p circulating in the third auxiliary circuit (equivalent to the single effect of the magnets).

[0049] In fact, the final resulting element can be obtained synthetically by reuniting in a unique new form of global current $I = I_n + I_p$, circulating in one and the same winding (the primary winding), the two distinct currents I_n and I_p which produce the evolution of the total flux F in the core.

[0050] This is obtained by driving directly only in the primary winding 14p a current I equal to the sum of the nominal primary current I_n and of the auxiliary primary current I_p . In this way, it is maintained the possibility of a pre-polarization of the core which can be regulated, avoiding the constructive complications due to the insertion of the auxiliary winding 14a.

[0051] Therefore, the circuital scheme of this solution substantially coincide with the one shown in figure 2, the differences being comprised in a different realization of the control means 10. With the integration in said means of a suitable control unit (of electric or electronic type, per se known) it is possible to obtain the new desired form of current circulating in the primary winding, as is evident in figure 4, which shows the variation in the time of the total primary current I , obtained by superimposing the two components I_n and I_p , in a temporary portion comprising two complete periods (indicated with T) corresponding to two operating cycles of the coil.

[0052] In the first diagram 4a it is shown the variation of the nominal primary current I_n . During the charge phase T_c of each cycle, the current I_n increases progressively from a minimum value zero to a maximum value I_f . During the discharge phase T_s it returns immediately to zero and is maintained at this value until the end of the cycle.

[0053] In the second diagram 4b it is shown, in correspondence with the variation of the nominal current I_n , the variation of the pre-polarization auxiliary primary current I_p regulated by the control means 10. During the active phase (charge, switching and discharge) of the coil, a current I_p is driven, having a constant intensity equal to I_m , but with a direction opposite to the nominal current. During the inactive rest phase of the coil, the pre-polarization is no more indispensable, therefore the auxiliary current I_p can be switched off if this is convenient, as assumed in figure 4.

[0054] In the third diagram 4c finally it is shown the variation of the total primary current I given by the algebraic sum of the nominal and auxiliary current. Just before the beginning of the charge phase, the total current is given only by the auxiliary current, in such way that the core is pre-polarized and the initial condition is establish in correspondence with point 1, as indicated in figure 1b. During the charge phase T_c , the current I decreases until it annuls and changes the direction in which it runs through the windings and return to increase until it reaches a value which is always less than the saturation threshold. At the beginning of the discharge phase, the nominal current I_n becomes abruptly zero as described in the first diagram and the intensity of the total current I returns to the one of the auxiliary component I_p . Subsequently, when the discharge is finished it is no more necessary the pre-polarization of the core, and the auxiliary current can be advantageously switched off thereby annulling also the total current I .

Claims

1. An ignition system for internal combustion engines, comprising:
 - a coil (14) comprising a magnetic core and a

primary electric winding (14b) run through by a nominal primary current (I_n) and adapted to generate a main magnetic flux;

- circuital control means (10) adapted to drive said nominal primary current (I_n) in such way to produce an operating cycle including a charge phase in the course of which the current (I_n) progressively increases from a minimum value to a maximum value (I_f) and a discharge phase in the course of which the current (I_n) returns abruptly to the minimum value and is maintained at such value for a predetermined period of time; and
- means for inducing in said magnetic core a pre-polarization magnetic flux superimposed to said main magnetic flux, so that the total magnetic flux is equal to the sum of said main flux and of said pre-polarization flux;
characterized in that said circuital control means (10) provide an auxiliary primary current (I_p) adapted to maintain said pre-polarization magnetic flux.

2. An ignition system according to claim 1, characterized in that said means for inducing the pre-polarization flux comprise an auxiliary electric winding (14a), said auxiliary winding being run through by that auxiliary primary current (I_p).
3. An ignition system according to claim 1, characterized in that said circuital control means (10) superimpose said auxiliary primary current (I_p) to said nominal primary current (I_n) so that the total primary current (I) circulating in the primary winding is equal to the algebraic sum of the auxiliary primary current (I_p) and of the nominal primary current (I_n).
4. An ignition system according to claim 3, characterized in that said means for inducing the pre-polarization flux coincide substantially with the primary electrical winding (14b) said winding being run through by the total primary current (I).

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Fig. 1a

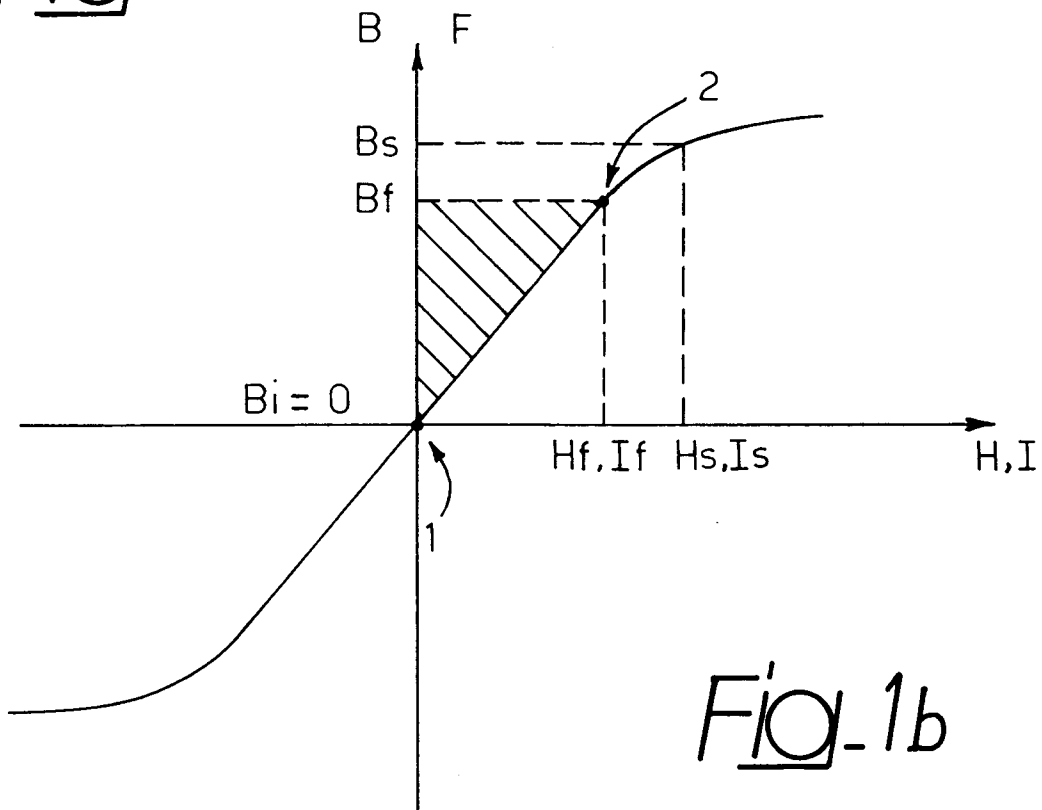


Fig. 1b

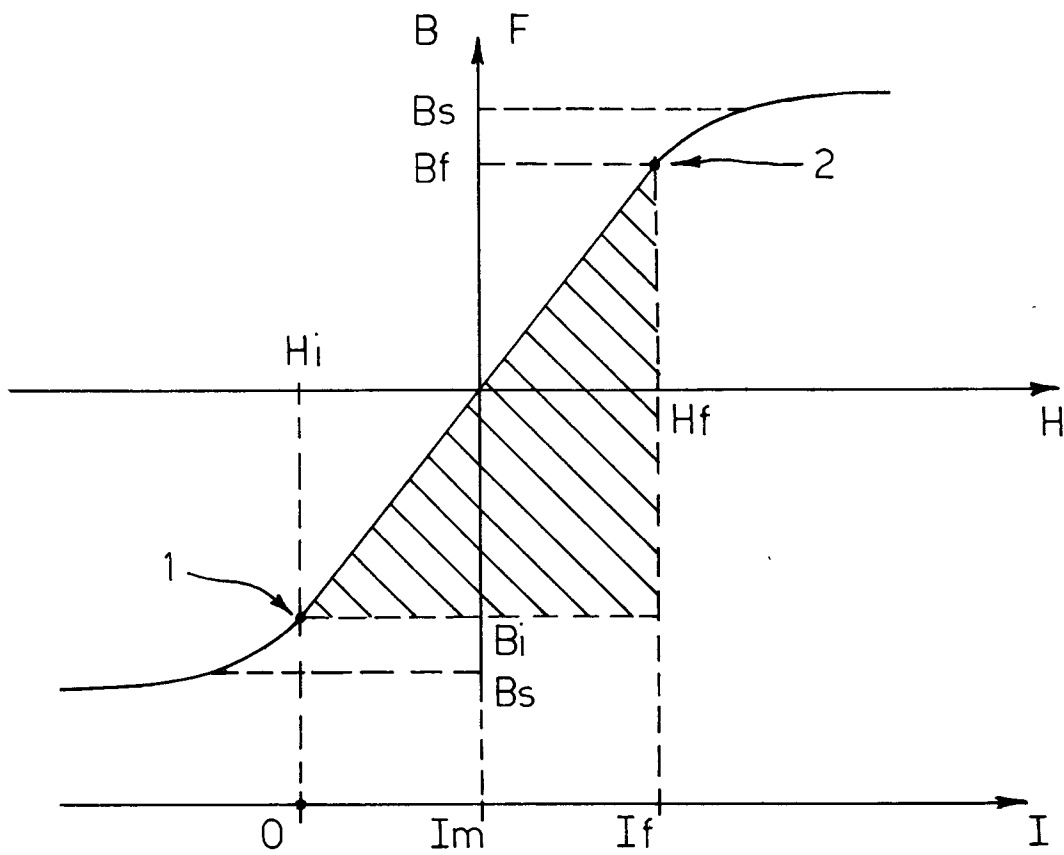


Fig. 2

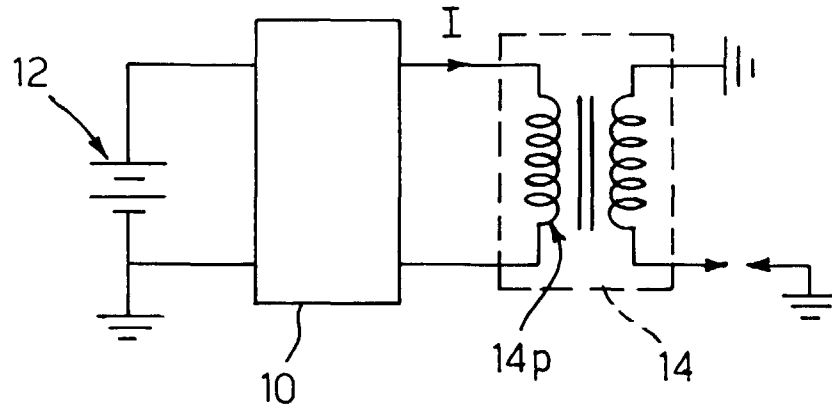


Fig. 3

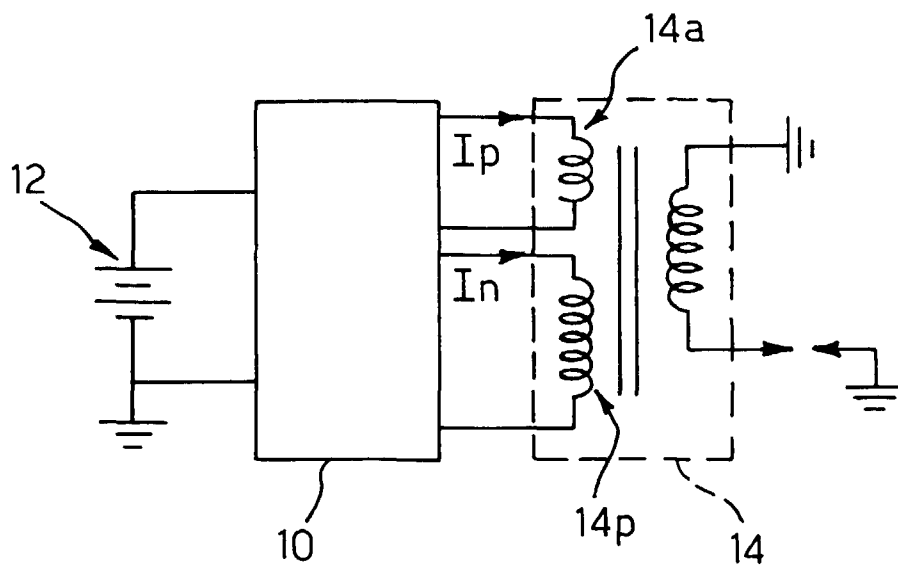
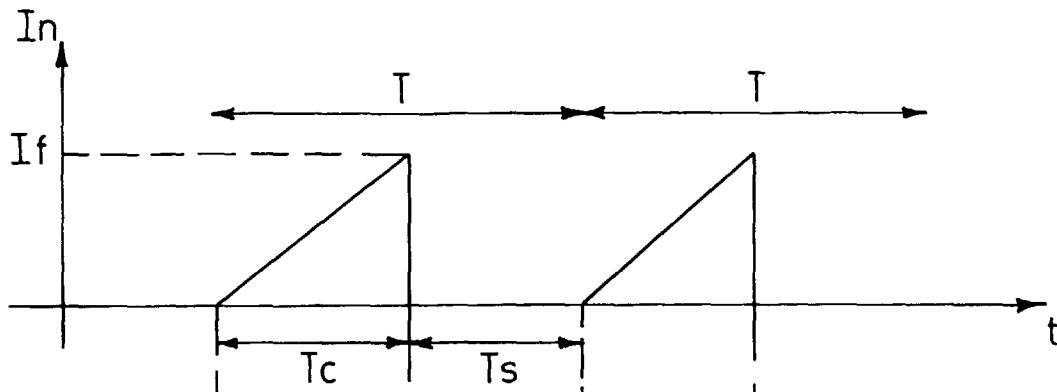
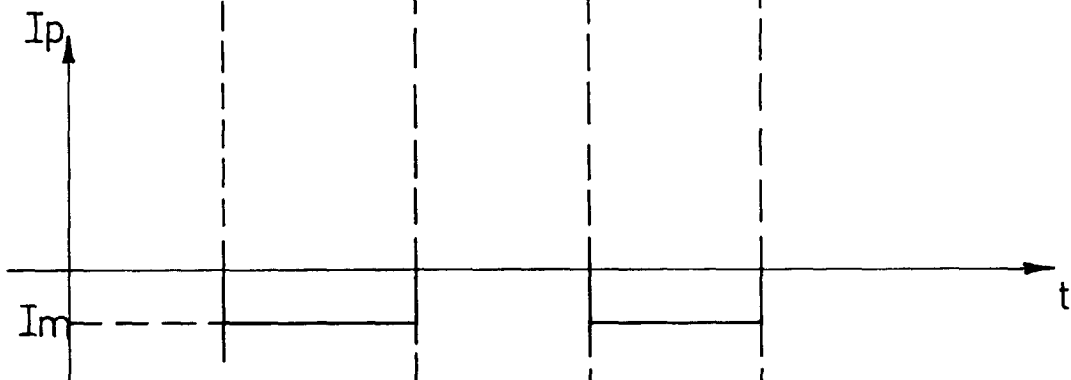
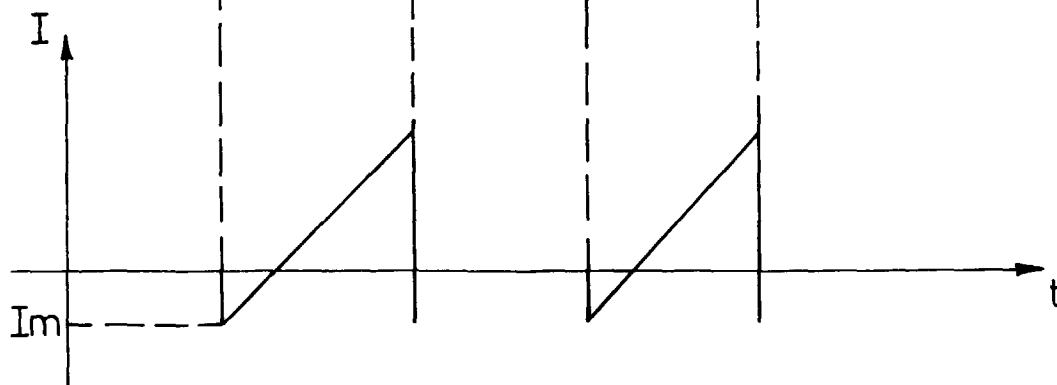


Fig. 4aFig. 4bFig. 4c



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Application Number
EP 98 83 0021

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 097, no. 008, 29 August 1997 & JP 09 092552 A (SUMITOMO WIRING SYST LTD), 4 April 1997, * abstract *	1,2	F02P3/04 F02P3/02
A	-----	3,4	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			F02P
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 27 May 1998	Examiner Fuchs, P
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