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(54) METHOD AND APPARATUS FOR THE GENERATION OF IGNITION SPARKS

(71) We, ROBERT BOSCH GMBH a German Company, of Postfach 50, 7 Stuttgart 1, Federal Republic of Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

5 The invention relates to a method of generating ignition sparks, for which a high ignition voltage is required, in particular for internal combustion engines, for an ignition system having an ignition coil whose primary circuit includes an electrical switch, and whose secondary circuit includes the series combination of a spark gap and a high-tension diode, and to apparatus for the performance of the method.

10 Ignition systems of the above type are already known, which, advantageously, are operated at each firing instant by means of a plurality of ignition sparks in order to improve ignition. This is normally adequate for the satisfactory, complete combustion of an ignition mixture in an internal combustion engine, but, when a high ignition voltage is required, and in unfavourable conditions of operation, misfiring may cause faulty ignition. Compensation by increasing the ignition current and the ignition voltage may be very complicated and costly and may lead to increased wear.

15 In accordance with one aspect of the present invention, there is provided a method of generating high voltage ignition sparks in an ignition system having an ignition coil, whose primary circuit includes an electrical switch and whose secondary circuit includes the series combination of a spark gap and a high-tension diode but does not include a discrete capacitor across the spark gap other than that provided by an ignition cable coupling the ignition coil to the spark gap, in which, at the occurrence of each ignition trigger signal (B), the electrical switch is operated by means of a plurality of successive signals (E), whose lengths and intervals are so controlled by means of an electronic control system that a build-up of potential across the spark gap is achieved in the ignition cable capacitance, the collapse of which potential is prevented by the high-tension diode until said potential reaches the breakdown voltage of the spark gap whereupon an ignition spark occurs.

20 When the ignition coil is to be operated as a flux transformer, the signal lengths of the multiple signals (E), during which the electrical switch is closed, are arranged to correspond substantially to the time required to achieve peak voltage across the spark gap, resulting from each particular signal (E) and the signal intervals between the multiple signals (E), during which the electrical switch is open, correspond substantially to the time required for the voltage across the winding capacitance of the secondary winding of the ignition coil to drop from said peak value to a minimum.

25 For operation of the ignition coil as a blocking transformer, the lengths of the multiple signals (E) move within the linear limits of the current rise on the primary side of the ignition coil, and the signal intervals between the multiple signals (E) correspond substantially to the time required to reach the peak voltage levels across the spark gap attainable as a result of each particular signal (E), respectively.

30 In order not to overload the electrical switch, which is preferably in the form of a transistor, voltage build-up on the ignition cable capacitance may also be achieved by charging the latter capacitance in a series of steps by means of sequences of current pulses. For this purpose, the lengths of the multiple signals (E), during which the electrical switch is closed, must move within the linear range of the primary current rise in the ignition coil, and the signal intervals between the multiple signals (E), during which the electrical switch is open, are very small

35 40 45

compared with the signal lengths.

In accordance with a second aspect of the invention, there is provided an ignition system comprising an ignition coil, whose primary circuit includes an electrical switch and whose secondary circuit includes the series combination of a spark gap and a high-tension diode but does not include a discrete capacitor across the spark gap other than that provided by an ignition cable coupling the ignition coil to the spark gap, means for producing an ignition trigger signal (A), and an electronic control system for producing a plurality of successive signals (E) during the period of each ignition trigger signal (B) which are effective to operate said electrical switch and whose lengths and intervals are so controlled by the control system that a build-up of potential across the spark gap is achieved in the ignition cable capacitance, the collapse of which potential is prevented by the high-tension diode until said potential reaches the breakdown voltage of the spark gap whereupon an ignition spark occurs.

For operation of the ignition coil as a flux transformer, the electronic control system can include a differentiator connected to the ignition coil, and a polarity identification circuit connected by way of a logic circuit to the control input of the electrical switch.

The advantages of the invention are, in particular, that owing to the effect of the build-up of the ignition voltage in the ignition cable capacitance, the amplitude of the ignition voltage achievable can be as high as desired. The ignition coil may accordingly have a relatively low transformation ratio. A relatively high after-discharge current (from a small primary current) and low internal resistance are thereby achieved. Moreover, the use of a low transformation ratio may provide an extremely high spark rate, which can be still further increased if an additional air gap is provided. The transformer may be so constructed that, during the first trigger pulse, the voltage achieved is just sufficient for ignition. In the event of ignition failure, firing then takes place at the next stepwise increase in the ignition voltage. During step-by-step charging by means of current pulse sequences, a small current flows through the electrical switch. Apart from not overburdening the switch, which is normally a transistor, a favourable degree of efficiency is also achieved.

The invention is described further hereinafter, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 shows one embodiment of an ignition system in accordance with the invention;

Figure 2 is a diagram showing a detail common to both the embodiments of Figures 1 and 7;

Figure 3 is a signal diagram which illustrates the method of operation of the arrangement shown in Figure 1;

Figure 4 is a voltage diagram illustrating the operation of the arrangement shown in Figure 2, when operating as a flux transformer;

Figure 5 is a current-voltage diagram illustrating the operation of the arrangement shown in Figure 2 when operating as a blocking transformer;

Figure 6 is a current-voltage diagram illustrating the operation of the arrangement shown in Figure 2 for operation as a flux transformer in an alternative mode;

Figure 7 shows a second embodiment of an ignition system in accordance with the invention; and

Figure 8 is a voltage diagram illustrating the operation of the arrangement shown in Figure 7.

In the embodiment shown in Figure 1 a transducer 10, which is preferably connected to the crankshaft of an internal combustion engine, is connected to a pulse shaping circuit 11 which is preferably in the form of a Schmitt trigger circuit. The transducer 10 shown is an inductive transducer; alternatively, however, it may, for example, take the form of a contact breaker. The output of the pulse shaping circuit 11 is connected by way of an electronic ignition timing circuit 12 and a connecting terminal 13 to one input of an AND gate 14. An electronic ignition timing circuit 12 for shifting the ignition signal in dependence, for example, upon engine data (engine speed n , inlet manifold depression p , temperature T and throttle valve position α) is widely known and will not be described here in detail. The outputs of two frequency synthesizers 15, 16 are connected to two further inputs of the AND gate 14. The terminal 13 is connected to a gate input of each of the frequency synthesizers 15, 16. Output signals of the frequency synthesizers 15, 16 are generated only when a signal appears at such a gate input. The output of the AND gate 14 is connected by way of a further terminal 17 to the control input of an electrical switch 18, which preferably is a transistor. The AND gate 14 and the two frequency synthesizers 15, 16 form an electronic control system 19 for controlling the electrical switch 18. A supply terminal 20, which is connected to the positive pole of a supply voltage, is connected by way of the switching path of the electrical switch 18 to a further terminal 21, which is itself connected to the primary winding of an ignition coil 22. The secondary winding of the ignition coil 22 is connected by way of a high-tension diode 23 to the spark gap 24, whose second electrode is connected to earth. Both windings of the ignition coil 22 are also connected to earth.

Figure 2 shows a detail diagram of part of the arrangement shown in Figure 1, namely, the

part between the terminal 17 and the spark gap 24. Identical components are identified by means of the same reference numerals and are not described again. The ignition-lead capacitance C2 of the leads to the spark gap is shown in parallel with the spark gap 24. The ignition coil 22, in particular its secondary side, is shown as an equivalent circuit diagram. The turns ratio of the secondary winding, which has a number of turns W2, and the primary winding, which has a number of turns W1, is represented by a so-called ideal transformer 220. The main inductance is shown as an inductor Lh in parallel with the secondary side of the ignition coil 22. Between the main inductance Lh and the secondary output of the ignition coil 22 there is shown the leakage inductance represented by an inductor Ls. The winding capacitance between the output and earth is represented by a capacitor C1.

The method of operation of the electronic control system 19 will be described with reference to the diagram shown in Figure 3. The output signal of the transducer 10 is converted to a square-wave signal A in the pulse shaping circuit 11. This signal A is shifted to the extent of the time To by means of the electronic ignition timing circuit 12 and appears as a signal B at the terminal 13. The first frequency synthesizer 15 generates a sequence of signals C, and the second frequency synthesizer 16 generates a sequence of signals D. Consequently, a signal E appears at the output of the AND gate 14, and thus also at the terminal 17, only when a B signal, a C signal and a D signal appear simultaneously. As will be explained hereinafter, successive E signals lead to a build-up of potential across the spark gap 24. This potential build-up proceeds until discharge takes place across the spark gap 24, whereupon it starts again. Thus, one spark or a series of sparks can be generated during a sequence of E signals, in dependence upon the amplitude of the ignition voltage required, that is, upon how often a voltage build-up is necessary. This is indicated by means of arrows to denote firing. The frequency of signal sequence D is constant and is substantially higher than the frequency of the transducer 10, that is, signal sequence A. The frequency of the frequency synthesizer 15 lies between the two. The number of ignition sparks at any firing instant can thus be adjusted by variation of the frequency and duration of signals C.

Optimum voltage build-up can be achieved only when the E and D signals, which cause the opening and closing of the electrical switch 18, exhibit a particular signal length and signal interval.

The voltage diagram shown in Figure 4 shows behaviour in the case of an ignition coil operated as a flux transformer. This means that the ratio of the numbers of turns W2 to W1 is high, and that the main inductance Lh is high compared with the leakage inductance Ls. During an E signal an increase takes place both in the voltage U1 across the secondary winding of the ignition coil 22 and in the voltage U2 across the spark gap 24. The signal length 1 is adjusted so that the signal ends approximately when the voltage U2 reaches its peak, that is, when the capacitors C1 and C2 are fully charged by way of the leakage inductor Ls to the maximum value of the U1 resulting from that particular E signal pulse. The approximate duration of an E signal is therefore expressed by the following equation:

$$1 = \pi \cdot L_s \cdot (C_1 + C_2)$$

The electrical switch 18 is opened by the succeeding signal interval, and a process of reversal of the charge across the capacitor C1 to the main inductor Lh takes place. The duration of the signal interval p must therefore be such that a fresh signal begins approximately when the voltage U1 has reached its peak in the opposite direction. The approximate duration of the signal interval p may therefore be determined by means of the following equation:

$$p = \pi \cdot L_h \cdot C_1$$

During the signal interval, discharging of the ignition lead capacitor C2 cannot take place owing to the high-tension diode 23 being blocked. The voltage U2 thus remains constant. At the next E signal there is a further rise in the voltage U1, until once more a peak is reached. Owing to the resonance effect of this oscillation, this maximum is higher than the maximum of the last oscillation process. When the voltage of the plateau of the voltage U2 is exceeded, the voltage U2 continues to rise parallel with U1, until, at the next signal interval, a plateau is again maintained but at a higher voltage level. This build-up process continues as long as is necessary, until the amplitude of the voltage U2 is sufficient for ignition. Thereafter, the same process starts again from the beginning, provided E signals are still appearing.

The current-voltage diagram shown in Figure 5 serves to clarify the operation of the ignition coil 22 when operated as a blocking transformer. In the case of the blocking transformer, the value of Lh must be relatively low in order to store magnetic energy, and Ls must be as small as possible, in order that the transistors shall not be overloaded by peak turn-off voltages.

The turns ratio W2 to W1 is low, and is limited only by the electric strength of the transistor serving as the electrical switch 18. This relationship is expressed by the following equation: $W_2/W_1 = U_2 \max / (U_1 - U_b)$. U1 represents the maximum permissible transistor voltage, and Ub represents the supply voltage. When this method of operation using a blocking transformer is used, during an E signal a linear increase in the current Jb through the ignition coil

22 takes place initially. The signal duration 1 of the E signal is advantageously limited so that the increase in the current Jb remains within a linear range. During the signal interval p which then follows, a reversal of the charge carriers from the main inductor Lh to the two capacitors C1 and C2 takes place. The current Jb decreases again, and the voltages across the capacitors increase, in particular the voltage U2 across the capacitor C2 and the spark gap 24. Due to the capacitor C1, this voltage rise is delayed for a period t1. In order to achieve maximum voltage build-up, the signal interval p must be adjusted so that a fresh E signal is initiated when the current Jb reaches approximately zero, or when the voltage U2 reaches its peak value resulting from that current Jb. The signal interval may therefore be expressed substantially by means of the following equation:

$$p = \pi/2 \quad L_h (C_1 + C_2)$$

The voltage U2 is maintained during the succeeding E signal by means of the high-tension diode 23, and thereafter the current Jb again starts to rise. During the next signal interval p, a decrease in the current Jb and a build-up of the voltage U2 again take place. This build-up of the voltage U2 continues until the necessary ignition voltage across the spark gap 24 is achieved and firing can take place.

In the arrangement in which the ignition coil is operated as a flux transformer, a build-up of voltage may also be effected by step-by-step charging by means of sequences of current pulses. The generation of E signals for this mode of operation will be described with reference to the diagram shown in Figure 6. The build-up of the voltage U2 is achieved in this case by means of a rapid succession of short current pulses Jb across the switching path of the electrical switch 18 and thus also through the primary winding of the ignition coil 22. In this case also, the length 1 of an E signal is so adjusted that the current rise Jb moves within a linear range. During this current rise the voltage U2 across the spark gap 24 increases. The signal interval p is set very short, so that the electrical switch 18 opens only very briefly. The current Jb, which then immediately drops to zero, immediately starts to rise again owing to a fresh E signal which immediately initiates. Associated with the further current rise is a further rise in the voltage U2. The level of the voltage U2 is also maintained by the high-tension diode 23 during a pulse interval. For building up the voltage U2 with this method, more build-up processes are, in fact, necessary in order to achieve a satisfactory ignition voltage; a higher frequency may be used for the E signals, however. A great advantage of this method is that the electrical switch 18 is not overloaded, since only a relatively small current flows across its switching path, and the transistor operates at saturation. Loss of efficiency at this electrical switch is thereby reduced.

The second embodiment, as shown in Figure 7, corresponds to the arrangements as shown in Figure 1 and Figure 2 except with respect to the electronic control system 19. The electronic control system 19 in this case comprises a differentiator 25 and a polarity identification circuit 26, both of whose inputs are connected to the terminal 21, and whose outputs are connected by way of a logic circuit 27 to the control input of the electrical switch 18. For the differentiator 25 a known differentiating circuit is provided, comprising the series combination of a capacitor 250, a resistor 251 and an inverting operational amplifier 252, with which a resistor 253 and a capacitor 254 are connected in parallel.

In polarity identification circuit 26, the input is connected to earth by way of a diode 260 and a resistor 261. The junction of the diode 260 and the resistor 261 is connected to a first output 262, and, by way of a reversing circuit 263, to a second output 264.

The output of the differentiator 25 is connected by way of a reversing circuit 270 to one input of each of two AND gates 271 and 272. The second input of the first AND gate 271 is connected to the output terminal 264, and the second input of the second AND gate 272 is connected to the second output terminal 262 of the polarity identification circuit 26. The output of the first AND gate 271 is connected to the set input, and the output of the second AND gate 272 is connected to the reset input of an RS flip-flop 273, whose output is connected to the control input of the electrical switch 18. The timing input of the flip-flop 273 is connected to the terminal 13.

In contrast to the first embodiment in which, in particular in accordance with Figure 4, the switching points of the voltage curve U1 are defined or set by means of a fixed frequency with a fixed signal-length to signal-interval ratio of the frequency synthesizer 16, in the second embodiment identification circuits are provided, which identify these switching points and then initiate the switching process by way of the electrical switch 18. Criteria for the identification of the switching points are, first, the slope of the curve U1', which is zero at the switching points, and, secondly, the polarity of the voltage at the switching points. U1' denotes the primary voltage across the ignition coil 22, which substantially follows the secondary voltage U1.

The differentiator 25 provides a signal at its output only when there is a change of voltage at the input. If the voltage at the input remains constant, the output voltage is zero. Since the slope of the curve of the voltage U1' becomes zero when it approaches a switching point, that

is, when the first process of reversal of the charges to the capacitors C1 and C2 has finished, the output voltage of the differentiator 25 drops to zero. Thus, above a predetermined threshold, an F signal is provided at the output of the reversing circuit 270.

If the switching point lies in the positive region, the diode 260 conducts, and a positive voltage is applied to the resistor 261 and appears as a G signal at the output terminal 262. At the same time, owing to the reversing circuit 263, no signal appears at the output terminal 264. If the voltage at the terminal 21 is negative, the diode 260 is blocked, no signal appears at the output terminal 262, and an H signal appears at the output terminal 264. If an F signal and an H signal appear simultaneously, a K signal appears at the set input of the flip-flop 273. If an F signal and a G signal appear simultaneously, an L signal appears at the reset input of the flip-flop 273. For the duration of a B timing signal at the terminal 13, the flip-flop 273 is set by means of a K signal and is reset by means of an L signal. At the output of the flip-flop 273 there appears a sequence of signals M, by means of which the electrical switch 18 is operable. The effect of the signal sequence M on the ignition voltage U2 corresponds to the effect of the E signal sequence in accordance with Figure 4.

Instead of the primary voltage U₁', the secondary voltage U1 may alternatively be used as the control voltage for the electronic control system 19. In the second embodiment, the different capacitors on the secondary side may be disregarded, as the switching points of the voltage characteristic U1, U₁' respectively, are identified by the electronic control system. Superimposition of a θ signal sequence of the type designated C in the arrangement of Figure 1, on the B signal sequence of Figures 7 and 8 for the generation of a plurality of ignition sparks at each firing instant is also advantageous.

As in the first embodiment, variation of the lengths of signals C and B leads again in the latter case to a plurality of ignition operations, as the voltage build-up of U2 in the second embodiment also starts again from the beginning after an ignition operation, so long as a B or a C signal is present.

WHAT WE CLAIM IS:-

1. A method of generating high voltage ignition sparks in an ignition system having an ignition coil, whose primary circuit includes an electrical switch and whose secondary circuit includes the series combination of a spark gap and a high-tension diode, but does not include a discrete capacitor across the spark gap other than that provided by an ignition cable coupling the ignition coil to the spark gap, in which, at the occurrence of each ignition trigger signal (B), the electrical switch is operated by means of a plurality of successive signals (E), whose lengths and intervals are so controlled by means of an electronic control system that a build-up of potential across the spark gap is achieved in the ignition cable capacitance, the collapse of which potential is prevented by the high-tension diode until said potential reaches the breakdown voltage of the spark gap whereupon an ignition spark occurs.

2. A method as claimed in Claim 1, in which the signal lengths (l) and signal intervals (p) of the multiple signals (E), during which the electrical switch is respectively closed and open, are so adjusted that time intervals can be defined which are necessary for achievement of peak voltage across the spark gap resulting from the respective signals (E).

3. A method as claimed in Claim 2, in which, for operation of the ignition coil as a flux transformer, the signal lengths (l) of the multiple signals (E) correspond substantially to the period necessary for achievement of peak voltage across the spark gap, resulting from each particular signal (E), and the signal intervals (p) between the multiple signals (E) correspond substantially to the period necessary for the voltage (U1) across the winding capacitance of the secondary winding of the ignition coil to drop from said peak value to a minimum.

4. A method as claimed in Claim 3, in which, for operation of the ignition coil as a flux transformer, the signal lengths (l) are given substantially by

$$l = \pi \quad L_s (C_1 + C_2) \quad 50$$

and the signal intervals (p) are given substantially by

$$p = \pi \quad L_h C_1$$

where C₁ is the effective winding capacitance of the secondary winding of the ignition coil, C₂ is the effective capacitance of the ignition lead to the spark gap, L_s is the leakage inductance of the secondary winding of the ignition coil, and L_h is the effective main inductance of the secondary winding of the ignition coil.

5. A method as claimed in Claim 2, in which for operation of the ignition coil as a blocking transformer, the signal lengths (l) of the multiple signals (E) move within the linear limits of the primary current rise (Ib) in the ignition coil, and the signal intervals (p) between the multiple signals (E) correspond substantially to the period necessary for achievement of the peak voltage levels across the spark gap attainable as a result of each particular signal (E), respectively.

6. A method as claimed in Claim 5, in which the duration of the signal intervals (p) is given substantially by the equation

$$p = \pi/2 \quad L_h (C_1 + C_2) \quad 65$$

where C_1 is the effective winding capacitance of the secondary winding of the ignition coil, C_2 is the effective capacitance of the ignition lead to the spark gap, and L_h is the effective main inductance of the secondary winding of the ignition coil.

5 7. A method as claimed in Claim 1, in which, for operation of the ignition coil as a flux transformer, the signal lengths (1) of the multiple signals (E), during which the electrical switch is closed, move within the linear limits of the primary current rise (Ib) in the ignition coil, and the signal intervals (p) between the multiple signals (E), during which the electrical switch is open, are very small compared with the signal lengths (1). 5

10 8. An ignition system comprising an ignition coil whose primary circuit includes an electrical switch and whose secondary circuit includes the series combination of a spark gap and a high-tension diode but does not include a discrete capacitor across the spark gap other than that provided by an ignition cable coupling the ignition coil to the spark gap, means for producing an ignition trigger signal (A), and an electronic control system for producing a plurality of successive signals (E) during the period of each ignition trigger signal (B) which are effective to operate said electrical switch and whose lengths and intervals are so controlled by the control system that a build-up of potential across the spark gap is achieved in the ignition cable capacitance, the collapse of which potential is prevented by the high-tension diode until said potential reaches the breakdown voltage of the spark gap whereupon an ignition spark occurs. 10 15

20 9. An ignition system as claimed in claim 8 in which the electronic control system for producing the multiple signals (E) includes a first frequency synthesizer whose output signal (E) has a fixed frequency and a fixed signal-length to signal-interval ratio, the frequency of the signal (E) of this frequency synthesizer being higher than the frequency of the ignition trigger signals (A). 20

25 10. An ignition system as claimed in Claim 9, in which the ignition trigger signals (A) are generated by means of a transducer which is adapted to be activated by means of the crankshaft of an internal combustion engine. 25

30 11. An ignition system as claimed in Claim 10, in which the output of said first frequency synthesizer and the transducer output for the ignition trigger signals are connected by way of an AND circuit to the control input of the electrical switch, a gate input, controlled by the ignition trigger signals, being provided in the frequency synthesizer for said AND circuit. 30

35 12. An ignition system as claimed in Claim 11, in which the output of a second frequency synthesizer, is connected to a further input of the AND circuit, the frequency of the second frequency synthesizer lying between the frequency of the multiple signals (E) and the frequency of the ignition trigger signals (A), and a gate input, which is controlled by means of the ignition trigger signals being provided in the frequency synthesizer for said AND current. 35

40 13. An ignition system as claimed in claim 8, in which the electronic control system comprises a differentiator which is connected to the ignition coil and a polarity identification circuit which is also connected to the ignition coil, the differentiator and the polarity identification circuit being connected by way of a logic circuit to the control input of the electrical switch. 40

45 14. An ignition system as claimed in Claim 13, in which, for controlling the electrical switch, there is provided in said logic circuit a bistable switching circuit, which is so controllable by means of the differentiator and the polarity identification circuit by way of logic gates, that a signal (L) appears at one input of the bistable switching circuit when the voltage (U_1') across the ignition coil reaches substantially a maximum, and a signal (K) appears at the other input of the bistable switching circuit when the voltage (U_1') across the ignition coil falls substantially to a minimum. 45

50 15. An ignition system as claimed in Claim 14, in which the logic gates are both AND gates. 50

55 16. An ignition system as claimed in any of Claims 13 to 15, in which the polarity identification circuit comprises a series combination of a diode and a resistor, which is connected to earth, the junction of the diode and the resistor serving as the output for the identification of positive polarity, and the same junction serving, by way of a reversing circuit, as the output for the identification of negative polarity. 55

60 17. A method of generating high voltage ignition sparks substantially as hereinbefore particularly described with reference to the accompanying drawings. 60

18. An ignition system substantially as hereinbefore particularly described with reference to and as illustrated in Figures 1 to 4 in Figure 5 in Figure 6 or in Figures 7 and 8 of the accompanying drawings. 60

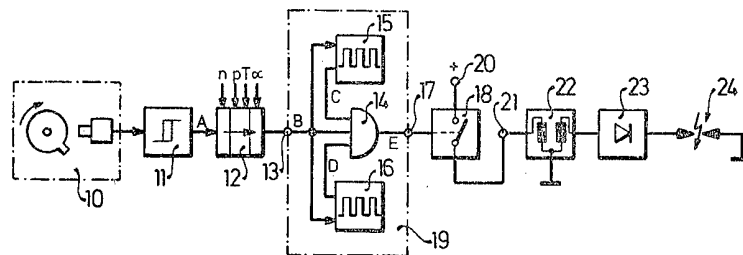
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Fig. 1



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Fig. 2

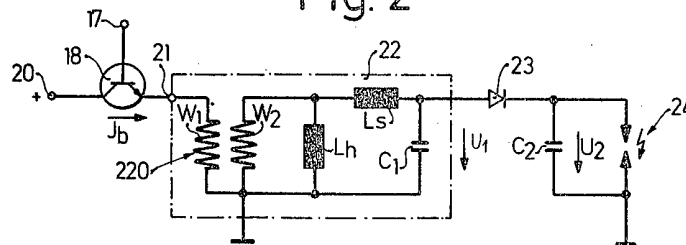
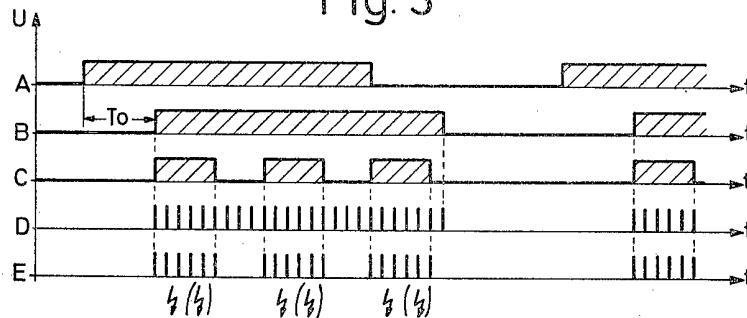


Fig. 3



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COMPLETE SPECIFICATION

4 SHEETS

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the Original on a reduced scale
Sheet 2

Fig. 4

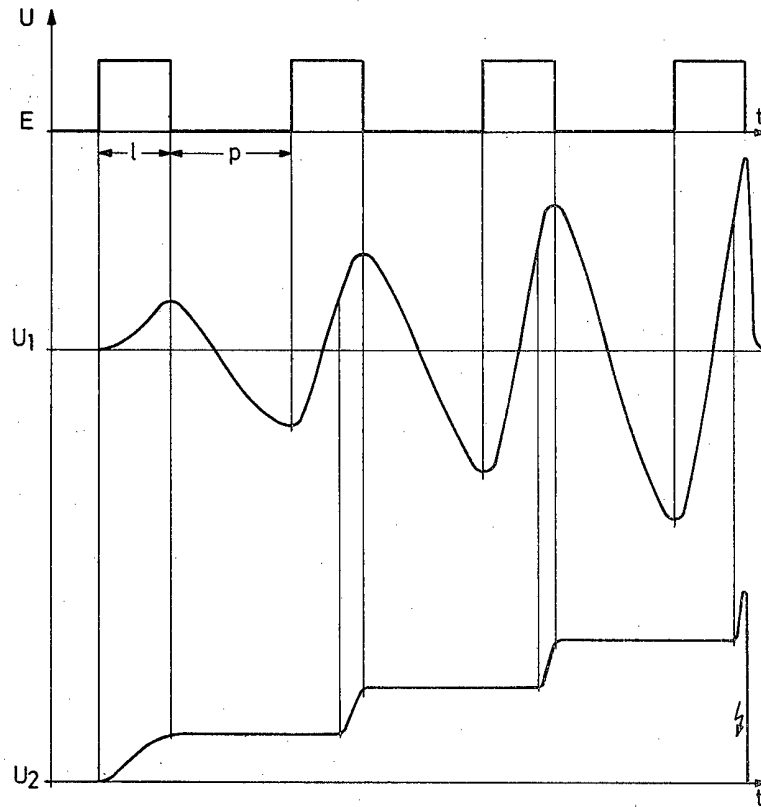


Fig.5

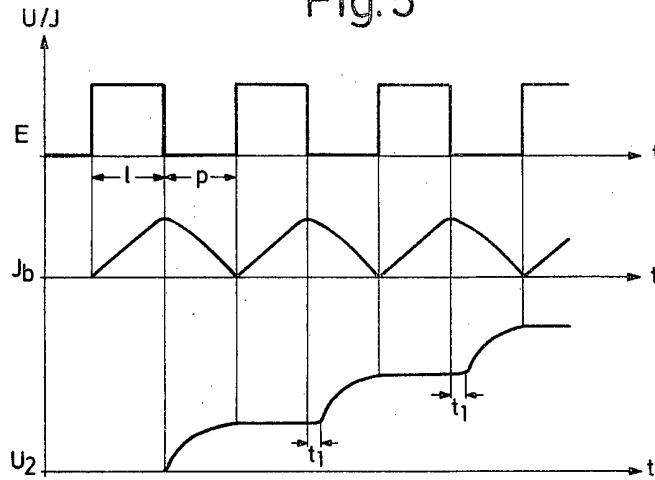
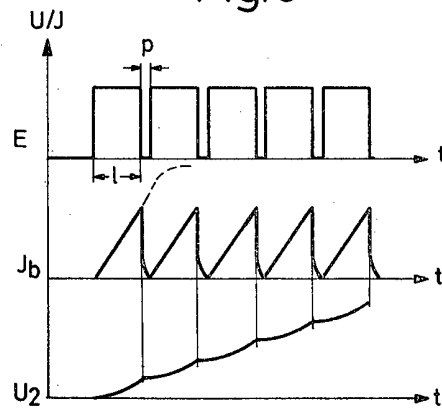


Fig.6



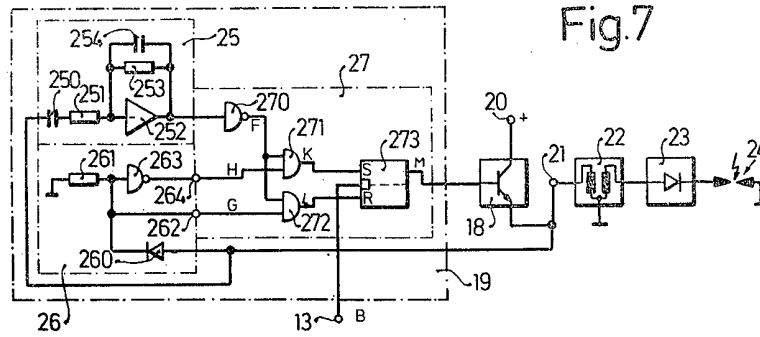


Fig.8

