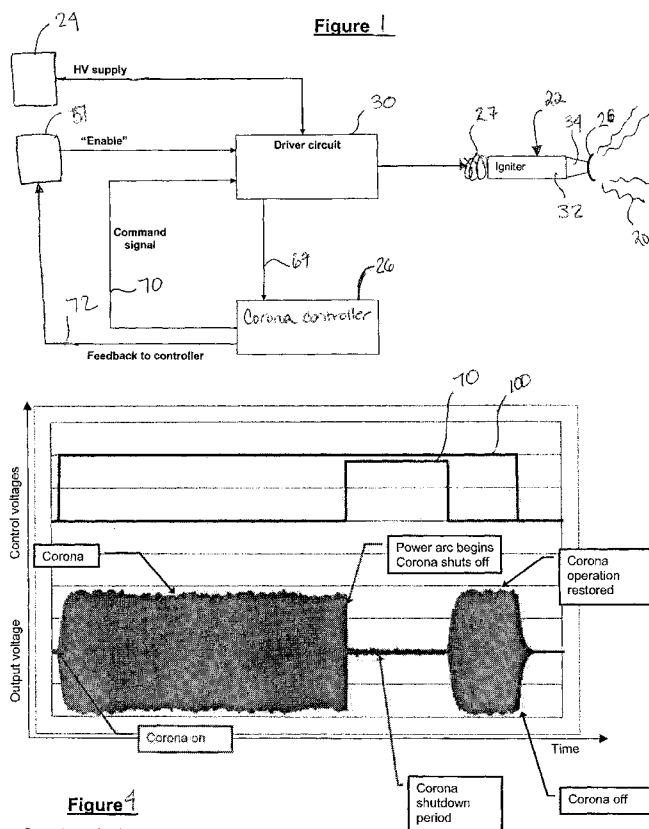




- | | |
|---|---|
| (51) International Patent Classification:
<i>F02P 23/04</i> (2006.01) | (74) Agents: STEARNS, Robert L. et al.; Dickinson Wright PLLC, 2600 W. Big Beaver Road, Suite 300, Troy, MI 48084-3312 (US). |
| (21) International Application Number:
PCT/US2012/032036 | (81) Designated States (<i>unless otherwise indicated, for every kind of national protection available</i>): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW. |
| (22) International Filing Date:
4 April 2012 (04.04.2012) | |
| (25) Filing Language:
English | |
| (26) Publication Language:
English | |
| (30) Priority Data:
61/471,452 4 April 2011 (04.04.2011) US
61/471,448 4 April 2011 (04.04.2011) US | |
| (71) Applicant (<i>for all designated States except US</i>): FEDERAL-MOGUL IGNITION COMPANY [US/US]; 26555 Northwestern Highway, Southfield, MI 48033 (US). | (84) Designated States (<i>unless otherwise indicated, for every kind of regional protection available</i>): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, |
| (72) Inventor; and
(75) Inventor/Applicant (<i>for US only</i>): BURROWS, John, Anthony [GB/GB]; 22 Yew Tree Drive, Northwich CW8 4NR (GB). | |

[Continued on next page]

- (54) Title:** SYSTEM AND METHOD FOR CONTROLLING ARC FORMATION IN A CORONA DISCHARGE IGNITION SYSTEM



- (57) Abstract:** A system and method for controlling an arc formation in corona discharge ignition system is provided. The system includes a corona igniter for receiving energy at a voltage and providing a corona discharge. An energy supply providing the energy to the corona igniter at a voltage. The system also includes a corona controller for initiating a decrease in the voltage of the energy provided to the corona igniter in response to the onset of arc formation. The voltage is decreased until the arcing is depleted, and then the voltage is increased again to resume the corona discharge. Controlling the arc formation provides improved energy efficiency during operation of the corona discharge ignition system.



LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, ML, MR, NE, SN, TD, TG).

— *before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments (Rule 48.2(h))*

Published:

— *with international search report (Art. 21(3))*

SYSTEM AND METHOD FOR CONTROLLING ARC FORMATION IN A CORONA DISCHARGE IGNITION SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. provisional application serial numbers 61/471,448 and 61/471,452, both filed April 4, 2011.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] This invention relates generally to corona discharge ignition systems, and more particularly to controlling arc formation in the system.

2. Related Art

[0003] Corona discharge ignition systems provide an alternating voltage and current, reversing high and low potential electrodes in rapid succession which makes arc formation difficult and enhances the formation of corona discharge. The system includes a corona igniter with a central electrode charged to a high radio frequency voltage potential and creating a strong radio frequency electric field in a combustion chamber. The electric field causes a portion of a mixture of fuel and air in the combustion chamber to ionize and begin dielectric breakdown, facilitating combustion of the fuel-air mixture. The electric field is preferably controlled so that the fuel-air mixture maintains dielectric properties and corona discharge occurs, also referred to as a non-thermal plasma. The ionized portion of the fuel-air mixture forms a flame front which then becomes self-sustaining and combusts the remaining portion of the fuel-air mixture. Preferably, the electric field is controlled so that the fuel-air mixture does not lose all dielectric properties, which would create a thermal plasma and an electric arc between the electrode and grounded cylinder walls, piston, metal shell, or other portion of the igniter. The electric arc, or arcing, can reduce energy efficiency and decrease the robustness of the ignition event of the system. An example of a corona discharge ignition system is disclosed in U.S. Patent No. 6,883,507 to Freen.

SUMMARY OF THE INVENTION

[0004] One aspect of the invention provides a method for controlling an arc formation in a corona discharge ignition system. The method includes providing energy to a corona igniter at a voltage; and decreasing the voltage of the energy provided to the corona igniter in response to an arc formation.

[0005] Another aspect of the invention provides a system employing the method. The system includes the corona igniter for receiving energy at a voltage and providing the corona discharge, and an energy supply for providing the energy to the corona igniter at a voltage. The system also includes a corona controller for initiating a decrease in the voltage of the energy provided to the corona igniter in response to the arc formation. Controlling the arc formation provides improved energy efficiency during operation of the corona discharge ignition system, improved durability of such a system, and may provide improved ignition performance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Other advantages of the present invention will be readily appreciated, as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0007] Figure 1 is a block diagram of a system for controlling an arc formation according to one embodiment of the invention;

[0008] Figure 2 is another block diagram of a system for controlling an arc formation showing components of a driver circuit according to another embodiment of the invention;

[0009] Figure 3 includes a graph illustrating operation of a corona ignition system without the present invention; and

[0010] Figure 4 includes a graph illustrating the advantage of operating the corona ignition system of Figure 3 with the present invention.

DETAILED DESCRIPTION

[0011] The invention provides a system and method for controlling an unintentional arc formation in an ignition system designed to provide a corona discharge 20. The system includes a corona igniter 22 for receiving energy at a voltage and providing the corona discharge 20 and an energy supply 24 for providing the energy to the

corona igniter **22** at the voltage. The system also includes an corona controller **26** for initiating a decrease in the voltage of the energy provided to the corona igniter **22** in response to an arc formation occurring after the corona discharge **20** is provided. The method employed in the system includes providing energy to the corona igniter **22** at a voltage; and decreasing the voltage of the energy provided to the corona igniter **22** in response to an arc formation.

[0012] The system and method provides several advantages over prior art systems used to control arcing. First, the system and method is low cost as it can use components of an existing corona discharge ignition system, without the need for complex digital components, calibration, or monitoring. Further, the system and method is extremely fast and can control arcing after the onset of the arc formation in a matter of nanoseconds or microseconds. Although the system and method is designed to provide corona discharge, it does not try to prevent the onset of arc formation. However, the arc formation is controlled and preferably extinguished if it does occur. Controlling the arc formation provides improved energy efficiency during operation of the corona discharge ignition system.

[0013] The system is typically employed in an internal combustion engine (not shown). The internal combustion engine includes a cylinder head, cylinder block, and piston defining a combustion chamber containing a combustible mixture of fuel and air. The corona igniter **22** is received in the cylinder head and includes an ignition coil **27** and a central electrode with a corona tip **28**, shown in Figure 1, extending into the combustion chamber. The energy supply **24** stores the energy and provides the energy to a driver circuit **30** and ultimately to the corona igniter **22**. The ignition coil receives energy from the energy supply **24** at a high radio frequency voltage, stores some of the energy, and then transmits the energy to the central electrode. In one embodiment, the ignition coil **27** receives the energy at a level up to 100,000 volts, a current below 5 amperes, and a frequency of 0.5 to 2.0 megahertz. The central electrode then emits a radio frequency electric field into the combustion chamber to ionize a portion of the fuel-air mixture and provide the corona discharge **20** in the combustion chamber. The corona igniter **22** typically includes an insulator **32** surrounding the central electrode, and the insulator **32** and central electrode are received in a metal shell **34**, as shown in Figure 1.

[0014] Figure 2 is a block diagram showing the corona ignition system and components of the driver circuit **30** according to one embodiment of the invention. The

driver circuit 30 includes a trigger circuit 36, a differential amplifier 38, a first switch 40, a second switch 42, a transformer 44, a current sensor 46, a low pass filter 48, and a clamp 50. The energy provided to the driver circuit 30 oscillates at the resonant frequency during operation of the corona ignition system. Figure 2 shows the energy being transmitted in signals 52 between the components. Figure 2 also includes a graph of the energy current between each of the components.

[0015] A main controller 51 of the engine control unit (not show) typically provides an enable signal 54 which turns on the differential amplifier 38. The trigger circuit 36 then initiates the oscillation of frequency and voltage of the energy flowing through the system to and from the corona igniter 22 in response to the enable signal 54. The trigger circuit 36 initiates the oscillation by creating a trigger signal 52 and transmitting the trigger signal 52 to the differential amplifier 38. The system has a period of resonance, and the trigger signal 52 is typically less than half of the period of resonance.

[0016] The differential amplifier 38 is activated upon receiving the trigger signal 52. The differential amplifier 38 then receives the energy at a positive input 56, amplifies the energy, and transmits the energy from a first output 58 and a second output 59.

[0017] The first switch 40 of the driver circuit 30 is enabled by the first output 58 of the differential amplifier 38, and directs the energy from the energy supply 24 to the corona igniter 22. The switches 40, 42 can be BJT, FET, IGBT, or other suitable types.

[0018] The transformer 44 of the driver circuit 30 includes a transformer input 60 for receiving the energy and transformer output 62 for transmitting the energy from the energy supply 24 to the corona igniter 22 and to the current sensor 46. The transformer 44 includes a primary winding 64 and secondary winding 66 transmitting the energy therethrough. The energy from the energy supply 24 first flows through the primary winding 64, which causes the energy to flow through the secondary winding 66. The components of the corona igniter 22 together provide the LC circuit of the system, also referred to as a resonant circuit or tuned circuit. By detection of the resonating current at sensor 46, the resonant frequency of the system is equal made to the resonant frequency of the LC circuit.

[0019] The current sensor 46 is typically a resistor and measures the current of energy at the output of the transformer 44 and the corona igniter 22. The current of energy at the output of the transformer 44 is typically equal to the current of energy at the corona igniter 22. The current sensor 46 then transmits the energy to the low pass filter 48. The low pass filter 48 removes unwanted frequencies and provides a phase shift in the current of energy. The phase shift is typically not greater than 180°.

[0020] The clamp 50 receives the energy from the low pass filter 48 and performs a signal conditioning on the current of energy. The signal conditioning can include converting the current of energy to a square wave and to a safe voltage. The clamp 50 then transmits the energy back to the negative input 68 of the differential amplifier 38.

[0021] Figure 2 shows the corona controller 26 between the clamp 50 and the differential amplifier 38, however it can be disposed in other locations in the system. Further, the corona controller 26 is shown in Figures 1 and 2 as a separate component, but may be coupled to or integrated integral with another component of the system. The onset of the arc formation is not intentionally prevented, but the system is typically designed to provide corona discharge 20, and therefore the onset of the arc formation is unintentional. The arc formation can be detected by a variety of different methods. It can be detected by the corona controller 26 or by a separate component. If the arc formation is detected by another component a notification signal 69 is transmitted to the corona controller 26.

[0022] Once the arc formation is detected, the corona controller 26 initiates a decrease in the voltage of the energy provided to the corona igniter 22. In one embodiment, the corona controller 26 initiates the voltage decrease by disabling the differential amplifier 38, or preventing the differential amplifier 38 from providing the energy to the corona igniter 22. The corona controller 26 can disable the differential amplifier 38 by sending a command signal 70 to the driver circuit 30, as shown in Figures 1 and 2. In another embodiment, the corona controller 26 initiates the voltage decrease by stopping the enable signal 54 provided by the main controller 26. In this case, the corona controller 26 sends a feedback signal 72 to the main controller 51, also shown in Figures 1 and 2. Once the main controller 26 receives the feedback signal 72 and stops the enable signal 54, the energy supply 24 decreases the voltage of the energy supplied to the corona igniter 22 or stops supplying the energy to the corona igniter 22.

[0023] The step of decreasing the voltage of the energy provided to the corona igniter 22 in response to an arc formation includes decreasing the voltage of the energy by at least 10%. For example, if the voltage provided to the corona igniter 22 is 40,000 volts, the voltage would be decreased to 36,000 volts or less. In one embodiment, the step of decreasing the voltage of the energy provided to the corona igniter 22 includes ceasing the step of providing energy to the corona igniter 22, such that no energy is provided to the corona igniter 22. Once energy supply is resumed, it may be at a lower level as previously described.

[0024] The step of decreasing the voltage of the energy provided to the corona igniter 22 in response to an arc formation includes decreasing the voltage for a period of time, preferably a short period of time. In one embodiment, the voltage is decreased for the duration of the command signal 70. The appropriate duration of the command signal 70 or amount of time is programmable and can be determined based on a variety of factors. For example, it may be appropriate to decrease the voltage or stop the supply of energy until a particular value or shape of voltage or current is observed, or until the frequency of the energy flowing through the system achieves a desirable pattern. Alternatively, the engine control unit (not shown) can determine the appropriate amount of time based on operating parameters.

[0025] The period of time may be for one oscillation period of the frequency of the energy flowing through the system, or may be for individual oscillation cycles at fixed intervals, or may be for a portion of each oscillation cycle. In one embodiment, the period of time is not greater than microseconds. After the appropriate amount of time and at a certain decreased voltage, the arc formation can no longer be maintained and is extinguished.

[0026] When energy is provided to the corona igniter 22, some of the energy is stored in the ignition coil 27. Therefore, the step of decreasing the voltage includes dissipating the energy from the coil 27. This causes the voltage of the energy at the corona tip 28 of the corona igniter 22 to fall as the energy stored in the coil 27 is dissipated. In one embodiment, the step of decreasing the voltage includes extinguishing both the arcing and the corona discharge 20 for the short period of time.

[0027] Immediately after the arc formation is extinguished, the method includes increasing the voltage of the energy provided to the corona igniter 22. The increased voltage of energy is applied immediately after the step of decreasing the voltage

applied to the corona igniter **22** for the period of time. Since it takes some time for the corona discharge **20** to grow large enough to reach a ground and form an arc again, there will be at least a period of time when the corona discharge **20** resumes. If the arcing occurs again, the system can again decrease the voltage of the energy provided to the corona igniter **22** to resume corona discharge **20**. The control of the arcing can occur very fast and the cycle can repeat several times in one ignition event.

[0028] In one embodiment, after the period of time when the voltage is decreased and after the arc formation is extinguished, the method includes increasing the voltage to the same voltage initially provided to the corona igniter **22**, before the period of time and before the onset of arc formation. For example, if the voltage initially provided to the corona igniter **22** is 40,000 volts, then the same 40,000 volts is again provided to the corona igniter **22**. In another embodiment, a lower voltage is provided to the corona igniter **22** after the arc formation is extinguished. For example, if the voltage initially provided to the corona igniter **22** is 40,000 volts, then 30,000 volts is provided to the corona igniter **22** after the arc formation is extinguished. Alternatively, a higher voltage could be provided to the corona igniter **22** after the arc formation is extinguished.

[0029] In one exemplary embodiment, the energy supply **24** is turned on and the energy supplied to the corona igniter **22** is at a first voltage. When arcing is detected, the energy supply **24** is turned off completely so that the voltage provided to the corona igniter **22** is decreased to zero and both the arcing and corona discharge **20** are extinguished for the short period of time. After the short period of time, the energy supply **24** is turned back on and the energy supplied to the corona igniter **22** is at a second voltage, which is greater than the first voltage.

[0030] Figure 3 includes a graph illustrating operation of a corona ignition system without the present invention. The voltage at the corona tip **28** is provided over a period of time. The enable signal **54** is shown at **100** and the command signal **70** is not employed. The voltage rises as energy is provided to the corona igniter **22** and the corona discharge **20** forms. Eventually, the corona discharge **20** contacts a grounded component and switches to arcing. The graph shows a sharp decrease in the voltage at the onset and during the arcing.

[0031] Figure 4 includes a graph illustrating operation with the present invention. The enable signal **54** is shown at **100** and the command signal **70** is employed. The voltage rises as energy is provided to the corona igniter **22** and the corona discharge

20 forms. Eventually, the corona discharge **20** contacts a grounded component and switches to arcing, and the voltage decreases sharply. However, when the arc formation occurs, the command signal **70** is transmitted from the corona controller **26** to the main controller **26** and the voltage of the energy supply **24** is decreased. The command signal **70** is transmitted for a predetermined period of time, which is until the arcing is extinguished. At that point, the command signal **70** ends, voltage increases, and the corona discharge **20** resumes.

[0032] Obviously, many modifications and variations of the present invention are possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the appended claims.

CLAIMS

What is claimed is:

1. A method for controlling an arc formation in corona discharge ignition system, comprising:
providing energy to a corona igniter at a voltage; and
decreasing the voltage of the energy provided to the corona igniter in response to an arc formation.
2. The method of claim 1 wherein the step of decreasing the voltage of the energy provided to the corona igniter includes decreasing the voltage by at least 10%.
3. The method of claim 1 wherein the step of decreasing the voltage of the energy provided to the corona igniter includes decreasing the voltage of the energy for a period of time.
4. The method of claim 3 wherein the period of time is not greater than microseconds.
5. The method of claim 3 including increasing the voltage of the energy provided to the corona igniter immediately after the period of time.
6. The method of claim 5 wherein the voltage of the energy provided to the corona igniter before the period of time is at a first voltage, and the step of increasing the voltage of the energy after the period of time includes providing the energy at a second voltage being less than the first voltage.
7. The method of claim 6 wherein the step of decreasing the voltage of the energy provided to the corona igniter includes ceasing the step of providing energy to the corona igniter for the period of time.

8. The method of claim 1 wherein the step of decreasing the voltage of the energy provided to the corona igniter includes ceasing the step of providing energy to the corona igniter for a period of time.

9. The method of claim 1 wherein the step of providing energy to the corona igniter includes providing energy to a coil of the corona igniter and storing the energy in the coil, and the step of decreasing the voltage includes dissipating the energy from the coil.

10. The method of claim 1 wherein the arc formation is unintentional.

11. The method of claim 1 including providing a corona discharge prior to the arc formation.

12. The method of claim 1 wherein the step of decreasing the voltage occurs until the energy achieves a predetermined voltage or current.

13. The method of claim 1 wherein the step of decreasing the voltage occurs until the energy has a predetermined frequency pattern.

14. A system for controlling an arc formation in corona discharge ignition system, comprising:

- a corona igniter for receiving energy at a voltage and providing a corona discharge;
- an energy supply for providing the energy to a corona igniter at a voltage; and
- an corona controller for initiating a decrease in the voltage of the energy provided to the corona igniter in response to an arc formation.

15. The system of claim 14 including a differential amplifier for receiving energy from the energy supply and amplifying the energy and providing the amplified energy to the corona igniter, and wherein the corona controller initiates the decrease in the voltage by preventing the differential amplifier from providing the energy to the corona igniter.

16. The system of claim 14 including a main controller providing an enable signal allowing the energy supply to provide the energy to the corona igniter and wherein the corona controller initiates the decrease in the voltage by stopping the enable signal.

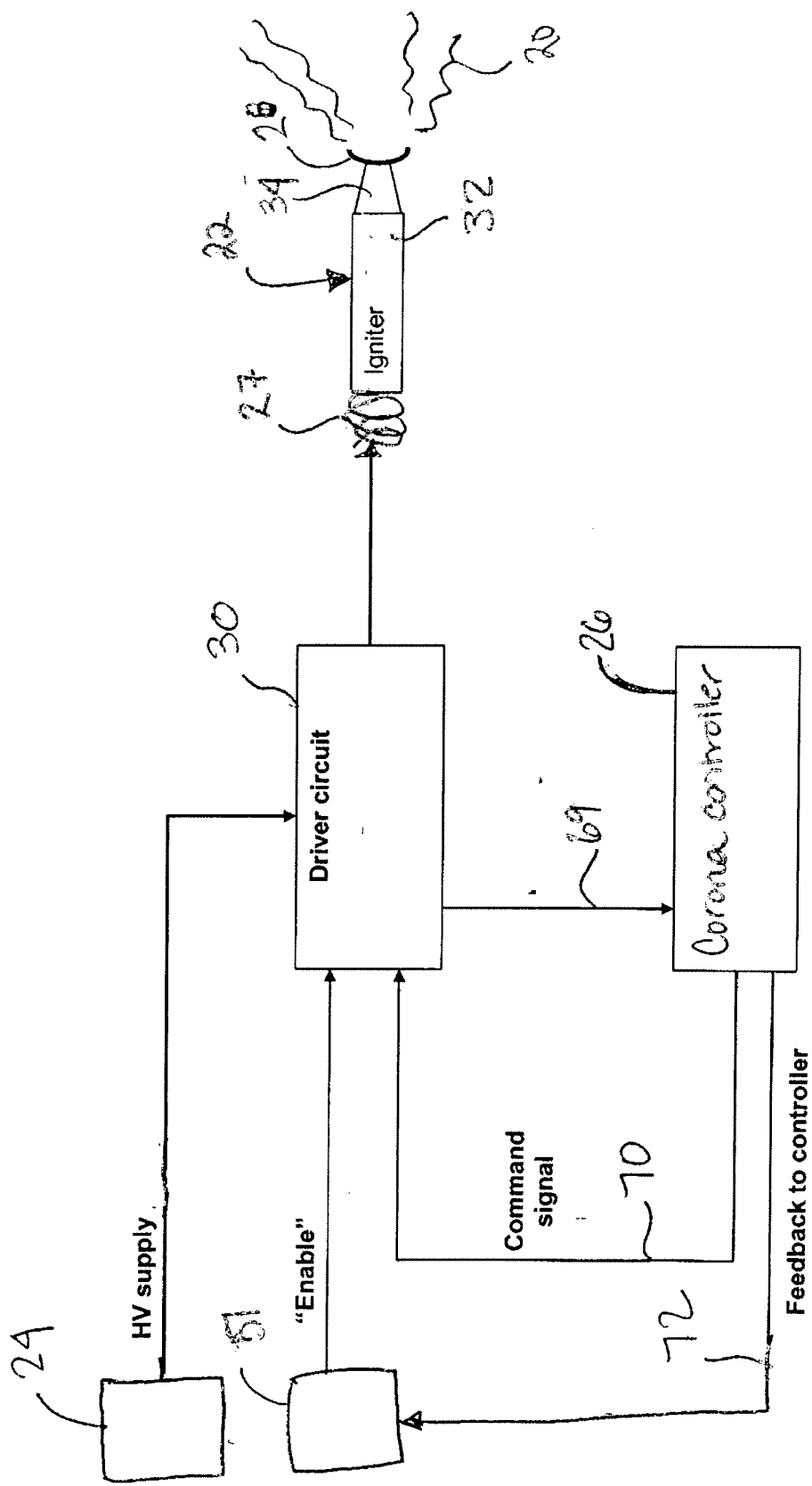


Figure 1

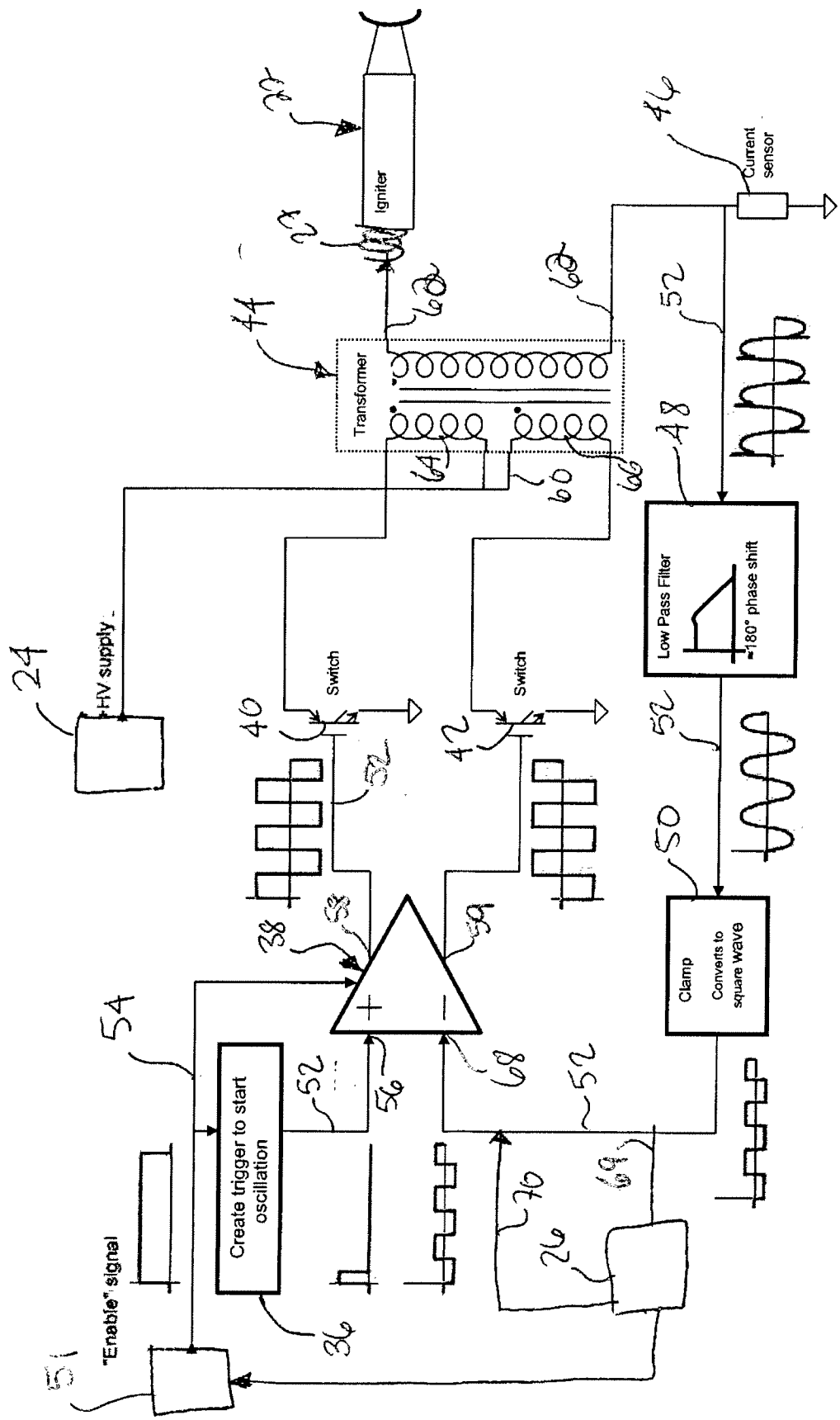


Figure 2

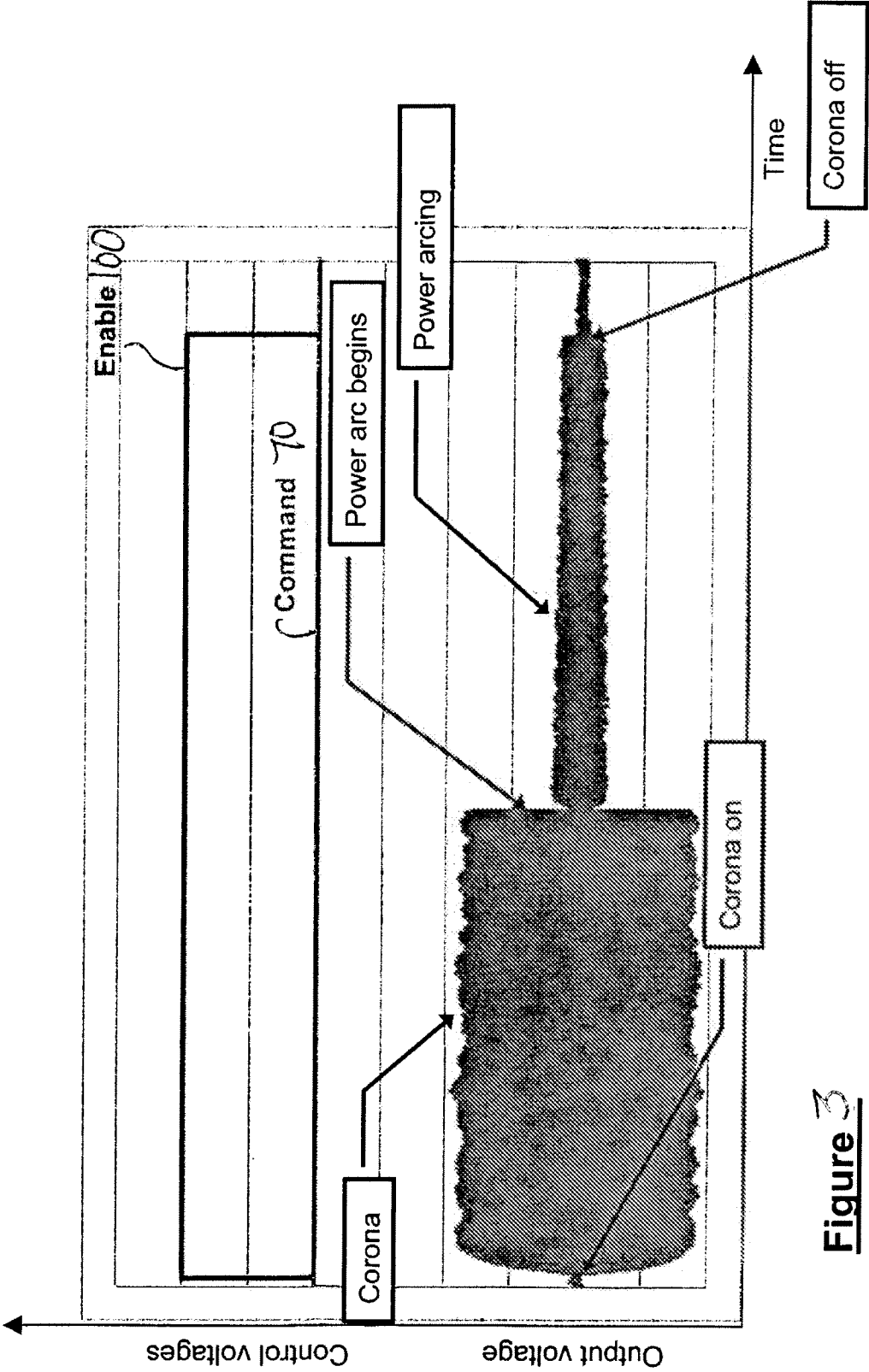


Figure 3

Operation without this invention

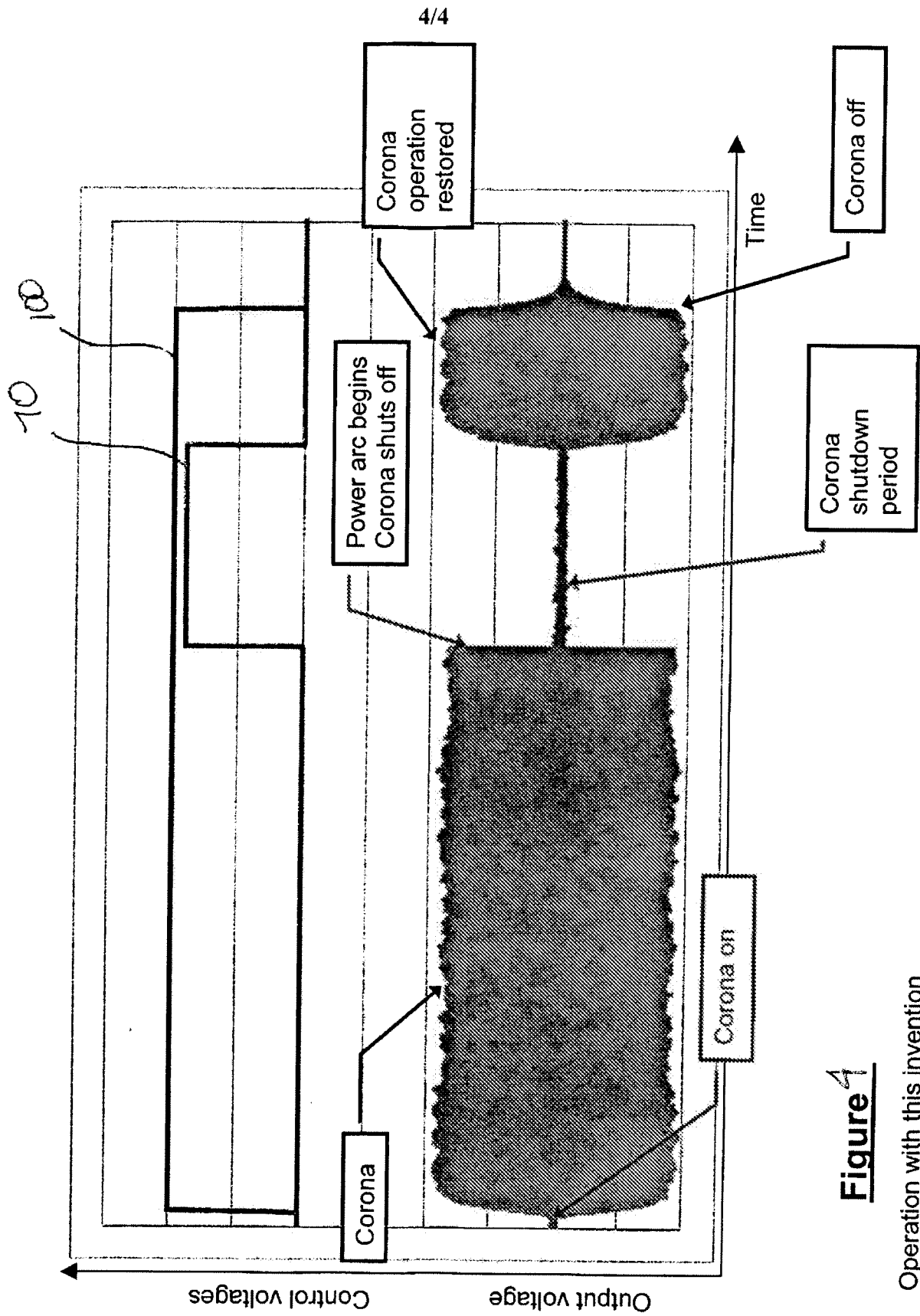


Figure 4

Operation with this invention

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/032036

A. CLASSIFICATION OF SUBJECT MATTER

INV. F02P23/04

ADD.

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)

F02P

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/011838 A1 (BORG WARNER INC [US]; FREEMAN PAUL DOUGLAS [US]) 28 January 2010 (2010-01-28) abstract paragraphs [0066] - [0078], [0099] figures 1,5,6,10,12	1-16
A	US 2004/129241 A1 (FREEMAN PAUL DOUGLAS [US]) 8 July 2004 (2004-07-08) cited in the application abstract figures 1-6 paragraphs [0036] - [0038] ----- -/-	1,14



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

30 August 2012

Date of mailing of the international search report

11/09/2012

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Trotureau, Damien

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/032036

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/147239 A1 (LU HANG [AT] ET AL) 17 June 2010 (2010-06-17) abstract figures paragraphs [0006], [0010] claims 1,7,12 -----	1,14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/032036

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2010011838 A1	28-01-2010	CN 102149917 A	10-08-2011
		EP 2318691 A1	11-05-2011
		JP 2011529154 A	01-12-2011
		US 2011114071 A1	19-05-2011
		WO 2010011838 A1	28-01-2010

US 2004129241 A1	08-07-2004	AT 487059 T	15-11-2010
		AT 543000 T	15-02-2012
		AU 2003297149 A1	10-08-2004
		EP 1588048 A1	26-10-2005
		EP 2067986 A2	10-06-2009
		JP 4240225 B2	18-03-2009
		JP 4731591 B2	27-07-2011
		JP 2006513351 A	20-04-2006
		JP 2009008100 A	15-01-2009
		US 2004129241 A1	08-07-2004
		WO 2004063560 A1	29-07-2004

US 2010147239 A1	17-06-2010	AT 12376 U1	15-04-2012
		AT 507748 A1	15-07-2010
		EP 2199597 A2	23-06-2010
		US 2010147239 A1	17-06-2010
