

METHOD AND SYSTEM TO USE COMBINATION FILLER WIRE FEED AND HIGH INTENSITY ENERGY SOURCE FOR WELDING WITH CONTROLLED ARCING FREQUENCY

INCORPORATION BY REFERENCE

[001] The present application claim priority to Provisional Application 61/943,633, filed on February 24, 2014, and US Patent Application 14/620,258, filed February 12, 2015, which are incorporated herein by reference in their entirety, and the present application is a continuation-in-part of and claims priority to U.S. Patent Application No. 13/212,025, filed on August 17, 2011, which is incorporated herein by reference in its entirety, which is a continuation in part of U.S. Patent Application No. 12/352,667, filed on January 13, 2009, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[002] Certain embodiments relate to filler wire overlaying applications as well as welding and joining applications. More particularly, certain embodiments relate to systems and methods to utilize a hot-wire deposition process with either a laser or an arc welding process. Still more particularly, the invention provides a consumable deposition system, a welding system and a method of depositing a consumable according to the preamble of claim 1, 12 and 18, respectively.

BACKGROUND

[003] Recently, advances in hot-wire welding have been achieved. However, some of these processes and systems may not provide the desired or necessary heat input

into the weld or overlaying operation. Thus, it is may desirable to provide additional heat into the weld or overlaying operation.

[004] Further limitations and disadvantages of conventional, traditional, and proposed approaches will become apparent to one of skill in the art, through comparison of such approaches with embodiments of the present invention as set forth in the remainder of the present application with reference to the drawings.

SUMMARY

[005] Embodiments of the present invention comprise a system and method to deposit material in either an overlaying, cladding, joining or welding process using a hot-wire technique. Embodiments of the present utilize a hot-wire deposition method in which a plurality of arcing events are created between the wire and the workpiece to aid in the process. The arcing events can aid in controlling the heat input into the process, as well as increase the performance of the process, without compromising the integrity of the process.

[006] These and other features of the claimed invention, as well as details of illustrated embodiments thereof, and further embodiments, are given and will be more fully understood from the following description, claims and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[007] The above and/or other aspects of the invention will be more apparent by describing in detail exemplary embodiments of the invention with reference to the accompanying drawings, in which:

[008] FIG. 1 is a diagrammatical representation of an exemplary embodiment of a hot-wire and laser system;

- [0009] FIG. 2 is a diagrammatical representation of an exemplary embodiment of a hot-wire and arc welding system;
- [0010] FIG. 3 is a further diagrammatical representation of an exemplary embodiment of a hot-wire power supply and a system in which it is utilized;
- [0011] FIG. 4 is a diagrammatical representation of exemplary voltage and current waveform for a hot-wire process in accordance with the present invention; and
- [0012] FIG. 5 is a diagrammatical representation of an exemplary hot-wire current waveform synchronized with an arc welding current waveform.

DETAILED DESCRIPTION

[0013] Exemplary embodiments of the invention will now be described below by reference to the attached Figures. The described exemplary embodiments are intended to assist the understanding of the invention, and are not intended to limit the scope of the invention in any way. Like reference numerals refer to like elements throughout.

[0014] FIG. 1 illustrates a functional schematic block diagram of an exemplary embodiment of a combination filler wire feeder and energy source system 100 for performing any of brazing, cladding, building up, filling, hard-facing overlaying, and joining/welding applications. The system 100 includes a laser subsystem capable of focusing a laser beam 110 onto a workpiece 115 to heat the workpiece 115. The laser subsystem is a high intensity energy source. The laser subsystem can be any type of high energy laser source, including but not limited to carbon dioxide, Nd:YAG, Yb-disk, YB-fiber, fiber delivered or direct diode laser systems. Further, other types of laser systems can be used if they have sufficient energy. Other embodiments of the system may include at least one of an electron beam, a plasma arc welding subsystem, a gas tungsten arc welding subsystem, a gas

metal arc welding subsystem, a flux cored arc welding subsystem, and a submerged arc welding subsystem serving as the high intensity energy source. The following specification will repeatedly refer to the laser system, beam and power supply, however, it should be understood that this reference is exemplary as any high intensity energy source may be used. For example, a high intensity energy source can provide at least 500 W/cm^2 . The laser subsystem includes a laser device 120 and a laser power supply 130 operatively connected to each other. The laser power supply 130 provides power to operate the laser device 120.

[0015] The system 100 also includes a hot filler wire feeder subsystem capable of providing at least one resistive filler wire 140 to make contact with the workpiece 115 in the vicinity of the laser beam 110. Of course, it is understood that by reference to the workpiece 115 herein, the molten puddle is considered part of the workpiece 115, thus reference to contact with the workpiece 115 includes contact with the puddle. The hot filler wire feeder subsystem includes a filler wire feeder 150, a contact tube 160, and a hot wire power supply 170. During operation, the filler wire 140, which leads the laser beam 110, is resistance-heated by electrical current from the hot wire welding power supply 170 which is operatively connected between the contact tube 160 and the workpiece 115. In accordance with an embodiment of the present invention, the hot wire welding power supply 170 is a pulsed direct current (DC) power supply, although alternating current (AC) or other types of power supplies are possible as well. The wire 140 is fed from the filler wire feeder 150 through the contact tube 160 toward the workpiece 115 and extends beyond the tube 160. The extension portion of the wire 140 is resistance-heated such that the extension portion approaches or reaches the melting point before contacting a weld puddle on the workpiece. The laser beam 110 serves to melt some of the base metal of the workpiece 115 to form a weld puddle and also to melt the wire 140 onto the workpiece 115. The power supply 170

provides a large portion of the energy needed to resistance-melt the filler wire 140. The feeder subsystem may be capable of simultaneously providing one or more wires, in accordance with certain other embodiments of the present invention. For example, a first wire may be used for hard-facing and/or providing corrosion resistance to the workpiece, and a second wire may be used to add structure to the workpiece.

[0016] The system 100 further includes a motion control subsystem capable of moving the laser beam 110 (energy source) and the resistive filler wire 140 in a same direction 125 along the workpiece 115 (at least in a relative sense) such that the laser beam 110 and the resistive filler wire 140 remain in a fixed relation to each other. According to various embodiments, the relative motion between the workpiece 115 and the laser/wire combination may be achieved by actually moving the workpiece 115 or by moving the laser device 120 and the hot wire feeder subsystem. In FIG. 1, the motion control subsystem includes a motion controller 180 operatively connected to a robot 190. The motion controller 180 controls the motion of the robot 190. The robot 190 is operatively connected (e.g., mechanically secured) to the workpiece 115 to move the workpiece 115 in the direction 125 such that the laser beam 110 and the wire 140 effectively travel along the workpiece 115. In accordance with an alternative embodiment of the present invention, the laser device 110 and the contact tube 160 may be integrated into a single head. The head may be moved along the workpiece 115 via a motion control subsystem operatively connected to the head.

[0017] In general, there are several methods that a high intensity energy source/hot wire may be moved relative to a workpiece. If the workpiece is round, for example, the high intensity energy source/hot wire may be stationary and the workpiece may be rotated under the high intensity energy source/hot wire. Alternatively, a robot arm or linear tractor may

move parallel to the round workpiece and, as the workpiece is rotated, the high intensity energy source/hot wire may move continuously or index once per revolution to, for example, overlay the surface of the round workpiece. If the workpiece is flat or at least not round, the workpiece may be moved under the high intensity energy source/hot wire as shown in FIG. 1. However, a robot arm or linear tractor or even a beam-mounted carriage may be used to move a high intensity energy source/hot wire head relative to the workpiece.

[0018] The system 100 further includes a sensing and current control subsystem 195 which is operatively connected to the workpiece 115 and the contact tube 160 (i.e., effectively connected to the output of the hot wire power supply 170) and is capable of measuring a potential difference (i.e., a voltage V) between and a current (I) through the workpiece 115 and the hot wire 140. The sensing and current control subsystem 195 may further be capable of calculating a resistance value ($R=V/I$) and/or a power value ($P=V*I$) from the measured voltage and current. In general, when the hot wire 140 is in contact with the workpiece 115, the potential difference between the hot wire 140 and the workpiece 115 is zero volts or very nearly zero volts. However, in other exemplary embodiments the voltage drop between the wire 140 and the workpiece 115 is in the range of 2 to 8 volts. As a result, the sensing and current control subsystem 195 is capable of sensing when the resistive filler wire 140 is in contact with the workpiece 115 and is operatively connected to the hot wire power supply 170 to be further capable of controlling the flow of current through the resistive filler wire 140 in response to the sensing, as is described in more detail later herein. In accordance with another embodiment of the present invention, the sensing and current controller 195 may be an integral part of the hot wire power supply 170.

[0019] In accordance with an embodiment of the present invention, the motion controller 180 may further be operatively connected to the laser power supply 130 and/or the

sensing and current controller 195. In this manner, the motion controller 180 and the laser power supply 130 may communicate with each other such that the laser power supply 130 knows when the workpiece 115 is moving and such that the motion controller 180 knows if the laser device 120 is active. Similarly, in this manner, the motion controller 180 and the sensing and current controller 195 may communicate with each other such that the sensing and current controller 195 knows when the workpiece 115 is moving and such that the motion controller 180 knows if the hot filler wire feeder subsystem is active. Such communications may be used to coordinate activities between the various subsystems of the system 100.

[0020] As described above, the high intensity energy source can be any number of energy sources, including welding power sources. An exemplary embodiment of this is shown in Figure 2, which shows a system 200 similar to the system 100 shown in Figure 1. Many of the components of the system 200 are similar to the components in the system 100, and as such their operation and utilization will not be discussed again in detail. However, in the system 200 the laser system is replaced with an arc welding system, such as a GMAW system. The GMAW system includes a power supply 213, a wire feeder 215 and a torch 212. A welding electrode 211 is delivered to a molten puddle via the wire feeder 215 and the torch 212. The operation of a GMAW welding system of the type described herein is well known and need not be described in detail herein. It should be noted that although a GMAW system is shown and discussed regarding depicted exemplary embodiments, exemplary embodiments of the present invention can also be used with GTAW, FCAW, MCAW, and SAW systems, cladding systems, brazing systems, and combinations of these systems, etc., including those systems that use an arc to aid in the transfer of a consumable to a molten puddle on a workpiece. Not shown in Figure 2 is a shielding gas system or sub arc flux system which can be used in accordance with known methods.

[0021] Like the laser systems described above, the arc generation systems (that can be used as the high intensity energy source) are used to create the molten puddle to which the hot wire 140 is added using systems and embodiments as described in detail above. However, with the arc generation systems, as is known, an additional consumable 211 is also added to the puddle. This additional consumable adds to the already increased deposition performance provided by the hot wire process described herein. This performance will be discussed in more detail below.

[0022] Further, as is generally known arc generation systems, such as GMAW use high levels of current to generate an arc between the advancing consumable and the molten puddle on the workpiece. Similarly, GTAW systems use high current levels to generate an arc between an electrode and the workpiece, into which a consumable is added. As is generally known, many different current waveforms can be utilized for a GTAW or GMAW welding operation, such as constant current, pulse current, etc. However, during operation of the system 200 the current generated by the power supply 213 can interfere with the current generated by the power supply 170 which is used to heat the wire 140. Because the wire 140 is proximate to the arc generated by the power supply 213 (because they are each directed to the same molten puddle, similar to that described above) the respective currents can interfere with each other. Specifically, each of the currents generates a magnetic field and those fields can interfere with each other and adversely affect their operation. For example, the magnetic fields generated by the hot wire current can interfere with the stability of the arc generated by the power supply 213. That is, without proper control and synchronization between the respective currents the competing magnetic fields can destabilize the arc and thus destabilize the process. Therefore, exemplary embodiments

utilize current synchronization between the power supplies 213 and 170 to ensure stable operation, which will be discussed further below.

[0023] As stated above, magnetic fields induced by the respective currents can interfere with each other and thus embodiments of the present invention synchronize the respective currents. Synchronization can be achieved via various methods. For example, the sensing and current controller 195 can be used to control the operation of the power supplies 213 and 170 to synchronize the currents. Alternatively a master-slave relationship can also be utilized where one of the power supplies is used to control the output of the other. The control of the relative currents can be accomplished by a number of methodologies including the use of state tables or algorithms that control the power supplies such that their output currents are synchronized for a stable operation. This will be discussed further below. For example, a dual-state based system and devices similar to that described in US Patent Publication No. 2010/0096373 can be utilized. US Patent Publication No. 2010/0096373, published on April 22, 2010, is incorporated herein by reference in its entirety.

[0024] A more detailed discussion of the structure, use, control, operation and function of the systems 100 and 200 is set forth in the U.S. Patent Applications to which the present application claims priority (at the beginning of the present application), each of which are fully incorporated herein by reference in their entirety as they relate to the systems described and discussed herein and alternative embodiments discussed therein, which are not repeated here for efficiency and clarity.

[0025] Figure 3 depicts a schematic representation of another exemplary embodiments of a system 300 of the present invention. Like the system 200, the system 300 util-

izes a combined hot-wire and arc welding process. The function and operation of the system 300 is similar to that of the system 200, and as such similar functionality will not be repeated. As shown, the system 300 comprises a leading arc welding power supply 301 which leads the trailing hot wire 140. The power supply 301 is shown as a GMAW type power supply, but embodiments are not limited to this as a GTAW type power supply can also be utilized. The welding power supply 301 can be of any known construction. Also depicted is a hot-wire power supply 310 (which can be the same as that shown in Figures 1 and 2) along with some of the components therein. As explained above, it may be desirable to synchronize the current waveforms output from each of the power supplies 301 and 310. As such a synchronization signal 303 can be utilized to ensure that the operation of the power supplies are synchronized, which will be further described below.

[0026] The hot-wire power supply 310 comprises an inverter power section 311 which receives input power (which can be either AC or DC) and converts the input power to an output power that is used to heat the wire 140 so that it can be deposited into a puddle on the workpiece W. The inverter power section 311 can be constructed as any known inverter type power supply which is used for welding, cutting or hot-wire power supplies. The power supply also contains a preset heating voltage circuit 313 which utilizes input data related to the process to set a preset heating voltage for the output signal of the power supply 310 so that the wire 140 is maintained at a desired temperature so that it is properly deposited onto the workpiece W. For example, the preset heating voltage circuit 313 can utilize settings such as wire size, wire type and wire feed speed to set the preset heating voltage to be maintained during the process. During operation the output heating signal is maintained such that the average voltage of the output signal, over a predetermined duration of time or number of cycles, is maintained at the preset heating voltage level. In some embodiments, the preset heating voltage level is in the range of 2 to 9 volts. Further, in

exemplary embodiments of the present invention, the wire feed speed of the wire 140 can affect the optimal preset heating voltage level, such that when the wire feed speed is low (at or below 200 in/min) the preset heating voltage level is in the range of 2 to 4 volts, whereas if the wire feed speed is high (above 200 in/min) the preset heating voltage level is in the range of 5 to 9 volts. Further, in some exemplary embodiments, when the current is low (at or below 150 amps) the preset heating voltage level is in the range of 2 to 4 volts, whereas if the current is high (above 150 amps) the preset heating voltage level is in the range of 5 to 9 volts. Thus, during operation the power supply 310 maintains the average voltage between the wire 140 and the workpiece W at the preset heating voltage level for the given operation. In other exemplary embodiments, the preset heating voltage circuit 313 can set an average voltage range, where the average voltage is maintained within the preset range. By maintaining the detected average voltage at the preset heating voltage level or within the preset heating voltage range, the power supply 310 provides a heating signal which heats the wire 140 as desired, but avoiding the creation of an arc. In exemplary embodiments of the present invention, average voltage is measured over a predetermined period of time, such that a running average is determined during the process. The power supply utilizes a time averaging filter circuit 315 which senses the output voltage through the sense leads 317 and 319 and conducts the voltage averaging calculations described above. The determined average voltage is then compared to the preset heating voltage as shown in Figure 3.

[0027] Of course, in other exemplary embodiments the power supply 310 can use current and/or power preset thresholds to control the output signal of the power supply. The operation of such systems would be similar to the voltage based control described above.

[0028] The power supply 310 also contains an arc detect threshold circuit 321 which compares the detected output voltage - through the sense leads 319 and 317 - and compares the detected output voltage with an arc detection voltage level to determine an arcing event has, or will occur, between the wire 140 and the workpiece W. If the detected voltage exceeds the arc detection voltage level the circuit 321 outputs a signal to the inverter power section 311 (or a controller device) which causes the power section 311 to shut off the output power to distinguish or suppress the arc, or otherwise prevent its creation. In some exemplary embodiments the arc detection voltage level is in the range of 10 to 20 volts. In other exemplary embodiments the arc detection voltage level is in the range of 12 to 19 volts. In further exemplary embodiments, the arc detection voltage level is determined based on the preset heating voltage level and/or the wire feed speed. For example, in some exemplary embodiments, the arc detection voltage level is in the range of 2 to 5 times the preset heating voltage level. In other exemplary embodiments, the anode and cathode voltage level for any shielding gas being used can affect the preset heating voltage level. In some exemplary applications the arc detection voltage will be in the range of 7 to 10 volts, while in other embodiments it will be in the range of 14 to 19 volts. In exemplary embodiments of the present invention, the arc detection voltage will be in the range of 5 to 8 volts higher than the preset heating voltage level.

[0029] The power supply 310 also includes a nominal pulsed waveform circuit 323 which generates the waveform to be used by the inverter power section 311 to output the desired heating waveform to the wire 140 and workpiece W. As shown the nominal pulsed waveform circuit 323 is coupled to the arc welding power supply 301 via the synchronization signal 303 so that the output waveforms from each of the respective power supplies are synchronized as described herein.

[0030] As shown, the nominal pulsed waveform circuit 323 synchronizes its output signal with the arc welding power supply 301 and outputs a generated heating waveform to a multiplier which also receives an error signal from the comparator 327 as shown. The error signal allows for adjustment of the output command signal to the inverter power section 311 to maintain the desired average voltage as described above.

[0031] It should be noted that the above described circuits and basic functionality is similar to that utilized in welding and cutting power supplies and as such the detailed construction of these circuits need not be described in detail herein. Further, it is also noted that some or all of the above functionality can be accomplished via a single controller within the power supply 310.

[0032] As discussed at length in the US Patent applications to which the present application claims priority, which are fully incorporated herein by reference as though the disclosures are included herein in their entirety, when using hot-wire joining and overlaying methods it is desirable to prevent the creation of an arc between the wire 140 and the puddle as the wire 140 is typically to be maintained in constant contact with the puddle. However, it has been discovered that in some hot-wire applications it may be desirable to have discrete arcing events occurring during the hot wire process to add heat to the process and puddle as desired. This is particularly true in joining or overlaying applications where at least one of the workpieces is coated, for example galvanized steel. This will be explained further below with reference to Figure 4.

[0033] Figure 4 depicts an exemplary voltage and current waveforms for a hot wire process as described herein. As shown, the current waveform 500 comprises a plurality of heating pulses 501 having a peak current level 503. The peak current level can be in the

range of 200 to 700 amps, and the peak current level 503 is chosen to provide the desired heating and melting of the wire 140 during the process. Similarly, the voltage waveform 400 shows a plurality of voltage pulses 401 having a peak voltage 403. However, also shown is an Arc Event in which an arc is generated briefly between the wire 140 and the puddle. During the arc event the wire 140 loses contact with the puddle causing the voltage to spike to an arc level 405. At that time, the hot-wire power supply detects that an arc event has occurred and turns off the current to extinguish or suppress the arc 507. In exemplary embodiments of the present invention, the arc exists for a time within the range of 350 to 1000 microseconds. In other exemplary embodiments, the arc exists for a time within the range of 500 to 800 microseconds. With such relatively short durations for the arc, heat can be added to the puddle without causing excessive turbulence in the puddle from the arc. The power supply can use various control methodology to detect an arcing event. In exemplary embodiments of the present invention, the power supply sets a threshold value such that when the threshold value is exceeded the power supply determines that an arc event has occurred. As explained previously, in some exemplary embodiments the arc detection voltage level is in the range of 10 to 20 volts. In other exemplary embodiments the arc detection voltage level is in the range of 12 to 19 volts. In further exemplary embodiments, the arc detection voltage level is determined based on the preset heating voltage level and/or the wire feed speed.

[0034] After an arc is created, the wire 140 is no longer in contact with the puddle and gap exists between the wire 140 and the puddle. After the power supply turns off the heating current (507) the power supply then provides an open circuit voltage (OCV) 407 having a peak level 409 to the wire 140 so that the power supply is capable of detecting contact between the wire 140 and the puddle again - because the wire 140 is still being fed by the wire feeder at the puddle. In exemplary embodiments of the present invention, the

OCV is in the range of 10 to 25 volts. In other exemplary embodiments, the OCV is in the range of 17 to 22 volts. The selected OCV for the operation can be based on a number of parameters, including but not limited to the wire type and wire diameter. When the wire 140 makes contact with the puddle (at 410) the power supply detects the contact (using any known contact sensing control methodology) and turns off the OCV and starts to provide a heating current to the wire 140. As shown in Figure 4, the current can peak at an after contact peak level 509 and is then maintained at a lead-in current 511 level.

[0035] The lead-in current 509 is a relatively low current level (compared to the pulse peak levels) and is used to allow the wire 140 to reenter the puddle for a predetermined distance and to allow for pulse synchronization (discussed further below). The lead in current is maintained for a duration TLI (which will also be explained further below). The lead in current is set by the power supply and is a current level selected based on a number of factors, including any one, or all of: wire feed speed, wire type, wire diameter, hot-wire pulsing frequency, and hot-wire pulse peak 503 current levels, and can be about 1/10 of the peak current level. Typically, the lead-in current 511 is low compared to the peak 503 levels. In exemplary embodiments, the pulse peak current to lead in current ratio is in the range of 10:1 to 5:1. In exemplary embodiments, the lead in current is in the range of 25 to 100 amps, and in other embodiments is in the range of 40 to 80 amps. In other exemplary embodiments, the lead-in can be set by using a power level, as opposed to setting using a current level. In such embodiments, the lead-in power level can be in the range of 100 to 1500 watts. In further exemplary embodiments, the lead in current level 509 is a level which is less than the average current for the waveform 500. In additional exemplary embodiments, the lead in current 509 has a current level which is less than the average current level of the hot wire portion of the waveform - for example, as shown in Figure 4 less than the average current for the heating pulses 501' between arc events. In exem-

plary embodiments, the peak and average current of the lead in current 509 is less than the average current for the waveform 500 and the average current of the hot wire current pulses 501' between arc events.

[0036] As explained above, the lead-in current is maintained for a duration TLI which allows the wire 140 to repenetrate the puddle to a desired depth. As such, the TLI is determined based on at least the wire feed speed of the wire 140. In exemplary embodiments, lead in duration TLI is in the range of 5 to 20 milliseconds, and the off time 507 is in the range of 1 to 7 milliseconds. In exemplary embodiments, the combined time for the off time 507 and the TLI is in the range of 6 to 20 milliseconds. However, as explained previously with respect to at least Figures 2 and 3, in some exemplary embodiments the hot-wire process is coupled with an arc welding process, such as GMAW, operating in the same puddle. In such embodiments, the lead-in duration TLI is a duration based on the wire feed speed of the wire 140 and based on the initiation of a current pulse from an arc welding process working with the hot-wire process. When using hot-wire processes coupled with arc welding processes it is desirable to synchronize the current pulses from each of the respective processes. Thus, in such embodiments the hot-wire power supply initiates the first pulse 501' after the duration TLI only after (1) the expiration of a determined lead-in delay to allow the wire 140 to properly penetrate the puddle, and (2) to coincide with the initiation of the next arc welding pulse in the arc welding waveform. By having the duration TLI extended to satisfy these conditions, it is ensured that the wire 140 has properly penetrated the puddle to start the hot wire pulses 501 again, and that the hot-wire current waveform is properly synchronized with a concurrently used arc welding process. This is pictorially represented in Figure 5, where the welding process utilizes a hot wire current waveform 500 synchronized with a pulsed arc welding process (for example GMAW) using the current waveform 600. As described in the priority applications referenced at the be-

ginning of this application and fully incorporated herein, and US Patent Application titled METHOD AND SYSTEM TO USE COMBINATION FILLER WIRE FEED AND HIGH INTENSITY ENERGY SOURCE FOR WELDING, which is also fully incorporated herein by reference in its entirety, and is filed concurrently herewith, it is desirable in some applications to synchronize the pulses of the respective waveforms. Thus, in exemplary embodiments of the present invention, as shown in Figure 5, the lead-in duration TLI is a combination of the penetration duration T_p and the synchronization duration T_s . The penetration duration T_p is determined by the hot-wire power supply, based on at least the wire feed speed of the wire 140, to ensure proper penetration of the wire 140 into the puddle and the synchronization duration T_s is the time between the expiration of the penetration duration T_p and the initiation of the next arc welding pulse 601'. That is, typically the maximum duration of the lead-in duration TLI (or lead-in period) will be the penetration duration T_p (or penetration period) and the duration of a background portion 603 of the arc welding waveform. This ensures that the wire 140 is fully penetrated into the puddle and that the two respective waveforms will be synchronized. Thus, during operation of exemplary embodiments of the present invention, the hot-wire power supply will determine a penetration duration T_p and hold the lead in current 511 at the lead in current level for that duration T_p , and after the expiration of the penetration period T_p the hot wire power supply waits for a pulse initiation signal from a controller or the arc welding power supply. Based on that initiation or synchronization signal, the hot-wire power supply initiates the first pulse 501' following the lead in current 511 to coincide with the next pulse 601' in the arc welding process.

[0037] It should be noted that Figure 5 shows the two respective waveforms 500/600 having no phase shift, such that the respective pulses 501' and 601' will be initiated at the same time. However, other exemplary embodiments can utilize a phase shift

between the current waveforms 500 and 600 such that the pulses of the respective waveforms are synchronized but phase shifted with respect to each other. In such embodiments, the lead in duration TLI will be of such a length to ensure that the pulses 501' and 601' are initiated at the appropriate times relative to each other, with the appropriate phase shift and after the expiration of the penetration duration. In some exemplary embodiments, the wire is allowed to penetrate the puddle by a distance which is about the same as the diameter of the wire.

[0038] As discussed previously, the arc events are used to input additional heat in the process. To accomplish this, the hot-wire power supply 170 is controlled such that the arcing events occur at a frequency in the range of 1 to 20 Hz. In other exemplary embodiments, the arcing events occur at a frequency in the range of 1 to 10Hz. By maintaining the arcing frequency at a regular interval, additional heat can be added to the process in a controlled manner without destabilizing the hot wire, or arc welding processes. In some exemplary embodiments, the frequency of the arcing events can be adjusted to change the heat input during the process. That is, during a first portion of a process it may be desirable to use an arcing frequency of 3 Hz, while in another portion of the process it may be desirable to have an arcing frequency of 10Hz. This the power supply 170 can control the waveforms 400/500 to achieve the desired arcing event frequency for different portions of a process, and thus provide greater control of the overall heat input of the process.

[0039] Figure 4 also shows a plurality n of current and voltage pulses in between arcing events. As shown, the current pulses 501/501' have a relative constant peak current level 503. That is the peak current levels of these pulses are about the same, but can differ due to the realities of the welding operation and may not be exactly the same for each pulse. However, as shown the corresponding voltage pulses have a generally increasing

peak voltage 403 from a first voltage pulse 401' (after an arcing event) to the last complete voltage pulse 401'' (after an arcing event). It has been discovered that, in some exemplary embodiments, it is desirable to allow the peak voltage level for pulses 401' to 401'' to increase gradually between arcing events. Typically, this voltage increase occurs - at least in part - due to increasing heat in the wire 140 and in the process, which affects the overall resistance of the wire 140 and thus causes the voltage to generally rise from a first peak voltage level to a second, higher, peak voltage level over the plurality of voltage pulses between arcing events. It should be noted, that although Figure 4 depicts the peak voltage level for the pulses 401' through 401'' increasing from pulse-to-pulse (which is applicable for some embodiments), some exemplary embodiments are not limited to this. That is, in some exemplary embodiments, although there is a general increase in voltage over the pulses (as shown by slope 413), not every following pulse will be higher in peak voltage than its preceding pulse. In some embodiments, following pulse can have the same, or even slightly lower peak voltage than its immediately preceding pulse. However, the last pulse 401'' will have a higher peak voltage than the first pulse 401'. Further, although the embodiment shown shows a generally linear increase in peak voltage (slope 413), other embodiments are not limited to a linear voltage increase. In exemplary embodiments, the difference in peak voltage from the first voltage pulse 401' to the last voltage pulse 401'' is in the range of 2 to 8 volts. In other exemplary embodiments, the difference is in the range of 3 to 6 volts. Further, in exemplary embodiments of the present invention, the number of voltage pulses 401'-401'' between arcing events is in the range of 8 to 22. In other exemplary embodiments, the number of voltage pulses are in the range of 12 to 18 in between arcing events.

[0040] While the invention has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made

and equivalents may be substituted without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from its scope. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed, but that the invention will include all embodiments falling within the scope of the present application.

Reference Numbers

- 100 system
- 110 laser beam
- 115 workpiece
- 120 laser device
- 125 direction
- 130 laser power supply
- 140 filler wire
- 150 filler wire feeder
- 160 contact tube
- 170 hot wire power supply
- 180 motion controller
- 190 robot
- 195 current control subsystem
- 200 system
- 211 welding electrode
- 212 torch
- 213 power supply
- 215 wire feeder
- 300 system
- 301 power supply
- 303 synchronization signal
- 310 power supply
- 311 inverter power section
- 313 preset heating voltage circuit
- 315 time averaging filter circuit

317 sense lead
319 sense lead
323 nominal pulsed waveform circuit
327 comparator
400 voltage waveform
401 voltage pulses
401' first voltage pulse
401'' last pulse
403 peak voltage
405 arc level
407 open circuit voltage (OCV)
409 peak level
500 current waveform
501 hot wire pulses
501' heating pulses
503 peak current level
507 off time
509 lead-in
511 lead-in
600 current waveform
601' Pulse

W workpiece

TLI duration

Tp penetration duration

Ts synchronisation duration

CLAIMS

1. A consumable deposition system (100), comprising:
 - a power supply (170) which provides a current waveform (500) to a consumable (140) to be deposited into a molten puddle on a workpiece (115), characterized in that said current waveform comprises:
 - an arc event portion which results in an arc between said consumable and said puddle; and
 - a hot wire portion during which a heating current is provided to said consumable and no arc is created between said consumable (115) and said puddle;
 - wherein said power supply (170) detects the creation of said arc during said arc event and after detection reduces said current waveform to extinguish said arc, and after extinguishing said arc provides an open circuit voltage to said consumable (115) to detect contact between said consumable (140) and said puddle, and upon detecting said contact said power supply (170) provides a lead in current to said consumable,
 - wherein said lead in current (509, 511) is less than said heating current (501') of said hot wire portion and where said lead in current is maintained for a predetermined duration, and
 - wherein at the end of said predetermined duration said power supply (170) provides said hot wire portion of said current waveform to said consumable (140).
2. The system of claim 1, wherein at least one current pulse is provided during said arc event portion.

3. The system of claim 1 or 2, wherein said heating current includes a plurality of current pulses.
4. The system of one of the claims 1 to 3, wherein said lead in current is less than the average current of said current waveform (500).
5. The system of one of the claims 1 to 4, wherein said lead in current is less than the average current of said hot wire portion of said current waveform (500).
6. The system of one of the claims 1 to 5, wherein said arc is maintained by said power supply for a duration in the range of 350 to 1000 microseconds; and/or wherein an arc detection voltage for said power supply to detect said arc event is in the range of 10 to 20 volts; and/or wherein said open circuit voltage is in the range of 10 to 25 volts.
7. The system of one of the claims 1 to 6, wherein a ratio of said peak current of said heating pulses to said lead in current is in the range of 10:1 to 5:1.
8. The system of one of the claims 1 to 7, wherein after the arc event portion said power supply (170) turns off its output current for a duration in the range of 1 to 7 milliseconds; and/or wherein said power supply provides said lead in current for a duration in the range of 5 to 20 milliseconds; and/or wherein a duration of time between said power supply (170) extinguishing said arc and providing a heating pulse is in the range of 6 to 20 milliseconds.

9. The system of one of the claims 1 to 8, wherein at least one of said lead in current and a duration of said lead in current is determined by said power supply (170) based on a wire feed speed of said consumable.

10. The system of one of the claims 1 to 9, wherein said power supply outputs a power in the range of 100 to 1500 watts during said lead in current; and/or wherein said power supply outputs said current waveform such that said arc event portion occurs at a frequency in the range of 1 to 20 Hz.

11. The system of one of the claims 1 to 10, wherein said power supply (170) changes a frequency of said arc event portion.

12. A welding system, comprising:

a welding power supply which outputs a welding current waveform having a plurality of welding current pulses, where said welding current waveform is provided to an electrode to create an arc between said electrode and a puddle on a workpiece (115); and

a hot wire power supply (170) which provides a second current waveform to a consumable (115) to be deposited into said puddle, said second current waveform comprising:

an arc event portion having at least one current pulse which results in an arc between said consumable (115) and said puddle; and

a hot wire portion during which at least one heating current pulse is provided to said consumable (115) and no arc is created between said consumable (115) and said puddle;

wherein said hot wire power supply (170) detects the creation of said arc during said arc event and after detection reduces said second current waveform to extinguish said arc, and after extinguishing said arc provides an open circuit voltage to said consumable to

detect contact between said consumable and said puddle, and upon detecting said contact said hot wire power supply provides a lead in current to said consumable,

wherein said lead in current is less than a peak current of said at least one heating current pulse and where said lead in current is maintained for a predetermined duration, and

wherein after the expiration of said predetermined duration said hot wire power supply (170) provides said hot wire portion of said current waveform to said consumable such that a first heating pulse after the expiration of said lead in current is synchronized with one of said welding current pulses of said welding current waveform.

13. The system of claim 12, wherein said welding power supply and said hot wire power supply are controlled such that the first heating pulse and said one of said welding current pulses are initiated at the same time.

14. The system of claim 18, wherein said arc is maintained by said hot wire power supply for a duration in the range of 350 to 1000 microseconds; and/or wherein an arc detection voltage for said hot wire power supply to detect said arc event is in the range of 10 to 20 volts; and/or wherein said open circuit voltage is in the range of 10 to 25 volts; and/or wherein a ratio of said peak current of said heating pulses to said lead in current is in the range of 10:1 to 5:1; and/or wherein after the arc event portion said hot wire power supply turns off its output current for a duration in the range of 1 to 7 milliseconds.

15. The system of one of the claims 12 to 14, wherein said lead in current is determined by said hot wire power supply based on a wire feed speed of said consumable.

16. The system of one of the claims 12 to 15, wherein said power supply outputs a power in the range of 100 to 1500 watts during said lead in current; and/or wherein said hot wire power supply outputs said current waveform such that said arc event portion occurs at a frequency in the range of 1 to 20 Hz.
17. The system of one of the claims 12 to 16, wherein said power supply changes a frequency of said arc event portion.
18. A method of depositing a consumable (140), said method comprising:
providing a consumable (140) to a molten puddle in a workpiece (115);
providing a current waveform (500) to said consumable (140) from a power supply (170), said current waveform (500) comprising:
an arc event portion during which an arc is generated between said consumable and said puddle; and
a hot wire portion during which a heating current is provided to said consumable and no arc is created between said consumable and said puddle;
detecting the creation of said arc during said arc event;
reducing said current waveform to extinguish said arc; and
providing an open circuit voltage to said consumable to detect contact between said consumable and said puddle;
after detection of said contact, providing a lead in current to said consumable;
wherein said lead in current is less than a peak current of said heating current and where said lead in current is maintained for a predetermined duration, and
wherein at the end of said predetermined duration, providing said hot wire portion of said current waveform to said consumable.

19. A consumable deposition system, comprising:

a power supply which provides a current waveform to a consumable to be deposited into a molten puddle on a workpiece, said current waveform comprising:

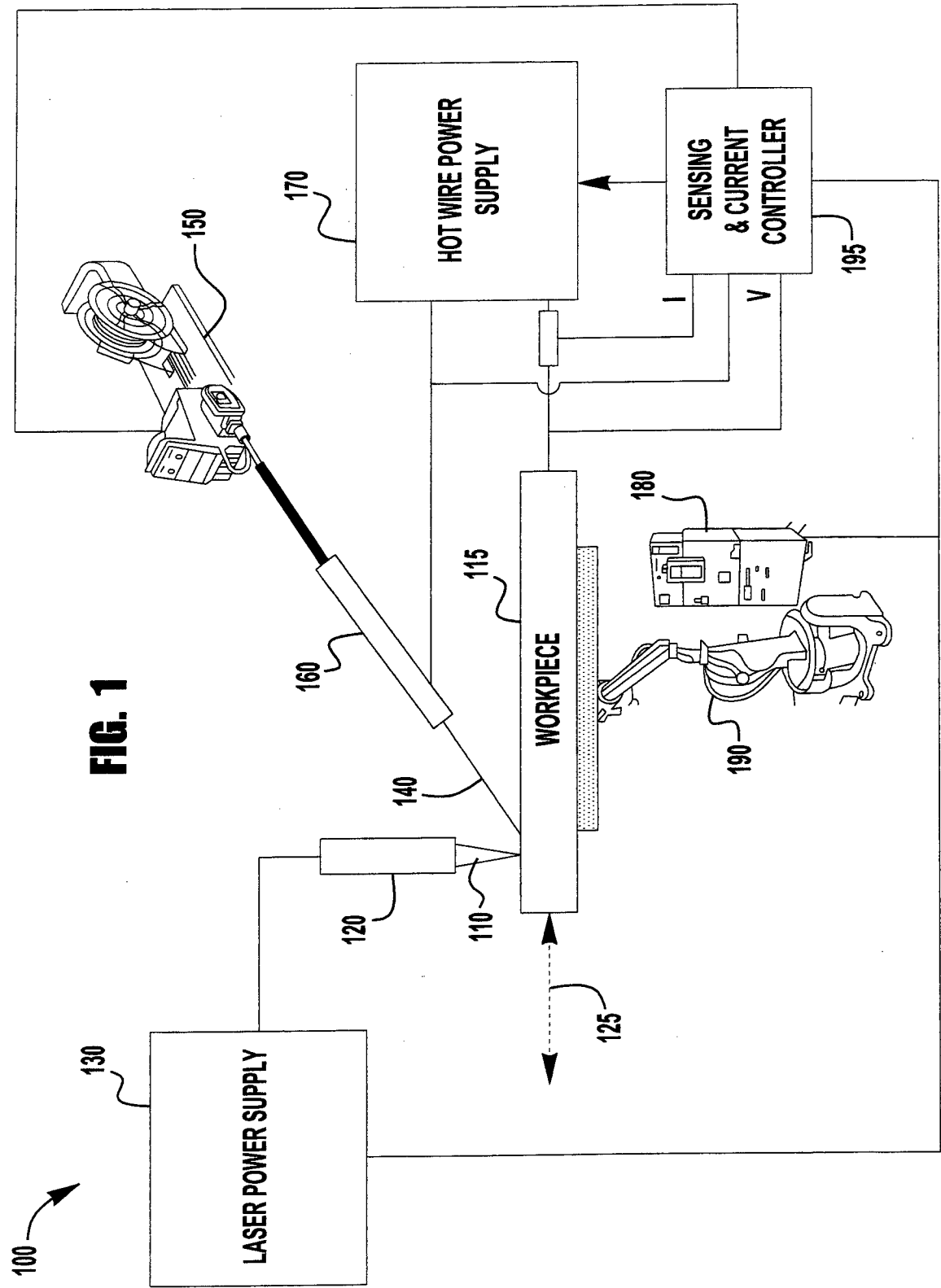
an arc event portion during which at least one current pulse is provided which results in an arc between said consumable and said puddle; and

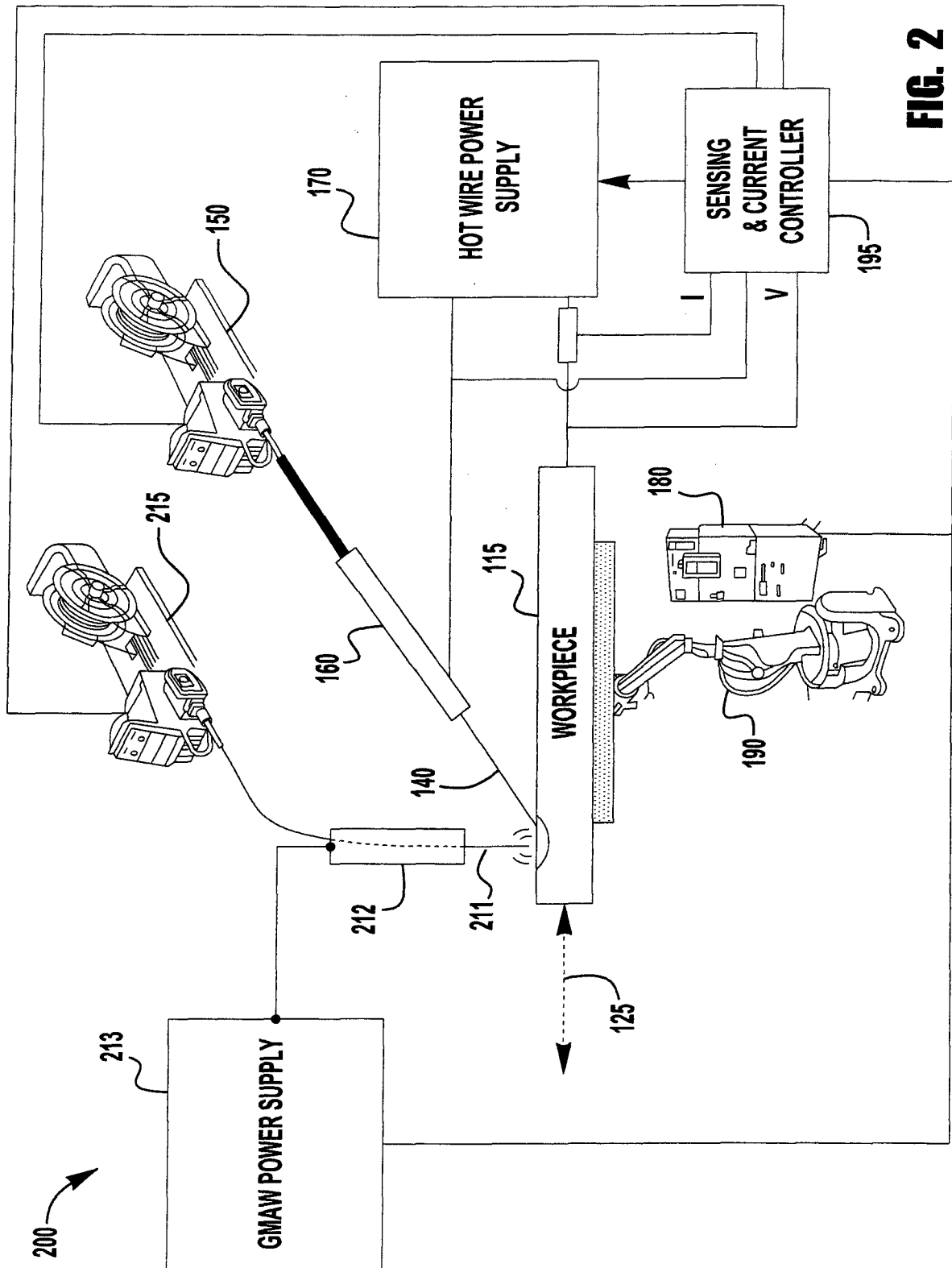
a hot wire portion during which a plurality of heating current pulses are provided to said consumable and no arc is created between said consumable and said puddle;

wherein said power supply detects the creation of said arc during said arc event and after detection reduces said current waveform to extinguish said arc, and after extinguishing said arc provides an open circuit voltage to said consumable to detect contact between said consumable and said puddle, and upon detecting said contact said power supply provides a lead in current to said consumable,

wherein said lead in current is less than a peak current of said plurality of heating current pulses and where said lead in current is maintained for a predetermined duration, and

wherein at the end of said predetermined duration said power supply provides said hot wire portion of said current waveform to said consumable.



**FIG. 2**

3/5

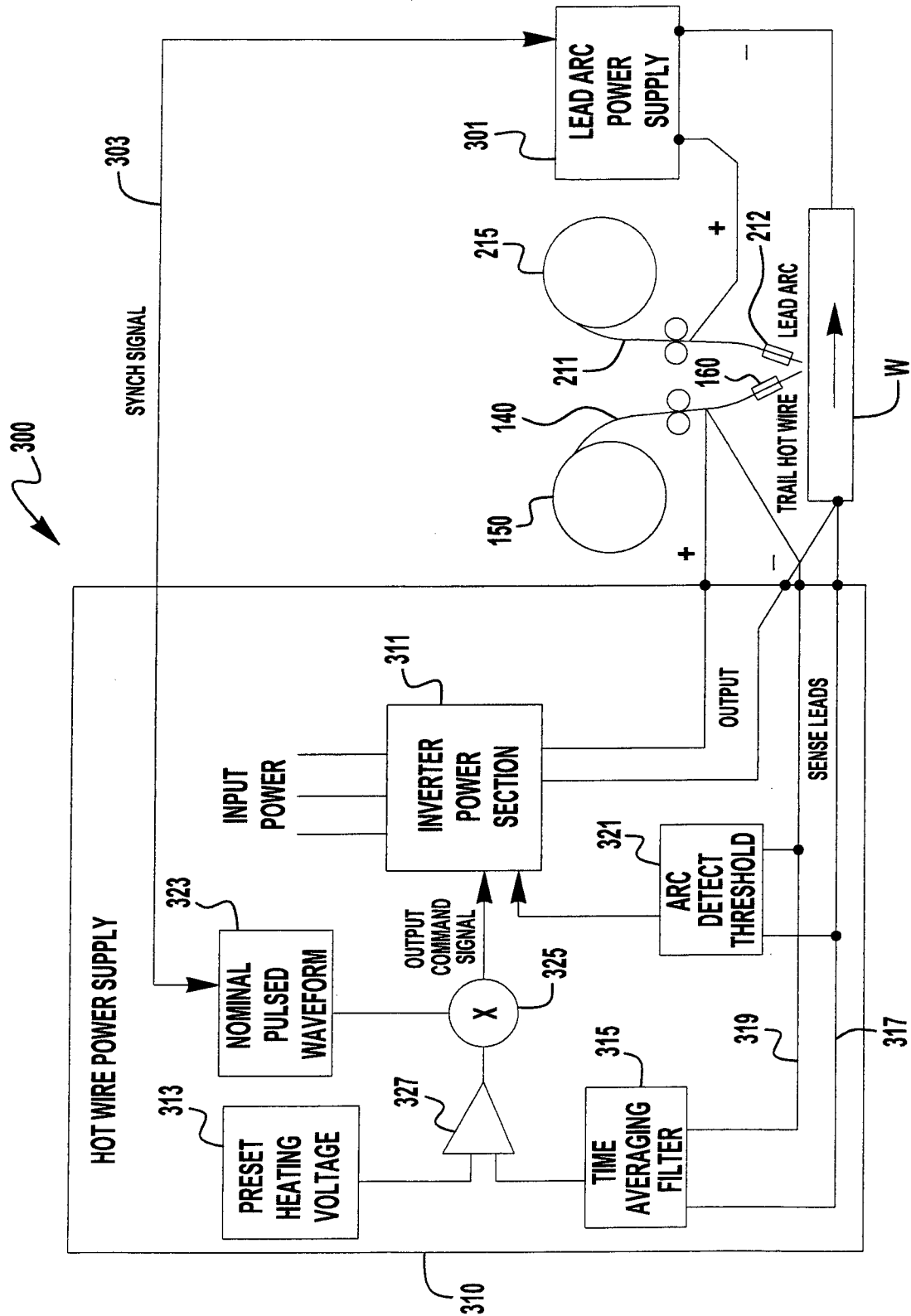


FIG. 3

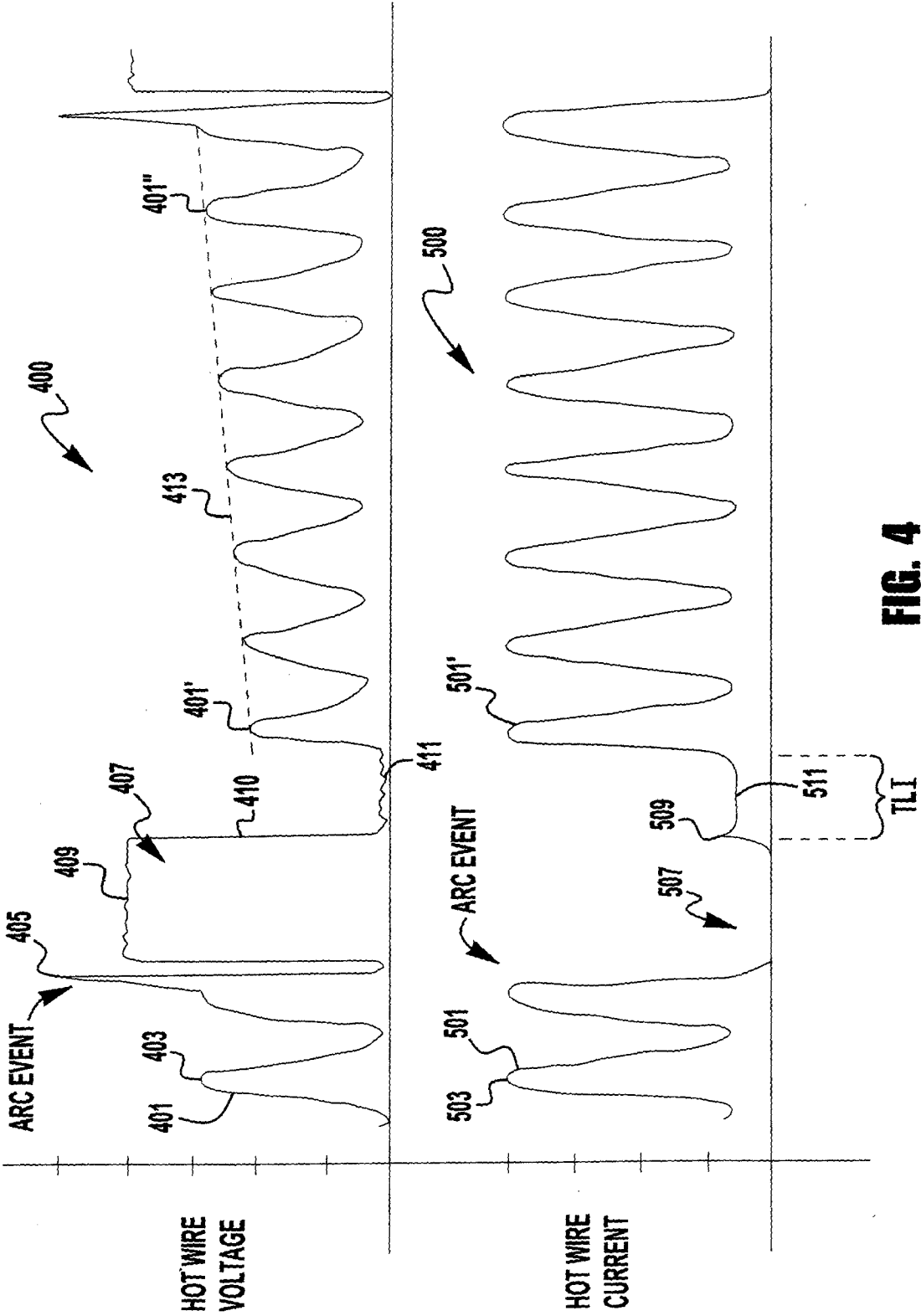


FIG. 4

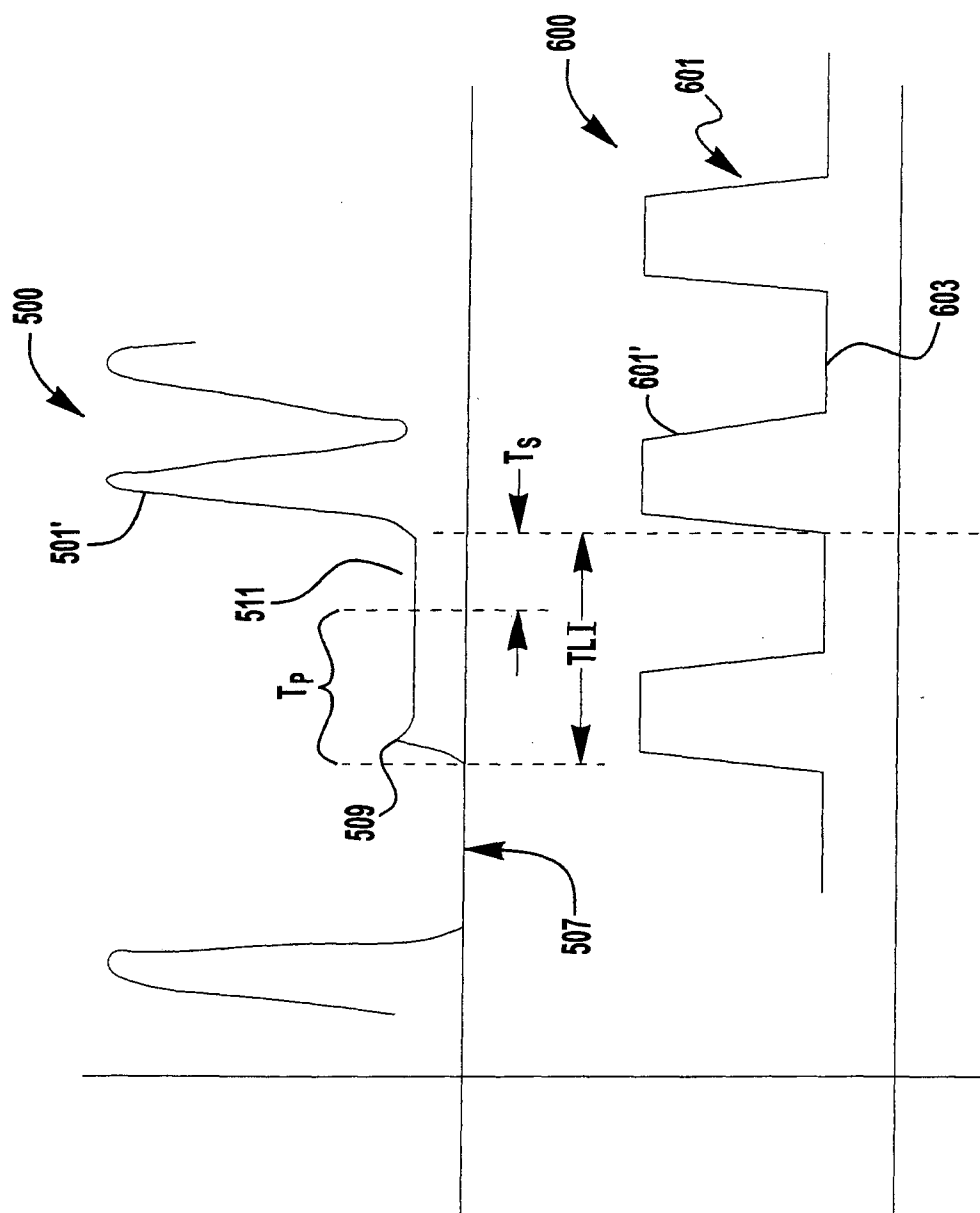


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/000206

A. CLASSIFICATION OF SUBJECT MATTER INV. B23K9/02 B23K9/04 B23K9/09 B23K9/10 B23K9/12 B23K26/34 B23K28/02 B23K26/20 B23K9/173 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) B23K 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 <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">Category*</th> <th style="width: 70%;">Citation of document, with indication, where appropriate, of the relevant passages</th> <th style="width: 20%;">Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>US 2008/128395 A1 (AIGNER GERALD [AT] ET AL) 5 June 2008 (2008-06-05) the whole document -----</td> <td style="text-align: center; vertical-align: top;">1-11,18, 19</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>US 2013/043219 A1 (PETERS STEVEN R [US] ET AL) 21 February 2013 (2013-02-21) paragraph [0003]; figures 21, 22 paragraph [0138] - paragraph [0170] -----</td> <td style="text-align: center; vertical-align: top;">1-19</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>DE 10 2006 050297 A1 (CLOOS INNOVATIONS GMBH [DE]) 24 April 2008 (2008-04-24) the whole document -----</td> <td style="text-align: center; vertical-align: top;">1-11,18, 19</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>US 4 614 856 A (HORI KATSUYOSHI [JP] ET AL) 30 September 1986 (1986-09-30) column 4, line 34 - line 64; claims 1-3; figure 4b -----</td> <td style="text-align: center; vertical-align: top;">12-17</td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	A	US 2008/128395 A1 (AIGNER GERALD [AT] ET AL) 5 June 2008 (2008-06-05) the whole document -----	1-11,18, 19	A	US 2013/043219 A1 (PETERS STEVEN R [US] ET AL) 21 February 2013 (2013-02-21) paragraph [0003]; figures 21, 22 paragraph [0138] - paragraph [0170] -----	1-19	A	DE 10 2006 050297 A1 (CLOOS INNOVATIONS GMBH [DE]) 24 April 2008 (2008-04-24) the whole document -----	1-11,18, 19	A	US 4 614 856 A (HORI KATSUYOSHI [JP] ET AL) 30 September 1986 (1986-09-30) column 4, line 34 - line 64; claims 1-3; figure 4b -----	12-17
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.															
A	US 2008/128395 A1 (AIGNER GERALD [AT] ET AL) 5 June 2008 (2008-06-05) the whole document -----	1-11,18, 19															
A	US 2013/043219 A1 (PETERS STEVEN R [US] ET AL) 21 February 2013 (2013-02-21) paragraph [0003]; figures 21, 22 paragraph [0138] - paragraph [0170] -----	1-19															
A	DE 10 2006 050297 A1 (CLOOS INNOVATIONS GMBH [DE]) 24 April 2008 (2008-04-24) the whole document -----	1-11,18, 19															
A	US 4 614 856 A (HORI KATSUYOSHI [JP] ET AL) 30 September 1986 (1986-09-30) column 4, line 34 - line 64; claims 1-3; figure 4b -----	12-17															
☐ 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 21 July 2015	Date of mailing of the international search report 03/08/2015																
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 Möller, Sebastian																

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2015/000206

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008128395	A1	05-06-2008	AT 403514 T 15-08-2008
			AT 501124 A1 15-06-2006
			CN 101072655 A 14-11-2007
			EP 1824634 A1 29-08-2007
			ES 2311242 T3 01-02-2009
			JP 5207740 B2 12-06-2013
			JP 2008522833 A 03-07-2008
			US 2008128395 A1 05-06-2008
			WO 2006063374 A1 22-06-2006

US 2013043219	A1	21-02-2013	NONE

DE 102006050297	A1	24-04-2008	NONE

US 4614856	A	30-09-1986	JP H0428470 B2 14-05-1992
			JP S6082278 A 10-05-1985
			US 4614856 A 30-09-1986
