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SAFETY AND INTELLIGENT CONTROL SYSTEM FOR PLASMATRON APPLICATION

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Abstract

This article presents safety and intelligent control systems essential for safe and reliable operation of DC arc plasmatron. Presented methods and techniques are also applicable to other types of plasmatrons and devices. Author presents and describes subsystems of DC arc plasmatrons including its: start up and operation algorithms, detection of malfunction's, control parameters and techniques for plasmatron operation. Moreover, issues and requirements identified in field operation are presented in case of plasmatron operation on site, communication and supervisory system for flexible integration of independent device in complex SCADA systems. Presented material covers also safety techniques, procedures and subsystems necessary for safe and reliable plasmatron operation, with examples of experience in plasmatrons applications.

Presented in this article plasmatrons control and safety systems with theirs functions together with operation algorithms were applied and validated in constructed and operated plasmatrons. Plasmatrons were tested in different environments. For example in the plasmatron plasma reactor where three 20 kW plasmatrons were used and installed directly in high temperature refractory that consisted of plasma incineration and smelting of metals chamber.

Keywords: *safety, intelligent control, systems, automation, plasmatron, arc, control, plasma*

1. Introduction

Plasma technologies become more popular in economy and they find new fields of application. The most known for broad public are plasma cutting and plasma TV, however taking as reference the power criteria the plasma technologies are used in metals processing i.e. iron from scrap smelting in electric arc furnaces (EAF). Another different criterion is number of products manufactured with use of plasma technologies. In this case, the low-pressure plasma is applied for example Plasma Enhanced Chemical Vapor Deposition (PECVD), or plasma etching and many others allowing microelectronics production and development. Also, other plasma applications are developed and used.

Plasma is generated in many ways depending on its application. Tokamaks allow generation and sustaining of hot plasma to perform research over plasmas and for example fusion as it is carried out in ITER project [1]. Plasmatrons allow generation of plasma that can be applied in broad range of applications, for example: plasma spraying, plasma melting, plasma incineration, plasma "drilling", plasma surface treatment, and coatings [2], plasma gas cleaning, plasma assisted chemical reactions, plasma heating, plasma ignition of fuels, and many others. Those devices are being developed and applied around the world allowing application of plasma technologies in everyday life.

2. Plasma source – plasmatron

In each plasma technology, the essential component is the "plasmatron". The plasmatron is the device where, or by which the plasma is generated. In some cases, it is hard to distinguish which part of the device is the plasmatron and which is the equipment that does not constitute plasma generation. This issue relates to many cases. For example, where is plasmatron in electric arc furnace (EAF)? There are electrodes that are installed in the furnace, and the furnace itself. The plasma is generated in the furnace between the electrodes, and the material that was loaded to the furnace chamber. It is hard to call a plasmatron the whole EAF furnace, but the plasma is generated inside it. It is also hard to point the electrodes as a plasmatron, but in this case, that is the key plasma generating equipment together with electric power supply, which powers the EAF through the electrodes. Due to above, considerations only some of plasma generating equipment and plasma technologies consists of a strict sense the plasmatron. Example of authors plasmatrons are presented on Fig. 1, 2.

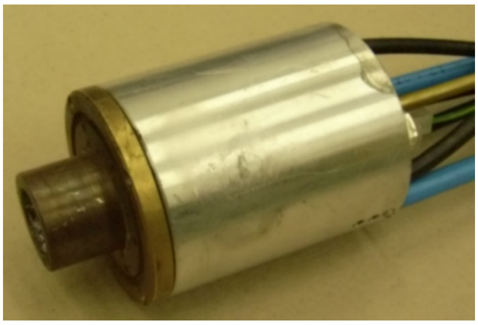

Fig. 1. Picture of 20 kW plasmatron used in plasma reactor for smelting metals from printed circuit boards

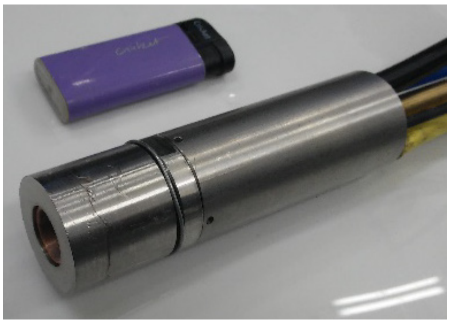

Fig. 2. Picture of 1-10 kW plasmatron

The plasmatron is the device that generates plasma. It does not matter what is the energy source of the plasmatron. It can be electric DC current – arc [3, 4], or AC current – arc, gliding arc [5], microwave radiation [6, 7], induction [8], and other techniques allowing plasma generation. The plasmatron produces stable stream of plasma in controlled conditions and parameters. The plasma flows out from the plasmatron and can interact with surrounding matter.

Plasma itself is ionized gas. Without gas, plasma cannot be produced. That is why plasmatron requires gas flow to produce plasma. In plasmatron, the gas is converted into plasma state by delivering enough energy to ionize the gas particles. Ionization energies are very high, that is why in typical plasmatrons only small amount of gas is ionized, and the rest of the gas is heated up but does not become ionized. Typically, in plasmatrons ionization of working gas is about few percent. For example, complete ionization of 1 g of Oxygen requires about 85 kJ to reach first level of ionization. Fig. 3 presents operating 20 kW plasmatron with visible plasma stream.

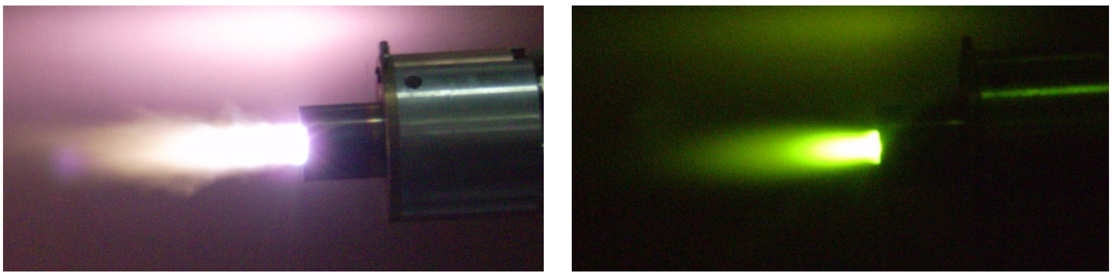

Fig. 3. Picture of plasma produced by operating 20 kW plasmatrons, left picture in visible light and right picture through light filter

Another essential part of the plasmatron is its cooling system that is required to cool down and remove excess of heat that is transferred from plasma to plasmatron parts. Cooling down of plasmatron is essential for its stable and long operation. Without cooling energy delivered to the electrodes or to plasma itself would melt them and cause plasmatron failure in seconds. That is why plasmatron cooling system is essential for its operation and allows extending of lifetime of the electrodes and other plasmatron parts.

Discussed above key plasmatron media constitutes plasmatron operation and parameters. Also important is plasmatron construction, but the construction is fixed and given for certain plasmatron. That is why for plasmatron operation, control and safety, only electrical energy, gas flow and cooling system are necessary to take into account. However, it is necessary to include also important factors that are crucial for plasmatron operation which are plasma ignition, and procedures – algorithms, to start and operate, and to guarantee safe and reliable device operation.

3. Plasmatron control and safety system

Plasmatron control and safety system can be implemented on various hardware PLC controllers. The PLC hardware allows stable and reliable operation of control and safety algorithms that are essential in case of plasmatron operation.

Plasmatron control system

Plasmatron control due to simple operating principles and only few controlled values is easy to implement from software and hardware point of view. It is possible and commonly applied that plasmatron medias are fixed: amount of gas flow and pressure, electrical power and cooling system parameters. In this case, the control function will only relate to discreet algorithms and execution as the only necessary action is to switch each system on or off.

Plasmatron can be operated in numerous operation conditions. Plasmatron operation conditions are located on continuum that represents electrical power with its parameters (amperage and voltage), and amount of plasma gas flow for each specific device construction and geometry.

For simple plasmatron operation given voltage, amperage and gas flow, are fixed and plasmatron operates only in this one set point. In this case, plasmatron power and plasma generation is constant and no online adjustment is required. For this fixed mode, plasmatron control requires procedure for ignition and operation, which are discreet values. Simple switching "on and off" of the cooling system, gas flow, and electrical power, allows plasmatron operation.

Plasmatron can also be also operated in flexible way, allowing adjustment of power and gas flow. Such operation is necessary in R&D works, and measurement of plasmatron parameters (efficiency, shape of plasma, stability of operation, etc.). In this case simple plasmatron control is not enough, and requires different approach as parameters are varied and unstable operation may occur, which might end up apparatus malfunction.

Another plasmatron way of operation is operating plasmatron in two or more fixed points. Such approach allows usage of plasmatron for example in minimum and maximum power. However, control of such operation requires different from simple operation. Simultaneously power and gas flow must be changed to set operation parameters for given work point. In this case, discreet control is not sufficient and analogue adjustment (via communication protocols for example RS485 ModBus) is required to set electrical parameters and gas flow to operate in different points.

Control system of the plasmatron on one hand carries out execution of control algorithm, but on the other hand needs also to collect data to verify actual operation correctness.

Safety system

In plasmatron applications, safety and control system are implemented in one algorithm, because safe plasmatron operation is only possible when every component works in scope of control algorithm, and in correct range of operation. That is why safety system requires supervision over plasmatron operation parameters in real time. This requires correct gas flow range, current and voltage that guarantee good plasmatron operation parameters for example: efficiency, power, stability, which are essential for decreasing wear of plasmatron electrodes.

Safety system is a part of plasmatron control system that is responsible for safe and reliable plasmatron operation. Measured in real time are voltage, amperage, gas flow, cooling water temperature, cooling water circulation, and gas pressure. Based on those values is implemented safety and control algorithm that allows reliable and easy plasmatron operation.

To implement such safety and control system next to PLC controller also other execution and measurement components are required.

Electrical values are measured by voltage and current transformers and those values are transmitted to PLC.

The gas flow control and reed back can be easily carried out using mass flow controllers that offer remote setting gas flow amount and reed back of current amount of gas flowing. Such solution allows simplifying the safety system as also the gas inlet pressure can be read from flow controller instead of use of independent pressure transducer.

The cooling water temperature requires thermometer and temperature converter to condition the signal for PLC input. In some applications, also heat meter can be applied to obtain flow signal and water temperature together with amount of waste heat.

Cooling water circulation monitoring can be executed on numerous of ways. From simple flow switch that generates discreet signal, to water flow meters or simpler pulse generators, which generate discreet pulses, related to water flow. Those pulsed signals allow additional safety function for cooling system, as pulses allow reliable identification of any possible faults in water flow measurement components, which sometimes due to water impurities can stop operation. Cooling system is equipped with water tank that should be monitored with one or two level switches to have information about water level in the cooling system.

That is why plasmatron safety and control system is bidirectional. When executing given control parameter also online feedback is essential to verify carrying out of control function. Fig. 4 presents plasmatron safety and control components together with schematic plasmatron circuits.

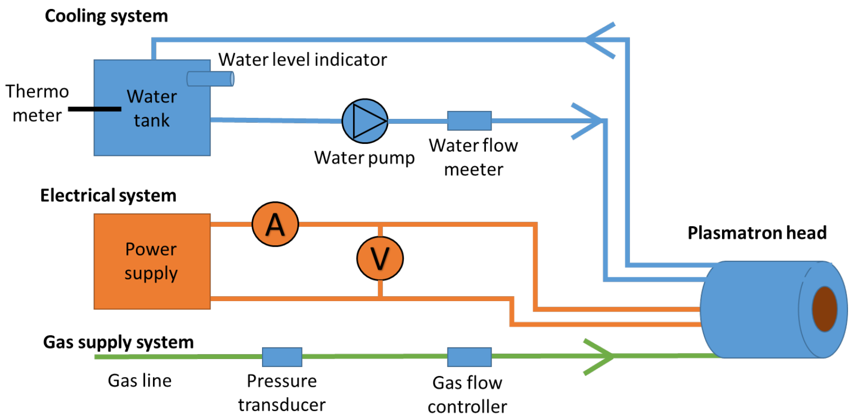

Fig. 4. Plasmatron safety and control components with schematic plasmatron circuits

Plasmatron operation algorithms

Plasmatron in order to meet reliable, stable, and repeatable operation needs to operate according to control and safety algorithms. Those algorithms are implemented in PLC in form of program including human machine interface, and communication to auxiliary systems. Such approach allows remote operation, supervisory and incorporation of one or more plasmatrons to bigger installations and systems. External communication protocols and signals together with operation principles are being always developed and adjusted to the needs of the installation and theirs control system. However, the plasmatron operation algorithms are in each device similar.

To demonstrate plasmatron algorithms it is essential to explain plasmatron operation. Plasmatron operation is a state that needs to be monitored, but before plasmatron operation, plasmatron needs to be ignited where most of transient states occur. Also, during its stable operation some malfunctions and accidents might happen so real time monitoring is essential to quickly react and avoid plasmatron destruction.

For correct operation plasmatron requires efficient cooling, electrical energy – amperage and voltage in correct range, and given gas flow. Before ignition, cooling and gas flow needs to be stabilized to create safe conditions for plasma striking and electrical power supply. Next within second operating conditions stabilize and plasmatron is heating up to its normal operating conditions. Fig. 5 presents simplified algorithm of plasmatron operation.

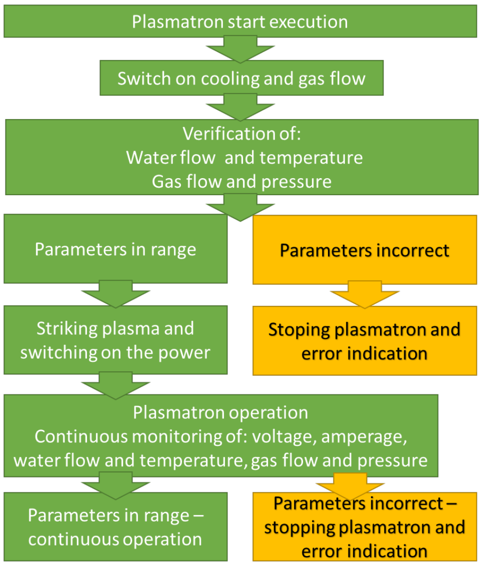

Fig. 5. Algorithm of plasmatron operation

Key role of operation algorithm is to monitor plasmatron and its subsystems parameters, states and instantaneously react to any signals or parameters that fall outside the safe range. For example, when voltage drops below 100 V arc might "burn" from cathode to external elements instead anode, which will cause meltdown of those elements. When gas flow will be too high arc might be broken. When the gas flow will be to low the arc might not be blown properly which might cause plasmatron elements to overheat, or will affect plasma shape, and plasmatron efficiency etc. Such situations require immediate reaction to switch off the power to prevent plasmatron from damage. In addition, signals form auxiliary plasmatron system is important. Water circulation malfunction will cause within few seconds overheating of plasmatron components, which will cause meltdown of plasmatron seals, and cooling water leakage. Further operation without cooling will cause to overheat other non-metallic plasmatron parts and theirs meltdown or ignition. Further operation without cooling will cause meltdown of plasmatron electrodes and shorting the electric power system.

Each risk and possible cause needs to be accounted and foreseen, together with estimation of the time that can pass before destruction of plasmatron parts. That is why some parameters need to be monitored in real time and reaction needs to be instantaneous. However, some of the variables for example level of water in cooling system tank can be at first indicated for operator or supervisory system, than after given time with no change the system needs to be stopped.

Plasmatron operation as a part of broader systems

Safety algorithms for plasmatron are one issue, but plasmatrons are not operated as standalone devices without any other surrounding structures or interactions. The typical plasmatron use is its operation as a heat source for example smelting furnace. Such plasmatron is in direct contact with hot furnace walls and is a subject of heat and pressure effects that are independent from it. In such operation safety algorithms needs to take into account also additional factors that can cause plasmatron failure and further disturbances. For example when working gas is switched off, the plasmatron will be switched off due to safety algorithm that switches off the power when gas pressure or flow is outside the safe range. In such situation if the plasmatron is operated in a submerged mode, the plasmatron will be flooded by molten metal or slag, and most likely partially destroyed. Another issue is when the plasmatron is being switched off. In this case, the cooling circuit must be still left on, so the cooling of the plasmatron will be continued otherwise the device will be overheated and destroyed. Also, contamination from furnace, combustion chamber, can clog the plasmatron inside and its striking will cause a damage or will be impossible. That is why to safety operate plasmatrons in broader systems, furnaces, combustion chambers, gas processing etc., it is necessary to back up some of the plasmatron functions in case of malfunction and damaging effects. One of solutions for above considerations is backed up, doubled cooling system in case of circulation pump failure or other situations. Another is to use plasma gas purging constantly to avoid contamination of plasmatron by dusts and other substances. Those and other issues needs to be taken into account and new operation procedures developed when applying plasmatron to broader complex systems.

4. Conclusions

Presented in this article plasmatrons control and safety systems with theirs functions together with operation algorithms were applied and validated in constructed and operated plasmatrons. Plasmatrons were tested in different environments. For example in the plasmatron plasma reactor where three 20 kW plasmatrons were used and installed directly in high temperature refractory that consisted of plasma incineration and smelting of metals chamber [9]. Also, other industrial applications were investigated and operated, for example combustion chambers or gas processing chambers. In each of those applications new knowledge and experience was obtained that allowed to find loose ends in control and safety algorithms and plasmatron system.

This experience in industrial applications pointed that every error might or most likely will cause appliance damage that will cause additional time and effort which is many times more costly than correctly developed and validated control and safety system.

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