

AUTOMATIZED INTEGRATED SYSTEM FOR PLASMA SPUTTERING

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Abstract – This article presents the development of an automated system for plasma sputtering. The proposed system is composed of a continuous current power source, flow mass controllers to control the inert gasses that produce the plasma, a rotary vane vacuum pump and pressure meters. The aim, in the first phase of the project, is to integrate the power supply to the human machine interface, to the microcomputer and to the voltage and current hall meters. The supervision of the elements will be done by a program developed in “LabVIEW®”.

Index Terms — Sputtering, Plasma, Automatized System, Isolated DC-DC Converters.

I. INTRODUCTION

Since man started the development and the conception of machines and tools, he has been looking for better materials or some with improved characteristics. For years, great effort of many researchers from the fields of chemical, physics, electric, mechanics and materials has been spent looking for new materials and/or improving the features of the present ones. Due to this fact, the industry chose steel as one of the most important materials, and it is part of most products, it has been used by naval industry, automotive, warlike, aeronautics, construction, and others.

One way to improve the features of materials is by means of surface treatment, allowing the refinement of the following characteristics: resistance to wear, resistance to corrosion, hardness, reflectivity or absorption of radiation, conductivity and more.

The industrial process best known to treat materials is the chemical, which is hazardous to the environment and leads to several problems such as high cost to recover the water spent on the process and reuse of residues. All these problems raise costs to achieve international standards, like ISO.

The application of plasma techniques has been an attractive way to overcome the technical shortcomings of conventional surface treatment. The plasma process presents several advantages namely; it doesn't spend water, which strongly recommends it because today spending water has a high cost, the economy of electrical energy, the reduction of time, the possibility of automating the process completely, of cutting costs, of reducing temperature, in addition, it also has an excellent reproducibility. Besides the financial advantages, there is the fact that this is an environmentally friendly process, and it preserves workers' health.

The reproducibility of plasma process is better than that of conventional process [3], because it has more parameters to

control, that is, applied voltage, current, gas pressure and temperature inside the plasma reactor.

The reproducibility guarantee is one of the reasons for the present study, that is, the development of an automated system to control the variables of the sputtering process, allowing that supervisory software checks and intervenes whenever it is necessary. The user just needs to choose what is the appropriate setup for the piece that will be treated according to the type of treatment, the final features of the piece, weight and volume of the piece.

In such case, it is suggested that one uses a DC-DC isolated converter, powered by a single-phase electric AC source using an AC-DC converter. The DC-DC converter will have a permanent control system of output current and voltage, seeking to eliminate electrical arches and using a soft switching technique to reduce the switching losses. This converter will have an interface with an alphanumeric display, a keyboard and a RS232 serial transmission, which will be used to control the process.

II. PRESENTATION OF PROPOSED SYSTEM

The present system will be formed by: 4 (four) inert gas cylinders, 4 (four) shut off, 4 (four) flow mass controllers, a DC power supply (1,000V / 3.5A), a plasma reactor, a rotary vane vacuum pump, a disk valve, an absolute pressure meter, a residual pressure meter, a microcomputer with data acquisition board and the supervision and control program. The diagram of the present system is shown at Fig. 1.

A. Operation of the System

The process starts with the microcomputer setup, chosen according to the type of the treatment to be carried out. This setup will have the basic pieces of information on the necessary gas mixture, voltage and current to the direct current power supply and standard value of pressure and temperature. Different setup files will be generated for each type of treatment, volume and composition of the piece under treatment and time wasted in the processes. The user just needs to choose one of them and start the system.

As soon as the system starts, the software built in LabVIEW® takes the control of the process. First of all, it needs to take away all air from plasma reactor, this is done by starting the vacuum system, so the pressure measurements could be started. The pressure control is achieved through acting on the disk valve that is interconnecting the rotary vane vacuum pump to the plasma reactor.

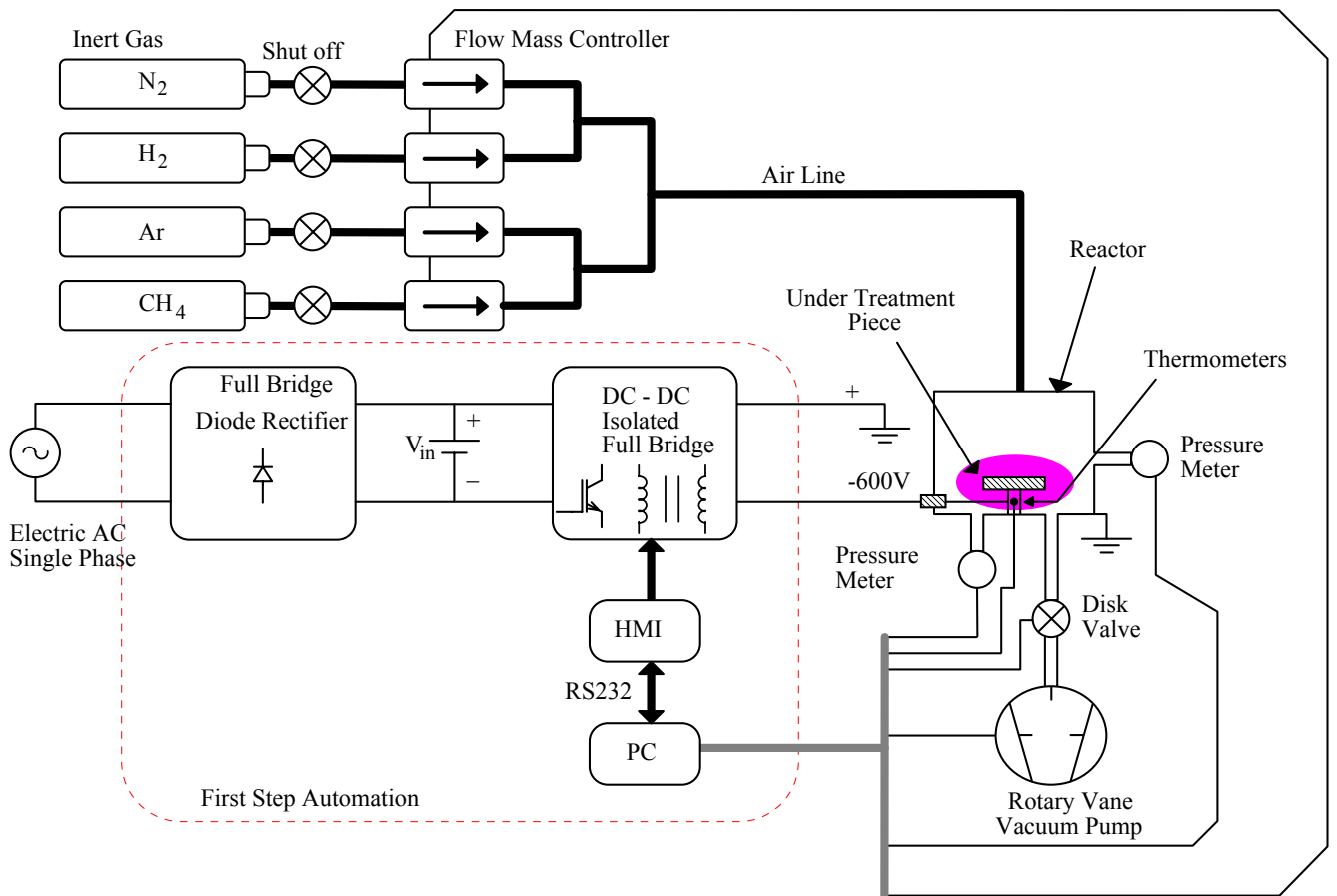


Fig. 1 Illustrative diagram of the automatized plant.

Next the program commands the mass flow controller to control the gas flow to form the plasma. Through RS232 serial transmission the microcontroller commands the direct current power source, adjusting the maximum output voltage and the maximum output current. The source is connected to the reactor with the positive terminal through the ground and the negative terminal is applied to the piece under treatment. The source tries to impose on load the adjustable voltage, if the current achieves the maximum value first, the current is limited to the maximum. If the maximum current can not be achieved, the power source will be controlled by the voltage mode, imposing on load the pre adjustable value.

Inside the plasma reactor there are 4 (four) thermometers, whose information will be used to redefine new maximum voltage and current values so as to keep the pressure and the process temperature stable.

During the first implementation phase of the automatization of the system, the integration of the direct current power source [1] is being carried out with the human machine interface, the power source control board, and the microcomputer.

III. ISOLATED DIRECT CURRENT POWER SUPPLY

The power source of the system has to be isolated, allowing the operator to connect the positive output to the box plasma reactor and to the ground, leaving the negative output to the piece under treatment. The chosen power source is based on a DC-DC FB-ZVS-PWM-PS converter [1, 4, 6,

7], shown in Fig. 2. This converter uses in its name the initials that describe its main features: FB – Full Bridge, ZVS – Zero Voltage Switching, PWM – Pulse Width Modulation e PS – Phase Shift.

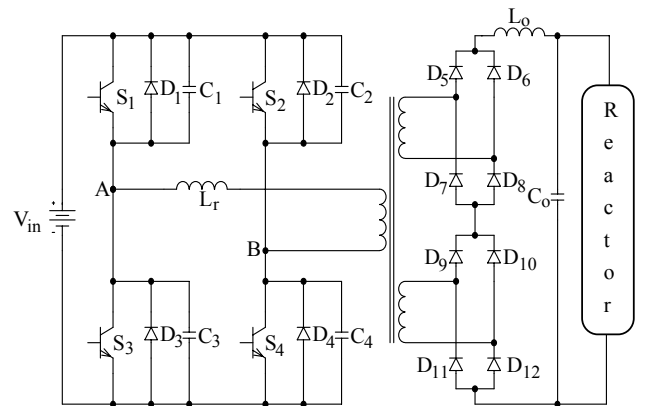


Fig. 2. Isolated power source supply.

The direct current power supply has as its main features: the use of a high frequency transformer that has the advantage of its low weight and volume when it is compared to low frequency ones and it will provide input to output isolation, the use of two full bridge diode rectifiers and the ZVS soft switching.

The converter technical specifications could be resumed as:

$V_{in} = 311V$	Link DC voltage;
$V_o = 1,000V$	Nominal output voltage;
$V_{o_{max}} = 1,030V$	Maximum output voltage;
$I_{s_{onomy}} = 3.5A$	Maximum output current;
$P_o = 3,500W$	Nominal power;
$F_s = 70kHz$	Switch frequency.

The control circuit has also received special care during the development. To avoid the generation of electric arcs inside the plasma reactor, logic to the control has been used and the control signals are independent, that is, both controller can act on the output directly, being the current control predominant. When output current is below the adjustable value, the current controller is kept saturated and the voltage controller controls the output. If the output current tries to exceed the limits, the current controller acts decreasing the output voltage and the output current is controlled. This logic allows the use of fast controllers and could control the power supply output in the same way. This system control output blocks can be seen in Fig. 3.

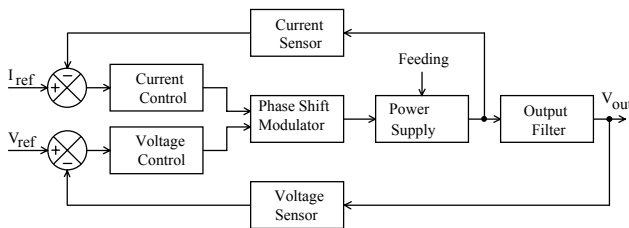


Fig. 3. Logic control output diagram blocks.

IV. HUMAN-MACHINE INTERFACE (HMI) AND SUPERVISORY BOARD

The supervisory and human-machine interface board is based on 8Bits microcontrolled system, which manages whole parameters and functionalities of DC-DC converter. The chosen microcontroller belongs to PIC family, model 16F877A, produced by Microchip®. This model attends to all the project requirements because it has some peripherals inside that are essential such as analog to digital 10Bits converters, PWM modules, RAM memory, E²PROM memory and USART serial transmission. In addition, it has 33 selectable output/input ports and 8kBits of program memory.

The HMI has a 7 (seven) keys keyboard to navigate between the screens and to adjust parameters, a crystal liquid display (LCD) with 20 (twenty) lines, 4 (four) columns and variable contrast, 3 (three) auxiliary LED's to visual identification modes and converter failure.

The main functions of the supervisory board are: voltage and current output limit adjusts, display contrast adjusts, output current and voltage readings.

There are also some software features in this supervisory board like: over temperature protection, driver failure, serial RS232 communication between the supervisory board and microcomputer and dv/dt and di/dt output controls to electric arcs suppression.

A. Supervisory board and HMI programming.

The logic operation sequence of the inside microcontroller program follows the flowchart shown in Fig. 4.

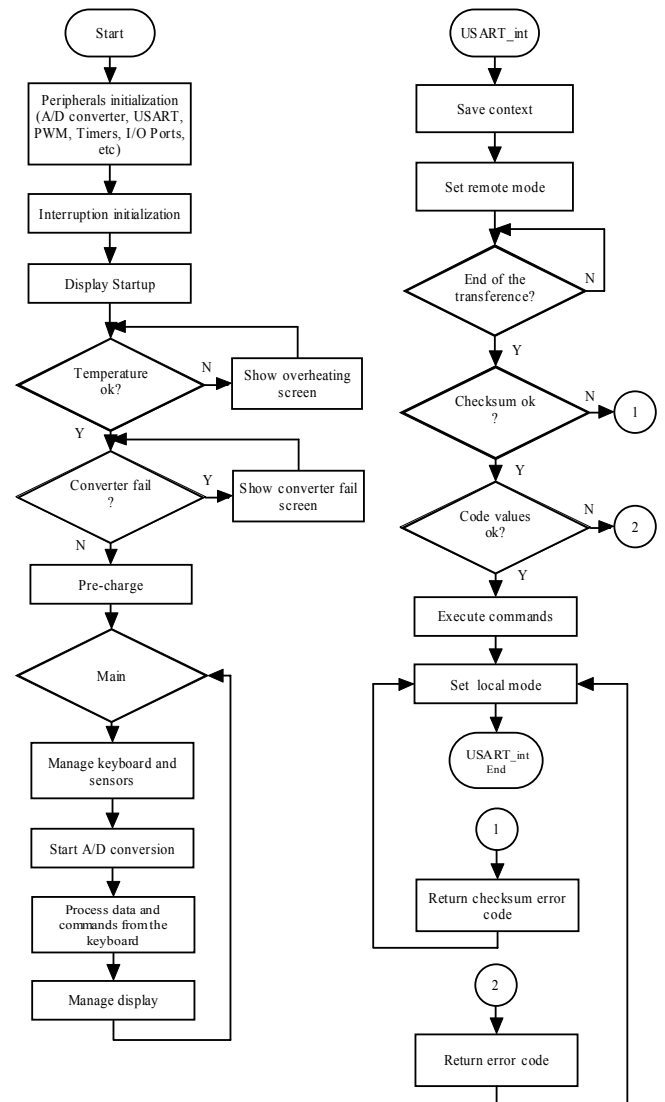


Fig. 4 Simplified supervisory board flowchart.

Initially, the responsible registrators are set for the peripherals used by the system, timers, interruptions and selectable input/output ports. Some interruptions are used to guarantee correct operation of the program when following steps. In this program, TIMER0 interruptions to the share keys and LEDs, TIMER2 to the LCD display backlight time e USART to serial transmission to the computer are used. The display is driven with a code sequence to define its visual characteristics and functionality mode, in the sequence, open screens and the converter menu in LCD are shown. Before it starts operating, some tests are carried out: a temperature test, that is, a thermometer connected in the heatsink converter informs through an open connection when the heatsink temperature reaches 70°C, if the converter fails, the IGBT switch drivers inform when the temperature goes beyond a pre-established value, thus avoiding short circuits by suppressing command signals and

generating an error signal that the supervision board understands as a converter failure by over current in the switches.

When the converter doesn't pass some kind of test, screens are shown in the display informing the problem type and, if the converter fails, a fail LED turns on to help the user visualization.

Next step, the converter starts the pre-charge procedures, turning on the input relay that connects the AC-DC converter to the line through a 2.5Ω resistor to limit the start current. After 250ms a relay is turned on, closing a contact that is in parallel to resistor, short-circuiting it and finishing a pre-charge procedure. After these steps the DC-DC converter is up to operate. During the execution of the main program, there are routines that check over-temperature sensor, converter failure, analog to digital conversion and in local mode, the keyboard.

The HMI, shown in Fig. 5, has windows to adjust the output current and voltage limit values, to visualize real output values and to vary the display contrast. The keyboard has 2 (two) keys responsible for raising and reducing the voltage limits, other 2 (two) keys to raise and reduce the current limits, a "SAVE" key to memorize the power source limits, a "MENU" key to navigate between HMI screens and an "OUT" key to turn on/off the output relay.

The HMI also shows the control source status information, it can not be in remote (REM) mode or local (LOCAL) mode, the output state on (ON) or off (OFF). When the power source is set in local mode the voltage and current limits can be varied by front panel and when it is in remote mode, frontal panel is disabled and the adjusts are made only by serial communication.

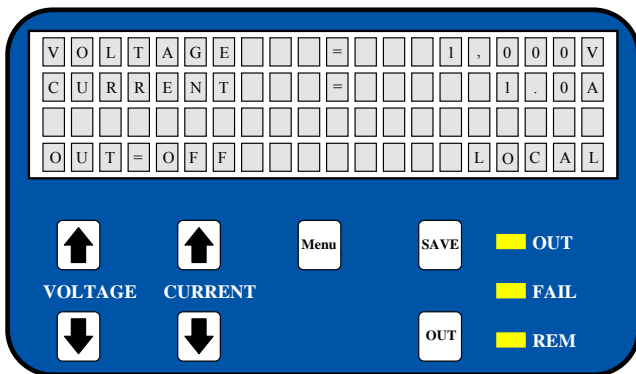


Fig. 5 Human-Machine Interface Layout.

The analog to digital conversion routine takes and watches the output current and voltage. Once that the measured voltage or current quickly changes, the microcontroller turns off the output, interrupting a possible electrical arc. These voltage and current measured values are presented on the screen, and the routine that manages the display refreshes them on each change.

The USART interruption imposes remote mode on the converter, turning off all keyboard functions. A 5 (five) bytes package is sent from the microcomputer and received by the microcontroller that verifies its fidelity through a checksum test, if it fails, an error command returns and the microcontroller goes back to the LOCAL mode. The codes are verified following converter limits, if any value is out of

range limit or any unknown code is identified, an error command's returns. The available functions are: read or write voltage and current settings, contrast adjusts, turns on and turns off the output, status checking and turn display backlight on. Before one of the commands listed is being set, the routine puts the converter in LOCAL mode and back to the main routine, where user can set the parameter by front panel.

V. PROGRAMATION IN LABVIEW® SOFTWARE

In order to automate, system's software LabVIEW® was chosen, due to its great usefulness with visual program language and easy configurations with available data acquisition boards. So the whole integration system will require a PC board that could capture signal from: 4 (four) thermometers, (4) flow mass controllers, pressure meters, and, in addition, it has to act on: flow mass controllers, a rotary vane vacuum pump and a disk valve.

During this integration step, there is no need for the employment of data acquisition board as communication between the power source supply and microcomputer will be done through RS232 serial transmission.

In the Fig. 6 the main control screen power source's on LabVIEW® software has been presented.

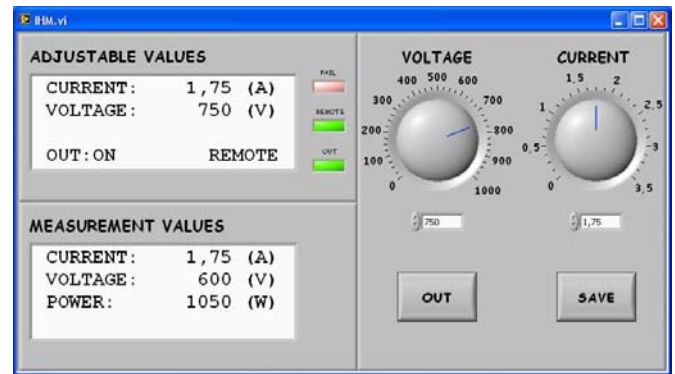


Fig. 6 Main screen power source control's built in LABVIEW®.

It can be noted the presence of digital dials for adjustable current and voltage values and for measured current and voltage outputs and the calculated power supplied by source, mobile dials to adjust voltage and current, and lights to show failure, mode and output status. To a fine adjustment of voltage and current two (2) text boxes located below respective rotary dials can be used. There are also buttons to turn on/off the output and to save the adjustable values. This interface allows that all operation can be done by remote form; in addition, it becomes easier to visualize pieces of information, showing on the same screen the adjustable and the measured values.

Besides the main power source control screen, another control screen was developed with the basic power source controls and the graphical of voltage, current and power values versus time. The voltage and current are sampled at 4 kHz with 10Bits resolution and this information is sent to microcomputer by a MODBUS based protocol four times per second. Previously, this acquisition used to be performed manually, being done very slowly and with many errors, thus not allowing detailed data analysis during a voltage arc in the

process. The window present in Fig. 7 shows an acquisition where could be observed that the voltage and current were adjusted in 800V and 0.8A and the graphics shows the converter are controlled in current mode providing to load 0.8A and 600V.

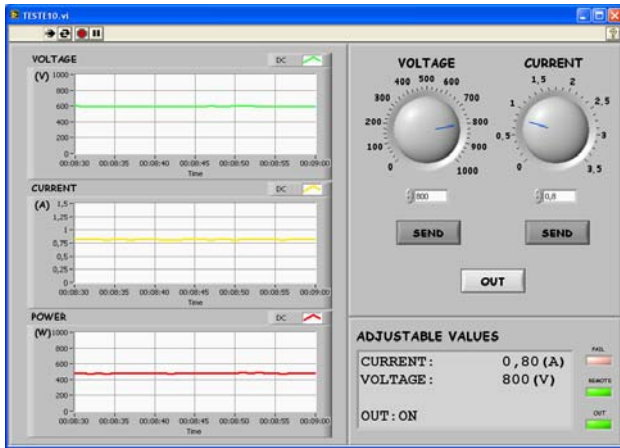


Fig. 7 Data acquisition and power source control screen.

The complete automation allows the acquisition of temperature and pressure meters, that adding to voltage, current and output power from DC source will provide researchers with reliable and accurate data so as to make it possible more detailed analysis and conclusions on the process.

VI. EXPERIMENTAL RESULTS

The proposed system integrating the directly current power supply, HMI, supervisory board and the microcomputer is present in Fig. 8.

At the left corner the plasma reactor could be observed, on the bench the power source supply and to the right the microcomputer with LabVIEW® program.

During the tests, the quality of RS232 serial transmission was confirmed, providing 2(two) way direction constant information flux between the power supply and the microcomputer without noise and interference. This robustness will be important mainly when whole system will have been complete, due to quantity of information processed by LabVIEW®.



Fig. 8 Proposed system.

The human-machine interface with the crystal liquid display, the keyboard and the indicators LEDs is shown in Fig. 9. It's characterized by its easier operation and intuitive way to navigate through the screens and perform the operations, allowing even less experimented users to operate the system easily.

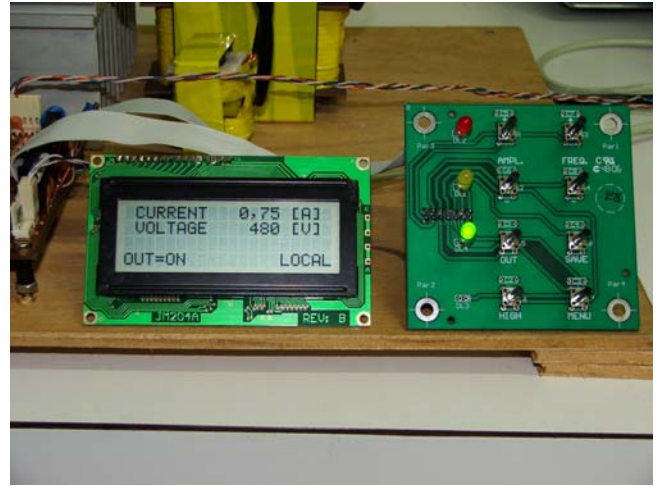


Fig. 9. Detail from human-machine interface.

Fig. 10 presents the output voltage and current from directly current power supply, connected to plasma reactor, with voltage control on. It could be observed that the voltage is almost constant and its amplitude is near 1,000V, showing a good behavior from voltage controller.

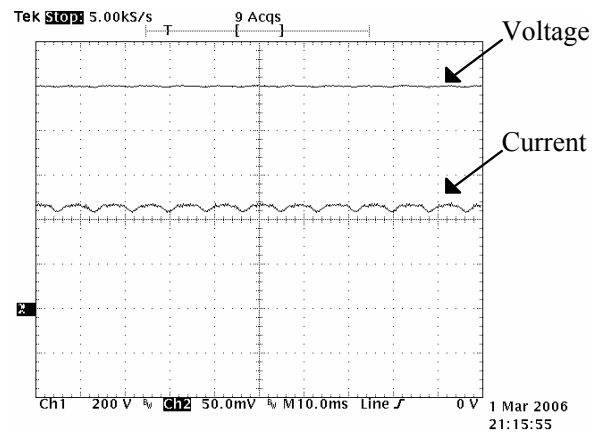


Fig. 10 Output voltage and current power supply. (Voltage 200V/div; current 0,5A/div)

Due to instabilities on plasma characteristics, its impedance could change its value very quickly, representing a short circuit to the power source. In this situation, if the source supply to the load requests current, trying to keep the voltage constant in the adjustable value, some power supply damage may happen or, if it supported the power requested by the load, the temperature may rise inside the reactor resulting in damage of the piece under treatment. To avoid this situation, the current control acts, limiting the output current, so, due to the low energy available to keep the electric arc, it is suppressed and the voltage control returns on. This situation of electric arc, its extinction and the return to adjustable value is presented in Fig. 11.

It's verified that the current rises abruptly while the voltage falls, but the current control limits the output current, so, when the energy of output capacitor is consumed, the output current falls too. When the energy available isn't enough to keep the voltage arc, it is suppressed and the voltage control imposes the output voltage to the reactor again.

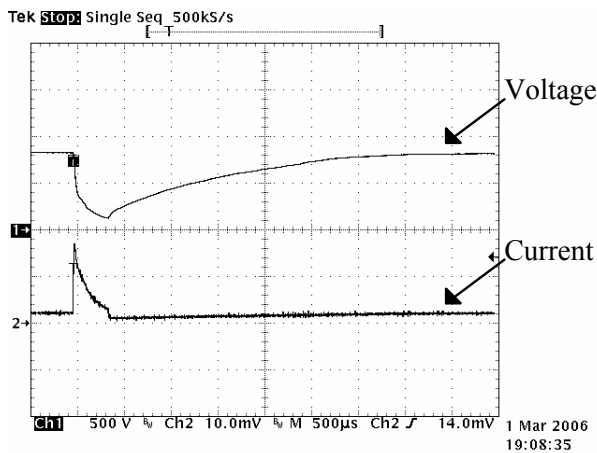


Fig. 11 Power source voltage and current during an electric arc occurrence.

In the Fig. 12, a cylindrical form piece under treatment is shown inside the reactor. It could be noted the ionization characteristic of plasma process around the piece.



Fig. 12 Under treatment piece inside plasma reactor.

VII. CONCLUSION

The use of an automatized system has sensibly improved the control process, allowing the user more agility and accurateness to setup the tests because there isn't a need for putting measurements in the system as HMI and LabVIEW® provides for operator voltage, current and power values.

The developed human-machine interface made by a PIC microcontroller, crystal liquid display and a keyboard has shown itself very easy and intuitive, allowing the user to learn how it works quickly.

The LabVIEW® software also presents itself as very easy to program, offering many options such as digital filters and a great variety of acquisition data modes. In the first automatized system step, the power source and the

microcomputer have been integrated, using a screen that makes it possible to control the power supply and a register of voltage, current and power versus time.

The RS232 serial transmission has presented itself as very stable and efficient, no failure or interference has been noticed during the process of sending and receiving information.

The use of CC-CC FB-ZVS-PWM-PS converter is an advantage because the circuits have many powered switched supplies with noticeable features such as: the soft-switching technique which reduces losses, raising the conversion efficiency and decreasing the EMC due the dv/dt and di/dt attenuations and reduced converter volume and weight due to the application of high frequency switching (70kHz).

It could be observed that the control systems have turned out to be very efficient to contain electric arcs. The use of current controller minimized the occurrence of electric arcs and its effects and, because of that, damage to the source was avoided.

The use of an independent voltage controller has another advantage, that is, it is possible to have an established output voltage, which is constant and controlled during normal operation (without electric arcs) and the current controlled during arcs. Due to the small output capacitor used, it could be verified that arcs are controlled and they don't have energy at output capacitor to generate problems on eventual electrical arcs occurrence.

The plasma produced in nitrogen atmosphere by this type of source has turned out to be very efficient for application in surface material treatment, for instance, sputtering. The ionic bombardment of cathode has provided a great energy transfer tax (about 100C/min) raising the temperature very quickly up to 1,000°C.

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