SOFTWARE APPLICATION FOR THE CONTROLLED HYDRIDING PLANT

ALEXANDRU FLOREA, COSMIN IVAN, ION PIRVU

Institute for Nuclear Research (RATEN ICN) Pitești, Romania

e-mail: alexandru.florin90@gmail.com

Abstract

This paper presents the development and implementation of a software application for the control of the controlled hydriding installation, through modern acquisition and control means, in order to optimize its operation. The process is based on the direct interaction between pure hydrogen and metal, the final composition of the hydride essentially depending on the hydrogen pressure and the temperature of the hydriding treatment. The quality of the rods obtained is significantly influenced by the speed at which the hydrogen is supplied, as well as its purity. The proposed optimized solutions provide a more precise dosage of hydrogen by controlling the quantity absorbed in the rods, completed when the pressure in the chamber is stabilized. In addition, precise temperature control of the oven chamber during heating and cooling was achieved through programmed ramp profiles over defined time intervals.

Keywords: *Controlled hydriding, Programmable logic controller, Smart instrumentation*

Introduction

Complex technological processes can be managed only by using control systems that include a significant number of control loops, most often in a strong interaction. The technological installation is part of automatic control systems. Knowledge of the laws governing technological installation operation according to their specifics (mechanical, electrical, chemical, nuclear processes, etc.) allows obtaining analytical models that characterize the operating regimes.

The objectives of any automatic control system are to ensure the rejection of disturbances and the tracking of reference. It should be noted that the objectives are correlated with the particularities of the controlled process, the variables to be controlled, and with the control system degree of complexity.

The controlled hydriding process can be measured and controlled by introducing well-determined quantities of hydrogen. Controlled hydriding process of U-Zr-Er alloys (in the form of rods) is carried out under certain pressure and temperature conditions [1]. The determination of the amount of hydrogen in the hydride rods is done by the difference between the mass of hydride rods and that of the metal rods. The controlled hydriding process aims to obtain a H/Zr ratio in a certain range, as well as avoiding the uranium hydride formation.

The present work aims to develop and implement software solutions for the automatic control of the hydriding installation. Solutions have been proposed for controlling the speed at which hydrogen is supplied in the process, the speed affecting the quality of the rods. Through the hydrogen distribution system, a solution has been proposed for performing the hydrogen purging stage of the controlled hydriding chamber. Extending the functionality of the vacuum system, optimal solutions for performing the vacuum stage have been proposed, by controlling the vacuum pump in order to obtain some process values based on setpoints in the controlled hydriding chamber.

The paper includes the controlled hydriding process presentation, a description of the automatic measurement and control systems (for temperature and hydrogen intake, respectively) related to the process, and the software solution implemented for controlling the controlled hydriding installation, including the graphic screen's structure and conclusions.

Controlled hydriding plant

The method generally used for the zirconium hydriding, as well as the ternary alloy Zr-U-Er, consists in the direct interaction between pure hydrogen and the metal. The composition of the hydride (hydrogen/zirconium ratio) depends on the hydrogen pressure and temperature used in the hydriding treatment. For this reason, the speed with which the necessary hydrogen is supplied has a significant impact on the quality of the rods [2, 3].

A controlled hydriding process requires an installation. Figure 1 shows the installation, which should include the controlled hydriding furnace, vacuum pump, buffer vessel and two automatic measurement and control systems (one for temperature and one for hydrogen intake).

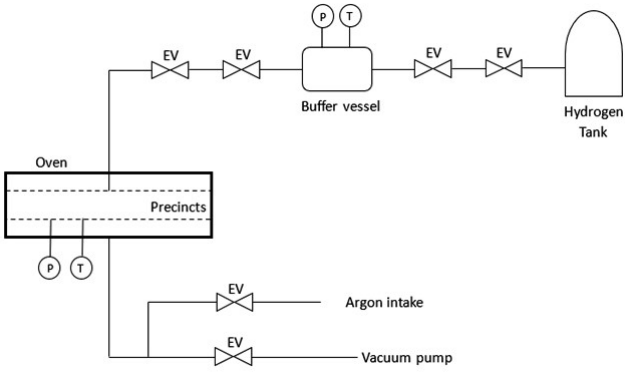


Fig.1. Controlled hydriding plant

The vacuum and hydrogen distribution systems are controlled by the automatic hydrogen intake measuring and control system. In addition, the automatic temperature monitoring and control system is used to regulate the temperature required in the hydrogen intake.

The automatic measurement and control systems (for temperature and hydrogen intake) include thermocouples, absolute pressure transducers, vacuum sensors, solenoid valves, pneumatic solenoid valves, and differential pressure transducers. The metal rod support system is introduced into the active area of the enclosure. Rod supports consist of numbered steel tubes. The enclosure is coupled to the vacuum pump and the automatic hydrogen intake system, and it includes a water-cooled area.

Figure 2 depicts the sequence of operations for controlling the hydriding process as a logical flow chart, based on the process stages.

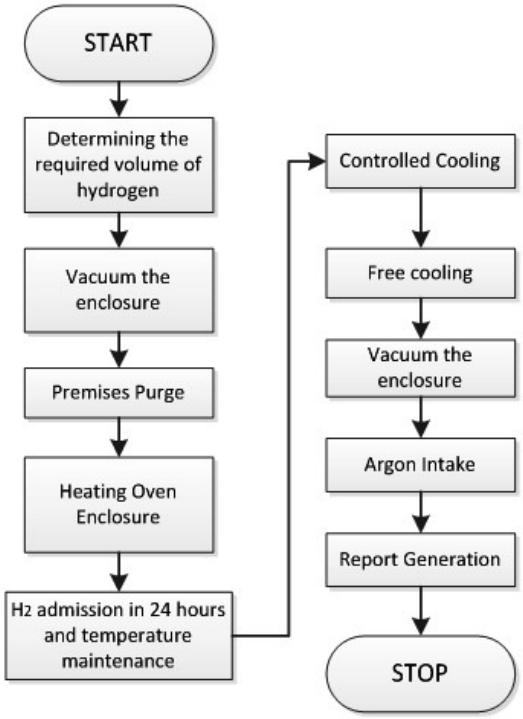


Fig.2. Flowchart of the controlled hydriding process

Using the HMI (Human Machine Interface) presented in Figure 3, the required hydrogen volume was determined based on the mass of the rod batch, the uranium concentration in the rods and the H/Zr ratio. Next, the programmable logic controller (PLC) will execute the script in the HMI and use the results of calculations, which will be saved in the controller's memory locations [4-6].

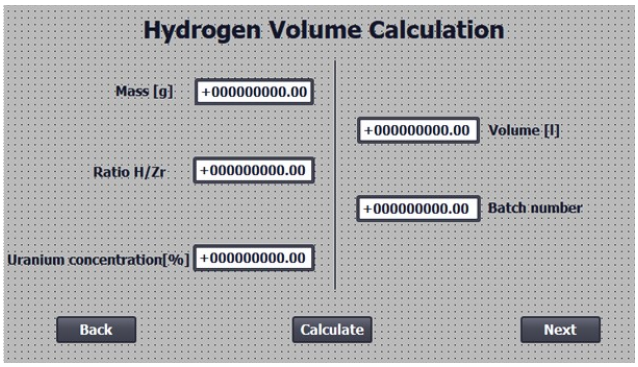


Fig.3. HMI for hydrogen volume calculation

The controlled hydroding process requires several initial vacuum stages aswell as a final vacuum stage following the free cooling of the furnace chamber. A vacuum stage begins by isolating the assembly (consisting of the furnace chamber, vacuum pump and vacuum sensor) from the rest of the process equipment by closing the two solenoid valves that connect the buffer vessel to the furnace chamber. The solenoid valves are closed by deactivating the associated Siemens PLC outputs. In addition, to achieve vacuum in the oven chamber, the pneumatic solenoid valve must be open. The pneumatic solenoid valve's position is determined by checking the status of the equipment position sensors (Figure 4). The PLC's digital output controls the pneumatic solenoid valve.

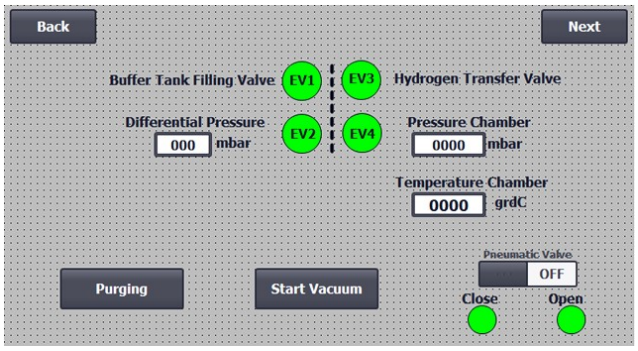


Fig.4. HMI for purging and vacuuming the chamber

Purging the controlled hydriding chamber of the hydrogen furnace is achieved by adding hydrogen in several stages via the buffer vessel. Theis approach has four solenoid valves: two between the hydrogen cylinder and the buffer vessel, and two between the buffer vessel and the furnace chamber. In a purging stage, the first two solenoid valves receive the opening command, allowing the buffer vessel to be filled from the cylinder by equalizing the two pressures, followed by gas being transferred from the buffer vessel to the furnace chamber by transmitting the opening command to the related solenoid valves.

Next, to completely purge the controlled hydriding chamber and obtain the required pressure, several staged activation and deactivation cycles of the two groups of PLC outputs are performed and counted (Figure 4).

According to the flow chart shown in Figure 2, when the vacuum and purge stages are completed, the process continues with the heating of the controlled hydrogenation chamber (Figure 5). As previously mentioned, there are two automatic measuring and control systems, one for the temperature and one for the hydrogen intake. The stages presented above are part of the automatic hydrogen intake measuring and control system.

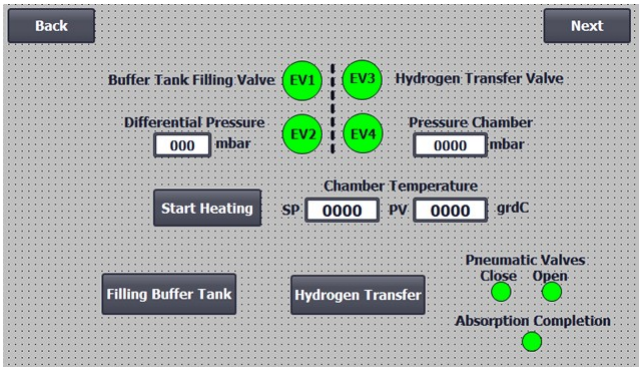


Fig.5. HMI for heating the furnace chamber

In addition, to achieve hydrogen intake, the temperature is maintained at a constant value by an automatic temperature measuring and control system. The automatic hydrogen intake measurement and control system monitors the hydrogen intake (Figure 6).

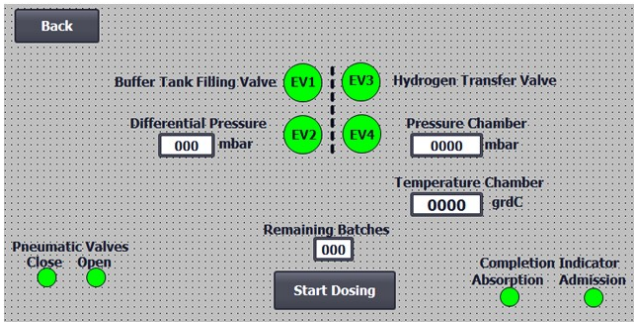


Fig.6. HMI for hydrogen intake

The rate at which the required hydrogen is supplied has a significant impact on the quality of the rods. At each batch, the hydrogen from the buffer vessel is fed into the controlled hydriding chamber in small "portions", obtaining a small instantaneous increase in pressure, followed by a reduction due to hydrogen absorption in the rods. The "portions" of hydrogen are introduced when the absolute pressure transducer detects a reduction below a preset value, due to absorption in the fuel rods of the controlled hydriding chamber. The differential pressure transducer monitors and controls the provision of hydrogen in the buffer vessel, and when it detects a decrease in the pressure difference below a certain threshold, it opens the solenoid valves between the cylinder and the buffer vessel.

The process is repetitive and finishes when the hydriding degree approaches the target ratio. At this moment, the pressure in the controlled hydriding chamber remains stable, with no decrease caused by rod absorption, implying that the pressure in the buffer vessel is roughly equivalent to the pressure in the furnace chamber.

The hydrogen admission, previously presented in the automatic mode, can now be manually operated by pressing the buttons for buffer vessel filling and hydrogen transfer (Figure 5).

The automatic temperature measuring and control system initiates the controlled cooling process (Figure 7), which is followed by a free cooling. The controlled cooling requires several cooling steps with constant value decrements in several stages. Following the free cooling of the furnace chamber, a vacuum stage occurs. Finally, to open the furnace chamber, argon will be supplied at atmospheric pressure.

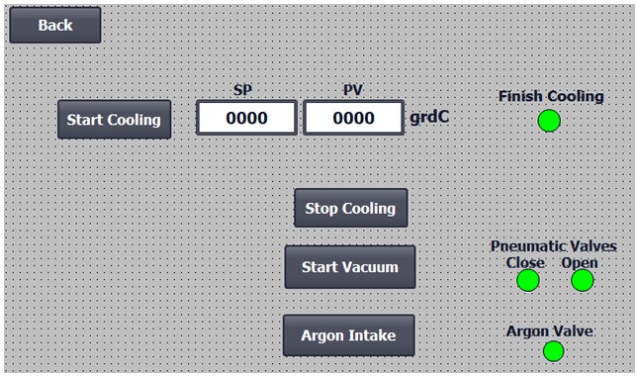


Fig.7. HMI for controlled cooling

In comparison with previous control methods, the software application and the optimized solutions proposed for controlling the speed at which hydrogen is supplied result in a more precise dosage, which is finalized when the pressure in the chamber stabilizes (Figure 8). This precise dosage has a significant impact on the quality of the rods, depending on the amount of hydrogen absorbed in the rods.

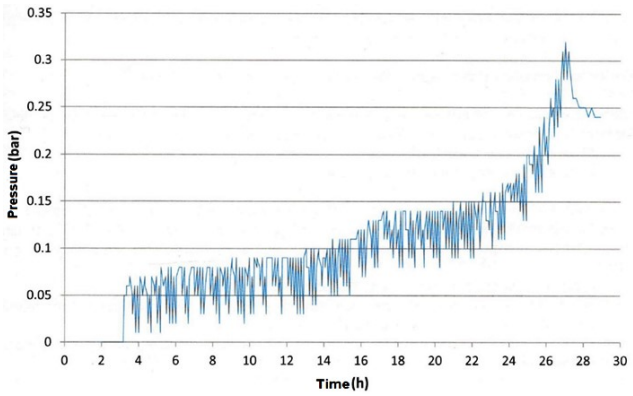


Fig.8. Variation in time of hydrogen pressure in the hydriding chamber

Furthermore, compared to previous control methods, for the temperature control required within the controlled hydriding process carried out by the automatic temperature measuring and control system, a more precise temperature control was obtained for heating and cooling the furnace chamber through ramps at certain time intervals.

The proposed software was developed by assessing various control possibilities and will be implemented within the Institute for Nuclear Research (RATEN ICN) Pitesti, as part of the modernization process of the controlled hydriding installation.

Conclusions

Based on the process steps, the control possibilities of the vacuum and hydrogen distribution systems, and the components of the two automatic measuring and control systems (one for temperature and one for hydrogen intake), optimized software solutions for the automatic control of the installation were identified.

Optimized solutions were proposed for controlling the rate at which hydrogen is supplied within the process, by determining, based on real-time process parameters, the volume of hydrogen absorbed in a batch and the related H/Zr ratio. This rate impacts on the quality of the rods.

A solution for performing the hydrogen purging step of the controlled hydriding chamber was also proposed, via the hydrogen distribution system, responsible for controlling the rate at which hydrogen is supplied within the process. By extending the vacuum system's functionality, optimal solutions for carrying out the vacuum stage can be obtained by controlling the vacuum pump, resulting in some process values based on setpoints in the controlled hydriding chamber. The mechanical protection of the pump was based on the number of days since the last start and the status of the pneumatic solenoid valve's position sensors.

Regarding the temperature control within the hydrogen intake stage, the stage in which the speed at which the hydrogen is supplied is controlled, heating and cooling ramps of the furnace chamber are proposed, under the control of the automatic temperature measuring and control system, at specific time intervals.

References

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