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DEVELOPMENT OF A COMPUTER BASED PROCESS CONTROL SYSTEM FOR AN AUTOCLAVE TO CURE POLYMER MATRIX COMPOSITES

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ABSTRACT

Autoclave is a process control system used in a number of industries such as aerospace, pharmaceutical, chemical, food processing and health care. NAL has pioneered the design and development of autoclaves in India to cure polymer matrix composites. This paper explains the development of a computer based multi-mode process control system for an autoclave, which is used to fabricate composites structures for aircrafts, satellites and other aerospace applications. This system comprises of a desktop computer, Programmable Logic Controller (PLC), analog data scanner, PID based Front-End Controllers (FEC) etc. It provides Auto, Semi-auto and Manual modes of operation. This paper also presents the strategies for control of autoclave temperature, part temperature and autoclave pressure along with the computer integration aspects. These techniques have been realized and successfully implemented in a couple of autoclaves.

**Key words: Autoclave, Computer control,
Part-temperature control**

1. Introduction

An autoclave is a pressure vessel with provision to load materials into it and subject them to various thermal, pressure and vacuum cycles in a controlled manner. Among numerous autoclave applications, curing of advanced composites structures is the most demanding one since these expensive structures are used for critical aerospace applications and their properties are determined by the cure conditions. Therefore, the autoclave and particularly its computer based control system must be highly reliable and operable even if its major systems such as the computer, PLC, scanner or FEC fail. These requirements were met by configuring the control system based on a supervisory computer running SCADA (Supervisory Control And Data Acquisition) software to provide auto, semi-auto and manual modes of operation.

In the auto mode, the computer executes the selected cure cycle by sequentially starting various subsystems, downloading set values at regular time intervals to the FEC, acquiring and storing the data, monitoring cure status and faults, generating alarms, sequentially shutting down and reporting. In the semi-auto mode, the operator initiates the subsystem operations such as ‘Start heat cycle’, ‘Start pressure cycle’ etc., and feeds the set value to the FEC at regular intervals or starts a ramp-soak program in the FEC. In auto and semi-auto modes, the PLC maintains the sequence of operation of the selected cycle with due status monitoring. In the manual mode, the operator maintains the sequence and operates the final control elements directly.

2. Autoclave subsystems

A schematic diagram of the autoclave is shown in figure1. The autoclave operating temperature typically ranges from ambient to 250^{o}C and the pressure from ambient to 10 bar. Its major subsystems include Door handling system, Heating system, Cooling system, Air circulation system, Pressurization system, Vacuum control system and Control and Instrumentation system [1] [2].

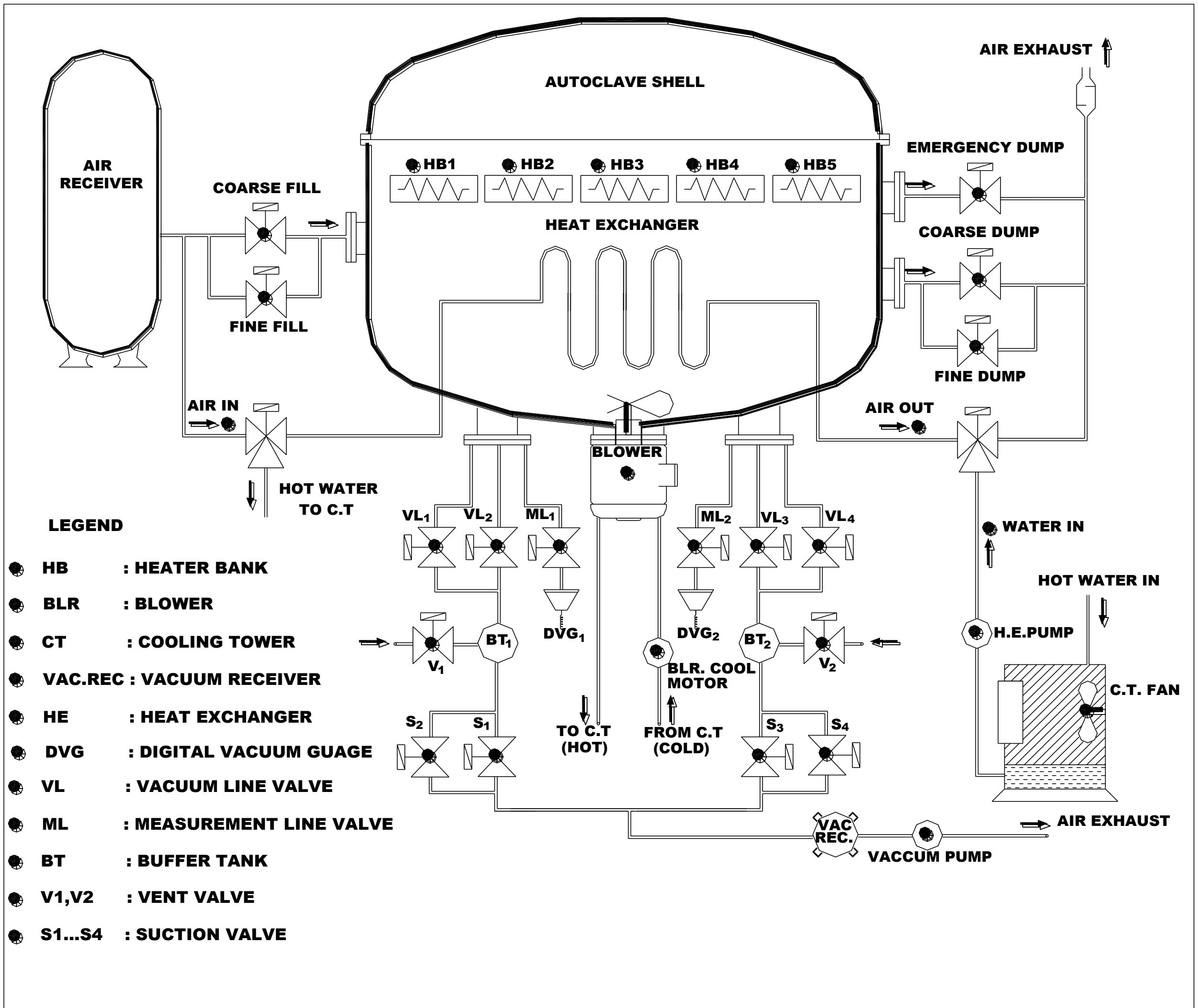

Figure.1 Schematic of autoclave system

3. Architecture of the computer based autoclave controller

The architecture of computer based autoclave controller with computer in a supervisory role is shown in figure 2. Major advantages of this architecture are low cost, three modes of operation, ease of maintenance and ease of up-gradation. Any of the constituent instrument or controller can be changed into a new model from the same or different manufacturer with only a minor modification in the software. The functions of major devices that constitute the control system are explained below.

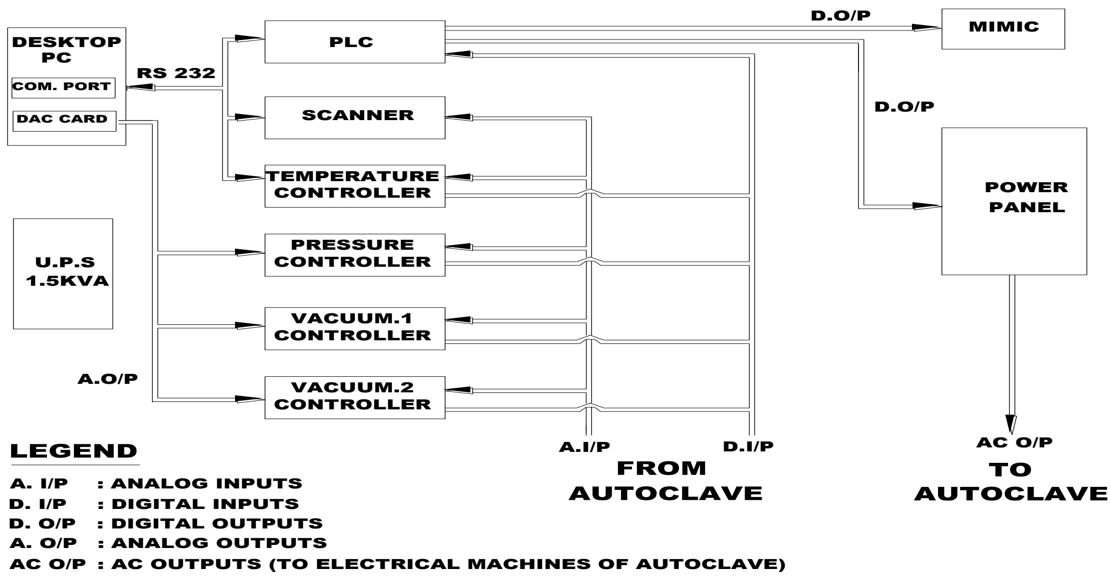

Figure.2. Architecture of computer based autoclave controller

- **Scanner**: It interfaces the analog input signals (32 channels) to the PC. It also displays the channel number and the data in engineering unit and serves as an alternative means for process data monitoring during computer failure.
- **Programmable Logic Controller (PLC)**: It interfaces the digital signals (over 200 I/O) from the autoclave to the PC, executes the commands received from the PC and the program for sequential operation, interlocks, safeties, alarm management etc.
- **Front-End Controllers (FEC)**: They perform closed loop control of temperature, pressure and vacuum based on the set values from computer or the user.
- **Mimic**: It depicts the autoclave schematic and displays the status of various motors, pumps, heaters, valves and safety devices through high bright LED that indicates on, off or failure (LED blinks) status in all the modes.
- **Power panel**: It consists of control and switchgears for electric power handling, pushbuttons and indicators for manual operation and a Variable Frequency-Variable Voltage drive for the blower motor.
- **Computer**: It is a desktop PC with a Digital to Analog Converter (DAC) and a serial communication add-on card. It continuously feeds the set values to the FEC, communicates with scanner, PLC, FEC and performs the SCADA software features. The control system is electrically isolated from the power system and powered through an **UPS** (Uninterruptible Power Supply) to retain the supervisory features, pressure and vacuum cycle control even if the power fails.

4. Temperature control system and its interface to the computer

Autoclave temperature control: The block diagram of autoclave temperature control system is shown in figure 3. It has multiple temperature transmitters, which receives part and autoclave temperature signal from ‘K’ type thermocouples and sends the standard signal to the scanner [5]. A self-tuned PID controller performs closed loop control of autoclave temperature based on set point from PC or operator. Heat output of the controller, a linear signal, is fed to a novel heater power control circuit, which produces few discrete outputs (heater bank on or off) and one linear signal such that the total heater power output in percentage matches the heat demand. Cool output of the controller, a cycle time controlled digital signal is fed to the PLC along with the deviation high signal. Based on these two signals, the PLC operates the Cool-Air/Water valves, which are pneumatically actuated and electrically controlled on/off valves. The PLC is programmed to purge the heat exchanger with air before and after every water-cool operation to prevent thermal shock to heat exchanger and to remove residual water. A set of Blind Temperature Controllers and an Overheat Controller provides protection against heater failure and control loop failure respectively. Part(s) temperature signals are fed to the scanner, which displays and uploads them to the computer through a serial communication link (RS 232).

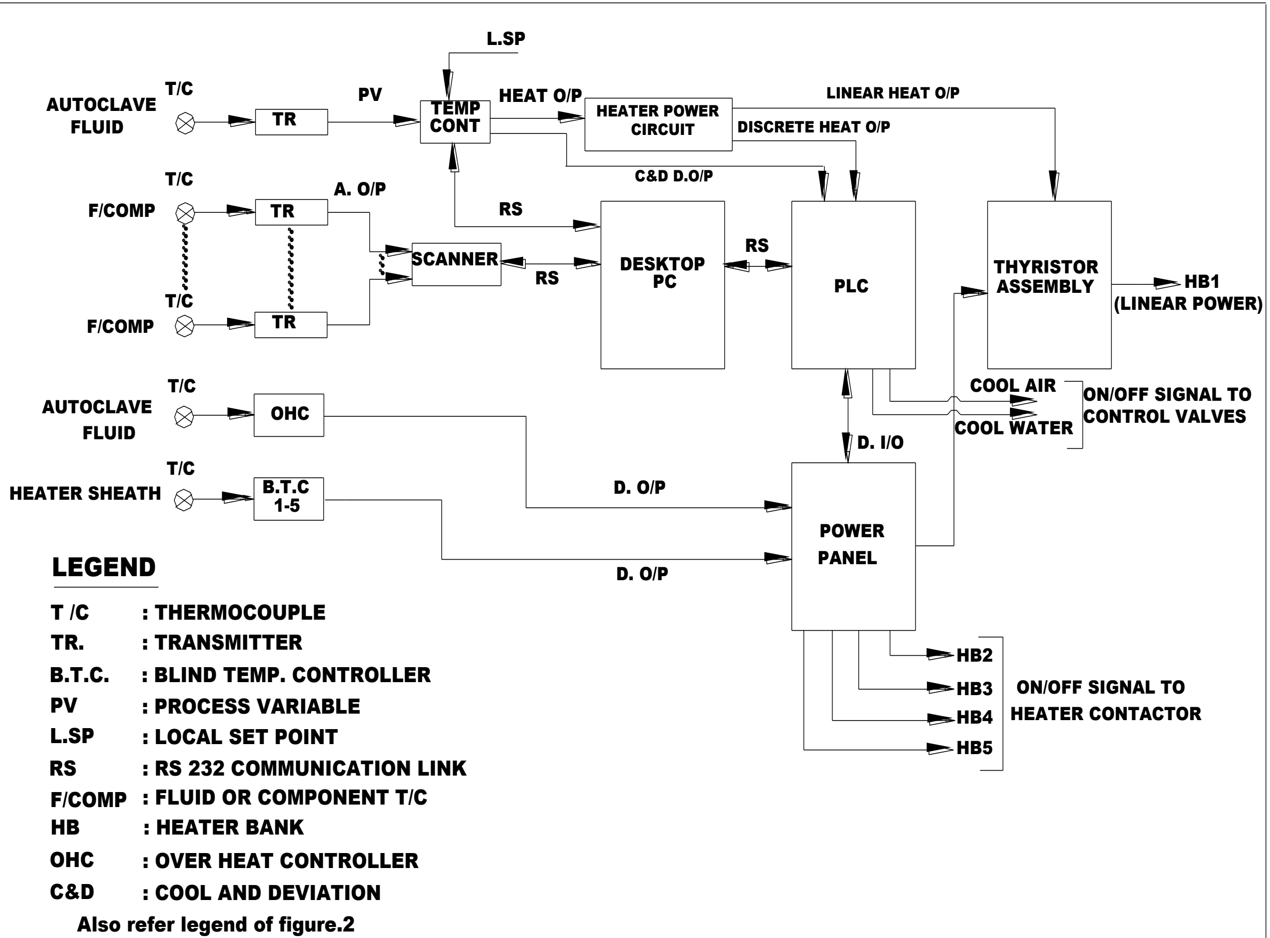

Figure.3 Block diagram of autoclave temperature control system

Part temperature control: Part temperature depends on many parameters such as autoclave temperature and its rate of change, thermal mass of the mould, vacuum bag and other bagging material that cover the part, part geometry, thickness and its placement inside the autoclave, heat generation due to polymerization, heat dissipation of the mould etc, [3]. A model based control approach, even if correctly implemented, would require most of the above data from the user, which is almost impossible for the user to generate [4]. Hence Part Temperature Control Algorithm (PTCA) that does not require any information about the part from the user was developed. The PTCA works based on the system constants such as maximum rate of heating, cooling, temperature of the autoclave etc. The PTCA accepts control inputs such as the part temperature profile, allowable temperature range and gradient on the part (or among the parts) and the basis of process variable selection (Lead, Lag, average, any given sensor or group of sensors). It computes the thermal head and hence modifies the autoclave temperature depending on the real time values of part and autoclave temperature, their rates of change, dwell temperature, estimated time to reach dwell temperature and the available cooling rate to bring down the thermal head as the part reaches dwell temperature.

5. Pressure control system and its interface to computer

The block diagram of the pressure control system is shown in figure 4.

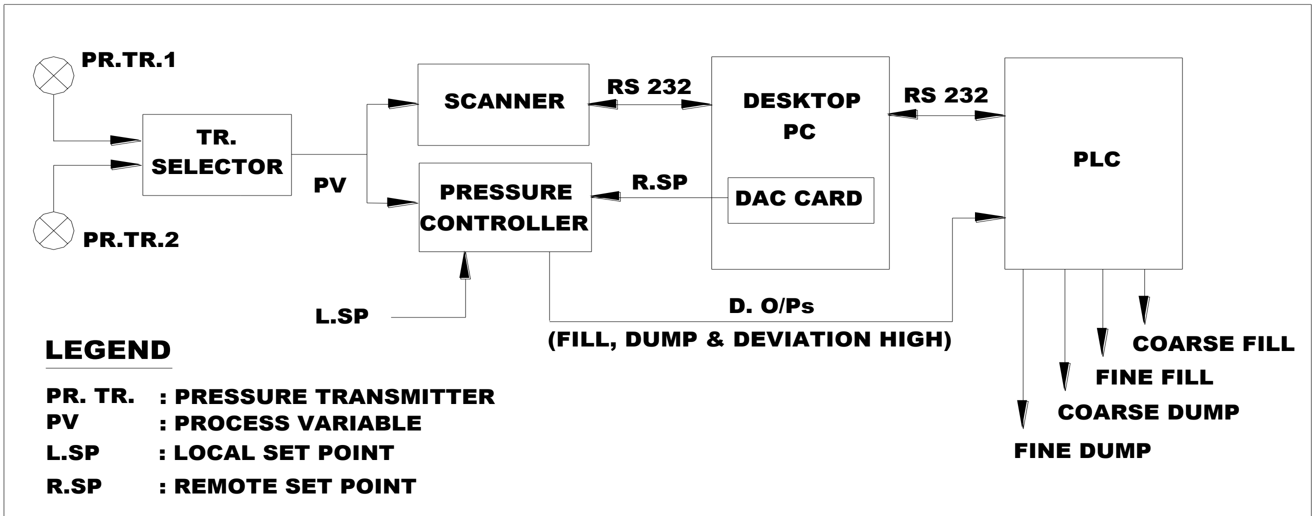

Figure.4 Block diagram of autoclave pressure control system

It consists of a pair of pressure transmitters that converts the autoclave pressure into standard signals. Output from either of the transmitter is fed to the pressure controller. Pressure controller receives the set value from the computer DAC card (auto mode) or from its front panel (semi-auto mode). It employs a PID and cycle time based control algorithm to maintain the set pressure using coarse and fine control valves (on/off type) mounted on Fill (pressurize) and Dump (depressurize) lines. It feeds three digital output signals to the PLC namely Fill, Dump and Deviation High. Based on these signals, after receiving 'Start pressure cycle' command and after mandatory checks, PLC actuates coarse or fine valve of Fill or Dump line. A good accuracy of ±0.1 bar was achieved with this method. Better accuracy and noise free operation are achieved with proportional control valves, however at higher installation and maintenance cost. A high-pressure protection device causes the PLC to dump the autoclave pressure, to safe limit, in case of excess pressure.

6. Results and Conclusion

The computer based autoclave cure controllers, which permit multiple modes of operation have been developed and commissioned for autoclaves within and outside NAL. **Part temperature control algorithm** was tested for the typical aircraft and satellite structures made of low bleed polymer matrix system; A control accuracy of ± 1.5^0C was obtained during soaking period on a single point control and ± 2^0C on a multi-point control (control based on a group of sensors). Autoclave pressure profile has been maintained within ±0.1bar during ramping and within ±0.05bar during constant set point through Coarse/Fine on/off control valves.

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