Development of PLC Program for Multi-Process Parameter and Multi Profile-based Control Logic for Heat Treatment Industrial Applications

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Abstract. The industrial heat treatment application is very critical generally. The implementation of process parameters like Temperature, Pressure, and vacuum should be controlled precisely along with pre-defined time slot, otherwise, it may impact the product quality in some applications. The process of vulcanization related to rubber, glass and aerospace products is done by hot air or steam autoclaves. The Temperature and Pressure are to be controlled with ramped setpoints and in some of the applications Vacuum is also considered. By using Industrial Autoclaves, there are two types of processes that can be carried out, namely the Vulcanization and Pre-Heating. Most of the Autoclaves were used for sterilization of medical equipment in the medical field also. The process parameters are controlled based on the Process time and pre-defined profile paths which are defined by the type of application used. Whatever the applications are available, the use of a control logic program remains same in all applications. The main agenda of control logic was to achieve the process set points and minimizing the amount of error and executing the Profile steps and logging the process data were purely depending upon the Control logic program and efficiency of logic. The development of the PLC program for Controlling the Autoclaves or Ovens, should capable to handle the Data acquisition, control and monitoring of Process parameters with the smooth functioning of associated sub-systems.

1. Introduction

In the present industrial process applications, there are many approaches available for controlling the process parameters. Among them, some of the research works are denoting the importance of PLC and associated sub-systems and their utilization in the industrial environment. For this proposed work various earlier research works are compared and analyzed. Most of the research works were pointing out the type of process and devices used for controlling the process parameters like temperature and pressure control in the industrial environment. The development of PLC program for controlling the Autoclaves and Ovens should be capable enough to handle the data acquisition, control and monitoring of process parameter with the smooth functioning of associated sub-system there are many kinds of control systems available.
2. Literature survey

For this proposed work, the literature survey was made and the results were inferred as followed. Arghya Ganguly, et. al [1] described the processes, related to the temperature control in the furnace using a PLC-based control system. This work particularly concentrates on automation of the furnace and reduction of man power since the earlier system was semi-automatic. Furthermore, the control of temperature in the furnace they have not implemented the ramp function for controlling the temperature may be precise control of temperature may not require for this project and observed that temperature disturbance also may not much.

Hu Jin [2] focused mainly on control system related to the furnace for hardening and tempering of the steel objects requirements. Further, this work made a suggestion that PLC is more reliable than the microcontroller-based control system because in an industrial environment, any process plant should run round the clock operations. It also described the profile of the temperature process, but in the implementation part how to achieve the profile by the PLC was not clearly stated. Kamalakannan G.M. et. al [3] explained the process related to an Autoclave and to cure the polymer matrix composites. It also concentrated on curing of composites and control by autoclave with a computer-based system with PLC. The realization of sub-systems for controlling the Autoclave was focused. The implementation of the single-loop controller for controlling the process parameters was done but control logic and achieving the cure cycle was not stated clearly. Krishnamoorthy et.al [4] demonstrated the effect of Trellis Coded Modulation (TCM) in underwater communication.

Rahul Pawar et. al [5] elevated the application of PLC and its features in different industrial process applications and compared the PLC with other systems. In addition to the PLC, microcontroller-based control concept also described. But it lacked in the control schematics of control systems and PLC control logic development code description. Upadhya A R, et. al [6] concentrated on the process cure cycle of the composite materials. This work described about the entire sub-system of the autoclaves and provided the various types of control system schematics that are possible. It did not describe much about the control logic code and the achievement of the process.

Dipika Kothari, et. al [7] proposed a methodology for processing of metal hardening by using Lab view as SCADA of PLC. The work was more focused towards the physical requirements and way of working with the associated sub-systems. This research work lagged in the execution of PLC code for process requirements. The automation of the heat treatment process was done with the help of lab view software with functional configuration details more elaborately. In [8], quality of image reception has been enhanced using Orthogonal Frequency Division Multiplexing (OFDM) method. Sanjib Kumar Jayapuria [7] described the process of heat treatment using low carbon steel material. This work concentrated on temperature of the material and controlling of the parameters with the help of PLC.

T.VRajan, C.P.Sharma, Ashok Sharma et. al. [9] studied the effect of heat treatment which had a great significance because of its vital role played in achieving the designed characteristics for a given material. This work skillfully blends the theoretical and practical aspects of heat treatment. D.P.Kadam, P.M.Sonwane, S.C.Landge, V.P.Dhote, S.S.Thorat et. al. [10] described the PLC & SCADA using Autoclave automation. In this work a single parameter only was used with PLC. Vilas Jadhav, Pratapvikhe,C.B.Kadu et al [11] described the use of high speed steam sterilizer using PLC. It also mentioned the temperature and pressure based sterilize the medical equipment and lab product. But the data block and function block were not used while it used ladder logic only.

S.Kalaivani,M.Jagadeeswari et al [12] described the use of PLC & SCADA effective boiler automation system using thermal power plant. Effect of equalizer [13] in wireless communication has been demonstrated. This work lagged in the Schematic Diagrams and FB, DB Blocks. Based on the above various research works and the result available were studied and found that the correct control logic design and implementation were not stated properly for which the more importance has to be given.
3. Methodology

The Equation of straight line will be used for process parameters scaling to engineering values conversion purposes, this formula used in the control systems logic. The same can be utilized for set point ramp(RSP) but with little modification. The modification of the equation was given below.

\[ Y = MX + PSP \]

where
- \( Y \) - Ramp set point output,
- \( X \) - 1 sec pulse count
- \( PSP \) - Previous Set Point,
- \( M \) - set point difference/total profile time,
- set point difference=FSP-PSP

The same formula can be common for Ramp-UP, RAMP-down and Constant set point generation can be achieved. This can be achieved by data handling of Program table data by logically. Same ramp function can be called many times by multi-call from, the entire eight profiles were assigned in single FB and Single DB so that data handling can be made easy while transferring from one profile to another during the execution of the PLC logic. Hence this proposed work can fulfil the requirement of PLC control logic program. Also, the code was developed in LADDER logic with FB's and DB's were used to increase the performance and retentive data was ensured. The typical process sequence is containing different process times and different Profiles. The table shown below has a total of seven profile steps and each has its own sequence of operations. The profile is nothing but within the pre-defined time, the type of process parameters need to be regulated from previous set point to final set point within the profile. The Development of PLC program can involve, Finalizing the User requirements (Project requirements), Selection of the Control system components and sub-systems, Completing the Hardware wiring and installations of sub-systems, Creation of Environment software for Digital Inputs(DI), Digital Outputs(DO), Analog inputs(AI) and Analog Outputs(AO) and developing the application software involves Simulation and Testing, Project realization, and finally Documentation.

**TABLE 1**

| Sl No | Program Sequence | Process Sequence | Process Time (h:mm:ss) | Total Process (h:mm:ss) | Temp (°C) | Pressure (bar) | Vacuum (bar) |
|-------|------------------|------------------|------------------------|-------------------------|-----------|----------------|--------------|
| 1     | STEP-1           | Start            | 00.00.00               | 00.00.00                | 30        | 0              | 0            |
| 2     | STEP-2           | Temp rise        | 2.00.00                | 2.00.00                 | 50        | 5              | 0            |
| 3     | STEP-3           | Pressure buildup  | 0.00.05               | 2.00.05                 | 50        | 4              | -1           |
| 4     | STEP-4           | Temp rise        | 2.00.05               | 4.00.05                 | 120       | 4              | -1           |
| 5     | STEP-5           | Constant         | 4.00.05               | 8.00.05                 | 120       | 4              | -1           |
| 6     | STEP-6           | Vacuum Vent      | 0.00.05               | 8.00.10                 | 120       | 4              | 0            |
| 7     | STEP-7           | Rapid cooling    | 1.00.00               | 9.00.10                 | 50        | 4              | 0            |
| 8     | STEP-8           | Slow cooling     | 3.00.00               | 12.00.10                | 30        | 4              | 0            |
| 9     | STEP-9           | De pressure      | 2.00.00               | 14.00.10                | 30        | 0              | 0            |
Fig: 1. Control Schematic

Fig: 2. Program Development Stages

Fig: 3. Control Data Flow
Control data flow represents how the program table data was fetched to the PLC database and same was fetched to Profile block for generating the RSP, PRT and TPRT. The initiation of control logic was created using the Reset, Hold and Start soft buttons from the SCADA mimic, after completion of profiles process will come to an end.

The actual set point ramp was generated in the above mentioned PLC logic flowchart. The profile running time calculation is done by counting the 1 Hz PLC clock pulse, and comparing with minute (≥ 60sec) and hour (≥ 60 min) counts and thus the running time was generated and same was represented in the SCADA mimic.
The total program remaining time calculation is done by counting the 1 Hz PLC clock pulse, and comparing with minute (≥ 60 sec) and hour (≥ 60 min) counts and thus the running time was generated and same was represented in the SCADA mimic.
4. Scope of the Proposed Work

The scope of the project is that wherever ever the precise temperature control is required, this program can be utilized. The program is developed based on the PLC ladder logic and multi-process parameters, suitable for all furnaces, Autoclaves and Ovens. The above all existing research works mentioned in the literature survey of chapter-2 were focusing about the process and how it was carried out by using the variety of control subsystems, in the sense briefing the process phases to achieve the desired user results. But when it comes to PLC control logic, not much information and not describing the PLC control logic approaches to fulfill this, the proposed work focuses much on the development of PLC control logic.

5. Present Investigation

The proposed work attempted and succeeded the development of PLC control logic for multi-process parameters and multi-profiles and made a success by using the well-known, simple and easy mathematical approach of “Equation of Straight Line” the slope equation for getting the desired ramp set point results. This newly developed control logic approach primarily meant for Industrial heat treatment applications, but it can be used furthermore for many applications. The methodology used for developing the PLC program control logic can be used to furthermore applications. At present, the application program was useful in the industrial process like pre-heating, vulcanization, metal hardening Furness, rubber and Glass industries. Also, it finds its application in medical equipment’s sterilization purpose also useful. For the implementation of PLC logic program, the data handling was all timers’ values taken by Integer and converted to Double integers, and process parameters set point entry data was taken in the form of real values. For running the control logic, lot of errors will arise and in spite of all errors, it was successfully resolved by taking the concept of Function block (FB) concept, all internal memory variables were assigned in FB itself to avoid the no of Data Bases (DB). Representing in SCADA Mimics, all data were unsigned 32-bit values, time data alone, display as Date, Time and data format as Time was assigned.

6. Results and Discussion

![Fig: 8. Set points entry mimic](image)

The second screen was configured with soft buttons as START, RESET, HOLD, PROGRAM and PID. 'START' soft button configured as by clicking the soft button a Boolean status can be changed from '0' to '1' this was linked with DB for start the Program 'RESET' soft button configured as by clicking the soft button a Boolean status can be changed from '1' to '0' this was linked with DB for resetting the Program.
'HOLD' soft button configured for holding the program, this is also configured as above, liked with DB address, the Boolean status can be changed from '1' to '0'. in the program this bit configured as closed contact, it is disconnecting the 1 Hz clock pulse, thus the counter will pause, by this we can hold the running program since the program was based on the clock pulse count value, by stopping the counter, running program can be paused. 'PROGRAM' soft button configured for popup of the 'Program data table'.

Fig: 9. Process trend mimic

The program table data was interfaced from the SCADA and transferred to the DB, and the resultant RSP’s was also represented in the SCADA mimic. The results were represented by dynamically in the trends mimic and the rising of the parameters as per the profile time, and the set points were executed successfully. Different profiles were changed during the demonstration and all the profile patterns were executed by the control algorithm dynamically and thereby to fulfill the objective of this proposed work.

7. Summary and Conclusions

The Control scheme was based on process data acquisition and fetching the user program set point and process time table has to process by PLC algorithm and generating the Set point RAMP or SOAK and the same is fed to the PID block. PID block will generate the control signal and further based on the error signal occurred in the PID loop will decide the switching between the either cooling or Heating for temperature control and air-in or air-out for pressure control will be carried out. Each process parameter will have dedicated PID block for control. Software’s used for development of PLC code and simulation and representing the process parameter data in SCADA are Siemens’ STEP-7 and WinCC 7.4. The ramp set points of multi-Process parameters for different process profiles was successfully demonstrated and outcome results were represented in the SCADA mimic, the dynamic response of the control logic were demonstrated.

This proposed work was executed by using the single control algorithm for different control schemes like temperature rising, constant and down, and representation of ongoing data in SCADA. The PLC control algorithms can be used for where ever the ramp based profile process applications can be used. As this proposed work mainly focused on temperature and pressure parameters applications, but this logic can be used in similar process requirements. Also not only for the control applications, this can be used for scaling the process from raw values to engineering values conversion purpose also used.
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