International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 1, Issue 5 (Nov-Dec 2013), PP. 33-40

DEVELOPMENT OF SCADA SYSTEM WITH REDUNDANCY FOR CASTING & CURING PROCESSES WITH RING/STAR NETWORK FOR SOLID PROPELLANT PRODUCTION IN AEROSPACE APPLICATIONS

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Abstract—- **Propellant Casting & Curing Processes are vitally important core processes in the production of Solid Propellant Stages of Rocket Missions. Basically the Casting process is pouring the semisolid propellant in slurry form, into steel/Kevlar chambers, lined with rubber & coated with liners. In the Curing process, the slurry cast, is subjected to temperature cycle and it gets solidified and hardened and attains the required mechanical properties, which is essential to get qualified as solid Propellant. Process Instrumentation systems play a vital role in monitoring and controlling the parameters for smooth and efficient execution of the processes. This paper presents the strategies for the Data acquisition and control of Vacuum & Temperature ,thro' SCADA and PID Controllers for Casting & Curing Operation and also networking of processes with redundancy. These techniques have been realized and implemented successfully in the Two Casting Facilities and for six Solid propellant Curing Ovens. The details are presented in the following chapters**

Index Terms— **SCADA, PLC, Propellant Casting, Propellant Curing, Discrete Control** *(key words)*

I. INTRODUCTION

. Casting process is the key element in the Propellant process stream, from which point onwards, all the sequences, flow in serial mode, till the final finished product, Solid Rocket Stages, are ready, in all aspects. The process cycles will vary according to type of segments, being cast, as no. of slurry batches, vary from four to thirteen. For all casting processes, the main parameter is Vacuum, which must be maintained at 5 Torr with allowable deviation of +/ 0.2 Torr. The process involves pouring of the propellant slurry, received in Bowls, after Final Mixing Sequence, from Vertical Mixers,

, in to the steel chambers, kept in Pit. The whole process is done under very high vacuum of the order of 5 Torr, to ensure that the product mix is cast without any defects, due to air entrapments. Major parameters -Vacuum, Temperature of Hot

Water circulated, Fire Fighting System Pressure Parameters, are monitored and displayed in user friendly manner for users. After completion of Casting process only, the vacuum will be released Another foremost criterion is that the process has to go on stream continuously without any interruption, since the propellant slurry has to be cast when the viscosity of the final mix batch, is within 4000-18000 poise and any delay must not shoot up viscosity and make the materials, not castable. Depending on the type of segments, the whole process will take about 8 hours to around 22 hrs.

Propellant Curing is an important process carried out after completion of Casting. In this process, propellant, cast in the form of slurry, is subject to temperature cycles, by placing in Hot air ovens where powerful blowers deliver hot air, for circulation and also circulation of hot water is effected, inside the mandrel, to maintain, thermal stability, along the propellant web thickness. The process cycle is to be followed strictly to get fine finished quality product. The main parameters to be maintained are air temperature and water temperature. As the volume of Oven is huge, Sensors are to be placed at different location to monitor the temperature at all points, so that the uniformity of the oven is determined. All the Major parameters are to be monitored and displayed in convenient fashion, to enable smooth process operations.. The Curing process comprises Hot and Cold cycles. The heater systems will be on during hot cycle .The Curing process is to be executed with high degree of accuracy and quality, since the worthiness of the final product, i.e. Solid Motor, is totally influenced and shaped by the elegant way

,this is done.

For ensuring total success of the Space missions, the impeccable performance of the solid motors of first stage, is highly essential and motors have to deliver the necessary thrust, in highly reliable and accurate manner, with excellent repeatability. For achieving this, all the propellant process sequences have to be executed with very good precision and stringent quality. Hence to support such critical applications, a SCADA system is considered to be more suitable, versatile, and user friendly. The salient feature of the scheme is that to support the programmers continuously and to meet contingencies, redundancy is built into the design and the operations are enabled in various modes, providing flexibility to users.. Another significant feature is that Data Acquisition from all Analog and Digital parameters will be independent of control modes. Essentially, what it means that the Process Instrumentation Systems have to be configured and realized in appropriate fashion with all enhancements, fine-tuned and streamlined, to provide the Process Engineers, a handy process monitoring tool. Further there is genuine need to employ latest trends, to the extent possible and to implement them effectively so as to facilitate smooth, reliable and consistent processing methods. With the above points as guidelines, new system has been conceived and designed, taking into account the various governing criteria involved in processing and developing state-of-the-art Instrumentation systems.

II. PROBLEM STATEMENT

As discussed in detail above, putting in place, versatile, reliable and accurate system for the Casting and Curing Processes, is of utmost priority. Any lacuna and inaccuracy in the scheme of things, will have direct consequence on the process performance and will affect the end product. Improper and imprecise data acquisition and inadequate presentation to process personnel ,due to deficiency of the Instrumentation impact on the objective of realizing defect free and high performance Rocket segments. Crux of the problem is realisation of robust Instrumentation System, with features, touched upon in the earlier part.

III. PROPOSED SYSTEM

Full pledged SCADA System with redundancy, expandability, flexibility and scalability, configured with versatile IO Modules, vibrant software with multiple aspects,, OFC communication for fast , smooth, EMI free and bulk data transmission, ergonomic consoles and panels with built in cooling facilities ,has been conceived ,and schematic finalized for establishing the state of art Instrumentation Systems for the vital Cast & Cure Processes.

IV. TECHNOLOGY

a. Latest SCADA Technology with sub-systems of current standard has been opted.
b. Optical Fiber Communication with many advantages is the medium for data transmission
c. Networking concepts of present trends prevailing in the market.

V. CONTROL SYSTEM FOR CASTING

The SCADA system of both the facilities have been conceived in similar to take care of acquiring

& storing data, Trending, MIMICs, generating reports , Selection of control Priority and controlling of sub-systems based on the process and user authentication as security .In addition Process events table display also is programmed, with manual entry, to present overall process view. The Control console & IO Panel of the System will be operating with UPS Power.

Salient features of Casting Console are as follows: For operating through Local & Remote mode, Panels should be ON. In Local Mode, the user can control manually from MCC (Master control Centre) which is located some 60 Meters away from the control room. The Control console in control room is having manual push buttons and SCADA system. In remote Mode, user has to select either Auto Mode or Manual mode. In Remote – Auto mode, the sub system will be controlled from SCADA. In Remote-Manual mode, the systems are controlled from Push buttons in Control console. In Casting Process the Hot water temperature will be maintained at 40 Deg C and Vacuum at 5 Torr.

All above three modes are available if UPS of the SCADA system is healthy. Over and above, there is Independent Mode, which will be activated automatically after the failure of UPS. The system architecture is shown in figure -1

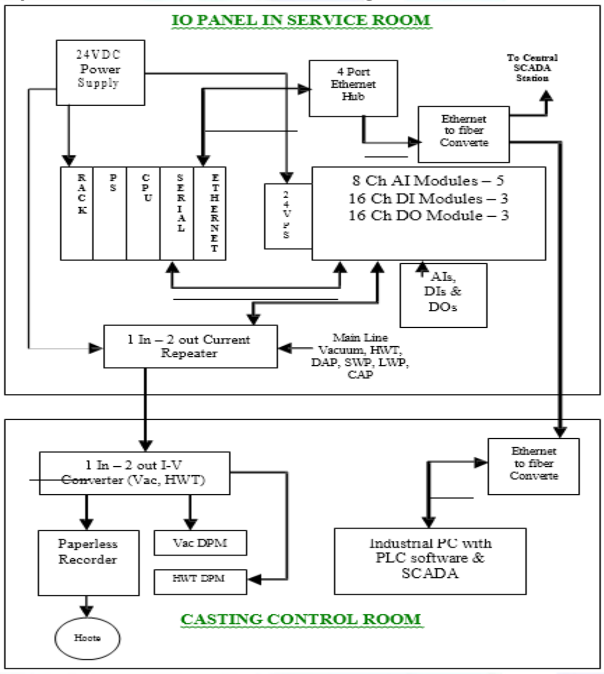


Fig 1 – System Configuration

VI. CONTROL SYSTEM FOR CURING

For Curing process, identical configuration is designed and in addition, we have, discrete PID controllers to control the temperature of Air and water. Three numbers of controllers are used for controlling the Air temperature of the oven. The oven heater banks are divided in to three banks to control the temperature. Each bank is controlled by separate controller. Two controllers are used in On/Off mode and another one as a PID controller. Initially set points and safety set point will be programmed in both the controllers. The On/off controllers will be active during temperature rise up to 45 Deg C & 55 Deg C and third controller will take over then to rise the temperature up to 60 Deg C through Thyristor control , which is triggered by proportional current signal from the controller, to maintain uniform temperature. The Oven can be operated from two controllers to main the temperature without Thyristor, in On/Off sequence. Still the oven temperature dispersion is maintained at +/- 2 Deg C, whereas with Thyristor Control, it is possible to achieve, uniformity within

0.5 deg C within the oven, of volume around 106 cubic meters. Similarly two controllers are employed for control of water temperature. Here also one unit acts as an On/Off controller and another as PID controller, connected to a Thyristor. The system has Provisions to control the sub systems with SCADA. The graphs pertaining to Temperature Profiles with On/Off Control & Thyristor Control are shown in the following pages.

VII. CASTING SUB SYSTEMS

The casting Sub Systems are: (i) Vacuum Pumps of 40 m3/hr Capacity with Main & Booster Pumps, (ii)

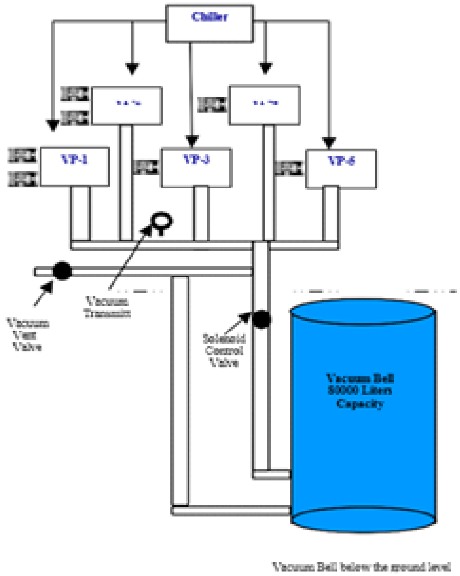


Fig 2: Casting Sub System Schematic (Bell in Pit)

vacuum pumps of 275 m3/hr Capacity, (iii) Cold Water pumps, (iv) Hot Water pumps, (v) Compressors, (vi) Chiller, (vii) Fire Fighting Systems (Deluge Systems), (viii) Vacuum Control Valves, (ix) Hot water heater banks, (x) PLC, (xi) PID Controller for Vacuum and Hot water System Control . All the above Systems controls are brought to Control console and linked to push buttons and also to SCADA. The schematic of the systems are shown in figure 2.

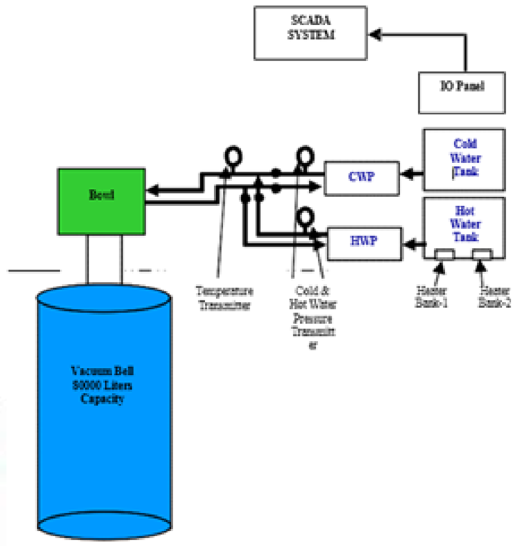


Fig 3: Casting Sub System Schematic (Bowl over Bell)

VIII. CURING OVEN SUB SYSTEMS

The curing Sub Systems are: (i) Blowers (Main & Redundant) , (ii) Three Heater Banks for Air, (iii) Hot water pumps (Main & Redundant) , (iv) Cold Water pumps (Main & Redundant), (v) Two Water Heater Banks for Water, (vi) Fire Fighting Systems (Deluge Systems), (viii) PLC/PAC, (xi) PID Controller Hot Air and Hot water System Control . All the above Systems controls are brought to Control console and linked to push buttons and Data Acquisition to SCADA. The schematic of the systems are shown below.

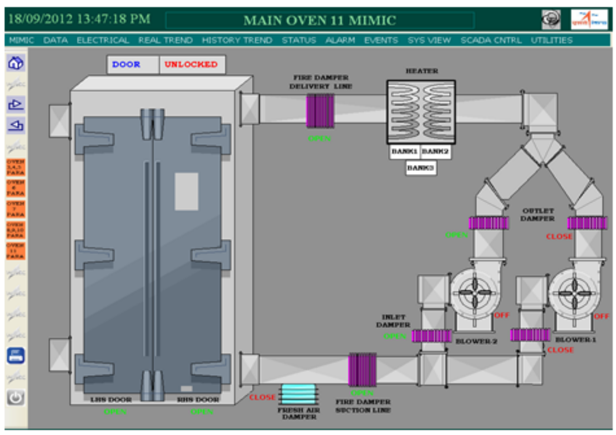


Fig 4: Curing Sub System Schematic

IX. SCADA SYSTEM FOR CASTING & CURING

Both the systems are equipped with powerful software. For Casting, the system architecture is shown in Fig-1. The system uses Remote IO modules & PLC for acquiring data and controlling the systems. The remote IO acquires the data and communicates with PLC through MODBUS RTU Protocol.

The PLC processes the data, based on programs written in PLC. The PLC transmits the data to SCADA software installed in Industrial PC, located at a distance of 60- 70 Meters. The PLC data is interfaced to SCADA through MODBUS TCP OPC Server. Since the distance is more, updating of certain values in SCADA, will be delayed. To overcome this, Ethernet Extenders are used for quick communication and fast updation of real time data. The Communication parameters are set equally in PLC, IO & OPC Server. Some Parameters are

a. In PLC

Primary PLC IP: 192.168.xxx.xxx Backup PLC IP: 192.168.xxx.xxx

Ethernet Card in PLC Rack IP: 192.168.xxx.xxx

b. In IO Modules

Address of Analog Input Modules: 1,2,3 Address of Analog Output Modules:4 Address of Digital Input Modules: 5,6,7 Address of Digital Output Modules:8,9

c. In MODBUS TCP OPC Server

T-Box IP: 192.168.xxx.xxx

In this scheme, 8 Channel Analog Input IOs, 4 Channel Analog output IOs, 16 Channel Digital Input IOs and 16 Channel Analog Output IOs have been employed. Each Analog IO channels has individual Sigma-Delta ADC, so conversion delay is very less. The Ethernet output of PLC is connected to hub and then to existing Intranet for transmitting data to centralized SCADA stationThe two casting facilities are interlinked through fiber optic network and hence the process parameters & status of one facility can be viewed from other facility.

For Curing, the SCADA system has been planned with 100% redundancy. The IO Panels are located at a distance of about 400 meters, from control console. The data from IOs is transmitted to control room through optical fiber cable to avoid EMI. In order to maintain redundancy, two parallel IO modules are used to acquire data from Duplex RTD sensors at a time. Each IO modules are interfaced with Ethernet/ PAC modules to transfer the data. Each Ethernet/PAC modules are connected to separate Ethernet to fiber optic converter having ring network connectivity provision. The distances between ovens are about 800 meters. There are two rings established. One for main chain and another for redundant chain. A link is established in control room between Main and redundant fibre converter through an Ethernet cable. So the data flow will be available on either communication fiber. In case of failure of one fiber, data transmission will continue from another fiber. Similarly failure of communication channel between IO panel and Control room will be reestablished through another fiber port. Such schemes of connections are established for all six ovens. The serial output of thyristors, which are for controlling temperature of the ovens, and power meter are suitably converted to Ethernet and connected to fiber converter. All the data from converter are patched to PLC in control room. In PLC, structure/ladder programs are written to acquire the data from field IOs. The PLC/PAC is connected to SCADA software to acquire the data. The screens are configured in two industrial PC, one as main and another as redundant. Apart from this, each PC has PLC card, which has capability to acquire data directly from the field IO modules. This feature will be used at the time of failure of main PLC. The PLC has Ethernet as well as MPI port and PAC has Ethernet, RS485 & USB ports as alternate communication to acquire the data. The configuration schematic is shown below

The system is equipped with software, to acquire process data. There are five IO panels in different process curing ovens in different ovens. IO Panel 1& 2 are connected to SCADA in Ring fashion and IO panels 3, 4 & 5 are connected to SCADA in Star connected fashion. The data acquisition system is configured in such a way to avoid minimum data loss in case of failure of communication network. The configuration of all ovens is shown below. In IO Module, Each analog IO channels has individual Sigma-Delta ADC, so conversion delay is very less. All Propellant curing ovens are interlinked through fiber optic network and hence the process parameters & status of one facility can be viewed from other facility.

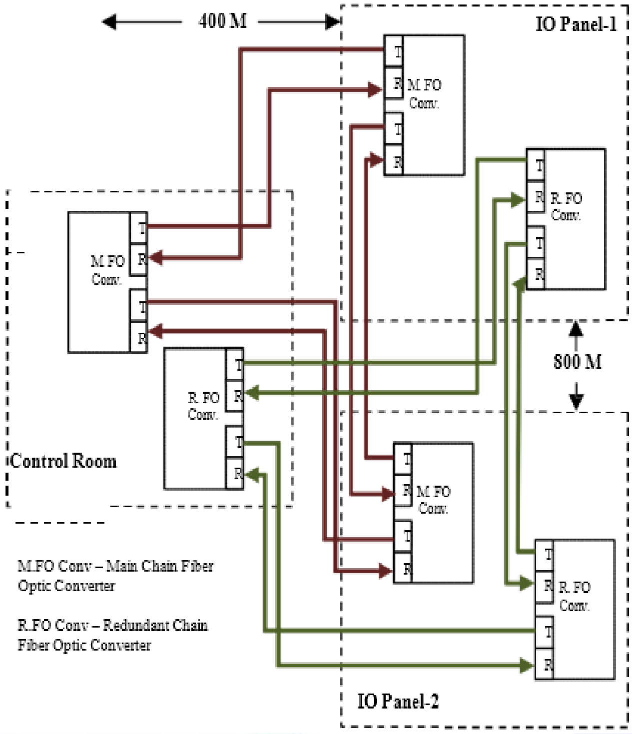


Fig 5 - Ring Configuration

IX. CASTING CONTROL LOGIC

The Casting process consists of two main parameters to control. One is Main Vacuum and other is Water temperature. The vacuum has to be maintained at the range of 5 to 5.5 Torr in the casting chamber of 80000 liters capacity and water circulation at 40 deg C. The Vacuum level is maintained with the help of solenoid valve, which is controlled from SCADA and DPM. In Remote- Auto Mode, the valve is controlled, based on the Set point in the SCADA and in Remote-Manual & Local mode, the valve is controlled from PID Controller. For 40 m3/hr Pump, there is separate push button for Main & booster pump, but single pushbutton from control console & SCADA. The Vacuum Pumps are controlled locally from MCC, based on the process parameter in Local Mode. In

Remote-Auto/Manual Mode, Main pump of 40 m3/hr is switched on from Push button, the booster will be switched on after 10 seconds delay, through timer. For 275 m3/hr Pump, off

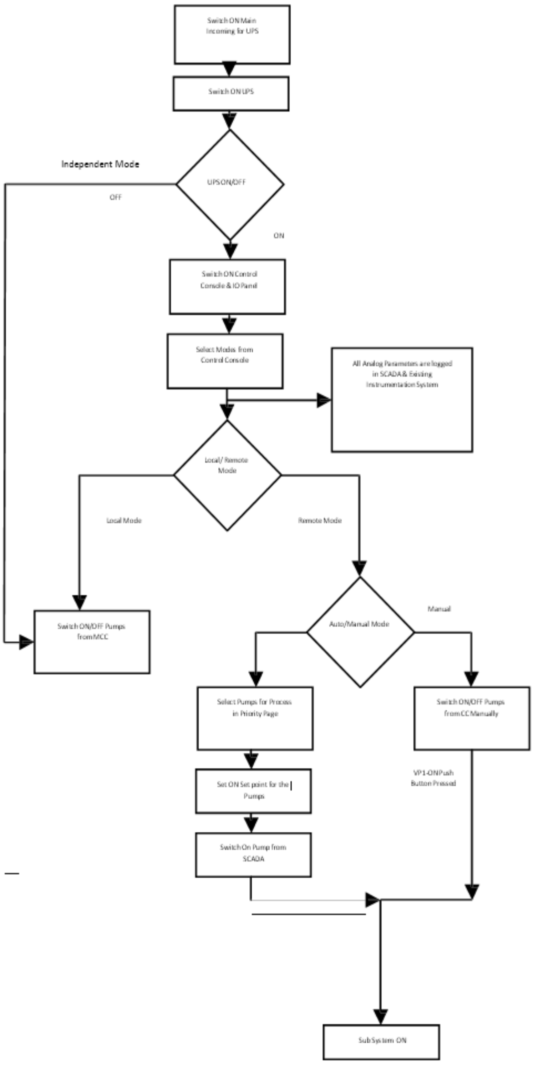


Fig 6: Pumps, Chiller, Compressor Control Logic

set point will be set at 10 Torr and for 40 m3/hr pumps, On set point will be set at 11 Torr. The 40 m3/hr pump will be running up to end of process, irrespective of the process value. Interlock is provided such that booster should get switched on, only after Main pump is on. The vacuum is controlled through a solenoid valve. This is triggered from PID controller in Local Mode & Auto-Manual mode and from SCADA DO/AO in Remote-Auto Mode. The nominal set point is 5.3 Torr with 0.2 Torr Hysteresis. In SCADA mode, there is priority selection option, in which the 40 m3/hr pumps can be run in a specific sequence based on the process.

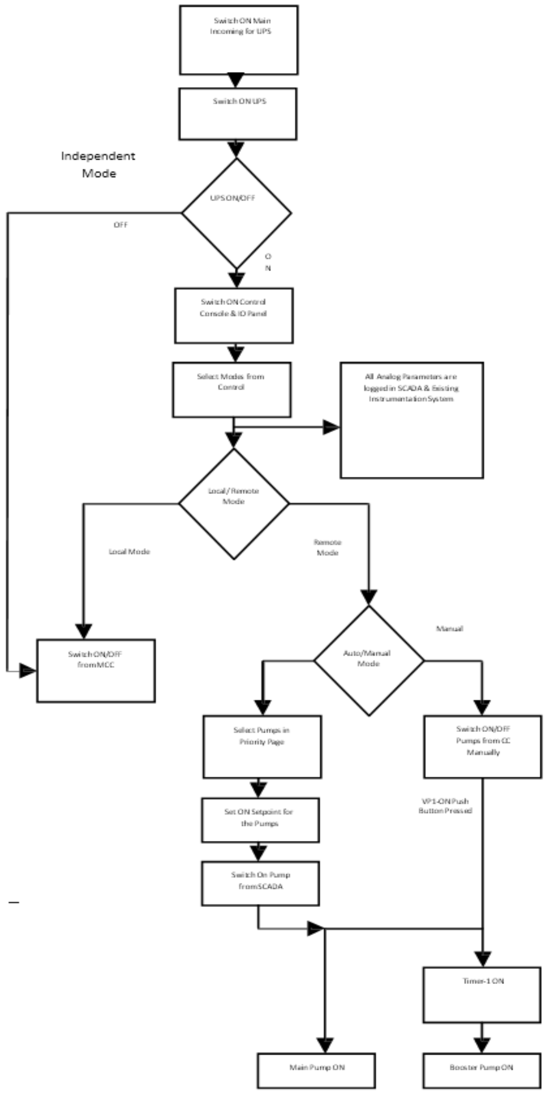


Fig 7: Vacuum Pump 40 m3/hr Control Logic

X. Data Acquisition Logic For Curing Process

The volume main ovens connected to IO panels 1 & 3 (2 Ovens) are about 106 m3, to IO panel 4 (1 Oven) is 76 m3 and to IO panel 2 (3 Ovens) & IO Panel 5 (3 Ovens) are 4.5 m3 & 22 m3 respectively. To monitor and control the temperature inside ovens, RTD sensors are distributed throughout the oven. All RTD sensors, Transducers, etc are of duplex type is used. Each output is connected to Main & Redundant IO modules respectively. The interface module of IO modules of IO panel 1 & 2 provides PROFI-NET output. It is converted to Dual fiber optic output which will transmit the data to PLC directly & thro IO panel 2 Ring network and vice versa. The CPU is located in control room which is common to both IO panel 1 & 2. The data of Main & redundant IO are acquired by the SCADA station thro a central managed hub. The IO panel 3, 4 & 5 connected thro Star fashion to the central hub. The Main & Redundant IOs in 3 & 4 has individual PAC to acquire & process the data with Ethernet output. The same was converted to fiber optic signal to transmit to SCADA station. The IO panel 5 doesn't have any IO modules. It has two numbers of Paperless Recorder with MODBUS RTU communication output. The MODBUS signal is converted directly to fiber optic signal and transmitted to control room located around 1500 meters away and reconverted to RS485 signal. The signal will be connected to RS485 to Ethernet to central hub.

XI. Redundancy Management For Casting Process

The Redundancy of the system can be classified in four levels: (i) Data acquisition Level in which In case of failure of SCADA, data will be taken from paperless recorder. Both SCADA and Paperless recorder will log the data for some critical parameters. (ii) PLC Level in which there are two hot stand-by PLC. The Backup PLC will take over the functions in case failure of primary PLC. (iii) Power supply level in which IO panel & Control Console by individual 24V/10A power supply. The ratings for supplies are 2.5 times of the required power for IO panel. The power supplies are "OR"ed together. During failure of one power supply, other supply will supply required power for both IO panels. (iv) UPS level in which all power supplied to Control console and IO panel are powered from the Hot Stand by UPS kept in Control room. During failure of One UPS, other will take over. The total system has been installed, tested and all simulations, trials, endurance tests and fault simulation and troubleshooting have been carried out for evaluating the system performance, and features

XII. Redundancy Management For Curing Process

The Redundancy of the system is classified in to six levels: (i) Data Acquisition Level in which, two parallel measurement chains acquires data from field IO modules. Failure of one chain will not affect other chain. The data are acquired in both industrial PC, so there is no data loss. (ii) PLC/PAC Level, in which, two PLC/PAC running parallel. One PLC/PAC will acquire the data of Main chain and another for redundant chain. The failure of one PLC/PAC will not affect another one.

(iii) Power supply level in which IO panel & Control Console by individual 24V/10A power supply. The power supplies are "OR"ed together. During failure of one power supply, other supply will supply required power for both IO panels. (iv) UPS level in which all power supplied to Control console and IO panel are powered from the Hot Stand by UPS kept in Control room. During failure of One UPS, other will take over.

As explained above, the systems have been equipped with effective contingency management

XIII. CALCULATIONS

A. PID Dynamics:

We have to tune the Controller according to above logic. We have to use KP to decrease the rise time, KD to reduce overshoot and settling time and KI to eliminate steady state error

Table-1 PID Dynamics

Response	Rise Time	Over shoot	Settling Time	Steady State Error
K_P	Decreases	Increase	Not Definite	Decrease
K_I	Decrease	Increase	Increase	Eliminated
K_D	Not Definite	Decrease	Decrease	Not Definite

B. Ziegler Nichols closed loop method for PID Tuning:

To get the good response, First, set the controller to P mode only. Next, set the gain of the controller (kc) to a small value. Make a small set point (or load) change and observe the response of the controlled variable. If kc is low the response should be sluggish. Increase kc by a factor of two and make another small change in the set point or the load. Keep increasing kc (by a factor of two) until the response becomes oscillatory. Finally, adjust kc until a response is obtained that produces continuous oscillations. This is known as the ultimate gain (ku). Note the period of the oscillations (Pu). The control law settings are then obtained from the following table,

Table -2 Ziegler Nichols Method

	K_C	T_I	T_D
P	$K_U/2$		
PI	$K_U/2.2$	$P_U/1.2$	
PID	$K_U/1.7$	$P_U/2$	$P_U/8$

C. Thyristor Current = Watts / (1.732 x Voltage load) + 20% safety factor.

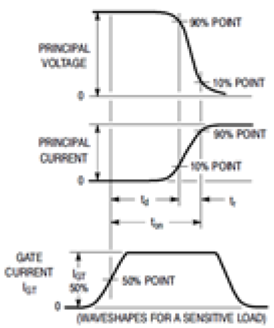


Fig 8 – Thyristor Current Response Curve

D. Thyristor Rating = Total Watts / (3 x 240)

= Amps

E. Heater power P = V /R x t/T, V = RMS

line voltage R = Load resistance

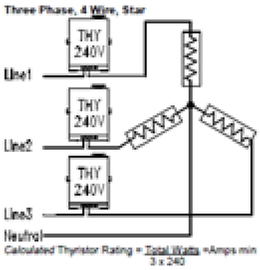


Fig 9 – Star Connected Thyristor Wiring

F. Parameters:

The fine tuning of 4-wire Thyristor will be achieved either from Auto tuning option from PID / PLC controllers. But since this method involves considerable amount of analysis, it will take more time to tuning, and accordingly, the temperature reaching and settling time will be more. The parameters are to be set in the thyristor and PID Controllers by trial and error methods, through number of processes and frozen so that the settings will ensure the stability. The stabilization of the oven can be controlled through thyristor either in Zero-cross firing mode or in Phase angle firing mode. The harmonic distortion in Phase angle firing mode is larger compared to Zero cross firing mode. It has been suggested that for resistive loads like heaters, Zero crossing mode is preferred. Because of larger volume of oven, zero cross firing of the thyristor is found more suitable. To avoid heater damage during failure of heaters in the phase, all heater are connected with respect to neutral and 230VAC heaters, were used. So heaters are connected in Star Mode to get the power equally. The basic parameters setting in thyristor are:

Table -3

Parameter in PID Controller	Value
Input	Current (4- 20 mA from TT)
Unit	Deg C
Display	0.1 Resolution
Hysteresis	0.1
Temperature Range	0 -15 Deg C
Proportional Range	0 -100 % = 0 to 150 Deg C

Table-4

Parameter in Thyristor	Value
Firing	Zero-Cross
Duty Cycle	1.1 Sec
Peak Voltage	230 VAC
Current Range	4 -20 mA
Proportional Range	0 -100 % = 0 to 150 Deg C

XIV. Results

The critical parameters are plotted in trend from internal history database in SQL for casting and curing operations separately. The real time values are updated in Mimics. The Pumps are controlled according to mode selection. The implementation of thyristor gives smooth control over temperature. The trend of temperature channels in data acquisition thro ON/OFF Control & Thyristor Control are shown in figure at different temperature.

Fig 10 – Casting SCADA Screens

Fig 11 : Vacuum Pump Priority Selection in Casting

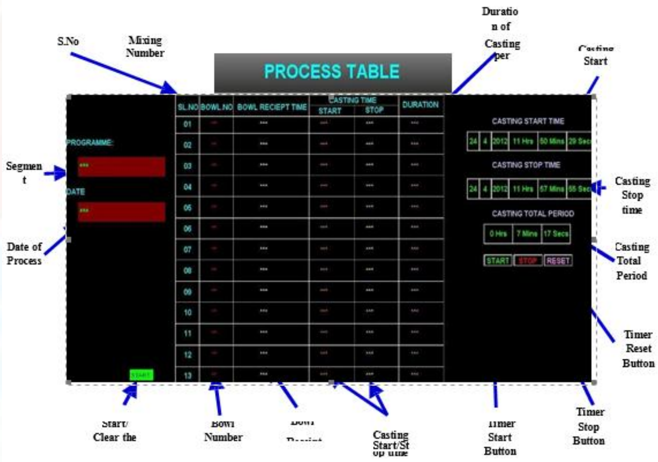
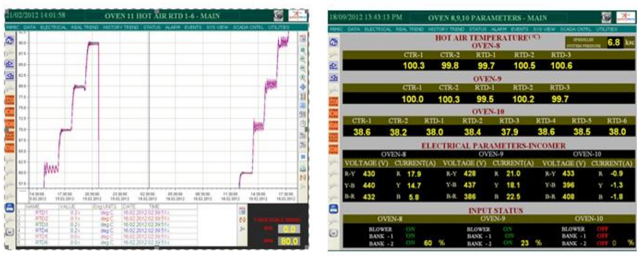


Fig 12 : Process Table for Casting



Trend at 60°, 70°, 80° & 90° in ON/OFF & Thyristor Control in Curing

Real Time Data

Fig 13 – Thyristor Response ON/OFF Mode & PID Mode

Fig 14 - Curing SCADA Screens

XV. Result Analysis

The system has given fine results, meeting the process needs, efficiently and in reliable manner. Final parameter dispersion values achieved, in terms of the Temperature, Vacuum, are well within allowable limits and show excellent agreement and compliance to expected values. With Thyristor Systems and proper tuning of the Process Controller, the control characteristics are showing remarkable precision and efficiency, resulting in Temperature Uniformity and Alignment. With vivid graphics, vibrant mimics, trendy and instantaneous displays of data, Status, Alarms and other desirable features, SCADA Systems have provided the Process Personnel, handy tool for managing the tasks with elegance, ease and professionalism .The systems are also expandable, scalable and can seamlessly integrate upward with Networks, Other advanced systems ,for further up gradation.

XVI. Conclusion

The SCADA system for Solid Propellant Casting & Curing Facilities, with multiple modes of operation for acquiring and controlling parameters, have been developed and commissioned. The control logic was tested in all modes of operation. With this system, accuracy of 0.1 Torr for vacuum and 0.2 Deg C for water temperature was achieved.

References

[1] David Bailey, Edwin Wright, Practical SCADA for Industry, Newnes Publication, 2003

[2] Deon Reynders, Steve Mackay, Edwin Wright, Practical Industrial Data Communication, Newnes Publication, 2003 Start/Clear the Bowl Number Bowl Receipt Casting Start/Stop time Timer Start Button Stop Button

[3] N.Mathivanan, PC based Instrumentation- Concepts and Practice, PHI,2009

[4] Iconics Genesis 32 Training Manual - © 2005 by Iconics, Inc

[5] Kissell,Thomas E-Industrial Industrial electronics: Applications to programmable controllers, Instrumentation and process control and electrical machines and motor controls,3rd Edition, PHI Science, 1989.

[6] Butterworth Heinemann–Tooley,Mike-PC- Based Instrumentation and Control–Oxford Publications,1995

[7] Bentley, John.P - Principles of Measurement Systems, 3rd Edition, Pearson Education 2005.

[8] [8] M.N. Lakhoua – SCADA applications in Thermal Power Plant, International Journal of the Physical Sciences Vol. 5(6), pp. 1175-1182, June 2010

[9] Prof.Y. Rajeswari –Real time Implementation of Hydro Electric Power Plant using PLC and SCADA, International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622, Vol. 2, Issue 3, May-Jun 2012, pp.899-902