Development of PLC Based Control System for Copper Vapour Laser System

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Abstract— Copper vapour laser (CVL) is an efficient, high power and high repetition rate pulsed laser, giving output at two wavelengths of the visible region- green (510.6 nm) and yellow (578.2 nm) and being used for many research and industrial activities. Development of copper vapour lasers is taken up at RRCAT, Indore. Laser system consists of several subsystems like pulse generator system, switched mode power supply (SMPS), vacuum and gas system, cooling system etc. Various parameters and signals of these subsystems are to be monitored and controlled. Project includes hardware development for interfacing field signals to PLC, programming of PLC and Human Machine Interface (HMI) for logic implementation and graphical user interface development required for CVL operation.

Key words: PLC (Programmable Logic Controller), HMI (Human Machine Interface), CVL (Copper Vapour Laser)

I. Introduction

Copper lasers are inherently pulsed lasers that operate with high efficiency, high power and high repetition rate. Copper vapour laser (CVL) is a pulsed gas discharge laser giving output at two wavelengths: green (510.6 nm) and yellow (578.2 nm) [1]. Copper vapour lasers are being used in various research and industrial applications. Various parameters related to subsystems of CVL are required to be monitored and controlled continuously during the operation. The main aim of this project is development of control system for CVL system for its efficient and reliable operation. The main challenges in development of control system are reliable operation of hardware in high electromagnetic interference (EMI) environment as well as development of efficient control program and graphical user interface (GUI) for user friendly operation of CVL system.

The control system is based on the programmable logic controller (PLC) and human machine interface (HMI). We have used Siemens make 1214 C (DC/DC/DC) CPU, with two signal modules (SM) -Digital Input SM and an Analog Input SM. This system can handle 22 digital inputs, 10 digital output and 6 analog inputs. Different peripheral circuits like digital input card, digital output card, optical fiber transmitter and receiver card, relay board have been developed for interfacing of field signals to PLC. HMI KTP-700 Basic panel has been designed for providing interface between PLC and user.

Totally Integrated Automation (TIA) Portal, version 13 is used as a software tool for programming and configuration. It contains a SIMATIC STEP 7 Basic version 13, and SIMATIC WinCC Basic version 13. STEP 7 is used to program PLC for control and monitoring of CVL system as per required sequence and interlocks using ladder logic (LAD) language. WinCC software is used for configuration of HMI and development of GUI screens. We have created five screens to control and monitor the process. Screens are welcome screen, control panel screen, diagnostics screen, run time meter screen and alarm screen. With the help of this control system the operation of the laser will become reliable, safe and user friendly.

II. System Design Description

The system has the following hardware components:
1) Copper Vapor Laser System
2) Programmable Logic Controller
3) Human Machine Interface

A. *Copper Vapor LAaser System*

A copper vapor laser makes use of vaporized copper atoms as the lasing medium. The primary wavelengths for this laser are 510.6 nm and 578.2 nm, and over 100 W can be generated in the green and yellow part of the visible spectrum. The copper vapor laser is unusual with respect to its high power and high efficiency in this region and in that its normal operation is at pulse repetition rates of several tens of kHz

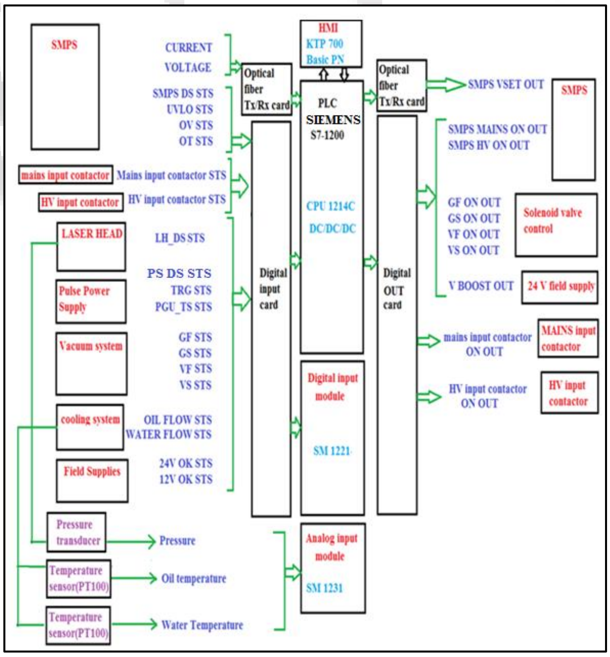


Fig. 1: Block diagram of CVL system

To control and monitor Copper vapour laser system; Following sub-systems are considered to be monitored for reliable operation of CVL:

1) *Vacuum and gas system*

To maintain required pressure in laser tube we need vacuum and gas system which is comprised of Vacuum pump, Gas cylinder and solenoid valves. Neon-gas is used as buffer gas. Operation of solenoid valves are controlled and monitored using switches on HMI.

To measure pressure inside laser, tube a Piezo-resistive thin film transducer is used. This senses the laser head pressure and transmits analog current (4-20 mA) signal to PLC.

2) Pulse power supply

Copper vapour laser requires fast high voltage excitation pulses. Capacitor to capacitor charge transfer pulse generator circuit with resonant charging scheme is commonly used for excitation of this laser. The pulse generator circuit (for a typical 40W average output power CVL) provides excitation pulses at around 6kHz repetition rate with peak voltage of around 20kV, peak pulse current of around 800Aand rise time of around 100ns.

Three phase input voltage 415 V AC, 50 Hz operated high voltage switch mode power supply (HV SMPS) provides variable DC voltage (300-400 V) with maximum load current of 20 A. This is used for resonant charging. The pulse generator for this power supply consists of four insulated gate bipolar transistors (IGBTs) in parallel connected in primary of a step up pulse transformer. IGBT and energy storage capacitor are used in primary side of step up pulse transformer, with capacitor to capacitor charge transfer circuit [2]. The desired voltage level at the secondary side is achieved by the turn ratio of the pulse transformer. The three magnetic pulse compression (MPC) stages are used in the high voltage side of the pulse generator. Use of MPC introduces switching action with different pulse rise times at output capacitor from the first compressor stage to the last compressor stage connected to the laser load.

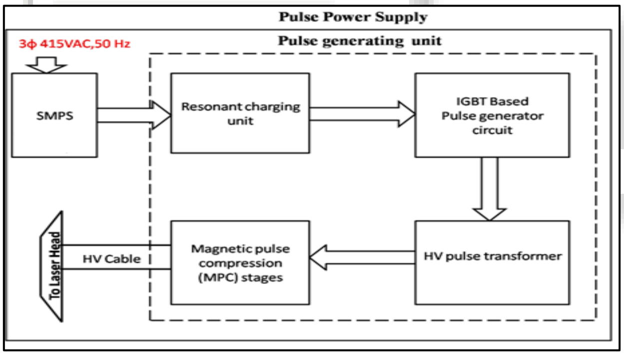


Fig. 2: Block diagram of Pulse Power Supply for CVL.

A properly designed MPC offers compression of the pulse rise time less than 100 ns with fairly high energy transfer efficiency. Temperature of the pulse generating unit is needed to be monitored for safety of the components like IGBT and transformer. For this a thermostat is mounted externally on unit which is set at 70 °C which turns off if temperature of unit exceeds limit. Status of this thermostat switch is read by PLC.

High voltage SMPS voltage, current signals are available in the form of optical pulse. These optical pulses have the pulse frequency proportional to the voltage or current. To read voltage or current, optical pulse needs to convert in to electrical pulses. Hence HFBR-2521 is used as receiver in receiver circuit which converts the optical pulses in TTL pulses. Similarly, to set the SMPS voltage at desired level it requires optical pulses of pulse frequency proportional to voltage. These pulses are generated using PLC which is electrical in nature and converted to optical pulses using HFBR-1521 transmitter in transmitter circuitry

3) Cooling system

Cooing system is required to maintain the oil temperature and laser glass tube temperature within operating limit. Cooling system comprises of water chiller unit, heat exchanger, oil circulation pump, flow meters, temperature sensors. Chiller unit cools the hot water and supply the cold water which is fed to the heat exchanger of pulse generator circuit. Heat exchanger is tube & shell type where the water flows in tube and oil flows in shell. Hence water exchanges the heat of oil and cools down the oil. Then this water goes to laser tube glass jacket where it takes the heat of glass tube and returns to the chiller unit. Flow of water and oil are also being monitored using KOBOLD make SWK-2190 flow switch such that lesser flow leads to improper cooling. Flow of water and oil are set to 7 liters per minute. Flow greater than 7 liters per minute makes the flow switch close and lesser flow than 7 liters per minute leads to open the flow switch. Interlock signal based on flow switch status, is generated for turning ON the HV input contactor.

For monitoring the performance of cooling system it is very much essential to monitor the water outlet temperature and oil tank outlet temperature. Hence two RTD temperature probes (PT100) are used. This probe senses the temperature and provides 4-20 mA current signals corresponding to 0-100 °C. For proper operation of system, maximum temperature limit for oil is set to 60 °C and for water is set to 50 °C. If any one of these temperature limit exceeds, HV contactor should be immediately turned off.

4) Field supplies

Two out of three are 24 V ratings and one of them is 12V rating. Out of two 24 V SMPS one is being used as clean power supply to power noise less system like PLC, HMI etc. While other one is used as Noisy power supply which powers signal conditioning circuits having noisy signals from field or the signals which go to field. 12V power supply is used for powering the solenoids. Status of these supplies is monitored:

B. Programmable Logic Controller

PLC is powerful controller and allows monitoring PLC have advantages of high reliability in operation, flexibility in control techniques, small space and computing requirements, expandability, high power handling, reduced human efforts and complete programming in a plant [3]. The CVL system is controlled by PLC with the help of ladder logic (LAD) language. Here, SIEMENS make S7 1200 PLC with CPU 1214C (DC/DC/DC) is used. The programming software for this PLC is Step 7 (TIA V13). Specifications of the used CPU 1214C are:

– On board input/output-14 digital inputs /10 digital outputs and 2 analog inputs
– User memory:-Work memory of 7 KB, load memory of 4 MB, retentive memory of 10 KB
– Signal module expansion-up to 8 modules
– No of High speed counters-6
– PROFINET- 1 Ethernet communication port

The proposed system has 20 digital inputs and 10 digital outputs and 3 analog 4- 20 mA current signal. Since used CPU has only 2 analog output in the form of voltages only so we need two signal modules(SM):

1) DI SM 1221(8×24 V DC)
2) AI SM 1231(4×13 bits)

C. Human Machine Interface

We have selected KTP700 basic panel which act as interface between user and PLC for supervisory control for our system. There are various parameters are to be monitored and input by the user. Various indicators, switches are required on HMI for operation of system. Hence graphical user interface has been designed using WINCC basic software of TIA portal. HMI is also configured to generate different alarms.

Following 4 screens are created in HMI:

1) Control panel screen:

This screen contains Boolean indicators for all interlock signals, status of solenoid valves & contactor, numeric indicators to display the analog parameters, switches for solenoid operation, SMPS control and contactor controls. On control panel screen numeric control is also provided to input the set point voltage to SMPS. Two keys F6 and F7 of HMI are also configured to increase and decrease the value of set point

2) Diagnostic screen:

screen which is designed to monitor all the field signals individually based on which interlock signals have been generated. This screen is used by user when any interlock fails and user wants to know due to which field signal interlock failed. This screen also has two very important controls i.e. "TRIGGER OVERRIDE" and "SYSTEM OVERRIDE"

3) Run time meter screen:

screen which is configured to see the present operation run time and total run time of system.

4) Alarm screen:

as "ALARM" screen which gives information of alarms. We have configured three alarms based on the analog parameters pressure, oil temperature and water temperature.

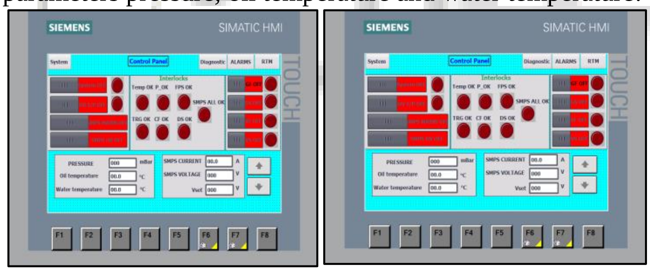


Fig. 3: "CONTROL panel" Screen and "Diagnostic" screen.

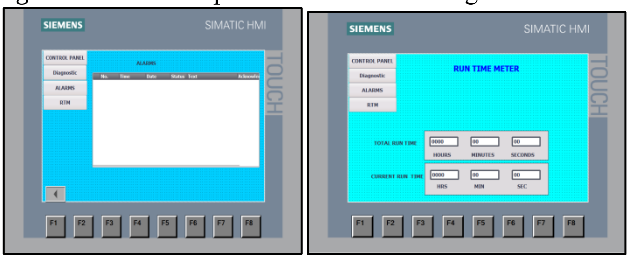


Fig. 4: "ALARM" screen and "Run time meter" screen of HMI.

III. FLOW CHART OF SYSTEM OPERATION

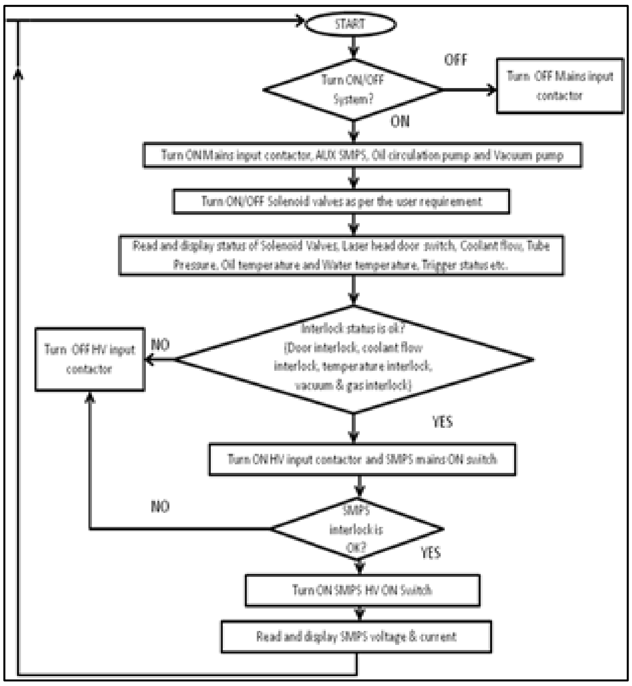
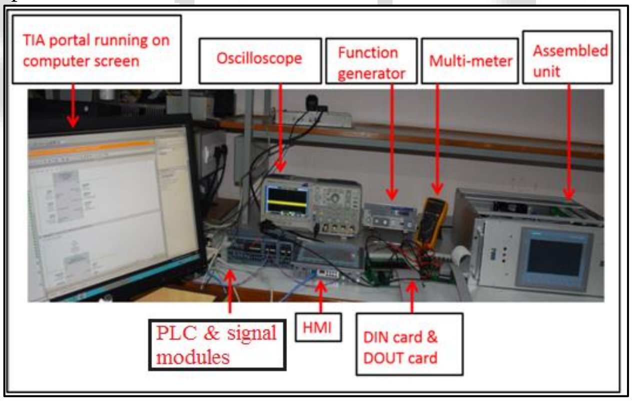


Fig. 5: Flow chart of CVL system operation.

A. Testing

In offline testing, card level and unit level testing are performed to check their proper functionally to avoid any problem after integration with actual system. Offline testing is done on table by simulating the input similar to the actual inputs.



Fg. 6: Test set up for offline testing.

Online testing is done after integrating developed 4U control unit in to 39U rack of copper vapour laser power supply. After integration, all the status signals shown on HMI screen are verified with actual status of field signals.

Fig. 7: (A)controller unit in 39U rack and (B) zoom view of HMI screen.

IV. Results

Developed system performs in efficient manner when control unit is interface with the copper vapour laser system. All the interlocks work as per their design, if some of interlocks fail, control unit immediately turn OFF the high voltage input. As laser power supply generate high EMI due to fast switching of high voltage across load. Even control unit performed satisfactorily in this high EMI environment. All the analog parameters are displayed with as per required accuracy which provides the efficient control to get the optimum performance of laser system. Human machine interface panel provided on front panel of unit provides user friendly operation of system, effective visualization of parameters. Alarms are generated based on violation of defined condition which provides ease to operator in troubleshooting. Data log creation helps to keep the record of crucial parameters to improve the overall performance of laser system. Runtime display enables operator to track for required timely maintenance

V. Conclusion

The main objective of project was to implement control system to control and monitor operation of CVL system. The project has been implemented successfully by developing a control unit and testing its various functionalities with actual CVL system under high electromagnetic interference (EMI) environment. Programmable logic controller has been selected as a controller due to its ruggedness, immunity to EMI, modularity, capability to handle different type of input/output and easy programmability. Siemens make 1214C CPU of S7-1200 series PLC with two input signal module has been used for the development. Different peripheral cards such as digital input card, digital output card, relay card, optical fiber transmitter and receiver card are also developed to interface field signals to PLC. The programming of PLC has been done in Ladder logic (LAD) using STEP 7 software of Siemens TIA (Totally Integrated Automation) portal V13. Apart from monitoring and controlling of signals, different interlock signals based on combinational logic has been implemented in PLC software for reliable and safe operation and of system. Siemens make coloured display with touch input human machine interface HMI panel KTP-700 has been used for interface between PLC and operator. Different graphical user interface (GUI) screens for different purpose have been developed for HMI panel using WinCC Basic software of TIA portal. HMI panels eased the monitoring and operation of the system. Developed control system has data logging, alarm generation features.

Developed control unit is modular in nature which can be easily integrated with similar system without any modification. Developed control system for CVL system provides safe, reliable, user-friendly operation of laser system

Reference

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