Automation of Heat Treatment Process using PLC and LabVIEW

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Abstract - **In this paper we had proposed methodology for development of heat treatment process for hardening of metal. Hardness of metal is achieved by applying heat treatment, in majority of small scale industry this process is done by manual way which consumes lots of energy, poor safety and uneven hardness of metal. The proposed system is providing solution of existing process. Motion control is key component in this system which is achieved by precisely controlling the movement of an object which is based on speed, distance, load, inertia. In the proposed system LabVIEW was used as a SCADA of PLC. In this work the metal rod was placed on platform which is having XY direction sliders. This Slider having controlled movement in millimeter scale in the X and Y directions which was controlled by Stepper motor in X axis and Servo motor in Y axis. These two motors communicate with PLC through AC, DC drives. We had provided the features in computer screen with the use of LabVIEW for controlling parameter of motor. The platform motion travelling direction(X, Y) and rate of travelling is entered by user in LabVIEW front panel, this data is received in PLC through KEPServerEX5. PLC was used for controlling purpose for slider and its move the slider in XY axes. The performance was the proposed system was tested by applying heating of various commercial rods and hardness was the rod was measured after heat treatment.**

Keywords – Heat treatment, Hardness of metal, PLC, Motion Control, Metal EN31, LabVIEW

I. INTRODUCTION

Automation of heat treatment process has large application in industry. Major of these process done in manual mode in industries. This is large energy consumption and poor in safety aspect. The main purpose of this automation for heat treatment process is to optimize the system and to find the hardness of metal in a less time. In conventional heat treatment method different method is use which is shown in Fig.1

Fig 1: Method in small industry, Manual and fully automated Heat treatment process

Small scale Industry: The person has to monitor heating chamber continuously, maintain the temperature and time duration of heat applied in metal to the entire heat treatment process and also adjust the metal in heating chamber with the help of person.

Manual method: All things are same as small scale industry but here, the main difference is metal adjust on the slider and slider is move with the help of person. Safety is better than method of small industry.

Automated method: This system is fully automated and it will require one time person to start the process with use of PLC and LabVIEW.

Heat Treatment is the controlled heating and cooling of metals to change their physical and mechanical properties without changing the product shape. Heat treatment is sometimes done unknowingly due to manufacturing processes that either heat or cool the metal such as welding or forming. Heat Treatment is much related with increasing the strength of material, but it can also be used to change certain manufacturability objectives such as improve machining, improve formability, restore ductility after a cold working operation. Heat treatment operation can be defined as heating a metal or alloy to various temperatures, holding these for different time durations and cooling at various rates which is in the brine, water and oil [1].

Different types of Heat treatment Processes:

Heat treatment processes consist of normalizing, hardening, tempering, annealing, quenching etc. which is described below.

Hardening:
The hardening process consist of heating the metal to a temperature of 30-50°c above the upper critical point for hypo eutectoid steels and by the same temperature above the lower critical temperature for hyper-eutectoid steels [2]. It is applied this temperature for some time and then quenched. The use of hardening is to increase the hardness of the metal and to make suitable cutting tools.

Quenching:
Quenching consists of cooling the heated work piece quickly by immersing it in a liquid solution of oil or water or molten salt. This process is done in environmental condition or surrounding it with gas or air.

Tempering:
In this process, the steel is heated to lower critical temperature (350-400 °C) keeping it there, about one hour and then cooled slowly at prescribed rate. Tempering consists of reheating the quenched steel one or more times to a lower temperature, 150 to 650 °C., and cooling it again to develop the desired levels of ductility and toughness. This process reduces hardness, strength and wears resistance marginally. When temperature is increase hardness will reduce [2].

Normalizing:
The process of normalizing consist of heating the metal above austenitic phase 1100°c and then quenched in suitable cooling medium like air. The purpose of normalizing is to refine grain structure, improve machinability and improve tensile strength, to remove strain and to remove dislocation[2.] Normalizing is less expensive than annealing. The process is similar to annealing and is carried out to avoid excessive softness in the material.

Annealing:
In annealing process cooling rate is very slow around 10°C per hour. This Process is carried out in a controlled atmosphere of inert gas to avoid oxidation which is used to reach ductility in work hardened steels. Annealing is performed to reduce hardness, remove residual stresses, improve toughness, restore ductility, and to alter various mechanical, electrical or magnetic properties of material through refinement of grains.

II.   MATERIALS AND METHODS

Our aim is to do automation of manual motion control device for Heat treatment process. The Manual motion control device XY position slider which is shown in Fig.2. We have use following materials Switched mode power supply, Programmable Logic controller, Servo motor, Servo driver, Stepper motor, Stepper driver, Slider, Thermocouple, Heating Coil, Metal, and LabVIEW.

Fig 2: Snapshot of XY position slider

SMPS: Switched mode power supply to converts the available unregulated ac or dc input voltage to a regulated dc output voltage. If SMPS with input supply drawn from the ac mains, the input voltage is first rectified and filtered using a capacitor at the rectifier output.

Programmable Logic Controller: PLC is an electronic device[3] which reads the status of the external input devices and execute by the microprocessor logic, sequential, timing, counting and arithmetic operations according the status of the input signals as well as the pre-written program stored in the PLC. The generated output signals are sent to output devices as the switch of a relay, electromagnetic valve, motor drive and control of a machine or operation of a procedure for the purpose of machine automation or processing procedure. The DVP-12SA series has 12-points in which 8 input points, 4 output points and PLC main processing unit along with multiple instructions.

Servo motor: Mirle product MA series AC Servo motor is used which have brushless commutation. Servo motor has 400w Rated output, 3000rpm Rated rotational speed and 1.27 Nm Rated torque, 60mm frame size, 2.9A Rated current, 1.3 Kg weight.

Servo Driver: The function of servo drive is to receive command signal from control system and provide sufficient current after amplification to servomotor. This current is proportional to command signal. The command signal represents a desired velocity, but can also represent a desired torque or position. Servo drive has 8.5A Maximum Peak current, 2.8 maximum Rated current and Power source is applied Ac 180V~240V Single phase.

Stepper motor: Stepper motor is electromagnetic incremental device that convert electric pulse to shaft motion (rotation). This motor rotates a specific number of degrees as a respond to each input electric pulse. Stepper motor has Step angle 1.8°, Max. Radial force 220N, Max.Axial force 60N, Rated Voltage 3.15V, Rated Current 4.2A. Stepper motors have many industrial applications such as: Printers, Disk Drives, Machine Tools, Robotics, and Tape Drives[4].

Stepper Driver: The M542 is an economical micro stepping driver based on patented technology of Leadshine. It is suitable for driving 2-phase and 4-phase hybrid stepping motors. By using the advanced bipolar constant-current chopping technique, it can output more speed and torque from the same motor compared with traditional

drivers, such as L/R drivers. Stepper driver has maximum 4.2A output current, maximum 50VDC supply voltage, Pulse input frequency maximum 300 KHz.

SLIDER: Slider is made by iron material and its weight is approx. 9 Kg and its load capacity is 0.7 Nm. The total size of slider is 18×17 cm and its height is 12.5cm

Thermocouple: A thermocouple is a device used extensively for measuring temperature. Here we used K type thermocouple and its sensor range is 100 to 1100°C.

EN31: The En31rod of size 16mm diameter has been used as work piece material for the present experiment because EN31 is a high quality alloy steel giving good ductility and shock resisting properties combined with resistance to wear. Hardness of EN31 is 5HRC. This steel is basically known as bearing steel and used for bearing production in industrial sector. Chemical composition of EN31[7] is shown in Table I.

Table I. CHEMICAL COMPOSITION OF EN31

Carbon	1.30%
Silicon	0.30%
Manganese	0.50%
Phosphorous	0.040 max%
Sulpher	0.050 max%
Chromium	1.40%

LabVIEW: Laboratory Virtual Instrument Engineering Workbench is a graphically-based programming language developed by National Instruments. Its graphical nature makes it ideal for test and measurement (T&M), automation, instrument control, data acquisition, and data analysis applications. LabVIEW software can communicate with any PLC in a variety of ways and easily communicate with any hardware [5].

KEPServerEX5: OPC server is designed for PLC and LabVIEW communication in which NI OPC server, KEPServerEX5, etc are used. We had use KEPServerEX5 for PLC and LabVIEW communication. OPC Servers are available for virtually all PLCs and programmable automation controllers (PACs). OPC is a standard interface to communicate between numerous data sources, including devices on a factory floor, laboratory equipment, test system fixtures, and databases [6]. KepserverEX5 software based server is designed for accurate communications, quick setup and unmatched interoperability between client applications, industrial devices and systems. Basic Server Components of KEPServerEX5 are following: Channel, Device, Tag, Tag Group, Alias Map, and Event Log. A channel represents a communication medium from the PC to one or more external devices. Devices represent the PLCs or other hardware with which the server communicates. A tag represents addresses within the PLC device with which the server communicates. The Event Log displays the date, time, and source of an error, warning, information, or security event.

III.   BLOCK DIAGRAM OF AUTOMATION OF HEAT TREATMENT SYSTEM

The basic block diagram of Automation of Heat treatment system is shown in Fig.3. The main object is to construct a system which would be able to travel object horizontally in two axes. For the fulfill this objective the mechanical movement as a main part, automatic control could control the motor quickly and accurately to make sure the moving parts or subsystem complete the corresponding movement in accordance with the operating parameter and the expected track.

The system will be build around SMPS, Delta PLC12SA2 unit, AC Servo Driver, AC Servo motor, Stepper Driver, Stepper Motor, One slider are use for automation part and Thermocouple, Temperature controller, Metal use for heat treatment process and Personal computer is use for software purpose. Heat treatment application is used in industry to change the properties of material for ex. hardness.
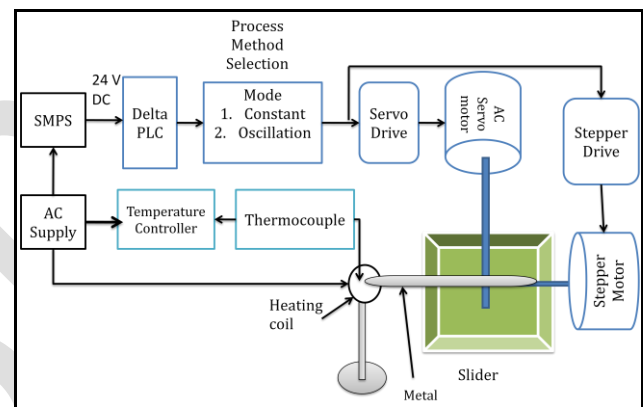

Fig 3: Block diagram of Automation of Heat treatment system

The simplest solution for movement in XY plane is to use two independent motors. This setup is mainly based on PLC and LabVIEW; it aims to control the motion of object in two dimensions. The PLC is connected to servo motor driver and stepper motor driver to drive servo motor and stepper motor respectively and control the movement of mechanical slider. The PLC interfaced with Personal computer through RS 232. PC is loaded with WPLSoft2.30 and LabVIEW for serial communication to PLC system. The heating coil is adjusted near the slider and thermocouple is adjusted in the coil.

The system preliminary design the XY axes of motion control and heat treatment of metal. PLC can control the motor position, interpolation drive, acceleration and decelerations by outputting frequency pulse to control the movement of servo motor and stepper motor speed and the pulse frequency rate control acceleration. After receiving signal from PLC, stepper Motor driver and servo motor driver will send motor signal and control signal to stepper motor and servo motor respectively. The servo motor moves slider in X- axis and the rotation of steeper motor moves slider in Y axis. The system is closed loop control, so it can feedback the slider locations. This setup is operating in two modes auto mode and manual mode. In auto mode process

select one mode Constant mode or Oscillation mode. In constant mode metal heated continuously one place constantly and in oscillation mode metal will move continuously with the help of slider.

In auto mode Servo motor receive signal from Servo driver so slider will firstly move in X axis forward direction then Stepper motor will start and move the slider in Y axis forward direction in a few cm which is set by number of pulses. At this position motor stop some seconds and heat is applied in metal with use of heating coil. After some time, time is set by operator; stepper motor will move in reverse direction after that the servomotor back to the home position. We can interrupt the system by stop switch at any instant of time. In manual mode the sequence of X Y axes is does not matter we can first drive any motor to move slider. There is one more advantage of manual mode that we can drive both motor simultaneously.

VI is creating in LabVIEW to read data from PLC and write data in PLC. Speed of the both motor and travelling of axes controlled by LabVIEW. Data will send through KepserverEX5 in PLC and PLC send pulses to motor driver. After that driver send the pulses into motor and motor will start some speed and travel few mm. The value of XY axes travelling and speed adjust in LabVIEW. Flow chart of working system is shown in Fig. 4
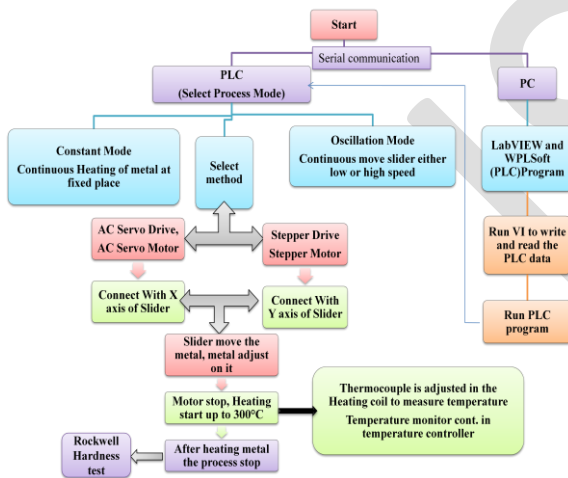

Fig 4: Flow chart of working system

Here, we use DVP12SA2 PLC which adopts 24V DC power supply from DR-75-24 Switch mode power supply. The Input terminals X0 – X5 of PLC are connected with Push button switch. The AC TECH digital servo driver provide high-precision and versatile functions for driving servo motor. The servo driver adopts 230V AC. The Output port of PLC Y0, Y2, UP connector is interfaced with Servo driver through CN1 connector. The Y0 terminal given a pulse to servo driver and Y2 provide direction to servo driver to drive a motor in either forward or reverse direction. The U, V, W, FG terminal of servo driver is connected with Servo motor. Servo driver is interfaced with encoder through CN2 connector. Due to inbuilt encoder in

servo motor it can use as a feedback device. The system is closed loop control, so it can feedback the object location speed and other information immediately.

The stepper driver operates at 24V DC from SMPS. The M542 micro stepping driver's connector P1 is interfaced with PLC through terminal Y1 and Y3. The Y1 terminal given a pulse to stepper driver and Y3 provide direction to servo driver to drive a motor in either forward or reverse direction. Temperature controller, Thermocouple and Heating coil operates at 230V AC supply. EN31 metal is adjusted on the Slider. Slider move some distance then metal reach in inner portion of the coil. After that the metal heated up to 300°c for 2.30 hour with using heating coil. At that time temperature is continuously measured by thermocouple. Thermocouple is adjusted inside the heating coil which is measure temperature continuously and display in temperature control meter. The purpose of heat treatment process is to change hardness of metal. The Hardware connection of experimental setup is shown in Fig.5
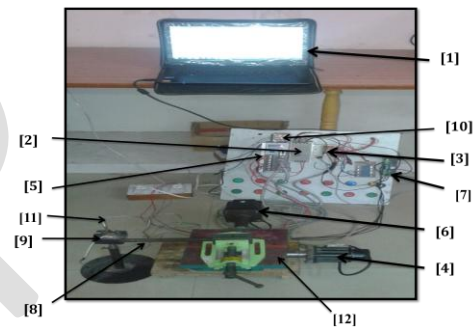

Fig 5: Hardware connection of experimental setup

[1] Personal Computer   [2] SMPS
[3] PLC   [4] Servo Motor
[5] Servo Drive   [6] Stepper Motor
[7] Stepper Drive   [8] Metal
[9] Coil   [10] Temperature Controller
[11] Thermocouple   [12] Slider

A.   Hardening process of tool steel:

The most important heat treatments are Hardening, Tempering, Normalizing and Annealing which is used to change the mechanical properties of engineering materials specially steels and change the microstructure. Hardening is the most common heat treatment applied to tool steels.

Hardening materials methods are used to change the properties of the material, hardening the material pass through two steps,

- The material is heated up to degrees above the critical point then the temperature is kept at that high to change the formation of the material.

- The second step is to cool the material to low temperatures by using coolants like water, oil, air or chemicals

This experiment was performed to harden the cast iron. The process involves putting the hot cast iron directly in to a liquid medium. The heat treated specimens hardness was

measured by means of Rockwell hardness tester. First the metal was inserted in the machine; the load is adjusted to150kg which is defined in Rockwell hardness C scale tester. The minor load was first applied to seat of the specimen. At this instant the major load applied and the depth of notch is automatically recorded on a dial gage in terms of arbitrary hardness numbers. The dial contains 100 divisions. The dial is reversed so that a high hardness, which results in small penetration, results in a high hardness number. The hardness value thus obtained which is seen in middle portion and small scale dial.

B. Interfacing of PLC & LabVIEW with KEPServerEx5:

Following steps are implemented to achieve desired objective:

1. Open the KepserverEX5 configuration. Next we create new file and creating new Channel.
2. After that define device driver, baud rate, data bits, parity, stop bit, flow control and duty cycle.
3. In next step create device and configure all parameter e.g. device id name, request time out, Modbus setting, etc
4. Then we add new OPC tags which are essentially the input/output variables under this group. For the access path we need to specify the same name as the OPC Topic which was specified in server. We give the addressing of the input/output variables as per the address of the PLC and the data type of the variable, client access type and scan rate which is same as what we define in LabVIEW VI. Fig.6 & 7 shown block diagram for data monitoring and controlling in LabVIEW and GUI of Read and Write command.
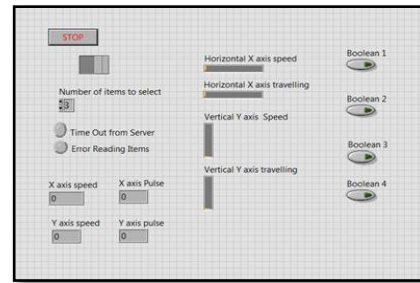

Fig 6: Block diagram in LabVIEW

Fig 7: GUI of read and write command

IV. RESULTS & DISCUSSION

To check the performance of the system metal rod EN31 was selected. The dimension of the rod is 16mm diameter. The metal was tested with various speeds and hardness of the metal was tested after and before heat treatment process. The various modes (Constant Mode, Oscillation mode) parameters can be set using these method to control X and Y axis position for placing the metal at precise location using different step size and speed of both motors. The value of XY axis travelling distance and speed set in the computer front panel, these data is transferred in PLC through KEPServerEX5. For the various modes Servomotor Pulse frequency, Servo motor pulse number, Stepper motor Pulse frequency, Stepper motor pulse number set in PLC through LabVIEW it is described in Table II. The data acquired into LabVIEW software and temperature displayed in temperature controller. After doing several experiments of this heat treatment processes, test is performed verify that the system is working smoothly. Figure 8 shows the chart of Measurement sample in different mode Vs Measured hardness value.
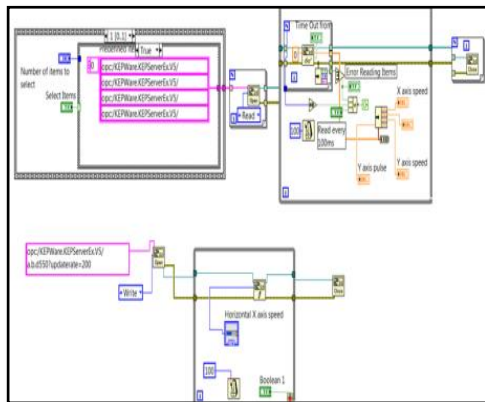
Table II. VARIOUS MODE CONFIGURATION OF PLC

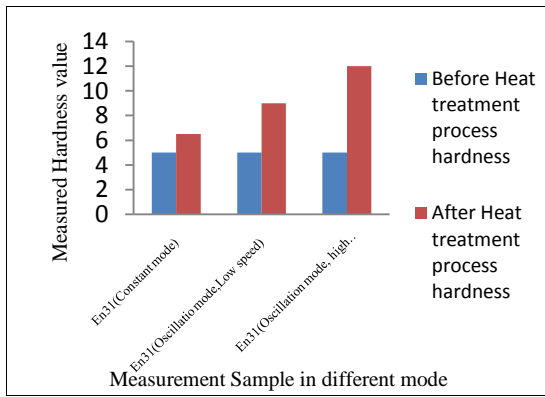| Mode	Servo Motor		Stepper Motor	
	Pulse O/P Frequency	Pulse O/P Number	Pulse O/P Frequency	Pulse O/P Number
Constant	16360	32720	834	4170
Oscillation (Low Speed)	32720	490800	4170	4170
Oscillation (High Speed)	49080	49080	2502	3336

Fig 8: Measurement sample in different mode Vs Measured Hardness value

LabVIEW is one of the well-known software packages used in process control applications. The experimental results at each step are shown in figure 9 & 10 for Ladder Diagram Indicating Pulse and Frequency of both motor and GUI in run mode after acquiring data from PLC.

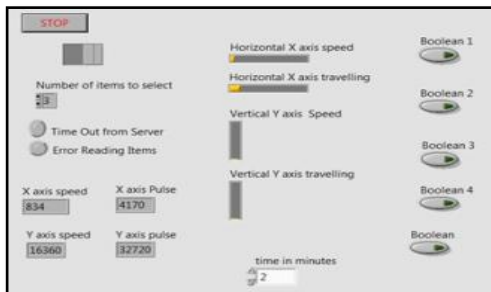Fig 9: Ladder Diagram Indicating Pulse and Frequency

Fig 10: GUI in run mode after acquiring data from PLC

CONCLUSION

Automation of heat treatment process for metal hardening using PLC and its communication with LabVIEW was presented. The develop system is user friendly, quite safe, easy to operate and enhance safety features. Motion control Parameters of the systems were monitored real time with the help of GUI developed in LabVIEW. Motor controlling of AC & DC drive was achieved with the PLC. To improve the hardness of metal three modes was implemented in PLC

program. For EN71 metal oscillating mode gives highest hardness improvement from 5 to 12 units. Similar motion control approach can also useful in small process of automation, cutting tool, turning machine application, heat treatment process.

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