A HEURISTIC APPROACH TO RETROFIT AND AUTOMATION OF MACHINES USING PLC

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ABSTRACT
The conventional machines become phenomenally productive and flexible by retrofitting them with automated controllers. Refurbishing and upgradation of old machines restore them close to their original performance levels. Today, the concept of remanufacturing machine tools is emerging. Additionally, these cost-effective solutions of automation are equally beneficial to small, medium and large industries. Industrial automation is largely based on PLC-based control systems. This paper highlights a case study of retrofitting and automation of a filament coiling machine for successful performance with increased productivity and accuracy. Technological upgradation in MSME sector can be brought about suitably by retrofits and automation for cost effectiveness and higher productivity.

KEYWORDS: *Retrofits and Automation, Electro-Pneumatics, Programmable Logic Controller (PLC), Human-Machine Interface (HMI), Micro Small and Medium Enterprises (MSME).*

I. INTRODUCTION

Over the years the demand for high quality, greater efficiency and automated machines has increased in the industrial sector of all kinds. They require systems with high accuracy, greater flexibility, continuous monitoring & control. But now-a-day's rapid growth in technology has come-up with different solutions such as PLC, SCADA, DCS and Microcontrollers, which will fulfill all the requirements of the industrial processes through automation.

Simplification of engineering practices and precision control requirements of manufacturing processes by absorbing technological changes can result in significant cost savings. The most cost-effective way which can pay rich dividends in the long run is adopting flexible automation via a planned approach towards integrated control systems. It requires a conscious effort on the part of plant managers to identify areas where automation can result in better deployment/utilization of human-machine-interface and its implementation to achieve higher productivity.

Automation need not be high-end or too sophisticated but should be innovative in approach. It could be a phased approach from the perspectives of comprehension or step-by-step approach to automate understanding the needs thus employing control systems engineered to one's specific requirements that would achieve the most attractive results [1]. This is where path breaking technologies can be deployed in automating Industrial processes. Automating the manufacturing industry would add phenomenal value to the MSME sector.

This paper will introduce the concepts of retrofits and automation of machines and their advantages in section II and III respectively. The advantages of electro-pneumatic over pneumatic systems are discussed in section IV. The introduction to PLC and its basic components are discussed in section V. The case study of retrofit and automation of a filament coiling machine with control methodology, hardware/software requirements, their functional description and implementation with performance results are discussed in section VI. Conclusions and future work are in section VII and VIII respectively.

II. RETROFIT

Since customers today have access to world markets due to globalization and liberalization of economies, they have at liberty to trade-off with innovative, indigenous solutions or readily available expensive solutions. The retrofit is an attempt of indigenous and innovative solution to contain the capital costs and add value to the processes by mix and match of inexpensive available technological inputs to result in improved quality at a lower price. Hence market life of products can be increased by absorbing technology through retrofits to addresses obsolescence.

Upgrading the existing machines through retrofits can bring many a benefits of new equipment at a fraction of the cost. Much of the savings depends on the application. For example, if the control circuitry and selection represents 10 to 20% of the machine value, and its replacement just would give a new-machine of same performance, the machine owner would save 80% of capital cost of new machine purchase. This justifies retrofitting the machine by changing the state-of–the-art control circuitry. Upgrading the machine for performance enhancements through retrofits is possible. These engineering solutions are ingenious and innovative which will render huge cost savings and higher productivity levels. MSME sector will survive adapting these engineering practices wherever it necessitates to remain competitive in the era of technological revolution by remaining ingenious and innovative.

The typical examples could be reduced machine’s productivity or increase in the cost of support systems would invite ingenious retrofit solutions. Another example could be increased down-time, increased repairs, increased maintenance costs and calibration costs would offer an opportunity to set right things by suitable retrofits ingeniously. Often a suitable closed loop control system can compensate for deficiency in performance [2].

Finally, a subtle factor affecting the new-versus-retrofit decision is the time needed to get a machine up and running productively and economically. It may be quicker to retrofit using off-the-shelf parts compared to typical lead times with new machine purchases. It is a good thing that innovations are happening at the start-up and MSME sector because they have to ever remain competitive.

III. AUTOMATION AND ITS ADVANTAGES

Industrial automation uses computers and controllers to control industrial machinery and processes to optimize productivity and delivery of services. Automation greatly decreases the need for human sensory and mental requirements [3]. The impact of automation in industries is as follows:

a) Increase productivity and reduce cost.
b) Emphasis on flexibility and convertibility of manufacturing process. Automation is now often applied primarily to increase quality in the manufacturing process, where automation can increase quality substantially.
c) Increased consistency of output.
d) Replacing humans in tasks carried out in hazardous environment.

IV. PNEUMATIC AND ELECTRO-PNEUMATIC SYSTEMS

In the mechanization and automation of industrial processes, pneumatics has gained great significance because of the easy implementation of often-needed straight-line, back and forward motion using pneumatic cylinders; swivel motion and rotation using rotary drives; revolving cylinder engines and stepping drives [4].

Until a few years ago the compressibility of the energy carrier, i.e. compressed air, basically limited the automation of fast motion sequences to simple adjusting movements where stop points were implemented by mechanical limit stops. Electro pneumatic controls combine the best features of electronic and pneumatic controls. Such system consists of pneumatically actuated valves, electrical/electronic controllers, sensors and control systems Electro-pneumatics is used in most areas of industrial automation. Production, assembly and packaging systems worldwide are driven by electro-pneumatic controls. Electro pneumatic controllers have the following advantages over pneumatic control systems:

a) Higher reliability.
b) Lower planning and commissioning effort for complex controls.
c) Lower installation effort.
d) Simple exchange of information between several controllers.

V. PROGRAMMABLE LOGIC CONTROLLER

Considering the varied demand and increasing competition, one has to provide for flexible manufacturing process. One of the latest techniques in solid state controls that offers flexible and efficient operation to the user is "Programmable Logic Controller". The basic idea behind these programmable controllers was to provide means to eliminate high cost associated with inflexible, conventional relay controlled systems. Programmable controllers offer a system with computer flexibility.

Programmable Logic Control or PLC as it is universally called is the 'work horse' of industrial automation. It is important because all production processes go through a fixed repetitive sequence of operations that involve logical steps and decisions. A PLC is used to control, time and regulate the sequence [5]. A schematic diagram illustrating the basic components of PLC is shown in Figure 1.

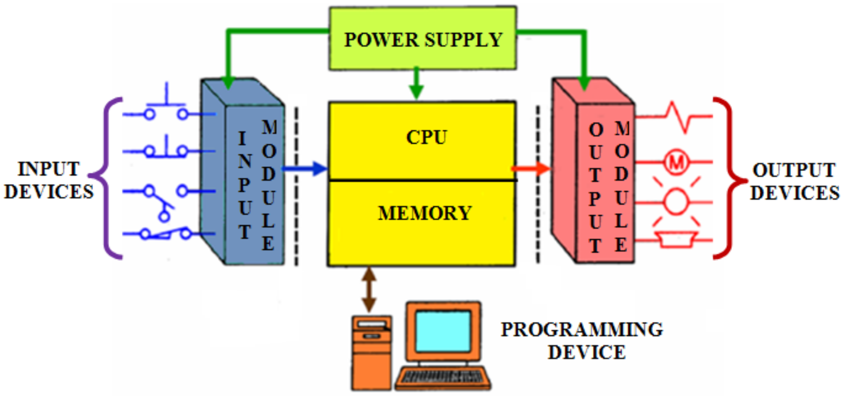

Figure 1. Basic Components of a PLC

5.1 PLC Module - The PLC Module consists of a central processing unit (CPU) containing the system microprocessor, memory and input/output circuitry. The internal structure of the CPU depends on the microprocessor concerned. In general they have an arithmetic and logic unit (ALU) which is responsible for data manipulation and carrying out arithmetic operations of addition and subtraction and logic operations of AND, OR, NOT, X-OR, etc. The memory (ROM, RAM, EEPROM, etc) located within the microprocessor is used to store information involved in program.

5.2 Power Supply - A power supply is needed to provide power to the PLC and other modules. Power supplies come in various forms: Power supply modules that fit into one of the slots in a chassis; External power supplies that mount to the outside of a chassis; Stand alone power supplies that connect to the PLC or I/O through a power cable or Embedded power supplies that come as part of the PLC block.

5.3 Input Modules- Input modules interface directly to devices such as switches, pushbuttons, temperature sensors, etc. These modules convert real world voltage and currents to signals such as 120VAC or 24VDC or 4-20mA signals to which the controller can understand.

5.4 Output Modules - Output modules interface directly to devices such as motor starter, hydraulic solenoid valve, indicators, etc. These modules take a signal from a PLC and convert it to a signal that a field device needs to operate such as 24V DC or 230V AC.

5.5 PLC Communication - There are several methods to communicate between a PLC and a programmer or even between two PLCs. Communications between a PLC and a programmer (PC or Hand held) are provided by the makers and only have to plug in a cable from PC to the programming

port on the PLC. This communication can be RS232 or RS485. There are many other methods of communication between PLCs and also from PLC to PC.
In addition to all this the PLC has a programming unit. The programming unit is used to build, test and edit the logical sequence that the PLC will execute. At a basic level PLCs are programmed in a simple form of assembly code. Each manufacturer has their own standards and definitions for these codes. There are other programming languages, including the IEC 61131-3 standard [6], Sequential Function Chart, Function Block Diagrams, etc.

VI. CASE STUDY

6.1 Overview of Project

The aim of the project was to retrofit and automate a Filament Coiling Machine using PLC. During the preliminary phase of project, the machine was found to be partially functional. Most of the pneumatic cylinders in the machine were in good condition and few required replacement. The control valves and the machine controller were to be replaced by electro-pneumatic (solenoid) valves and PLC respectively. Also the whole operation of the machine was to be automated. With these considerations, the main objective set for the project was to design, develop and implement automated controller for the machine in order to upgrade the technology. The major steps in achieving this objective are as follows.

a) Disassembly and inspection of the machine to identify the faulty or defective.
b) Assembly of the machine and check for its functionality along with replaced parts.
c) Design the control circuit for automation of the machine as per the requirements.
d) Build the control panel as per the designed control circuit by proper selection of equipment.
e) Developing Automated control program using PLC software.
f) Implement the control program developed and verify it for the desired automated control operation of the machine.

6.2 Control Methodology

The design stage on the project includes control design, hardware design, material selection and automation for the machine. All the aspects or factors are taken into consideration during design of automated control process of the machine. Although every step in the project was very important, the automated control developed based on PLC acts as heart of the project. This is illustrated in the block diagram shown in figure 3.

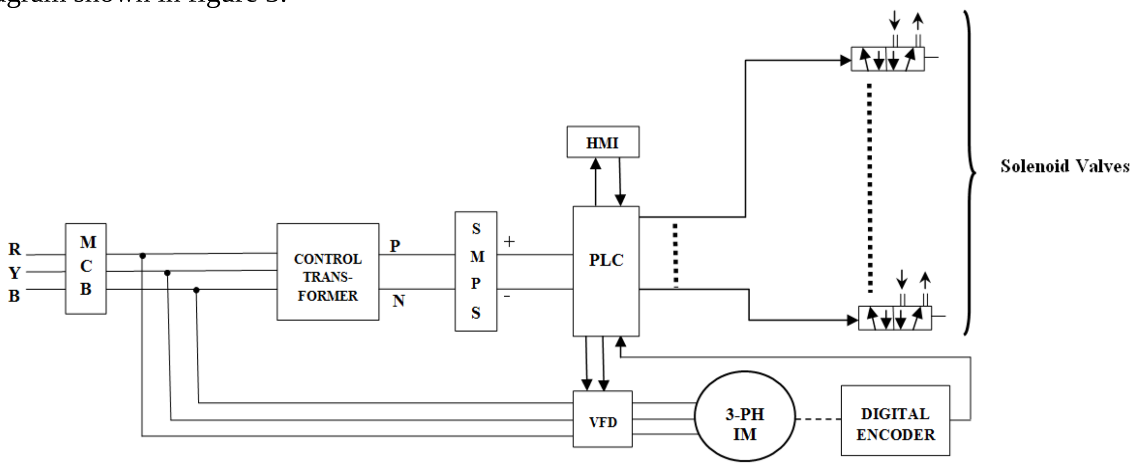

Figure 3. Control Scheme of the Filament Coiling Machine

A closed-loop control system for constant speed operation is configured with speed feedback via digital encoder (incremental rotary encoder) and the induction motor drives the load with variable speed using VFD [7]. The PLC monitors and controls all the input / output devices through HMI.

6.3 Hardware Requirements

In the hardware part, overall component such as PLC, HMI, Motors, Solenoid valves and switchgear circuit will be integrated to form the complete machine [9]. The detailed list of all the hardware used in the project is listed in Table 1.

Table 1. List of hardware used in the project

Sl No	Hardware Description	Make	Rating	Qty nos
1	Enclosures a) AE 1058 b) AE 1522 c) AE 1005	Rittal	(800x600x210) (150x300x80) (380x300x210)	01 01 01
2	PLC Modules a) DVP 28SV b) DVP 16SP c) DVP 08SN	Delta	24V DC - each 16 I/P, 12 O/P 8 I/P, 8 O/P 8 O/P	01 01 01
3	HMI DOP-B07S411	Delta	24V DC, Class 2 / 250mA	01
4	Induction Motor	Siemens	2.2KW, 50Hz, 230/400V, 8.3/4.7A, 1420rpm, PF-0.82	01
5	Induction Motor	Leroy Somer	0.75KW, 50 Hz, 220/380V, 3.3/1/9A, 2780rpm, PF-0.86	01
6	VFD 160-BA06NSF1P1 (Series-C)	Allen Bradley	2.2KW/3HP I//P - 3ph, 380-460V, 7A, 50/60Hz O/P - 3ph, 380-460V, 6A, 0-240Hz	01
7	Control Transformer	LCS	500VA, 50Hz 0-415-440V/ 0-210-230V	01
8	Power Supply	Omron	I/P – 50/60Hz, AC 100-240V, 1.9A O/P – DC 24V, 5A	01
9	Relay logic Board NA-20061(16-Channel) NA-20081(8-Channel)	Nandi Power-tronics	DC 24V, 5A	01 02
10	Incremental Rotary Encoder ES3-01CG6941	Delta	DC 7-24V	01
11	MPCB 3VU1340-1MG00 (1NO+1NC)	Siemens	415V, 50/60Hz 1-1.6A	01
12	MCB 5SX42 5SX43	Siemens	2-Pole, 2A, 240/415V 3-Pole, 10A, 240/415V	01 01
13	Air Break (Power) Contactor 3TF 30 10-0A (1NO)	Siemens	9A, 415/500/660V	01
14	Rotary Switch	L&T	AC 25A, 415/440V	01
15	Exhaust Fan	LCS	AC 5A, 230V, 50Hz	01
16	5/2 Port Solenoid Valves	SMC	DC 24V	20
17	FRL	SMC	-	01
18	Pneumatic Accessories (Fittings, Tubings, Regulators, Screws, etc)	SMC	-	l / s
19	Panel Wiring Accessories (cables, lugs, ferrules, TB's, Din Rail, Wire Duct, Hose pipe, Glands, Screws, etc)	-	-	l / s

6.4 Hardware Description

The project consists of various types of hardware related to pneumatics, electro-pneumatics, switchgears & automation. Thus the whole project hardware can be divided into two main categories.

i. The machine with solenoid valves and Pneumatic cylinders.
ii. The Control panel with accessories.

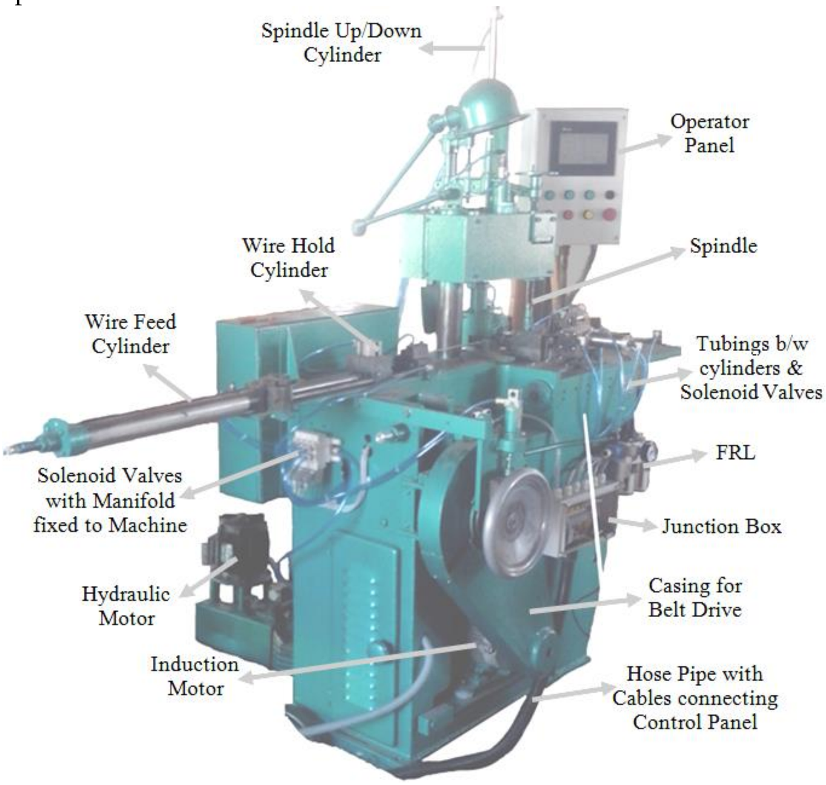

Figure 4. Front view of Filament Coiling Machine with details

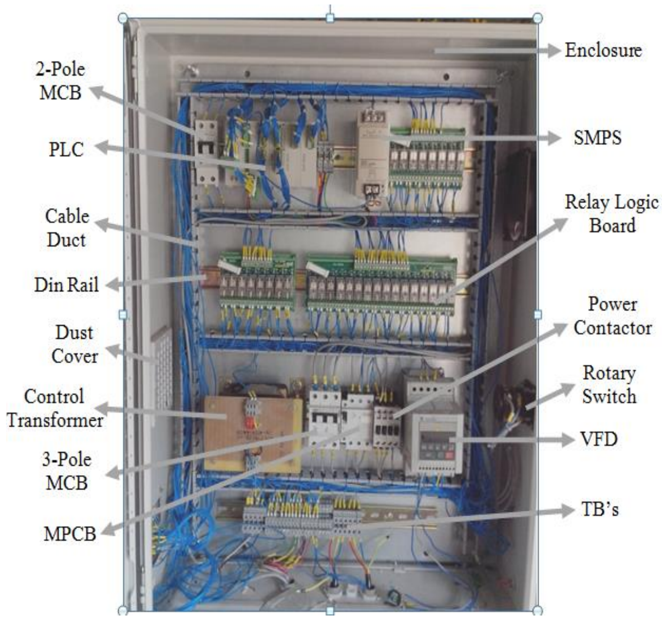

Figure 5. Control Panel with Accessories

The descriptions of major hardware used in project are as follows.

PLC – The PLC acts as heart of the project, as it controls all the inputs/ outputs according to the control program there by controlling all the sequences of operations for entire working of the filament coil winding machine.

Solenoid Valves **-** A solenoid is an electromechanical device which allows for an electrical device to control the flow of a gas or liquid. It acts as the final control element. The project includes around 20 solenoid valves for operating the pneumatic cylinders during different instants of time for their sequence of functions.
Manifold **-** Manifold is a device on which valves are mounted and divides a single compressed air source into several outlets.
FRL **-** Air preparation unit consisting of Filter, Regulator and Lubricator is commonly known as FRL. Along with it set a pressure gauge is fixed to the regulator to monitor to inlet air pressure.
Induction Motors –In the project two Induction motors (also known as asynchronous motors) are used for different purposes. One of them is the 2.2kw rated motor used to rotate the spindle of the machine during coiling winding process and is connected to PLC through VFD for speed control purpose. The other is 0.75kw rated motor used in machine to pump the oil to the wire cutter for lubrication purpose.
Incremental Rotary Encoder **-** An encoder is used to extract information about a rotating shaft. When it is switched on, it simply outputs a 1 or 0 on its phase A and phase B output line. Also when zero position of shaft is reached gives an output 1 on its phase Z. By counting the number of pulses received and multiplying the count by the encoder's resolution the rotation of the shaft in degrees or RPMs is determined.
SMPS **-** Switched mode power supply is used to convert ac single-phase supply (230v ac) to dc voltage (24v dc). It houses a voltage regulator IC that regulates the ripples in the output voltage of the SMPS. It supplies DC power to PLC and other components inside the panel.
VFD **-** Variable Frequency Drive is used for speed control of the Induction Motor [8]. The VFD provides a wealth of features that make the system more versatile and provide protection for the motor being controlled. These include features such as over current monitoring, automatic adjustable overload trip, speed ramping, ramp shaping, rotation direction control and dynamic braking. VFD is controlled from a PLC by providing an analog (0-10 volts) dc signal from the PLC to the VFD which controls the VFD between zero and rated frequency. Direction control is done using a discrete output from the PLC to the VFD.
Air Break Power Contactor - A contactor is an electrically controlled switch used for switching a power circuit, similar to a relay except with higher current ratings. A basic contactor will have a coil input which may be driven by either an AC or DC supply depending on the contactor design. Most motor control contactors at low voltages (600 volts and less) are air break contactors.
MCB's **-** Miniature Circuit Breakers are electromechanical devices which protect an electrical circuit from short circuit, overload or faults.
MPCB - Motor-protective circuit-breakers are circuit-breakers used for switching, protection and isolation of circuits primarily associated with motor loads. At the same time, they protect these motors against destruction from locked-motor starting, overload, short-circuit and phase-failure.
Human Machine Interface **-** A human machine interface abbreviated as HMI is the apparatus which presents process data to a human operator through which, the human operator controls the process. The use of HMI in the system makes it much easier to operate at the field level. HMI based system are more controlled, as the visual supervision and graphical supervision are being present at the field level. HMI based system in places where the environment is not user friendly like high/low temperature , industrial toxic gases in such system operator can work easily by maintain a certain distance. The HMI in the project is used for selection of various the parameters like no. of coils, type of coils, etc and also to control the machine manually and automatically.
Relay Board **-** One of the most common types of outputs available is the relay outputs. A relay can be used with both AC and DC loads. Each relay draws approximately 20mA from the +24V power supply when energized. Typically a diode, resistor or other snubbed circuits are used to prevent any damage to the relay. In project, all the outputs of PLC are connected to output devices (solenoid) through relays of relay logic board and few are left unused for future expansion options.
Control Transformers **–** Generally in most of the industries three phase, three wire power lines are available as supply source terminals. But inside control panels, some of the devices used (like exhaust fan, SMPS, etc) need single phase power and is supplied using a control transformer. Also in view of safety of panel components, it acts as isolator between power lines and control panel equipments.

6.5 Software Requirements and Description

A control program specifies a series of operations that tell the programmable controller how it has to control a system. For example, a control program might be the series of operations that tell the PLC how to use open loop control or close loop control for a specific system. The control program uses Delta PLC with its associated ladder network program.

PLC programming is based on the logic of input devices and the programs implemented are logical instruction rather than numerical computational algorithms. Most of the programmed operation works on simple state of "on" or "off" conditions. PLC offers a flexible programmable alternative to electric circuit relay-based control system built using analog devices. The programming method used is the ladder diagram method.

The PLC system provides a design environment in the form of software tools running on a host computer terminal which allows ladder diagrams to be developed, verified, tested and diagnosed. The ladder diagram is converted into binary instruction codes so that they can be stored in random-access memory (RAM) or erasable programmable read-only memory (EPROM). Each successive instruction is decoded and executed by the CPU. The CPU controls the operation of memory and I/O devices and to process data according to the program. Each input and output connection point on a PLC has an address used to identify the I/O bit. The method for the direct representation of data associated (for Delta PLC's) with the inputs(X), outputs(Y), Memory(M), Timer(T), Counter(C) and Data Register(D) is referenced directly using X, Y, M, T,C and D respectively.

In the project, programming of PLC is done using WPL Soft 2.33 version software (suitable for programming all types of Delta DVP Series PLC's). This software integrates all the modules connected to the PLC and the devices connected to its HMI, VFD, Solenoid Valves, Induction motor and Hydraulic motor. Also the monitor and control are through HMI and its screens are developed using DOP Soft 1.01.04 version software (suitable for screen development of all types of Delta HMI's).

WPL Soft 2.33 - WPL Soft is a program editor of Delta DVP series PLC for WINDOWS computers. In addition to general PLC programming and WINDOWS editing functions (e.g. Cut, paste, copy, multi-window display, etc) WPL Soft also provides various comment editing as well as other special functions (e.g. register editing and settings, file accessing and saving, contacts monitoring and setting, etc) [10].

DOP Soft 1.01.08 - DOP Soft software program is a user-friendly program editor of DOP-B series HMI for Windows. DOP-B series HMI is manufactured by adopting easy-to-use software and high-speed hardware to provide a powerful and stable programmable interface. DOP-B series HMIs support more than twenty brands of external controllers, including Delta, Omron, Siemens, Mitsubishi, etc. One DOP-B series HMI is able to connect to multiple controllers in serial through RS-485 interface of COM2 and COM3 ports. Up to 16 languages can be selected and used without installing a multilingual operating system. A multi-language environment is very important and enables the users to work more efficiently [11].

6.6 Results

The final automation process of the machine was finalized through several testing and modifications in the control program. This was done by manufacturing sample pieces of two types of filament coils, of three stranded Tungsten wire. All the samples of Filament coils were tested for their right shape and their dimensions obtained were verified by the company as per their required standards. At first instant Filament coil Type-1 in figure 6 was selected with 5.5 numbers of turns and few filament coils were produced. In the next instant Filament coil Type-2 in figure 7 was selected and same number of turns as that of the type-1. The obtained Results are tabulated in table 2 as follows.

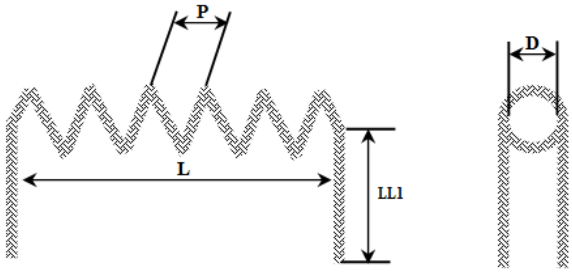

Figure 6. Side view and Top view structure of Filament coil Type-1

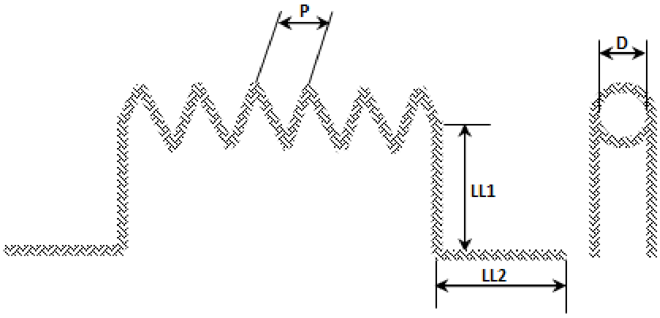

Figure 7. Side view and Top view structure of Filament coil Type-2

Table 2. Tested results of Filament coils type-1 and type-2

Description	Filament coil Type-1	Filament coil Type-2
Numbers of turns of the Coils (T)	5.5 turns	5.5 turns
Full length of the coil (L)	42mm	42mm
Leg length of the coil (LL1)	25mm	25mm
Leg length of the coil (LL2)	-	25mm
Inner Diameter of the coil (D)	8mm	8mm
Pitch of the coil (P)	7mm	7mm

Many samples of Filament coil type-1 and type-2 were tested for their right size-shape and obtained results of dimensions were verified as per the company requirements. Finally the verified results were found satisfactory and accepted by the company and thus the retrofit and automation of the filament coiling machine undergone during the project was successfully completed.

VII. CONCLUSION

In the filament coil industry, few simple electrically operated and manually operated machines were used for filament coiling process that is time consuming requiring manual labor. Thus the retrofit and automation of the machine paved the way for increasing the productivity and reliability, time saving and HMI enables the operation of machine easier for non-skilled labors too. Also the machine operation requires less labor power with good quality of product. As the project focuses on the closed loop control of the process, this will fulfill all the requirements of the industry with good levels of accuracy and repeatability thereby yielding a more robust system.

VIII. FUTURE WORK

Though the automation of the machine was found to be successful, the machine operation mainly depends on the Induction Motor, its belt drive and gear systems associated with it. Due to gear systems in the machine, there will be mechanical wear and tear in the system. Therefore, it is recommended to replace the induction motor by a servo or stepper motor, this will eliminate the wear and tear in the machine and also yields high level of accuracy and increase the production and reduce the maintenance cost.

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