CONTROL AND AUTOMATION OF A HEAT SHRINK TUBING PROCESS

Murali Sankar Harikrishnan
University of North Texas
muralisankarharikrishnan@my.unt.edu

Robert G. Hayes
University of North Texas
robert.hayes@unt.edu

Huseyin Bostanci
University of North Texas
huseyin.bostanci@unt.edu

Enrique Barbieri
University of North Texas
Enrique.Barbieri@unt.edu

Abstract

This paper discusses the control and automation of heat shrink tubing process that benefits the wire harness industry. A prototype of heat shrink tubing process is under development consisting of a custom-made radial heat chamber with two heat guns designed to move horizontally along a wire harness fitted into shrink-tubing material. The prototype is automated using a linear positioning system that continuously monitors the chamber position, speed, temperature, and achieve the desired heat treatment of the tubing material for proper shrinkage. This process is currently being performed manually in industries resulting in the loss of resources such as human operator time and energy. This article reports on recent progress made to interface an Allen Bradley PLC with a servo translational system by Kollmorgen and compare with computer simulations. In particular, it is shown that the controller can effectively maintain the desired

chamber temperature and chamber speed to meet industry-standard specifications of heat-tubing shrinkage around a 3-inch diameter wire harness of multiple wires. Further implementation research is needed to develop a feedback switch to monitor whether the cable shrunk properly and a graphical user interface (GUI) for turn-key operation with an alarm monitoring system.

Introduction

Heat shrink tubing is ordinarily used to provide sealing, termination, insulation, and strain relief for cables. It has many uses in automotive, aerospace, and military applications, and virtually all other industries [6]. It is typically made of nylon or polyolefin, which has the ability to shrink about wire harness's diameter when heated, and it includes adhesive lined heat tubing for tight seals that keep out dust and moisture. This unique feature helps the tube to be utilized in various applications, from near microscopically-thin-wall tubing to rigid and heavy-wall tubing. Among all applications listed above, heat shrink tubing is used to insulate wire conductors in wire harness processes [1].

Automation is defined as the use of various control systems for operating machinery, processes in factories with minimal or no human intervention depending on the application. The most important benefit of the automation is that it reduces human labor. It also saves energy and materials to improve quality of the cable. Automation is achieved by the combination of mechanical, electrical, and electronic systems.

A functional block diagram of the control system is shown in Figure 1.The main objective of the project is to control and automate the heat shrink tubing process that can control the speed and maintain position accuracy to evenly heat up the cable to be harnessed using the heat guns. The heat shrink tubing process is completed by establishing Ethernet/IP communication between programmable logic control and servo drive with the linear motion system. The task to accomplish in this project is to set up hardware and software required to establish Ethernet /IP communication between them such that a closed loop motion profile is created and implemented.

A control loop is a process management system designed to maintain a process variable at a desired set point [5]. The heat shrink tubing process described in this paper is implemented as a closed loop control system, where feedback plays a significant role to get the exact desired set point. A system has been developed using velocity and position control loops. The velocity loop control is based on the chamber temperature, which is directly proportional to chamber speed. The position loop control is based on the chamber position. Servo drive internal feedback data monitors the position accuracy whether the chamber is moving forward or backward. Based on the data, a feedback switch can be implemented to control the proper cable shrinkage.

Hardware Implementation

The hardware implementation shown in figure 1 and also discussed in introduction section is the best approach to test the automation. Hardware components are connected together to achieve the required linear position and speed control. The signal flow in the functional diagram are both unidirectional and bidirectional.

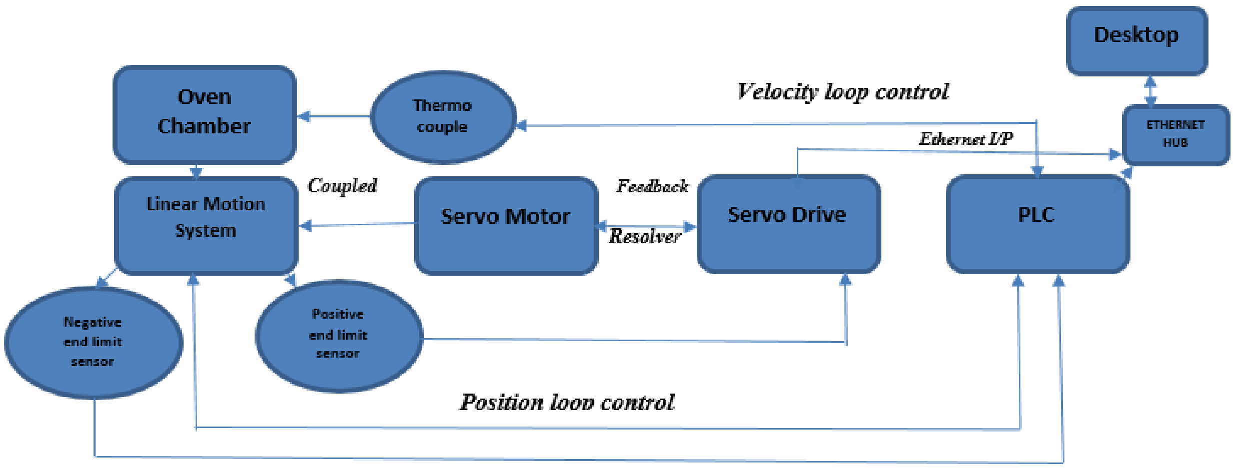

Figure 1. Functional Diagram

Conceptual system design

The heat chamber is fabricated to be equipped with two heat guns, which is configured to allow up to 3-inch diameter wire-bundle cables wrapped by heat-shrink tubing. The heat chamber assembly is further connected to a motor-driven linear motion system which can accommodate varying wire harness lengths from 1 to 800mm, i.e. total 2.6 foot length of linear motion system. The chamber linear speed is controlled based on the heat chamber temperature and is uniformly harnessed with the appropriate temperature for a pre-determined time, resulting in the desired tubing shrinkage [2]. A prototype machine of heat shrink tubing shown in Figure 2 was developed to evaluate the control loop automation.

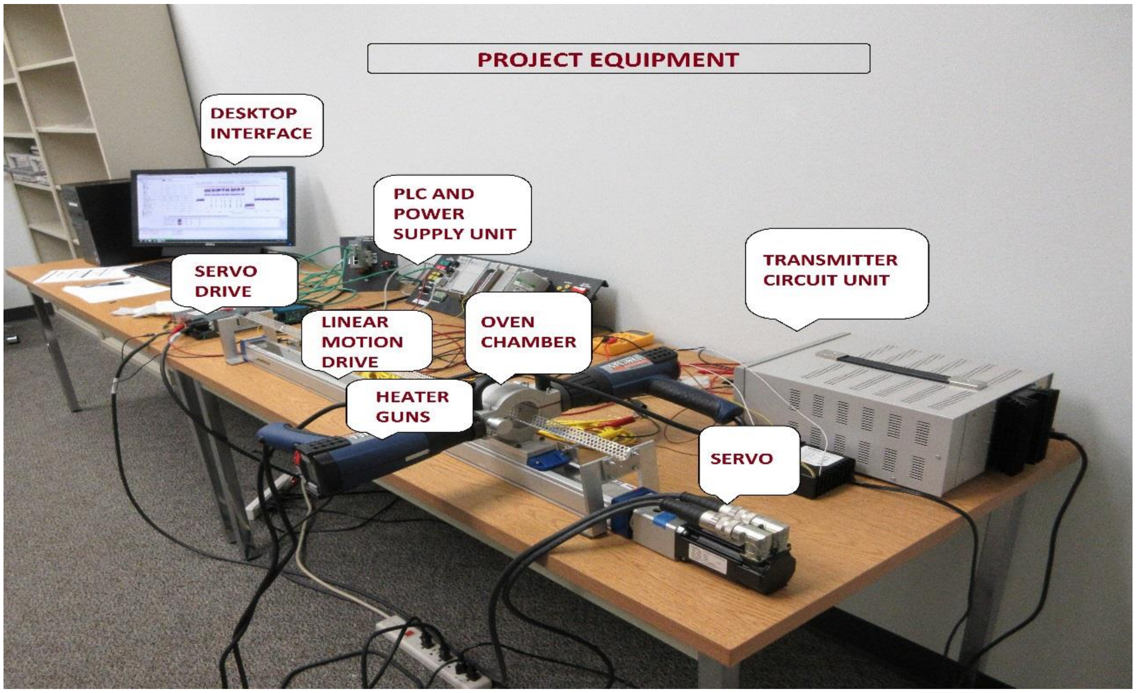

Figure 2. Prototype Heat Shrink Tubing

The chamber design, shown in Figure 3, is fixed above the saddle in the linear motion system. This prototype consists of an instrumented heat chamber on a linear motion system and is fitted with two symmetrically located heat guns. The chamber design allows for the directing of hot air from the heat guns onto the wire harness through channels. These air channels inside the oven are radially distributed to provide uniform heating and also angled in the direction of movement to pre-heat the unshrunk portion of the harness [2].

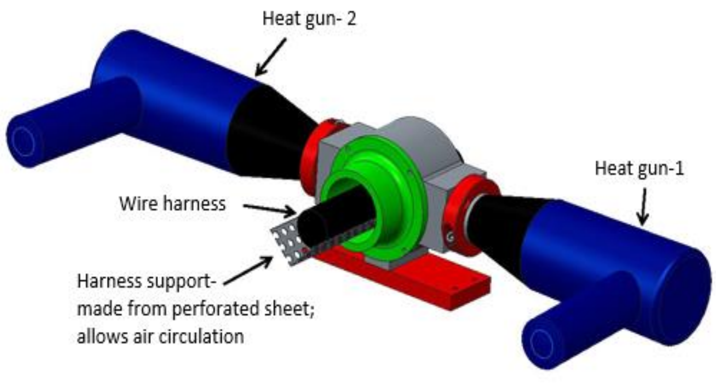

Figure 3. Prototype Heat Chamber Design [2]

Servo Drive

The main function of the servo drive is to receive a command signal from a control system implemented via a PLC in our project, amplify the signal and transmit an electric current to a servo motor in order to produce motion proportional to the command signal [8].

Servo Motor

A servomotor is a rotary actuator that allows precise control of angular position. It consists of a motor coupled with a sensor for position feedback. It also requires a servo drive to complete the system. The drive uses the feedback sensor present in the motor to control the rotary position of the motor. This is called closed-loop operation [8].

Linear Motion System

A rodless actuator is to provide guided linear motion through a ball screw drive and a saddle that rides along the top of the actuator to carry the load. The ball guided units provide high load capacity with low friction for precise positioning that is able to produce high thrust, high precision, stiffness, and long stroke capabilities [9]. The linear motion system is coupled with the servo motor to achieve the smooth linear motion [7]. A positive end limit sensor and negative end limit sensor are attached to the linear motion system ends to prevent the saddle from hitting the edges of the linear actuator.

PLC (Programmable Logic Controller)

Based on the industrial environment process, the compact logix PLC, medium end processor was selected for this application over other kinds of embedded controllers such as ASIC, FPGA, DSP [10]. The main reason for this selection is that a heat shrink tubing machine has to work in a harsh industrial environment, and in such cases, PLCs are the best choices. The other reason is that since a PLC is an integrated control system, it provides isolation, signal conditioning, and current/voltage amplification needed for interfacing with sensor and actuator layers. Eventually, PLCs can communicate easily with other devices such as GUI panels and personal computers (PC) via predefined standard protocols [2].

Ethernet I/P

Ethernet I/P is the standard protocol type of communication between the PLC, servo drive, and PC. It is one of the leading industrial Ethernet networks and is widely used in industries ranging from factory, hybrid, and process. It is very easy to configure with the devices and can transfer the I/O messages between the devices at the rate of 100 Mbps. This type of communication will help the PLC to monitor and retrieve the data from the servo drive in order to maintain the chamber speed and position accuracy [3].

Software Implementation

The software implemented in this project is in the Compact RS LOGIX 5000 environment. RS Logix 5000 is a medium end processor which offers an easy-to-use, IEC61131-3 compliant interface, symbolic programming with structures and arrays, and a comprehensive instruction set that serves many types of applications. It provides ladder logic, structured text, function block diagram and sequential function chart editors for program development as well as support for the equipment phase state model for batch and machine control applications [4].

The software can be operated using the PLC program through Ethernet/IP communications. The code is built using the add-on instructions provided by the drive manufacturer. This code communicates with the drive using the IP address. The drive, PC (i.e.192.168.1.xxx), the PLC (i.e.192.168.1.xxx) and the servo drive (i.e.192.168.1.xxx) should be on the same IP address for this operation. After setting up the servo drive configuration, the ladder diagram is developed based on the control loop logic.

Velocity loop control

The velocity loop control is established based on the chamber temperature where the PLC reads the analog value from thermocouple to determine the chamber speed and command the servo drive. Initially, the heat chamber mounted on the saddle takes the home position based on the home reference sensor, i.e. the positive end limit sensor. Once the nominal temperature level is reached, a timer starts to delay the process for settling up time. After the timer completes, the heat chamber starts to move forward to shrink the cable down to desired length of 800mm. Once it reaches negative end limit sensor, the heat chamber starts to move backward to reach the home position of 0 mm. Speed of the heat chamber is controlled based on the heat chamber temperature, which is set to maximum prescale of 400^{o}C to get the temperature accuracy. A thermocouple calibration performance chart is shown in Figure 4.

PLC reads the analog input voltage from the thermocouple and multiplies with the scale factor of 10 to boost up the required chamber speed. An example of the calculation is given below:

$$Analog\ Input\ Voltage\ from\ Thermocouple\ Temperature\ 265^{o}C = 13.1mV$$

$$PLC\ counting\ Value = 13000$$

$$Scale\ Factor = 10$$

$$Max\ velocity = \ PLC\ counting\ Value * Scale\ factor = 13000 * 100$$
$$= 130000 \sim 130\ rpm\ for\ servo\ drive$$

THERMOCOUPLE CALIBRATION REPORT				
Sl.No	Thermocouple Input Voltage (mV)	Chamber Temperature 'C	Chamber Temperature 'F	DC Voltage (Vdc)
1	13.1	265	509	4.25
2	12.8	260	500	4.15
3	12.5	250	482	4.09
4	12.2	240	464	4.01
5	11.6	228	442.4	3.82
6	11.1	219	426.2	3.69
7	10.7	212	413.6	3.6
8	10.4	204	399.2	3.51
9	10.2	202	395.6	3.46
10	10.1	200	392	3.44
11	10	198	388.4	3.42
12	9.9	197	386.6	3.4
13	9.7	194	381.2	3.35
14	9.5	190	374	3.3
15	9	181	357.8	3.2
16	8.7	176	348.8	3.11
17	8.6	175	347	3.1
18	8.4	171	339.8	3.05
19	8.3	168	334.4	3.02
20	8.2	165	329	2.99
21	7.9	162	323.6	2.94
22	7.5	154	309.2	2.84
23	7.1	147	296.6	2.76
24	6.9	142	287.6	2.7
25	6.7	139	282.2	2.68
26	6.2	131	267.8	2.56
27	4.8	118	244.4	2.25
28	4.4	110	230	2.16
29	4.1	105	221	2.11
30	3.9	100	212	2.06
31	3.8	99	210.2	2.04
32	3.6	94	201.2	2
33	3.4	90	194	1.96
34	0	23	73.4	1.38

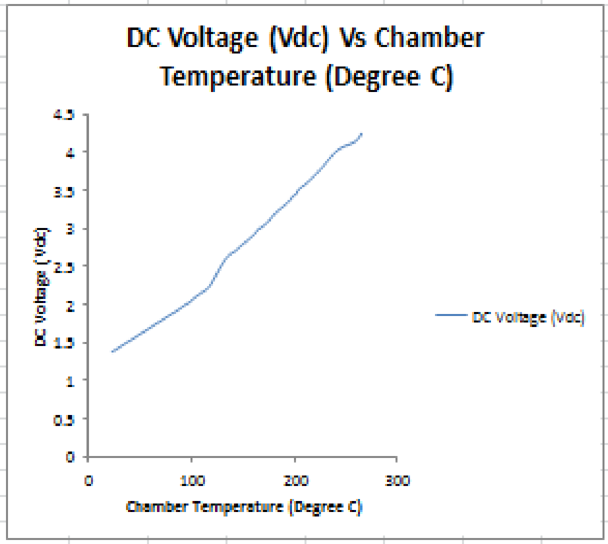

Figure 4. Thermocouple Calibration Chart

Position loop control

The position loop control is established based on chamber position which reads the counting value from the servo drive parameter position feedback. Based on this counting value, the PLC will know the chamber's exact position. Future implementation of this position loop control may include a feedback sensor that can be mounted behind the heat chamber to read the thickness of the cable and therefore monitor the shrinkage accuracy. If the cable shrinkage based on the feedback switch is not done properly, according to the PLC program, heat chamber will start the reheating process profile. In this profile, it will move backward and reheat the area which is not properly shrunk. This way the tubing is confirmed with proper shrinkage, and hence the quality concern is reduced.

Analysis and Results

Results are captured in the servo drive workbench software to analyze the control loop performance. The heat shrink tubing process is shown in full view for various parameters in Figure 5. The various parameters are

Position command (PL.CMD) [mm] — Position feedback (PL.FB) [mm] — Velocity command (VL.CMD) [rpm] — Velocity feedback (VL.FB) [rpm] — Analog input signal (AIN.VALUE) [V]

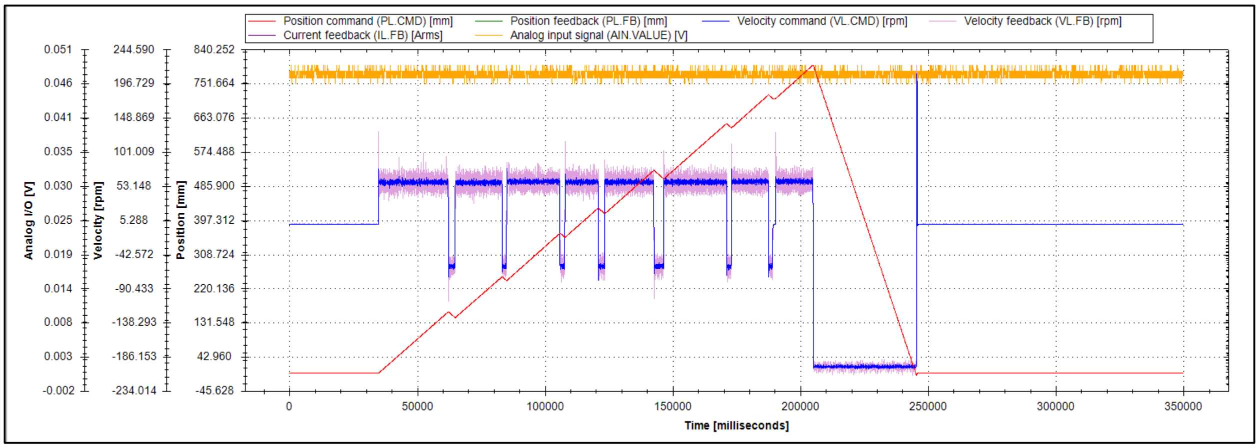

Figure 5. Scope Full View

Position command and feedback scope are shown in Figures 6 and 7 respectively, to show the motion along the full length of 800 mm of the positioning device, where the steps indicate the reheating process.

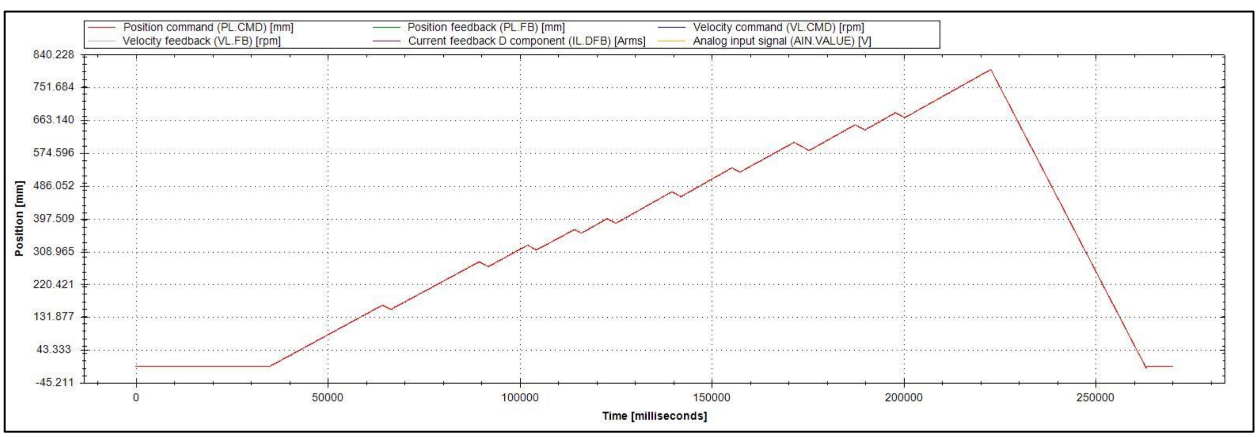

Figure 6. Position Command Scope

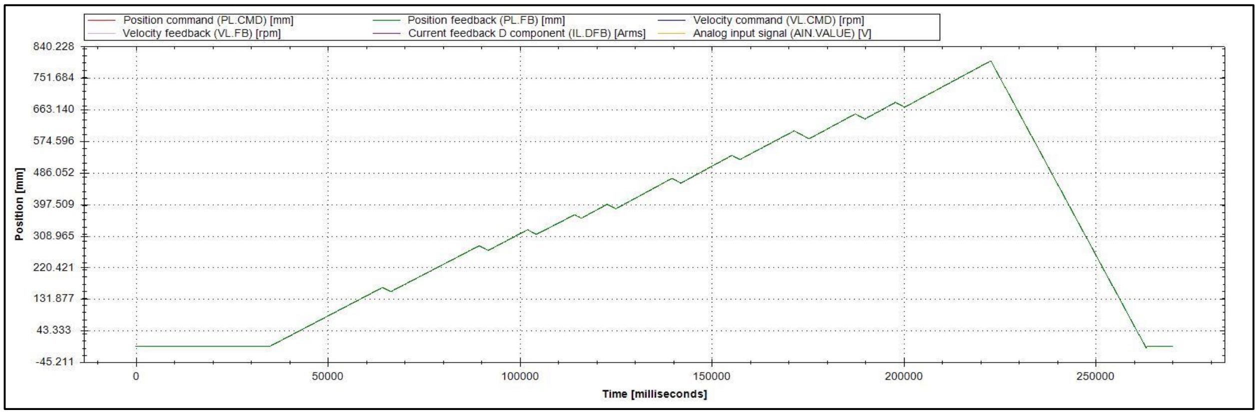

Figure 7. Position Feedback Scope

Velocity and analog input values are shown in Figures 8 and 9 to show the actual analog input value from the servo drive based on the velocity loop control process and sense the fluctuation based on the chamber temperature.

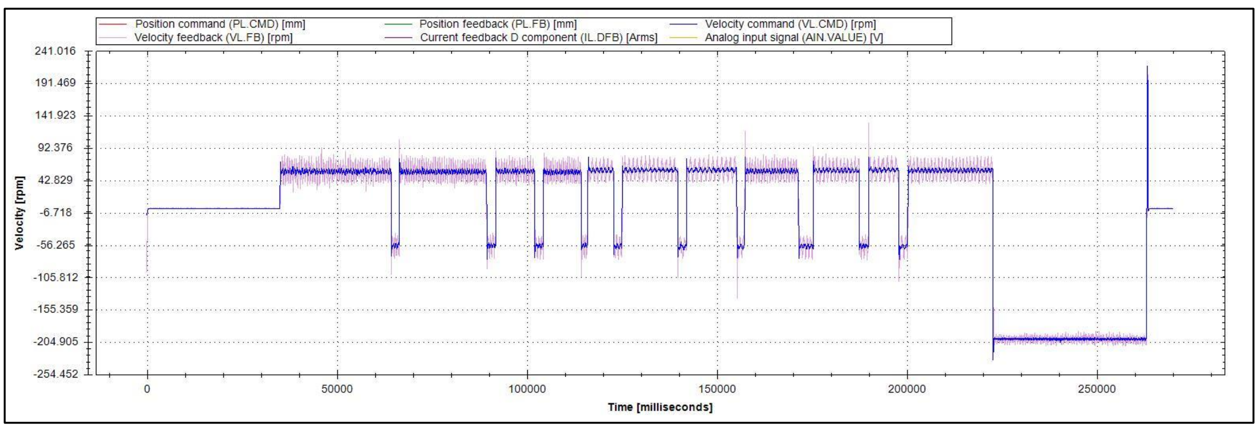

Figure 8. Velocity Scope

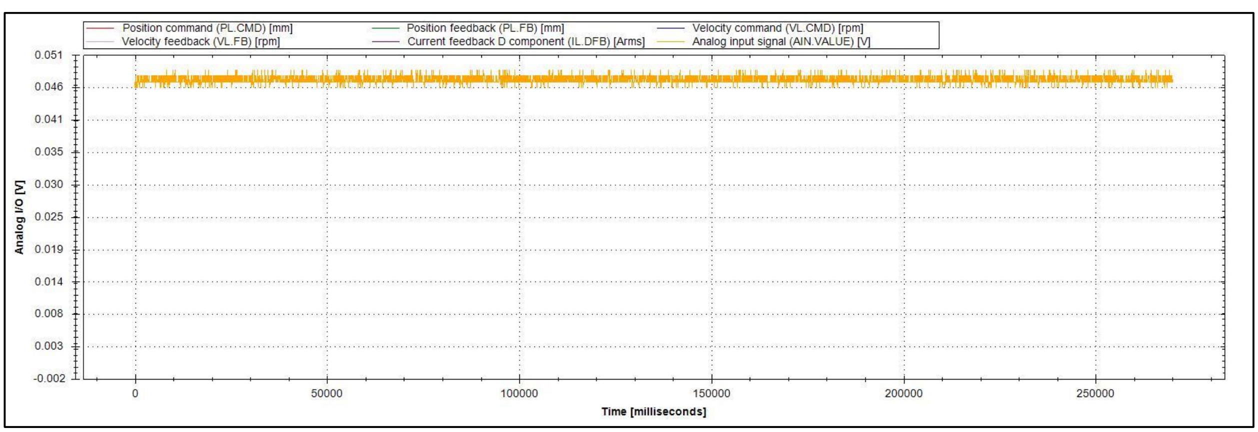

Figure 9. Analog Input Signal Scope

The above figures show the movement of one complete task from home position to desired length of 800mm and then returns back to the home position.

Conclusion

Despite technological advancement, manual heat shrink tubing process is still practiced by many industries. However, there are some manufacturers in the market that provide automated solutions to this application. When a long wire harness needs to be heated, the operator has to move the work piece manually. Based on this understanding, this project implements a practical solution in the wire harnessing industry with respect to the current technology in the field of industrial control and automation. A PLC automation based control system is introduced that benefits the long wire harness. A prototype model is developed to test 2.6 foot long cable with the control loop transfers and evaluated the best scope result to find the performance of before and after process of heat shrink tubing are shown in Figure 10 and 11.

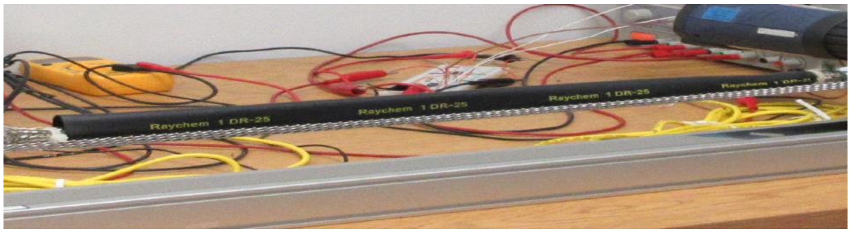

Figure-10: Before Process

Figure-11: After Process

Heat exposure time is a major factor in the heat shrinking tubing process which can be managed by controlling the linear speed and position of the heat chamber. An automated heat shrink tubing process minimizes the operator's direct interaction, lowers the production cost over the long term, and improves quantitative and qualitative production indexes.

Future Implementation

As suggested earlier Position loop control is needed to develop the feedback switch which can be mounted behind the heat chamber. This feedback switch is shown in the Figure 12. To measure the shrinkage performance, the feedback switch should directly sense the tube thickness before and after heating (like a human operator does visually in case of manual operation). Any appropriate thickness measurement method can address this need. Flexible strain-gauge measurement instrument is fixed on the exit side of the chamber to detect the cable thickness and gives the counting value to the PLC to sense the actual position and command the servo drive to initiate the reheating process [10]. The logic of reheating process is based on

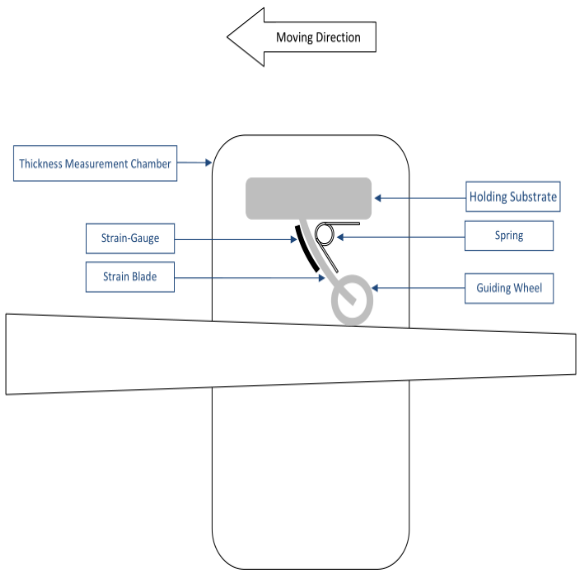

Figure 12. Cable Thickness Measurement [10]

the cable thickness. If it is greater than 1 mm, it will change the direction of the motor and reheat the cable with the desired running temperature, or if it is less than or equal to the thickness counting value, it will continue the velocity loop control process. Further implementation research is also needed to develop a GUI for turn-key operation and an alarm monitoring system triggered by one of several failure modes.

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Biographies

MURALI SANKAR HARIKRISHNAN is a graduate student in the Department of Engineering Technology at the University of North Texas. His project area is mostly focused on industrial control and automation. He will receive the MS degree in Electrical Systems in December 2015.

ROBERT G. HAYES joined the University of North Texas in 1990 and is a principal lecturer of Electrical Engineering Technology. He received the MS in Electrical Engineering from the Oklahoma state University in 1978, and received the PhD in Electrical Engineering from the Oklahoma state University in 1989. He is also the director of Denton County Boosting Engineering Science and Technology (DCBEST). He served as a Senior Engineer with Boeing Military Airplane Company.

HUSEYIN BOSTANCI joined the University of North Texas in 2012 and is an assistant professor of Mechanical Engineering Technology. He received the MS in Nuclear Engineering from the University of New Mexico in 2001, and the PhD in Mechanical Engineering from the University of Central Florida in 2010. He was previously a lead R&D engineer at RINI Technologies in Oviedo, FL (2001-2012). His main research interests include high heat flux thermal management methods via two-phase heat transfer (immersion and spray cooling), and Stirling-cycle-based innovative energy conversion technologies. He is a member of ASME, ASEE, and ASHRAE.

ENRIQUE BARBIERI joined the University of North Texas in 2012 and is professor and chair of the Department of Engineering Technology. He received the PhD in Electrical Engineering from Ohio State University in 1988. He was on the faculty of the School of Engineering at Tulane University, New Orleans, LA, (1988-2002) as assistant professor of Electrical Engineering and associate professor of Electrical Engineering & Computer Science. He served as chair of Electrical Engineering & Computer Science during (1996-98) and in 2002, joined the College of Technology at the University of Houston as professor and chair of the Department of Engineering Technology (2002-09). He served as the college associate dean for research and graduate studies (2009-10), as a member of the Executive Council of the Texas Manufacturing Assistance Center (2006-11), chair of the council (2007-09), and director of the Center for Technology Literacy (2006-10). He is a senior member of IEEE—Control Systems Society and a member of ASEE.