

8-2010

# AUTOMATION OF NON-DESTRUCTIVE TESTING TECHNIQUES USED FOR FINDING DEFECTS

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AUTOMATION OF NON-DESTRUCTIVE TESTING TECHNIQUES USED FOR  
FINDING DEFECTS

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A Thesis  
Presented to  
The Graduate School of  
Clemson University

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In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science  
Mechanical Engineering

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By  
Bhanu P. Singh  
August 2010

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## **ABSTRACT**

This master thesis focuses on the automation and fusion of non-destructive testing methods. The research includes the fusion of non-destructive testing methods done with infrared micro-bolometer and ultrasonic transducers. A control system which utilized mechanical, electrical, electronic systems and computer aided technologies was developed. Conveyor belt system, PLC (programmable logic controller), XYZ mechanism and different sensors were utilized to automate the process of capturing images and a communication link was set up between thermal camera and system that controls the ultrasonic testing apparatus, to integrate the two techniques. The test results from the thermal camera were utilized in ultrasonic testing.

It is observed that in thermal imaging as well as in ultrasonic testing, the results after automating the process were promising and helped to make testing easier. In thermal imaging we were able to find defects at different moving speeds of the sample and at different distances between sample and heating source, from which we understood the relation between different testing conditions and were able to predict the best factory conditions for testing and using ultrasonic testing method the nature of the defects were found in more accurate and faster way.

## **ACKNOWLEDGEMENTS**

I would like to acknowledge Dr. Mohammad Omar for his continuous help and support throughout this work. I would like to thank Dr. Beshah Ayalew and Dr. Steve Hung for their valuable suggestions and comments that helped in improving the quality of work.

Mr. Rohit Parvatneni is greatly acknowledged for his support in conducting the experiments and in the review of the topic. I would also like to thank all my friends Sree Harsha, Suhas Vedula, Konda Reddy, Qin Shen for their help.



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# CHAPTER 1

## INTRODUCTION

To understand the behavior of a material, performance and properties two types of tests are carried out, either destructive testing or non-destructive testing. Destructive testing is carried out on those objects which are mass produced but on objects that cannot be subjected to destructive testing, non-destructive testing is suitable. There are various ways of carrying out non-destructive testing but this thesis focuses on thermal imaging or thermography. Thermal Imaging or thermography is the technique of producing images of objects by capturing the thermal radiations emitted by the body, using the thermal cameras. The amount of radiations emitted by a body depends on its temperature, so thermal imaging doesn't depend on the visible illumination.

Liquid penetration, magnetic particle, radiography were the methods used for non-destructive testing of materials but with the improvement in thermal cameras, thermal imaging is emerging as one of the best option for non-destructive testing of many material samples [1]. It has now become global testing method for full field testing and can provide go or no-go decisions pretty very quickly. It has qualitative output in certain scenarios but involves manual examination of the captured images and processing, which is time consuming.

Ultrasonic testing uses a high frequency sound wave for inspection. Pulse echo and through transmission are the two methods for ultrasonic testing. In pulse echo a single transducer is used to send and receive the pulse. The received signal comes from the body of the object and a diagnostic machine displays these signals as amplitude. The

amplitude of signal determines the intensity of signal. While in through transmission, a transmitter is used on one side of object and receiver on other. In both the cases, if there are defects in the sample, the intensity of the signal received will be less at that particular area. The benefit of using ultrasonic testing is that the method is highly accurate and also the equipments produce instantaneous results [2].

So, the idea was to develop an automation system that can utilize the go or no-go feature of the thermal imaging and then finding the nature of defect using ultrasonic testing. A system which makes the process automated, fast, reliable and which doesn't disrupt the flow of manufacturing in an industry. Therefore, a system which includes a conveyor belt, PLC (programmable logic circuit), PLC simulator, photoelectric sensors, safety sensor and XYZ motion mechanism is proposed to automate the process, which is feasible in industries. It also includes a software for analyzing the data collected from the thermal imaging and controlling the XYZ used for ultrasonic testing both in installation itself and via web.

Most of the times, NDT is carried out with a stationary thermal camera and sample. But instead of using a stationary camera and sample, if a movable camera is used or the sample is made to move, the system can be easily made to fit in an industrial environment.

For the design of a control system the understanding of control systems and human machine interface is very important. In an industry the design of controller system needs an organized hierarchy. This hierarchy as shown in figure 1.1 consists of human



machine interface, a programmable controller and actuators or equipments to be controlled.

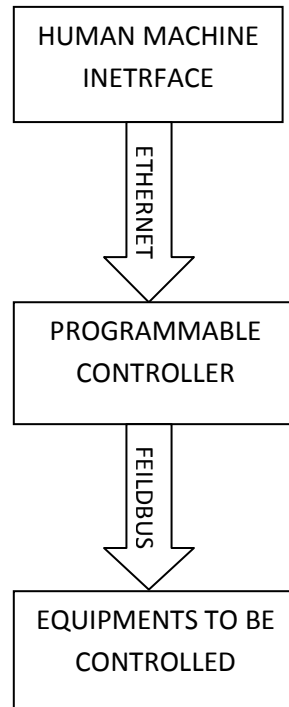


Figure 1.1 Control System Diagram.

### **1.1 HUMAN MACHINE INTERFACE**

While designing an industrial system the human machine interaction is an important thing to consider. Human machine interface also known as man machine interface, is useful in making the operation easier for the operator. Operator of the machine can use the man-machine interface to feed the information to the machine, get feedback from the machine control the parameters etc. Some of the examples of such interfaces are, a touch screen panel used in industries to control machines, computer operating system, remote systems to control various devices etc.

Whenever a command is given to a machine by the user, machine should react and gives back a signal to the user that the command has been understood [3]. This way the user will come to know that the command has been under execution by the machine. With the feedback, the time of the feedback by the machine is also very important. If the reaction time by the machine is high then there can be confusion in the mind of the user that the machine has not accepted the command and he will feed the same command again, due to which error will occur and system sometimes stops working unless restarted.

For the ease of use and understanding how the process is actually going, an interface can be used which will tell the user what exactly is taking place in the process. Let's take an example of PLC; we don't understand when a sensor is giving signal to the PLC and when the signal is further passed to the actuator. For this purpose I/O terminal blocks on the PLC are kept with small LEDs next to each terminal so that user can understand which input and which output is ON or OFF.

## **1.2 CONTROL SYSTEM**

Controller is a device that monitors and changes the operational behavior of a dynamic system. Control systems can be open loop or closed loop controls systems. An open loop control system does not use feedback from system to check if the system has reached the desired goal, it just computes the authorization of the control depending on the input supplied. While the closed loop control system uses the feedback to control the output. Control system also depends on the type of system to be controlled. Based on this, major classification of control systems can be done as:

1. Continuous value change.
2. Discrete value change.

A continuous and a discrete system can be understood by the example of a motor. To turn the motor on and off, it is an example of discrete system and controlling the speed of motor is an example of continuous system. A continuous system can be further distinguished as linear or non-linear and a discrete system can be conditional or sequential. Most the systems in the world can be controlled sequentially and logically which makes the control easier. But some systems require to be controlled continuously which makes the problem complex.

With the use of mechanical and electronic components in control systems, now a day's computer technologies are also used widely in control systems, PLC is one of the examples of that. Before PLC, relays were used for simple logic signals but now PLC is in use for simple as well as complex logics. PLC work on ladder logic programming which actually represents circuit diagram of relay based logic hardware. PLC needs an input from the sensors and based on the input the PLC will give the signal to actuators. So, the working of controllers depends on the sensors. Input/output devices associated with the PLC can be digital or analog. Digital input devices include pushbuttons, limit switches, photoeyes and common output devices include relays, motor starters and solenoid. Few analog input examples are pressure, speed, temperature etc and output signals include motor speed, air pressure, valve position, etc.

## 1.2.1 INTRODUCTION TO CONTROLLER CODING

### PROGRAMMABLE LOGIC CONTROLLER (PLC)

As discussed above, PLC programming is creating ladder logics, which corresponds to the relays in a circuit. The first thing to know about PLC programming is that there are two rails on the left and right side as shown in figure 1.2. The rail on the left is hot rail which is always high, and the rail on the right is neutral [4]. Then there are rungs in the program which contains inputs and outputs. The output signal is achieved only if the input circuit is closed. Input can come from a sensor, switch, or any other type of sensor and output will be some actuator.

Input and output instructions:

In general all the PLC types have input/output instruction given below:

1. Normally Open Contact- It is a contact type that rarely allows current to pass through. The symbol shows two parallel lines with no contact. When activated the contacts close.
2. Normally Closed Contact-When at rest the contact is closed and when energized contact opens up.
3. Contacts for comparing two values- There are various contacts for comparing values. In this case the contact energizes if it satisfies the condition.
4. Latch/Unlatch output- Latching is used to turn a particular function permanently ON. Once the output with latch is turned on it will stay on unless another input i.e. unlatch is given.

5. Reset output- Reset output is like turning the output on again. Once we have turned an output OFF from ON state, we can use the RES output command to turn that ON again.
6. Timers and counters- Timers and counters also fall into the category of outputs. A timer is used to run a particular output for certain period of time whereas, a counter is used to run an output for particular counts of an input.

To understand the concept let consider this example:



Figure 1.2 Various Contacts and Outputs.

In this example, C0, C1, C2 are the inputs and Y0, Y1, Y2 are the outputs. C0 and C2 represents normally open contact and C1 shows normally closed contact. Considering few inputs for this example.

Case 1. C0 is ON-

Rung#1- C0 will close and allow the signal to pass through. C1 is already closed contact so it will also allow the signal to pass and output Y0 will turn ON.

Rung#2- C1 will complete the circuit and output Y1 will turn ON.

Rung#3- Y1 is acting as input so it will turn the output Y2 ON.

Case 2. C0 and C1 both ON-

Rung#1- No output

Rung#2- Y1 ON

Rung#3- Y2 ON.

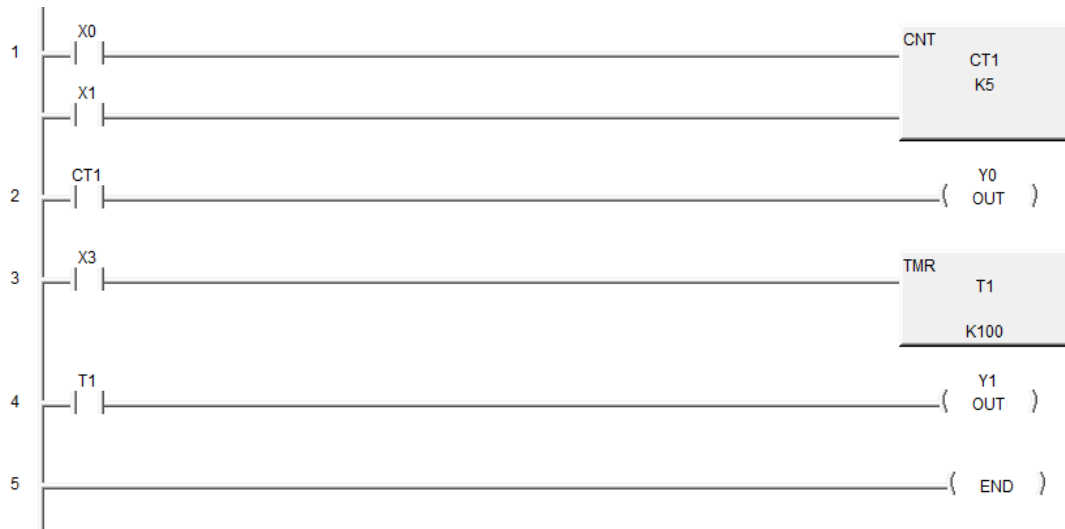


Figure 1.3 Working of Counters and Timers.

In this program, the counter will count the transitions of contact X0 from OFF state to ON state. When the counter will reach the pre-set value i.e. 5 counts it will turn the counter status contact CT1 ON. Each time the contact X1 will turn on, the counter will reset its value to 0.

In case of timer, when the contact X2 will turn ON, timer T1 will start. It will run until the pre-set value 10sec (K=100) is reached and then it will turn the timer status contact T1 ON.

### **1.3 WEB BASED CONTROL**

Web based control of machines is an application programming interface. Using such an interface we can control the machines remotely. There is a client/user agent, which submits the request to HTTP (Hypertext Transfer Protocol) and there is a responding server which stores the request and creates resources. User can log on the web and control the parameters from a remote client to a web server that is connected to a controller.

CGI (Common Gateway Interface) and TCP (Transmission Control Protocol) are two common methods to setup a client-server communication link. In CGI, client can connect to the server using the web browser, access the web page and communicate with the server. But for web based control of equipments TCP is preferred over CGI, as in TCP the connection between the client and the server doesn't get lost unless the clients closes it, but on the other hand CGI works on per session basis [5].

### **1.4 VARIOUS EXPERIMENTS AND CONTROL SYSTEMS**

Case 1. The research work in Clemson University ICAR center in Greenville, S.C., focuses on non-destructive testing of different material samples using thermal imaging cameras. The main heating sources that are used are pulse, induction and halogen light. The two types of sample that are used are galvanized steel panel and galvanized steel sheet with zinc coating. Few of the experiments done using different heat sources and samples are discussed below:

1. Flash light as heating source (pulse heating):

Heating Source- Flash Lamp is used to excite the sample.

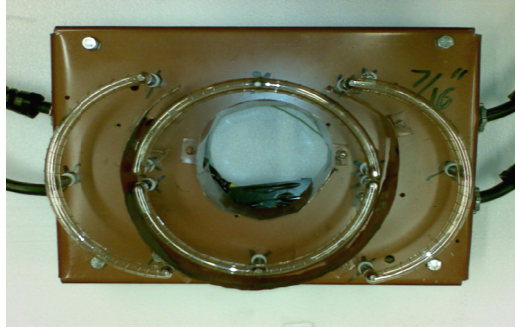


Figure 1.4 Flash Lamp used as Heating Source [6].

Sample Used- Test sample used is galvanized steel panel with three circular adhesive spots of different dimensions.



Figure 1.5 Test Sample [6].

Experimental Setup- The flash lamp is used to excite the test sample. The sample is kept vertical with camera and flash light focusing towards it. The camera is kept in such a way that it can see through the flash light. This is done to keep a corresponding distance between the different spots on the sample from the camera and flash light. The experimental setup is shown in figure 1.6.



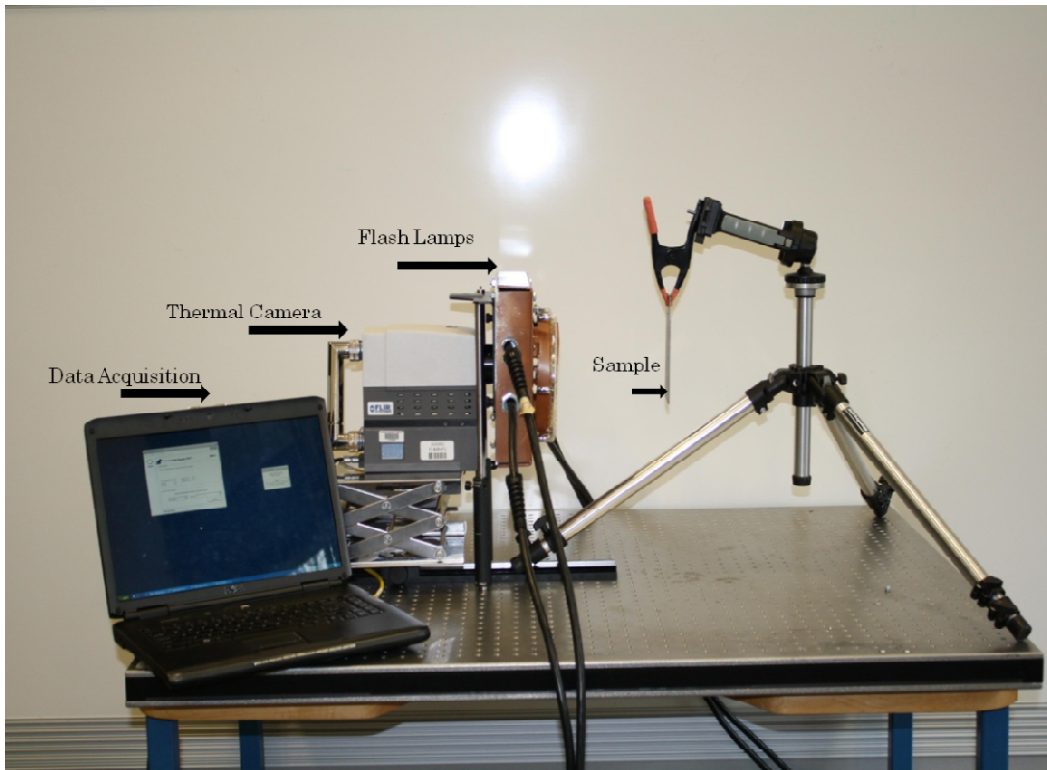


Figure 1.6 Experimental Setup for Thermographic Testing with Flash Light as Heat Source [6].

## 2. Halogen light as heat source:

Heating Source- Halogen Lamps are used to excite the sample.



Figure 1.7 Halogen Lamps used as Heating Source [6].

Sample Used- Sample used in this case is the same galvanized panel with three circular adhesive spots.

Experimental Setup- Halogen lamps are used to excite the sample. The Setup is quite similar to the one used in the case of flash lights. In this case, 2 lamps are used as heating source. The halogen lamps are kept on both left and right side of the camera, to keep equal distribution of the light on the sample from both the lamps.

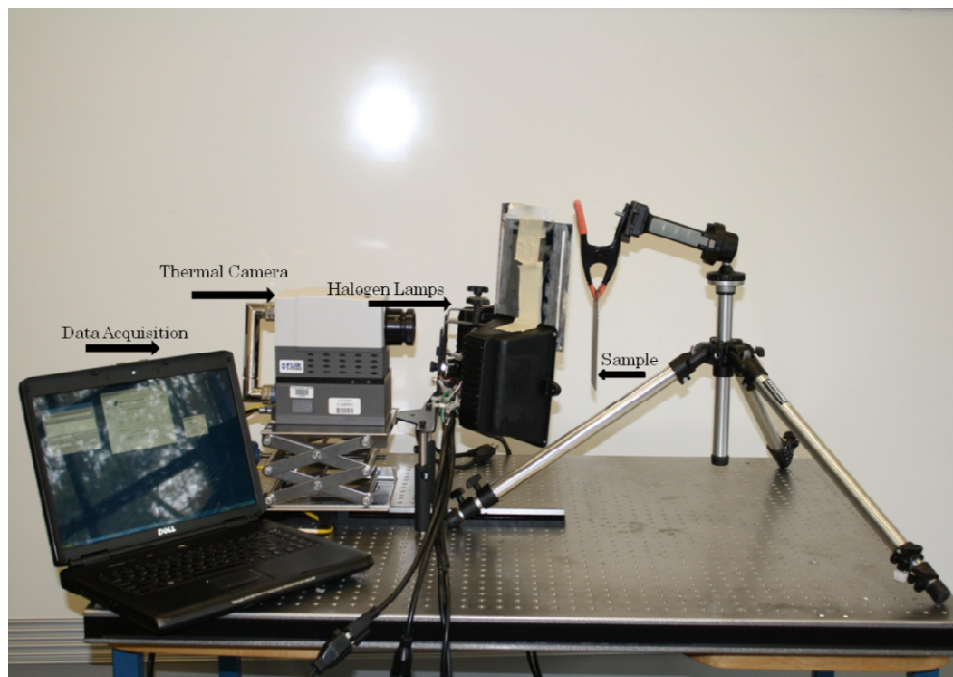


Figure 1.8 Experimental Setup for Thermographic Testing with halogen Lamp as Heat Source [6].

Experiment done by Jiangang S. et al., at university of Chicago, IL, for determining the thickness and depth of the defects using thermal imaging in plastic, ceramics, metal and other products the excitation sources for the sample used was flash light [7]. The setup used for the experiment was quite similar to what is being used at ICAR center,

Greenville, S.C. The thermal imaging system includes a pair of flash lamps on either side of sample. Thermal camera was placed in between the flash lamps and a computer was controlling the camera. The only difference in this setup was that the triggering of the flash lights was coupled with the computer, whereas in the earlier case triggering was done manually, due to which the timing of the flash can vary. This will result in different temperature values of the sample in different experiments, while the camera is capturing the image.

### 3. Induction coils as heat source:

Heating Source- Induction heater and coils were used in this case to excite the samples.



Figure 1.9 (a) Induction Heater [6].



Figure 1.9 (b) Induction Coils [6].

Sample Used- In this case the sample used is a galvanized steel sheet with zinc coating.



Figure 1.10 Galvanized Steel Sheet with Zinc Coating.

Experimental Setup- In this case two types of coils are used pancake coils and circular coil. The heating is done near the defects in the sample and the camera is also focused on the same spot. The coil is kept at the back of the sample and camera on the other side.

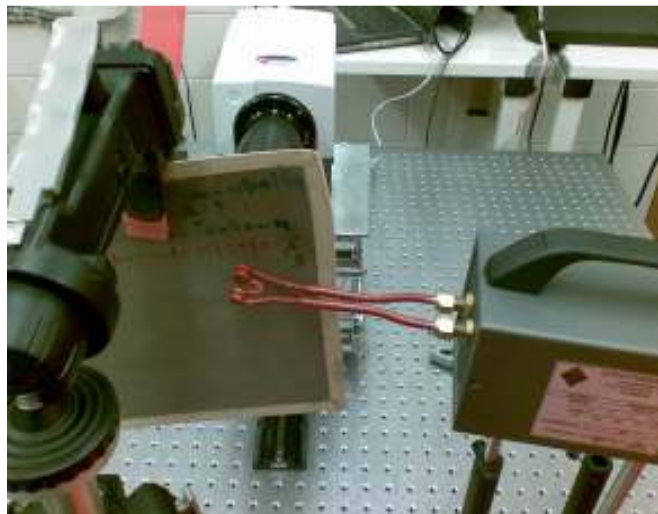


Figure 1.11 Experimental Setup for Thermographic Testing with Induction Coils as Heat Source.

Case 3. In a study of thermographic crack detection in Germany by G. Zenzinger et al. [7], using eddy current as excitation source the process was fully automated. An experiment was conducted on the compressor blade of an aircraft engine. In the experiment an induction coil was used to induce eddy current in the compressor blade.

An industrial robot was used to for pick and place purpose. Robot picks the compressor blade and places it in the coil and then an induction pulse is released. The heat waves from the blade are then captured by the thermal camera. Inhomogenities in the temperature pattern are recognized and above a threshold value the cracks are marked.

Case 4. Recent study by T. Zweschper et. al. [8] on ultrasound burst phase thermography, the mechanism involved for excitation of samples was friction generated between sample and ultrasound converter which turns the defect into a heat source and thus the heat radiations emitted by the defect are captured by the infrared camera.

In this experiment, an ultrasound generator, ultrasonic converter, infrared camera and a control and processing unit were used. When the ultrasonic waves are generated the converter excites the sample and the heat radiations generated by the defect are captured by the infrared camera. The camera is further connected to the processing unit i.e. computer, to process the images captured. The control unit is synchronized with the infrared camera which takes the signal from the camera and operates an ultrasound amplifier.

## CHAPTER 2

### STRATEGIES FOR PROCESS AUTOMATION

Most of the systems used for thermographic testing involves, capturing images of the samples and then processing it. This process takes a lot of time and every time the new sample has to be tested the previous sample is taken out from the setup and another one is fixed. This system cannot be implemented in the industries because of the slowness of the process. The process should have the heating of sample and image capturing in such a manner that it does not disturb the samples in the manufacturing environment.

To find the defects in different samples thermal imaging and ultrasonic testing are the two methods that are being used in the lab. The proposed idea is to use the thermal imaging to detect the defects in the samples used and then separating the defective samples and using ultrasonic testing to find the nature of the defect. This system will allow the good samples (without defect) to pass through the testing apparatus without stopping for inspection, only the defective samples would be separated and inspected.

To build such a system, a new experimental setup using conveyor belt, PLC, a XYZ mechanism, a touch screen panel and a web based control system was considered. The conveyor belt used for material handling, PLC will control the conveyor belt motion, XYZ system to mount and move the transducer for ultrasonic testing, touch screen panel for HMI and web based control system which will take the input from thermal camera and control the motion of XYZ mechanism.

## 2.1 ELECTRICAL SYSTEM

The main objective of this system is to operate the conveyor belt based on the signal given by different sensors. PLC is the actual programming unit that is used in this system to take input from the sensors and give the output to the motor controller that operates the conveyor belt.

List of equipments used:

- PLC- Direct Logic DL205.
- Touch screen panel.
- Techno-electric switch.
- 3 phase motor.
- A Rhino power converter.
- Cutler-hammer switch.
- 5Port Ethernet switch.
- Motor driver.

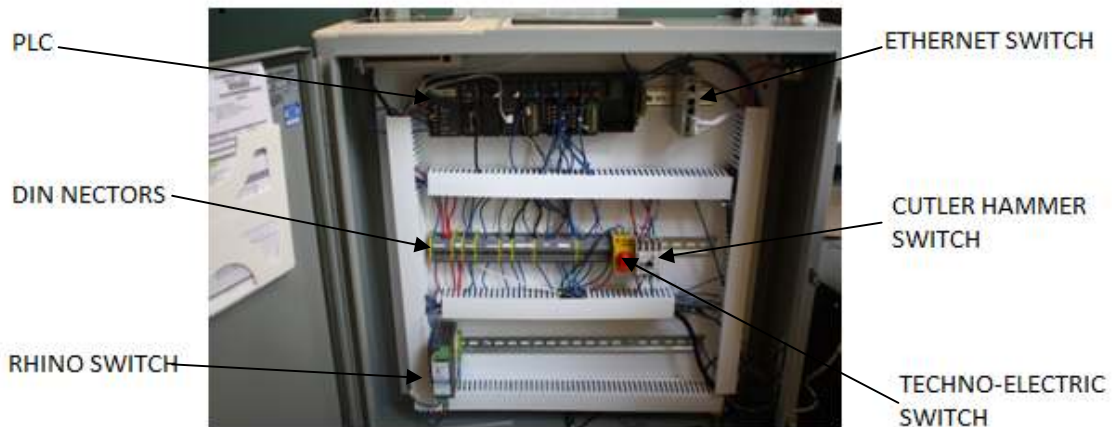


Figure 2.1 Electrical System for PLC and Conveyor Belt.

## 2.2 PLC PANEL DESCRIPTION

A big steel panel is used to mount all the equipments used for electrical setup. A mounting plate is used which is used to fix all the equipments and then fixing the plate inside the panel. There are six set of din-nectors used, each one for different power options. Techno-electric switch is the main switch for power supply to the panel. After taking the AC supply from the wall, Rhino switch converts the AC to DC as most of the equipments works on DC. The PLC is connected to the sensors and the motor drive. It takes the input from the sensors, checks the program and gives the output to the motor drive. A cutler hammer switch is used between PLC and motor drive, which basically acts as a motor starter. Based on the signal from the PLC, motor drive runs the motor and hence the conveyor belt. Figure 2.2 shows the signal flow between the sensors and conveyor belt.

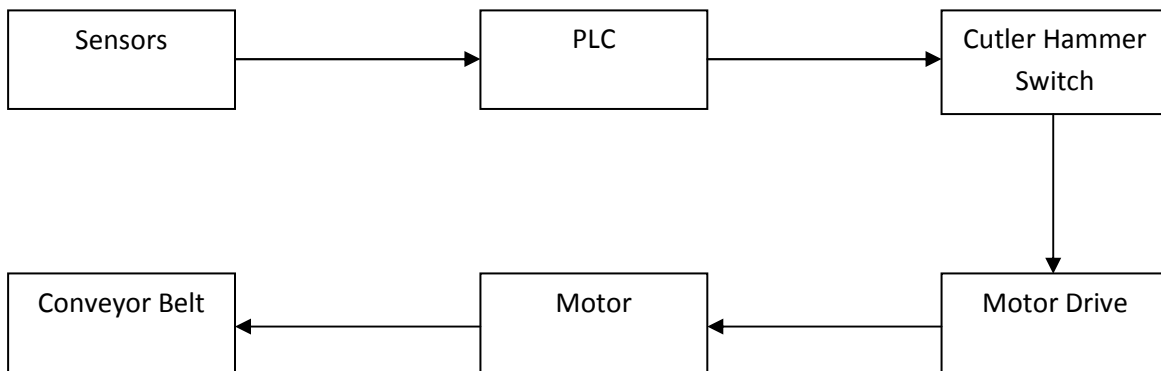


Figure 2.2 Flow of Signal from Sensors to Conveyor Belt.



## 2.3 PLC I/O WIRING

Figure 2.3 describes the physical layout of the Direct Logic's DL205 PLC.

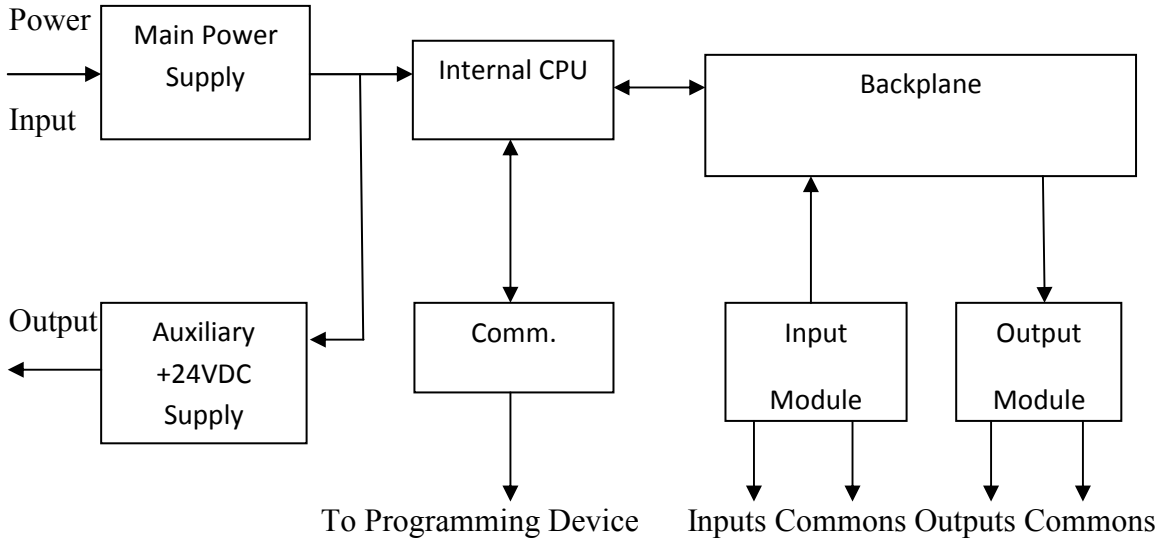


Figure 2.3 Physical Layout of PLC [9].

PLC circuitry is divided into 3 parts separated by isolation boundaries. This is done to avoid the damage of all the areas due to fault in one. The three sides are primary side, secondary side and field side. The main power supply and auxiliary output are in primary side, input and output modules comes in field side and rest the CPU and backplane are in secondary side.

In this PLC type, auxiliary +24VDC output is there which can be used for powering the external devices. The supply to the output load should be same as to the PLC, so the motor connected to the PLC is supplied with same AC supply. To wire PLC with field devices and external supply the sinking and sourcing concepts should be considered. A sinking digital I/O provides a ground and sourcing digital I/O provides a voltage source. In our case, the sourcing digital input is connected to sinking digital

output. The input provides us the voltage source and output provides the path to ground. In case, if the circuit is built wrong the current will not flow.

## **2.4 MOTOR DRIVE**

The motor drive is the controller for the motor. It is used to control the signal parameters that act as input to the motor. The motor drive is taking signal from the PLC and starts/stops the motor based on the input from the PLC. Motor drive is used to change signal parameters. VS1MX from Baldor Electric controls 46 parameters such as speed, frequency, voltage, current, power etc. These parameters can be changed from the panel at the front of motor drive using up and down arrow keys. These parameters are represented as P-00, P-01..., and P-45.

Another very important feature of this motor drive is the signal processing. Depending on the application, the parameters are changed and based on the parameters selected the terminals starts behaving differently. Our requirements are to start/stop motor, forward/reverse motion of motor and different speeds of motor. To achieve this, the value of parameter P-07 and P-08 are important. P-07 is the start/stop source and P-08 is for operating mode. By setting both the values to 0 we can configure the terminals to achieve our requirements, see Table 2.a.

Terminal No.	Signal Description
1.	+24VDC output
2.	Digital Input 1. Open- Stop                      Close- Run
3.	Digital Input 2 Open- Forward                      Close- Reverse
4.	Open- Analog Speed Ref. (Analog Input 2) Close- Preset Speed Ref. ( Digital Input 3)
5.	+10VDC output (for potentiometer)
6.	Analog Speed Ref. (Analog Input 1)
7.	Common- 0V.

Table 2.a. Motor Drive Terminal Description.

Terminal 2, 3, 4 and 6 can be different in case different values of parameter P-07 and P-08 are selected.

In case some kind of change in the input to motor is required, like achieving different speeds of the motor, the manual interruption in between the experiment would occur and process will have to be stopped. To avoid this, a touch screen panel is used which the operator can easily access and make changes without disturbing the ongoing work. Touch screen panel has been described below.

## **2.5 TOUCH SCREEN PANEL**

Touch screen panel is used to simulate the project. It has build in project simulation and has good memory space. The project is simulated on PC using the C-More programming software and tested before sending it to screen. This software contains various shapes which can be used to represent the actual experimental equipments and machines, and these objects are tagged in the database. An even manager is used to create a list of events. The event manager will trigger actions based on the sequence in the list.

The panel can be connected to the PLC using Ethernet or RS232 cable. By giving IP address or selecting the PLC type in the serial port communication link of C-More software the communication between PLC and panel will start.



Figure 2.4 6Inch TFT Touch Screen Panel.

## **2.6 SENSORS**

Safety light curtain and color sensor are used in this system. Safety curtain sensors are used for the safety of the operator and color sensor are used for the stopping the sample at the end of conveyor system. The safety curtain sensor is used at the side of the conveyor belt where the operator is working. This will avoid the contact of the

operator with the moving conveyor and XYZ which comes under operator's safety. Moreover, operator can also misalign the samples while experiment is running.



Figure 2.5(a) Color Sensor.



Figure 2.5(b) Safety Light Curtain.

### 2.6.1 SAFETY LIGHT CURTAIN

The type of safety light curtain used is SL-VL by Keyence Corporation. It has one transmitter and one receiver. Transmitter creates an optical path by sending the light beams and receiver end captures these light beams. The total area that it covers depends on the distance between the transmitter and receiver, and the distance between the center of the top beam and the center of the bottom beam. If anything comes in the way of this area it will turn the auxiliary output on that is connected to the controller.

### 2.6.2 COLOR SENSOR

In the color sensor, CZ-H32 is the unit having the transmitter and the receiver, and CZ-V21A is the amplifier unit. The receiver and the transmitter are installed in the in one unit. This sensor is a reflective type sensor as it transmits light beam and observes the

reflection from any object in the way. The amplifier unit stores the values captured by the receiver. It has 2 color banks, each having 4 storage spaces. The target of which the color has to be used is placed in the focus position and by pressing the SET button on amplifier the color can be stored. Similarly more colors can be stored in the memory and in case two colors are having close setting value that it becomes difficult to discriminate the setting value can be manually set in the amplifier unit.

### 2.6.3 PROXIMITY SENSOR

Another type of sensor that is installed in the system is a proximity sensor. Sensor used is PZ-M51, by Keyence Corporation. This sensor also has a transmitter and receiver installed in the same enclosure. It doesn't require any programming for getting the output, we just need to do the sensitivity adjustment. There is a sensitivity adjustment trimmer on the sensor. This trimmer is turned clockwise with no object in the way when the sensor light turns orange that means this value is maximum for the sensor to emit in that particular environmental light. This particular point is considered as max point and then bringing the object in front of sensor the trimmer is turned in anticlockwise direction and the point where the sensor light turns green is considered as minimum light that can be captured by sensor. So the trimmer is adjusted between these two points.

## **2.7 THERMAL CAMERAS**

The two types of cameras that are used for finding the defects are cooled and un-cooled camera shown in Table 2.b.



Sr. No.	Thermal Camera Specifications		
1.	Model Name	FLIR Phoenix DTS	FLIR A40M
2.	Camera Images		
3.	Resolution of Camera	620x512	320x240
4.	Frame Rate	Depends on Integration Time and Resolution.	7.5Hz, 15Hz, 30Hz and 60Hz.
5.	Focal Plane Array Cooling	Cooled Camera (74K)	Un-Cooled Camera
6.	Alarm System	No	4 Digital and 2 Analog Output Alarms

Table 2.b Thermal Camera Specifications.

The testing done with the help of cooled cameras include following steps:

1. Capturing the images of the samples for a particular time and motion of conveyor belt.
2. Finding the frame where the defect shows up.
3. Generating Voxel plots for 10 frames before and 10 frames after that frame.
4. Converting the Voxel plots into excel sheet.
5. Plotting graphs between temperature and time by comparing values from the excel sheet.

Testing also includes changing the variables like current supplied from the heat source, distances between the sample and the camera, and speeds of the conveyor belt.

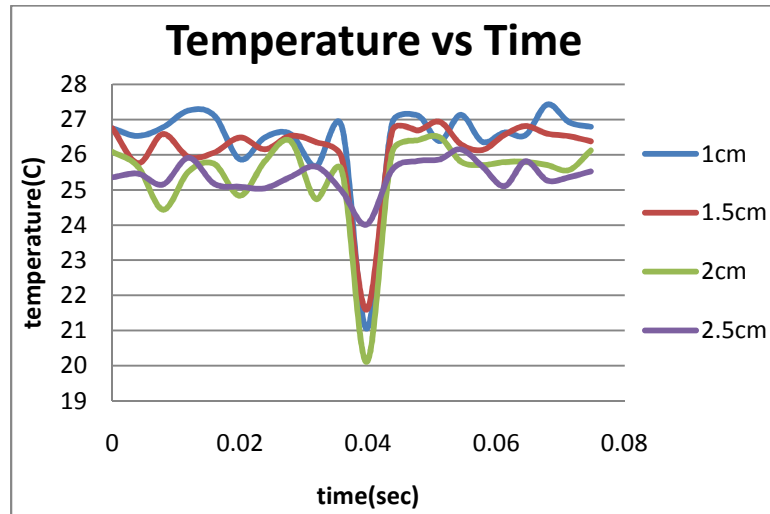


Figure 2.6 Temperature vs Time Graph for Different Distances between Camera and Sample.

Figure 2.6 shows the graph between temperature of the sample and the time for different camera to sample distances. The dip in the graphs is the dip in the temperature observed by the camera, which occurs because of the defect.

For integrating the camera system with the ultrasonic testing we just need a trigger signal from camera when it sees certain increase or decrease in temperature value. But cooled camera doesn't have this alarm system feature. So, un-cooled camera was used in the new system which has such alarm feature.



## **2.8 UNCOOLED CAMERA'S CONTROL**

The camera is always in the operating mode once the testing has started. The samples will keep on passing from the camera focus area and it is required that the camera decides whether the sample is good or defective. In case the sample is good the sample will move pass camera and if the sample is defective the camera should give signal to the ultrasonic testing apparatus to check the defect. As the samples are excited using heat sources, the camera captures the heat radiations coming out of the sample. The area of the sample with defect will have non-uniform pattern of radiation. The user setting in the camera has to be set according to the requirements, i.e. whether the camera triggers the output when temperature drops or when temperature increases. Due to the defects in the samples the temperature falls, which can be set in the camera and camera will trigger output when it sees a drop in temperature by that amount.

To control the camera output and to change the setting of the camera we can use the web. Web interface can be made by connecting the PC with the camera using the FireWire and then by using the IP address of the camera accessing the camera web server. We can change the image settings, object parameters, change the configuration of spots, boxes, isotherm etc. We can also configure camera ports and change general settings by using the web server. A live image of the spots can also be seen with the temperature of the spots at every moment.

## **2.9. CONTROL SYSTEM FOR ULTRASONIC TESTING**

After getting signal from the camera, the next task is to make a control system that can take the input from the camera and move the ultrasonic transducer to further check the defect. For this purpose the XYZ mechanism was chosen.

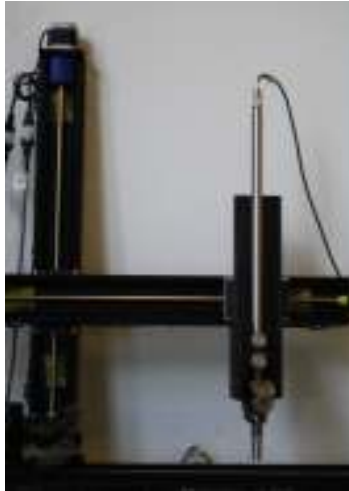


Figure 2.7 XYZ Mechanism with Transducer Rod fixed.

The XYZ mechanism has three motors, one motor for each direction. The motor controller has switches on it which can be used to move the transducer in all three directions or the controller can be programmed using COSMOS software. The manual interface cannot be used because for that operator will have to sit in front of the image viewer of thermal camera to check if there is any drop in the temperature value and there are chances of operator missing any sample defect. On the other hand the speed of the process will also slow down as every time a defect is found the operator will have to adjust the position of the transducer and also, in case of more than one sample at a time finding defect and adjusting position will become a headache for the operator.

The COSMOS software allows us to make a program in which we can specify the different positions and motions of the XYZ mechanism and thus the transducer depending on the inputs from the camera.

### **2.10 ULTRASONIC TESTING**

Pulse Echo Method is used for the testing of the samples. An electronic device is used to generate high voltage electronic pulses and same device receives the pulse back from the transducer [2]. Transducer driven by this device generates the high frequency sound waves. The transducer transmits the waves to the object surface and waves propagate through the material. The waves reflect from the surface of material and are converted to electronic signal again by the transducer, which is then displayed on the screen. If there are defects in the material the reflected waves will have discontinuity.

The ultrasonic waves do not propagate easily from contact transducer to the solid material under inspection, so a gel is used as coupling agent. Water bath can also be used if immersion transducer is used but in that case the sample has to be in the water bath. These coupling agents help the waves to travel from the transducer to the sample.



As discussed in last chapter, an analog output card has been used with the PLC. For analog output cards, there are two methods of calculating the digital values to send analog module:

1. The Pointer Method.
2. Multiplexing Method.

For DL260 CPU type either of the method can be used, but in the above shown program, the pointer method has been used for the ease of programming. To obtain the output data and to update the number of channels, the V memory location of base slot of analog output card has been included in the program. These values can be seen in the first rung of the program. This rung can be included anywhere in the program but in case the stage programming is used this rung has to be at the top.

The output card can be kept in any slot of the PLC but this particular slot will determine the memory location that has to be included in the program. CPU is always kept at first slot on the left and this slot is considered as slot 0. The analog module has been installed at slot 5. The values are converted to binary automatically using The Pointer Method.

#### Description of the Program-

1. The SP0 is normally open switch which closes when the power is supplied to the PLC. This will energize the outputs on the rung. The command 

LD
K8

 loads a constant which specifies the number of channels to scan and data format. The most significant nibble selects data format i.e. 0= BCD and least significant nibble selects number of channels i.e. 8 channels.

2. Output 

OUT
V7665

 tells the V memory location for slot 5, which contains the number of channels to scan.
3. Output 

LDA
O2000

 tells the octal value of the V memory locations, O2000 shows the Ch1-V2000, Ch2-V2001...Ch8-V2007 memory locations to store the output data.
4. Output 

OUT
V7705

 provides the storage space for the octal value. V7705 is for slot 5. The CPU will see the octal value to determine where to store the output data.
5. X0, X1... and similarly Y0,Y1.... shows the inputs and outputs. X0 represents the input at first terminal on input card, X1 represents input on second terminal and so on, and same is in case of outputs. Y0 is attached to the first rung to keep the output ON whenever the PLC is running. This output goes to the controller of XYZ mechanism, which requires TTL signal whenever the XYZ mechanism is in operation.
6. X0 and X1 represents the color sensor and safety light curtain which gives the output Y1 and Y2 which are connected to the motor drive to control the motion of conveyor. Both the inputs when turns on stops the motor.
7. X2 represents the photoelectric sensor. It is used to start the motor, output Y2.
8. X3 is the output from the camera. When X3 turns on, it will start the timer T0 and turn on Y2. After 10 seconds (K100) the timer will stop and turns on the timer status T0 which will turn on the contact Y1 to stop the motor.

### 3.1.2 TOUCH PANEL PROGRAMMING

The purpose of using touch screen panel is to control the speed of conveyor belt. Touch panel cannot communicate with the motor directly, it sends signal to the PLC first through Ethernet cable and then PLC sends signal to the motor drive. To control the

speed, the speed reference to the motor drive should be an analog signal. So, an analog output card is used with PLC.

Equipment Specifications:

Sr. No.	Touch Panel Specifications	
1.	Manufacturer	Automation Direct
2.	Screen Size	5.7 Inch viewable
3.	Operating Range	20.4-28.8VDC
4.	Resolution	320x240 Pixels

Table 3.a Touch Panel Specifications.

Sr. No.	Analog Output Card	
1.	Manufacturer	Automation Direct
2.	No. of Channels	8
3.	Operating Range	24VDC, 4-20mA
4.	Configuration	Sink/Source configurable

Table 3.b Analog Output Card Specifications.

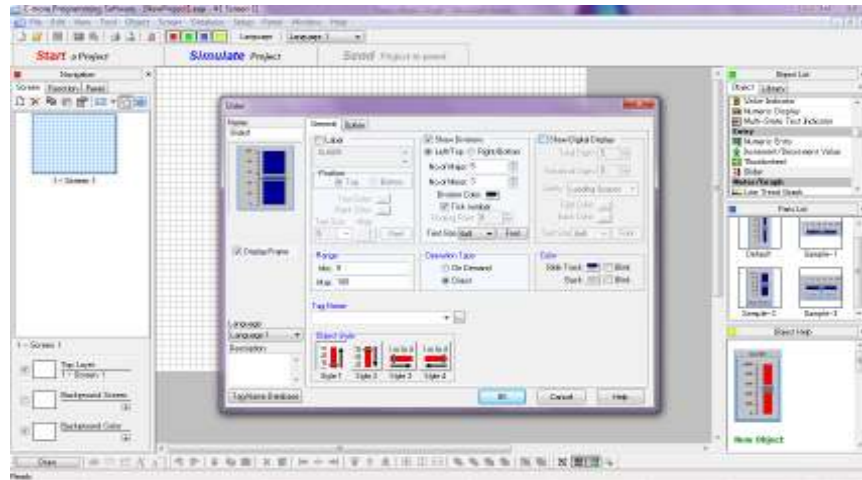


Figure 3.2 Creating New Object in Touch Panel Programming (CMORE Programming Software).

Figure3.2 shows the programming window. The first step in the touch panel programming is to select the object type or create a new object using different shapes in the object library. A Slider has been selected from the library which can be used for changing the speed values. The main tasks in simulating this slider are to tag the slider, set a range for slider and to set the scale between the actual value and value on the screen. Tag name is given to the object to add it in the event manager list. There are few tag names given in the list to choose from. The name given here is slider itself. Then for setting the range the minimum and maximum value has been in the database.

Speed Range		
Slider	Motor	Conveyor Belt
0-100	0-2000rpm	0-37m/min

Table 3.c Speed Range Comparison.



After setting the values for the slider, the next step is to add the slider to the tag name database, specify the data type and the PLC address has to be specified according to the tag name. Once this is done, the project can be simulated to see if the slider is working fine and then by doing the setting for Ethernet port IP address and selecting the panel type the program can be transferred.

### 3.1.3 PLC OUTPUT PROCESSING

There are two types of signals from the PLC, digital and analog signal. The signal has to be fed into the motor drive and as discussed before the parameters P07 and P08 has to be set to value zero to make the circuit compatible for the two types of signals. There are few other parameters which are required to be set according to the input and output to the motor drive. The values of these parameters are shown below in Table 3.d:

Sr. No.	Parameter #	Parameter Name	Value set	Range
1.	P01	Motor Rated Voltage	230VAC	0, 20-250VAC or 0,20-500VAC
2.	P02	Motor Rated Current	1.6A	25-100%
3.	P03	Motor Rated Frequency	60Hz	25-500HZ
4.	P04	Motor Rated Speed	1750 rpm	0-30,000rpm
5.	P05	Minimum Output Speed	Variable	0 to P06
6.	P06	Maximum Output Speed	Variable	0 to 5*P03
7.	P07	Start/Stop Source	0	0-6
8.	P08	Operating Mode	0	0-12
9.	P10	Acceleration Time	0.5sec	0-600 seconds

10.	P11	Deceleration Time	0.5sec	0-600 seconds
11.	P17	Analog Input Format	4-20mA	0-10V, 0-20mA, 4-20mA, 20-4mA

Table 3.d Parameter Values for the Motor Drive.

### **3.2 CONTROL SYSTEM FOR UNCOOLED CAMERA**

After supplying the power to the camera and connecting the camera to the computer using FireWire cable, the images in front of the camera can be seen by using the thermocam researcher's software. As discussed before the alarm system in un-cooled camera can be used to trigger the output signal, so this alarm system is connected to the live image produced by software. Boxes are created on the image produced by the camera and images are tagged with the alarms. 4 alarms can be at maximum, as there are 3 digital outputs and 1 I/O configurable digital port. The boxes made on the image produced by the camera are used to check the minimum temperature, maximum temperature and average temperature.

For changing the settings of the alarm system and configuring the output, the camera is controlled by the web interface. Following are the steps to create a web server interface:

1. Computer and camera are connected using FireWire protocol.
2. Command window is opened and by typing 'ipconfig' all the networks present are shown on screen.
3. Copy the default gateway number for the infrared camera.

4. Default gateway number for the camera is entered Internet Explorer (5.5 or later), or Mozilla (1.1 or later) and web page is created for the camera control.

Using the web server interface the required setting can be done. Following is a list of major settings that are helpful in the experiment:

1. Boxes

- a. Go to image viewer, and click on Boxes.
- b. Then go to the image to create a Box on the image.
- c. For adjusting size and distance from object, go to measurement and spots.

2. ALARM

- a. The boxes created are tagged with the alarms by clicking box and mentioning its number in the alarm page.
- b. The condition of alarm can be adjusted by entering a numeric value in the text box.
- c. Alarm can be set to trigger either when the temperature of selected box goes above the threshold value or when it goes below the threshold value.

3. CAMERA OUTPUT

- a. The signal sources are assigned to the camera outputs by selecting sources from the list.

4. All the setting and the conditions of the box are checked on the image viewer page.

### 3.2.1 CAMERA OUTPUT PROCESSING

To feed the output from the camera to the control system of the ultrasonic testing apparatus, the camera output is connected to the motor controllers for the XYZ mechanism.

Sr.No.	Motor Controller Specifications	
1.	Type	Programmable Control and Drive
2.	Manufacturer	Velmex
3.	Model	VMX Stepping Motor Controller
4.	Number of Axes	1,2,3or 4
5.	Simultaneous Motors	Yes
6.	Steps/Revolution	400
7.	Program Storage	5 (Ram/Flash)
8.	Interface	RS232
9.	Auxiliary in/out	4in/2out
10.	Speed Range (steps/sec)	1-6000
11.	Manual Jog Input From Front Panel	Yes

Table 3.e Motor Controller Specifications.

For simultaneous motion of two motors, two controllers are linked together by VMX bus, figure3.2.1.1.



Figure 3.3 VMX Stepper Motor Controller.

For the reference of signal from the camera the input/output connections of the motor controller were checked.

Pin #	Name	Function
1.	0V	Logic Reference Ground for Inputs and Outputs
2.	5VDC	Voltage for Joystick Power and Other Logics
3.	Ain	Analog Input for Speed Settings
4.	Run	Run Input to Start Program (active low)
5.	In1	Input 1(active low)
6.	In2	Input 2(active low)
7.	In3	Input 3(active low)
8.	In4	Input 4(active low)

Table 3.f Auxiliary Input/output Connections of Motor Controller.

The camera's output is TTL (transistor transistor logic) signal, which is 0.8-5VDC. On the other hand the all inputs and outputs on the motor controller are TTL level

but inputs have 2200ohm resistor to a +5VDC source and are activated by connecting to 0V. So, when the camera sends the 5VDC signal to the controller, it does not trigger the input as the input is already high. Due to this, a solid state relay is used, which triggers the input signal to the controller whenever the camera sends a signal.

### 3.2.2 MOTOR CONTROLLER PROGRAM

The motor controller has been programmed such that whenever the camera triggers the input of the motor controller the program will start and runs the XYZ motors.

#### PROGRAM

F, C, U0, I1M400, I2M400, U30, I-1M4000, I-2M4000, RSM

#### DESCRIPTION:

1. F- Enable Online Mode.
2. C- Clear All Commands From Current Selected Program.
3. U0- Wait for Low on User Input 1.
4. ImMx- Set Steps To Incremental Motor, m- motor#, x- 1 to 16777125.
5. U30- Wait for Low to High Transition on User Input 1.
6. RSM- Run Save Memory.

## CHAPTER 4

### TESTING AND RESULTS

In this chapter the testing done using the cooled and un-cooled camera has been discussed. Previously the objects were kept stationary while finding the defects. But cameras have to be installed on the conveyor belt in industry. So instead of stationary conditions, the samples were kept on moving conveyor belt and tested.

The testing done using the cooled camera now involves different speeds of conveyor and changing other experimental conditions. The results so obtained using these conditions are collected and compared with the previous results. On the other hand, the un-cooled camera is used to collect the temperature values obtained from samples using different heat sources. Using these values an appropriate source and conditions of heating the samples are predicted.

#### 4.1 COOLED CAMERA

##### 4.1.1 SAMPLE USED

Galvanized steel plate with zinc powder attached to coating surface.



Figure 4.1 Galvanized Steel Plate with Zinc Powered Coating.

#### 4.1.2 EXPERIMENTAL SETUP

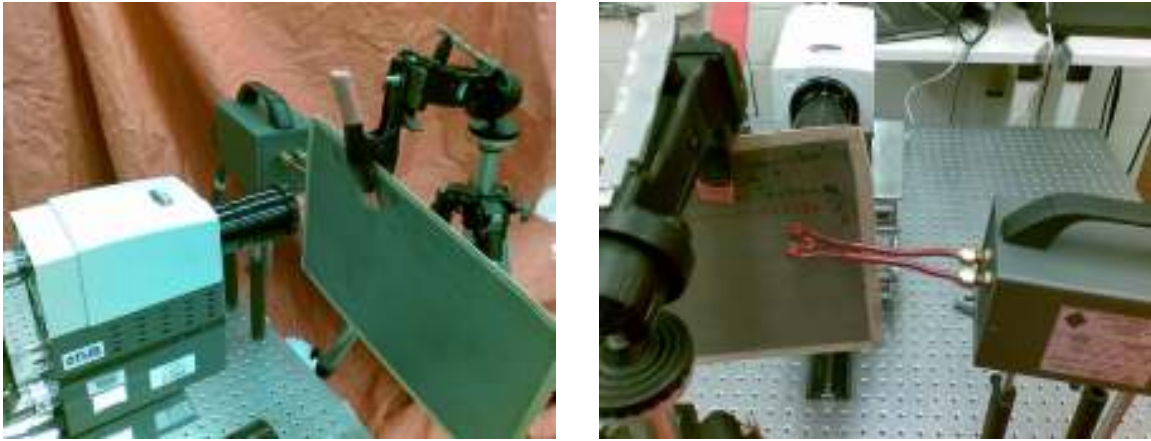


Figure 4.2 Experimental Setup with Stationary Conditions.

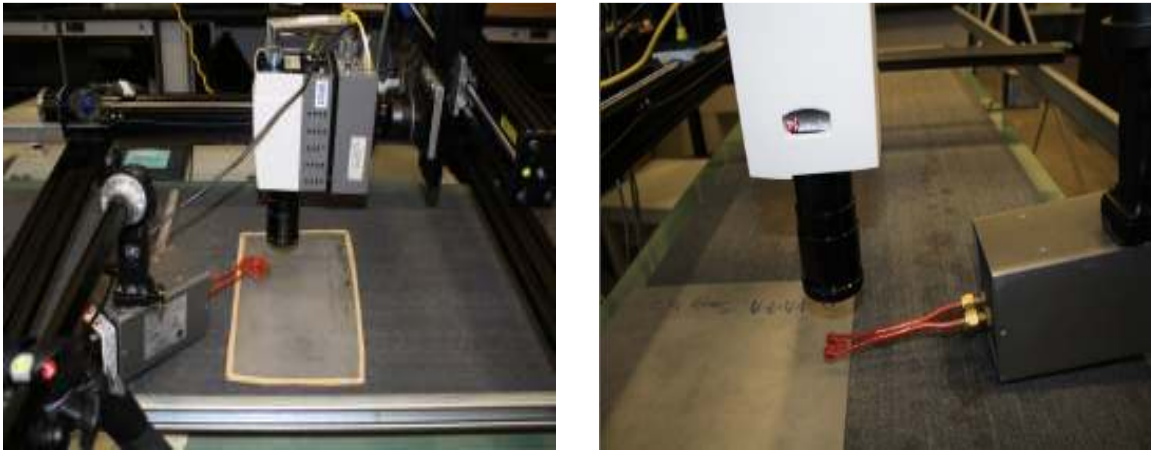


Figure 4.3 Experimental Setup with Sample Moving on Conveyor Belt.

List of equipments used-

1. Cooled camera.
2. Induction heater.
3. Induction coils.
4. Conveyor belt.
5. XYZ mechanism



Table 4.a shows the induction heater specifications

Sr. No.	Induction Heater Specifications		
1.	Manufacturer	Induction Heater	Ameritherm Inc.
		Coils	Ameritherm Inc.
2.	Model		Hot Shot
3.	Current		0-300 amps

Table 4.a Induction Heater Specifications.

Induction Coils Used

1. Pancake coil.
2. Circular coil.

#### 4.1.3 EXPERIMENTAL CONDITIONS

The experiments done using the cooled camera involved different experimental conditions to get good results. The samples were tested at different speeds of the conveyor belt and different amperages of the induction heater. The distance between the coil and the sample has also been changed. Table 4.b shows the different experimental conditions.

Coil To Sample Distance (cm)	Conveyor Belt Speed (rpm)				
	400	800	1200	1600	2000
	Amperage (amps)				
1	50,75,100	50,75,100	50,75,100	50,75,100	50,75,100
1.5	50,75,100	50,75,100	50,75,100	50,75,100	50,75,100
2	50,75,100	50,75,100	50,75,100	50,75,100	50,75,100
2.5	50,75,100	50,75,100	50,75,100	50,75,100	50,75,100

Table 4.b Experimental Conditions for Cooled Camera.

#### 4.1.4 CAMERA SETTINGS

- Camera – Flir Phoenix DTS(Cooled Camera)
- Lens Used – Microscopic Lens.
- Frame Size – 640x100.
- Frame Rate – 407 (frames/s).
- Integration time – 0.5 ms.
- Ambient Temperature – 20°C.

#### 4.1.5 RESULTS

Images shown below are taken from the videos captured by the camera during the experiment. The frames in which the camera shows the sample are shown.

Randomly selected images:

For 1cm gap between sample and coil-

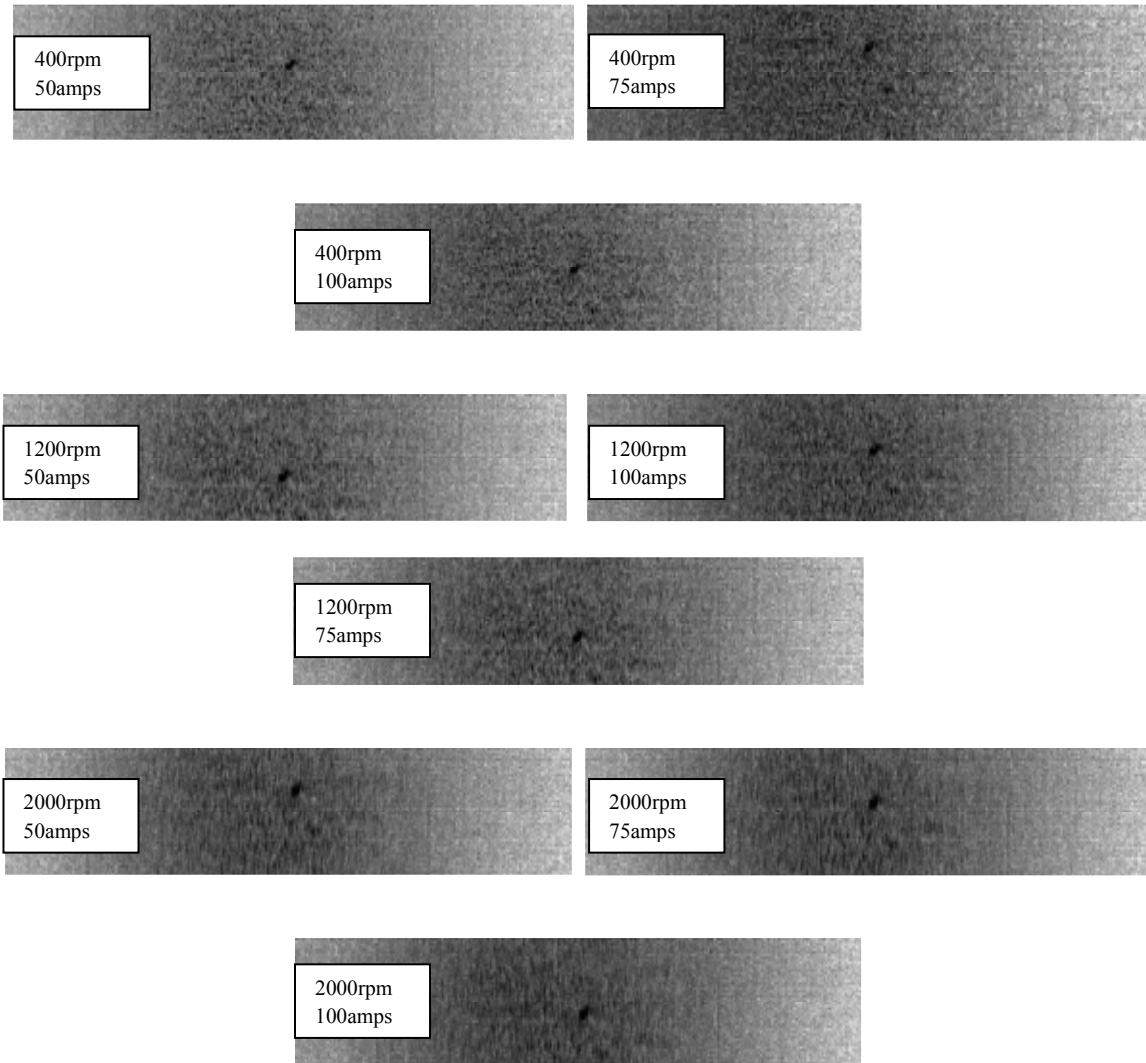


Figure 4.4 Defect Images For 1cm Gap.

For 2 cm gap between sample and coil-

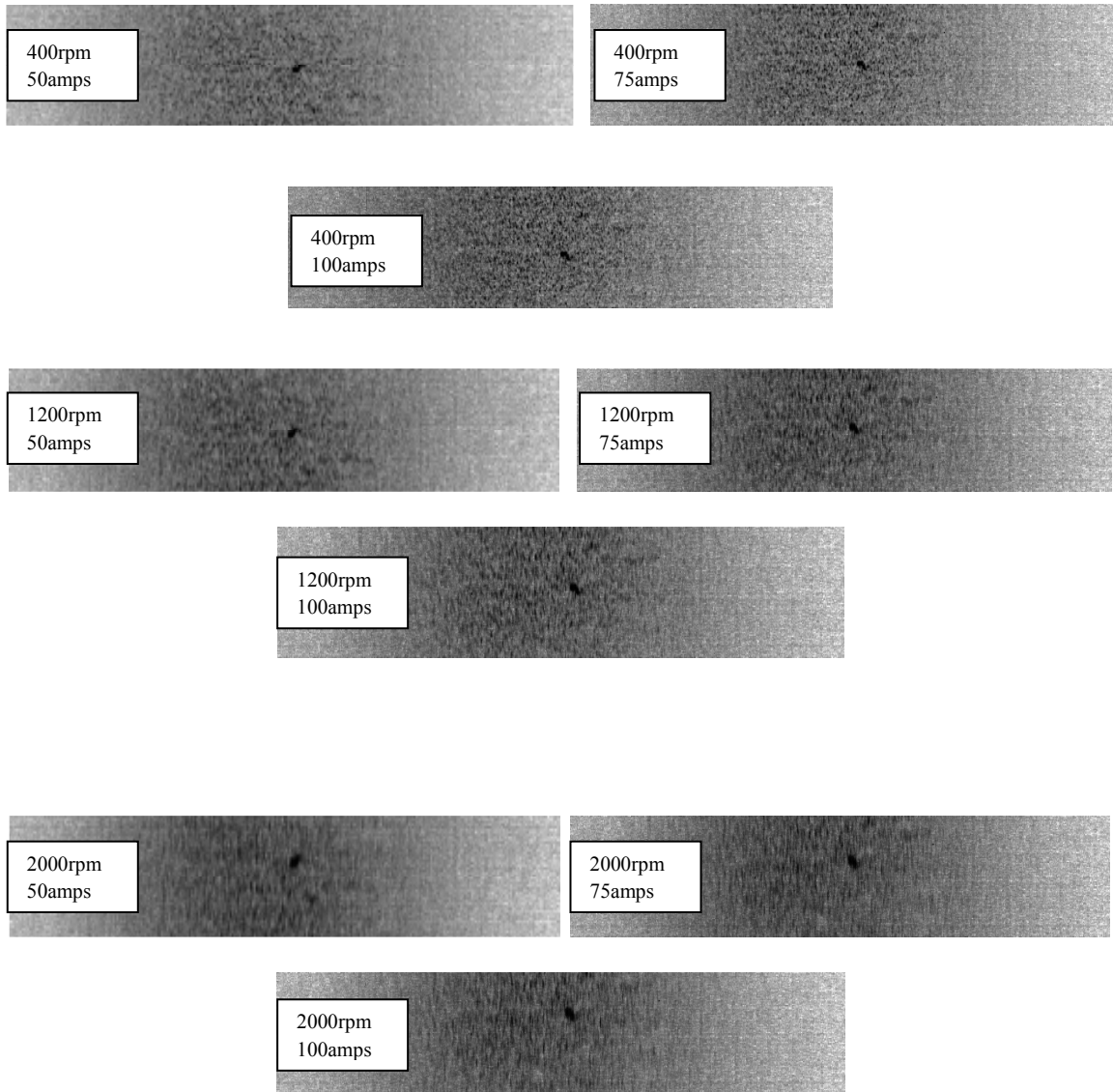


Figure 4.5 Defect Images For 2cm Gap.

#### 4.1.5 CONCLUSIONS

1. Visibility of the defect is very good for current values between 50amps to 100 amps and:
  - a. 400 rpm of motor with distance between coil and sample up to 2.5cm.

- b. 800 rpm of motor with distance between coil and sample up to 2 cm.
  - c. 1200 rpm of motor with distance between coil and sample up to 2 cm.
2. Upto 1200 rpm of motor the defect can be seen in 3-4 frames but for 1600 rpm defect appears in 2-3 frames and for 2000 rpm 0-2 frames. So, for 2000 rpm there is a chance of camera not capturing the defect.
  3. For speeds more than 1200 rpm, 100 amps current produces good images.

#### 4.1.6 TEMPERATURE PLOTS FOR THE IMAGES CAPTURED

As discussed in section 2.2 the Voxel plots were created by comparing the defect (region of interest) with rest of the area, then the temperature versus time graphs were created and compared. Graphs shown below are the graphs for 75amps at different speeds for pancake coil.

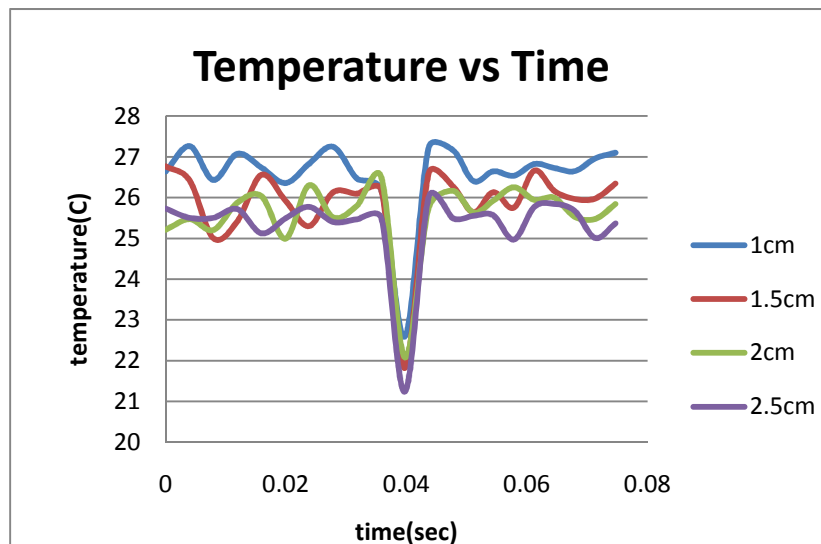


Figure 4.6 Temperature- Time Graph for 400 rpm.

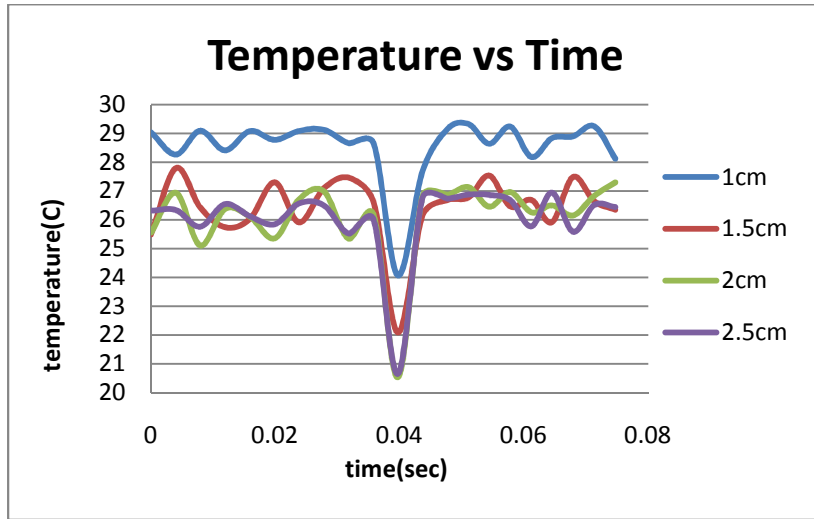


Figure 4.7 Temperature- Time Graph for 800 rpm.

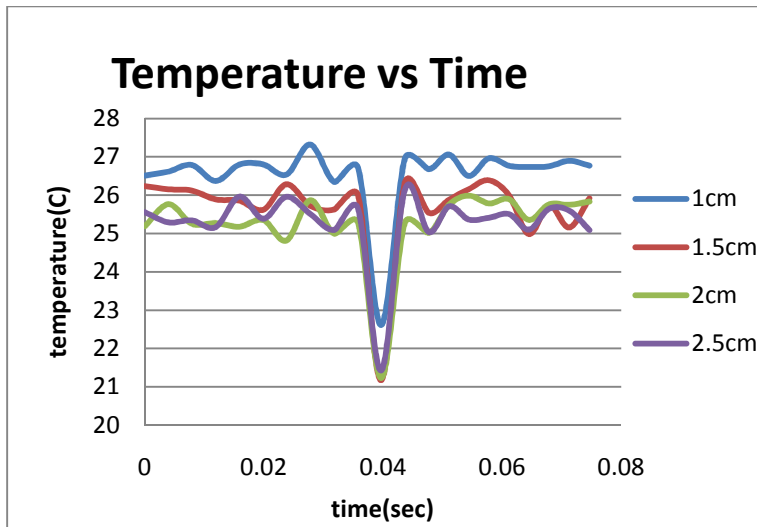


Figure 4.8 Temperature- Time Graph for 1200 rpm.

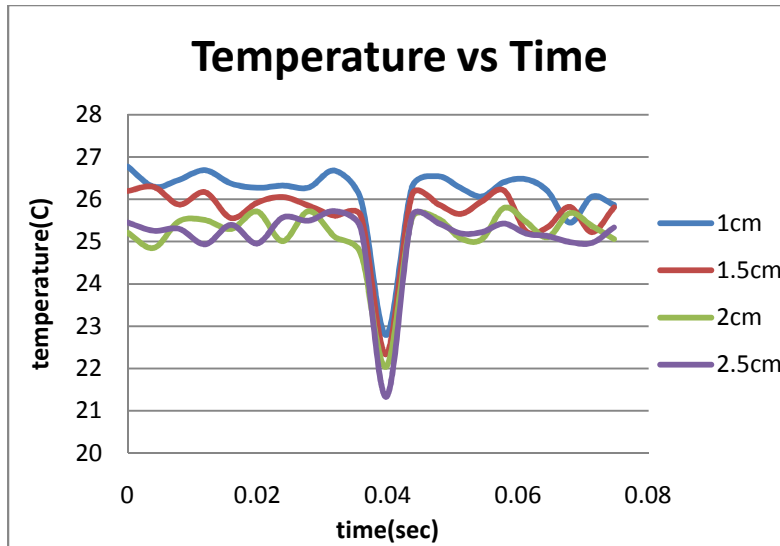


Figure 4.9 Temperature- Time Graph for 1600 rpm.

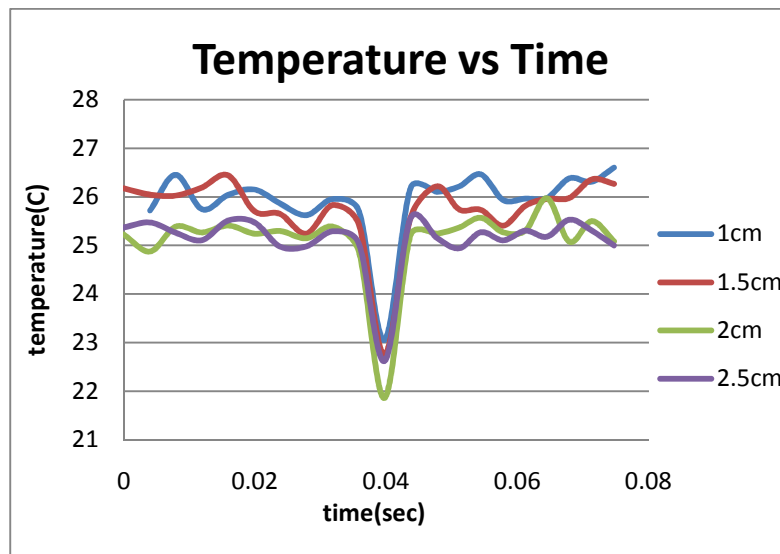


Figure 4.10 Temperature- Time Graph for 2000 rpm.

#### 4.1.7 CONCLUSIONS

1. For 400 rpm temperature drop is  $5^{\circ}\text{C}$  -  $6^{\circ}\text{C}$  for all current values and gaps.
2. For 800 rpm temperature drop is  $4.1^{\circ}\text{C}$  -  $4.7^{\circ}\text{C}$  for 1cm gap,  $4.2^{\circ}\text{C}$  -  $5.2^{\circ}\text{C}$  for 1.5cm gap and  $3.6^{\circ}\text{C}$  -  $5.2^{\circ}\text{C}$  for 2cm gap.

3. For 1200 rpm temperature drop is  $4.1^{\circ}\text{C} - 4.6^{\circ}\text{C}$  for 1cm gap,  $4.2^{\circ}\text{C} - 4.7^{\circ}\text{C}$  for 1.5cm gap,  $4.1^{\circ}\text{C} - 4.5^{\circ}\text{C}$  for 2cm gap and  $3.5^{\circ}\text{C} - 4^{\circ}\text{C}$  for 2.5cm gap.
4. For 1600 rpm temperature drop is  $3.4^{\circ}\text{C} - 3.9^{\circ}\text{C}$  for 1cm gap,  $3.4^{\circ}\text{C} - 3.8^{\circ}\text{C}$  for 1.5cm gap,  $3.2^{\circ}\text{C} - 3.8^{\circ}\text{C}$  for 2cm gap and  $3.2^{\circ}\text{C} - 3.8^{\circ}\text{C}$  for 2.5cm gap.
5. For 2000 rpm temperature drop is  $3.1^{\circ}\text{C} - 3.3^{\circ}\text{C}$  for 1cm gap,  $3.0^{\circ}\text{C} - 3.3^{\circ}\text{C}$  for 1.5cm gap,  $2.8^{\circ}\text{C} - 3.4^{\circ}\text{C}$  for 2cm gap and  $2.6^{\circ}\text{C} - 2.9^{\circ}\text{C}$  for 2.5cm gap.

For spring coil, no relation between the temperature values could be established due to non-uniform heating and small size of the coil.

## **4.2 UN-COOLED CAMERA**

### 4.2.1 EXPERIMENTAL CONDITIONS

To provide a signal to the controller the un-cooled camera is used. To see the defect in the samples the temperature of the samples (excited using heating sources) are observed. Good samples have a fixed range of minimum temperature but the samples having defect have minimum temperature value less than the good samples. This temperature difference is used to find the defective samples. The problem that occurs in this process is that this camera cannot be used when the conveyor is in motion. This is because when the samples are moving, the camera sometimes sees the conveyor instead of sample. In that case the temperature of the conveyor belt is less than the temperature value of the good sample so the camera gives output even if it sees conveyor belt.

To avoid this, the samples are kept stationary and the images of the camera are taken only when a new sample is placed on the conveyor.



#### 4.2.2 TEST SPECIMEN

Test specimen used is a panel galvanized steel plates with adhesive spots between them. Total of three adhesive spots are there between plates and these spots represents the hem joints in industries. The specimen is painted black to reduce the effect of reflection as the surface of specimen is highly reflective. Figure 4.11 shows the specimen used.



Figure 4.11 Galvanized Steel Plates With Adhesive Spots.

#### 4.2.3 HEATING SOURCE

As discussed in before, the heating source used for testing in the lab are induction heating, flash heating and halogen heating. With this particular sample type induction heating and flash heating are used and the temperature pattern that are obtained, are good enough to distinguish between the good and the bad sample.

##### INDUCTION HEATING-

The power source used for heating the samples is same as used with the cooled camera i.e. same induction heater, but the coil used is different in shape. The pancake and circular coils cannot be used in this case because in previous experiments the coils were used to heat the sample before the camera can see it, so the coils were placed before the

camera. In this case the coils are placed at the top of sample so that sample is heated evenly. For this purpose, a coil is designed that does not block the view of sample.



Figure 4.12 Experimental Setup for Thermal Imaging with Induction Coil as Heat Source.

#### EXPERIMENTAL SETTINGS

Sr. No.	Settings For Induction Heating	
1.	Distance Between Sample and Induction Coil	5 cm
2.	Current	300 Amps
3.	Power	226 Watts
4.	Frequency	702 Hz

Table 4.c Experimental Settings for Induction Heating.

## RESULTS

Different temperature values are obtained if the time of heating the sample is changed. It has been observed that for smaller duration of time, the temperature difference between the good sample and bad sample is very less. Figure 4.13 (a) and (b) shows the sample with adhesive spots before and after heating the sample.

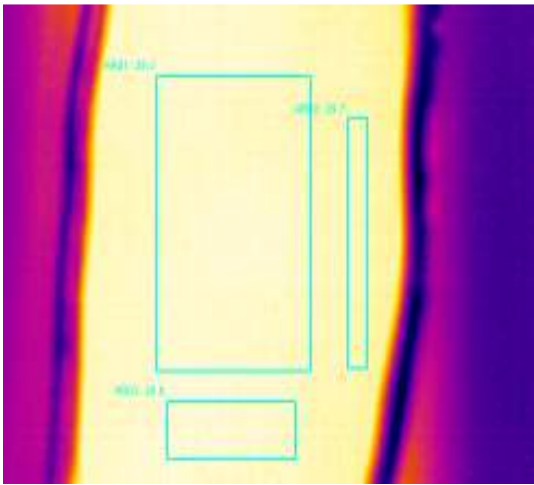


Figure 4.13 (a) Sample before Induction Heating.

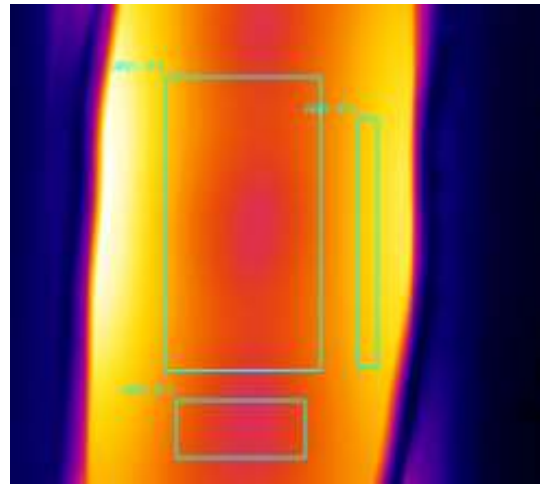


Figure 4.13 (b) Sample after Induction Heating.

As shown in figures above, three areas were created to see the temperature difference between the areas with adhesive spots and areas without spots. The minimum temperature values for all three areas were observed.

- Area 1 is the area at the center of the plate with adhesive spots.
- Area 2 is the area near the outer edge of the plate.
- Area 3 is the area at the center of the plate without the adhesive spots.

Test #	Heating Condition	Temp. Area	Temp. Area	Temp. Area
		1 (°C)	2 (°C)	3 (°C)
Test 1	Before Heating	26.1	26.5	26.5
	After Heating	29.9	32.3	35.5
Test 2	Before Heating	26	26.5	26.5
	After Heating	29.9	32.9	35.3
Test 3	Before Heating	25.8	26.3	26.3
	After Heating	28.4	33	36.5
Test 4	Before Heating	26.2	26.6	26.6
	After Heating	30	33.2	36.6

Table 4.d Temperature Values before and after Heating (Time for Heating=5sec).

Test #	Heating Condition	Temp. Area	Temp. Area	Temp. Area
		1 (°C)	2 (°C)	3 (°C)
Test 1	Before Heating	29.3	29.7	29.7
	After Heating	33.2	49.5	44.3
Test 2	Before Heating	29.1	29.4	29.5
	After Heating	33.3	49.2	44.2
Test 3	Before Heating	29.2	29.6	29.6
	After Heating	33.4	49.4	44.3

Test 4	Before Heating	29	29.3	29.2
	After Heating	33.2	49.1	44.1

Table 4.e Temperature Values before and after Heating (Time for Heating=10sec).

Conclusion-

- It was observed that the area at the center with adhesive spots (area 1) is getting less heated than the areas without the spots. As the induction coil is heating the sample at the edges the area 2 is getting more heated than the areas at the center of the plate (area 3) without the spots.
- The distance between the coil and the sample should be 5 cm, because for distances more than that the heating of the sample is not sufficient to differentiate the temperature of defect with other areas and lesser distance can destroy the properties of the joint.
- The time duration of heating the sample with current and power values shown above should be 10 seconds because of the same reason that for less time the temperature is not sufficient and for more time sample gets over heated.
- The amperage of the heating unit should be 300amps because less value will not heat sample properly and increasing this value with decrease in time of heating can again destroy the joint.

## FLASH HEATING

In flash heating, a flash of light is generated to excite the sample. Two flash lamps are joined to make a circle and two more are kept at the outer side, which gives even heating throughout the sample. This flash lamp is same (figure 1.4) as used for previous experiments with cooled camera, as the camera can see through the heating source. Figure 4.14 shows the experimental setup for thermal imaging with flash light as heating source.



Figure 4.14 Experimental Setup for Thermal Imaging with Flash Light as Heat Source.

Sr. No.	Flash Light Specifications		
1.	Manufacturer	Power Pack	Bowens
		Flash Lamps	Caulmet
2.	Model	Quadx 3000	

3.	Maximum Power Output	2x3000 watt/sec
4.	Minimum Power Output	31 watt/sec

Table 4.f Flash Light Specifications.

## RESULTS

In this experiment the flash light is heating the sample equally from all sides. So instead of creating three spots only two spots are created on the image generated by the camera.

Figure 4.15 (a) and (b) shows the sample before and after heating with flash light.

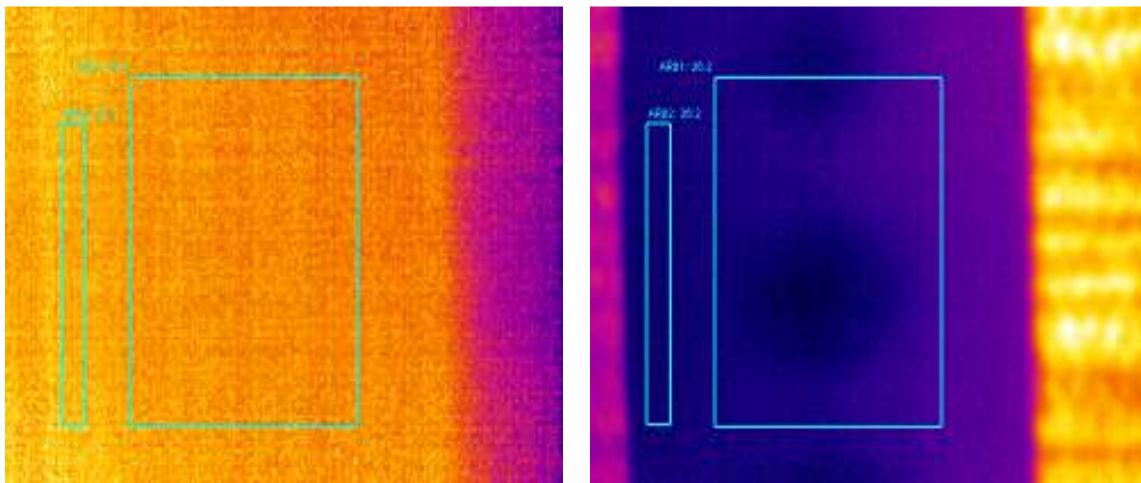


Figure 4.15 (a) Sample before Heating.

Figure 4.15 (b) Sample after Heating.

- Area 1 is the area with adhesive spots.
- Area 2 is the area without adhesive spots.

In this case again the minimum values of the spots are observed. Table 4.g and table 4.h shows the minimum temperature values of the areas generated on the sample image before and after heating the sample.

Distance between Sample and Flash Lamp-20cm.

Test #	Heating Condition	Temp. of Area1(° C )	Temp. of Area2(° C )
Test 1	Before Heating	25.4	25.5
	After Heating	26.2	26.3
Test 2	Before Heating	25.4	25.4
	After Heating	26.2	26.2
Test 3	Before Heating	25.2	25.3
	After Heating	26.1	26.2
Test 4	Before Heating	25.4	25.4
	After Heating	26.2	26.2

Table 4.g Minimum Temperature Values for Different Areas (Distance- 20cm).

Distance between Sample and Flash Lamp-15cm.

Test #	Heating Condition	Temp. of Area 1(° C )	Temp. of Area 2 (° C )
Test 1	Before Heating	23.7	23.7
	After Heating	24.7	24.6



Test 2	Before Heating	23.6	23.6
	After Heating	24.7	24.7
Test 3	Before Heating	23.6	23.6
	After Heating	24.7	24.6
Test 4	Before Heating	23.8	23.8
	After Heating	24.7	24.8

Table 4.h Minimum Temperature Values for Different Areas (Distance- 15cm)..

## CONCLUSIONS

The temperature values observed from different areas of the images does not show a difference even after heating the flash light is not considered as a good source for these experiments.

## FINAL CONCLUSIONS FROM THERMAL IMAGING

- Induction heating is a good source to excite the samples that are used and flash light cannot be used with these samples.
- Temperature difference between different areas should be compared while using the U-shape coil.
- 5cm distance between the coil and sample and 10 sec of heating is required for reliable testing with the settings of heating unit mentioned.

- The average temperatures observed for good area of sample (Area#3) and area with defect (Area#1) are approximately 44° C and 33° C. So, with all the mentioned settings the temperature for the trigger of output of thermal camera can be set in between these values.

### **4.3 ULTRASONIC TESING**

The defective pieces that are obtained from the thermal imaging experiments are then sent to the ultrasonic testing apparatus to confirm the presence of defect and to find its location, size and other features. The apparatus used for conducting the ultrasonic tests are:

1. Hardware Interface- Scan Master.
2. Transducer- Delay Line Transducer.



Figure 4.16 (a) ScanMaster.



Figure 4.16 (b) Contact Transducer.

Sr. No.	Transducer Specifications	
1.	Manufacturer	Panametrics
2.	Type	Contact Transducer
3.	Model	V2435
4.	Frequency	20 Mhz

Table 4.i Transducer Specifications.

Specifications of Hardware Interface:

Sr. No.	Hardware Interface Specifications	
1.	Manufacturer	ScanMaster
2.	Model	SWI-100 X
3.	Software	Spotweld Inspector

Table 4.j Hardware Interface Specifications.

SAMPLE USED

Galvanized steel sample with adhesive spots.

## RESULTS

The results obtained from the ultrasonic testing confirm the presence of defects in the sample. Figure 4.17 and figure 4.18 shows the area without the defect and area with the defect.

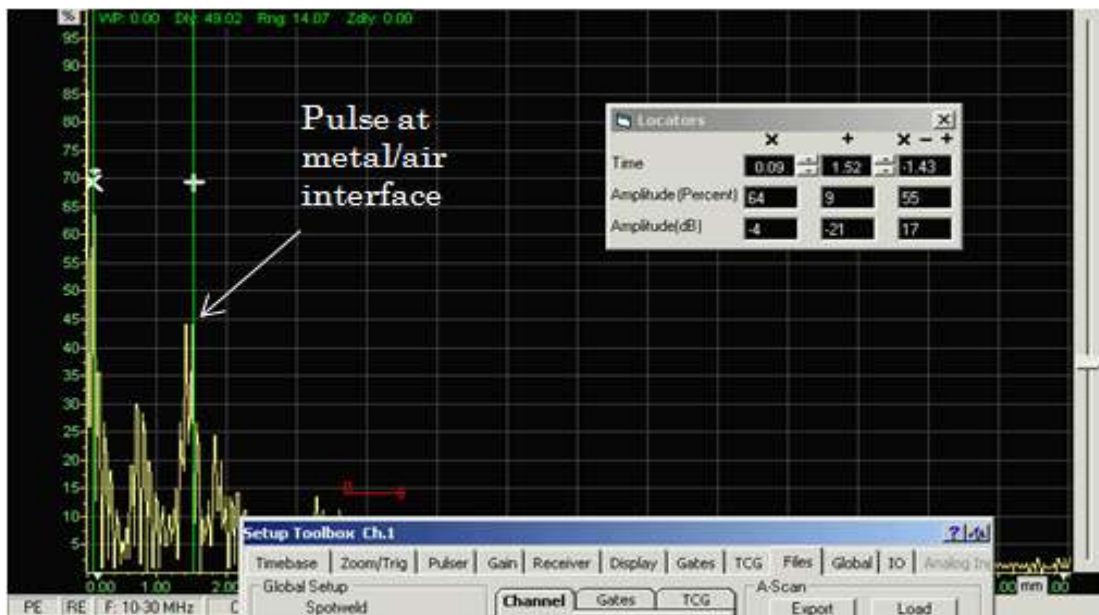


Figure 4.17 A Scan Over Non-Defective Area of the Sample.

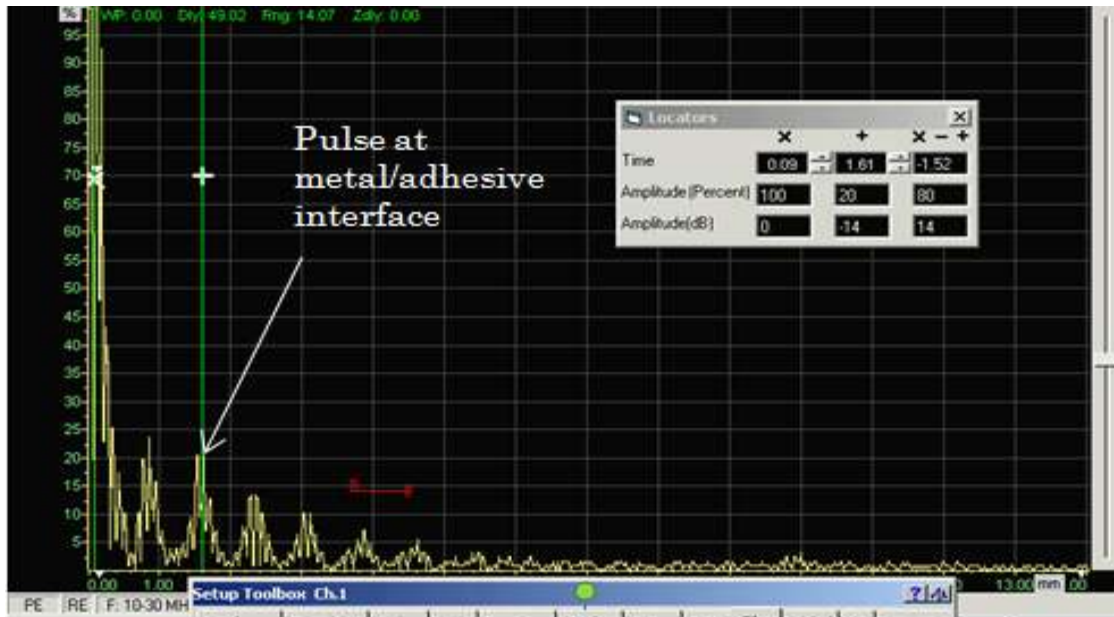


Figure 4.18 A Scan Over Defective Area of the Sample.

The amplitude of the wave forms in the A scan of the sample over defective area decays slower than that of the A scan over the non-defective area. The percentage reflectivity at the metal/air interface is higher as the acoustic impedance of air is very low. This explains the rapid decay in the amplitude of the wave over metal/adhesive interface at the defective area. In case of metal/air interface the difference in impedance is greater than in case of metal/adhesive interface. In figure 4.17, the pulse generated at the metal/ air interface is very high in magnitude due to big difference of impedance but the same pulse in the defective area in figure 4.18 is very less in magnitude due to the less reflections from the metal/adhesive interface. This explains the presence of a defect in the second scan image.

## CONCLUSION

Ultrasonic testing confirmed the presence of defect in the samples that are rejected by the thermal camera due to the presence of adhesive spots. These samples can be further tested by ultrasonic techniques to observe the location, size and nature of defect.

## CHAPTER 5

### CONCLUSION AND FUTURE WORK

The automation of the non-destructive testing methods has been explained. Advantages of both, thermography and ultrasonic testing techniques are used to make the testing fast, reliable and more accurate. Thermal camera is used to detect the images for go/ no go purpose and ultrasonic testing is utilized for confirming the defects and the nature of the defect. Induction heating was found to be the appropriate heating method to find the defects using thermal cameras. The control system worked according to the signals sent by various sensors, camera and PLC. Benchmarking of the proposed technique is done with the test results and settings for thermal camera and ultrasonic machine.

Future work includes finding the methods to identify defects in samples with non-uniform shape using the thermal camera. Using un-cooled camera and induction heat source the samples with non-uniform shapes were difficult to identify defects in them for go/no go purpose. Future work also includes, the identification of thermal imaging methods using which the samples with different types of defects can be identified without changing the settings of the camera.

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