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DesignOf An Automated Thermostat Testing Station

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Abstract: In today's competitive world designs are developed to simplify and improve quality wherever and whenever necessary. Certain tasks completed by human labour are necessary but are monotonous and dangerous. Designs aim to eliminate such risks by performing these specific tasks. At present complete non-intervention of humans is not at a great scale but will soon turn into a reality. The rise in technology and modernization has led people from unskilled sector to shift to the skilled sector. A novel automation system that tests thermostats are designed that would solve these problems and that aims to provide higher efficiency. The designed automated system measures the amount of metal (copper) that extends in the thermostat during the heating at a cycle time of a maximum of 8 seconds. The water bath must be maintained between 95°-99°C. The time of the thermostat in the water bath must be between 150-800 seconds and the range of metal that extends in the thermostat must be between 7-12 mm. The condition put forth is the optimum condition to measure the validity of the thermostat. The result of this design must classify the thermostat as a valid or defective item. The testing system is designed based on these considerations. The industry at present is seeking a design that is efficient, cost effective, high performing, and mainly which fulfils the conditions put forth at a shorter time span than the existing solutions.

Index Terms; Automation system design, Thermostat testing station, Substation automation, Sensor systems.

1. INTRODUCTION

Cooling System

The automotive thermostat is a small device that is used in any liquid-cooled car engine that sits between the engine and the radiator to cease the flow of coolant to the radiator until the engine has warmed up. Today, the thermostat plays a paramount role as it is used to increase combustion efficiency, decrease fuel consumption and as a result a reduced frictional loss [10]. For small cars the thermostat is typically about 2 inches in diameter. When the temperature leaps above the allowable level (generally 180 degrees Fahrenheit), a valve opens which releases the coolant due to the location of a small cylinder on the engine side of the thermostat. The cylinder is filled with wax that starts to melt at a certain temperature, expanding the cavity and hence opening the valve [1]. When the engine is cold, the thermostat is closed and prevents coolant from flowing into the engine, and allows the engine to warm up.

The thermal energy generated must be released and that is the main purpose of the engine cooling system. It comprises a radiator, radiator pressure cap, coolant recovery tank, hoses, water pump, fan, thermostat, and fan belt. The engine running must be kept at ambient temperature. If the heat is very high the cylinder walls and pistons will break. Also if the temperature is too low it will contribute to excessive fuel consumption and thus causing pollution emission. To maintain the ambient temperature automotive engines use a thermostat for coolant circulation. It is located between the radiator and the engine. Rating which is the temperature at which the thermostat is designed to open is about 80-90 ° C, with & 50 ° C tolerance [13]. The thermostat regulates the flow of coolant to the engine. It has a wax in it that melts when the thermostat heats and the bypass closes and allows the coolant to the radiator [2].

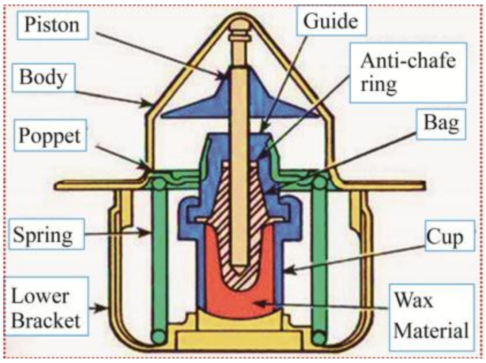

Figure 1. Schematic view of the thermostat (wax type)

Source: https://automationforum.co/what-are-thermostats-different-types-of-thermostats/

Market Analysis

The growing demand for the passenger cars as well as commercial vehicles have led to an increase in the need for thermostats in countries such as Asia, North America and Europe. The engine safety is ensured by the proper flow of coolant. The need for automotive thermostats will increase as the need for cars increases. Companies manufacturing automotive thermostats can focus on specific opportunities in Europe, and Asia Pacific, attributed to the quick growth of the automobile industry and high demand for better-performing vehicles which is predicted to increase over the period. Companies have a huge opportunity in the global automotive thermostat market by collaborating with other automobile vendors. The only restraint to the market is that few mechanics feel that the thermostat is not a necessary component in the engine. Some engineers argue that use of thermostat puts the engine at greater risk as the thermostat can fail or its opening may get delayed due to some reason.

Asian countries like China and India are developing their thermostat market, prolific growth is expected in the market due to increase in job opportunities and noveltechnologies [4]. Overall, the scope for automotive thermostat market is sanguine over the forecast period.

2. PROPOSED SOLUTION

The current automation solutions present in the market are scarce and the efficiency is not up to mark. The designed system is flexible and more number of thermostats can be tested at the same time as per requirement.

The proposed design aims to measure the amount of metal (copper) that extends in the thermostat during the heating at a cycle time of maximum 8 seconds. The water bath must be between 95°-99°C. The time of the thermostat in the water bath must be between 150-800 seconds and the range of metal that extends in the thermostat must be between 7-12 mm. The condition put forth is necessary for the optimum condition in order to measure the validity of the thermostat. Then further the component is classified as valid or defective.

System outline and process

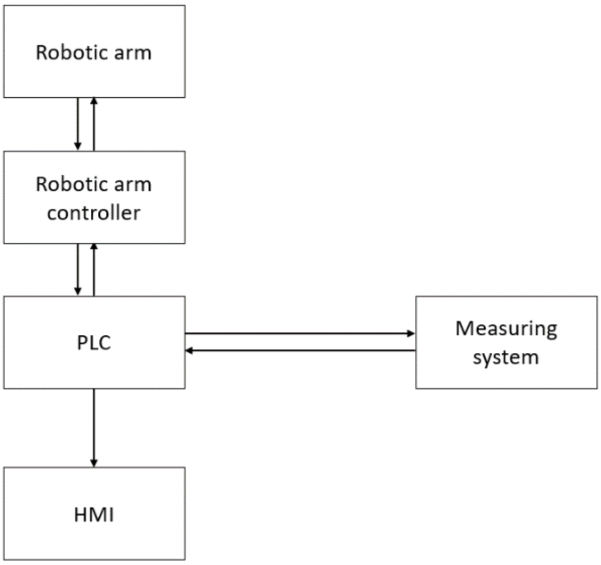

Figure 2. System outline

The basic outline of the models discussed will have the following system outline. The thermostat from the previous stations will approach the testing station. Various measuring devices will be present in the system which will enable the completion of the testing tasks. The measuring system is connected to the PLC and vice versa. This is because only after receiving and confirming data from the first set of measuring devices the PLC can command the next set of measuring devices to perform the next one. The first mode of communication will be from the measuring system to the PLC. Once PLC receives the data from the measuring system simultaneously it will display data on HMI and give further instructions to the robotic arm to complete the process like sorting it as defective or non-defective products. The data for the robotic arm through the controller is updated and stored using PLC for system checking and future verifications.

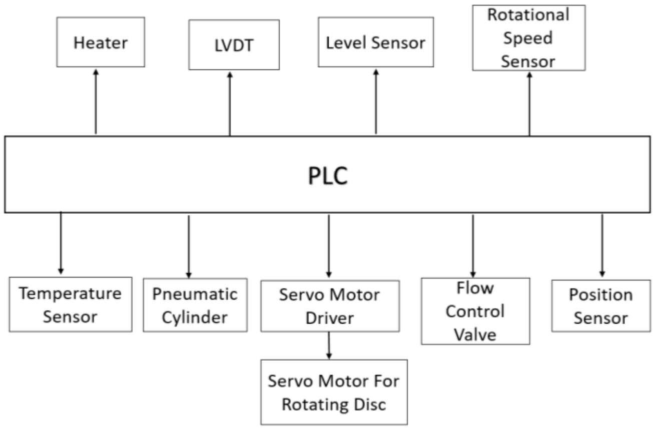

Figure 3 Process flowchart

The designed model portrays the following solution. The first element in the system is the temperature sensor. This is the most vital part of the system as the temperature of the water bath needs to be maintained between 95°-99°C. The PLC checks the temperature data and ensures that the temperature is maintained by controlling the heater [11]. When the temperature goes below 96°C then the intensity of the heat is increased. The heater is then brought down to a normal state after some time. The LVDT is attached to the pneumatic cylinder as the displacement of the thermostat is measured using this system. As the disc rotates there may be a possibility that the position and orientation may change. Hence below the pneumatic system, an inductive sensor is placed so that only when the thermostat is exactly above the sensor the operation of the measurement will begin. Only when this is ensured our measurement will be accurate. The servo motor which runs the disk with the driver is connected to PLC where the required speedis specified at which the disc must rotate. The level sensor which is present in the water will ensure that the water remains at the specific level. The flow control valve will control the amount of water supplied to the bath. If this system is not maintained then the entire system will fail. The data from the level sensor is read and the PLC sends instructions towards the flow control valve. As it is important to maintain the rotation speed proximity sensors are used. Then further when the thermostat reaches the end the condensed data from the system will enable the PLC to classify as valid or invalid.

3. STRUCTURAL LAYOUT

The structure of the designed system mainly contains the following component. The motor driven disc, PLC, HMI, Robotic arm and the associated controller and the heating element in the water bath.

Motor Driven Disc

The disc oriented with this design is a novel concept introduced for the testing. The disc is designed to fulfil the optimum condition set forth for testing. This is the place where the thermostat will spend most of its time and the accuracy of this disc is important. The disc basically contains smaller circular holes where the thermostat will be seated which is in the water bath. To calculate the diameter and radius of the circular disk the number of holes to place the thermostat is set as 36. As 36 thermostats need to be placed the circle is divided into

36 sectors .To find the radius the arc of the sector is needed. Each sector angle = 360/36 = 10 degrees.

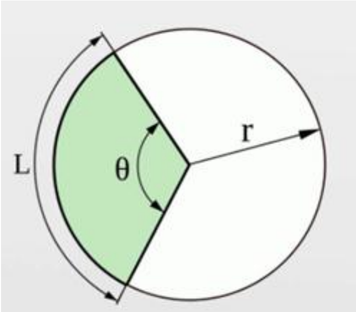

Figure 4. Sector Formula representation

Source:https://precalculusdotblog.wordpress.com/2018/10/10/angles-in-a-unit-circle-arc-length-and-area-of-a-sector/

Converting this formula into degrees, the perimeter of a Sector = 2*Radius + ((θ/360) × 2πr).The 2*Radius is not a requirement. So, Arc Length of the sector = ((θ/360) × 2πr).

To calculate the radius, diameter, perimeter, and area of the circle first assumption is that the distance between each thermostat (centre to centre) is 10cm which is the arc length of the sector. Converting this formula into degrees, the centre to thermostat end is assumed to be 2.5cm and the distance between end-end of thermostat is 3cm. So the Arc length of sector = (2.5+2.5+5) cm= 10cm.

θ=10degrees.

So, r= ((arc length/10)*360)/2π.

r=57.295cm or r=579.25mm is the radius.

d=114.591 cm or 1145.91mm is the diameter.

P= 2*π*r =3639.53mm.

A= π*r*r= 1054100.35 mm^2.

The distance calculated is excess so a portion is removed from end to end of the thermostat. The centre to thermostat end is assumed to be 2.5cm and the distance between the end- end of the thermostat is 3cm.So the Arc length of sector=(2.5+2.5+3)=8cm.

θ=10degrees.

So, r = ((arc length/10)*360)/2π.

r = 45.836cm or r = 458.36mm is the radius.

d = 91.673 cm or 916.73mm is the diameter.

P = 2*π*r =2879.96mm.

A= π*r*r= 66002.942 mm^2.

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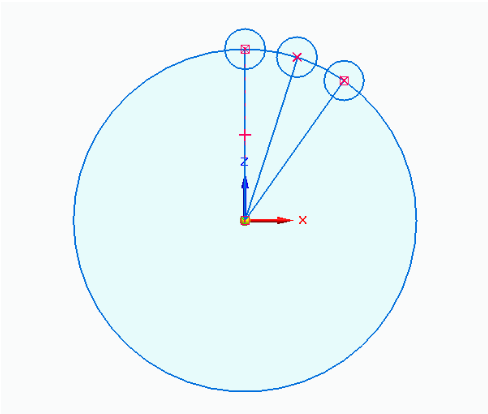

Figure 5. Disc model outline

The calculated values has the centre of the thermostat as the perimeter of the circle. In the above figure an outline is shown where the discs are placed. An additional portion must be added so that the holes can be placed and the thermostat will stay in the disc. Since the thermostat covers a radius of 25 mm and an additional 40mm is added to the radius. The final values of the disc containing 36 thermostats in one line with the centre to centre thermostat distance of 8 cm are shown below.

r = 498.36mm is the radius.

d = 996.72mm is the diameter.

P = $2*\pi*r$ = 3131.288mm is the perimeter of the disc.

A = $\pi*r*r$= 780254.40mm^2 is the area of the disc.

These values are when the thermostat count is considered to be 36 but the problem associated with this is that the cycle time and the total time are not as per requirement if the above calculated is assumed. Now from previous calculations, the radius of the sector and the arc length is obtained.

The radius of sector=460mm.

Diameter of sector=920mm.

Arc length of sector=65mm.

Now with these given data, the theta from the arc length of the sector= $((\theta/360) \times 2\pi r)$.

$\theta = (65*360)/ (2*\pi*460) = 8.09$degrees.

Therefore assuming 8 degrees and calculating,360/8= 45 the amount of thermostats that can be placed in the circular disk of radius 460mm is obtained. Similarly adding the excess of the circular disk because the calculation is from centre-centre.

The radius of the disk = 500mm.

Diameter of the disk=1000mm.

The perimeter of the disk=3141.59mm.

Area of the disk=785398.16 mm².

Components in the disk=45.

Each sector is paused for 4 seconds which is the time allotted for the SCARA robot to pick and place the thermostat at the same time LVDT measurement.

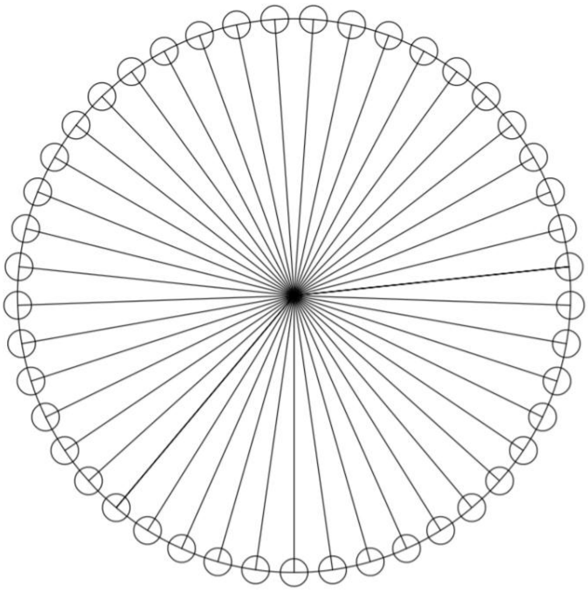

Figure 6. Final disc configuration

Speed measurement techniques

Measurement of rotational speed is important when it involves the speed of motors, conveyors, and various other devices. A sensor is necessary to sense the speed. These devices send speed data in the form of pulses. The quality of this data is mainly on two factors. PPR (pulses per revolution), Higher results in better resolution. The symmetry of pulses provides a consistent rpm reading so provides more accurate data. Various sensors used are encoders, proximity Sensors, photoelectric Sensors.

Methods of determining rotational speed are frequency measurement and period measurement. In sensors, encoders are most suitable for sensing. High resolution and clear symmetrical pulses are obtained. It is inconvenient to mount an encoder on a shaft.

Proximity sensors provide low resolution sensing based on the number of pulses measured per second. Proximity sensors are controlled and tested with the use of a PLC [10]. This sensing typically has options for 60, 120, or 240 PPR, and the pulses are symmetrical and defined which is most suitable as per the requirement of the project. Photoelectric sensors give low resolution. This requires a reflective target. If more than one reflective surface is used the pulse is likely to be poor. The methods involved in determining rotational speed are the frequency measurement method and the period measurement method. Frequency measurement is used for fast-moving devices and period measurement is basically for devices that move at a slow rate. As shown earlier the estimated speed of our disc will be at 0.13

radians per second. Low PPR is considered less than 60 PPR. Proximity or photoelectric sensors are most suitable for this action. The time from the start of one pulse to the start of the next pulse is called the period. The proximity sensor chosen model is Rectangular Type (standard)-CJF18E-05NA. To calculate the angular speed of the disk the linear speed needs to be found.

$V=\omega * r$

Where V = linear velocity, ω = angular velocity, and r=radius

To calculate V the arc length is 65mm is taken as calculated before. The radius is 500mm. so V=d*t. The time taken from position 1 to position 2 of the disk is assumed to be 1 second.

V=1*65.

V=65mm/s.

$\omega = V/r = 65/500 = 0.13$ radians per second is the angular speed of the disk. The time taken for LVDT to measure considering stroke length = 100mm, velocity = 1m/s. So the time taken for the piston to go down or up is 0.1s. So 0.1 + 0.1 = 0.2 seconds and this will be added to sensor response time.

So in each sector, the movement is for 1 second.

Time during rotation = 45*1 = 45s.

Time for pauses = 45*4 = 180s.

Therefore total time = 180+45 = 225 seconds which is the required time for the thermostat to be in the water bath. The cycle time calculated is 4.5 - 5.5 seconds. Thus the final values of the disc are depicted below.
Radius of the disc = 500mm.
Diameter of the disk = 1000mm.
Perimeter of the disk = 3141.59mm.
Area of the disk = 785398.16.mm
Components in the disk = 45.
Angular velocity of the disc = 0.13 rad/sec.

PLC and HMI

The PLC which is responsible for monitoring and giving instructions for the process is the most vital component of the system. All the data from the sensor systems are condensed and the PLC decides the validity of the thermostat. The model of PLC chosen is SIEMENS S7 1200, 1214C DC/DC/RELAY with a supply voltage of 24VDC. The number of digital inputs is 14 and the number of analog inputs is 2. The number of digital outputs is 10, relay. The operating temperature range is from 40-70° C. Dimension of the PLC are (W x H x D) - 110x100x75 mm and it weighs 435 grams. The HMIplays a crucial part as several real time operations are able to be visualised. The process which goes on inside the control system are monitored through HMI [9].The model of HMI chosen is SIEMENS TP700 series touch screen HMI and the display type is TFT. The display size is 7inches and the display resolution is 800 x 480pixels. The total number of ports present is 3 and they are Ethernet,

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Vol 12, Issue 02, 2021

mpi, Profibus DP, and USB. It is available with a backlighting feature and its supply voltage is 24Vdc.The dimensions are 214 x 158 x 63 mm. The main reason for choosing this HMI is that it provides with maximum data security, integrated system diagnostics, a graphical user interface for intuitive machine operation and monitoring and the power consumption is 12W.

Figure 7. PLC and HMI

Source:https://www.automation24.com/siemens-cpu-1214c-6es72141ag400xb0

Source: https://uk.rsonline.com/web/p/hmidisplays/8643970/

Robotic arm and controller

The robotic arm is in charge for picking and placing the thermostats before and after testing. The most suitable arm to maintain cycle time was selected for this process robotic arm. The robotic arm selected is the 4 axis SCARA robot. The Denso robotics have LPH, HM, HS-A1, and HSR series. The series suitable for our need is the LPH series with a max payload of 3kg and a reach of 400 mm. The LPH-040 four-axis SCARA robot is best for this kind of automation and is compact and lightweight, LPH-040 handles lighter-duty applications with ease, such as electronics, assembly, and pick-and-place. This robot has a three- to five-year duty lifecycle.

Max Payload	Reach	Cycle Time	Repeatability
3	400	0.45	±0.020
kg	mm	sec	mm

Figure 8. Details of the robotic arm

Figure 9. SCARA robot and the details of the arm

Source:https://www.densowave.com/imageupd/21002/24496_contents4.gif

The controller which was selected for the LPH-040 SCARA robot is RC8A, this controller is used for controlling the motors of the robot, and this controller can also be connected to a PLC with profinet interface. The controller is also equipped with a lot of safety features to ensure the safety of the labourers, the controller will automatically slow down the robot if it detects a person within its operating workspace. This is achieved by placing two optical sensors, one at the top and one at the bottom of the cell which creates virtual safe zones that trigger an incremental reduction in the speed of the robot to safe levels depending on the distance of the operator. It also comes with a teach pendant which can be used for easy programming of the robot.

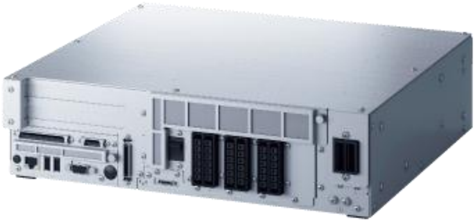

Figure 10. Robot controller

Source:https://www.densoroboticseurope.com/fileadmin/_processed_/c/6/csm_RC8_A_Safety_Motion_ab66d4250d.jpg

Heater

The thermostats need to be placed in a hot water bath, to achieve this a heating element is placed in the tank. There are a lot of heaters available but the most suitable heater will be screw plug immersion heaters [12]. Screw Plug Immersion Heaters consist of tubular elements welded or brazed into a threaded screw plug which can then be inserted into a threaded opening in a tank wall or through a mating full or half coupling. This type of heater meets the requirement of this process as it will be screwed along the wall of the tank, so the rotating disk containing the thermostats can be rotated without any obstruction. The temperature range of this type of heater will vary from 60-550ºF, the heater also can be automatically turned off with the help of an inbuilt temperature sensor.

Figure 11. Screw plug immersion heater

Source: https://www.tempco.com/Tempco/Data-Assets/11-Process-Images/WebH698.jpg

4. FINAL MODEL

The final model was designed combining all the explained concepts and processes above. The process starts with the thermostats approaching from the previous station in the conveyor. Once the thermostat reaches the desired position the robotic arm picks and places it in the disc which is in the water bath. Before this process starts the water bath will be heated to a temperature which is greater than 96°C.Once the desired temperature is reached which will be monitored by the PLC using the temperature sensor the heater will cease to function and similarly when the temperature drops below 96°C the heater will start and this process ensures that the heat in the water bath is maintained. The level sensor in the water bath will ensure that the level of water does not decrease as heating water generates a lot of heat. Water is added once the water level reduces below the specified level with the help of flow control valve. The motor driven disc which uses AC servo control system which achieves rotation at different speeds at an accuracy of 0.05 degrees [14]. The disc will continue to rotate at an angular speed of 0.13 rad/s. The thermostat placed in the disc will continue to heat and when the next empty position in the disc comes in front of the arm, it will place the next thermostat in the disc. This process will continue until all the holes in the disc are filled. After 225 seconds approximately the first thermostat will reach the LVDT station which is confirmed by the position sensor. The LVDT attached to the pneumatic cylinder enables it to measure the displacement of the metal in the thermostat. The measured data will be sent to the PLC and validated.

The robotic arm is not only responsible for picking and placing in the disc but also sorting out the valid and invalid pieces. Three bins, red, green and yellow are placed next to the arm. Valid condition indicates that the displacement of metal piece in the thermostat lies between 7-12mm and anything below or above is deemed as invalid. The PLC uses its received data so far on the thermostat and decides the status. The red bin indicates the failed or invalid pieces and are rejected. The green bin represents that the thermostat is tested and fulfils the necessary conditions to go into the market. The yellow bin indicates re-testing which means the measurement cannot be determined. Once a thermostat is sorted accordingly the robotic arm places another thermostat from the conveyor in the empty hole in the disc. This process ensures that the disc is used efficiently.

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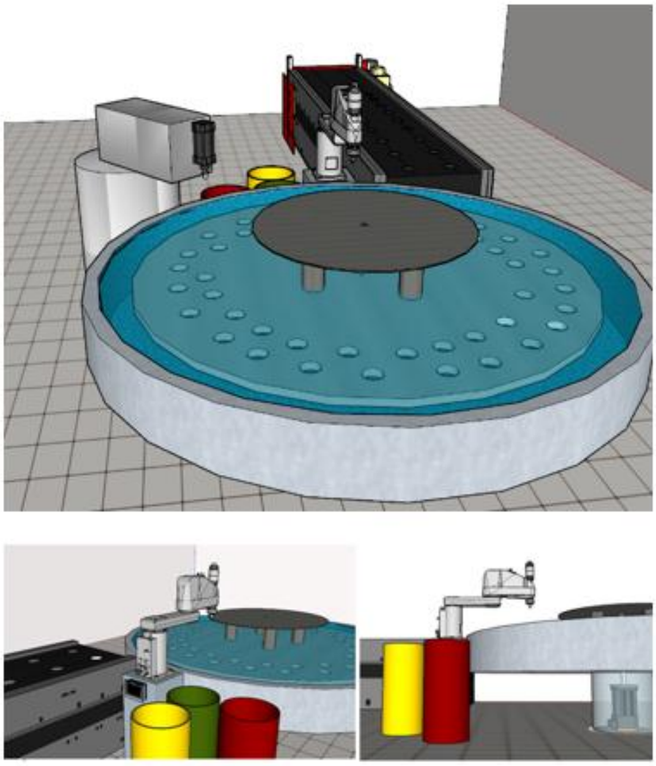

Figure 12. Designed Model

5. WORKPLACE SAFETY

The involvement of robots are very beneficial but there are few issues one must be concerned when designing and implementing the system. The main concern is the robot workplace safety. A lot of cases has been registered where a safety mechanism failed and led to fatal outcomes because only one system was implemented. The National Institute of Occupational Safety and Health (NIOSH) is responsible for conducting proper research in order to prevent work-related injuries. In order to mitigate the risk that can occur proper safety precautions are taken during the automated system design, training of workers and the supervision of workers. The safety measures implemented are as per the recommendations of NIOSH.

Robot workplace safety is becoming the major concern as the safety of a human life is of prime importance. The understanding of workplace safety begins with the understanding of the workspace of the robot. The workspace of robot manipulator is defined as the set of points that can be reached by its end-effector. Dexterous and Reachable are the two main types of workspace. The reachable workspace is that the robot can reach the point with at least one orientation. When the orientation is such that a point can be reached using any orientation and not limited it is known as dexterous workspace. In summary:

Workspace- The volume of space which can be reached by the end effector. Dexterous Workspace-The volume of space where the end effector can be arbitrarily oriented. Reachable Workspace-The volume of space which the robot can reach in at least one orientation. This distinction is important as the dexterous workspace is the subset of the reachable workspace. These terms are important as when the safety protocols are designed it must not be done with consideration of dexterous workspace but with the overall workspace as there is a possibility a technical error may lead to its change of planned path. The image below classifies the reachable and dexterous workspace.

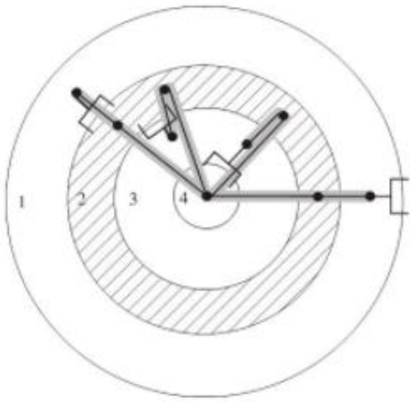

Figure 13.Workspace Representation

Source: https://slideplayer.com/slide/4239214/

Automated System Design:

Over the years the integration of robots and humans in the manufacturing working surroundings are increasing at an exponential rate [5], [6]. Around the globe the companies and the workers benefit from this integration as productivity is enhanced [7].The automated system design contains robots and other mechanisms which is dangerous for the worker. The following are implemented for the protection:

In order to reduce the risks and safety hazards the safety precautions are implemented at the design stage itself. This process enables to add more protection for this design[8]. The automated system is equipped with gates which acts as the physical barrier with electrical interlocking mechanism which ensures that the heater and the robot in the system shuts down hen the gate is opened. Additionally fingerprint access is required with key card from the manager as all monitoring is performed outside the barrier.

For backup purposes motion sensors, light curtains and floor sensors are placed around the system in case of entry of worker or anything else that crosses the barrier.

The operation space of a worker and a robot arm is not same and varies. The human worker may require less space compared to the robotic arm. The space required by the robotic arm can be calculated accurately and the system is designed accordingly. The workspace of the robot is calculated and other objects related to the system are not present in order to prevent possible collision.

Remote diagnostic instrumentations are present such that maximum troubleshooting is performed outside the operating range which involves minimal risk. In case the worker need to troubleshoot within the operating range an emergency system is present outside where a co-worker can shut down the system at an instant in case of any danger. The operating instructions, configuration of buttons are all designed to be under adequate illumination in the control and operational areas so that it is clearly visible. Each and every step and movement of the system is marked and represented in a chart which includes the zones of movement of robots.

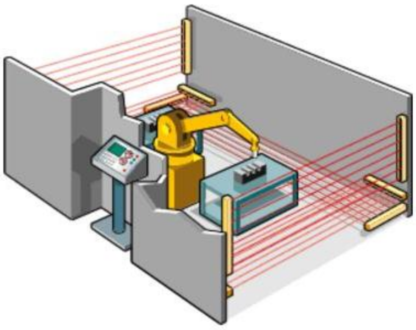

Figure 14. Barriers

Source:https://www.thefabricator.com/thewelder/article/automationrobotics/playing-it-safe-with-robotic-welding

:

Figure 15. Interlocking mechanism

Source https://www.keyence.com/products/safety/safety-interlock-switches/

Training of Workers:

As much as the safety of design the workers need to be trained in order to refrain from coming in contact with such dangers. Training related to programming, operating and maintaining robots along with emergency shutdown process and all the safety systems must be provided. The major emphasis must be on safety.

Workers must be instructed about the heater and the entire working of the thermostat testing station along with the cycle time and all the process involved. The troubleshooting process, robot programming and safety protocols must be provided in detail and refreshed at a constant pace.

Access of robot to the worker must be with high restriction as the system is designed to operate without the worker near the workspace of the robot.

The workers need to ensure that the process occurs at consistent speeds and must be aware of all the surrounding parts and its usage in order to enter the barrier if needed.

Supervision of Workers:

The most important aspect is supervision of the workers. The industry manager is appointed to check from time to time the operation of the worker in order to ensure safety.
The barriers of the system cannot be breached until the key card from the manager is obtained as the control is present outside.
The supervisor is to ensure that as time passes experienced workers tend to become overconfident or inattentive and this may lead to a hazard. These workers must be kept in check.

The hazards that can lead to a fatal outcome is removed by following and implementing these methods. Further as the system is implemented minor hazards can be prevented but adding extra preventive and safety measures [3].

5. CONCLUSION

An automated thermostat testing station has been designed for the quality check of an engine thermostat. This designed system has been designed considering a lot of problems faced by the industry. This design maintains the industrial constraints put forth. The temperature of the water bath is maintained above 95°C.The amount of time the thermostat must be immersed in the water bath was kept at 225 seconds approximately which 150 seconds and below 800 seconds. The specified cycle time is to be below 8 seconds and the designed model is shown to have a cycle time of 4.5 - 5.5 seconds. The conditions put forth ensured that the thermostat were declared valid only if the displacement of metal was between 7-12mm and others as invalid. Thus the fully automated thermostat testing station was designed eliminating the need of human intervention.

6. ACKNOWLEDGEMENT

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