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Robot Handling the Spent Sub-Assembly Storage with Monitoring and Control of Bay in Nuclear Power Plant

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Abstract : This paper presents the robot handling the sub assembly with monitoring and control of sub assembly system in nuclear power plant. In nuclear power plant, cooling and maintaining the temperature of the components is very important. The whole cooling process which takes place in the sub-assembly system is controlled by level sensors, temperature sensor. An ON/OFF solenoid valve is used to maintain demineralized water level in the sub-assembly system. Apart from controlling and monitoring, replacement of burnt fuel bundles in the sub-assembly system is very important. In power plant, crane system is used for the replacement of fuel bundles. In this paper a prototype robot is developed and implemented for the replacement of fuel bundle.

Keyword : Fuel bundle, temperature sensor, solenoid valve, level sensor.

I. INTRODUCTION

The purpose of this paper is to explain about the cooling system in sub-assembly of Prototype Fast Breeder Reactor (PFBR). This prototype fast breeder reactor is used in Bharatiya Nabhikiya Vidyut Nigam Limited. Plutonium is used as a fuel in this plant. Kalpakkam PFBR is using Uranium-238 to breed new fissile material in a sodium-cooled fast reactor design. The surplus Plutonium (or uranium-233 for thorium reactors) from each fast reactor can be used to set up more such reactors and grow the nuclear capacity in tune with India's needs for power. The PFBR is part of the Three-stage nuclear power program [1]. The PFBR will be cooled by liquid sodium creates additional safety requirements to isolate the coolant from the environment, since sodium explodes if it comes into contact with water and burns when in contact with air [2]. Another hazard associated with the use of sodium as a coolant is the absorption of neutrons to generate the radioactive isotope. It is important to maintain the temperature and level of de mineralized water in the sub-assembly system to avoid hazardous condition.

In this paper it is developed a scale-down model of this sub-assembly system. The developed model of this sub-assembly system includes a robotic arm, a water tank, Temperature controller, level sensor, water heater, decoder and synchronization assembly, and a LED display device. The temperature controller is used to monitor and control the temperature. A Resistance Temperature Detector (RTD) is used to measure the temperature. A capacitive level sensor is used to measure the level and it is connected to a display device to display the level. Then the sensor is connected into an ON/OFF control valve to maintain level in sub-assembly system. The valve which used for the proto type ON/OFF control is solenoid valve.

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A robotic arm is used for the pick and place of the used fuel bundles from the sub-assembly. Thus the robotic arm is already programmed and the control is made by the human interface [3]. The robotic arm is developed by a decoder and the synchronization is made in the robotic arm.

The proposed system of this paper is that to reduce the hazardous accident due to the cooling system in the power plant. For example: an accident which happens in the FukushimaDaiichi nuclear power plant.It is disabled BWR nuclear power plant located on a 3.5-square-kilometer site in towns of Okuma and Futaba of Fukushima Prefecture, Japan. The plant suffered major damage from the magnitude 9.0 earthquake and tsunami that hit japan on March 11, 2011. The incident permanently damaged several reactors making them impossible to restart. Due to the political climate, the remaining reactors will not be restarted. The disaster disabled the reactor cooling systems, leading to releases of radioactivity and triggering a 30 km evacuation zone surrounding the plant; the releases continue to this day [4].

2. SPENT SUB-ASSEMBLY STORAGE BAY

Spent Sub-Assembly Storage Bay (SSSB) serves as an interim for the spent as well as failed sub assembly to reduce this decay heat to a level of less than 2kW suitable for reprocessing. The demineralized water acts as a cooling as well as shielding medium for the stored spent sub assembly. SSSB is provided with an inbuilt leak detection and collection arrangement to achieve leak tightness of the facility. The storage capacity is planned to cover SSSB is planned to cover SA discharged from two fuel handling campaigns and one full core emergency unloading. It houses number of Spent SA Storage Racks with storage locations for storing spent SA& containers. It also supports under trolley at floor level and spent sub assembly storage bay transfer machine at operating level carry out the transfer of spent sub assembly and container. It also supports the floor mounted part of the equipment of spent sub assembly inspection facility (SAIF). The SSSB also serves to support the spent sub assembly transport cask vertically in order to facilitate loading of spent SA to the cask.

The inner concrete surface of the SSSB is lined with SS 304 L liner. The wall is lined with 3 mm thick liner and the floor is lined with 6mm thick liner. The spent SA storage racks are bolted to the SSSB floor through embedded plates. The storage capacity of the SSSB is 711. The requirement of water column above spent SA head (4.5 m) and the concrete thickness (1700 mm) are arrived based on the radiological safety of operating personnel. Due to the restricted entry, the specified dose rate at accessible areas in the storage bay area is 10μ Sv/h.

The leakage collection channels are interconnected to form a number of modules. Totally, 43 modules are provided within the SSSB. The different modules are connected to the leakage collection header with redundant leak detection arrangement for each module and finally the leaked water gets collected in a leakage collection sump [5]. There are two sumps provided at raft level. In case of any leak in the SSSB liner or ground water seepage, the water gets collected in the sump, which is collected and finally disposed through the liquid effluent system.

A. Cooling and Purification System

SSSB cooling system is provided to maintain the water temperature within the prescribed limits. SSSB purification system is provided to maintain the required water purity and clarity level within limits. The required quantity of water level in the SSSB is also maintained to achieve the allowable radiation level in the SSSB operating area.In cooling circuit three numbers of centrifugal pumps (50% capacity) are provided. During normal operation, two pumps are in operation and the third pump is standby. During emergency condition, all the three pumps are operated. Initially heat load of the SSSB is less and also SSSB water temperature at the top of the bay is also less. Heat exchangers are not required to operate during initial periods.

Bypass line is provided to prevent bay water entering heat exchanger during initial periods. Pump is operated only when pump suction and discharge side valves are in open position. Whenever discharge flow falls below preset value, the pump is tripped [4].

The purification pumps consist of two centrifugal pumps of 100% capacity. Out of two, one pump is in operation and other will be stand-by. Pump is operated only when pump suction and discharge side valves are in open position. Whenever discharge flow falls below preset value, the pump is tripped. The main characteristics of the pumps are as follows:

Capacity (based on 72-h turn over time)

Flow (Nominal) : 24 m^3/h

Flow (max) : 30 m^3/h

Heat developed : 40 m (400kPa)

Classification/ categorization :

Tabe 1

Material for Cooling Bay

Sl. No.	***Name of Components***	***Material***
1.	Cooling and purification pump shaft	AISI 410
2.	Cooling and purification pump impeller & casing	ASTM A351Gr CF8m(SS)
3.	Heat exchanger, submergible pump	SS 316L

Table 2

Design Conditions for Control System

Sl.No	***Name of the Component***	***Specification***
1.	Temperature Normal operating condition Full core unloading condition Loss of cooling	 318K 328K 338
2.	Fluids in contact	De-mineralized water
3.	Quality of De-mineralized Water pH Conductivity Chlorides	 7 ± 0.2 1µs/cm < 1 ppm

(LPBS) or from DDCS by suitably selection of the Local/Remote

B. Instrumentation and control:

The Cooling system of SSSB is designed for continuous operation. The purification system is designed for intermittent operations. All signals of the SSSB cooling and purification system are hardwired to the DDCS in FB-LCC. To carry out an operation from the FB-LCC, the operator will get the authorization from the CR. The SSSB System is remote manually operated from the DDCS. Operation of the pumps can be achieved from the local Push Button Stationselector switch, provided in the MCC of the respective pump. The status check backs for the pumps are monitored in the DDCS in FB-LCC and CR.

C. Temperature Measurement

Temperature sensors are provided at the following locations for indication and alarm in FB-LCC. 3-wire RTD's have been provided for this operation. The display of the temperature sensor is shown in Fig.1.

- At four (4) different elevation in each compartment of the bay with provision of two (2) elements per elevation in compartments 1 and 2 and one (1) elements per elevation in compartment 3.
- One (1) RTD at the discharge headers of each of the three (3) compartments.
- One (1) RTD at the outlet of the storage bay.
- One (1) RTD at the inlet and outlet of each of three (3) heat exchangers.
- One (1) RTD at the common discharge of the three (3) heat exchangers.
- Locally mounted temperature gauge is provided at outlet of each Heat Exchanger.
- The controller performs the automatic operation of the temperature in various aspect of the temperature range [6].

Figure 1: Temperature controller

The RTD is more linear device than Thermocouple, but still it requires curve-fitting. RTD are accurate, but require excitation current and are generally used in bridge circuits. It resistance changes with temperature. It is typically built of platinum (pt) wire wrapped around a ceramic bobbin [15].

D. Ultra-sonic Level Measurement

Ultra-sonic sensor is used to measure the level with certain distance to avoid the disturbance in the band of frequency. This type of level transmitter is a non-contact thus it can be able to measure from a long distance. The pictorial view of the Ultra-sonic level transmitter is shown in Fig.2.

Figure 2: Ultra-sonic level transmitter

This type of sensor is used because of the sub assembly bay is consist of a thick steel material thus the non-contact type level sensor is highly reliable for this type of bay. The ultra-sonic sensor consists of a transmitter and a receiver through which the frequency wave is passed and from the level of fluid it is again received at the receiver end named as echo. This work in the DC supply acquires the pulse signal and then it is passed to the display to indicate the level of the fluid in the bay [7]. Ultrasonic sensors are versatile in distance measurement. They are also providing the cheapest solutions. Ultrasonic waves are used both in air and in underwater. Ultrasonic sensors are also quite fast for the most of the operations. Ultrasonic sensor uses the physical characteristics and various other effects of ultrasonic signal of a particular strength. The ultrasonic wave propagation velocity in the air is approximately 340 m/s at 15 degree Celsius of air or atmospheric temperature, the same as the sonic velocity [14].

E. Radiation Monitoring

Radiation monitors are provided for indication and alarm in FB LCC in case of high radiation level. Window alarm is provided in CR for high radiation level [8]. Area Gamma monitors is provided near to the cooling water pumps and heat exchangers. Inline Gamma monitors are provided at the following locations:

- At the suction of the cooling circuit pumps.
- At the outlet of the filters.
- At the outlet of the ion exchangers.

F. ON/OFF Valves

Pneumatically and manually operated ON/OFF valves with open and close limit switches are provided. Pneumatically operated valves are used to control the water level in the bay as shown in Fig. 3. High-speed solenoid valve is an executive body in a control system has a great significance to the accurate control of brake pressure, which has the basis of active safety in power plant.

Fig. 3. Solenoid valve.

G. Spent Storage Bay Transfer Machine (SSTM)

Spent SA Storage Bay Transfer Machine (SSTM) is used for transferring spent SA/ Container with failed SA/ container with absorber SA one at time within the spent SA Storage Bay(SSSB). SSTM is working in different positions namely, Under Water Trolley (UWT), Spent SA Storage Racks(SSSR), Spent SA Inspection Facility (SSIF) and Spent SA Transport Cask (SSTC). The spent SA/ Container are transferred from UWT to SSSR for cooling and after sufficient cooling it is transferredfrom SSSR to SSTC for shipping to reprocessing facility.

H. Gripper Locking Arrangement

Figure 4: Robotic arm with gripper

The gripper assembly is locked to the top structure during transfer of SA/ container after the SA/ container is lifted fully within the shielding tube as shown in figure 4 with respect to table III. The locking is provided using pins, which engage into holes provided in the top structure. Movement of the pin is done using linear arrangement provides safety against fall of gripper assembly during LT and CT movement of SSTM [9].

I. Gripper assembly and drive system:

The gripper sub assembly is made up of two concentric tubes. The size of outer tube is 138mm OD & 124 mm ID and the size of inner tube is 87mm OD & 75mm ID. It has two taper roller bearings and an actuator rod for opening/closing of gripper fingers. The taper roller bearings are provided to get auto orientation while inserting spent SA in the spent SA inspection facility in SSSB. One end of the inner tube is connected to a linear actuator and the other end of the inner tube is connected to an actuator rod. Translation of the actuator rod is achieved by the linear actuator, which is an electrically, operated geared motor with an in-built ball screw nut mechanism. The actuator rod is provided with a cam arrangement. When the cam translates upward and downward, it moves the gripper fingers causing the fingers to move radially. There are three distinct positions of gripping fingers [10].

1. Fingers in closed position (SA released condition)
2. Fingers in open position (SA gripped condition)
3. Fingers fully open position (without SA)

Indication about position of gripper fingers is provided through two sets of proximity switches [11]. Anyone of the three positions can be selected and accordingly electrical power supply to the linear actuator gets cut off when the selected position of gripper fingers has been achieved. Indication of position of gripper fingers is continuously obtained on the control console through a draw wire potentiometer coupled to the inner tube of the gripper sub assembly.

Table 3

Material for Robot Gripper

Sl. No.	*Name of Components*	*Material*
1.	Gripper finger	A 453 Gr 660
2.	Pin for Gripper finger	A 453 Gr 660
3.	Finger bush and holder	RNiCr-B and SS 304 L
4.	Gripper inner and outer tubes	SS 304 L
5.	Pool bridge components	FE 410 WB as per IS 2062
6.	Wire rope	IS 2266
7.	Wire rope drum	FE 410 WB as per IS 2062

J. Safety features in I&C design against events

(*i*) Collision with compartment walls

All the end limits with approach towards a wall are sensed using dual redundant limit switches. Separate actuators are provided for the redundant switches and ½ logic is followed to stop drive motors. Continuous position sensors will be used as an additional defense to stop drive motors when the boundary limits are reached.

(*ii*) Collision with partition door walls or partition door

- Movement of LT is possible through partition door area only when CT is positioned at the center line of the opening between two components.

- Movement of CT is not possible when LT is moving along partition door area. The movement of LT along the partition door area is continuously tracked using dual redundant limit switches.
- Partition door is not present as sensed by Proximity switch.

(*iii*) Inadvertent rising of sa/container above the permitted water level leading to additional radiation dose

When SSTM gripper hoist is loaded (sensed automatically by the load cells and manual mode selection by the operator), hoist movement above fixed elevations are not possible. Dual redundant limit switches are fixed at two elevations, one for SA load and the other for container load. SA and container loads are distinguished automatically by the control system based on the expected weight and also upon manual selection by the operator. Continuous sensors are used as an additional defense to stop motors when permitted elevation is crossed [13].

(*iv*) Collision of SA/container with storage location during LT/CT movement

- When gripper hoist is loaded with SA, LT/CT movement is possible only when gripper hoist in SA transfer elevation.
- When gripper hoist is loaded with container, LT/CT movement s possible only gripper hoist in container transfer elevation.
- When gripper hoist is loaded, LT/CT movement is possible only when the gripper hoist is locked using locking pins, The locked/unlocked status are sensed using proximity switches.

3. IMPLEMENTATION

The cooling system of sub –assembly in nuclear power plant is shown in Fig.5. Each sensor is inter linked with the controller, the temperature sensor and level sensor plays an important role on the feedback control with respect to the solenoid valve and heater. The heater is used for the demonstration of the heat liberated from storage sub-assembly [10]. The bay is used to hold the demineralized water to minimize the radiation; the total bay is made of a thick stainless steel which absorbs the radiation that emitted from the sub-assembly. The Fig.5 includes the components such as 1-Controller, 2-Heater, 3-Pick and Place Robot, 4-Cooling bay with Sub-Assembly, 5-Level Transmitter, and 6-Temperature Transmitter.

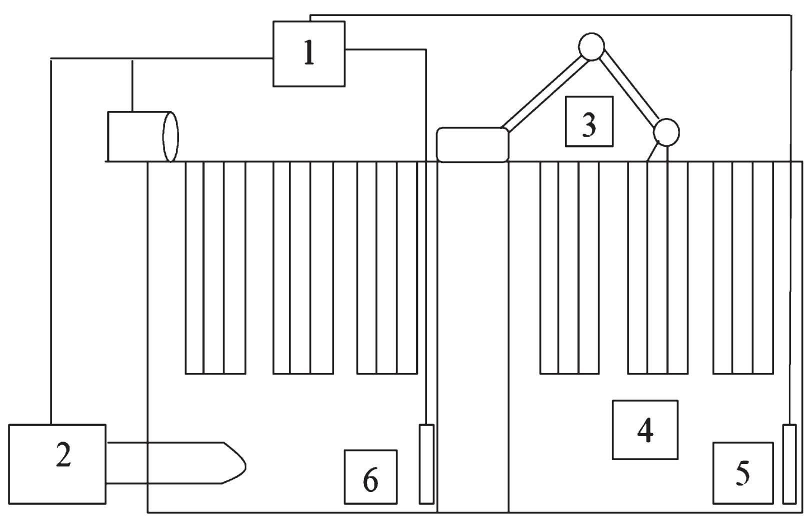

Figure 5: Cooling system of sub –assembly in nuclear power plant

The Gripper robot performs two degrees of freedom, this automatic pick and place robot integrates object detection with the pick and place process. With the objective of creating a user friendly and affordable system, the developed model high significantly demonstrates the use of technology in material handling systems [12].

4. RESULT AND DISCUSSION

The proto type model is developed and implemented, which shows the clear cut vision of the nuclear power plant with a simple control system as shown in Fig.6. This proto type is to show thecoolingprocess in the spent sub-assembly storage bay.

Figure 6: Hard ware model of sub assembly bay with robotic arm

The hard ware model shows the level monitoring system in the tank with the controller of solenoid valve. The hard ware model shows the operation with the solenoid valve for On/Off control process, with the help of non-contact level transmitter.

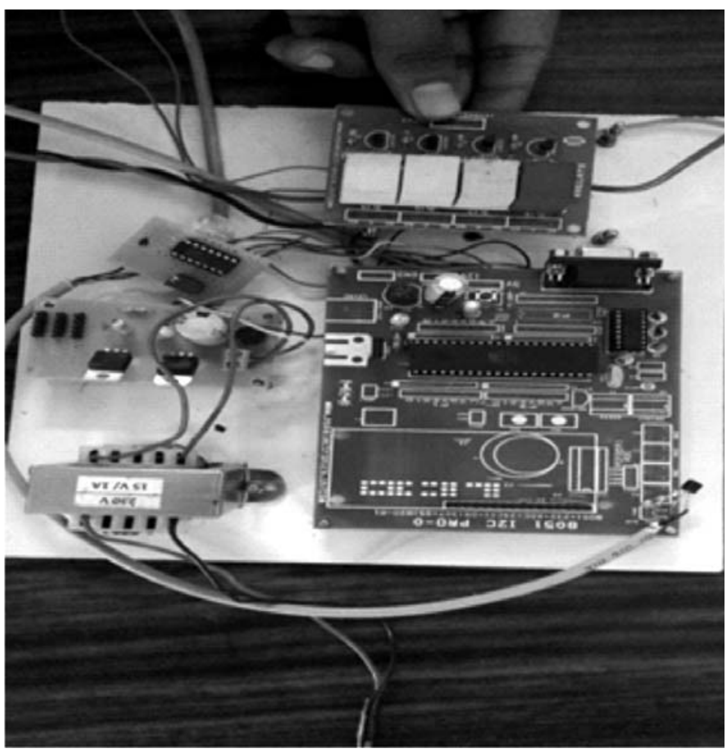

Figure 7: Circuit board with relays and sensors

The results characteristics of solenoid valve, temperature control and level control is studied and the graphical representation is placed below in the Fig. 7 and 8 respectively as shown below. The temperature is controlled over the temperature controller and hence it consists of set point and process variable this can able to perform the operation of the controller process in well efficient manner.

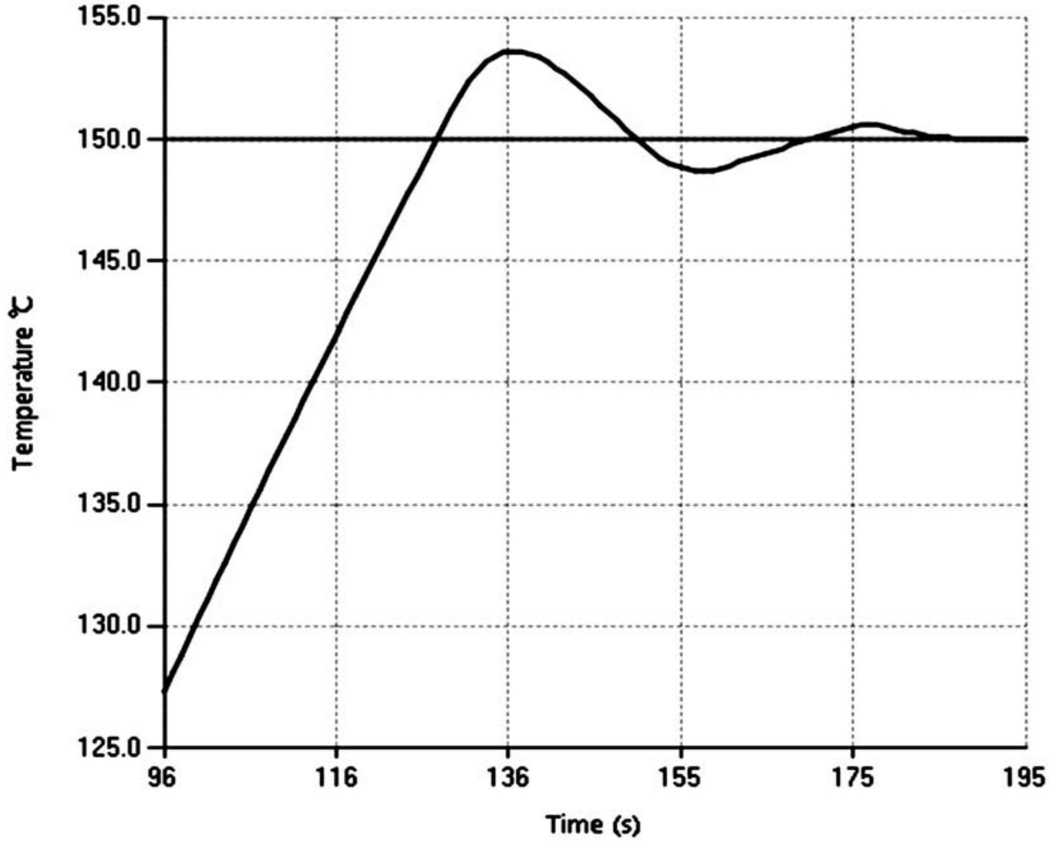

Figure 8: Temperature characteristics

The characteristics curve shows the operation performed by the solenoid valve according to the controller operation. Thus the overall paper shows the proto type study on the sub-assembly cooling system in nuclear power plant. The control over the solenoid valve characteristics used to solenoid valves given in the figure below.

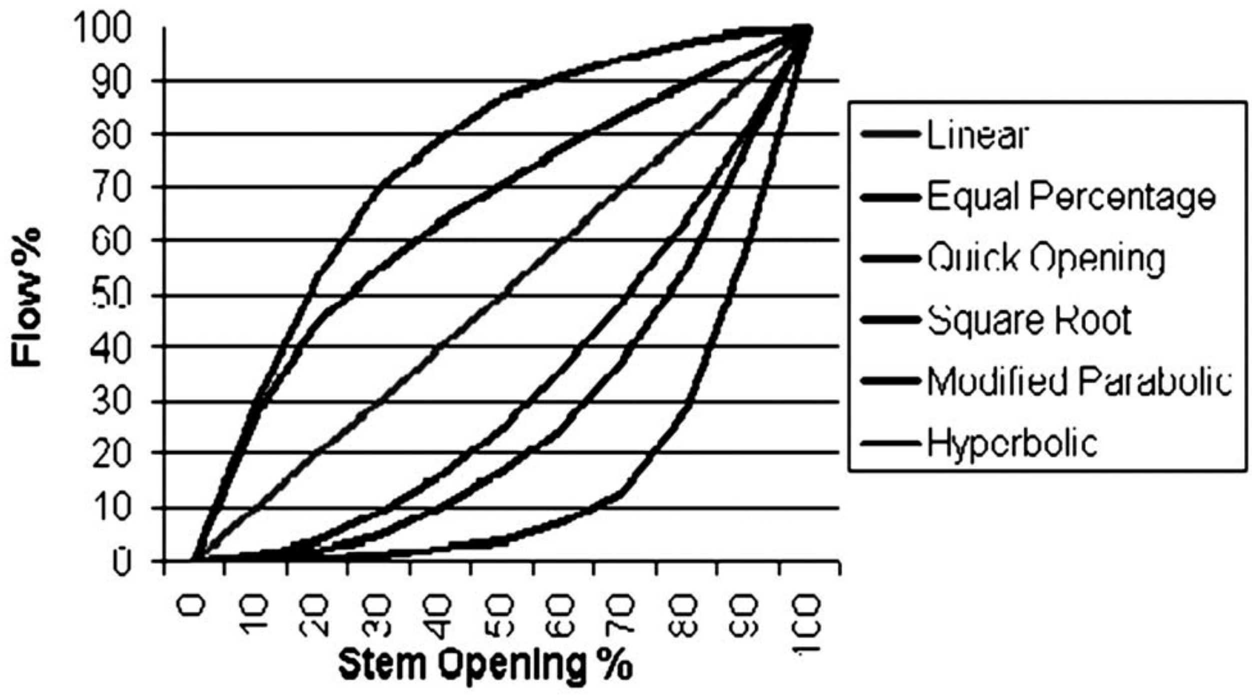

Fig. 9. Characteristics of Solenoid valve.

Table 4

Result Based on Bay Temperature

Sl. No	*Time in Seconds*	*Temperature in °C*
1	96	127
2	116	143
3	136	153
4	155	148
5	175	151

The temperature increases gradually with the increase in time. On a particular set point the temperature becomes constant based on the ON/OFF process of the relay where the control of the process variable is done by the temperature controller the above table shows the temperature is fluctuated by the range near to the set point. The set point of the temperature is set as 150 ^{0}C with the band range the temperature is varied as shown in the table IV.

Table 5

Result Based on Level in the Bay

Sl. No	*Time in Seconds*	*Level in Centimeter*
1	0	0
2	900	15
3	1800	30
4	2700	30
5	3600	30

The level of spent sub assembly bay is much important in order to avoid the hazardous situation thus the de mineralized water is used to pump from the reservoir and thus it could able to pass through the solenoid valve the stem movement of the valve is based on the controller provided with the set point. The set point of the value is about 30 cm through which the water is maintained by the level sensor as ultra-sonic sensor it senses the level and provides the feedback to the controller through which the water is maintained constant.

5. CONCLUSION

In this paper a proto type module is developed and implemented for the safety of the nuclear power plant to minimize the radiation in the environment. The simple control system implies in the large nuclear power plant to enhance and control operation for the production of nuclear energy in future generation with minimum of radiation. The paper also states the control parameters like level and temperature is monitored and controlled with the controllers with adequate set point and the process variable will be under the control by the on off process. The spent sub assembly rod is continuously displaced by the robotic arm in order to dissipate the heat from the assembly and also ensure to avoid the radiation from the cooling bay.

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