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Plc Based Control System Applied To Industrial Automated Fixture with Category 4 Safety

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Abstract : *A fixture is a mechanical setup that holds a job so that it will aid the industrial processes carried out on it with ease, in terms of accessibility and reach. The processes may include manipulation of a job like rotation, clamping, declamping and positioning. Fixtures can be handled manually to hold a job. But such a manual process becomes tedious in complex processes. Hence PLC (Programmable Logic controller) can be used to automate the industrial fixture, to reduce the complexity of the process. In the following research we have developed a hardware simulator for a PLC based control system to simulate the automation of an industrial fixture and analyzed it for Category 4 safety.*
Keywords: *fixture, PLC, simulator, control system, category 4 safety*

I. Introduction

The main concept of this research is implementation of a control system, by using an intelligent device, which controls the fixture so that manipulation of job becomes easy. There are basically two types of fixtures:

a) General purpose Fixtures: They are relatively more expensive and can be used to hold a variety and sizes of work pieces (Job) e.g. Vices, chucks, splits, collets, etc.
b) Special Purpose Fixtures: They are designed and built to hold a particular work piece (Job) for a specific operation on a specific machine or process.

In this research we built a simulator for the above mentioned special purpose fixture. The simulator Will basically consist of a hardware setup consisting of an operator pendant and an electrical cabinet. The PLC (intelligent device) will be the integral part of the simulator and will help us in understand the automation process of the special purpose fixture. The research will also implement a dual channel safety function for the system achieved by Category 4 safety. Basically a category is a parameter in order to achieve required 'Performance Level' (Pl_r). The corresponding category describes the behavior of the safety- related function, with regard to the behavior in case of failure.

Fig 1: Special Purpose Fixture Snapshot

II. System-Block Diagram

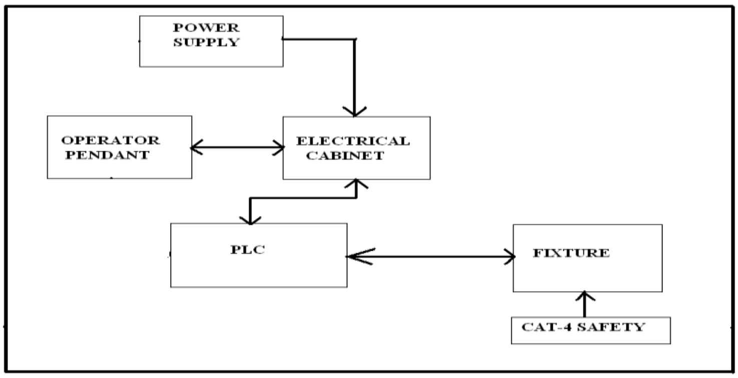

Fig 2: System Block Diagram

The above block diagram shows us the various integral parts that build the desired control system. Let us understand the various components that are included in the individual blocks of the control system with their specifications and their contribution to simulator:

1) Electrical Cabinet

Function of an electrical cabinet is to receive the input supply from the A.C mains and to convert it to suitable voltage required for operating the PLC and other machine controls. SMPS is important for AC to DC voltage conversion as the PLC operates on DC voltage. We also use MCB fuses and safety control relays for protection and safety.

The electrical cabinet consists of the following electrical components:

1.1) Switch Mode Power Supply (SMPS)

SMPS is an electronic power supply that incorporates a switching regulator, to convert electrical power effciently. Voltage regulation is achieved by varying the ratio of On-to-Off time. The main objective of SMPS in the setup is to convert AC mains voltage to regulated DC voltage of 24 Volts that is required to drive the PLC.

❖ Specifications (Allen Bradley 1606-XLP SMPS)

- Output Rating: 50 watts
- Output Voltage: 24VDC
- Efficiency: 88.5%

1.2) Miniature Circuit Breakers (MCBs)

MCB automatically switches off the electrical circuit during abnormal conditioning of the network, basically during current overload and faulty conditions. The cabinet will consist of two MCBs to prevent current overload and provide safety of the other mounted components. The ratings of MCBs will be 1A and 2A respectively of the Siemens 5X2 series.

❖ Specifications (Siemens 5X2 Series)

- RATED VOLTAGE: AC VOLTAGE : 230/400 V
- OPERATING VOLTAGE: MIN AC/DC : 24 V
MAX DC: 60V
MAX AC: 440 V
- RATED BREAKING CAPACITY: AC: 6 KA

1.3) PLC (Programmable Logic Controller)

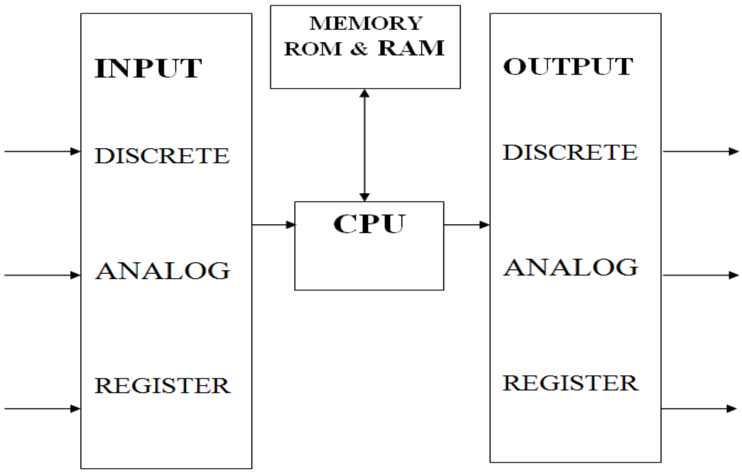

Fig. 3: Block Diagram of PLC

A Programmable Logic Controller, PLC, is an electronic device used for Automation of industrial processes, control of machines and automation of factory assembly lines. Unlike general purpose computers, the PLC is designed for multiple inputs and output arrangements, immunity to electrical noise, and resistance to vibrations and impacts. Hence we can say that PLC is an industrial computer used in rugged and harsh conditions to execute complex industrial processes. The PLC is the core of our research and will carry out the desired automation of fixture as discussed earlier. Let us understand in detail the exact nature of the device and its various components

1.3.1) Basic Components of PLC:-

a) CPU and Memory module

This is the device where PLC program is stored and processed. The size and type of CPU determines the programming functions available, size of the application logic available, amount of memory supports and supported and processing speed.CPU includes features like higher math functions, PID control loops and optional programming commands. The processor also consists of serial communication ports for printer, PLC LAN link and also external programming devices.

b) Power supply:

The power supply given to a particular PLC depends upon the Manufacturers specifications. A power supply may be inbuilt processor module or a separate module. Common voltage levels required by the PLC are 24Vdc, 120Vac, 220Vac.

c) Input and output modules:

Input and output modules are specified according to the requirements of a particular application. I/O can be either discrete, analog or register. Discrete I/O modules are capable of handling 8/16/32 ON-OFF type inputs or outputs per module. Analog I/O modules are specified according to desired resolution and voltage or current range. Pulsed inputs to the PLC are accepted through a high speed counter. Register I/O modules transfer 8 or 16 words (BCD or Binary) to and from the PLC.

d) Programming Unit:

Programming Unit allows the engineer to enter and edit the program to be executed. More advanced systems em -ploy a personal computer which enables the programmer to write, view and edit the program and download it to the PLC. This is accomplished using licensed software provided by the manufacturer. The software allows the programmer to simulate the program in real time scenario to determine proper operation. It also allows easy de-bugging of the program.

1.3.2) Operation of PLC:

The PLC performs mainly two functions while executing the program

1. Update the input/outputs

In this step, all discrete input states are recorded from the Input unit and all the discrete states to be O/P are transferred to the O/P unit. In simple words we can say that the information in Input and Output image registers of the processor is updated.

Image registers help in storing the information in memory. As inputs are received in real time by the PLC, I/P image register stores the received information in the memory and also transfer the executed information to the O/P image register. The O/P image register then sends the O/P data to the O/P unit. This process is also called as scanning.

2. Solve the Ladder logic

After the I/O update, PLC begins executing the commands in the user program (Ladder diagram) In other words, the ladder logic is executed. The PLC executes the ladder left to right and top to bottom. Usually the contact configuration on the left side of each rung can be visualized as switches and contacts while the coils on the right as O/P lamps.

❖ Specifications(ALLEN BRADELEY PICO PLC)

- Analog inputs— two 0-10V dc analog inputs are provided on DC controllers.
- Controller line power — 12V dc, 24V dc, or 120/240V ac versions available
- Expandability— 18-point Pico controllers accommodate expansion I/O modules, providing up to 20 additional I/O points.
- Small size— smaller than many relays, saving panel space and reducing system cost.

1.4) Limit Switches

There are 4 limit switches that act as position sensors in the system. A limit switch basically converts mechanical stimuli generated during a process to electrical stimuli. The system comes to a halt as soon as the switch is activated. Thus a desired position of a fixture can be achieved via a limit switch. Also we can say that a limit switch can act as a feedback device stating the completion of the process.

1.5) Safety Relay

Safety relay is an important component in safety systems, due to various safety regulations and attempts to safeguard operators from hazards. A safety relay is designed with an internal circuit that will allow power to be removed from a load even if an internal contact welds. A safety relay monitors faults in the input (e.g. Start and Stop Buttons) and output (e.g. Auxiliary Relay) devices. A safety Relay typically replaces the master control relay that interfaces between input devices and contactors or starters. The contacts are called "monitored outputs" or "safety outputs", and have two or more contacts in series to achieve redundancy for each load. The safety relay will implement category 4 safety in the designed control system.

❖ Specifications (SCHEMERSAL 301SRB SAFETY RELAY**)**

- Safety category according to wiring
- Dual channel inputs
- 8 N.O. safety outputs
- 2 N.C. auxiliary outputs

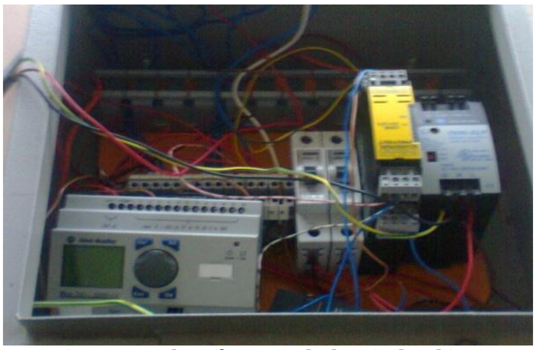

Fig. 4: Snapshot of Mounted Electrical Cabinet

2) Operator Pendant (or Operator box)

The operator pendant is a box consisting of push buttons and actuators required for operating the fixture. The operator handles the fixture from a safe distance using this pendant. Operator pendant consists of different buttons required for operations such as ON/OFF, Mode Selection, Emergency Stop. The various pushbuttons and indicators mounted on the cabinet are:

- Flush type momentary Actuators
- Projecting type momentary Actuators
- Momentary Mushroom Actuators
- 2 position selector Actuators
- Illuminated flush
- Pilot Light with LED

Fig.5: Snapshot of Operator Pendant

3) Power Supply Circuit

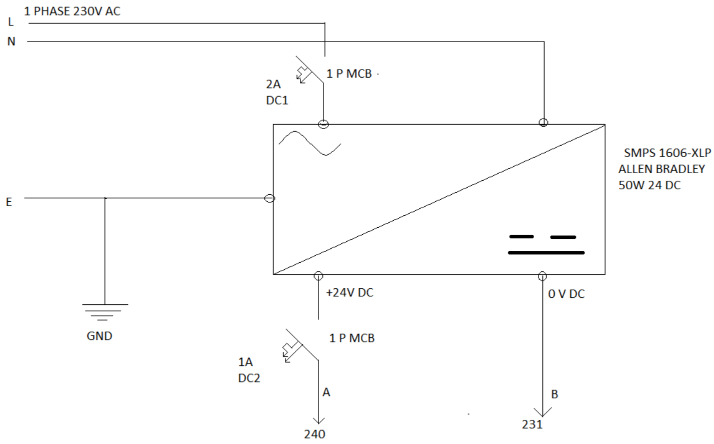

Fig. 6: Power supply Circuit

As shown in the block diagram of the power supply circuit, the mains AC voltage of 230V is given to the SMPS via a 2A MCB. Mcb will trip in case of current overload. SMPS will provide a DC output of 24V for the desired operation of the components in the cabinet, specially the PLC. A 1Amp MCB is placed at the output side of SMPS to disconnect supply from SMPS to cabinet components in case of current overload. The Electrical load calculations for various components in the cabinet are given below.

❖ Electrical load Calculations

- SMPS
  - Output Power Rating: 50 W
  - Output Voltage Rating: 24 VDC
  - Output Current Rating: 2.1 A
  - Efficiency: 88.5%
- Input Voltage : 230 VAC

- Efficiency (n) = Output power/Input power

  Input Power = 50 W/88.5%
  = 56.49 W
  = 56.49 W/0.7 [power factor=0.7]
  = 80.71 VA

Actual Load Connected:

- Outputs

  Total Number of Lamps (Outputs) = 4
  Power consumed by each Lamp = 2 W
  Total power consumed by all lamps = 4*2 = 8 W
  Total current for connected lamps is = 8 W/24 VDC
  = 0.33 A

- PLC

  Total Power consumed by PLC = 5.28 W
  Total Current consumed by PLC =5.28 / 24V
  = 0.22 A

- Inputs

  Total Number of Inputs connected to High speed ports = 8
  Total current for the high speed ports = 8 * 8.8mA
  = 0.07 A
  Total Number of inputs connected to standard ports = 1
  Total Current for the standard port = 1*8.5mA
  Total Actual Load Current = 0.33A+0.22A+0.07A+0.0085A
  =0.6285 A

Total Actual Load Connected =24V*0.6285A
= 15.084 W
= 21.55 VA

4) Category 4 Safety Implementation

Selection of a category for a safety function is based on the following parameters:

- The risk reduction achieved by the safety function,
- The required performance level (PL_r)
- The technology used,
- The risk occurring in that part in case of fault,
- The prevention of faults,
- The probability of faults in that part in the corresponding parameters,
- The mean time to dangerous failure ($MTTF_d$),
- The diagnostic coverage (DC_{avg})

EN ISO 13849-1 defines the following categories depending on their performance level

1) Category B: Characterized by a single-channel structure. Loss of safety function may be possible in case of a fault. $MTTF_D$ is low. PL_r = b.

2) Category 1: characterized by a single channel structure and accumulation of faults may lead to loss of safety function. $MTTF_d$ is medium to high. PL_r = c. use of well tried safety principles and components.

3) Category 2: characterized by single channel structure along with check function for realization of the safety function. $MTTF_d$ is medium to high. PL_r= d.

4) Category 3: consists of a two channel structure for realization of the required safety function. Safety related function has to be designed in such a way that loss of the safety function cannot be caused by a single fault in one of these parts. All the safety related parts are designed in a redundant way. Failure of one component of a channel would lead to a safe state via the other channel. Although accumulation of unidentified faults may lead to loss of safety function. $MTTF_d$= high. PL_r= e.

5) Category 4 Safety

The architecture of category 4 consists of a two-channel structure for realization of the safety function. The requirements of category B, that is application of basic safety principles and the service conditions to be expected, as well as well-tried safety principles according to category 1, shall be observed.

The safety-related function has to be designed to exclude loss of safety function in case of single fault detection of one of these parts during or before the next demand of safety function. The structure of category 4 safety should be designed in a redundant way to make sure a safe state even in case of failure of one component of any channel via the other channel.

In contrast to category 3, loss of safety function is not allowed in category 4 if fault detection is not achievable. Thus, accumulation of undetected faults shall not lead to a dangerous failure of the safety function. This is significant difference between category 4 and previous categories.

❖ Features of Category 4

- Diagnostic coverage, that is DC_{avg} = high
- $MTTF_d$ = high
- Maximum possible performance level PL = e
- Measures against CCF(common cause failure) = required (65 points)

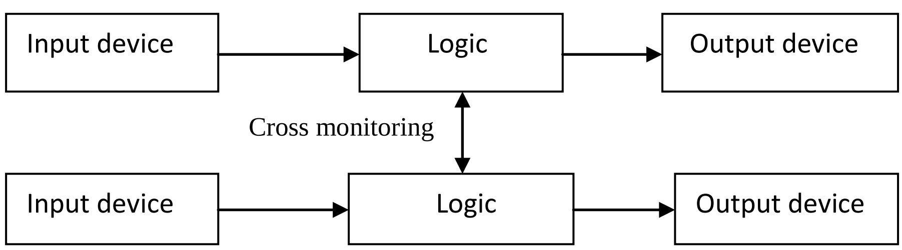

Fig. 7: Category 4 safety block diagram with cross monitoring logic

Measures against common cause failures (CCF) are relevant to reduce the likelihood that both channels of the safety function fail due to one fault.

For the redundant structure of category 4 it has to be observed, as is the case for category 3, that the two channels of the structure do not have to be identical. Here, the diverse redundancy is not obliged.

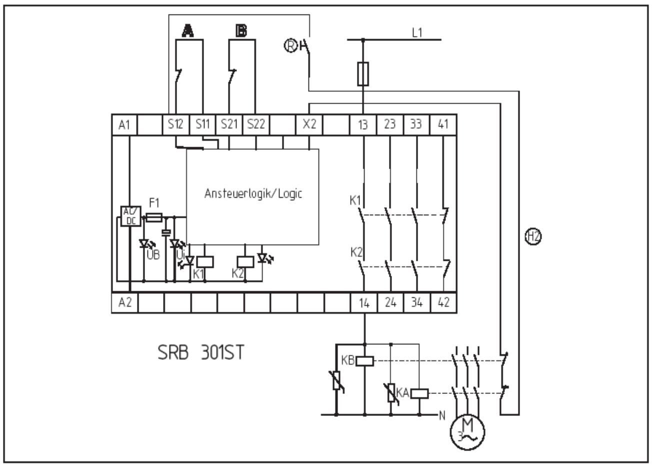

Fig.8: Category 4 implementation in the desired Control System

III. System Operation

The system as stated earlier is a miniature simulation of special purpose fixture. There are two modes of operation in Auto and Manual mode. A selector switch is present on the pendant to toggle between the auto and manual mode. When the auto mode is activated, the Auto on lamp will glow. There are four sensor positions namely, OVERTRAVEL (+), POSITION 1, OVERTRAVEL (-) and POSITION 2.In the AUTO mode the cycle FWD button present on the pendant is pressed once and released. The system starts to move in the forward direction and keeps moving until it encounters a sensor. The system then stops to move forward. The indication lamp remains continuously on till the button is pressed. The system will not move forward after it encounters the OVERTRAVEL(+) sensor, and not move in reverse direction after it encounters OVERTRAVEL (–) sensor. There is an EMERGENCY STOP mushroom push button also, available on the operator pendant. Once this button is pressed, the system goes in emergency mode. That means SafetyRelay SRB 301 ST is activated and the pause indicator goes on. The whole system stops operating. The PAUSE indicator remains on even when the emergency button is released. It remains so till the safety relay is not reset using the reset switch. Until then no operation takes place. Even if the cycle REV/FWD button is pressed, there is no change in the system. The PAUSE indicator is also used to indicate an abnormal condition in the system. That is when both the CYCLE REV/FWD buttons are pushed together. In manual mode the fixture can be moved forward and reverse in an inch type situation. That is the fixture stops its motion as soon as the button is released and starts when the button is pressed. This goes on till the limit switch is occurred (Sensor).

IV. Results

As stated in the system operation, as per the push buttons pressed for the desired movement of fixture the following results were obtained:

Fig.9: Selection of Auto mode

Fig.10: Operation on Pressing Cycle REV push button

Fig.11: Activation of Emergency Mode

Besides this the $MTTF_D$ for the Safety Relay and Emergency Push Button was also carried out to see how effective is Category 4 safety, in the following way:

a) $MTTF_D$ for Safety Relay

$MTTF_D$= B(10d)/(0.1*n(op))

Where B(10d)= number of switching cycles during which 10% of the components have degerously failed

n(op)= number of operating cycles per year

T_{10d} for a given system is the time elasped until 10% of the components have failed dengerously.

T_{10d}=B(10d)/(n(op))

Thus for the given SRB-301 ST safety relay

$B_{10d=}$4000,000

n(op)=10,950

thus by the formula of $MTTF_D$ we have

- $MTTF_D$ =730.59 years
- And T_{10d} = 73.05 years

b) $MTTF_D$ for Emergency Push button

For the emergency push button

$B_{10d=}$ 1000,000

n(op)=10,950

- thus, $MTTF_D$ = 1826.48 years
- and T_{10d} = 182.6 years

Thus as $MTTF_D$ values are above 100 years we can assume the $MTTF_D$ of the system to be 100 years. That means $MTTF_D$ value is high.Due to this high range according to EN ISO13849-1 $MTTF_D$ falls between 30 and 100 years. Thus looking at this we can say that the system belongs to category 4 and the Dc_{avg} can be considered high.

V. Software Implementation

The PLC in the research was operated by programming the ladder logic on the software PICO Soft 6. The software helped in realizing the function of the simulator in terms of the ladder diagram. Basically 5 modules of ladder diagram were developed consisting of forward auto and manual mode operation, reverse auto and manual mode operation and one module for emergency condition.

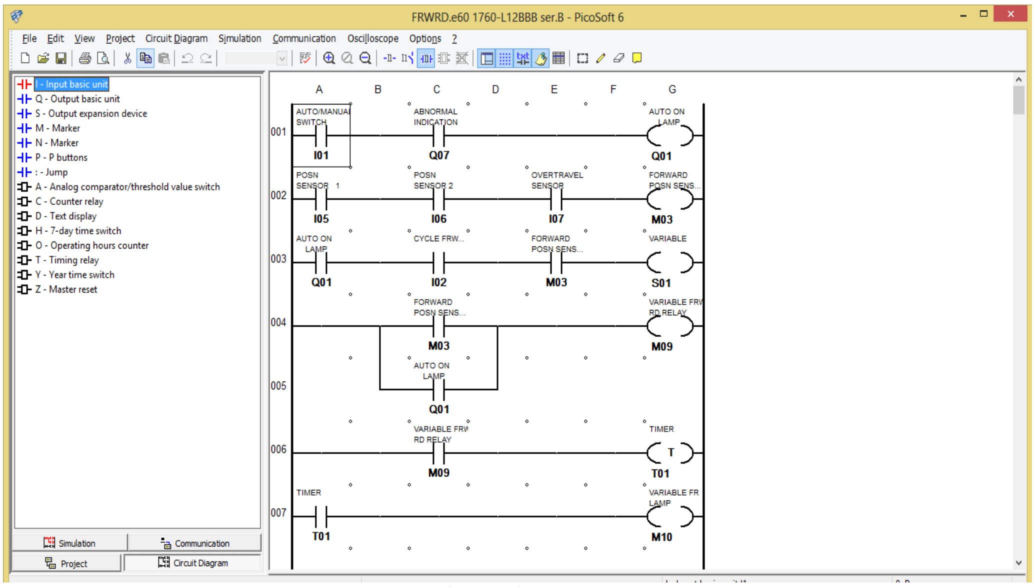

Fig. 12:Screen shot of picosoft 6 ladder program

VI. Applications and Future Modification

The control system finds its usage in many industrial applications concerning the manipulation of a fixture. Following are a few of the applications:

- Designed System can be used for a simple manipulator fixture.
- It can be used for hydraulic clamping and declamping-fixture.
- Systems can be used for the motors with direct start (with DOL) as well as for the motors with soft start (using VFDs)

The future modifications may include:

- System may include a robotic fixture.
- Modifying the system for controlling a clamp de-clamp action with manipulator (rotation upto a certain angle).

VII. Conclusion

Thus we have successfully designed and implemented a simulator for the control system of a special purpose fixture. A detailed study of the various sections of the system that is the operator pendant with all push buttons and indication required, components placed in the electrical cabinet and the implementation and realization of category 4 safety to the system was carried out.

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