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AUTOMATING HORIZONTAL BORING AND MILLING MACHINE

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Aiming at the requirements of modification for many old import machine tools in industry, the schemes suited to the renovation are presented in this paper. A horizontal boring and milling machine (HBM) involved in machining of tank Al-Khalid has been modified using Mitsubishi FX-1N and FX-2N PLC. The developed software is for control of all the functions of the said machine. These functions include power on/off oil pump, spindle rotation and machine movement in all axes. All the decisions required by the machine for actuation of instructions are based on the data acquired from the control panel, timers and limit switches. Also the developed software minimize the down time, safety of operator and error free actuation of instructions.

Keywords: Automating Manufacturing System, Horizontal boring and milling machine, Programmable logic controllers (PLCs), Tank Al-Khalid

1. Introduction

Programmable logic controllers (PLCs) are used in large variety of automated systems and processes [1]. PLCs have become very popular and will remain a predominant as well as a preferred choice for many control tasks [2]. The increasing complexity of heterogeneous systems poses new challenges to achieving reconfigurability, interoperability and reliability. A commonly industry adopted solution for addressing these requirements in the low-level control area is currently associated with programmable logical controllers (PLC) [3]. In this paper, a particular horizontal milling and boring machine (HBM) had been selected for renovation to automate its different operations, using PLC. Figure 1 shows the photograph of that particular horizontal milling and boring machine (HBM). HBM is being used for manufacturing of Hull (lower part of tank, Figure 2a) and Turret (upper part of tank, Figure 2b). The HBM had been used in tank manufacturing factory, Heavy Industries Taxila, Pakistan since 1991. Also this machine had been involved in machining of tank Al-Khalid and is being modified using Mitsubishi FX-1N and FX-2N PLC. This machine was manufactured by Wuhan Heavy Duty Tool Works, People's Republic of China. The exact name of the machine is 'Wuhan Horizontal Milling and Boring Machine' and Model No. is TX6216C.

Table 1 shows the production amount alongwith name of the products being produced by this machine. These machines were being operated through the relay control logic. It is also worth mentioning that huge numbers of relays as shown in Figure 3 were being utilized to control the operation of the said machine. With the passage of time, wiring to relays and contacts of these relays became worn out which results in frequent faults. Due to electromechanical nature of operation of these relays, faults such as contact sticking, carbon deposit at contact and contact pitting were being developed. Due to complexity of relay-wiring, troubleshooting of these faults had become difficult and time consuming task.

As stated earlier that due to switching action and having mechanical moving parts, the wear and tear process of relays contact was much frequent. On the other hand, when fault occurs due to malfunctioning of relay, it was very difficult to diagnose the exact problem. There was no direct indication that which relay is not working. Consequently, the concerned machine had to stop for long duration which adversely affects the production targets of defense equipment. The data for the three years had been collected and plotted to show different synopsis of the said machine. Figure 4(a) describes the fault-history for the years 2006, 2007 and 2008 due to the relay and other

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reasons that are not related to relay operation. Similarly, Figure 4(b) shows the unproductive time for the years 2006, 2007 and 2008 due to the relay fault and other types of faults. Figure 4a and Figure 4b depict the percentage of fault and unproductive time respectively. Figure 4a and Figure 4b show that 70% of faults in the machine occurred due to non functioning of relays and 83% of down time is due to rectify these relay based faults, respectively.

Figure 1. Horizontal boring and milling machine being automated through PLCs.

Figure 2a. Hull of Tank.

Figure 2b. Turret of Tank.

Table 1. Total Products by horizontal milling and boring machines.

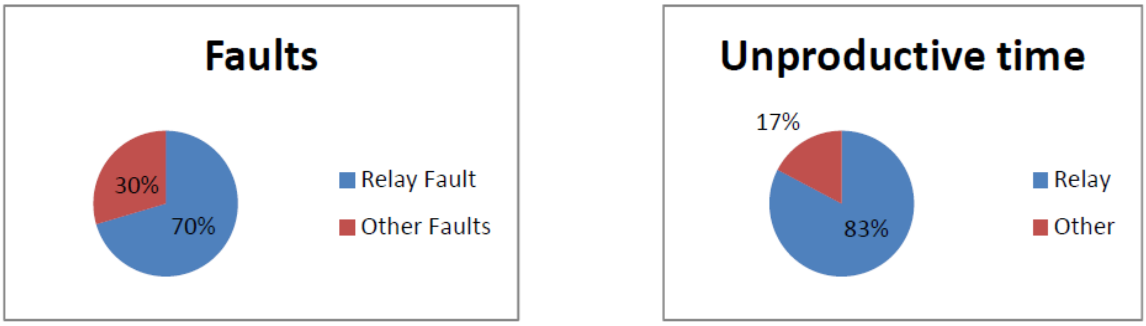
S.No.	Products	Quantity
1	Tank T-69 II AP	300
2	Armoured Recovery Vehicle	50
3	Tank T-85 II AP	25
4	Tank Al-Khalid	300
5	Tank Al-Zarrar	430
Total production amount		1105

To overcome the number of faults, their duration and to meet the production targets on time; relay logic based machine operation had been converted to PLC-based control logic operation.

Figure 3. Snapshot of relays to control the operation of machine.

2. Problem Statement

Renovation of old machines is common in the manufacturing units [4]. The control of flexible manufacturing systems (FMSs) is generally characterized by logical and sequential functions under the auspices of a programmable logic controller (PLC) [5]. Operational faults associated with control processes are often confusing to maintenance personnel at workshop level. This had resulted in the wastage of valuable production time. Industrial control engineers continue to make extensive use of ladder logic to program PLCs although the limitations of the language are well



(a) (b)

Figure 4. (a) Percentage of relay fault and other faults, (b) Percentage of unproductive time due to relays fault and other faults.

recognized [6]. In this research work, the operation of a horizontal milling and boring machine, installed at a production unit, had been modified through the implementation of PLCs. All of the operations, controls, and processes of the said machine had been completely automated and hence the overall efficiency had been much improved.

3. Methodology

The systematical approach to address the specific control task i.e. to renovate the said horizontal boring and milling (HBM) machine operation through PLCs to automate the desired operation described in the preceding sub-sections.

3.1. Control Task

In problem solving procedure one of main step is control task which is directly related with the problem to be addressed [7]. In order to define control task process, operator and maintenance persons closely related with the machine were consulted. It was investigated through the operators of the said machine that the function of the machine is not reliable. If machine was shut off in operational condition at any time, it is not operational on the next day. Due to this, work schedule planned is badly affected. When maintenance person were inquired they stated that trouble shooting of this machine is very difficult, laborious and time consuming. For rectification of fault, following procedural steps were carried out:

i. Every wire was checked separately

ii. Each relay was also checked

iii. Relay contacts (2~6) was also checked

which takes days to point out the problem. Mostly problems are due to lose connection to relays or pitted relay contact.

3.2. Control Strategy

After defining the control task through consultation with the operators and maintenance personals, control strategy has been developed to get desired result. For accomplishment of different control task, followings steps were taken to reach at desire results:-

i. Process of machine operation was understood.

ii. Repair manual of the machine was studied in depth.

iii. Flow charts of operation were made.

iv. Complete schematic circuit diagram was drawn.

v. Relay logic incorporated was studied and decoded.

vi. Real and internal input/output assignment was done.

vii. Programming of PLC done in sequence with the existing relay logic.

viii. Conversion of existing wiring for PLC implementation.

ix. Removal of previous installed relays.

x. Renumbering of wire as per PLC.

4. Organization of the Program and Implementation of Control Solution

Control program implementation technique is different for different programmers. Below are guidelines opted for renovation of the machine:

a. The actual process and machine function was thoroughly understood.

b. Logic of operation of machine was reviewed and optimized where possible.

c. Real I/O and internal addresses to inputs and outputs were assigned

d. Relay ladder diagram was translated into PLC coding.

Organization of the program and implementation of the control solution is a main step in renovation process of the said machine. Proper and perfect implementation of the ideas will result into successful control solution [8]. The control program writing was started with the complete understanding of the following tasks before modernization of the said machine:

i. PLC control task

ii. Controlled devices

iii. Correct equipment for the job (hardware and software)

iv. Basic understanding of the PLC system.

4.1. Development of Flow Charts, Timing Diagrams and I/O Assignment Tables

After fully understanding the tasks that this machine had to performed, flowcharts for all the tasks as shown in Figure 5 were developed. Figure 5a shows the flow chart of the oil-pumps-start. The functions of hydraulic and lubrication system are to lubricate all the gears, bearings and electromagnetic clutches in the headstock. As all these are critical functions and operation of machine and without certain oil pressure can damage it. Hence PLC before switching on the oil pump checks followings in addition to the status of oil pumps and is then used in other machine operations;

1. Status of thyristor module and control modules.
2. Status of circuit breakers (CB) of oil pumps, air pump and control transformer.
3. Status of over current relay.

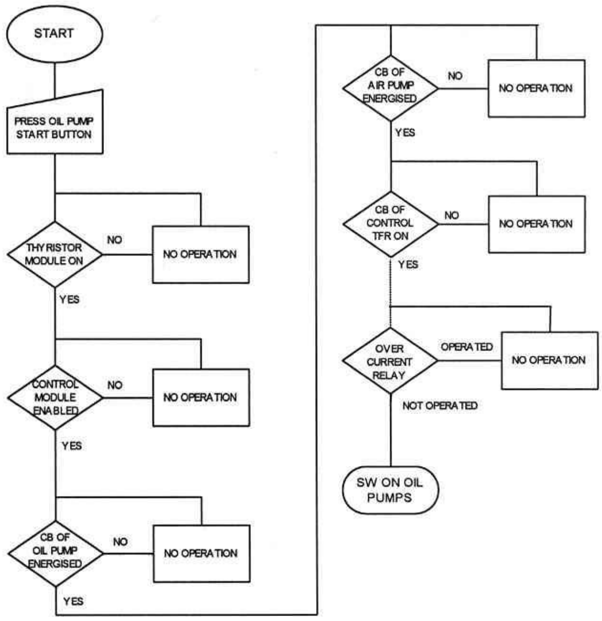


Figure 5a. Flow chart of the oil pumps start.

Figure 5b shows the flow chart of the spindle rotation. Metal cutting tool is fixed in the spindle which rotates the tool and cutting is achieved. Before spindle rotation start the appropriate spindle speed is selected and PLC checks the following status;

1. Oil pump is operational or not.
2. Required gears are meshed and clutch is operated.
3. Power to thyristor module is available.
4. Control is enabled.
5. Check emergency spindle stop button is pressed or not and if pressed spindle will not rotate.
6. Spindle brake is released or not.

If every status is acceptable spindle rotation will be enabled but spindle will only rotate if the direction of rotation is as required.

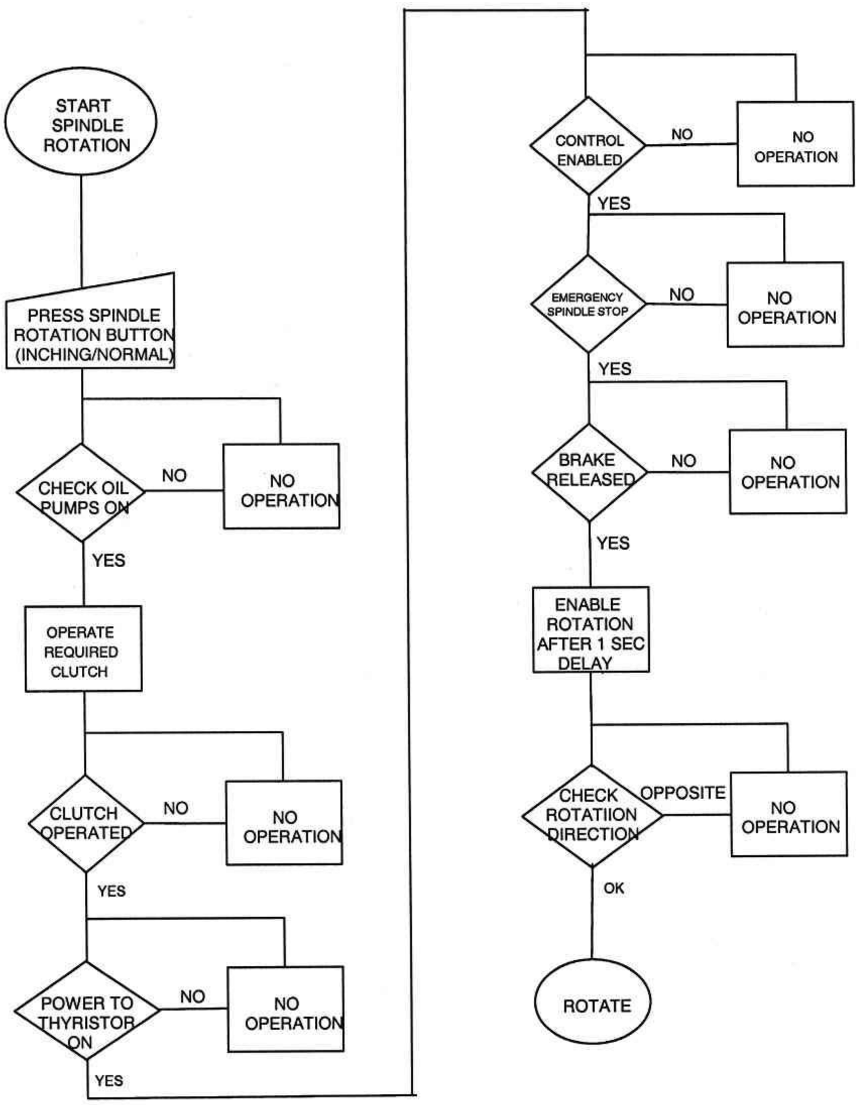


Figure 5b.   Flow chart of the spindle rotation.

Figure 5c shows the flow chart of the axis movement. The machine operates in three axes but only one axis is enabled at a time. Axis movement is necessary for milling and boring operations. Before any axis movement PLC checks the following status;

1. Operation of machine is required automatically or manually,

2. Feed of axis is switch off, if not then machine will not work,

3. Select required axis i.e. face plate, headstock, spindle or column base,

4. Checks that required gears are meshed and clutch is operated,

5. Axis brake is released or not.

Select any of two modes of movement i.e. rapid or inching.

For rapid movement

Select direction of movement. Check whether spindle rotation inching is off, zero interlocking is locked, feed inching is off, machine is within axis limit, feed rate is correct and direction of movement is as required.

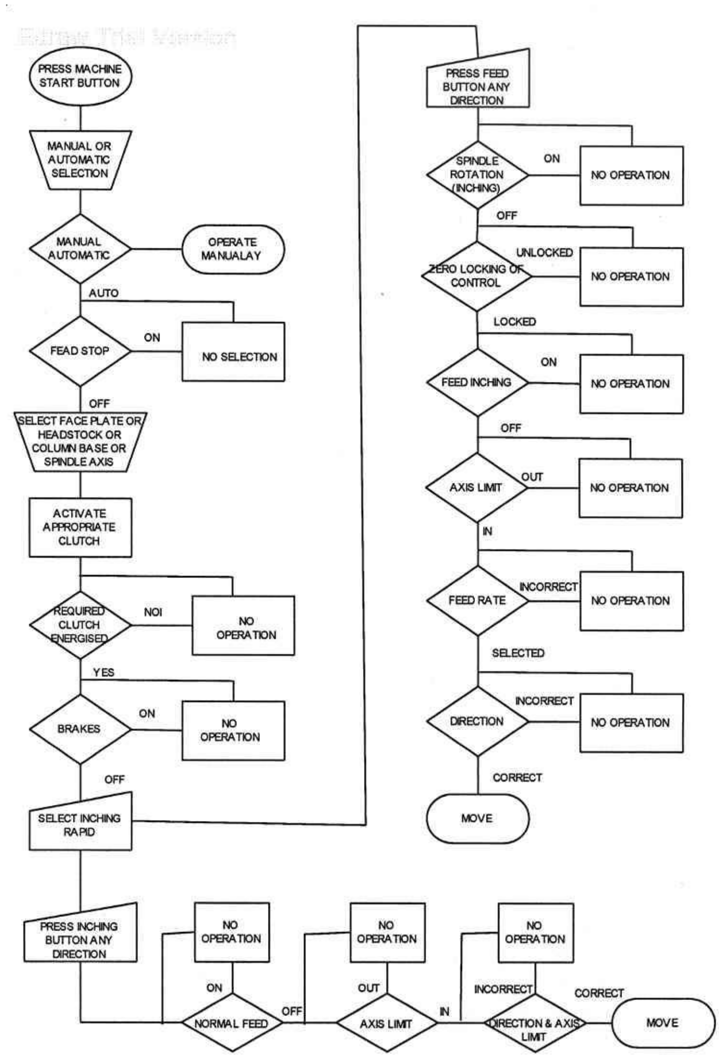


Figure 5c. Flow chart of the axis movement.

For inching movement

Select direction of movement. Check feed rate is correct, machine is within axis limit and direction of movement is as required.

At the end, an Appendix has been included which shows the two different tables namely Table 2 and Table 3. Table 2 and Table 3 had been developed considering above mentioned flow charts shown in Figure 5. All the inputs and outputs used during programming of the PLC have been organized and documented in these tables. The assignment of internals including timers and counters also takes place here. These assignments are the actual contact and coil representations that are used in the ladder diagram program. Table 2 shows inputs/outputs (I/O) address assignment for all real inputs and outputs. Table 3 shows inputs/outputs (I/O) address assignment for the internal outputs.

4.2. PLC System Configuration

Flow charts and logic sequences were considered for PLC configuration. This configuration defines how many PLC I/O modules will be used and what types of I/O are available. Location of modules is also important for assignment of I/O to the device [9]. In this particular case following I/O modules were used for implementation of the ladder diagram;

Table 2. Inputs/outputs (I/O) address assignment for all real inputs and outputs.

Module Type	I/O Address		Description
	Rack	Group	
Input (X0)	Main	1	SB1.2 (Emergency Stop at Pendent)
Input (X1)	Main	1	SB2.2 (Emergency Stop at Cabinet)
Input (X2)	Main	1	SB3 (Sw on Thyristor from Cabinet)
Input(X3)	Main	1	SB4 ((Oil Pump Start from Cabinet)
Input (X4)	Main	1	SB5 ((Sw on Thyristor from Pendent)
Input (X5)	Main	1	SB6 (Oil Pump Start from Pendent)
Input (X6)	Main	1	SB7 (Spindle Inching CW)
Input (X7)	Main	1	SB8 (Spindle Inching CCW)
Input (X10)	Main	2	SB9 (Spindle Rotation CW)
Input (X11)	Main	2	SB10 (Spindle Rotation CCW)
Input (X12)	Main	2	SB11 (Spindle Stop)
Input (X13)	Main	2	SB12 (Feed Stop)
Input (X14)	Main	2	SB13 (Feed inching Left)
Input (X15)	Main	2	SB14 (Feed Inching Right)
Input (X16)	Main	2	SB15 (Feed Left)
Input (X17)	Main	2	SB16 (Feed Right)
Input (X20)	Main	3	SA1(a) (Feed Speed Gear I)
Input (X21)	Main	3	SA1(b) (Feed Speed Gear II)
Input (X22)	Main	3	SA1(c) (Feed Speed Gear III)
Input (X23)	Main	3	SA2(a) (Face Plate Engage)
Input (X24)	Main	3	SA2(b) (Face Plate Disengage)
Input (X25)	Main	3	SA3(a) (Manual Operation)
Input (X26)	Main	3	SA3(b) (Powered Operation)
Input (X27)	Main	3	SA3(c) (Spare)
Input (X30)	Main	4	SA4(a) (Normal Traverse)
Input (X31)	Main	4	SA4(b) (Rapid Traverse)
Input (X32)	Main	4	SA5(a) (Face Plate select)
Input (X33)	Main	4	SA5(b) (Spindle Select)
Input (X34)	Main	4	SA5(c) (Neutral)
Input (X35)	Main	4	SA5(f) (Head stock Select)
Input (X36)	Main	4	SA5(e) (Column Select)
Input (X37)	Main	4	SA5(d) (Spare)
Input (X40)	Main	5	SQ1 (Head Stock Limit Sw)
Input (X41)	Main	5	SQ2.1 (Head Stock Limit Sw)
Input (X42)	Main	5	SQ2.2 (Head Stock Limit Sw)
Input (X43)	Main	5	SQ3 (Head Stock Limit Sw)
Input (X50)	2^{nd}	5	SQ7 (Head Stock Limit Sw)
Input (X51)	2^{nd}	5	SQ8 (Head Stock Limit Sw)
Input (X52)	2^{nd}	5	SQ9 (Head Stock Limit Sw)
Input (X53)	2^{nd}	5	SQ10 (Head Stock Limit Sw)
Input (X54)	2^{nd}	5	SQ11.1 (Head Stock Limit Sw)
Input (X55)	2^{nd}	5	SQ11.2 (Head Stock Limit Sw)
Input (X56)	2^{nd}	5	SQ12 (Face Plate Limit Sw)
Input (X57)	2^{nd}	5	SQ13 (Face Plate Limit Sw)
Input (X60)	2^{nd}	6	SQ14 (Column Base Limit Sw)
Input (X61)	2^{nd}	6	SQ15.1 (Head Stock Limit Sw)
Input (X63)	2^{nd}	6	SQ15.2 (Head Stock Limit Sw)
Input (X63)	2^{nd}	6	SQ16 (Head Stock Limit Sw)
Input (X64)	2^{nd}	6	SQ1M (Column Y-axis Limit SW)
Input (X65)	2^{nd}	6	SQ22 (Column Y-axis Limit SW)
Input (X66)	2^{nd}	6	QM1 (CB for Thyristor Unit)
Input (X67)	2^{nd}	6	QM2 (CB for Thyristor Unit)
Input (X70)	3^{rd}	7	QM3 (CB for Oil Pump Motors)
Input (X71)	3^{rd}	7	QM4 (CB for Oil Pump Motors)
Input (X72)	3^{rd}	7	QF3 (CB for Control Transformers)
Input (X73)	3^{rd}	7	FAO (Thyristor Enabled Signal)
Input (X74)	3^{rd}	7	JJ (Thyristor Control Enabled Signal)
Input (X75)	3^{rd}	7	FR (Over Current Relay Oil Pumps)
Input (X76)	3^{rd}	7	SB1.1 (Emergency Stop at Pendent)

Contd.

Input (X77)	3rd	7	SB2.1 (Emergency Stop at Cabinet)
Input (X100)	3rd	8	SQ4.1 (Column Base Limit Sw)
Input (X101)	3rd	8	SQ4.2 (Column Base Limit Sw)
Input (X102)	3rd	8	SQ5 (Column Base Limit Sw)
Input (X103)	3rd	8	SQ6 (Column Base Limit Sw)
Input (X104)	3rd	8	Spare
Input (X105)	3rd	8	Spare
Input (X106)	3rd	8	Spare
Input (X107)	3rd	8	Spare
Output (Y0)	Main	1	KA4+KA5+Ka6 (Spindle Power On)
Output (Y1)	Main	1	KA9 (Sw off Zerolocking)
Output (Y2)	Main	1	KA5+KA6 (Spindle Rotating)
Output (Y3)	Main	1	KA5.KA6 (Safety Spindle Rotation Motor)
Output (Y4)	Main	1	KA15 (Feed preset Zerolocking)
Output (Y5)	Main	1	KA11+KA12 (Feed Started)
Output (Y6)	Main	1	KA11.KA12 (Safety For Feed Motor)
Output (Y7)	Main	1	HL3 (Indication of Gear Engaged)
Output (Y10)	Main	2	SB9H (Indication of CW Rotation of Spindle)
Output (Y11)	Main	2	SB10H (Indication of CCW Rotation of Spindle)
Output (Y12)	Main	2	SB15H (Indication of Gear Engaged)
Output (Y13)	Main	2	SB16H (Indication of Gear Engaged)
Output (Y14)	Main	2	KM9 (Main Power Supply Contactor)
Output (Y15)	Main	2	Spare
Output (Y16)	Main	2	Spare
Output (Y17)	Main	2	Spare
Output (Y20)	Main	3	KM1 (Contactor of Thyristor Power Suplly)
Output (Y21)	Main	3	KM2 (Contactor of Oil Pump)
Output (Y22)	Main	3	KM3 (Contactor CW Rotation Spindle Motor)
Output (Y23)	Main	3	KM4 (Contactor CCW Rotation Spindle Motor)
Output (Y24)	Main	3	KM5 (Contactor of Brake)
Output (Y25)	Main	3	KM6 (Not Used)
Output (Y26)	Main	3	KM7 (Contactor of Feed Motor +ve Direction)
Output (Y27)	Main	3	KM8 (Contactor of Feed Motor –ve Direction)
Output (Y30)	2nd	4	YV1 (Speed Step Spindle)
Output (Y31)	2nd	4	YV2 (Face Plate Engage)
Output (Y32)	2nd	4	YV3 (Facing Plate in Operation)
Output (Y33)	2nd	4	YV4 (Facing Plate Feed)
Output (Y34)	2nd	4	YV5 (Head Stock Calmping)
Output (Y35)	2nd	4	YV6 (Lubrication of Column Base Relief)
Output (Y36)	2nd	4	YC1 (Slow Speed)
Output (Y37)	2nd	4	YC2 (Rapid Speed)
Output (Y40)	2nd	5	YC3 (Column Base Traverse)
Output (Y41)	2nd	5	YC4 (Column Base Brake)
Output (Y42)	2nd	5	YC5 (Headstock Traverse)
Output (Y43)	2nd	5	YC6 (Headstock Traverse)
Output (Y44)	2nd	5	YC7 (Spindle Traverse)
Output (Y45)	2nd	5	YC8 (Spindle Traverse)
Output (Y46)	2nd	5	YC9 (Headstock Brake)
Output (Y47)	2nd	5	YC10 (Spindle Brake)

a. Mitsubishi main unit FX1N-60MT-ESS/UL with 36 inputs and 24 relay outputs.

b. 2 X input extension modules FX2N-16EX-ES/UL with 16 inputs.

c. 1 X Output extension module FX2N-16EYR-ES/UL with 16 relay outputs.

The modules will be located in the local enclosures. This enclosure is previously used for relays.

4.3. Hardwired Elements

The elements which have no effect on the Logic of PLC will remain hardwired. These elements are emergency stop-switch, hydraulic pumps master switch, main switch, cabinet close switch and cabinet main switch.

4.4. Programming of PLC

After the complete conception of wiring diagram, timing diagrams, flow charts and assignment for all the inputs and outputs: coding of the relay logic was started and loaded in the PLC [10]. During this phase, machine thyristor control was made disable to avoid any accident and output of PLC was judged by the state of main magnetic contactors. When all the bugs were removed, machine thyristor control was enabled and machine was given first trial run. After several rehearsals, PLC program was authenticated and machine was given to the concern operator for further checking.

Table 3. Inputs/outputs (I/O) address assignment for the internal outputs.

Device	Internal	Description
KA3	Y70	+ve Inching Spindle
KA4	Y71	-ve Inching Spindle
KA5	Y72	CW Rotation Spindle
KA6	Y73	CCW Rotation Spindle
KA11	Y74	Power and Manual Selection
KA12	Y75	Feed Inching
KA1	Y100	Speed Change Spindle
KA2	Y101	Interlocking
KA7	Y102	Stop Spindle
KA8	Y103	Interlocking Switch
KA13	Y106	Feed Inching
KA14	Y107	Start Feed
KA17	Y111	Feed Speed Change
KA18	Y112	Feed Speed Change
KA19	Y113	Facing Plate Engage
KA20	Y114	Spindle Engage
KA21	Y115	Head Stock Engage
KA22	Y116	Column Base Engage
KT1	T0	SW on Spindle 1 Sec Delay
KT2	T1	Stop Spindle in 1 sec Delay
KT3	T2	Sw off Spindle from Thyristor 1 sec delay
KT4	T3	Sw off Spindle from Thyristor 1 sec delay
KT5	T4	Sw on Spindle Brake 1 Sec Delay
KT7	T5	Cut off main Contactor 1 Sec Delay
KT8	T6	Feed Preset and Zerolocking 1 Sec Delay
KT9	T7	Sw on Main Contactor 1 Sec Delay
KT	T8	Sw on/off Thyristor 2 Sec Delay

5. Test Faults

Before illustrating the test cases, it is worth mentioning that implementation of PLC result in the reduction of haphazard wiring. Fig. 6 shows the overall picture of the machine and the PLC wiring cupboard altogether.

Figure 6. Overall picture of the machine and the PLC wiring cupboard.

To test that new system installed in the machine is also friendly to the maintenance persons, following test faults were set up in the machine. The said tank manufacturing factory has another identical machine in this shop; following faults were also established in that machine. Same team of maintenance staff was asked to rectify the faults.

1. Open connection of relay.
2. One limit switch was short circuited with ground.
3. Missing of voltage at movable component selection switch.
4. Open connection at the clutch.
5. Open connection at the valve.
6. Magnetic contactor not energized.
7. Push button of feed not working.
8. No enable signal from thyristor control.
9. Breakage of connection at head stock electrical box.
10. Jammed limit switch.

Table 4. Detail of test faults results for the modified and unmodified machine.

S.No.	Faults	Time to Clear Fault (Mins)	
		Modified	Unmodified
1	Open connection of relay	25	1600
2	One limit switch was short circuited with ground	15	1400
3	Missing of voltage at movable component selection switch	25	60
4	Open connection at the clutch	20	900
5	Open connection at the valve	20	900
6	Magnetic contactor not energized	20	15
7	Push button of feed not working	20	720
8	No enable signal from thyristor control.	25	1000
9	Breakage of connection at head stock electrical box.	60	1700
10	Jammed limit switch.	30	1300

Rectification of these faults in the PLC based i.e. renovated machine have taken only 25~60 minutes. However, rectification of these faults in unmodified identical machine took 60~1700 minutes except for the fault number 6 which was cleared in only 15 minutes. Detail result of these faults has been shown in the Table 4.

6. Conclusion

The developed software using PLC had been successfully implemented in the existing horizontal boring and milling machine at Tank Manufacturing Factory, Heavy Industries Taxila (HIT), Pakistan. The automated system for the smooth operation of the said machine had been working for over four months. Due to this renovation, i.e. the development of efficient and accurate fault location mechanism result in the reduction of downtime. As a direct result, availability of the machine had been much improved. The requirement of inspecting each relay and each wire had also been reduced.

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