PLC Control Of Electro-Pneumatic System For Modern Manufacturing Plant

by

Mohd Zawawi Bin Md Abdul Jabar

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical and Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(DR. NORDIN BIN SAAD)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

DECEMBER 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(MOHD ZAWAWI BIN MD ABDUL JABAR)

ABSTRACT

This report discusses the application of Programmable Logic Controller (PLC) control in a modern manufacturing industry, the programming approach in the ladder diagram design and development and the associated design software tools, namely the OMRON CX programmer, Automation Studio and LADSIM simulator.

A case study on the development and simulation of a manufacturing plant process design was conducted to investigate for the viable and efficient approach in design and development of a PLC program. The usage of PLC has grown rapidly over the last 20 years to control process sequences ranging from small devices up to large process plant applications. This project is very much related to mechatronics and instrumentation design.

Throughout this research, rigorous literature review on the basic method of programming a PLC programming and the mechanical and the electronic devices used in the manufacturing plant design had been conducted to produce a reliable system for the design. Exposure to new design software such as Automation Studio and LADSIM has allowed simulations of the process sequences to be performed.

In this research, the manufacturing process was divided into three sections of process control systems. Each section has its own programming sequences. In the final program, all the programming systems are integrated together to form a full programming system.

The work provides the following main conclusions; the systematic and organized approach, as used in solving the sequential controls in a modern manufacturing plant, provides a better and flexible approach as well as better documentation. Although this research has been applied to a case study, however, the results and outcomes provide possible means of solving other similar systems or subsystems.

ACKNOWLEDGEMENTS

First and foremost, the author would like to thank God for all His blessings that made all things possible for while doing this research project.

The author would like to convey his highest gratitude to Dr. Nordin bin Saad for his guidance and assistance through the period of this project as supervisor. Without his advices and helps, the project may not be able to be completed within the given period of time.

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Last but not least, the author would like to thank all the people that have contributed in completing this project especially to all the lab mates and friends for their advices, support and comments.

TABLE OF CONTENTS

LISTS OF FIGURES

Page Number

LISTS OF TABLES

ABBREVIATIONS AND NOMECLATURES

FYP	Final Year Project
PETRONAS	Petroliam Nasional Berhad
PLC	Programmable Logic Controller
UTP	University Technology PETRONAS
CPU	Central Processing Unit

CHAPTER 1
INTRODUCTION

1.1 Background of Study

PLC continues to be important in modern process control. One reason for this is that PLC has become more sophisticated, with the availability of more powerful processors and sophisticated software. Basically, the target of this project is to design a realistic process of modern manufacturing plant using PLC. The process is divided into three sections; each section has its own programming sequence to control the process.

The three sections are; the refilling process, the product inspection for sorting process, and packaging line/sequence control process. Automation Studio Software has been used in the process design of the electro – pneumatic system. The PLC program has been developed using the OMRON PLC programming software and LADSIM software simulator.

Through out the research, the student has gained a lot of information about the usage of PLC in the manufacturing process system and learns new way in developing ladder diagram using several different approaches for example flowchart technique and the general rule technique. The design tools such as Automation Studio and Ladsim are very useful to simulate the develop design system before the next stage of testing with the real electro-pneumatic equipment.

To undertake this challenging project, extensive research and literature review has been concluded to acquire more understanding and knowledge. The study covers the fundamental programming of PLC, familiarization with the design software such as Automation Studio and OMRON, and circuit assembly and finally the experiments and system development.

1.2 Problem Statement

Basically each of the section represents a case study which needs to be solved to produce the right sequence of program to control the process. For each case, it involves a lot of analysis, and in fact some of the processes are very challenging. The design software is used to assist the student in finding a solution to a problem. The problem was first simulated on the simulation software before the implementation on the actual system.

The design process system need to be simulated first to ensure that the design is working as expected. If it is successful, then the design will proceed to the next section of the process until the whole manufacturing plant process system is completed. The overall diagram of the manufacturing process system is shown in *Appendix M.*

This project allows the student to learn a lot of things on PLC programming, software designs and simulations, the combination of mechatronics and instrument designs and on how improvement on a manufacturing system can be conducted. This would lead to a manufacturing system that is more reliable and more economical in terms of operational cost.

1.3 Objective and Scope of Study

The objectives of the design are as per below:

i. To design and develop a system that can be considered as not yet exist or to improve the system performance and efficiency of a current existing conventional system to be upgraded using PLC control.
ii. To enhanced the usage of PLC programming in modern manufacturing process system and create an organized and systematic approach for PLC programming.
iii. To gain more understanding on PLC programming, electro-pneumatic and manufacturing process systems, and also the design software application involved.

Therefore, the instrument and mechatronics design work is relevant to be developed since it has commercial value for applications in manufacturing plant requirement besides enhancing the student's understanding on the operation of manufacturing plant process system, and improves PLC programming skills.

The followings are several aspects that need to focus during the completing this project:

i. Research, design and develop the manufacturing process system.
ii. Electro-pneumatic diagram construction using Automation Studio for the operation of the overall manufacturing system.
iii. Development of ladder diagrams and mnemonics language for the overall process system using the OMRON PLC programming software.
iv. Simulation using laboratory equipments and real application LADSIM software simulator.

Although the availability of the electro-pneumatic sensors and actuators, and the relevant software's and controller in the instrumentation and control laboratory are still in their loose form, but the student are still able to complete this project within the project time frame.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 What is Programmable Controller?

A PLC consists of a Central Processing Unit (CPU) containing an application program and Input and Output Interface modules, which is directly connected to the field I/O devices. The program controls the PLC so that when an input signal from an input device turns ON, the appropriate response is made. The response normally involves turning ON an output signal to some sort of output devices[1].

The CPU is microprocessor that coordinates the activities of PLC system. It executes the program, processes I/O signals and communicates with external devices.

2.2 Block Diagram of PLC

The PLC consists of three major parts:

- Input signal from the process indicator/sensor
- PLC unit
- Output signals to the electro – pneumatic actuator to control the process

Basically, the block diagram of the design is as per below:

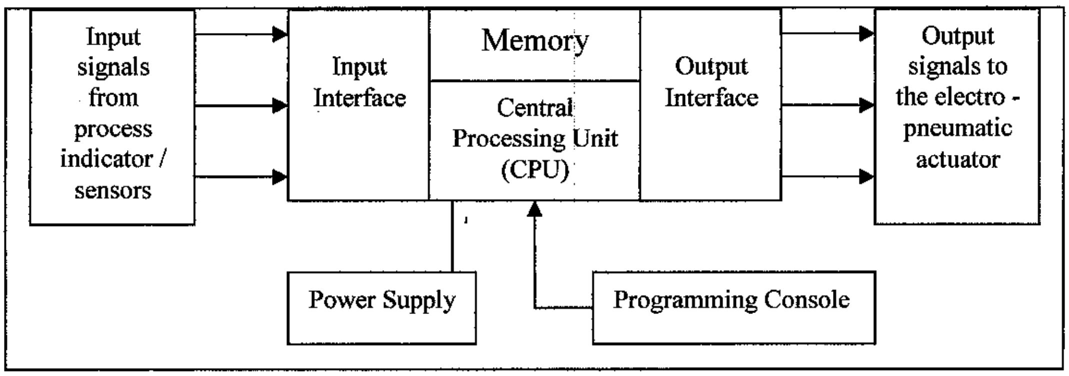


Figure 1: The block diagram of PLC design

[1] this definition is taken from 'Beginners Guide To PLC, OMRON PLC Programming Manual '.

2.3 Applications of PLC

There are three control types of PLC, and each type has its own control functions. Listed below are the types of PLC control and its function:

1. **Sequential Control** – Auto/Semi-auto manual control of machine/process
2. **Sophisticated Control** – Analog control (Temperature, Pressure, Flow, Level), Servo motor control, Stepper motor control
3. **Supervisory Control** – Process monitoring and alarm, Fault diagnosis and monitoring Flexible Manufacturing System (FMS), Computer Integrated Measurement System (CIMS), etc.

The figure below shows a typical control system of PLC:

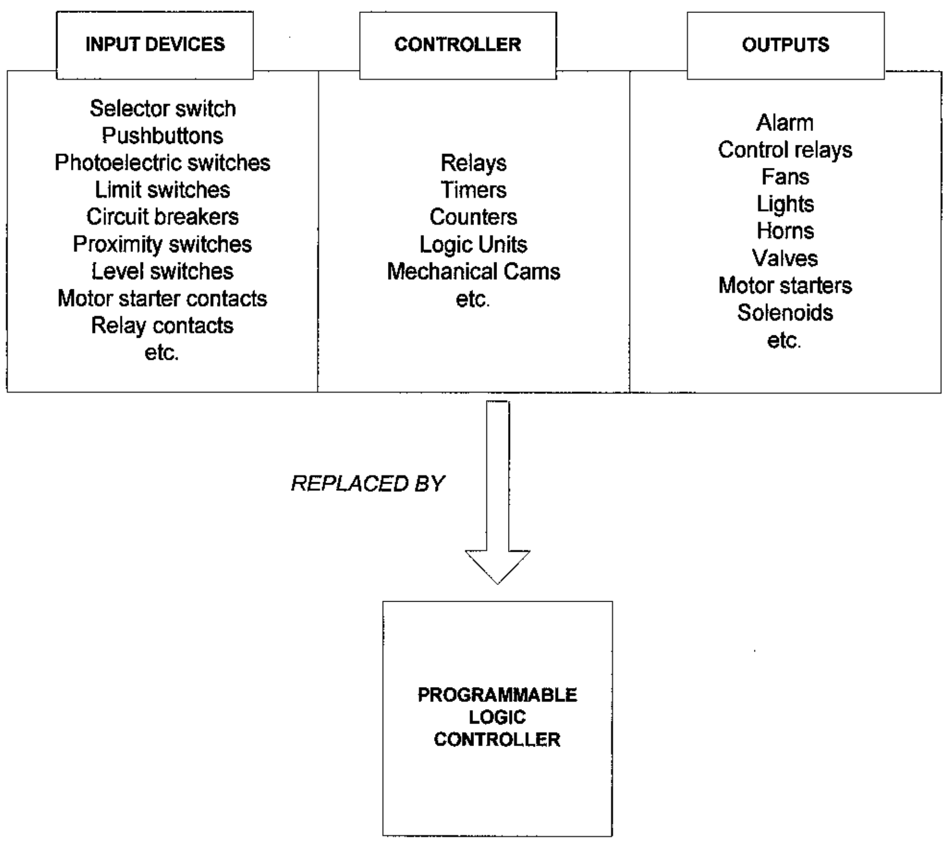


Figure 2: A typical control system

2.4 PLC Programming Language

2.4.1 Scan Time

Scan time is the process of reading the inputs, executing the program and updating the outputs. Scan time is normally a continuous and sequential process of reading the status of inputs, evaluating the control logic and updating the outputs. Scan time indicates how fast the controller can react to field inputs and correctly solve the control logic.

2.4.2 Types of Language

There are a few types of programming language for PLC. The most commonly used to design a control process sequence is ladder diagram. Listed below are other types of PLC language:

- Flowchart
- Boolean mnemonics
- Functional Block Programming (FB)
- Sequential Function Chart (SFC) [Grafcet]
- Logic diagram
- Structure Text Programming (ST)
- Instruction List (IL)

2.4.3 Ladder Diagram

A ladder diagram is a means of graphically representing the logic required in a relay logic system, representing +V and 0V. It consists of a number of rungs connecting two vertical lines. The ladder diagram instructions consist of:

- Relay
- Program Control
- Arithmetic
- Sequencers
- Timer and Counter
- Data Manipulation
- Data Transfer

Figure 3 shows an example of a PLC wiring diagram. The diagram shows basically how the external circuits integrate with the PLC and executes the sequence program (ladder diagram) stored in the PLC memory.

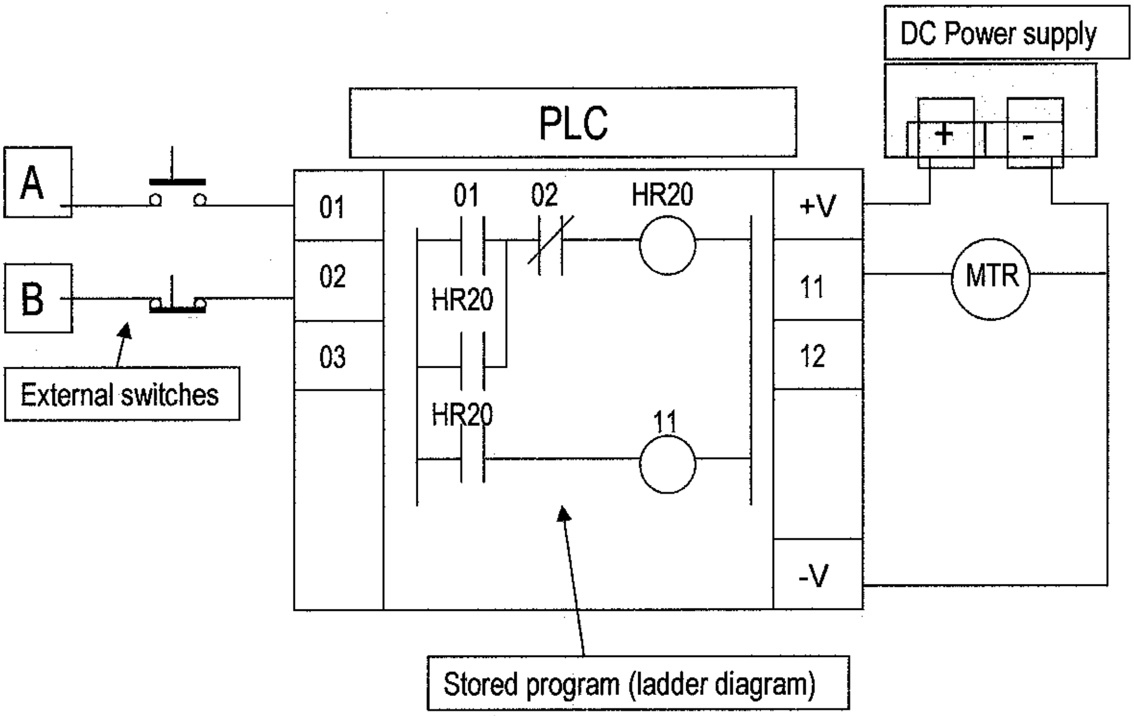


Figure 3: PLC wiring diagram

Figure 4 below shows the 'general rule' that is used extensively for the development of the ladder diagram. The general rule consists of four main sections; SET, RESET, LATCH and OUTPUT. From a timing diagram, an equation that describes the SET and RESET function is first established. The general equation is; OUTPUT = (SET+LACTH).$\overline{\text{RESET}}$. The corresponding ladder diagram can then be developed from the formulated equations. Detail examples on its implementation will be discussed in Chapter 4.

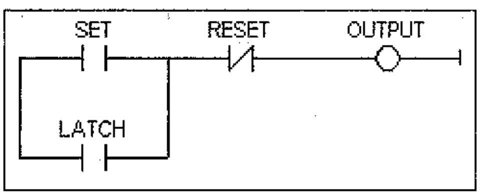


Figure 4: The ladder diagram general rule

CHAPTER 3
METHODOLOGY

3.1 Project Timeline

As a guide for monitoring the project time frame, a Gantt chart is developed, refer to *Appendix A*. The purpose of having the Gantt chart is to determine whether all the required tasks have been completed and to be aware of any outstanding works.

Based on the developed plan as shown in the Gantt chart, the progress of this project is within the time range allocated. Given such scenario, there is no overload of work, any outstanding works or delayed works. However, some changes of timeline in terms of duration of work have been made and the student successfully completed this project on time.

3.2 Project Work

Figure 5 shows the flow chart of the project works in order to complete the project.

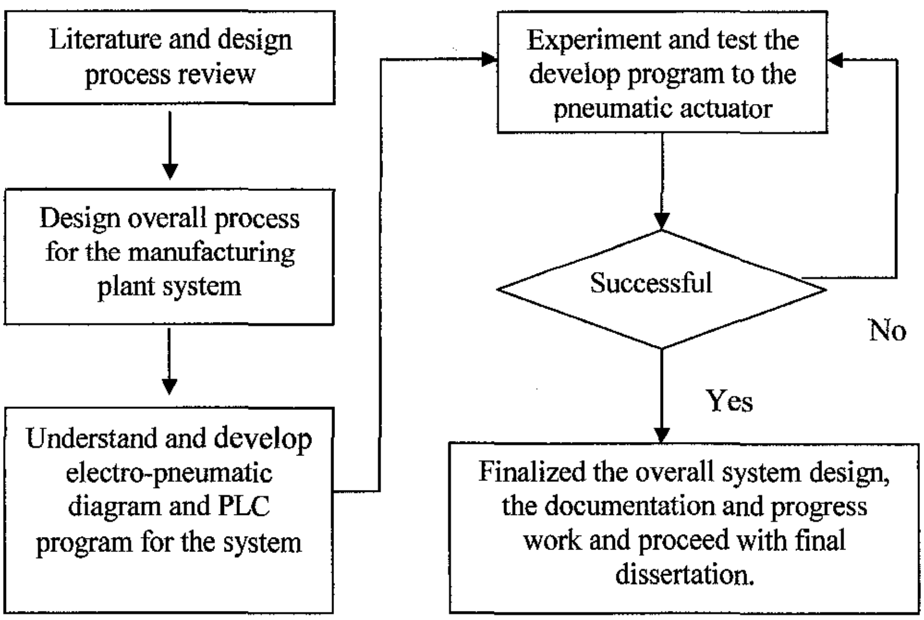


Figure 5: Flow chart for the project design

3.3 Design Tools

3.3.1 Automation Studio Design Tool

Automation Studio is a design, animation and simulation software tool created for the automation industry, specifically to fulfill training and testing requirements. This simulation utility makes Automation Studio an efficient tool for the student in completing the project. The software consists of several workshops, but only a few will be used because of the requirements in the project such as usage of electro-pneumatic components only in the manufacturing system design. The workshops relevant to be use as a design tool for the student's project are the *Pneumatic* and the *Electrical Control Workshop.*

The features of Automation Studio observed by the student when browsing through the software includes:

- Simulation modes can be triggered simply by clicking an icon. The simulation pace can be controlled by functions such as Full-speed, Slow-motion, Step-by step and Pause modes
- During simulation, circuits come to life, becomes animated and lines are colour-coded according to their status.
- Availability of a user-friendly valve editing dialog box that allows any valve configuration to the user's preferences.
- Variety of optional library modules, such as pneumatic and ladder logic modules available
- On-line help on components includes pictures, text and cross-sectional animation provides help to the user on most components.

The Automation Studio design software interface is shown in *Appendix B.*

3.3.2 CX Programmer (OMRON) Design Tool

CX-Programmer is a PLC programming tool for the creation, testing and maintenance of programs associated with Omron CS/CJ-series PLCs, CV-series PLCs and C-series PLCs. It provides facilities for the support of PLC device and address information and for communications with OMRON PLCs and their supported network types.

CX-Programmer is a support tool for the programming of OMRON PLCs and for maintenance of their device settings. It supersedes the OMRON applications SYSWIN and SYSMAC-CPT. The following list describes important features that are available in the CX-Programmer:

- Support for new PLCs – Full support has been added for the, CJ1M, and CS1D series PLCs.
- Changed the sizes and positions of dialogs for editing Contact/Coil/Instruction, Find and Replace, and Commented Rung.
- Auto Online, Work Online Simulator - Enhanced the online functionality making it easier to connect to PLCs and debug programs.
- Combine and Split rungs - The combine and split functions have been added making it easy to add and divide rungs.
- Watch Window - The watch window has been enhanced to enable addresses to be entered directly on the watch sheet.
- Key Mapping - The data of Keyboard Mapping can be saved to a file (*.mac) and loaded into a CX-Programmer.
- Section/Rung Manager - A function to edit a structure of Program is supported. Sections, Rungs and comments can be edited on this dialog.
- I/O Comment view - A View to edit comments of addresses is now supported.

The CX – Programmer OMRON design software interface is shown in *Appendix C.*

3.3.3 LabVolt Electrical Control of Pneumatic Systems Simulation Tool

The Lab-Volt Pneumatics Training System is an innovative, modular system that uses state-of-the-art hardware and courseware to deliver comprehensive training in the principles of pneumatic energy and its control applications. The Pneumatics Training System uses the same workbench and many electrical components of the Hydraulics II Training System, Model 6080, providing a convenient interconnection between both systems.

The Pneumatics course is divided into three levels. At the first level, Pneumatics I (Model 6081-1), students are introduced to the basic principles of pneumatics and gain hands-on experience in using them to perform a variety of functions. At the second level, Pneumatics II (Model 6081-2), students are introduced to electrical control of pneumatic systems using ladder diagrams. The third level, Advanced Fluid Controls Applications, expands upon the first two levels into pneumatic and hydraulic applications, demonstrating the use of servo controls, proportional controls, and programmable controls.

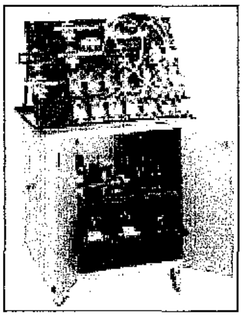


Figure 6: LabVolt Eletro Pneumatic Equipment

The basic system comes with a work surface assembly consisting of a solid metal, universal drip-tray, hinged to a perforated tiltable work surface. This work surface provides a large area for mounting the pneumatic components, using easy push-lock fasteners. All components meet industrial safety standards and are identified with ANSI symbols.

The equipment features are as follows:

- Engineered for extreme ease of use
- Components exceed industrial safety standards
- Optional support bench and dressing panels are available
- Components mount/dismount with easy push-lock fasteners
- Work station can be configured to accommodate a variety of space and teaching needs

3.3.4 Ladder Logic Editor and PLC Simulator (LADSIM by Bytronic)

This design tool software covers a brief history of the control plant equipment and the introduction to PLC control. It also covers types of PLC and the terminology used in programming. It introduces logic terms such as AND, OR and NOT, the equipment used for programming, and common languages used in programming.

The software element is called LADSIM. It has been developed to teach how to program a PLC without the expenses of buying PLC equipment. The package will simulate not only the programming elements of a PLC but it also contains working plant graphics to provide real simulation in the programme.

On the completion of this software, valuable experience has been obtained in the basics of PLC programming and sufficient confidence has been gained to proceed with learning to greater depth if required.

The LADSIM design software interface is shown in *Appendix D.*

CHAPTER 4
RESULTS AND DISCUSSION

As mentioned earlier in Chapter 1, to construct a ladder diagram more systematically, there are several steps need to be considered:

1. Description on the operation of the manufacturing process system
2. Identification of respective variables used in the system based on the timing diagrams
3. Solving the truth table and the respective equations of the timing diagram constructed
4. Construction of the ladder diagram based on the equations obtained using the 'general rule' as guide.

4.1 Conceptual Design for Section 1 Process System

The first section of the design is based on a problem involving the use of electro-pneumatic actuators given by the supervisor. Figure 7 shows the diagram of the design concept. The basic design concept consists of the following three electro-pneumatic actuators:

- Solenoid A – transportation / clamping
- Solenoid B – stamping / labeling
- Solenoid C – ejection

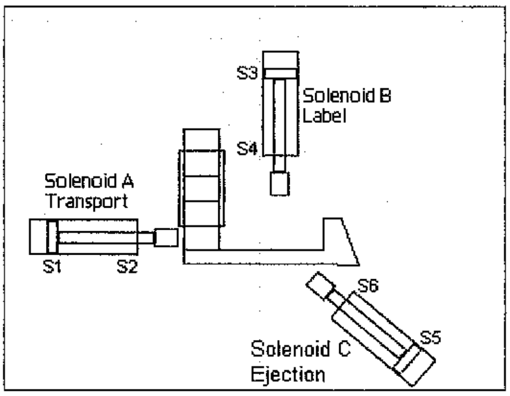


Figure 7: Conceptual design for section 1 process system

4.1.1 Design Description

Solenoid A will push the product and actuator A will stay at the S2 position. Subsequently, Solenoid B will energize and label the product. When Solenoid B return to its initial position (S3), Solenoid A also will return to its initial position (S1), Solenoid C will be energized and eject the product to a different process and then return to its initial position (S5). This operation is basically for one cycle of process system.

4.1.2 Variable Identification

Before developing the ladder diagram, the variables need to be identified based on the timing diagram. The timing diagram describing the operation of the actuators A, B and C is shown in Figure 8. The (+) and (-) symbol indicates the whether the solenoid is energized (+) or de-energized (-). The groups of the variables are identified as follows:

- V1 for A+ and B+
- V2 for B-, A- and C+
- V3 for C+

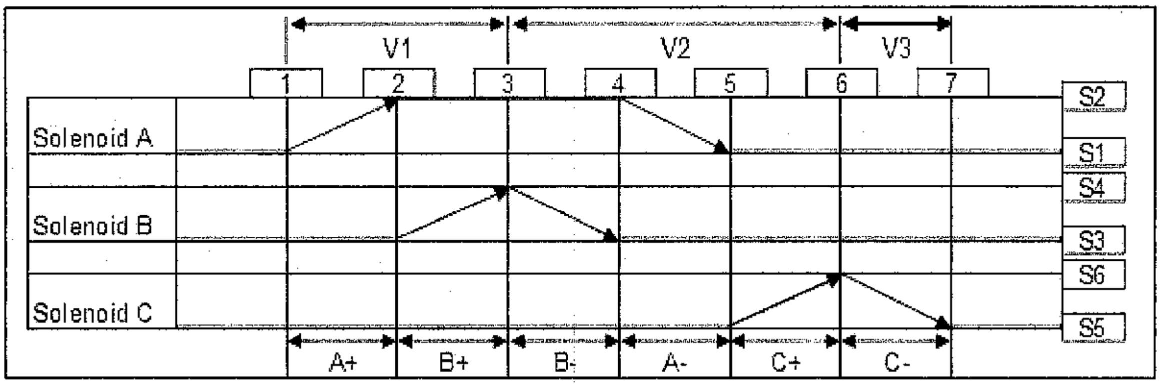


Figure 8: Conceptual design timing diagram

4.1.3 Truth Table and System Equations

The truth table needs to be developed first before the equation can be determined. Below are the truth table for the variables and the solenoids:

Variables	Set	Reset
V1	Start and S1	S4
V2	V1 and S4	S6
V3	V2 and S6	S5

Table 1: Truth table for Variables

Solenoids	Set	Reset
A	V1	V2 and S3
B	V1 and S2	V2 and S4
C	V2 and S1	V3 and S6

Table 2: Truth table for Solenoids

Using the general rule equation form:

$$\boldsymbol{OUTPUT = (SET + LATCH).\,\overline{RESET}}$$

the respective equations for the system are determined. The equations are:

$$V1 = (Start.S1 + V1).\overline{S4}$$
$$V2 = (V1.S4 + V2).\,\overline{S6}$$
$$V3 = (S6.V2 + V3).\,\overline{V1}$$
$$A = (V1 + A).\,\overline{V2.S3}$$
$$B = (V1.S2 + B).\,\overline{V2.S4}$$
$$C = (V2.S1 + C).\,\overline{V3.S6}$$

4.1.4 Development of Ladder Diagram

The construction of the system ladder diagram is now can be carried out. The full ladder diagram for this first section design concept is attached in *Appendix E.*

4.2 Section 1 Manufacturing Process System Design

The first section manufacturing process system is where the product is being process for refilling. Figure 9 below shows the overall design for section 1 process system. The basic design concept consists of four electro-pneumatic actuators:

- Actuator A – initial product transfer on to the conveyor
- Actuator B – product opener
- Actuator C – opening and closing of the refilling silo gate
- Actuator D – product sealer

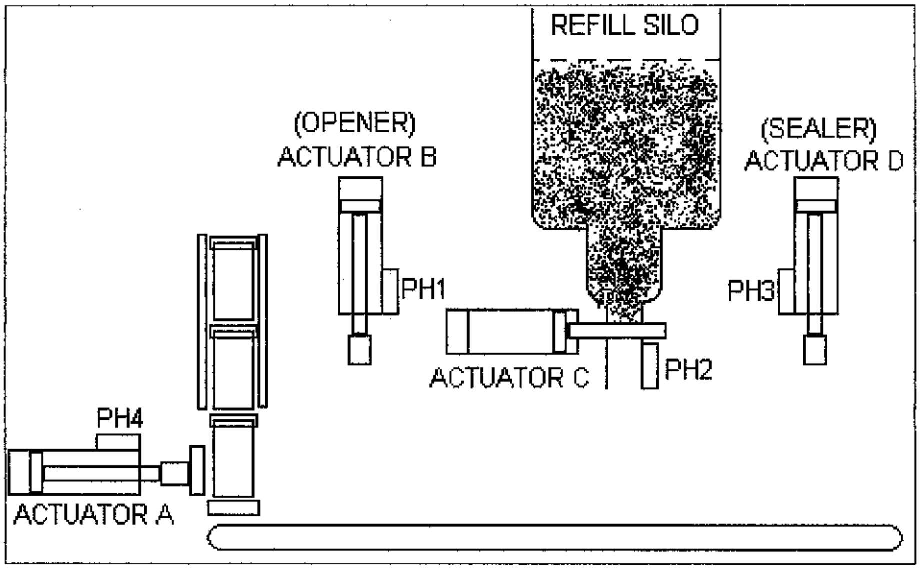


Figure 9: Section 1 design process

4.2.1 Design Description

When the Start button is pushed, PH4 will detect whether there is any product to be processed. If there is, Actuator A will push the product on to the conveyer and at the same time, the conveyer will start to move. When PH1 detects the product, the conveyer will stop and Actuator B opens the top of the product, then the conveyer will move again.

When PH2 detects the product, Actuator C releases the refill powder by opening the silo gate. After the product is filled, the conveyer will move. When PH3 detects a product, the conveyer will stop to let Actuator D to sealer the top of the product then conveyer will move again. This whole process is for one cycle and the process will repeat until PH4 detects no more products to be process.

4.2.2 Variables Identification

For this design, the student uses two different approaches to produce the ladder diagram. The approaches are as follows:

1. **Method 1** – Finding the timing diagram for the four actuators and develop the ladder diagram of the actuator process. In this approach, the only consideration of the ladder diagram is to observe whether the operation of the actuators is in the correct sequence.
2. **Method 2** – Finding the timing diagram for all the overall process and develop the ladder diagram for section 1 process system. In this approach, the input and output of the system need to be identified in order to get the right timing sequence between the output components and the input components.

4.2.2.1 Method 1 Variable Identification

Before developing the ladder diagram, the variables need to be identified based on the timing diagram. The timing diagram for method 1 section 1 process system is shown in Figure 10. The (+) and (-) symbol indicates the whether the solenoid is energized (+) or de-energized (-).

The groups of the variables are identified as follows:

- V1 for A+
- V2 for A- and B+
- V3 for B- and C+
- V4 for C- and D+
- V5 for D-

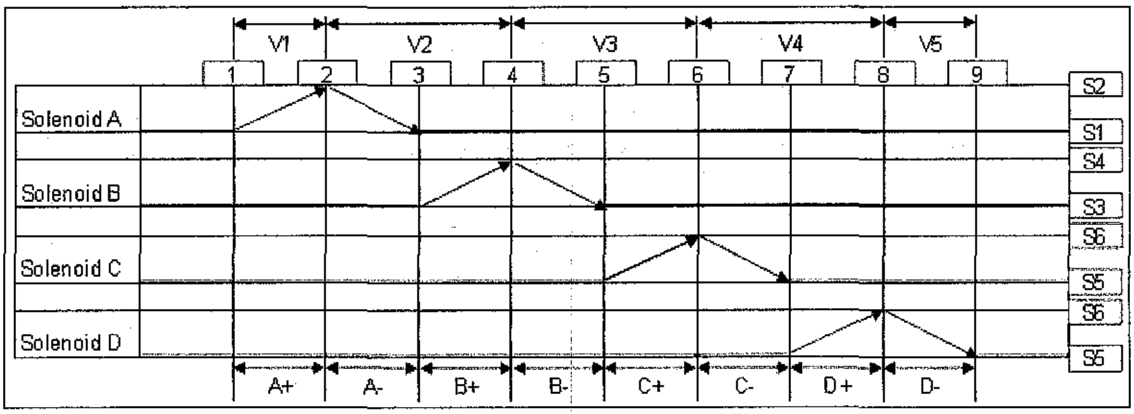


Figure 10: Method 1 timing diagram

4.2.2.2 Method 2 Input and Output Components Identification

Before developing the ladder diagram, the input and output components need to be identified based on the section 1 design process. The timing diagram for method 2 section 1 process system is shown in Figure 11. The input and output are identified as the following:

The input components are:

- Input 1 – Start button
- Input 2 – Photo sensor 1
- Input 3 – Photo sensor 2
- Input 4 – Photo sensor 3
- Input 5 – Photo sensor 4

The output components are:

- Output 1 – Actuator A
- Output 2 – Actuator B
- Output 3 – Actuator C
- Output 4 – Actuator D
- Output 5 – Conveyer motor

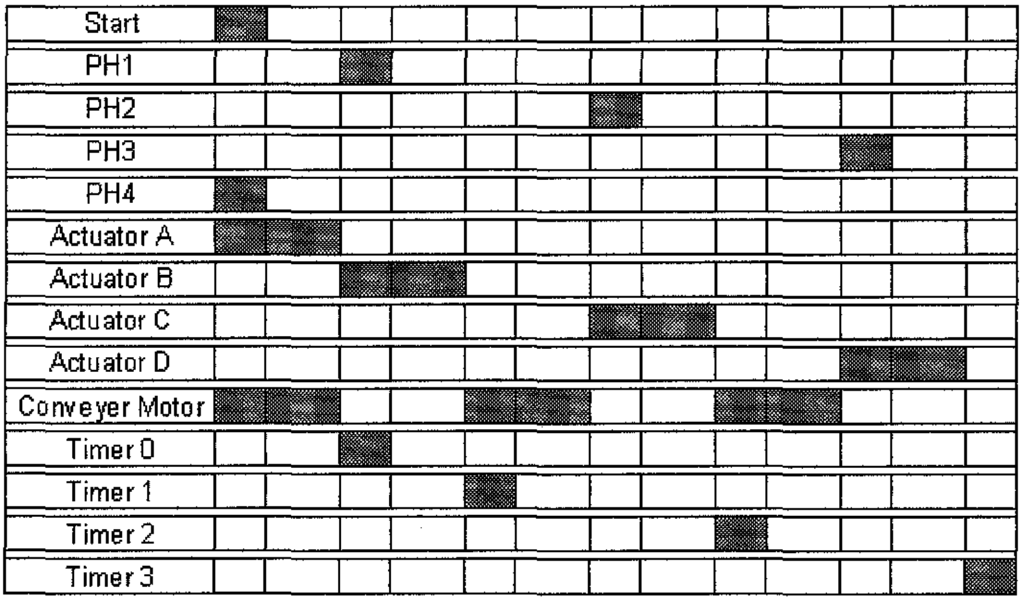


Figure 11: Method 2 timing diagram

4.2.3 Truth Table and System Equations

4.2.3.1 Method 1 Truth Table and System Equations

The truth table needs to be developed first before the equation can be determined. Below are the truth table for the variables and the solenoids:

Variables	Set	Reset
V1	Start and S1	S2
V2	S2 and V1	S4
V3	S4 and V2	S6
V4	S6 and V3	S8
V5	S8 and V4	S7

Table 3: Truth table for Variables

Solenoids	Set	Reset
A	V1	V2 and S2
B	V2 and S1	V3 and S4
C	V3 and S3	V4 and S6
D	V4 and S5	V5 and S8

Table 4: Truth table for Solenoids

Using the general rule equation form:

$$OUTPUT = (SET + LATCH).\overline{RESET}$$

the respective equations for the system are determined. The equations are:

$$V1 = (Start.S1+V1).\overline{S2}$$
$$V2 = (S2.V1+V2).\overline{S4}$$
$$V3 = (S4.V2+V3).\overline{S6}$$
$$V4 = (S6.V3+V4).\overline{S8}$$
$$V5 = (S8.V4+V5).\overline{S7}$$
$$A = (V1+A).\overline{(V2.S2)}$$
$$B = (V2.S1+B).\overline{(V3.S4)}$$
$$C = (V3.S3+C).\overline{(V4.S6)}$$
$$D = (V4.S5+D).\overline{(V5.S8)}$$

4.2.3.2 Method 2 Truth Table and System Equations

The truth table needs to be developed first before the equation can be determined. Below is the truth table for the holding relays based on the timing diagram of the input and output components:

Variables	Set	Reset
HRSTART	START BUTTON	STOP BUTTON
HRACT(A)	PH4	TIM 0 (5seconds)
HRACT(B)	PH1	TIM 1 (5seconds)
HRACT(C)	PH2	TIM 2 (5seconds)
HRACT(D)	PH3	TIM 3 (5seconds)
HRCONV	HRSTART	HRACT(B) or HRACT(C) or HRACT(D)

Table 5: Truth table for Holding Relays

Using the general rule equation form:

$$\boldsymbol{OUTPUT = (SET + LATCH).\ \overline{RESET}}$$

the respective equations for the system are determined. The equations are:

$$\begin{aligned}
&HRACT(A) = (PH4+HRACT(A)).\overline{TIM0} \\
&HRACT(B) = (PH1+HRACT(B)).\overline{TIM1} \\
&HRACT(C) = (PH2+HRACT(C)).\overline{TIM2} \\
&HRACT(D) = (PH3+HRACT(D)).\overline{TIM3} \\
&HRCONV = (HRSTART+HRCONV).\overline{(HRACT(B)+HRACT(C)+HRACT(D))} \\
&HRSTART = (START\ BUTTON + HRSTART).(\overline{STOP\ BUTTON})
\end{aligned}$$

4.2.4 Development of Ladder Diagram

The construction of the system ladder diagram can be carried out using the equations developed in the previous sections. The full ladder diagram for Method 1 Section 1 process system is attached in *Appendix F* and full ladder diagram for Method 2 Section 1 process system is attached in *Appendix G.*

4.3 Section 1 Manufacturing Process Design System Modification for Method 1

The main purpose for the modification is to eliminate the effect of the conveyer operation as one of the input to the system.

4.3.1 Design Description for Modification

For this new modification, the student has added one more pneumatic actuator to hold the product while it is being processed. This modification is to exclude the control for the conveyor in the process system, which means that the PLC program is independent to the conveyor movement setting.

So, when the Start button is pushed, PH4 will detect whether there is any product to be processed. If there is, Actuator A will push the product on to the conveyer and at the same time, the conveyer will start to move.

When PH1 detects the product, the Actuator B will expand and stop the product from moving. Then, Actuator C will opens the top of the product, Actuator D will release the refill powder by opening the silo gate and, after the product is filled, Actuator E will seal the top of the product and this process is based on the timing sequence developed.

This whole process is for one cycle and the process will repeat until PH4 detects no more products to be process and the product will proceed to the next section which is the visual inspection section.

4.3.2 Modified Method 1 Variable Identification

The modifications of the sequence timing diagram are as below:

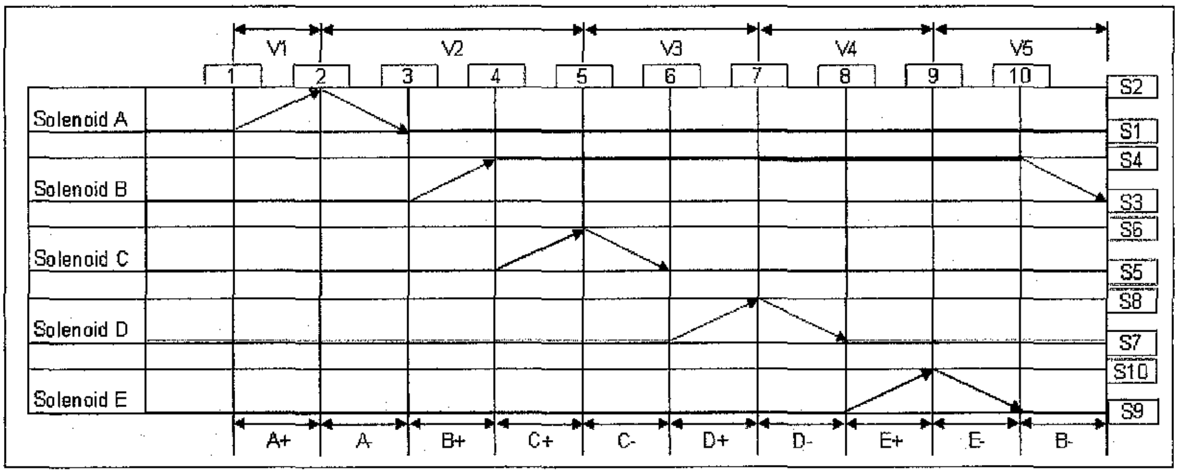


Figure 12: Modified section 1 process system sequence timing diagram

4.3.3 Modified Method 1 Truth Table and System Equations

The modified method 1 truth table and system equations are as follows:

Variables	Set	Reset
V1	Start and S1	S2
V2	S2 and V1	S4
V3	S6 and V2	S6
V4	S8 and V3	S8
V5	S10 and V4	S7

Table 6: Truth table for Variables

Solenoids	Set	Reset
A	V1	V2 and S2
B	V2 and S2	V5 and S9
C	V2 and S4	V3 and S6
D	V3 and S5	V4 and S8
E	V4 and S7	V5 and S10

Table 7: Truth table for Solenoids

Using the general rule equation form:

$$\boldsymbol{OUTPUT = (SET + LATCH).\overline{RESET}}$$

the respective equations for the system are determined. The equations are:

$V1 = (START.S1+V1).\overline{S2}$	$A = (V1+A).\overline{(V2.S2)}$
$V2 = (S2.V1+V2).\overline{S4}$	$B = (V2.S2+B).\overline{(V5.S9)}$
$V3 = (S6.V2+V3).\overline{S6}$	$C = (V2.S4+C).\overline{(V3.S6)}$
$V4 = (S8.V3+V4).\overline{S8}$	$D = (V3.S5+D).\overline{(V4.S8)}$
$V5 = (S10.S4+V5).\overline{S7}$	$E = (V4.S7+E).\overline{(V5.S10)}$

The full ladder diagram for modified Method 1 Section 1 process system is attached in *Appendix H.*

4.4 Section 2 Manufacturing Process System Design

The student has completely developed the PLC programme for this section using a timing diagram method. The diagram of section 2 process system is as follows:

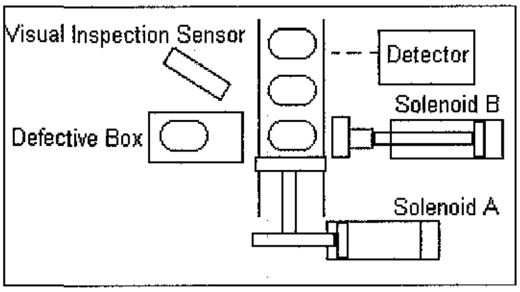


Figure 13: Section 2 Design of Manufacturing Process System

4.4.1 Design Description

The detector act as an input to Solenoid A where when it detects the product, it will send a signal to Solenoid A and the pneumatic actuator will engage. Actuator A will act as a blocker to the product so that the visual inspection to detect the defective product can be done. If the visual inspection sensor indicates a defect, it will send a signal to Solenoid B to activate Actuator B and pushing the product in to the defective box. Then the process continues on section 3.

4.4.2 Input and Output Components Identification

The timing diagram for section 2 process system is shown in Figure 14. The input and output are identified as the following:

The input components are:

- Input 1 – Product detector sensor
- Input 2 – Visual inspection sensor

The output components are:

- Output 1 – Actuator A
- Output 2 – Actuator B

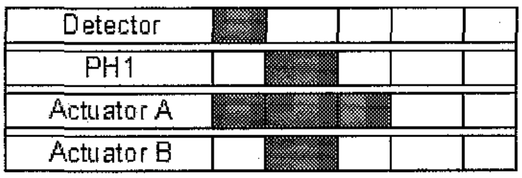


Figure 14: Section 2 timing diagram

4.4.3 Truth Table and System Equations

Below is the truth table for the holding relays based on the timing diagram of the input and output components:

Variables	Set	Reset
HRSTART	START BUTTON	STOP BUTTON
HRACT(A)	PH1	TIM 0 (5seconds)
HRACT(B)	PH2	TIM 1 (2seconds)

Table 8: Truth table for Holding Relays for Section 2

Using the general rule equation form:

$$\boldsymbol{OUTPUT = (SET + LATCH).\ \overline{RESET}}$$

the respective equations for the system are determined. The equations are:

$$\text{HRSTART} = (\text{START BUTTON} + \text{HRSTART}).(\overline{\text{STOP BUTTON}})$$
$$\text{HRACT(A)} = (\text{PH1} + \text{HRACT(A)}).(\overline{\text{TIM 0}})$$
$$\text{HRACT(A)} = (\text{PH1} + \text{HRACT(A)}).(\overline{\text{TIM 0}})$$

The full ladder diagram for Section 2 process system is attached in *Appendix I.*

4.5 Section 3 Manufacturing Process System Design

This section will be the part that is going to be simulated using LADSIM software simulator. The diagram of the system is as below:

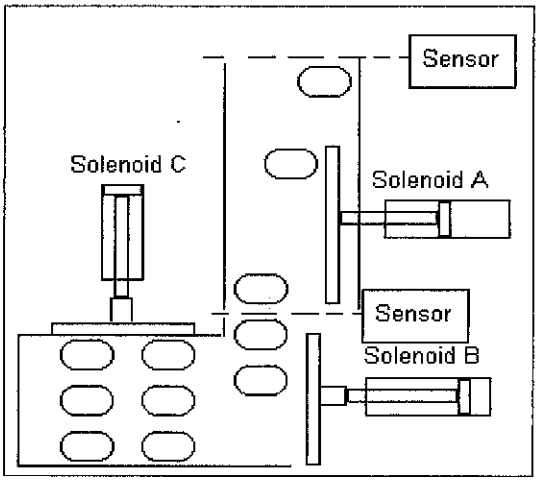


Figure 15: Section 3 Design of Manufacturing Process System

4.5.1 Design Description

This section of the system will focus on the product packaging process. When the sensor detects the product, it will trigger Actuator A to start sorting the product into position. Then, another sensor will start counting for three times, three products are sorted, and it will initial Actuator B to push the product to the stacking conveyer. Actuator C will stack the product into the boxes after completing 2 cycles of product sorting by Actuator B.

4.5.2 Variables Identification

The sequence timing diagram and the truth tables for section 3 process systems are as follows:

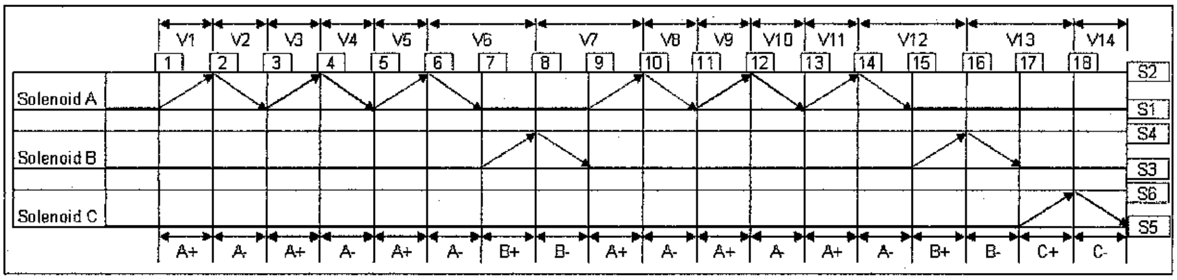


Figure 16: Section 3 Process System Sequence Timing Diagram

4.5.3 Truth Table and System Equations

The truth table and system equations for section 2 process system are as follows:

Table 9: Truth table for Variables

Variables	Set	Reset
V1	Start and S1	S2
V2	S2 and V1	S1
V3	S1 and V2	S2
V4	S2 and V3	S1
V5	S1 and V4	S2
V6	S2 and V5	S4
V7	S4 and V6	S2
V8	S2 and V7	S1
V9	S1 and V8	S2

Table 10: Truth table for Solenoids

Solenoids	Set	Reset
A	V1 or (S1 and V3) or (S1 and V5) or (S3 and V7) or (S1 and V9) or (S1 and V11)	(S2 and V2) or (S2 and V4) or (S2 and V6) or (S2 and V8) or (S2 and V10) or (S2 and V12)
B	(S1 and V6) or (S1 and V12)	(S4 and V7) or (S4 and V13)

V10	S2 and V9	S1
V11	S1 and V10	S2
V12	S2 and V11	S4
V13	S4 and V12	S6
V14	S6 and V13	S5

C	S3 and V13	S6 and V14

Using the general rule equation form:

$$OUTPUT = (SET + LATCH).\ \overline{RESET}$$

the respective equations for the system are determined. The equations are:

$V1 = (START.S1+V1).\overline{S2}$
$V2 = (S2.V1+V2).\overline{S1}$
$V3 = (S1.V2+V3).\overline{S2}$
$V4 = (S2.V3+V4).\overline{S1}$
$V5 = (S1.V4+V5).\overline{S2}$
$V6 = (S2.V5+V6).\overline{S4}$
$V7 = (S4.V6+S2).\overline{S2}$
$V8 = (S2.V7+V8).\overline{S1}$
$V9 = (S1.V8+V9).\overline{S2}$
$V10 = (S2.V9+V10).\overline{S1}$
$V11 = (S1.V10+S2).\overline{S2}$
$V12 = (S2.V11+V12).\overline{S4}$
$V13 = (S4.V12+V13).\overline{S6}$
$V14 = (S6.V13+V14).\overline{S5}$
$A = ([V1+S1.V3+S1.V5+S3.V7+S1.V9+S1.V11]+A).\overline{(S2.V2+S2.V4+S2.V6+S2.V8+S2.V10+S2.V12)}$
$B = ([S1.V6+S1.V12]+B).\overline{(S4.V7+S4.V13)}$
$C = (S3.V13+C).\overline{(S6.V14)}$

The full ladder diagram for Section 3 process system is attached in *Appendix J.*

4.5.4 Modification for Section 3 Variable Identification

The main purpose for the variable modification is to include a counter in the sequence in order to minimize the repetition sequence operation of the same actuator. The sequence timing diagram and the truth tables for section 3 process systems are as follows:

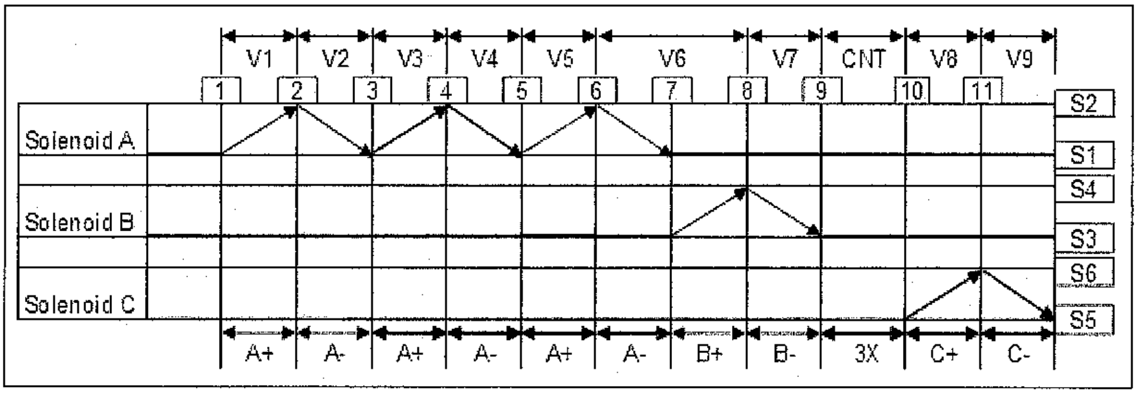


Figure 17: Modified Section 3 Process System Sequence Timing Diagram

4.5.5 Modification for Section 3 Truth table and System Equations

The truth table and system equations for section 2 process system based on the modified timing sequence are as follows:

Table 11: Truth table for Variables

Variables	Set	Reset
V1	Start and S1 or S3 and V7	S2
V2	S2 and V1	S1
V3	S1and V2	S2
V4	S2 and V3	S1
V5	S1and V4	S2
V6	S2 and V5	S4
V7	S4 and V6	S3

Table 12: Truth table for Solenoids

Solenoids	Set	Reset
A	V1 or (S1 and V3) or (S1 and V5)	(S2 and V2) or (S2 and V4) or (S2 and V6)

CNT 1	S3 and V7	S6
V8	CNT 1	S6
V9	S6 and V8	S5

B	S1 and V6	S4 and V7
C	CNT 1	S6

Using the general rule equation form:

$$\boldsymbol{OUTPUT = (SET + LATCH).\ \overline{RESET}}$$

the respective equations for the system are determined. The equations are:

$$
\begin{aligned}
&V1 = ([START.S1+S3.V7]+V1).\overline{S2}\\
&V2 = (S2.V1+V2).\overline{S1}\\
&V3 = (S1.V2+V3).\overline{S2}\\
&V4 = (S2.V3+V4).\overline{S1}\\
&V5 = (S1.V4+V5).\overline{S2}\\
&V6 = (S2.V5+V6).\overline{S4}\\
&V7 = (S4.V6+S2).\overline{S3}\\
&CNT\ 1 = (S3.V7).\overline{S6}\\
&V8 = (CNT\ 1+V8).\overline{S6}\\
&V9 = (S6.V8+V9).\overline{S5}\\
&A = ([V1+S1.V3+S1.V5]+A).(\overline{S2.V2+S2.V4+S2.V6})\\
&B = (S1.V6+B).(\overline{S4.V7})\\
&C = (CNT\ 1+C).\overline{S6}
\end{aligned}
$$

The full ladder diagram for Section 3 process system is attached in *Appendix K.*

4.6 Hardware Implementation and Software Simulation

Before beginning the development of the hardware simulation, there are a few preparations that the student needs to consider so that the development of the hardware systems will be according to the design and the time consumption will be minimized. The initial tasks that had to be done are:

1. Test the PLC programme in Automation Studio software simulation.
2. Initial checking on the LabVolt Electro- Pneumatic actuator equipment.
3. Testing the equipment to see how it is worked.

4. Gather information on how to operate the equipment.
5. Identify problems that might occur in order to develop the hardware simulation for section 1 process.

4.6.1 Automation Studio Software Simulation

The student had tested the developed PLC programming in the Automation Studio Design Tool and as a result, the actuator moved according to the expected sequence.

4.6.1.1 Section 1 Manufacturing Process System Simulation

For this simulation, the components consist of:

- 4 electro-pneumatic actuators
- 8 limiting switch
- 4 solenoid valve positioner

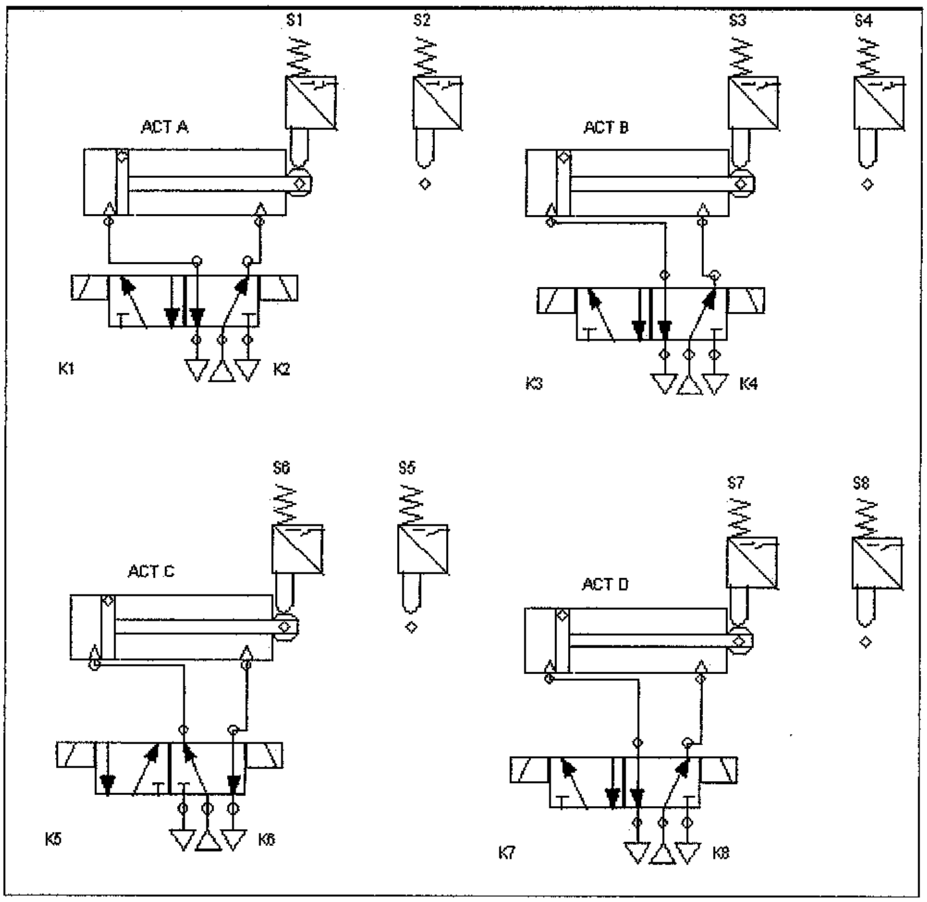


Figure 18: Section 1 Automation Studio Software Simulation

4.6.1.2 Section 3 Manufacturing Process System Simulation

For this simulation, the components consist of:

- 3 electro-pneumatic actuators
- 6 limiting switch
- 3 solenoid valve positioner

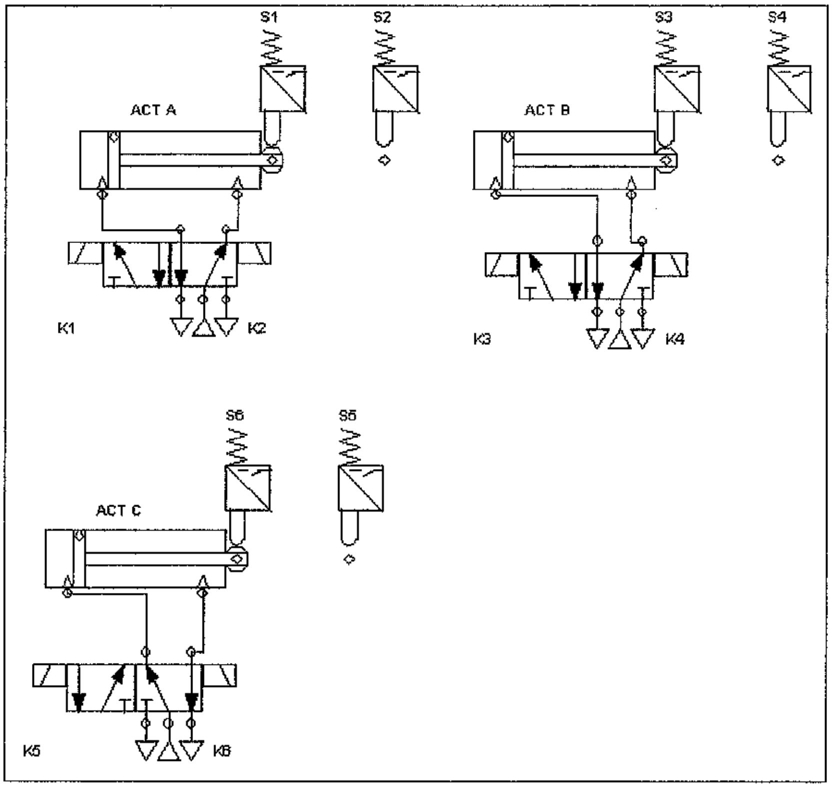


Figure 19: Section 3 Automation Studio Software Simulation

4.6.2 Section 1 Electro-Pneumatic Hardware Implementation

After performing all the preliminary procedures and starts to develop the hardware, the student encounter a few problems are as per below:

1. Not enough double acting actuators to cater for the new modified design.
2. The connections for the equipment are analog and it does not provide digital PLC.
3. The ladder diagram needs to be modified in order for the hardware to perform properly.

4. The tagging for the input and output in the ladder diagram needs to be suited with the PLC (CMP1A or CPM2A).

For the first problem, the student precedes the hardware simulation using the original design rather than the modified design because of lack of actuators. For the connection to the equipment, the student able to mitigate the problem by using the OMRON PLC integrate with the LabVolt equipment to avoid tedious analog connection using the actual equipment provided.

The ladder diagram need to be modified because of the switching timing used in the ladder diagram used in the software simulation is to fast and it is not suitable for the OMRON PLC. The initial sequence of the truth table is as per below:

Variables	Set	Reset
V1	Start and S1	S2
V2	S2 and V1	S4
V3	S4 and V2	S6
V4	S6 and V3	S8
V5	S8 and V4	S7

Table 13: Truth table for Variables

Solenoids	Set	Reset
A	V1	V2 and S2
B	V2 and S1	V3 and S4
C	V3 and S3	V4 and S6
D	V4 and S5	V5 and S8

Table 14: Truth table for Solenoids

These truth tables are valid for the software simulation but need to be modified for the hardware simulation. In order for the hardware to work using the PLC model CPM1A, the student had to remove the variable in the set position. The truth tables for the hardware simulation are as follows:

Variables	Set	Reset
V1	Start and S1	S2
V2	S2	S4

Solenoids	Set	Reset
A	V1	V2 and S2
B	V2 and S1	V3 and S4

V3	S4	S6
V4	S6	S8
V5	S8	S7

Table 15: Truth table for Variables

C	V3 and S3	V4 and S6
D	V4 and S5	V5 and S8

Table 16: Truth table for Solenoids

The pictures for the hardware simulations are attached in *Appendix L.*

4.6.3 Section 2 Automation Studio Software Simulations

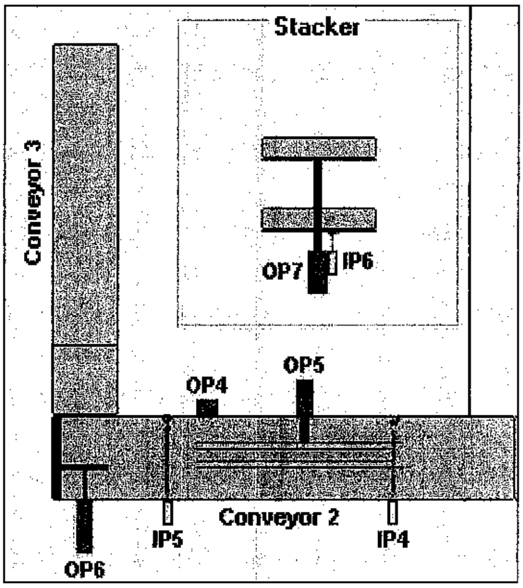


Figure 20: Section 3 Packaging System Ladsim Simulation

4.6.3.1 Input and Output Components

Input components:

IP4 – initial positioning sensor

IP5 – counter sensor

IP6 – limit switch for stacker

Output components:

OP5 – positioning actuator

OP6 – stacker actuator

OP7 – stacker to conveyer 3 actuator

4.6.3.2 Process Description

As it enters conveyer 2, a sensor IP4 will detects it presence and activates the initial stacking actuator OP5. This operation is to guide the product to the right position before stacking it in a row. After it reaches the end of conveyer 2, it will trigger IP5 which will:

- Deactivate actuator OP5
- Count the number of product into stacker
- Will activate actuator OP6 when number of product reaches the expected number based on the counter settings

After the stacker is completed will enough product, then it will lower down to conveyer 3 for packaging purposes. As a result, the section 3 process system animation simulation of real application is completed.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Understanding how the PLC operates, electro-pneumatic and the manufacturing process systems, as well as capable of using the design tool software is the basis of creating a guideline on developing the manufacturing process system by using electro-pneumatic plc programming.

Learning to use the systematic approach to develop the ladder diagram is also one of the most crucial progresses in this project. This method provides a more flexibility approach than the conventional flowchart method. It is recommended to use this systematic approach method because the program sequences are clearly documented in an equations form. Any error occurs while developing the ladder diagram would be easily troubleshot.

By using conventional approach would require performing trial and error methods to detect the error, thus involve much more time consumption especially during troubleshooting of the program. Although this project is considered new and challenging, but the work has been successfully completed in the specified time.

On overall, the student has gained a lot of experience and technical knowledge on PLC programming, ladder diagram design and development and also on industrial instrumentation equipment, applications and control systems. The experiences in both technical hands on work and project management are very important to enhance the student's programming skills using PLC for modern manufacturing plant system, or other similar system and subsystems.

REFERENCES

References books:

1. *Beginners Guide To PLC*, OMRON PLC Programming Manual
2. FAMIC Technologies 2000 Inc, 2000, *User's Guide for the Automation Studio*, FAMIC Technologies 2000 Inc.
3. CX – Programmer Manual Version 3.0
4. LADSIM Manual PDF File.

References Web site:

1. www.automationstudio.com
2. www.murata.com
3. www.allenbradley.com
4. www.omron.com

APPENDICES

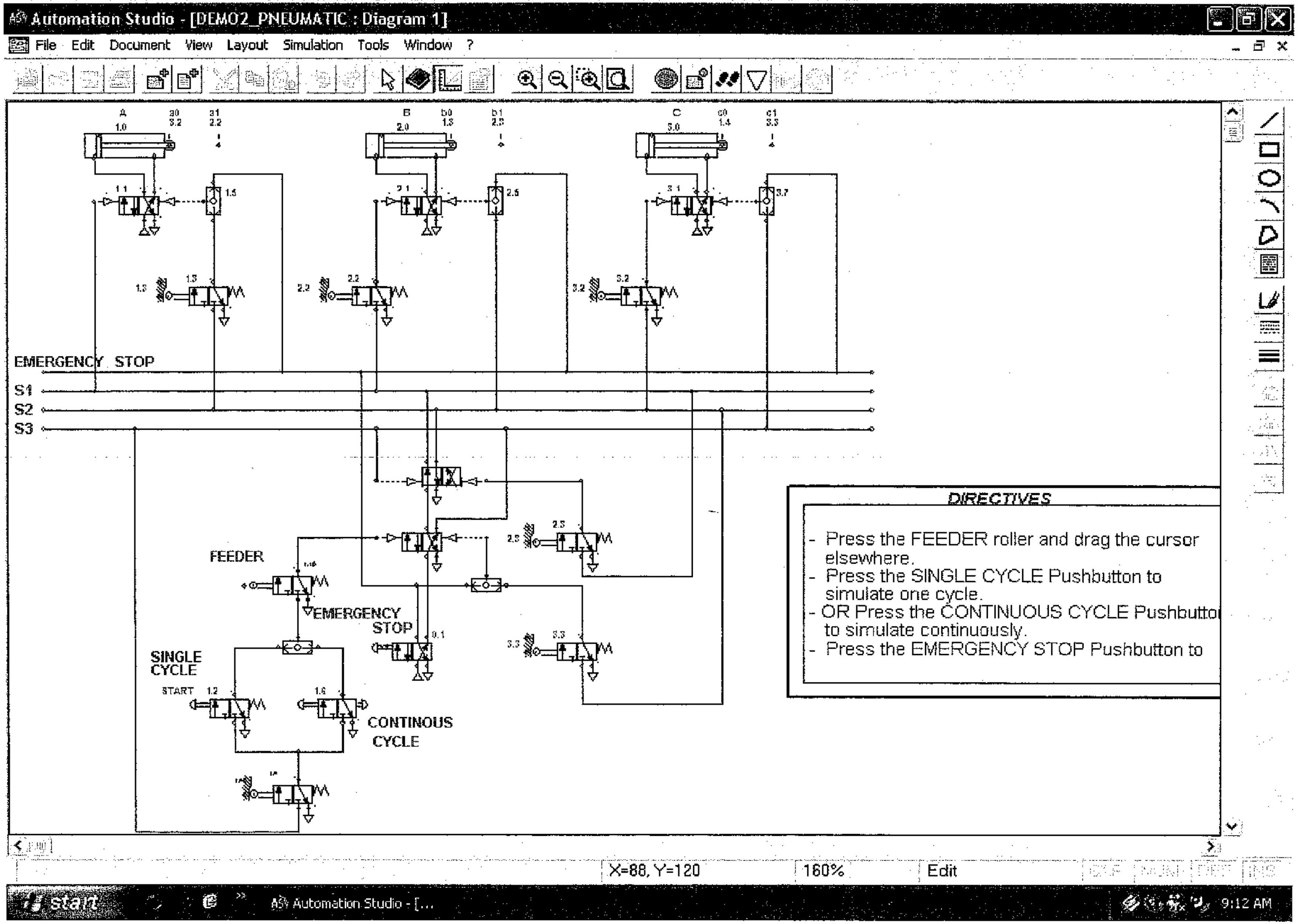
1. Final Year Project Gantt Chart for the first semester (19 January 2004 – 18 July 2004)
2. The Automation Studio design software interface
3. The CX – Programmer OMRON design software interface
4. LADSIM Software Simulator interface
5. Full ladder diagram for Conceptual Design system
6. Full ladder diagram for Method 1 Section 1 process system
7. Full ladder diagram for Method 2 Section 1 process system
8. Full ladder diagram for Modified Section 1 process system
9. Full ladder diagram for Section 2 process system
10. Full ladder diagram for Section 3 process system
11. Full ladder diagram for Modified Section 3 process system
12. Section 1 Hardware Simulation pictures

APPENDICES

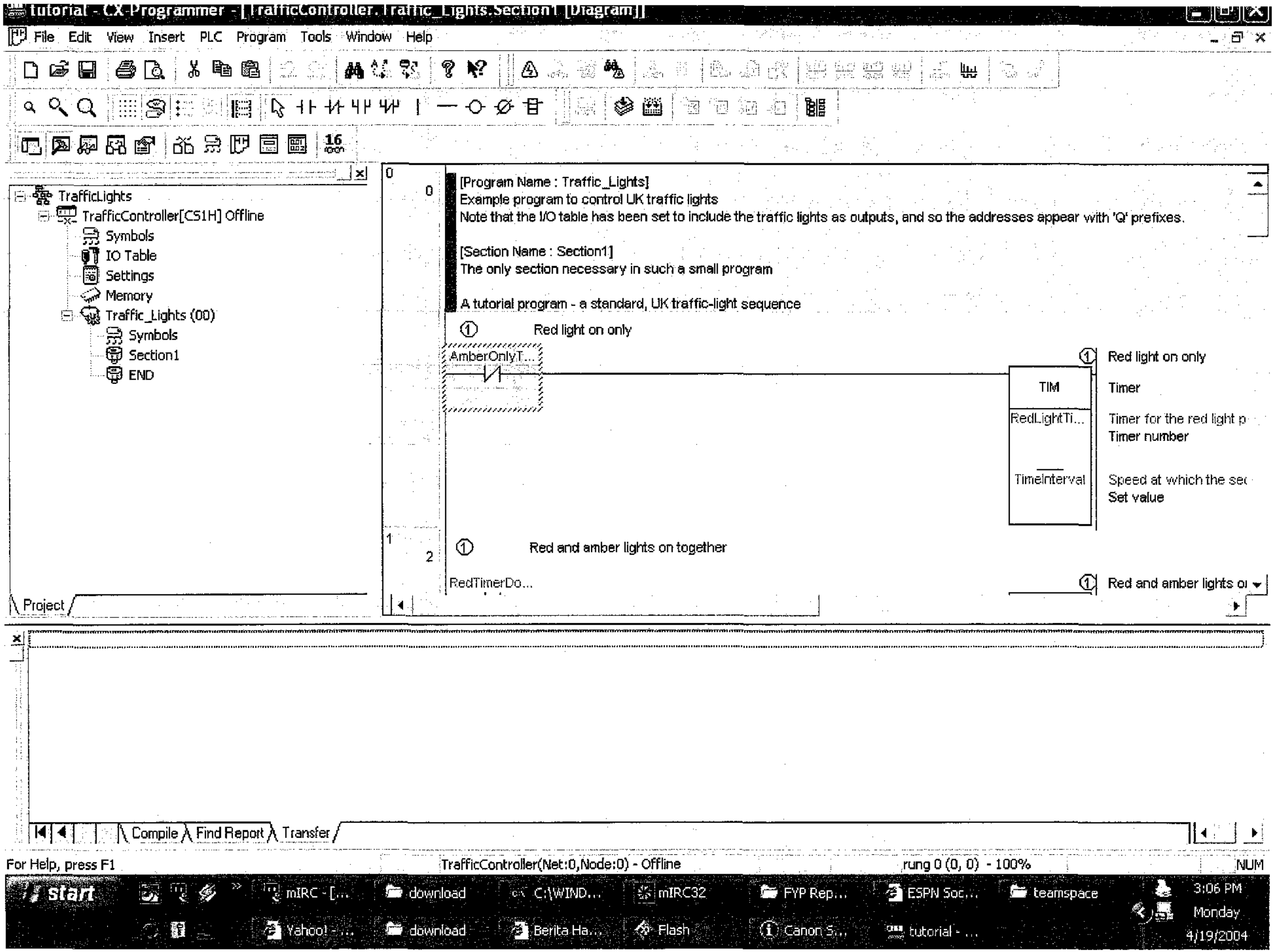
APPENDIX A

No	Detail/Week	1	2	3	4	5	6	7	Break	8	9	10	11	12	13	14	15	16	17	18	19	Remarks
1	Continuation of PLC Programming																					
	- Modification on Section 1 System																					
	- Development of Section 2 & 3 System																					
2	Preliminary Research Work for Hardware Sim.																					
	- Problem Definition																					
	- Equipment PLC programming concept																					
3	Submission of Progress Report 1																					
4	Further Development																					
	- Test the design PLC Programming																					
	- Fimiliarization with hardware equipment																					
	- Understanding the equipment process																					
5	Methodologies and Planning Documentation																					
6	Project Work																					
	- Overall Design system																					
	- Drawings, and																					
	- Concept																					
	- PLC hardware programming																					
	- Basic of manufacturing process design																					
7	Submission of Progress Report 2																					
8	Project Work (continue)																					
	- Finalise the hardware programming																					
	- Intergrate hardware and software design																					
	- Finalise overall system experiment																					
9	Finalised all the findings and results																					
10	Revision on the project status																					
11	Submission of Final Report - Final Draft																					
12	Submission of Final Report Softcover																					
13	Technical Report																					
14	Oral Presentation & Final Report Hardcover																					

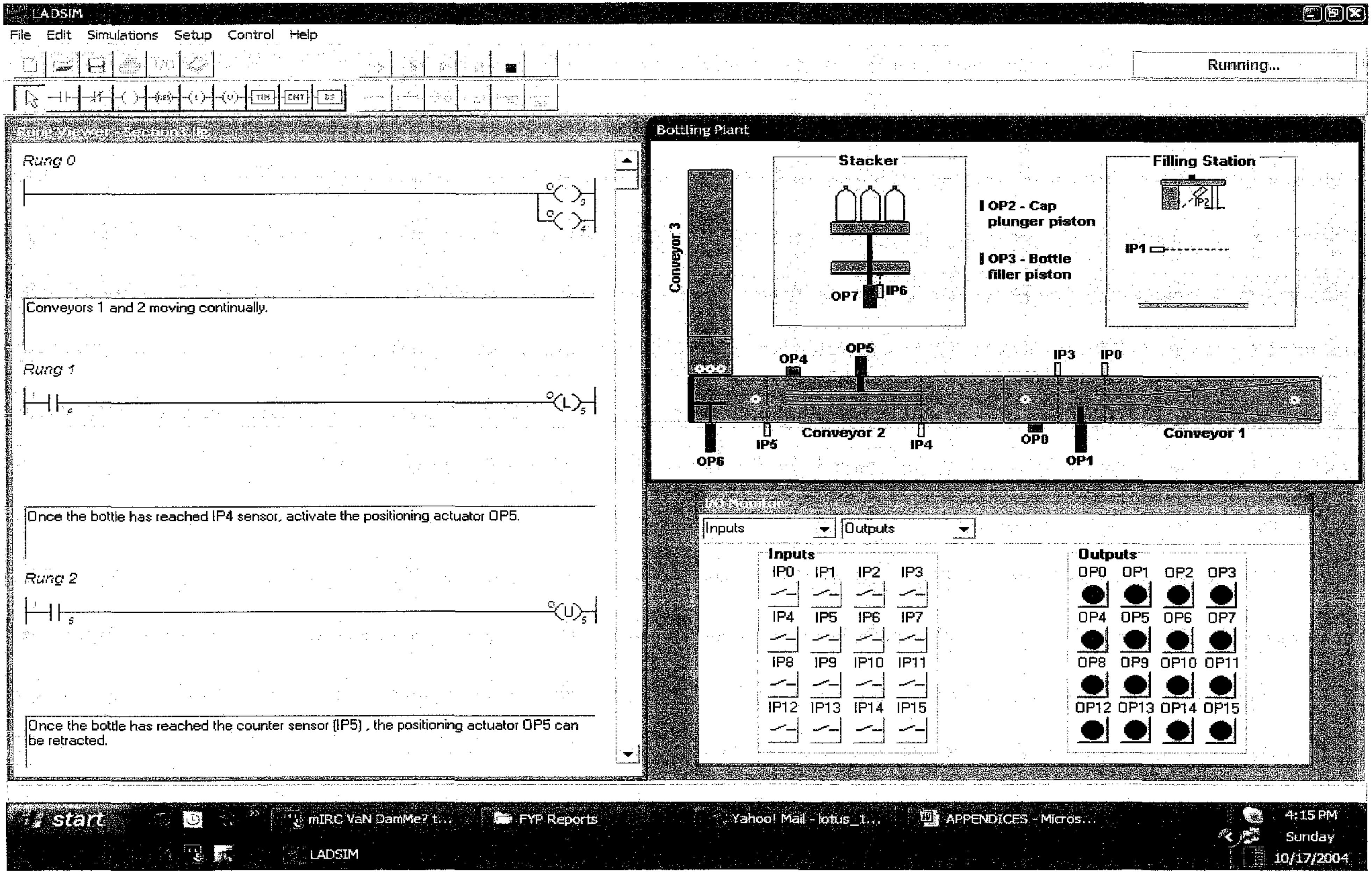
APPENDIX B


Automation Studio - [DEMO2_PNEUMATIC : Diagram 1]
File Edit Document View Layout Simulation Tools Window ?
A
B
C
EMERGENCY STOP
S1
S2
S3
FEEDER
EMERGENCY
STOP
SINGLE
CYCLE
START
CONTINOUS
CYCLE
DIRECTIVES
- Press the FEEDER roller and drag the cursor elsewhere.
- Press the SINGLE CYCLE Pushbutton to simulate one cycle.
- OR Press the CONTINUOUS CYCLE Pushbutto to simulate continuously.
- Press the EMERGENCY STOP Pushbutton to
X=88, Y=120
160%
Edit
start
Automation Studio - [...
9:12 AM

APPENDIX C


tutorial - CX-Programmer - [TrafficController.Traffic_Lights.Section1 [Diagram]]
File Edit View Insert PLC Program Tools Window Help
TrafficLights
TrafficController[CS1H] Offline
Symbols
IO Table
Settings
Memory
Traffic_Lights (00)
Symbols
Section1
END
Project
[Program Name : Traffic_Lights]
Example program to control UK traffic lights
Note that the I/O table has been set to include the traffic lights as outputs, and so the addresses appear with 'Q' prefixes.
[Section Name : Section1]
The only section necessary in such a small program
A tutorial program - a standard, UK traffic-light sequence
Red light on only
AmberOnlyT...
Red light on only
TIM
Timer
RedLightTi...
Timer for the red light p
Timer number
TimeInterval
Speed at which the sec
Set value
Red and amber lights on together
RedTimerDo...
Red and amber lights o
Compile
Find Report
Transfer
For Help, press F1
TrafficController(Net:0,Node:0) - Offline
rung 0 (0, 0) - 100%
NUM
start
3:06 PM
Monday
4/19/2004

APPENDIX D

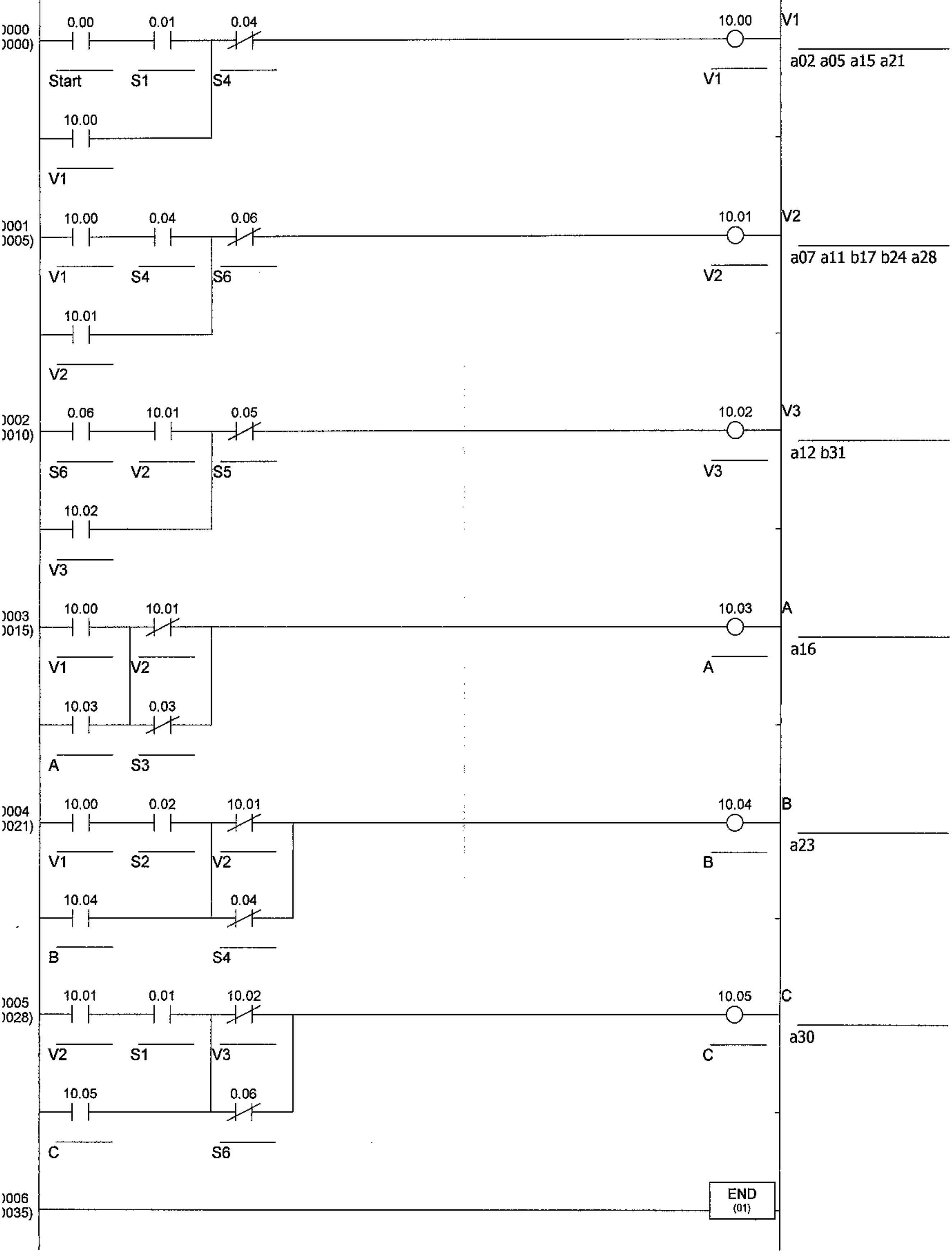


LADSIM
File Edit Simulations Setup Control Help
Running...
Rung 0
Conveyors 1 and 2 moving continually.
Rung 1
Once the bottle has reached IP4 sensor, activate the positioning actuator OP5.
Rung 2
Once the bottle has reached the counter sensor (IP5) , the positioning actuator OP5 can be retracted.
Bottling Plant
Stacker
Filling Station
OP2 - Cap plunger piston
OP3 - Bottle filler piston
Conveyor 3
Conveyor 2
Conveyor 1
OP7 IP6 IP1 IP2 OP4 OP5 IP3 IP0 IP5 IP4 OP0 OP6 OP1
Inputs
Outputs
IP0 IP1 IP2 IP3 IP4 IP5 IP6 IP7 IP8 IP9 IP10 IP11 IP12 IP13 IP14 IP15
OP0 OP1 OP2 OP3 OP4 OP5 OP6 OP7 OP8 OP9 OP10 OP11 OP12 OP13 OP14 OP15
start
FYP Reports
APPENDICES - Micros...
LADSIM
4:15 PM
Sunday
10/17/2004

APPENDIX E

[Program Name : Section1]
Design Concept Ladder Diagram

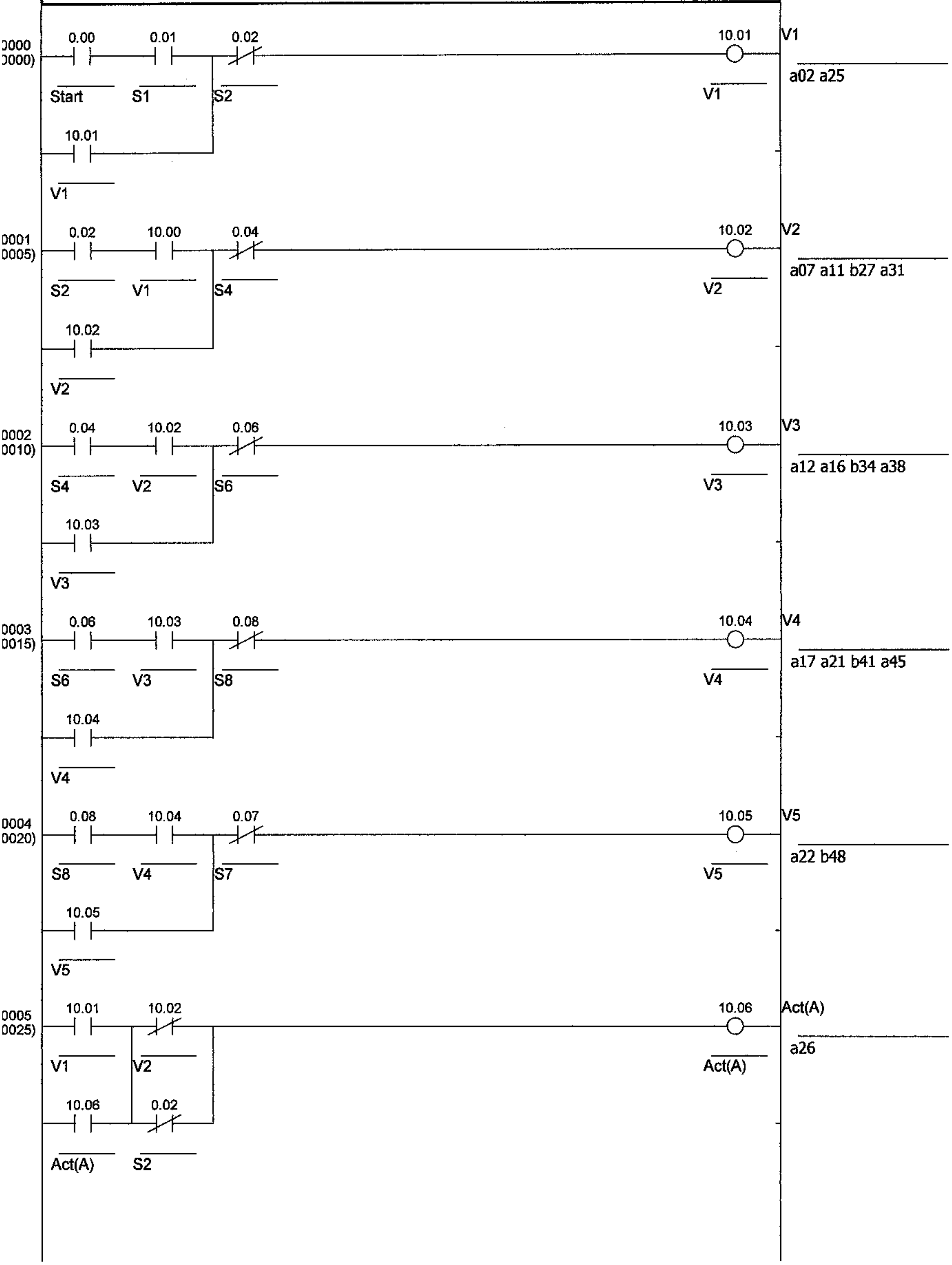
[Section Name : Section1]
First Section Design Concept for Manufacturing Process System

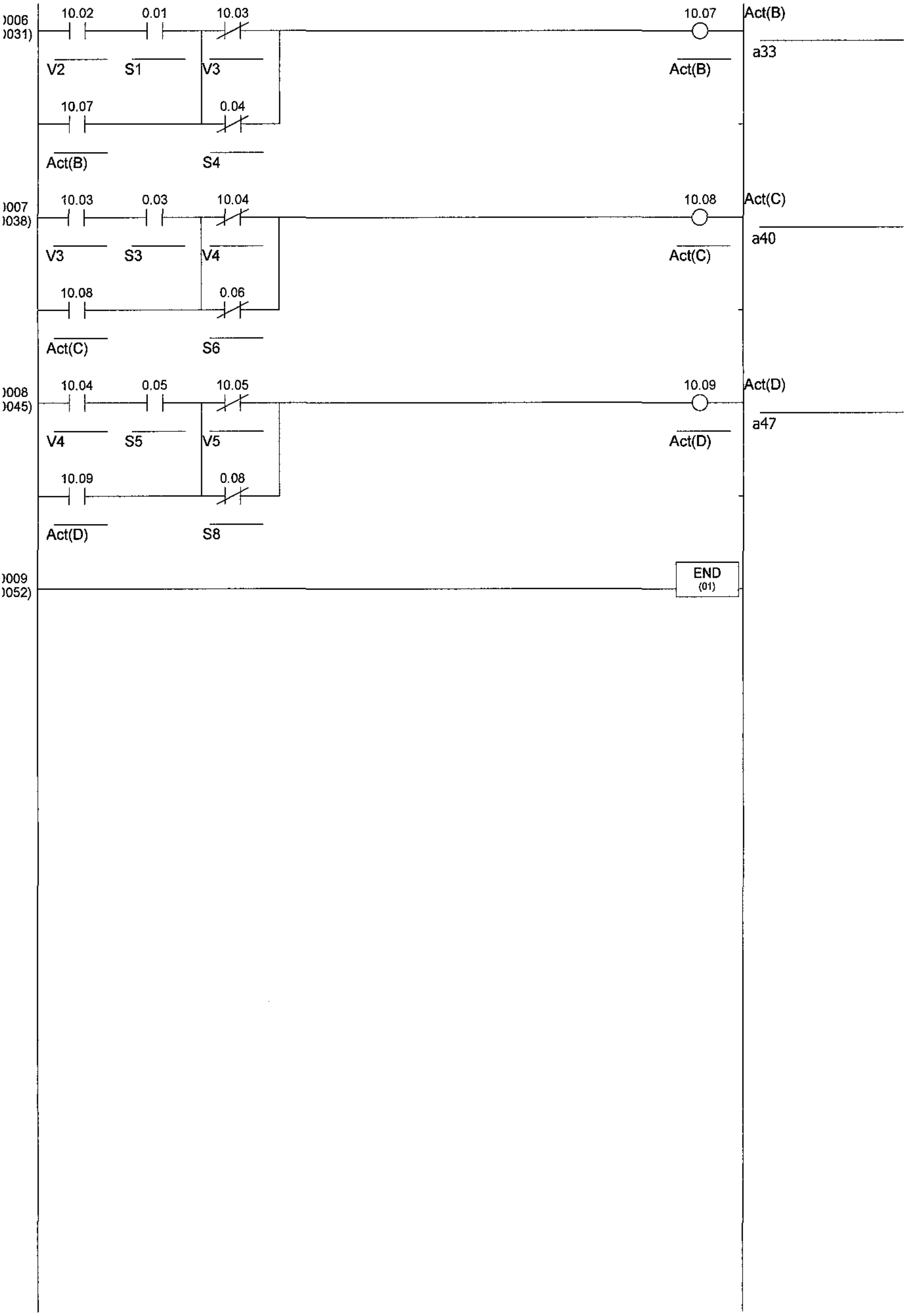


APPENDIX F

[Program Name : Section1]
Electro-pneumatic Sequence Ladder Diagram (Method1)

[Section Name : Section1]
Section 1 for Manufacturing Process System



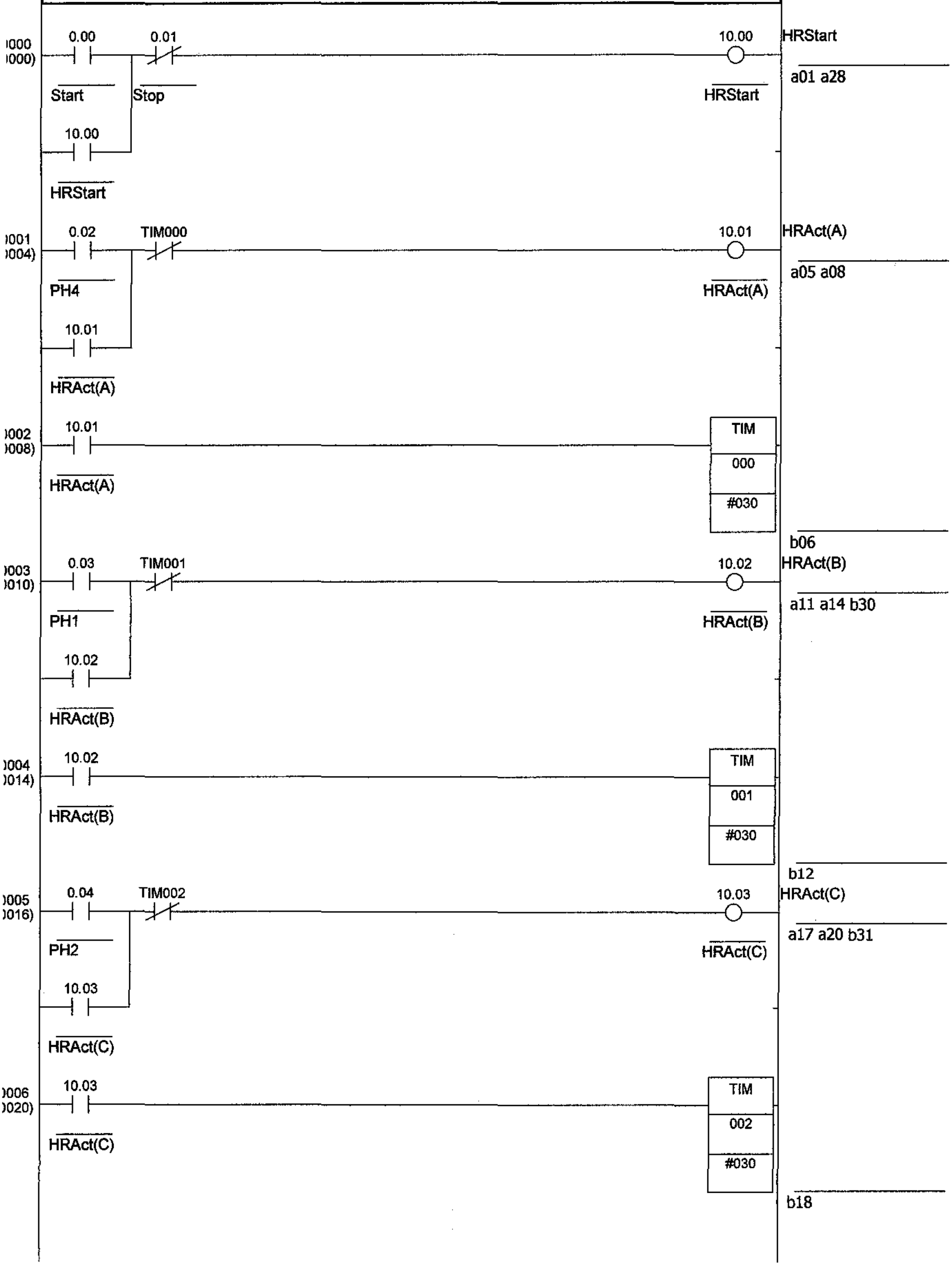


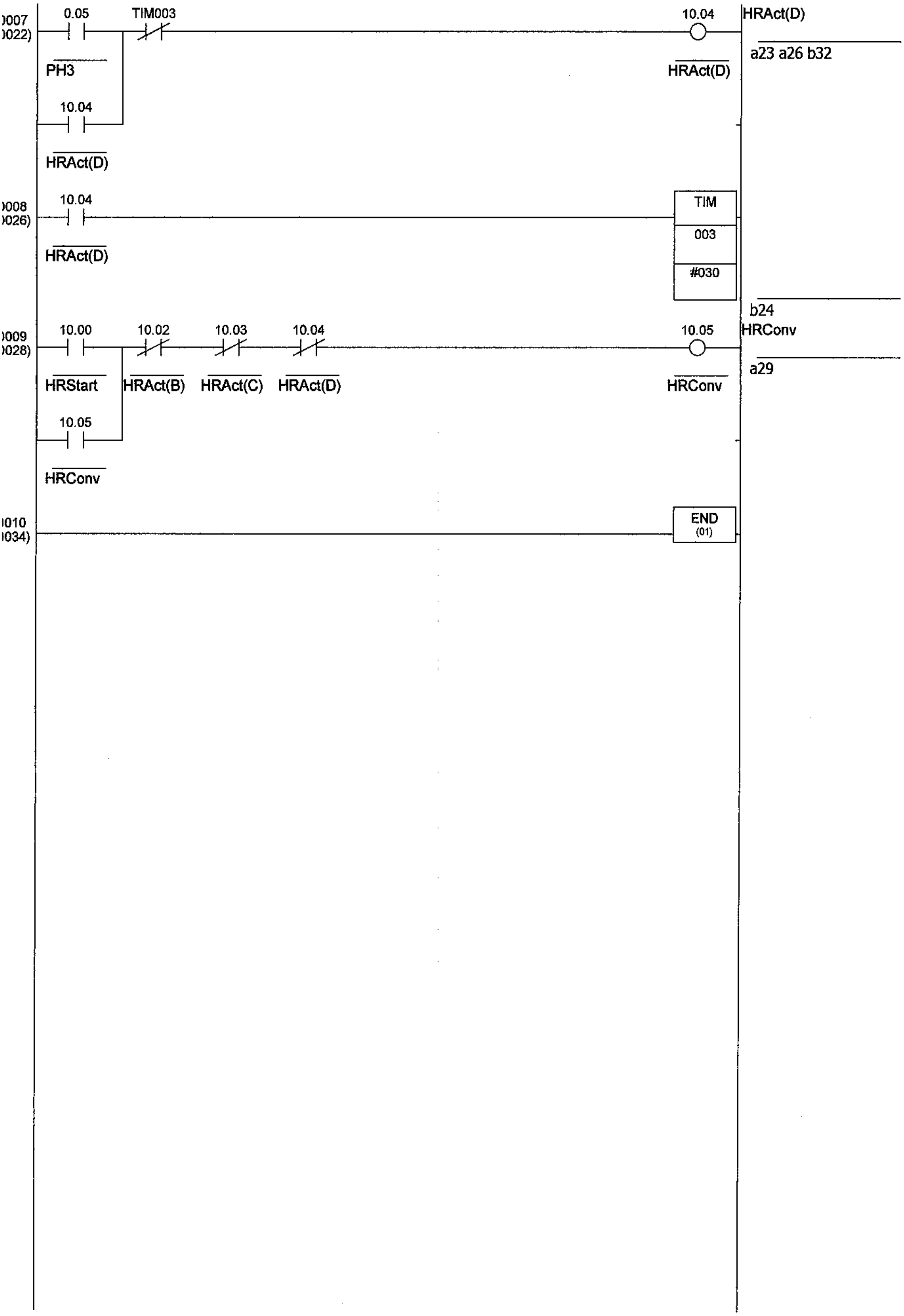
)006
)031)
10.02
0.01
10.03
10.07
Act(B)
a33
V2
S1
V3
Act(B)
10.07
0.04
Act(B)
S4
)007
)038)
10.03
0.03
10.04
10.08
Act(C)
a40
V3
S3
V4
Act(C)
10.08
0.06
Act(C)
S6
)008
)045)
10.04
0.05
10.05
10.09
Act(D)
a47
V4
S5
V5
Act(D)
10.09
0.08
Act(D)
S8
)009
)052)
END
(01)

APPENDIX G

[Program Name : Section1]
Holding Relay Ladder Diagram (Method2)

[Section Name : Section1]
Section 1 for Manufacturing Process System



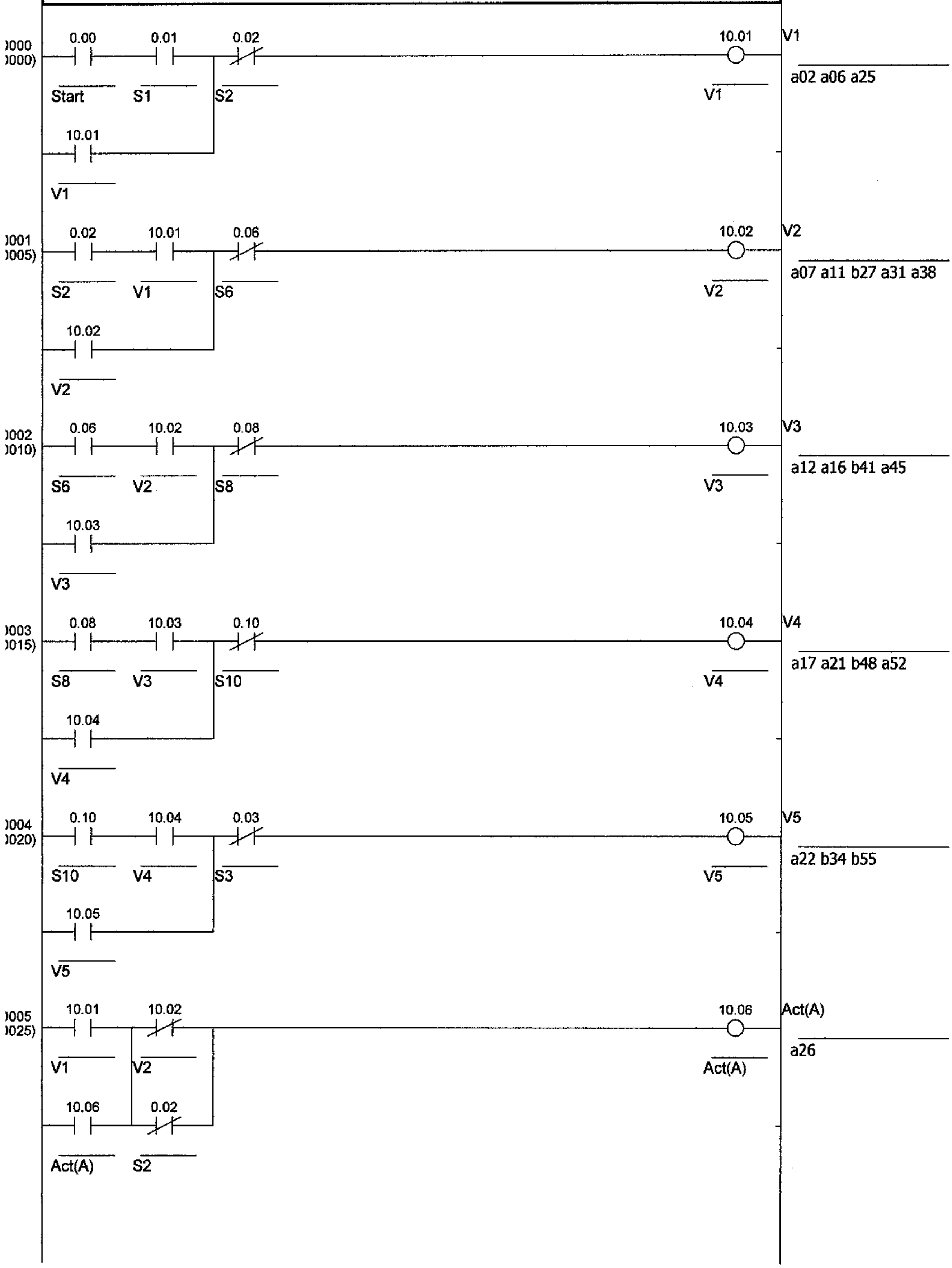


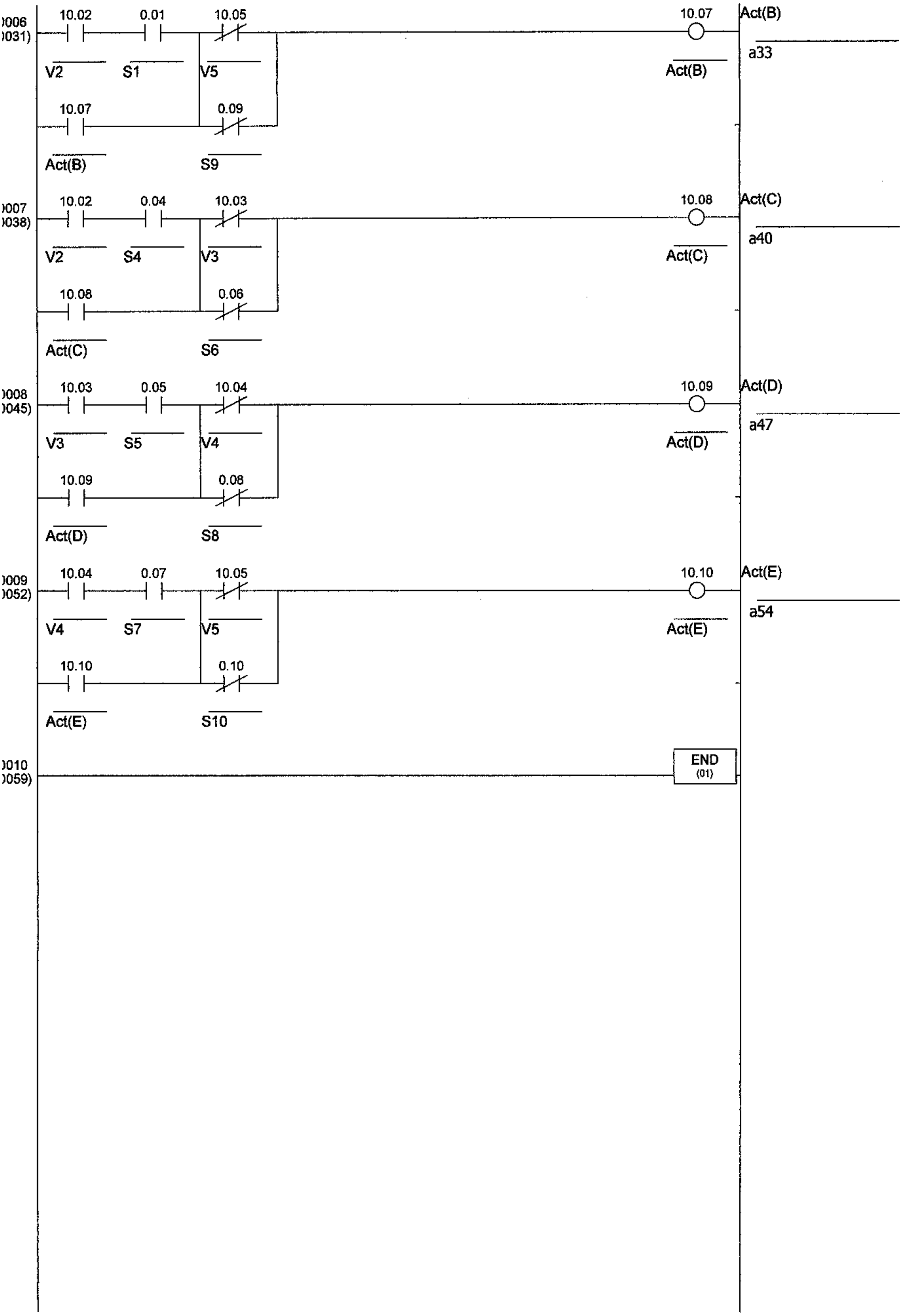
)007
)022)
0.05
TIM003
10.04
HRAct(D)
a23 a26 b32
PH3
HRAct(D)
10.04
HRAct(D)
)008
)026)
10.04
TIM
003
#030
HRAct(D)
b24
)009
)028)
10.00
10.02
10.03
10.04
10.05
HRConv
a29
HRStart
HRAct(B)
HRAct(C)
HRAct(D)
HRConv
10.05
HRConv
)010
)034)
END
(01)

APPENDIX H

[Program Name : Section1]
Electro-pneumatic Sequence Ladder Diagram (Modified Method1)

[Section Name : Section1]
Section 1 for Manufacturing Process System

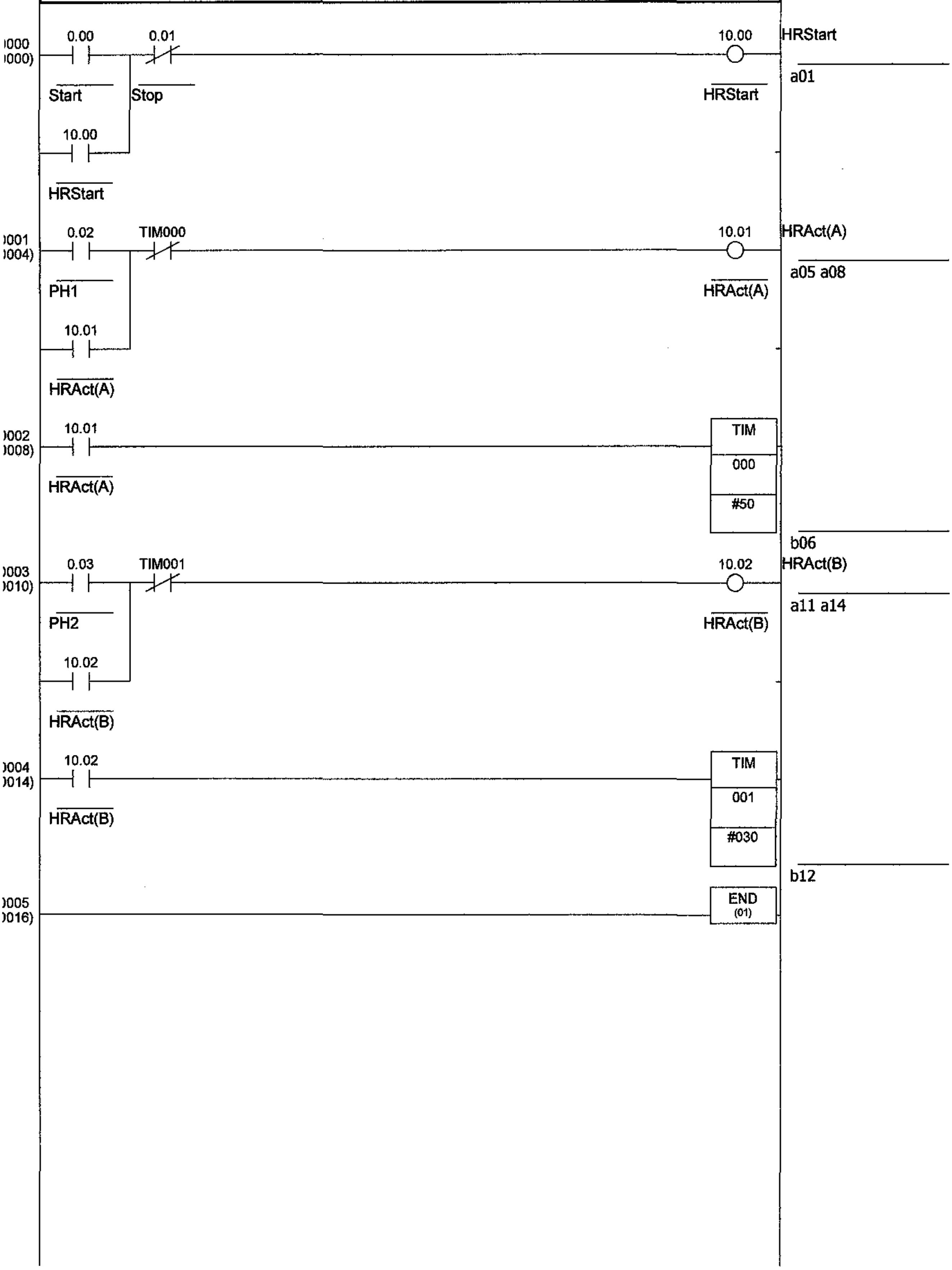



)006
)031)
10.02
V2
0.01
S1
10.05
V5
10.07
Act(B)
0.09
S9
10.07
Act(B)
Act(B)
a33
)007
)038)
10.02
V2
0.04
S4
10.03
V3
10.08
Act(C)
0.06
S6
10.08
Act(C)
Act(C)
a40
)008
)045)
10.03
V3
0.05
S5
10.04
V4
10.09
Act(D)
0.08
S8
10.09
Act(D)
Act(D)
a47
)009
)052)
10.04
V4
0.07
S7
10.05
V5
10.10
Act(E)
0.10
S10
10.10
Act(E)
Act(E)
a54
)010
)059)
END
(01)

APPENDIX I

[Program Name : Section1]
Holding Relay Ladder Diagram

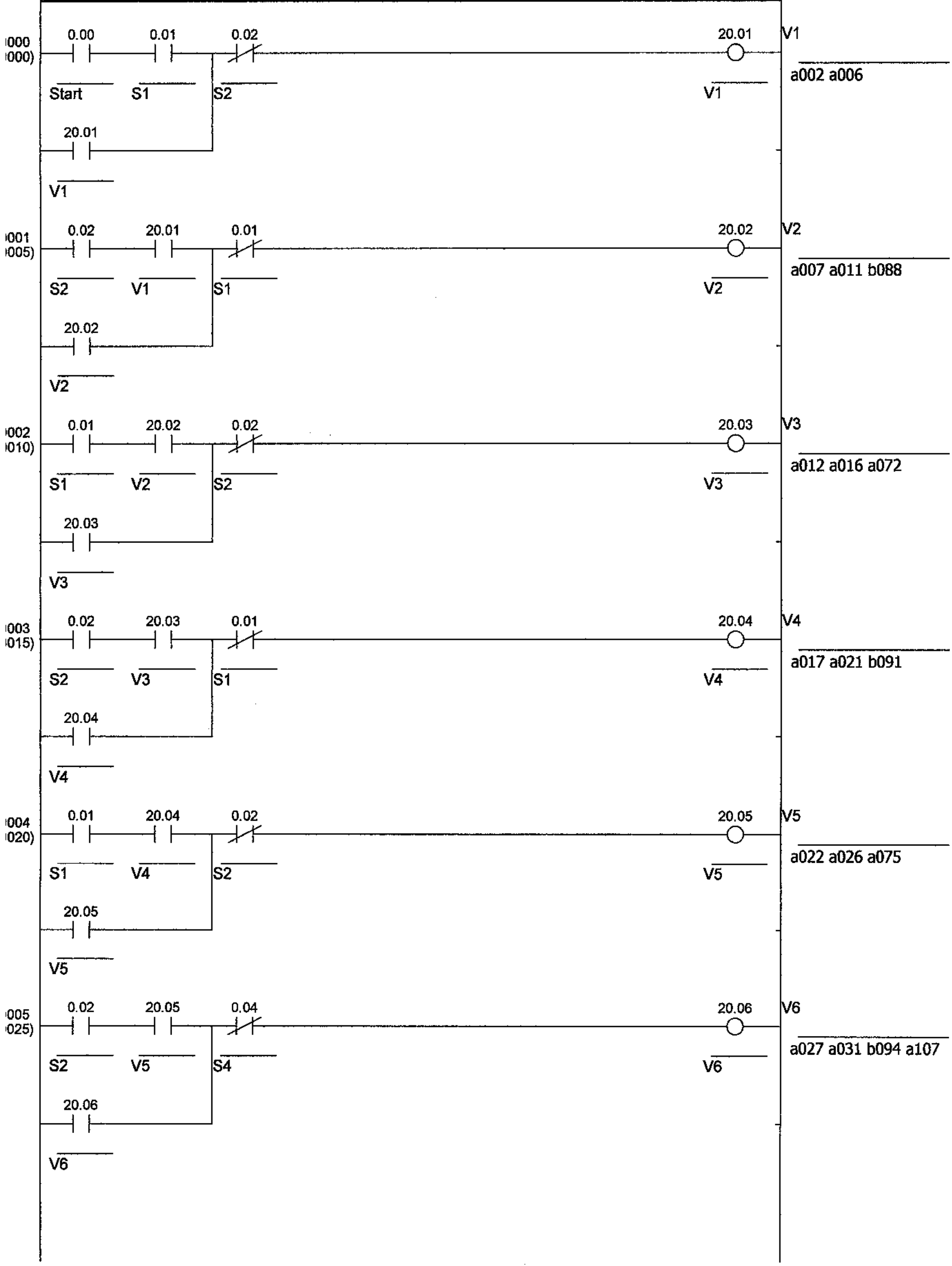
[Section Name : Section1]
Section 2 Manufacturing Process System

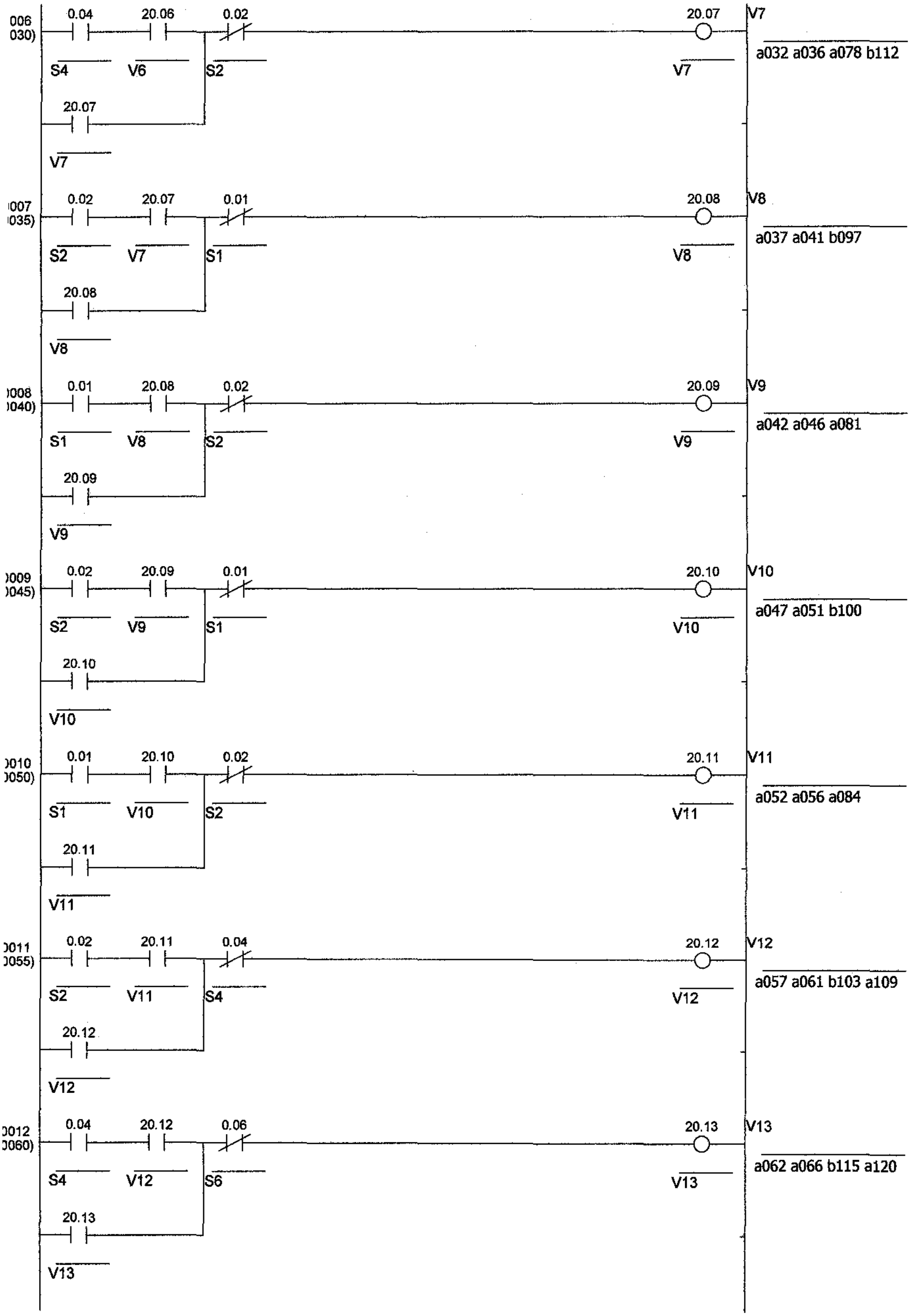


APPENDIX J

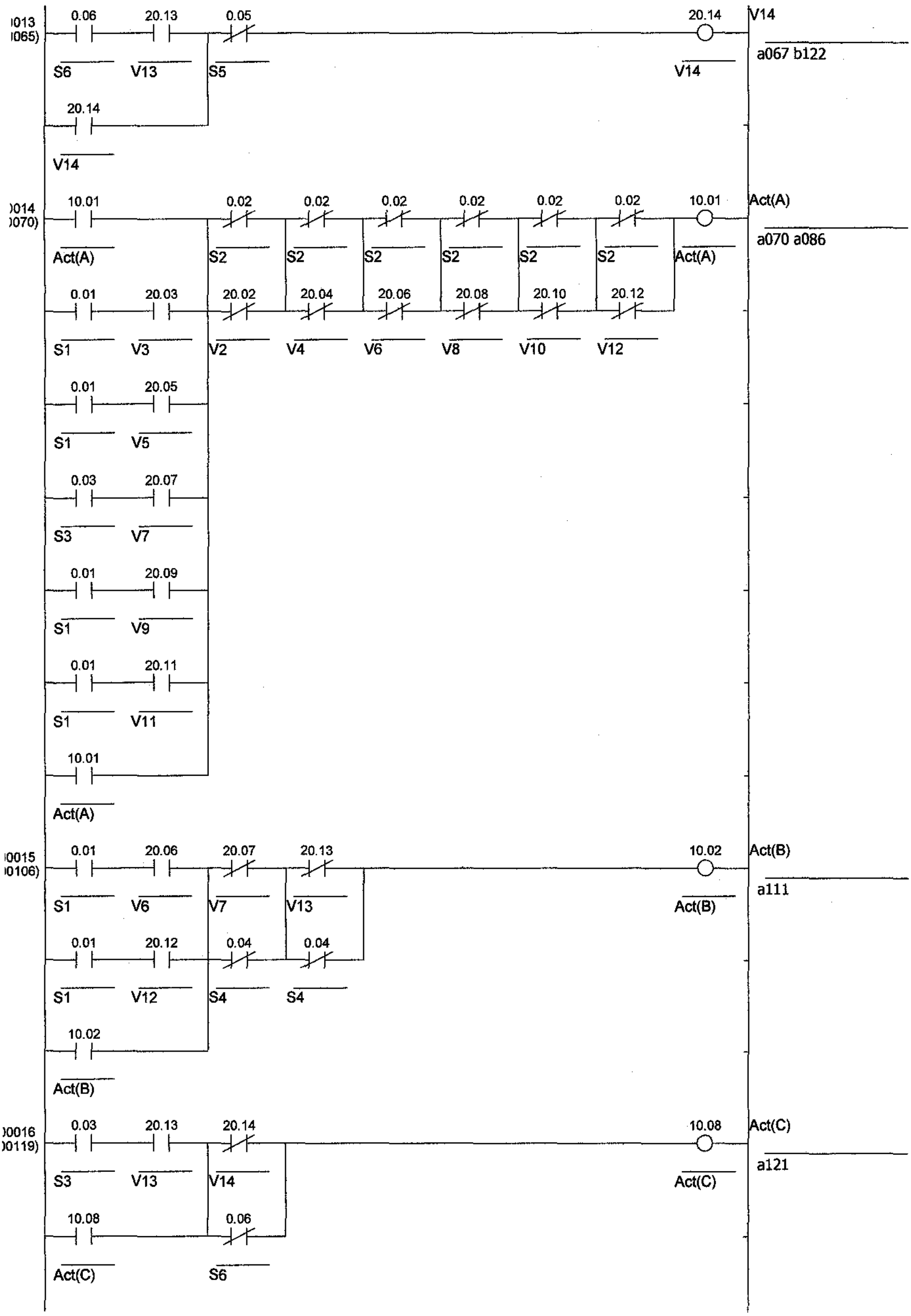
[Program Name : Section1]
Electro-pneumatic Sequence Ladder Diagram

[Section Name : Section1]
Section 3 for Manufacturing Process System





006
030)
0.04
20.06
0.02
20.07
V7
S4
V6
S2
V7
a032 a036 a078 b112
20.07
V7
007
035)
0.02
20.07
0.01
20.08
V8
S2
V7
S1
V8
a037 a041 b097
20.08
V8
008
040)
0.01
20.08
0.02
20.09
V9
S1
V8
S2
V9
a042 a046 a081
20.09
V9
009
045)
0.02
20.09
0.01
20.10
V10
S2
V9
S1
V10
a047 a051 b100
20.10
V10
010
050)
0.01
20.10
0.02
20.11
V11
S1
V10
S2
V11
a052 a056 a084
20.11
V11
011
055)
0.02
20.11
0.04
20.12
V12
S2
V11
S4
V12
a057 a061 b103 a109
20.12
V12
012
060)
0.04
20.12
0.06
20.13
V13
S4
V12
S6
V13
a062 a066 b115 a120
20.13
V13



)013
)065)
0.06
20.13
0.05
20.14
V14
S6
V13
S5
V14
a067 b122
20.14
V14
)014
)070)
10.01
0.02
0.02
0.02
0.02
0.02
0.02
10.01
Act(A)
Act(A)
S2
S2
S2
S2
S2
S2
Act(A)
a070 a086
0.01
20.03
20.02
20.04
20.06
20.08
20.10
20.12
S1
V3
V2
V4
V6
V8
V10
V12
0.01
20.05
S1
V5
0.03
20.07
S3
V7
0.01
20.09
S1
V9
0.01
20.11
S1
V11
10.01
Act(A)
)0015
)0106)
0.01
20.06
20.07
20.13
10.02
Act(B)
S1
V6
V7
V13
Act(B)
a111
0.01
20.12
0.04
0.04
S1
V12
S4
S4
10.02
Act(B)
)0016
)0119)
0.03
20.13
20.14
10.08
Act(C)
S3
V13
V14
Act(C)
a121
10.08
0.06
Act(C)
S6

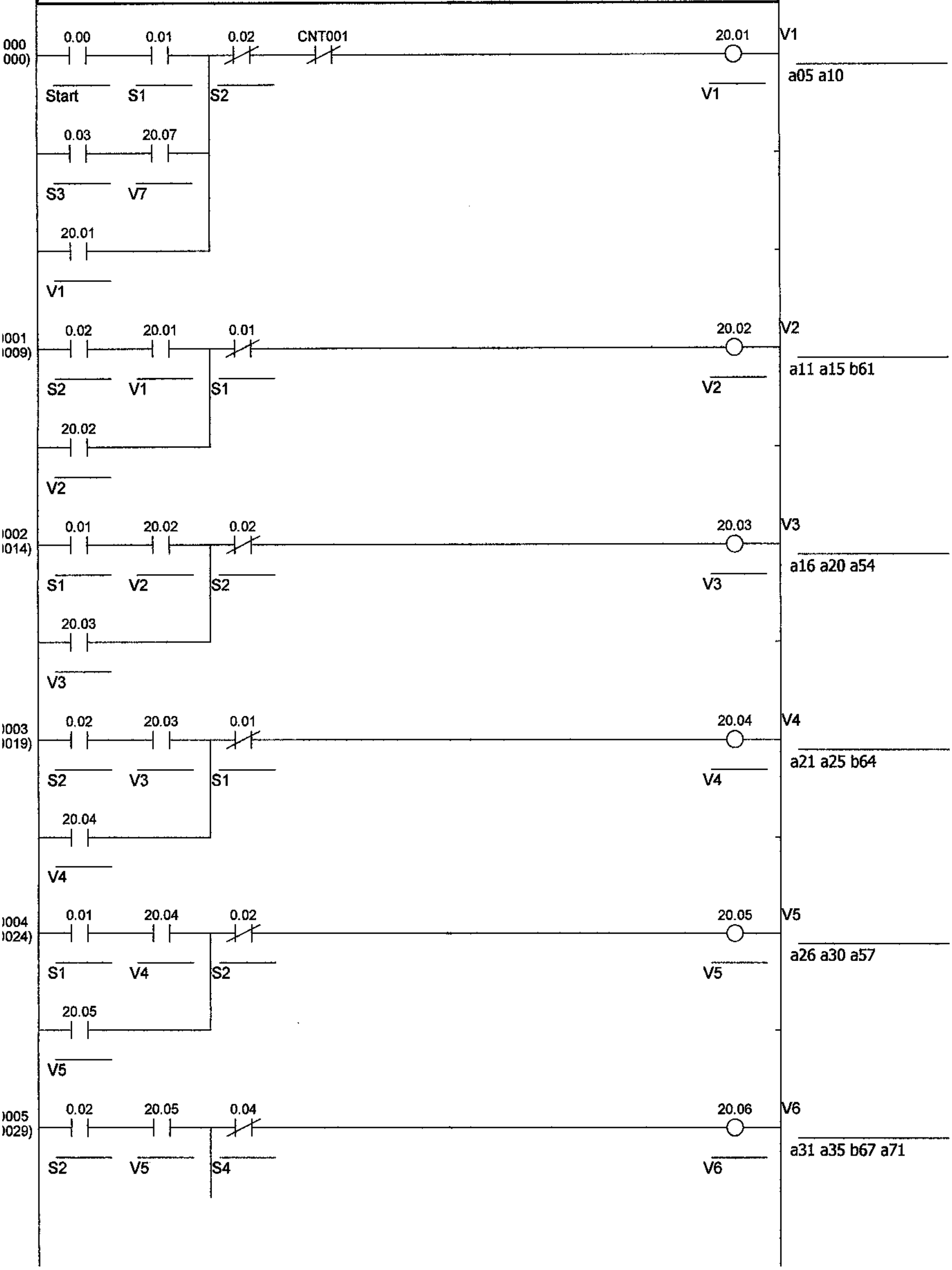
)017
)126)

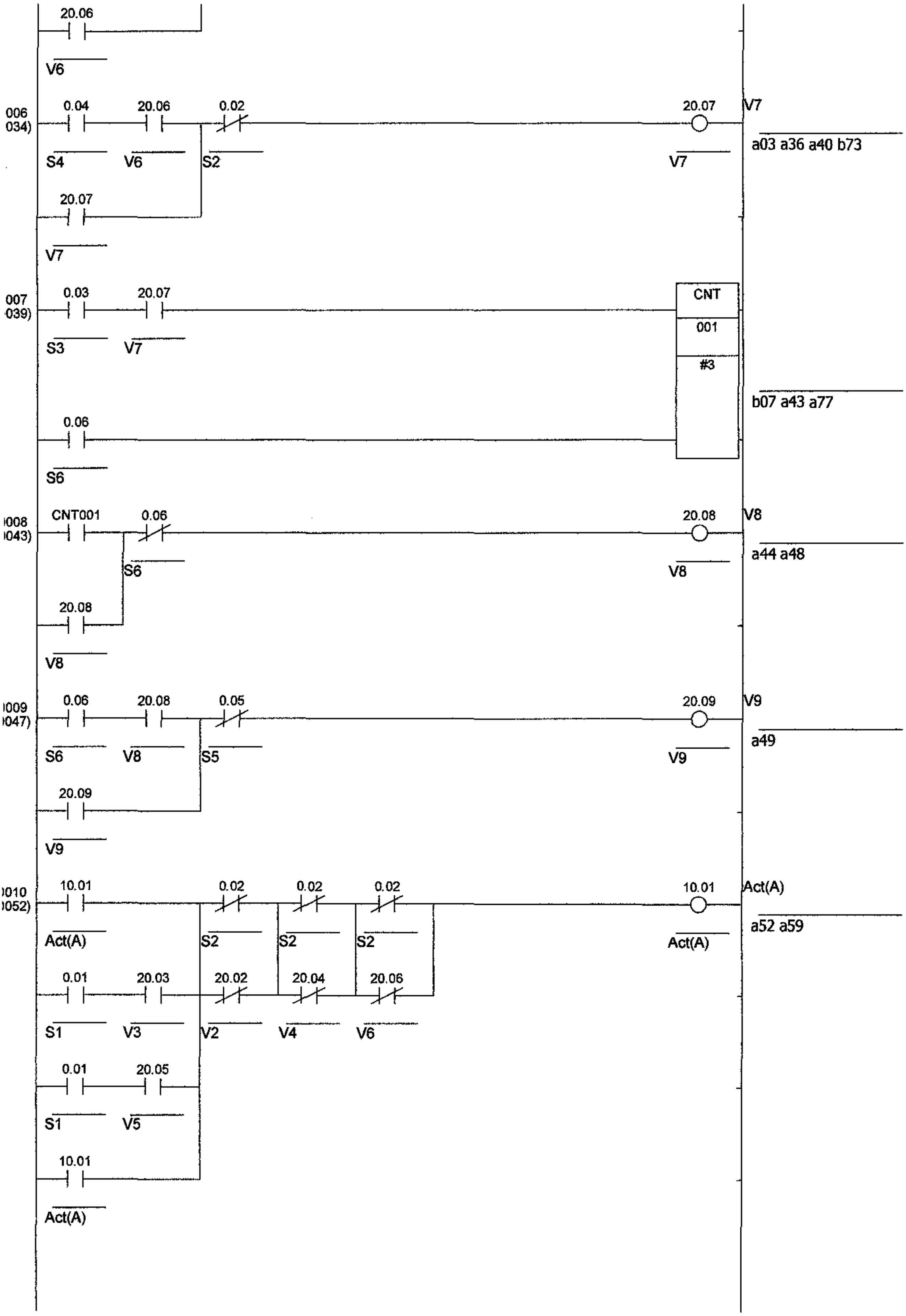
END
(01)

APPENDIX K

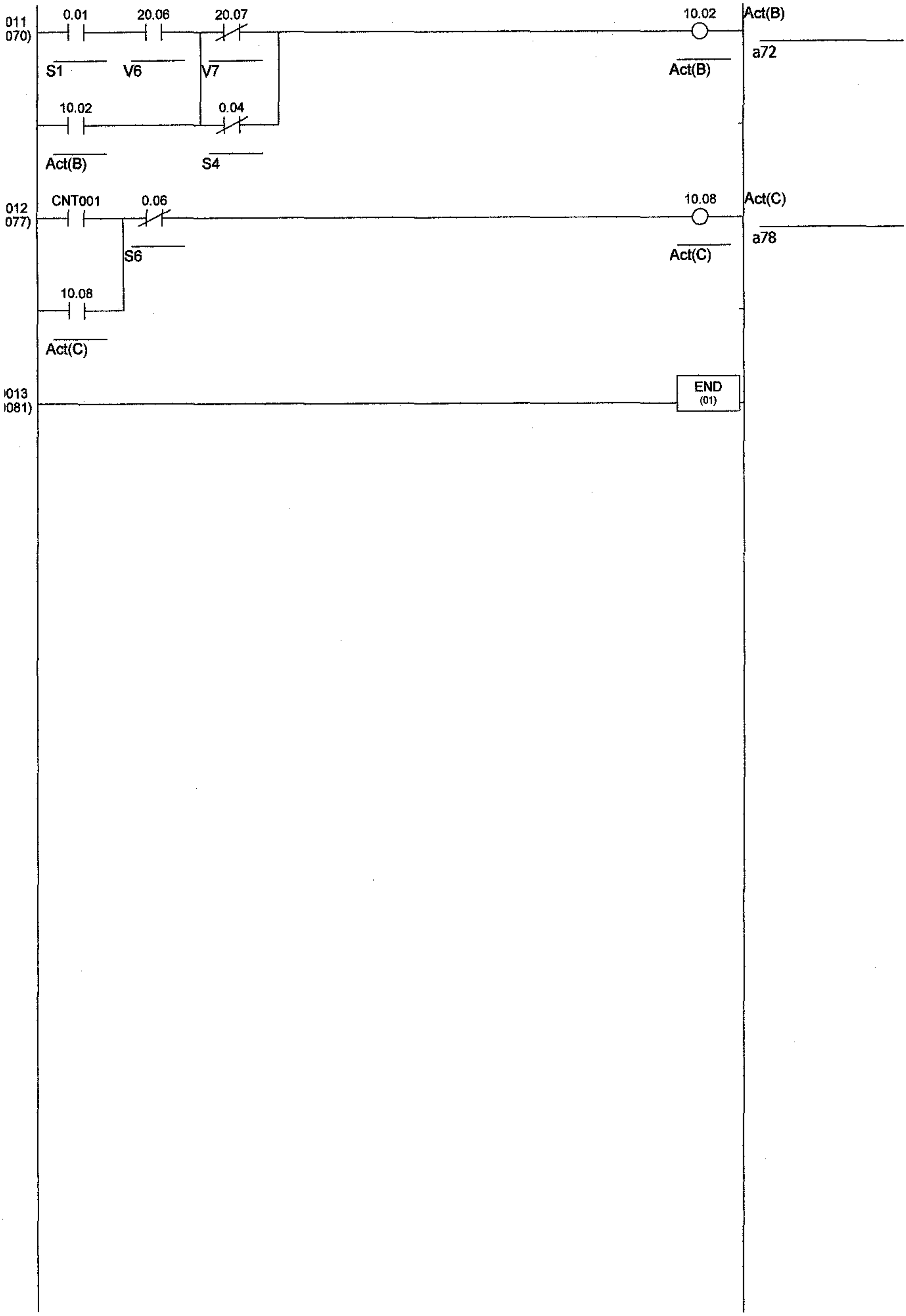
[Program Name : Section1]
Electro-pneumatic Sequence Ladder Diagram

[Section Name : Section1]
Section 3 for Manufacturing Process System (with counter)





20.06
V6
006
034)
0.04
20.06
0.02
20.07
V7
S4
V6
S2
V7
a03 a36 a40 b73
20.07
V7
007
039)
0.03
20.07
CNT
001
#3
S3
V7
b07 a43 a77
0.06
S6
008
043)
CNT001
0.06
20.08
V8
S6
V8
a44 a48
20.08
V8
009
047)
0.06
20.08
0.05
20.09
V9
S6
V8
S5
V9
a49
20.09
V9
010
052)
10.01
0.02
0.02
0.02
10.01
Act(A)
Act(A)
S2
S2
S2
Act(A)
a52 a59
0.01
20.03
20.02
20.04
20.06
S1
V3
V2
V4
V6
0.01
20.05
S1
V5
10.01
Act(A)



011
070)
0.01
20.06
20.07
10.02
Act(B)
a72
S1
V6
V7
Act(B)
10.02
0.04
Act(B)
S4
012
077)
CNT001
0.06
10.08
Act(C)
a78
S6
Act(C)
10.08
Act(C)
013
081)
END
(01)

APPENDIX L

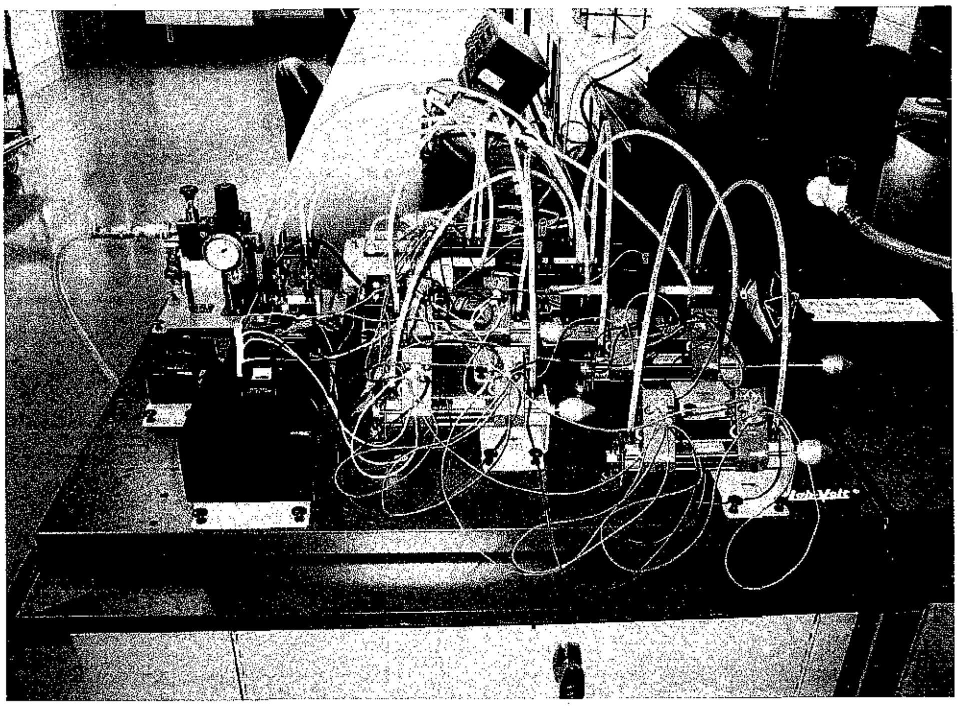


Figure 1

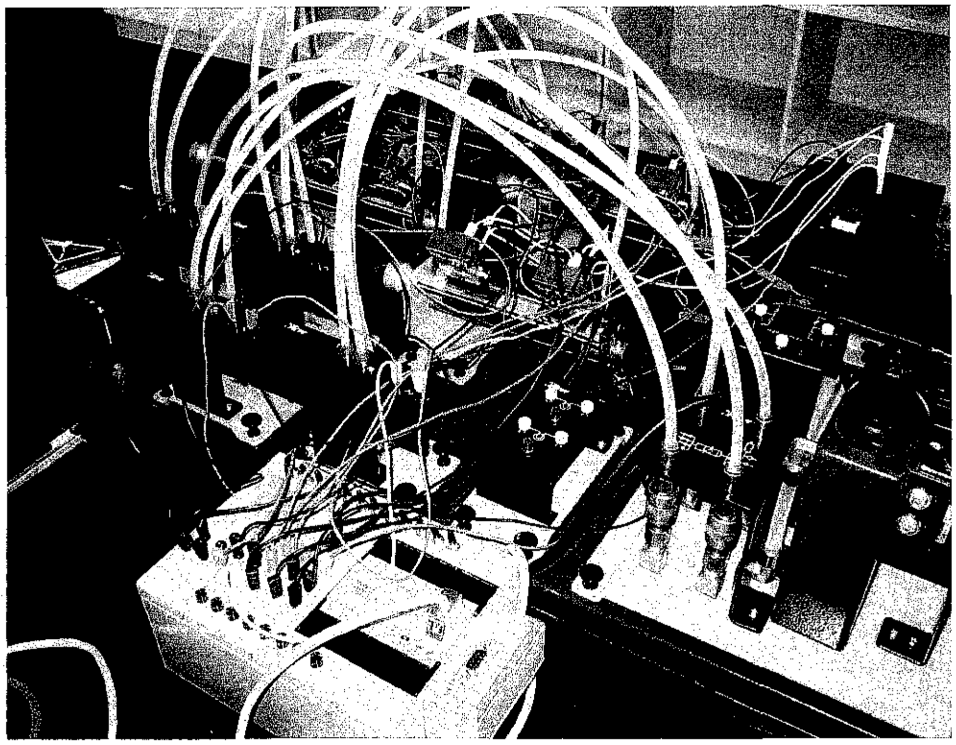


Figure 2

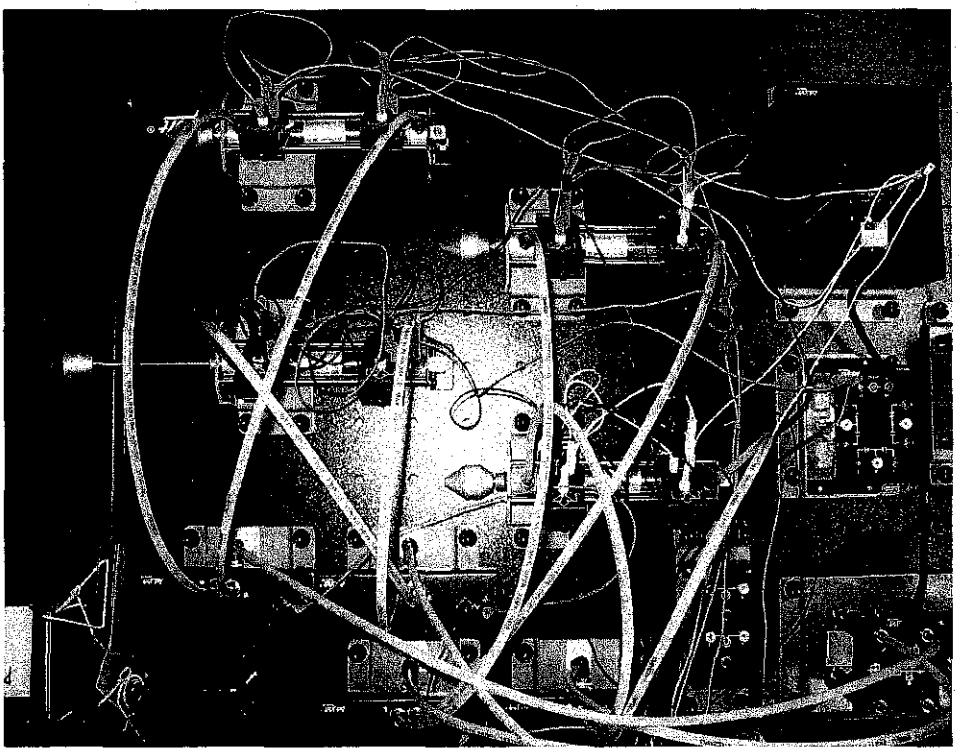


Figure 3

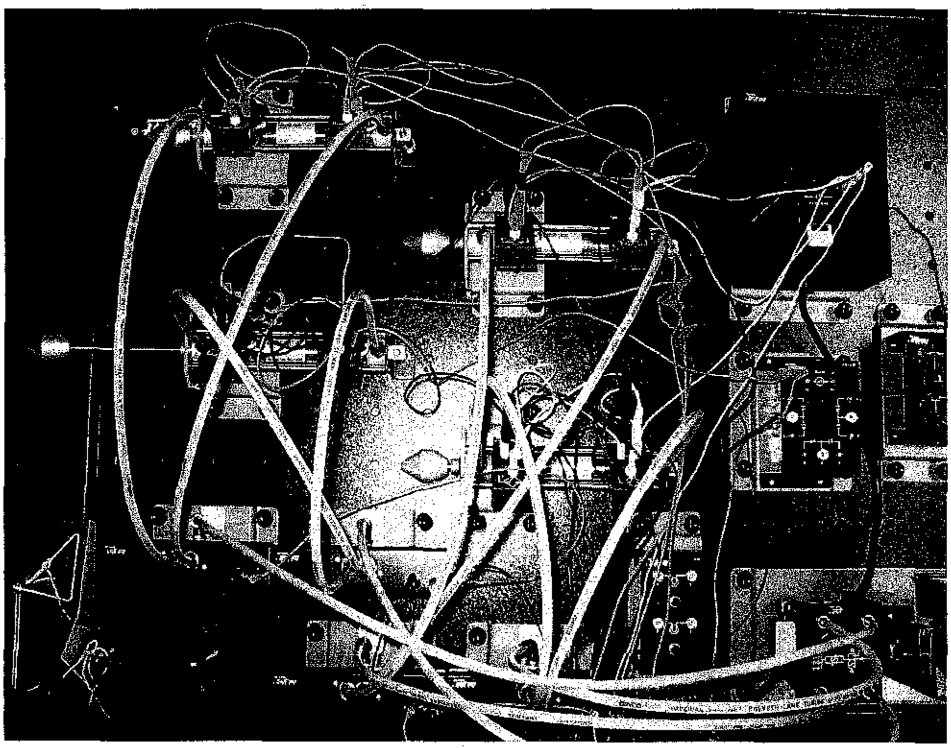
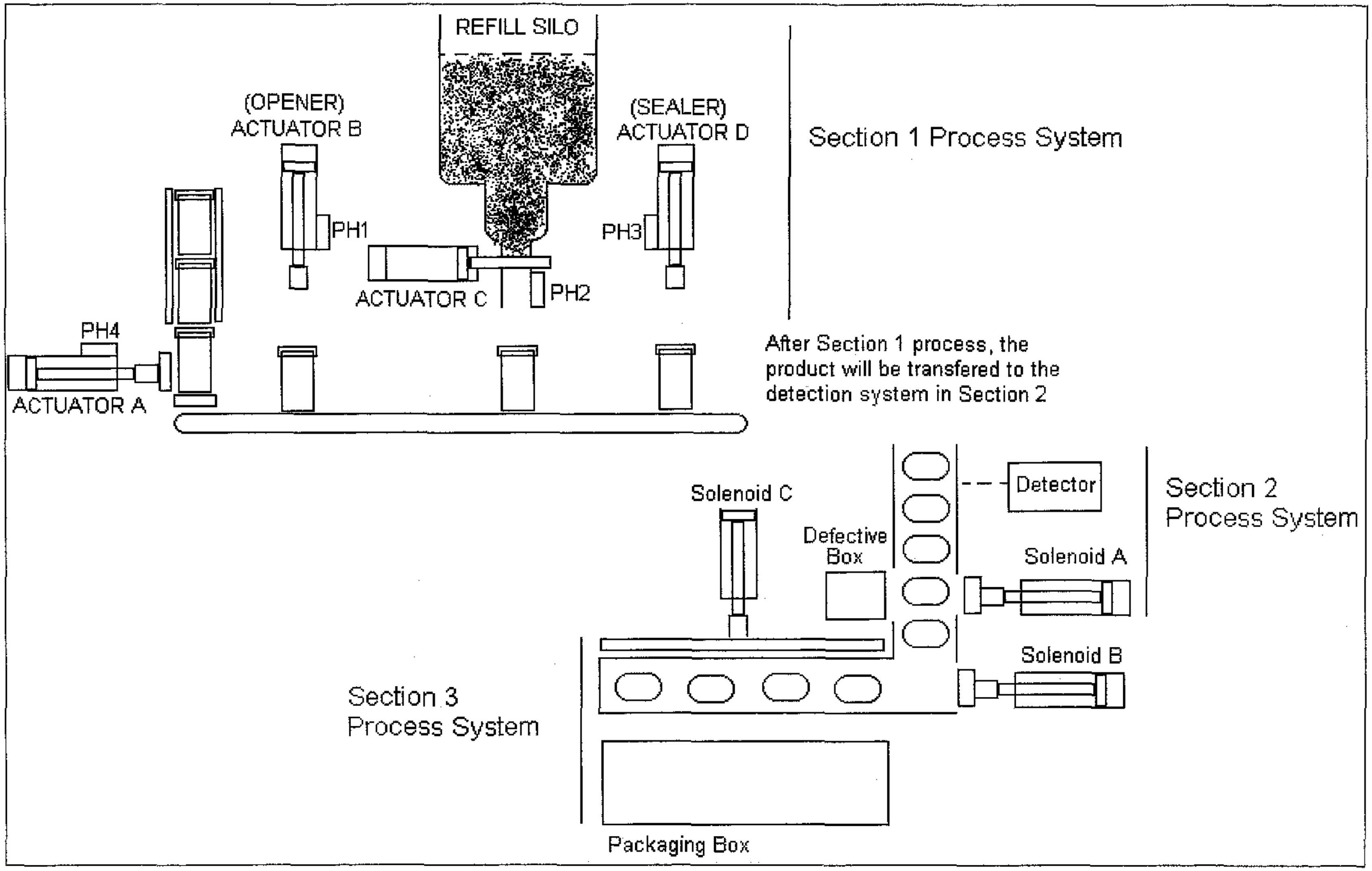


Figure 4

APPENDIX M



Overall View of the Modern Plant Process System