THE DEVELOPMENT OF A CUSTOMIZED DATA LOGGER FOR QUALITY CONTROL IN BREWING PASTEURIZATION

PC PELSER

The Development of a Customized Data logger for Quality Control in Brewing Pasteurization.

by

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DECLARATION

I hereby certify that the work in this document is my own work and has not been submitted for the purpose of obtaining a degree at any other institution.

.... 18/03/97

PC Pelser Date

Student

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SYNOPSIS

Recent market research has shown that a need has arisen for new pasteurizing measuring equipment that is more dedicated to the beer brewing industry. New standards in product quality forced brewers around the world to optimize pasteurizing processes. The current equipment which measures these processes, has fulfilled the need up to a few years ago, but does not meet the latest standards.

In this developmental research study, a new data logging instrument has been developed for measuring P.U.s (Pasteurization Units) which are calculated from temperature conditions during the brewing pasteurization process. The instrument or recorder has been developed in four phases, namely:

- Feasibility study concerning the development of the product.
- Literature study concerning the brewing pasteurization process.
- User requirement analysis.
- Design and implementation.

The design was basically done in three components. Firstly, the hardware circuit design in which the Intel 80C31 formed the central component of the design with interfacing to the temperature probes and RS232 computer interfacing. The software development both for the instrument processor control and the Personnel Computer (PC) interface formed the second part of the design. The third component of the design was concerned with the development of the mechanical housing and frame to comply with the user requirements.

Experimental results on the stability, repeatability and accuracy of the instrument formed part of this study. These tests have shown that the instrument developed in this study is superior to the current imported commercial instrument in terms of accuracy and measurement stability. Secondary advantages of the product is its cost effectiveness and user friendliness.

UITTREKSEL

Onlangse marknavorsing het getoon dat daar 'n behoefte ontstaan vir 'n meer gesofistikeerde instrument waarmee pasteurisering in broueryе gemonitor kan word. Moderne produkstandaarde het brouerye wêreldwyd gedwing om die pasteuriseerproses te verbeter, maar die ontwikkeling van instrumentasie het nie by die snelle ontwikkeling van pasteuriseerders bygebly nie. Huidige ingevoerde toerusting wat gebruik word om die proses te analiseer, is duur, terwyl die akkuraatheid onder huidige spesifikasies onvoldoende is.

In hierdie ontwikkelingsnavorsingsprojek is 'n nuwe instrument, waarmee die kwaliteit van die pasteuriseerproses gemonitor word, ontwikkel. Die instrument verwerk die data wat deur 'n stel temperatuursensors gemeet word en gebruik dan formules om die kwaliteits grense van die proses met die neergelegde fabriekstandaarde te vergelyk. Die instrument is in vier fases ontwerp, naamlik:

- Uitvoerbaarheidstudie.
- Literatuur studie oor bestaande ontwerpe.
- Verbruikersbehoeftebepaling.
- Harde- en sagtewareontwerp en implementering.

Die harde- en sagtewareontwerp is in drie fases uitgevoer: Eerstens, die stroombaanontwerp, waar die Intel 8051-mikroverwerker die sentrale deel van die ontwerp vorm. Hierdie gedeelte fasiliteer die koppelvlakte met die temperatuursensors en die RS232-koppelvlak. Tweedens, is sagteware vir die mikroverwerker, sowel as vir die persoontlike rekenaar ontwikkel, waarna die meganiese ontwerp van die elektroniese beskermingshouer en raamwerk gevolg het.

Eksperimentele resultate t.o.v. stabilitiet, herhaalbaarheid van resultate, sowel as akkuraatheid van die instrument het getoon dat die ontwikkelde instrument in alle opsigte beter presteer as die bestaande, ingevoerde kommersiële produkte. Die ontwikkelde instrument is verder ook goedkoper en meer gebruikersvriendelik as bestaande instrumente.

INDEX

Central University of Technology, Free State

CHAPTER 3

DESIGN SPECIFICATIONS FOR THE P.U. RECORDER

CHAPTER 4

P.U. RECORDER DESIGN AND DEVELOPMENT

LIST OF FIGURES AND TABLES

List of Figures

List of Tables

ACRONYMS

A/D	Analog-to-Digital
ACLK	Analog Clock
ALE	Address Latch Enable
CS	Chip Select
D/A	Digital-to-Analog
DIN	Data Input
DIP	Dual Inline Package
DOUT	Data Output
EPROM	Erasable Programmable Read Only Memory
I/O	Input / Output
LCD	Liquid Crystal Display
MIL spec	Military Specification
MIS	Management Information System
NI-CAD	Nickel Cadmium
PC	Personnel Computer
PCB	Printed Circuit Board
PLC	Programmable Logic Control
P.U.	Pasteurization Unit
PUR	Pasteurization Unit Recorder
RAM	Random Access Memory

ROM	Read Only Memory
SAB	South African Breweries
UART	Universal Asynchronous Receiver Transmitter

CHAPTER 1

INTRODUCTION

1.1 Overview

The P.U. (Pasteurization Unit) recorder is an instrument used to measure the temperature variation and conditions during the pasteurization of packaged beer. It is effectively a data logging instrument used for quality control in the beverage brewing industry. The P.U. recorder is unique in the sense that it has to do measurements and complicated calculations in very harsh humid temperature conditions while providing a PC interface in order to download data to the factory MIS (Management Information System).

The project is aimed at developing a new improved and customized instrument that could replace an imported product used in the SA brewing industry. Furthermore, this product has the potential to penetrate international markets. Although the development is focused on the design and implementation of electronic hardware and software, it also includes a unique mechanical design of the instrument enclosure arrangement.

Pasteurization is the process applied to a beverage product (in this case beer) to obtain sterility and micro-biological stabilization [15]. In this process, heat is applied to a product in a container in order to kill unwanted bacteria and micro-organisms that impair the flavour and shelf-life of the product. A product that is pasteurized can be stored at room temperature in a warehouse with much longer shelf-life than normal products.

In the brewery, pasteurization of packaged beer is accomplished by moving the beer containers on a wide conveyor through a tunnel pasteurizer [2]. The container line moves slowly through different compartments where water is sprayed over them. In each zone, nozzles spray water with specific zone temperatures over the beer containers. The beer containers move through the pasteurizer on the conveyor, and are subjected to a sequential range of temperature zones which correlate with the specifications required by SAB. Pasteurizer specifications are supplied by the manufacturers of this equipment.

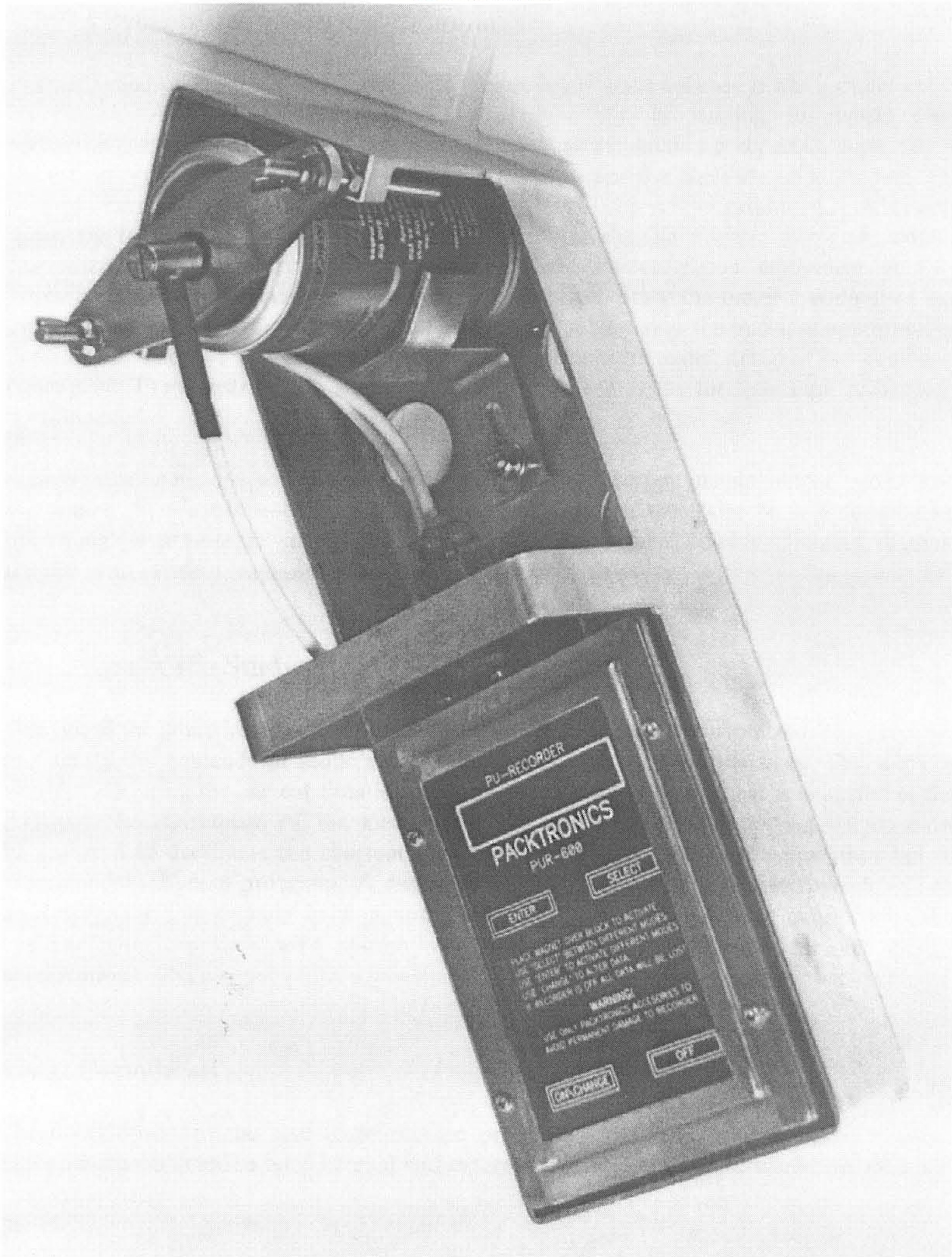

Figure 1.1 Photograph of the P.U. Recorder Developed in this Study Project.

1.2 Problem Definition and Solution

Pasteurization of food and beverages is of utmost importance because it has a direct effect on the shelf-life and the flavour of the product [8]. In striving for world class competitiveness, this process became more important to production companies, especially in the export market. Since under-pasteurization can shorten the shelf-life of a product and over-pasteurizing can be detrimental to the taste or flavour of the product [3], it is very important to measure and control this process effectively. To achieve this goal, quality pasteurizer and laboratory equipment are required. Pasteurization equipment is very expensive and many companies abroad exploited this field. Since the monitor equipment is a byproduct and not in great demand, companies tend not to realize the business opportunities in this field. There is very little competition, thus leaving the major designer the choice of equipment. These instruments are outdated and the need arose for new high technology instruments.

A new instrument has to be designed to fulfill all the current needs of the production companies. This instrument must be accurate and reliable. It must also be in a competitive price range. Furthermore, it must be easy to operate without specialized training. It must interact with existing computer systems for PC analysis.

1.3 Aim of the Study

The aim of the study is to develop a local South African and SAB customized P.U. recorder that meets the demands of modern technology in brewery production lines. The study is aimed at analyzing the current situation in order to determine exactly what is expected of the P.U. recorder instrument. All the specifications for the process and important criteria must be analyzed to determine the shortcomings of existing instruments and where they fail to accommodate modern processes. A design specification can then be defined which will be used as a basis to design, develop and integrate a new P.U. recorder instrument. The evaluation of the developed system will then be conducted using the set design specifications.

1.4 Hypothesis

The effectiveness of the beer pasteurization process can be monitored by using a micro processor-based solution with internal and external sensors housed in a watertight stainless steel enclosure.

1.5 Importance of Product

In order to analyze the demand for a new P.U. recorder, one has to keep in mind that the instrument is used as a quality control instrument in factory production lines. The demand for the product is thus proportional to the quality control standards enforced in factory lines. SAB envisaged a goal of world class status and have became the fourth largest brewery in the world. One of the pillars on which this success is based, is the very strict quality control standards for South African beers [20].

In light of the above, there is a need to develop a P.U. recorder because of two current factors. Firstly, most of the current P.U. recorders used in brewing production lines are imported. The turn-around time on service and repair on these instruments are between two to three months This results in instruments not being calibrated and serviced regularly. This also leads to the fact that additional costs are involved since one has to keep additional instruments in backup stock, should there be an instrument failure.

Secondly, the imported instruments are not customized for South African conditions and are very expensive. The imported instruments are not compatible with the technology that is used in SAB factories. This means that the instruments are currently only used as laboratory equipment where facilities exist to download data. There is a need to download data from within the factory to the PC for MIS purposes.

1.6 Method of Research

Research regarding this project is conducted in the following four phases:

Phase 1: Feasibility Study
The first phase in this project will be to identify the market and demand for a P.U. recorder. This will be achieved by establishing exactly who will use such an instrument and then make contact with the relevant people. It can then be established whether there is a demand for this product. Once the market is established, supply and demand analysis will show whether this project is viable or not.

Phase 2: Literature Study
When entering a new field of development, all information available should be studied to ensure that important factors are not missed during discussions. This will prevent unnecessary research and the wasting of valuable time. This information can be found in SAB libraries, where all researched information is kept.

Phase 3: User Requirement Analysis
Meetings with end users and QC (Quality Control) personnel must be held to identify and list all the relevant requirements and specifications for the project. Since this is a new development project, the specifications and requirements must be determined before the designing process begins.

Phase 4: Final Design Proposal

At this phase the final design proposal is presented for approval. All the requirements and specifications agreed upon, should be recorded in detail. Supply and demand, including the price, should be negotiated and agreed upon. This phase should be seen as the final opportunity to consider possible adaptations to the design proposal.

The design is then conducted on the basis of the listed specifications and requirements. This includes the electronic hardware design and implementation, software development for the instrument processor and computer interfacing as well as the design of the watertight housing and frame for the product.

1.7 Uniqueness of Project

The project is aimed at developing a new instrument around the end user which incorporates all his requirements. Preliminary research indicated that a need arose for peripheral interfacing, which can easily be adapted to suit individual needs. An instrument that interacts with modern computer systems and networks, and provides room for future development, will definitely have an advantage over other products available. None of the existing instruments on the market comply with these specifications. Further advantages are, a local product with excellent backup service and quick turn-around times for sales and service.

1.8 Summary

This chapter is an introduction to the development of a P.U. recorder. Chapter 2 describes the theory of brewing pasteurization and gives an overview of the parameters involved by ensuring pasteurization quality control. Chapter 3 discusses the product specifications and the user requirements. Chapter 4 deals with the design of the system in terms of hardware and software. An experimental evaluation of the instrument is conducted in Chapter 5. Chapter 6 is a summary of the development and presents directions for future research.

CHAPTER 2

BREWING PASTEURIZATION

2.1 Introduction

This chapter describes the theory of brewing pasteurization, the mathematical calculations involved in deriving the P.U. measurement as well as the parameters which have to be measured in order to monitor the effectiveness of beer pasteurization.

The aim of the discussion is to provide the reader with an introduction to brewing pasteurization and the processes and theories associated with the process. This information will assist in understanding the environment in which the recorder has to operate, as well as the requirements for designing an advanced data logging instrument.

2.2 Brewing Pasteurization Process

2.2.1 Introduction

Pasteurization may be defined as a process in which elevated temperature is used over a prescribed period of time to destroy undesirable organisms in a product. The process should not detrimentally alter the product's quality, but the primary objective is to secure the biological stability of the product, thus prolonging its shelf-life [15]. Pasteurization is commonly measured in terms of pasteurization units (P.U.). One P.U. is defined as the exposure of a product to a temperature of 60°C for one minute. To a degree, lower temperatures also have a lethal effect on organisms, but they are not as effective as high temperatures. This process was developed by Louis Pasteur in the early 1860's, who demonstrated that beer could be preserved by heating it above 57.2°C. Many researchers through the years, have refined these specifications to those used at present. Most breweries adopted the process of in-package pasteurization to ensure that no external infection can occur after the product is pasteurized [14].

2.2.2 Micro-organisms and Bacteria

The pasteurization of beverages by heating destroys the micro-organisms and bacteria without significantly impairing the flavour and appearance of the product [15]. These micro-organisms and bacteria cause disease and spoilage to the product. It is up to each brewer to determine which process is the most suitable for his product, as each product is unique with regard to the type of bacteria and micro-organisms. However, the task of the brewer is simplified by the fact that beer is not a good micro-biological growth medium and growth is restricted to a relatively small group of micro-organisms, yeasts and bacteria. This characteristic of beer can be attributed to its low levels of nutrients and oxygen, low pH, and the presence of alcohol, esters and hop bitters. It does not support the growth of pathogens [3].

The objective of micro-biological stabilization processes relates primarily to the protection of the product quality, and not to the protection of the consumer. The aim is to destroy only the harmful yeasts and bacteria which are capable of impairing the quality of beer, and not to achieve complete sterility. Certain harmless spore forming molds and bacteria may survive but present no problem to the brewer, since they cannot propagate in beer. Research was done by Dallyn [5] to determine the heat resistance of yeast in beer and how pasteurization should be accomplished. He recommended that pasteurization of 10-12 P.U.s should be adequate.

Dissolved oxygen has a negative effect on the shelf-life and flavour of beer [18]. A high oxygen content in over-pasteurization will result in a haze build-up and impair the flavour and the quality of beer. This deterioration of the flavour may only become apparent after one to four weeks. The most important factor concerning the storage of beer, is the temperature. The coldest temperature possible without freezing is recommended for storage [21]. In cold temperatures the micro-biological spoilage is retarded and non-microbial transformations proceed less rapidly. Hop oils seem particularly susceptible to undesirable changes in flavour with time, and are prone to become less acceptable in beers after pasteurization [18].

2.2.3 Recommended Pasteurization Parameters

Pasteurization in the brewing industry is achieved by spraying the beer containers in different stages with warm and cold water through a tunnel pasteurizer. The water forms a hot film over each container and the heat is transferred to the product by a forced convection process. Through the years, much research has been done on pasteurizing equipment. Control parameters have been refined and determined for different pasteurizers. The main reasons for these actions are to reduce energy consumption by preventing over-pasteurization, which in turn prevents flavour deterioration after a few weeks in storage [8].

The time required to pasteurize a product normally depends on the container size and type, the chemical and physical qualities of the beer, the number and type of micro-organisms present and the equipment used in the process. There are, however, a few guidelines with regard to the control settings. Del Vecchio [6] conducted research in optimizing the pasteurization control parameters to determine the minimum requirements. He determined that the beer in the coldest part in the container should reach 60°C and then be kept at this temperature for 5.6 minutes or 5.6 P.U.s. He used a slope or "Z" value of 12.5. Pasteurization is calculated by the following equation [3].

Lethal effect = P.U. = Lt

$$\text{Where } L = \text{Lethal Rate} = \frac{1}{\operatorname{Log}^{-1}\left(\frac{140-T}{Z}\right)}$$

t = time held at temperature T
Z = slope of lethal rate curve (12.5 for beer organisms)
T = temperature in °F

Research in the past to quantify the pasteurization treatment, led to the adoption of 12.5 as a "Z" value to be used in these calculations. Later research by Patino [16] shows that this value can change depending on the particular organisms and conditions under which tests are conducted.

A typical temperature time curve for pasteurizing beer is shown in Figure 2.1. The product enters the pasteurizer at the temperature at which the beer is packaged (±4°C). It then passes through several heating zones until it reaches 60°C. This temperature is then maintained in the holding zone for approximately 5 minutes. The product then passes through several cooling zones and leaves the pasteurizer at a temperature of approximately 25°C. This process is referred to as a Time-dependent process [1].

SAB set the minimum required P.U. specification as 9 P.U.s to suit their requirements [14]. The range of 9 - 15 P.U.s is merely to provide some flexibility to allow for stoppages etc. The aim is, however, to reach 9 P.U.s. The maximum beer temperature must be 60°C (±1°C tolerance). The holding time is a minimum of 5 minutes to achieve at least 5 of the 9 P.U.s at this temperature. Lastly, the exit temperature of the beer from the pasteurizer should be less than 30°C although it is desirable not to exceed 25°C. These measurements should be recorded in the cold spot in the container to ensure effective pasteurization. The cold spot is approximately 0.75 inch (19mm) from the bottom in the middle of the container [2].

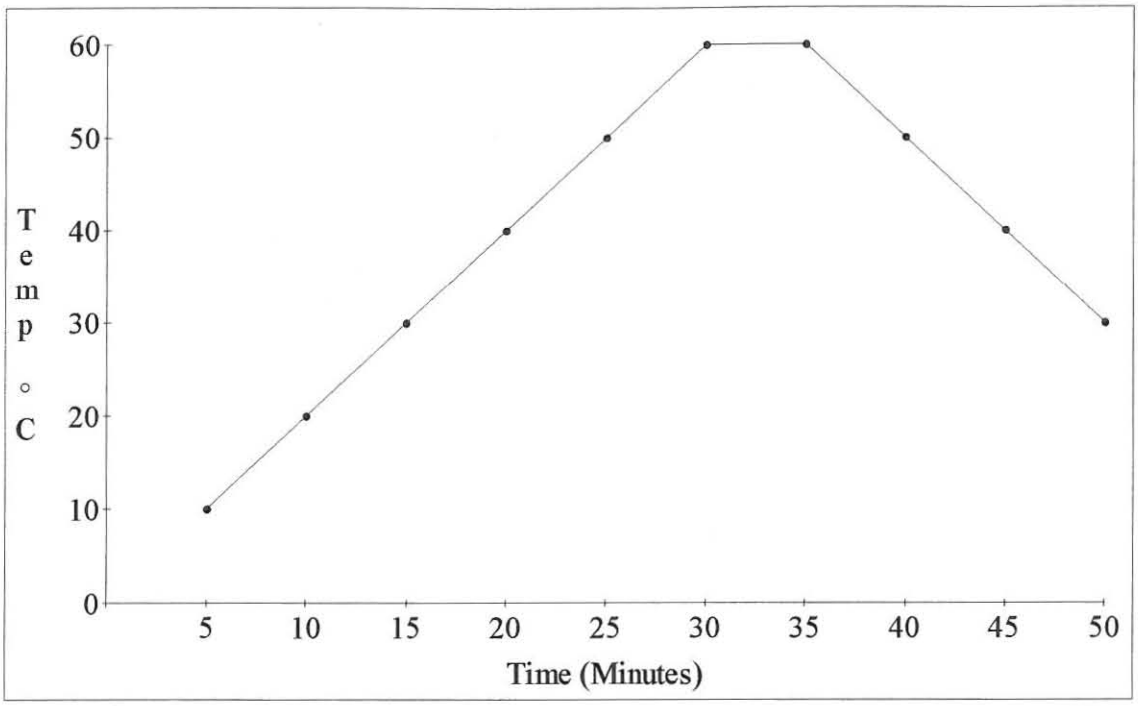

Figure 2.1 A Typical Temperature Time Curve for Pasteurizing Beer.

2.2.4 Pasteurizer Operation Criteria

As mentioned in Paragraph 2.2.3, the supplier will provide the necessary equipment to achieve the results required by SAB. How this pasteurizer process works is up to the supplier. There are, however, certain criteria that the supplier will require to design a pasteurizer. These design specifications are based on the following criteria:

1. The shape and size of the containers
2. Production rate or capacity
3. The number of P.U.s required
4. Maximum spray temperature for beer
5. The in and out temperatures of the containers
6. Summer and winter service temperature

Some kind of intelligent controller is required to ensure proper automatic operation of this important process in beer pasteurization. The latest form of control in the industry is a Programmable Logic Controller (PLC). This is an industrial control computer which can be programmed to control any process via input sensors and output control devices. Some of these control parameters for a pasteurizer are as follows:

1. The speed of the conveyors
2. Spray temperatures for each zone
3. Flow rate of service water
4. Steam requirement

A sample of the process variables of a tunnel pasteurizer as listed by Broderick [3], is shown in Table 2.1. This pasteurizer is set up for 340ml non returnable bottles at a speed of 1800 BPM, to achieve pasteurization of 7.5 P.U.s.

Table 2.1 Process Chart for a Tunnel Pasteurizer.

Zone	Spray Temp	Spray Time	Proc Time	Beer Temp
1st Preheat	22°C	3.30 Min.	3.30 Min.	1°C Infeed
2nd Preheat	27	3.30	6.60	2
3rd Preheat	36	3.30	9.90	13
4th Preheat	46	3.30	13.02	25
Heat	68	5.15	18.35	36
Hold	60	5.15	23.05	60
1st Precool	45	3.30	26.80	60
2nd Precool	34	3.30	30.10	51
3rd Precool	24	3.30	33.40	41
4th Precool	21	3.30	36.07	32
Cooling	19	2.570	39.27	26
				23°C Exit

The main concern of the brewer is to ensure proper running conditions in order to ensure proper pasteurization. Criteria for the pasteurizer which will effect proper pasteurization are; plugged spray nozzles, improper cycle times, incorrect zone temperatures, loosely packed or toppled bottles, and bottle breakage. Bottle breakage can be due to poor glass or rough handling, overfilling, abrupt temperature changes and/or overheating, jams and toppled bottles. Bottles entering the pasteurizer should be cleaned of beer overflow, to prevent slime build-up. This could block sprays and effect proper pasteurization. Incorrect spray temperature in the pasteurizer could result in bottle breakage's which would also lead to slime build-up.

Another requirement for proper operation is to ensure a steady flow of bottles through the pasteurizer. The flow of bottles has an effect on the pasteurizer temperature. If intermittent stops or improper filling due to line inefficiency occurs, the correct P.U. value may not be achieved. Maintenance schedules set by the supplier will help to prevent incorrect operation of the pasteurizer.

One way of checking all these operation criteria is with the help of a P.U. recorder. This instrument is used by floor personnel who perform periodic checks on the pasteurizer. The instrument is inserted in the container stream through the pasteurizer and records the criteria such as spray temperature, container temperature and transit time. P.U. results could then be derived from the data sheets.

2.3 Parameters for a P.U. Recorder

Working through all these specifications and criteria, one can see the importance of an instrument which could accurately measure what is happening inside the pasteurizer as well as inside the container which moves through the pasteurizer. Transit time and zone temperature directly inflict upon the effectiveness of the pasteurization process. The pasteurizer controls must be double checked in some way, to ensure correct operation. This would be the task of the P.U. recorder, as a laboratory instrument. This instrument must be able to perform the following measurements:

1. Measure and record the spray temperature every 5 seconds
2. Measure and record the beer temperature every 5 seconds
3. Measure the transit time and the time duration through each zone

With these measurements, all the necessary data discussed in Paragraph 3.2.2 can be calculated. The accuracy of these measurements is discussed in Paragraph 3.2.4.

2.4 Summary

This chapter described the theory of brewing pasteurization with specific reference to the parameters involved in pasteurization quality control. The discussion dealt with the theory concerning brewing pasteurization as well as the technical and operating criteria and parameters. The discussion closed by describing the parameters that have to be measured by an advanced P.U. recorder to be used as a laboratory instrument.

The next chapter summarizes the technical specifications for accurately measuring the parameters described in this chapter as well as the user requirements for the development of the data logger as a factory quality control instrument.

CHAPTER 3

DESIGN SPECIFICATIONS FOR THE RECORDER

3.1 Introduction

The previous chapter described the brewing pasteurization process and the parameters that have to be considered when designing a P.U. recorder for pasteurization quality control. This chapter describes the technical design specifications as well as the user requirements for the instrument as a marketable product in terms of packaging, price, durability and service considerations.

3.2 Requirements and Technical Design Specifications

Before designing the instrument, all the requirements and specifications have to be identified. It can be costly to remedy should any requirements be omitted. As part of the R&D, all requirements were first listed. Meetings with relevant end users, as well as management personnel of SAB, were held to list as many opinions and ideas as possible. Since this is a new development, there are only a few guidelines to follow. Careful consideration was given to the items listed, until only the final requirements remained. These requirements were placed in the following three categories, namely: What should be included in the software, what data is required from the instrument and what kind of hardware should be included. Once the requirements were listed, the specifications were identified. These specifications were determined by the design criteria and SAB requirements. A few of the SAB requirements were traced back to their Packaging Standards Manual [22]. The following four paragraphs discuss the requirements and specifications criteria which were listed.

3.2.1 Software Requirements

Software is basically the programming requirement of all the intelligent blocks of this project. This programming simplifies the hardware requirements to a minimum which in turn will minimize expenses. Software can also be adapted fairly easy without any hardware changes. For this reason, all software possibilities will be considered before the hardware is designed. This software can be divided into two main categories namely: the instrument processor software and computer software. This will be discussed in detail in Paragraph 4.3. In writing this software, certain requirements must be incorporated and are as follows:

1. User friendliness, menu driven and easy to operate.
2. Battery condition indication
3. Real time clock and calendar
4. User input on unit details for printouts
5. Recording must stop if connector is unplugged
6. Windows compatible software for PC's
7. Stand alone printer software with choice of graphics printout
8. Results to be viewed on the instrument itself
9. Thermometer menu for testing
10. Password needed for parameter changes
11. Adjustments for clock and calendar
12. Adjustable Lethal cutoff temperature
13. Probe calibration
14. Reset to factory calibration
15. Instrument calibration

The software is responsible for all calculations and data processing. The main hardware requirement for the software is Random Access Memory (RAM) and Read Only Memory (ROM).

3.2.2 Data Requirements

The user is interested in certain results and data from the pasteurizer. The main function of the P.U. recorder is to obtain these results. Some data relates to measurements taken while other information requires complex calculations and derivations. The complete recorder development evolves around these data requirements. They are as follows:

1. Unit details on printout - unit number, position, container size and serial numbers
2. Start time and date
3. Transit time
4. Total P.U.s
5. Lethal P.U.s and time
6. Maximum temperatures
7. Beer exit temperature
8. Full temperature listings
9. Graphics for beer and spray temperature

This data will be obtained from the P.U. recorder and is mainly written in the instrument processor software.

3.2.3 Hardware Requirements

Hardware is the electronic and mechanical equipment required to obtain the data required by the user. This hardware can be divided in two main categories, namely: electronic and mechanical requirements. The design criteria are evolved around the user requirements and the data requirements. The user requirements for this instrument are as follows:

1. Compact, rugged and lightweight stainless steel frame
2. Integrated bottle and can holders
3. Interchangeable temperature probes
4. Stainless steel enclosure for instrument processor board
5. Built in spray temperature probe
6. Glass front panel with 16 Character LCD display
7. Rechargeable batteries
8. RS 232 interface with relevant cables
9. Standard computer printer (EPSON LX300)
10. Battery charger with battery full detection
11. Calibrating resistor set
12. Operating manual

These requirements must be carefully planned as changes are costly and time consuming. A prototype electronic hardware design is recommended because of the extent of circuitry that is required to meet the user data requirements.

3.2.4 Technical Specifications

Specifications must be listed before the design can commence. The design of the hardware must comply with these criteria. These specifications will determine the validity of the accumulated data when using this instrument. Each part of the P.U. recorder will be designed according to set criteria or specifications. The main components of this integrated system fall under the following specifications:

P.U. Recorder

Number of channels	2
Temperature range	0 - 80°C
Temperature resolution	0.1°C
Temperature accuracy	± 0.2°C
Sampling rate	5 sec interval
Total sampling time	1.5 Hours
P.U. range	0 - 999.9
P.U. resolution	0.1 P.U.
P.U. calculation accuracy	± 1%
Time system	24:00
Time resolution	1 second

Time accuracy	± 3 seconds per 24 hours
Charged battery life	over 10 hours

Probe specs

Probe accuracy	± 0.1°C

Battery charger specs

Charge Time	10 Hours max.
Charging Current	85mA DC max.
Charging Voltage	6.8 V DC max.

Packaging specs

Instrument housing	1.2mm stainless steel
Dimensions LxWxH	160 x 114 x 55mm
Glass panel	4mm thick
Connector	Chassis mount - MIL spec
Spray probe	6mm stainless steel tube
Operating temperature	0 - 70°C
Frame	3mm stainless steel
Dimensions LxWxH	370 x 126 x 110mm

Interface specs

User	6 x 6 x 20mm general purpose magnet
Printer / Computer	RS 232 3-wire protocol

Security specs

Password no1	Alterations menu
Password no2	Instrument calibration

These specifications will be the user's indication as to the accuracy of data recorded or calculated. It can also indicate to the user if his equipment is still in good condition or if failures occur.

3.3 Marketing Requirements and Product Design

3.3.1 Marketing Requirements

Most market requirements became evident during the R&D. The high technology equipment already available on the market has given the users sufficient experience to know exactly what they would require. Their frustrations with lengthy and complicated manuals and instructions clearly became evident. When the instrument requirements were discussed, they pointed out what their expectations of a new instrument on the market would be. The following criteria were discussed:

1. **User friendly** - This instrument should not require any specialized training. The menu driven program should lead the user as to what his next action would be. Where computer software is used, programming must be standardized with existing software with which they are familiar.
2. **Reliability and Durability** - This is a standard requirement for all SAB equipment. The recorder must be of high quality and durability to function in the factory environment. A suggested minimum of a one year guarantee should apply.
3. **Serviceability** - This is one of the most important requirements. Most of the SAB's equipment of is imported and has a poor and expensive backup service. Spares and accessories for this recorder should be a stock item with the agent to ensure quick turn-around times during sales or service. The suggested exchange units would be a plus point.
4. **Compactness** - The requirement is for a lightweight unit which could easily be carried around in the factory and inserted onto conveyor systems. It must also be strong to handle the pressures found on conveyor systems.
5. **Windows adaptable** - The trend with most equipment is to work in the Windows environment. Since most factory personnel are already familiar with Windows, it would definitely be an advantage for the instrument software to function in this environment.
6. **Adaptability** - With ongoing R&D on pasteurizing equipment and processes, there is a need for this P.U. recorder to be adaptable to accommodate future standards and processes.
7. **Cost effectiveness** - Price is always of concern to any user. Details will not be discussed but a locally developed product with carefully designed principles, will definitely ensure a cost effective product.

These market requirements concern the majority of users as well as would be users. Future requirements which are included might result in greater demand for this instrument.

3.3.2 Product Design

Now that all the requirements and specifications have been listed, the instrument design can be planned and finalized. Figure 3.1 shows a block diagram of all the main design blocks. This block diagram includes software and hardware design. Each block has a number which indicates the order in which the design will take place. It is noteworthy how the hardware is designed before the software.

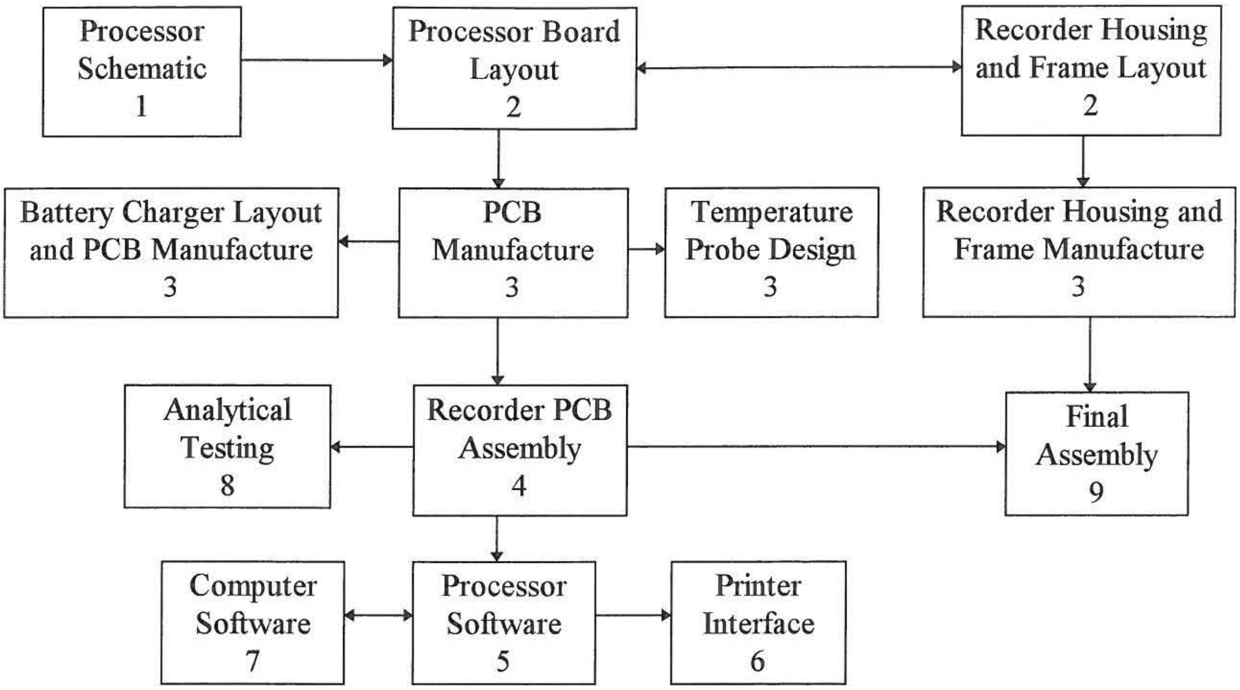

Figure 3.1 Block Diagram of the Design Phases of this Project.

Phase 1 of the design will be the instrument processor board schematic. It must provide for the necessary software features which will be programmed later. Phase 2 is the layout of the processor PCB and the housing and frame. The number of components on the PCB influences the size of the housing, and the housing influences the layout of the PCB. The frame also has a desired form which will in turn have an influence on the housing. The enclosure and PCB must have the necessary standoffs and mating holes to fit each other.

In phase three all the relevant design hardware is manufactured. Some of the manufacturing requires specialized equipment which is also time consuming, for instance, the PCB for the electronics and the laser cutting and welding of the stainless steel. This time consuming work should be addressed first. Phase 4 is assembly and testing of the processor board to prepare it for programming.

Phase 5, 6 and 7 is the software development phase. Processor software is written first and then the printer interface software. Lastly, the computer software will be written. This software is written by personnel working with SAB PC software. Phase 8 concerns analytical testing and to remedy the final faults in the software. Phase 9 will be the final assembly and trial runs in the factory.

3.4 Summary

This chapter described all the design specifications and requirements for the P.U. recorder design. It is important to know exactly what is required before the design can be started. Any changes after this step can be costly or time consuming. It is also important to know the market requirements before starting a design. This could mean that the design does not suit the user and is rejected.

The next chapter will discuss in detail how the P.U. recorder design is integrated into a product. Each part of the recorder is discussed in separate paragraphs.

CHAPTER 4

P.U. RECORDER DESIGN AND DEVELOPMENT

4.1 Introduction

Chapter 3 discussed the design specifications for the instrument and the user requirements that have to be considered in the technical design. It identified all the building blocks and the order in which the design must take place.

This chapter describes the design and development of the data logging instrument in terms of the hardware and software. Paragraph 4.2 describes the hardware development in terms of processor printed circuit board design, temperature probe design and the design of the printer and PC interfaces. The software development of both the instrument processor and PC software are described in Paragraph 4.3. Paragraph 4.4 details the integration of the system into a marketable product enclosure with an accompanying NI-CAD battery charger.

4.2 Hardware Development

Figure 3.1 in Chapter 3 showed the different design blocks for hardware and software. Once the planning is completed, all the relevant hardware can be manufactured. The software evolves around the hardware, meaning that the hardware must be completed before the software is commenced with. The main design blocks of the P.U. recorder system, for the hardware, consists of the micro processor board, temperature probe, battery charger, enclosure and frame. The design of these component blocks is discussed in the following paragraphs.

4.2.1 Processor Board Design

Referring to Figure 4.1, the most critical decisions which have to be taken in the design phase is the choice of the most suitable and reliable components that would meet the specifications required for the instrument. These components are the micro processor, the real time clock, the program and data memory (ROM/RAM), analog to digital converter, sensor amplifiers and the RS232 and user interfaces. All these components require low power for operation which is essential for battery operated circuitry. The next few paragraphs will discuss the relevant component blocks.

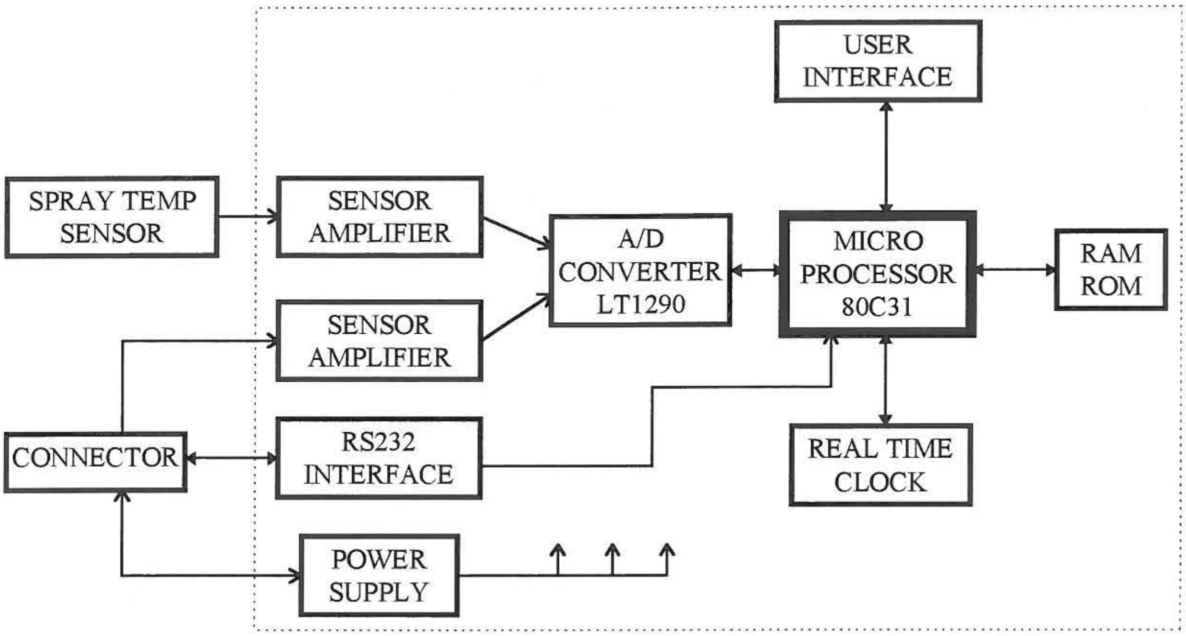

Figure 4.1 Block Diagram of the Micro Processor PCB.

4.2.1.1 Micro Processor

In deciding what micro processor to use, a few criteria are listed. The future availability of this micro processor is important to ensure a backup service for the recorders which will be in use. It must have a relatively low cost since no special functions or high performance micro is required to do this task.

The micro processor chosen for this task is the 80C31 from Intel [9]. This device is so popular that other suppliers have just recently brought out exact copies as well as upgraded versions of the same product. It is one of the cheapest micro processors available and a number of developmental kits and programming languages are designed for this chip. The micro processor communicates with, and links all the other intelligent devices together. It collects data from the building blocks and then processes it before allocating it to other blocks or making decisions about them.

Appendix B shows one such communication to the A/D converter. This communication is serial which saves on Input / Output (I/O) required from the micro processor. These I/O lines are accessed through the instrument software which is discussed in Paragraph 4.3.1. The communication between the micro processor and the A/D converter is discussed in Paragraph 4.2.1.3.

4.2.1.2 Memory

As mentioned in Chapter 3, memory is required for the instrument processor software and for the data which will be collected. The 80C31 micro processor requires two types of memory. Firstly, for the source code, which is compiled from the micro processor software, Erasable Programmable Read Only Memory (EPROM) is required. This memory is non-volatile and can only be erased by ultra-violet light. This means that the micro processor cannot alter this memory.

Secondly, the data and calculations require Random Access Memory (RAM). This memory is used to store the data collected, as well as any calculations performed by the micro processor. It is a volatile memory which means that data will be lost in power off situations.

The Printed Circuit Board (PCB) should have the option of selecting between different sizes of these memory devices. The reason, therefore, is that the demand for larger memories is greater than for smaller memories, resulting in improved availability and cost effectiveness of the larger devices. The PCB must be able to take a 32K or 64K EPROM and a 8K, 16K or a 32K RAM.

4.2.1.3 Analog to Digital Converter

This device will interface the analog signals from the sensor amplifiers to the digital signals of the micro processor. This is called an Analog to Digital (A/D) converter. It is a serial communication device which helps to maintain the component count to a minimum and saves on PCB dimensions. An excellent choice is the LT1290DCN from Linear Technology [11, p6.67]. This is a narrow Dual In-line Package (DIP) and consists of 4 dual- or 8 single-ended analog inputs or a combination thereof. The inputs required for the instrument are 2 dual inputs from the two sensor amplifiers and one single ended input to read the battery voltage. It is a 12 Bit A/D converter with very good thermal operating stability. This A/D converter requires no external components which minimise on PCB dimensions.

Appendix B show the LT1290DCN A/D converter with its connections to the sensor amplifier and the micro processor. This device requires four I/O pins from the micro processor for the serial communication process. It also requires that the Analog Clock (ACLK) of the A/D converter be connected to the Address Latch Enable (ALE) of the micro processor. This signal is used as a clock signal for the internal circuitry within the A/D converter. It does not require any programming in the instrument software. The Serial Clock (SCLK) signal is an output from the micro processor, and is used to clock data to and from the A/D converter. The data to the A/D converter is done via the Data In (DIN) line, which is an output from the micro processor. The data from the A/D converter is done via the Data Out (DOUT) line which is an input to the micro processor. The Chip Select (CS) line is used to enable or disable the A/D converter. The A/D converter uses less power in the disable mode.

The A/D converter requires an eight bit control word from the micro processor to activate different operations within the device. These operations will indicate to the A/D converter which input is to be converted and made available on the output.

4.2.1.4 Real Time Clock

Another serial device is the Real Time Clock from Dallas, the DS1202 [4]. This is a very popular device as it is cost effective and is offered in an eight pin DIP package. The only external components required are, the popular 32KHz clock crystal and a 3.6V lithium cell to power the clock during power off conditions. The DS1202 times in seconds and keeps track of calendar dates. It has 24 bytes of non-volatile static RAM whose data will be retained by the lithium cell. This is useful to store the setup and calibration values of the main program. This device requires three I/O pins from the micro processor.

4.2.1.5 User Interface

The user interface provides the user with the necessary means of communicating with the micro processor. User input is done via four magnetic Reed switches through the glass front panel. These switches are activated with a small cost effective magnet. Only three switches are used to operate the instrument and the fourth switch is used to switch the power off. The three operating switches function as follows:

- SELECT - This switch is used to search for the desired function on the instrument. It is also used to end a function which was activated by the ENTER switch.
- ENTER - This switch is used to enter a certain menu or function. It is also used to enter data that is changed by the ON/CHANGE switch.
- ON/CHANGE - this switch is used to change parameters where changes are required. It is also used to switch on the instrument.

The micro processor communicates with the user via a 16 Character Liquid Crystal Display (LCD) from Samsung, UC-161-01 [23]. There are a number of replacement displays from other suppliers, as this is a very popular and standard device. This device has its own circuitry which is memory mapped and is programmed like RAM memory. The user program is written in such a way as to lead the user to his next action. The LCD display will provide messages and results to the operator. It is situated behind the glass panel.

4.2.1.6 Sensor Amplifier

The sensor amplifier is an interface between the temperature sensor and the A/D converter. The sensor is a PT100/15P [24] resistance thermometer, with a positive temperature coefficient. It has a very small resistance deviation at temperatures between 0°C and 80°C which is 100Ω to 138.5Ω respectively. This means that the signal from the sensor needs to be amplified approximately 33 times in order to be read by the A/D converter. Appendix B shows a circuit diagram of one of the sensor amplifiers circuitry, the A/D converter and the micro processor.

The sensor amplifier is a critical part of the instrument because of the sensitivity of the small signal that is conditioned. Therefore, any noise must be eliminated to provide a pure signal to be measured by the A/D converter. Here a low power precision op-amp, LT1013CN8 [11, p2.19], from Linear Technology is selected. This is a very stable operational amplifier that also guarantees repeatability between devices. The resistors around this amplifier are of the 1% metal film type to ensure temperature stability.

As shown in the schematic in Appendix B, the sensor is connected in a Wheatstone bridge with R1, R2 and R3, to compensate for a resistance offset. The offset is the result of the sensor resistance at 0°C, which is 100Ω. The bridge is set to be in balance at 0°C temperature on the sensor. Any out-of-balance signal on the bridge, due to the resistance increase of the temperature sensor, is amplified by the op-amp. The amplification is determined by resistors R5 and R4. R6 is for internal compensation in the op-amp and is the same value as R5. R7, R8, C1, C3, and C4 form part of the filtering circuitry to eliminate noise on the analog signal. The amplified signal from the op-amp is connected to a dual input on the A/D converter. The A/D converter will only convert the voltage difference between the two signals into a digital signal.

Calibration of these sensor amplifiers is done by the supervisory software as discussed in Paragraph 4.3.1 (Calibrate Instrument). The second sensor amplifier is a copy of the one discussed above.

4.2.1.7 RS232 Interface

The RS232 interface connects the micro processor to the Mil Spec connector and provides the correct RS232 protocol and 5V Universal Asynchronous Receiver Transmitter (UART) voltage levels. Since RS232 converters use charge pump capacitance circuits to generate the ±15V from the single 5V supply, they require lots of energy.

A good choice of component for this task is the LT1180ACN from Linear Technology [12]. This is a low power device that has a chip enable input to shut the charge pump circuitry down when it is not required. This device requires one I/O pin from the micro processor for the shutdown feature. The interface is directly connected to the UART on the processor and provides the correct voltage levels for communication. This component requires only four 0.1uF chip capacitors in surface mounting packages to generate the required voltage levels. The small capacitors will help to ensure minimum PCB dimensions.

4.2.1.7 Power Supply

The power supply consists of the rechargeable batteries as well as the electronic circuitry to condition their voltage output to a usable voltage level required by all the relevant components. The precision 5V voltage regulator from Linear Technology, LT1121CN8 [13], was chosen for its output stability. This output will be used on the A/D converter as a reference voltage. It is a low dropout regulator that requires the minimum of 5.4V to regulate at a 5V output. This means that only five NI-CAD cells of 1.2V and 850mAH rating, which are equivalent to 6V, are required for the energy source.

The regulator is a low power component with an external shutdown for the ON/OFF circuitry. It has an internal current limit for protection against external component failure. The instrument is required to run consistently for a minimum of 10 hours on its own power source without the need for recharging. This means that the total power dissipation for 10 hours must be less than approximately 750mAh.

All the passive components are preferably surface mounted and of high temperature stability. Each active component has a de-coupling capacitor situated as close to the component as possible. This will minimize digital noise which could create distortion on the analog circuitry.

4.2.2 Temperature Probe Design

A photograph of the temperature probe designed for this project is shown in Figure 4.2. The probe basically consists of stainless steel housing, a PT100/15P resistance thermometer [24], a flexible cord and a MIL spec connector [17]. This temperature probe is exposed to the same harsh environment as the instrument. All the connections must be watertight and have a sturdy design.

The probe housing is made from 6mm stainless steel tube which is welded onto the probe body. The sensor is soldered onto the end of the flexible cord and inserted to the bottom of the tube. Aluminium oxide powder is vibrated into the tube to prevent vibration of the sensor and the cord. This is a heat transfer compound which would transfer the heat from the tube to the sensor. The probe body has a sealing cap on the top, which is sealed with a non acid base silicone sealer. A piece of heat-shrink with glue on the inside is shrunk over the probe and cord junction, in order to make that connection waterproof. The connector is also filled with the same silicone sealer to prevent corrosion.

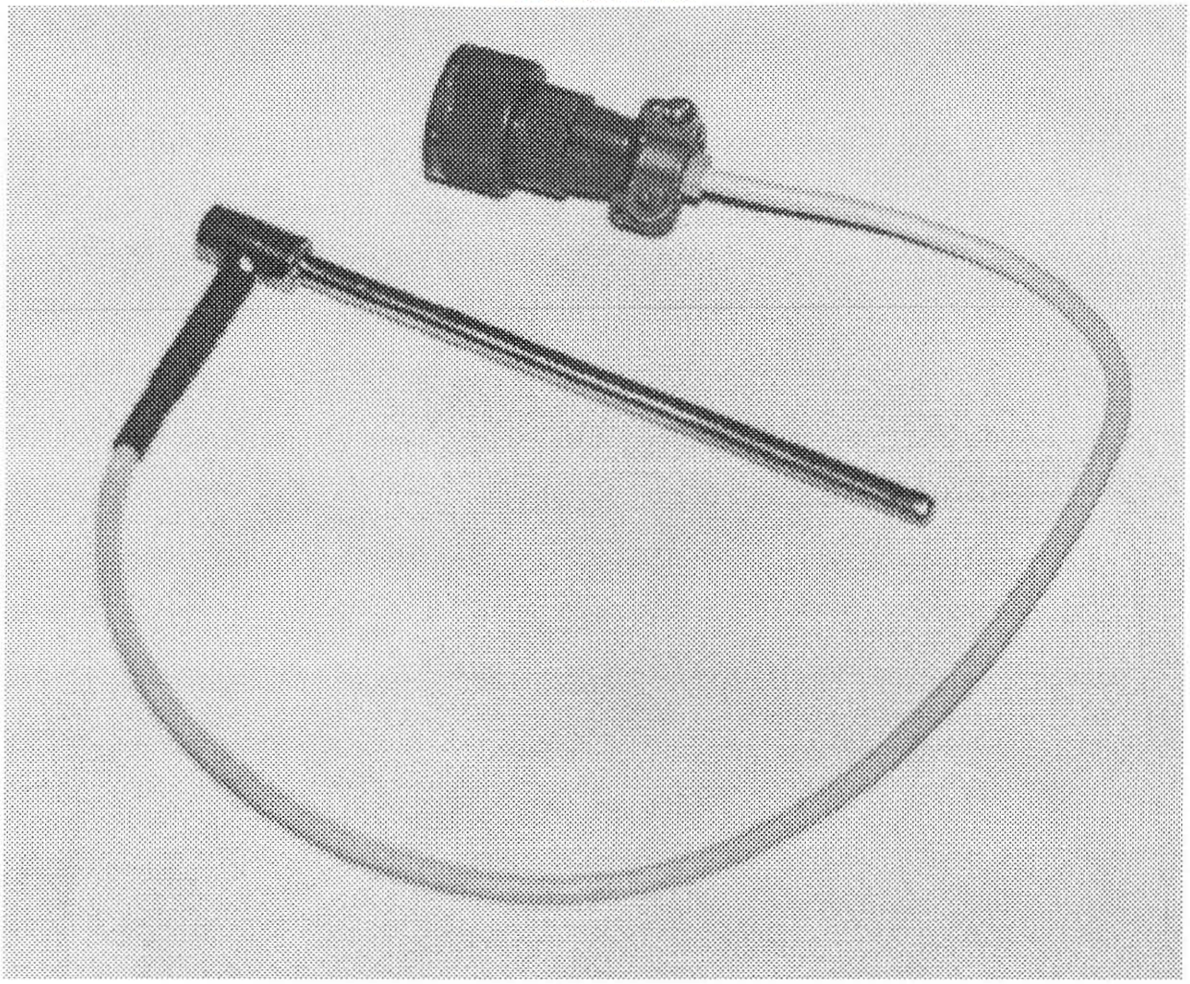

Figure 4.2 Photograph of a Temperature Probe.

The sensor used for this application is an industry standard PT100/15P resistance thermometer [24]. This temperature sensor has a positive temperature coefficient and is 0.1% accurate. This will be adequate for 0.1°C measurements. These sensors can only accommodate currents less than 4mA in order to keep power dissipation as low as possible. Higher currents will result in heating the sensor and cause inaccurate readings. Since these sensors have a resistance of 100 ohm at 0°C and 138.89 ohm at 80°C [24], the deviation in resistance is very small. Leads must be kept as short as possible and solder connections must be proper to keep external resistance as low as possible.

4.2.3 Interface Design

The data logging instrument has two types of interfaces. A **user interface** and a **peripheral interface** for connecting to a printer or a PC. According to the technical design specifications for the packaging enclosure, given in Paragraph 3.2.4, all interfacing to and from the instrument has to be watertight. The user interface will be on the instrument itself, while the peripheral interface will be via the watertight connector.

4.2.3.1 User Interface

User interfacing to the program menus can be accomplished by using indirect connecting mechanisms such as an optical or a magnetic communication link. In using an optical connection to allow the user to select software menu parameter, one has to consider the fact that the optical devices are fairly technical, and would require a relatively clear view through the glass for effective communication. In a typical brewery packaging environment, the glass window of the instrument is wet most of the time, meaning that the operator would have to clean the glass each time he wishes to do menu selection. Furthermore, one would have to supply additional electronics for communicating with the instrument which would have to be maintained. These electronics would have to be installed at selected places in the factory. A battery operated hand-held interfacing module can be supplied but this option has the disadvantage in that it can be lost or misplaced in the factory environment.

In contrast, by using a magnet with a matrix of four Reed switches, user interfacing can be accomplished through clever manipulation of the menu software. A magnet is a passive device, while the replacement cost for losing a magnet in the factory environment is also very low. For these reasons, the user interfacing will be accomplished using the magnet option. The micro processor software for interpreting the Reed switch selection will be described in flow charts in Paragraph 4.3.

4.2.3.2 Peripheral Interface

The peripheral interface connection, if using optics, would be difficult to accomplish, especially the interfacing to the battery charger for recharging the NI-CAD batteries inside the packaging enclosure. The battery charging function requires a direct connection through the watertight enclosure. One way of accomplishing this connection is by using a MIL spec circular connector [17].

Interfacing with the printer and the PC can be accomplished through an optical link as described above, but the problems associated with this method are also mentioned. For these reasons, the printer and PC interfacing will also be done through a 6 pin watertight circular connector.

Interfacing with the P.U. recorder is kept as simple as possible. This means that it does not require any special training to accomplish normal operating tasks.

4.3 Software Development

SAB envisaged a goal of World Class Status [19] through their products. They invested in high technology equipment and training to achieve this goal. One great achievement is the latest technology in computer network systems. Since most of the new instrumentation and PLC equipment can communicate with these computers, it was essential to produce a P.U. recorder that also meets these requirements. They require that this P.U. recorder interface with their current computer systems as well as being able to work as a stand alone instrument at locations where no computers are available. This is the case, at present, at some of their breweries in remote locations throughout Africa. In these situations, the P.U. recorder should interface directly to a printer.

With these requirements it became evident that the software could be divided into two parts; software for the P.U. recorder and software for their PC's. The micro processor software is part of the P.U. recorder and will be developed with the instrument. This processor software must be able to run completely on its own as well as interfacing with their computer software. The computer software will be developed by SAB software contractors. They would interface the instrument with all their relevant programs to suit the end user's needs.

4.3.1 Processor Software

The instrument processor software is the program required by the micro processor to perform all the required tasks. This program is written in a high level language and then compiled to produce machine code which could be interpreted by the processor itself. This code is stored in Erasable Programmable Read Only Memory (EPROM). This program is written in PLM51 which is a high level, developmental program language supplied by INTEL for developing micro processor circuits with the 8051 micro processor family.

Since this program consists of approximately 80 pages of instructions, only the communication part for the circuitry in Appendix B is discussed. The source code is attached in Appendix C. The first part of the software is where all declarations is done. Here the writer can declare registers with explanatory names to use throughout the program. These registers contain various forms of data and values which is used by the micro processor for calculations, etc. These registers also indicate to the micro processor at which address certain data will be obtained.

The second part of the program contains all sub routines or procedures. A procedure is a small part of program that can be used throughout the main program without the need of repeating it several times. It is placed outside the main program, and can be called from within any part of the main program. The main program will execute this routine as if it were part of the instruction set.

The third part of the program forms part of the main program. It is not situated within the main program but will only be executed once. This part is used to load certain values and settings in registers as well as programming external components with the required set-up parameters.

The fourth part is the main program. Here the writer adds all the building blocks together to create an even flow with interfaces and data. This program is executed continuously using all the different subroutines to create an instrument with all the end user's requirements.

The program realises this user interface, which will interact with the user as to what his inputs to and from the P.U. recorder are. This can be divided into two sub-components, namely, the **operator menu** and **supervisor menu**. The menu software is written and developed around the user requirements discussed in Paragraph 3.2. The main criteria, when writing this software, are **user friendly** and **menu driven**. This program must be self explanatory and lead the user through his actions.

4.3.1.1 Operator Menu

The operator menu gives any operator, with an activating magnet, means of using the P.U. recorder for normal operational functions. Only minor setup details can be changed while the instrument can be fully utilized for data logging and pasteurization testing. This menu is driven via the glass window with a magnet as discussed in Paragraph 4.2.3. Flowcharts of the main operator menu can be seen in Figure 4.3. Each function and sub menu in Figure 4.3 is described below:

Display Time

The real time is displayed for operator verification. It is important to indicate the precise time when the test was done, on the printout data. The clock times in seconds and is in the 24:00 hour format.

Display Date

The real date is important and printed as well. The operator should ensure that the time and date is correct before using the recorder. The calendar will keep track of leap years.

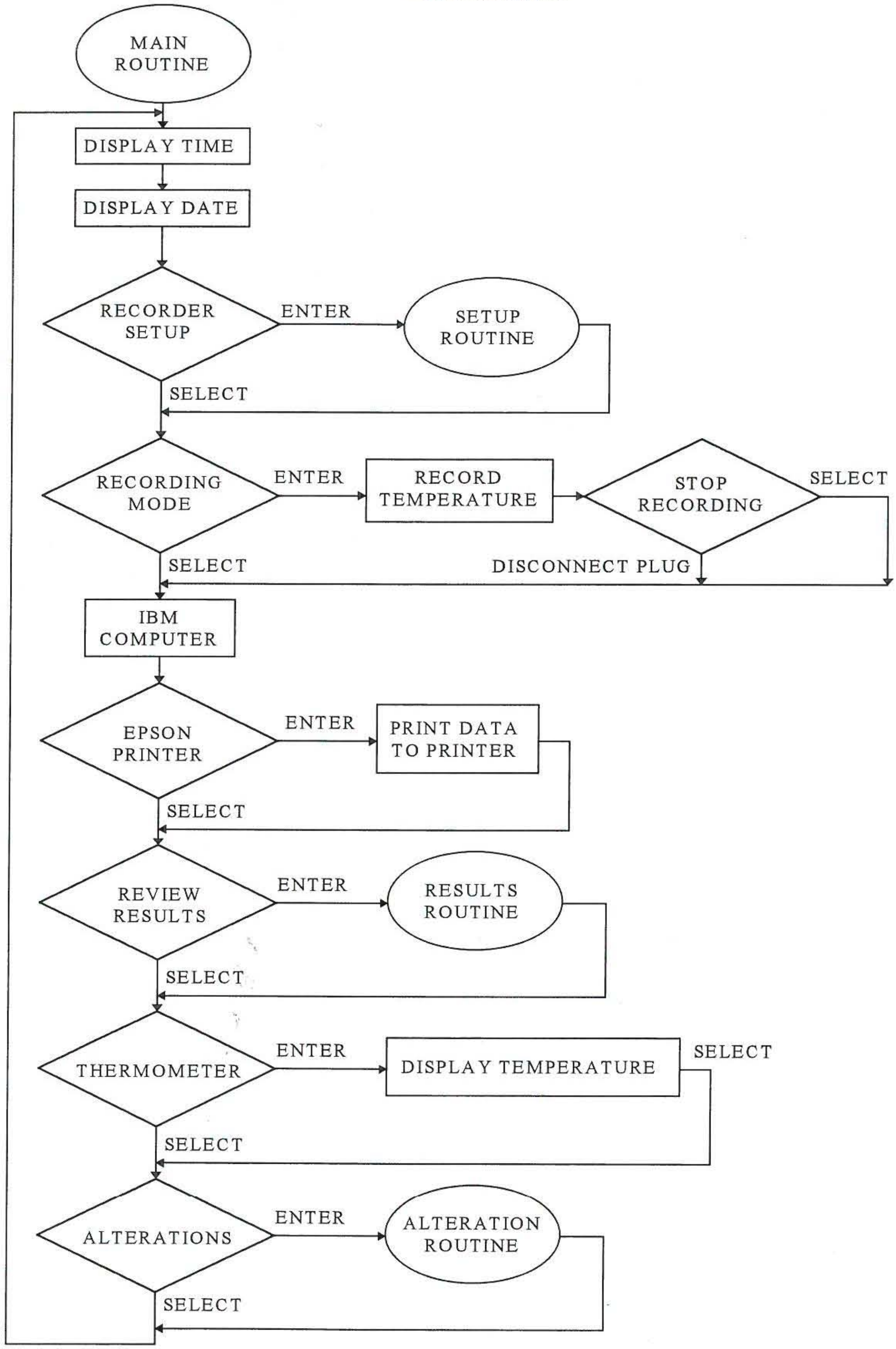

Figure 4.3 Flowchart of Main User Program.

Recorder Setup

This function allows the operator to add relevant line details to his printout. The instrument software requires this information from the user in order to display it on the printout or data display. This data is entered and saved into the instrument until it is changed again. Figure 4.4 shows a flowchart of this setup routine. The unit details will consist of the following:

- **Unit Number** - This is the packing line number on which the pasteurization test is to be done.
- **Deck Used** - This indicates the location where the instrument is inserted into the pasteurizer, the top or bottom DEC.
- **Position** - This indicates on which side of the pasteurizer the instrument is inserted and could be left, middle or right.
- **Pack-size** - This will indicate which size of container was tested.
- **Graphics** - This allows for a short or extended printout to be printed on the Epson LX300 printer. The short printout will only print the important details on one page while the extended printout will contain a graph of the data. This graph is helpful to separate the different pasteurizer zones with the time intervals. Appendix A shows an example of a factory pasteurization test. The same test is shown for a computer data display.
- **Probe Serial Number** - Each probe has a serial number which will be displayed on the printout. This is useful for statistics and fault-finding when consistent errors in measurement occur.

Recording Mode

This is the main function of the instrument. In this menu, the actual pasteurization test is done. The instrument is inserted into the pasteurizer and the temperature is logged during the time it passes through the pasteurizer. When the instrument is stopped after it has reached the exit, all the relevant calculations are done by the instrument and stored in the results database. Temperature is recorded every five seconds and the P.U. calculations are done.

IBM Computer Interface

This menu places the instrument in an active state to communicate with the computer software. Communication is activated by the computer software. The operator needs only to connect the instrument to the communication cable.

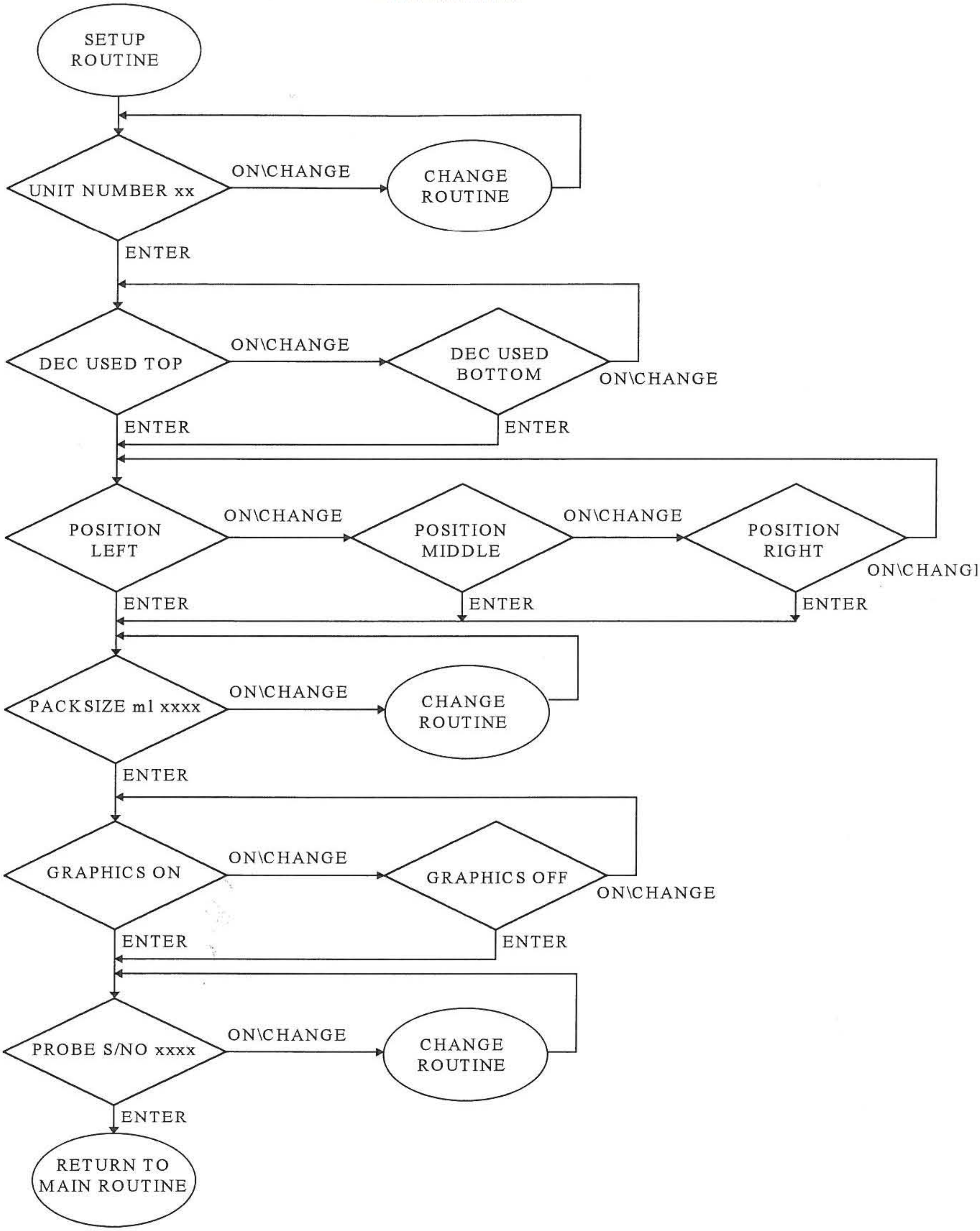

Figure 4.4 Flowchart of Setup Routine.

Epson Printer Interface

This menu interfaces with the Epson series printers. The printer used with the instrument, for its reliability and cost effectiveness, is the Epson LX300 serial/parallel printer. It also has excellent perforated paper feed capabilities. This software prints all the relevant data as well as a graphic display. The printing process is activated by the user via the instrument. Handshaking between the instrument and printer takes place via a three wire RS232 protocol. An example of a printout is displayed in Appendix A.

The first part of the printout contains all the unit details entered by the operator and all the important results achieved, as discussed later in this chapter. It then contains two listings and two graphs. The first listing displays the temperatures of both probes every 30 seconds, as well as the P.U value of the beer probe for that interval. The second listing displays the temperature in the beer container every 5 seconds while it was above the lethal cutoff temperature, which would be 59.9°C in this case.

The first graph displays the temperature measured in the beer container in accordance with the time. The second graph displays the pasteurizer spray temperature measured in accordance with the time. It is useful to see at which time intervals the instrument passed through each zone in the pasteurizer. At the bottom of the printout the serial number of the instrument and probe are printed. This is useful for future reference, where the errors which were as a result of the failure of equipment and which occur consistently can be analyzed. If a short graphics printout is selected, the printout will not contain the two listings and the two graphics. This printout will use only one page of printing paper and is useful for savings and storage.

View Results Achieved

With this menu, the operator can view all the important test results without requiring the use of the interfacing software or printing equipment. This feature is useful to set the pasteurizer parameters correctly and to achieve the required results when pasteurizing beer. Figure 4.5 indicates a flowchart of this results routine. The following data can be viewed in this menu:

- **Total P.U.** - This is the total number of P.U.s achieved through the entire test.
- **Lethal Time** - This is the time accumulated while the product was above the lethal cutoff temperature. This temperature can be adjusted in the alterations menu and the standard is usually 60°C.
- **Lethal P.U.** - This is the P.U.s achieved while the product was above the lethal cutoff temperature. This is important and indicates whether the pasteurizer process was effective.
- **Maximum Temperatures** - This will indicate the highest temperature reached on each temperature sensor during the test.
- **Transit Time** - This is the time duration from the start of the recording till the end. This should indicate if the pasteurizer stopped during the test. In order to achieve good results, this time should be as close as possible to the transit time of the pasteurizer.

* **Beer Out Temperature** - This will indicate what the beer temperature is in the container when it exits the pasteurizer.

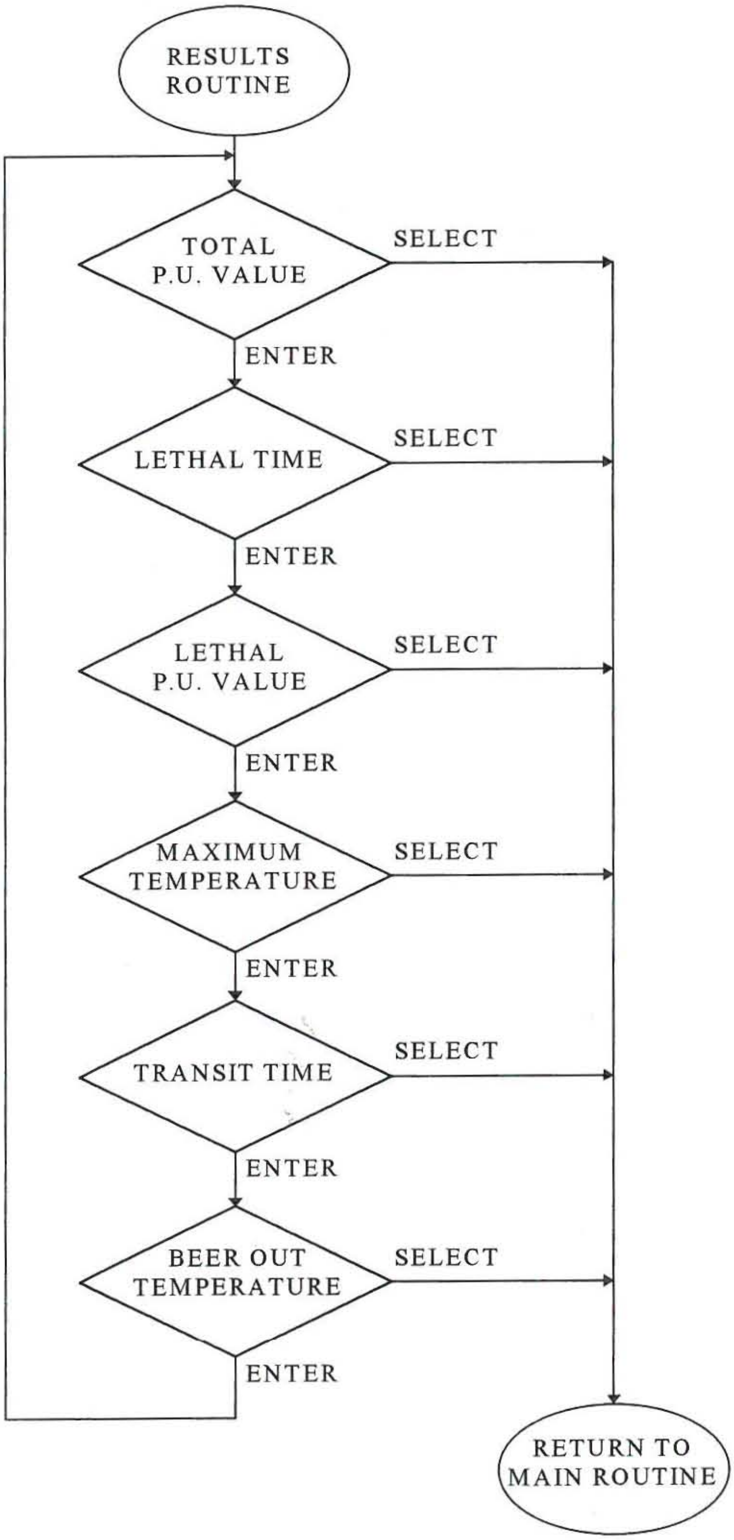

Figure 4.5 Flowchart of Results Sub Routine.

Thermometer

This menu will indicate the temperature on both sensors as measured at that instant. The operator can use this menu to verify whether the probe or instrument calibration is still intact. This temperature is updated approximately three times per second.

Data Change Routine

Figure 4.6 show a flowchart of the data change routine. Whenever the data needs to be changed for the different routines, this is the basic routine to be used.

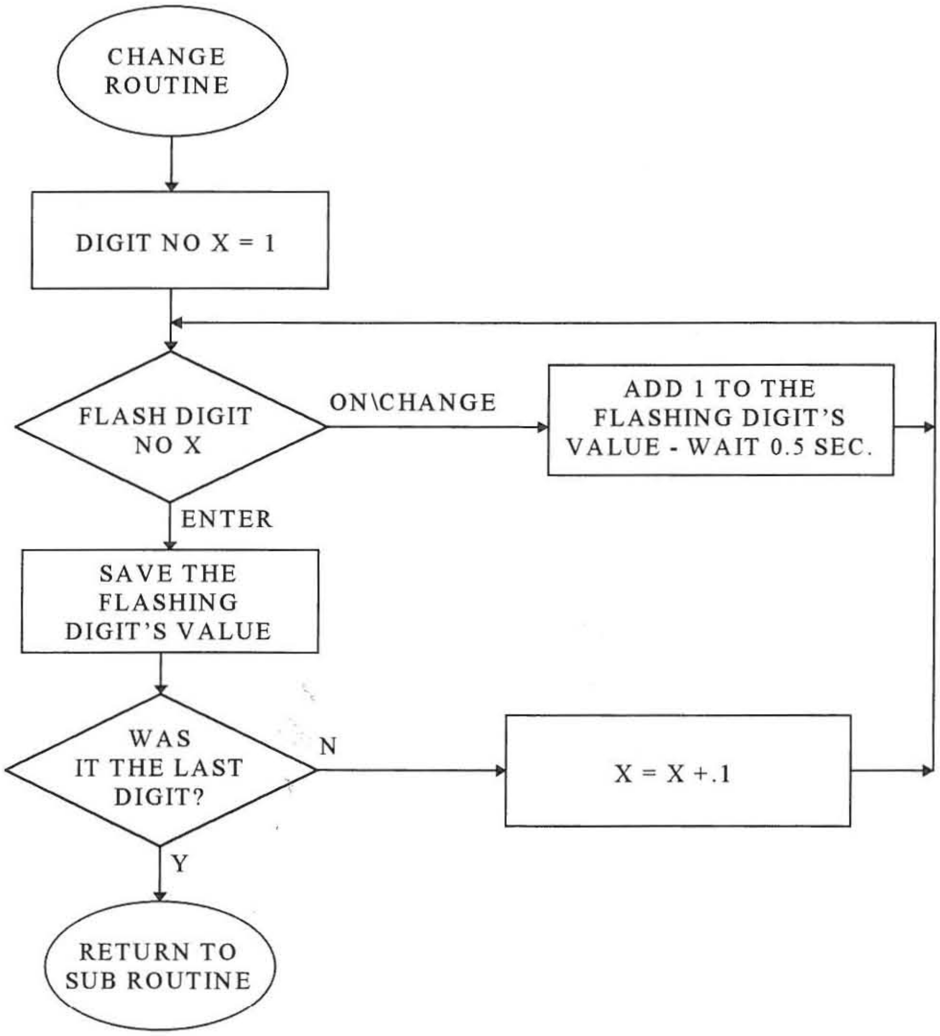

Figure 4.6 Flowchart of Change Sub Routine.

The operator menu will start from the beginning once the alterations menu has been passed again. No passwords are required for any of the above menus.

4.3.1.1 Supervisor Menu

This menu is used to change certain parameters of the P.U. recorder. It is protected by two passwords to ensure that only authorized operators can change these parameters. Password No1 is to protect the whole alteration menu of the P.U. recorder. Password No2 is required if the P.U. recorder needs to be calibrated. This password belongs to the supervisor who will have the responsibility for the maintenance of the instrument. The flowchart in Figure 4.7 indicates the main supervisor menu. Each function of this menu is discussed below:

Set Time

This menu is used to adjust the real time clock. Once the last digit has been entered, the clock will start ticking. Seconds are not adjustable but start from zero when the clock is set.

Set Date

This menu adjusts the calendar as the date also appears on the printout. The calendar will keep track of leap years.

Set Lethal Rate

This lethal limit is the minimum temperature required to kill unwanted organisms in beer and is specified by SAB to be 60°C [14]. It is, however, adjustable to suit customer needs for different products.

Calibrate Probe

This menu is used to calibrate an instrument with a specific probe. The measurements will be more accurate as both errors are eliminated at the critical temperature, namely 60°C. It is recommended to restore calibrations before using another probe, as this could increase the possibility of measuring errors.

Restore Defaults

When an instrument is assembled, the calibration parameters are written into EPROM. This will allow the user to do his own calibration and restore the manufacturing calibration when he so desires. This will reset the last probe calibration to the factory calibration.

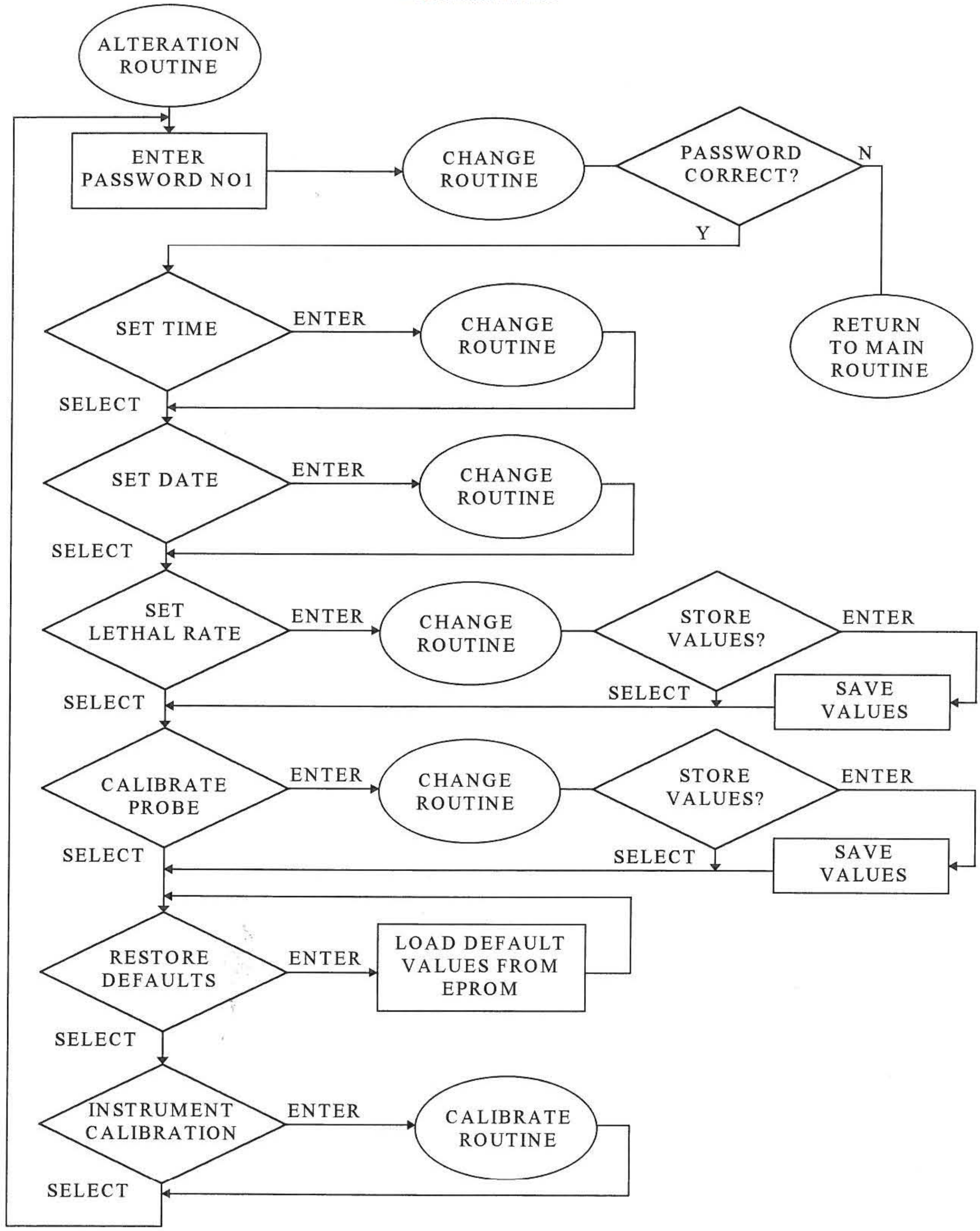

Figure 4.7 Flowchart of Alterations Sub Routine.

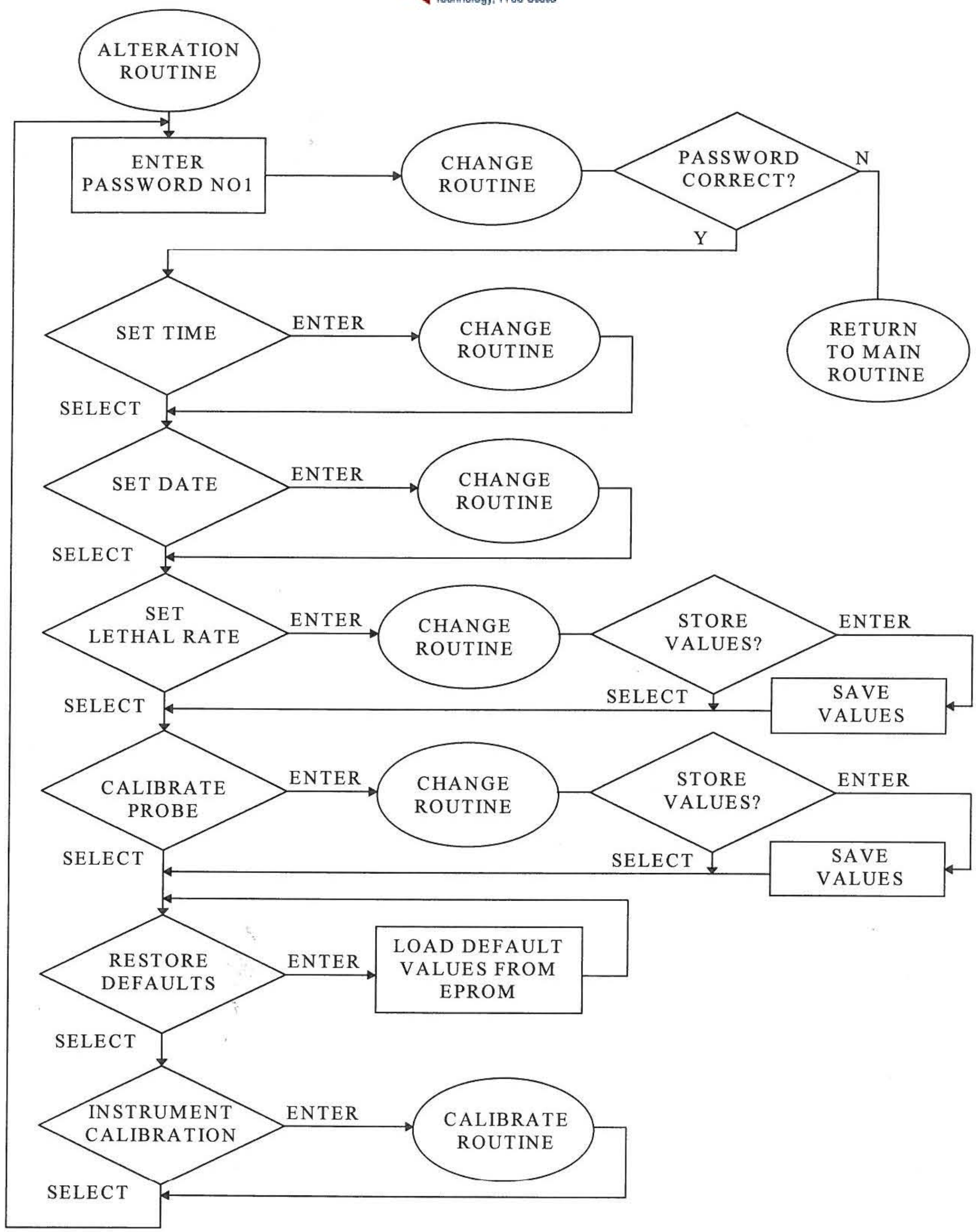

Figure 4.7 Flowchart of Alterations Sub Routine.

Calibrate Instrument

The instrument can be calibrated by the user with the aid of a resistor set. These resistors are fixed value resistors which are calibrated by the manufacturer. The supervisor will connect the low resistor that would simulate a low temperature of approximately 5°C. He then enters the value engraved on the resistor into the instrument. He then repeats the procedure with the high value resistor which would simulate a temperature of approximately 75°C. The instrument will calibrate both sensing amplifiers at the same time. Figure 4.8 indicates a flowchart of the calibrate routine.

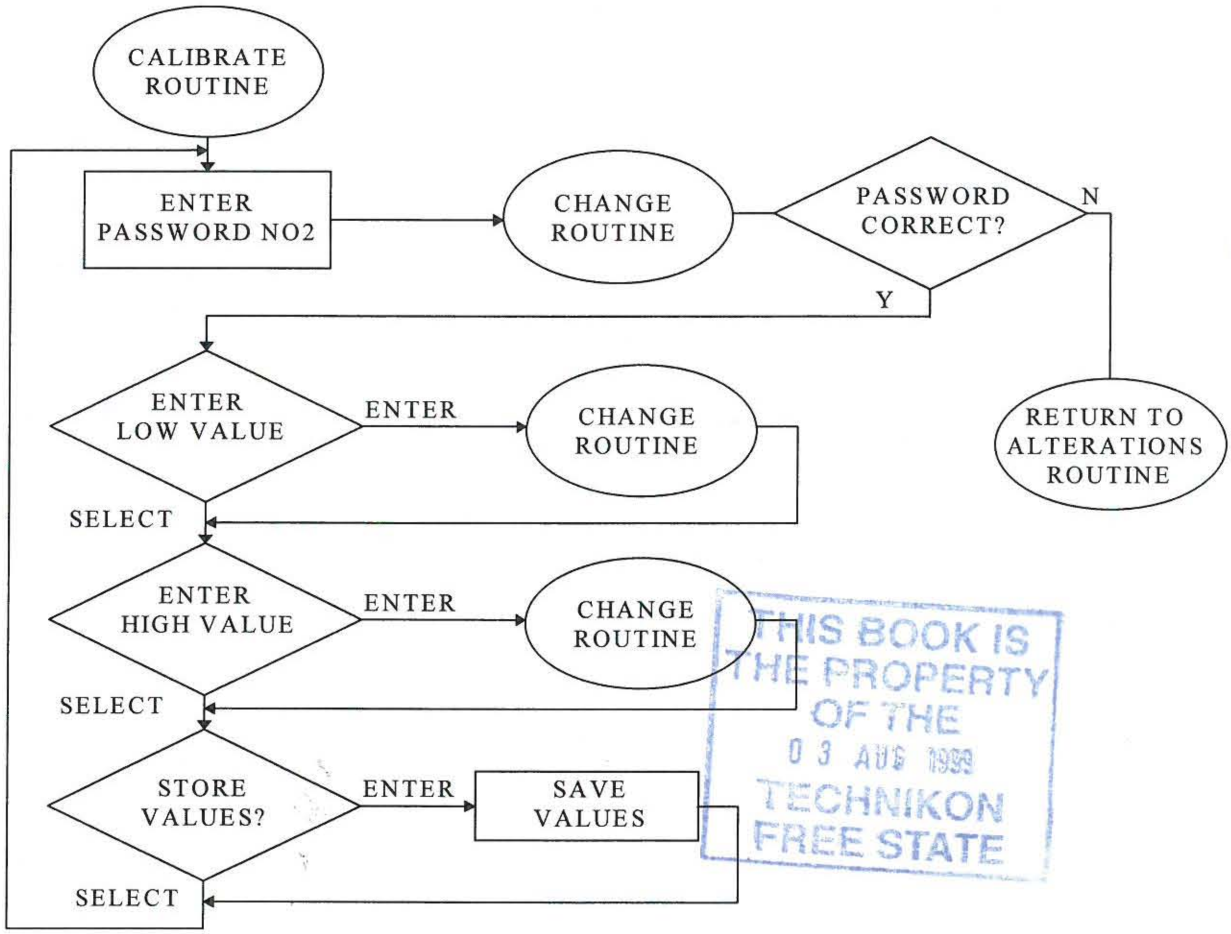

Figure 4.8 Flowchart of Calibrate Sub Routine.

The supervisor will keep track of the calibration and accuracy of these instruments and can ensure that these parameters are protected against tampering. This menu will start from the beginning of the supervisor menu when this point in the menu has been passed. The recorder must be switched off to exit from this menu.

4.3.2 PC Interfacing Software

The P.U. recorder software for data interfacing with the factory PC's, is integrated with the instrument processor software as described in Paragraph 4.3.1. The recorded data is downloaded through the MIL spec connector on the instrument to the factory PC through a serial computer interface in RS232 protocol. Dedicated software has been developed for performing the data display on the PC and network data saving functions. The Windows based software was developed for one of the major breweries in SA under subcontract and did not form part of this study project. The basic operation of the software, as well as the display of recorded data, forms an integral part of the project and will, therefore, briefly be described below:

4.3.2.1 Data Display

Figure 4.9 shows a typical computer display of recorded data captured during a pasteurization test. The data was recorded on 12 July 1996, at SAB Rosslyn Line 5 in the middle of the top deck of a Simonazzi pasteurizer. The same test is shown for printout from an Epson printer in Appendix A.

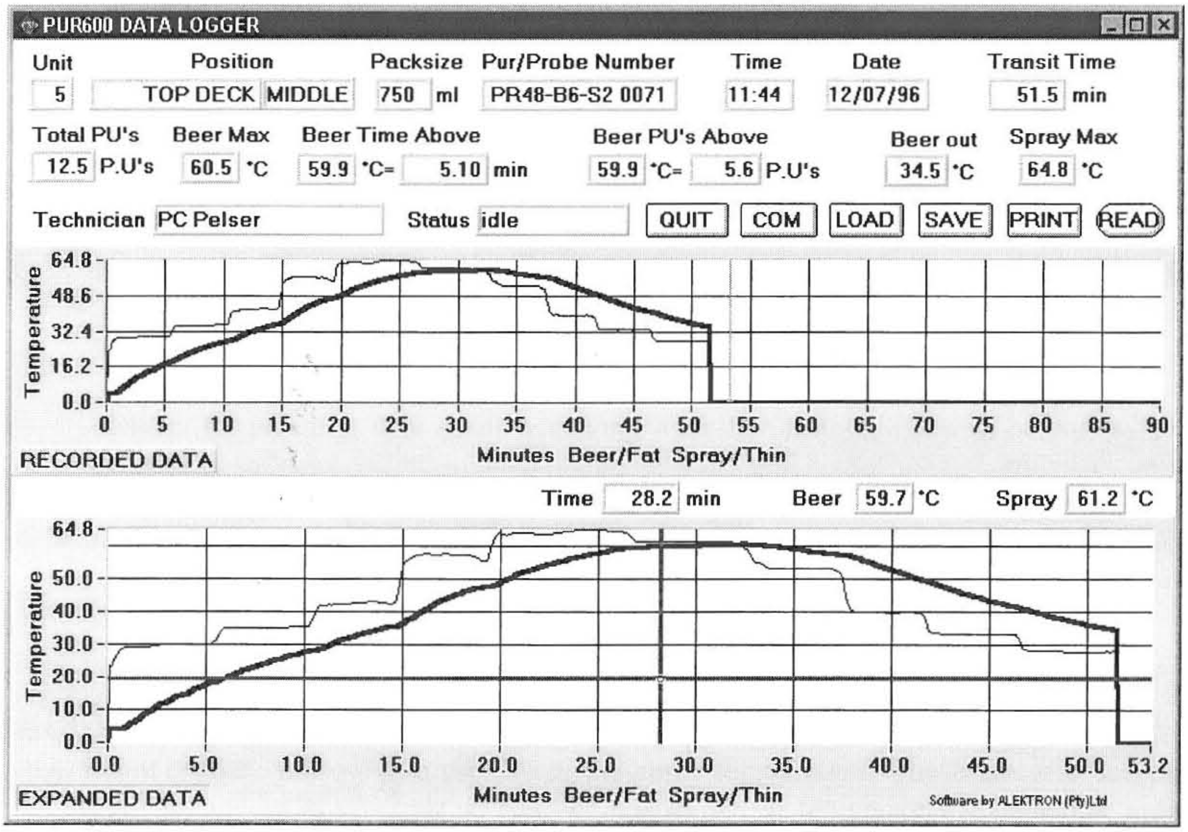

Figure 4.9 Computer Software Data Display.

The top graph indicates the unit details entered by the operator in the **Recorder Setup** menu. It will show all the results as discussed in the **Review Results** menu. It indicates the exact starting time as well as the date when this test was initiated. Another feature is the space where the operator can enter his name. There is a status block to indicate to the operator which task the program is performing. The six buttons namely, **Quit, Com, Load, Save, Print** and **Read** forms the integral operation of this software which activates different parts of this program. These actions are described below:

1. **QUIT** - This button is used to exit the PUR-600 software. The standard Windows **quit** button will not work with this software. The recorded data must be saved before quitting, otherwise the data will be lost.
2. **COM** - This button will give the operator access to the different serial interface ports installed on the computer. This software can handle eight different serial port selections. The selected serial port will be saved until it is changed.
3. **LOAD** - This button will load the old files from the hard disk of the computer. These files contain all the data of a certain test which was saved at an earlier stage. This will provide unit managers with the opportunity to view pasteurization tests on other PC's on the network.
4. **SAVE** - After data is extracted from the P.U. recorder into the computer program, it must be saved on the hard disk of the computer. This button will activate the file save menu. A file name system should be created, which may combine the unit number with the date, etc. If this data is not saved before quit is activated, the data will be lost. If the computer is connected to a factory computer network, the data can be stored on the network server disk. By using the prescribed disk and sub-directory, the data will be available to all users of the Management Information System (MIS). The factory Quality Control Manager can use his own computer to evaluate the success of the pasteurization process in order to verify the pasteurizer specifications.
5. **PRINT** - This button will initiate a screen print of the data display. The operator must put the cursors where he prefers, before initiating PRINT. Printing can be re-directed to any type of printer connected to the computer or to the network. This software has no control over the printer drivers and will thus use the Windows drivers for printing. Any errors occurring with the printout will thus be part of the Windows software.
6. **READ** - This button initiates the RS232 communication with the instrument. The operator only needs to put the instrument menu on **IBM Computer menu** and connect the logger to the serial cable provided. Data will be extracted in a few seconds while the status block indicates **Reading**.

The graph in the middle indicates the two temperatures in accordance with the time, as it was logged during the test through the pasteurizer. The broad line represents the beer temperature and the narrow line represents the spray temperature. These are at 5 second intervals over a period of 90 minutes. The 'Y' axis shows the temperature scale and is 'auto ranging'. This means that the maximum of the scale will be the maximum temperature measured. The 'X' axis has a fixed scale of 90 minutes which is the maximum data logging length of the P.U. recorder. There are two cursors in this graph. They can be dragged with the computer mouse to a specific location in the graph. The left cursor must stay on the left and the other on the right. The portion of the graph between the two cursors will be expanded onto the bottom graph. This allows the user to zoom in on a specific part of the graph.

The graph at the bottom indicates the expanded graph between the top graph cursors. The broad line represents the beer temperature and the narrow line represents the spray temperature. The 'Y' axis will adopt the same range as the middle graph. The 'X' axis will adopt the axis length between the two top cursors. The graph will be expanded over the whole axis. There is one cursor in this graph which could be dragged with the mouse. It could be placed anywhere in the bottom graph. On the top of this graph there are three blocks namely, **Time**, **Beer** and **Spray**. They indicate the exact location on the 'X' axis where the cursor is placed.

This software requires a good knowledge and understanding of the Windows environment. Devices such as a printer are not controlled by this software, therefore, any queries must be referred to the Windows operating manual.

4.4 Integration of the System

4.4.1 Electronic Enclosure Design

With reference to the design specification given in Paragraph 3.2.4, the P.U. recorder electronics must be enclosed in a package that would be able to provide protection against the pasteurizer's inside environment. A few criteria were listed as follows:

- The enclosure must be of stainless steel to prevent any oxidation buildup. The same applies to the frame, accessories and screws.
- The enclosure must be watertight and withstand the pressure buildup as a result of heating. Any sealer used must be able to withstand the temperatures it is exposed to.
- The front glass panel must be a minimum 4mm thick to withstand a certain amount of rugged handling and temperature fluctuations.

For the enclosure, a 1.2mm stainless steel sheet-metal was used. The sheet is cut with laser cutting equipment for precise measurements. The spray water sensor housing is made of 6mm stainless steel tube which is welded shut at the end and welded onto the enclosure at the other end. A bezel is made to fit over the glass front plate and allows for a high temperature silicone sealer to be used. It is then bent and welded together. The stainless steel work is done by sub contractors because of the need for specialized equipment.

- Protection for the spray temperature probe

Figure 4.11 shows a picture of the frame designed for the P.U. recorder. The frame dimensions are kept as small as possible to ensure minimum weight. It is laser cut and bent from 3mm stainless steel sheet metal. The sturdy low profile design with a pointed front will ensure a rugged frame which can easily be inserted in a moving container stream. An adjustable fork which presses any bottle size into the front point of the frame, will ensure a precise container fit. The can attachment will fasten any length of can currently in production. All these parts are assembled with wing-nut fasteners which do not require any extra tools.

The spray probe and the watertight connector are situated below the frame wall and are protected against container pressure on the conveyor. The frame has a carry handle which is fairly balanced with different containers sizes. The enclosure is fastened by two counter sunk screws from the bottom. Five large holes are made in the bottom of the frame to drain trapped water from the container.

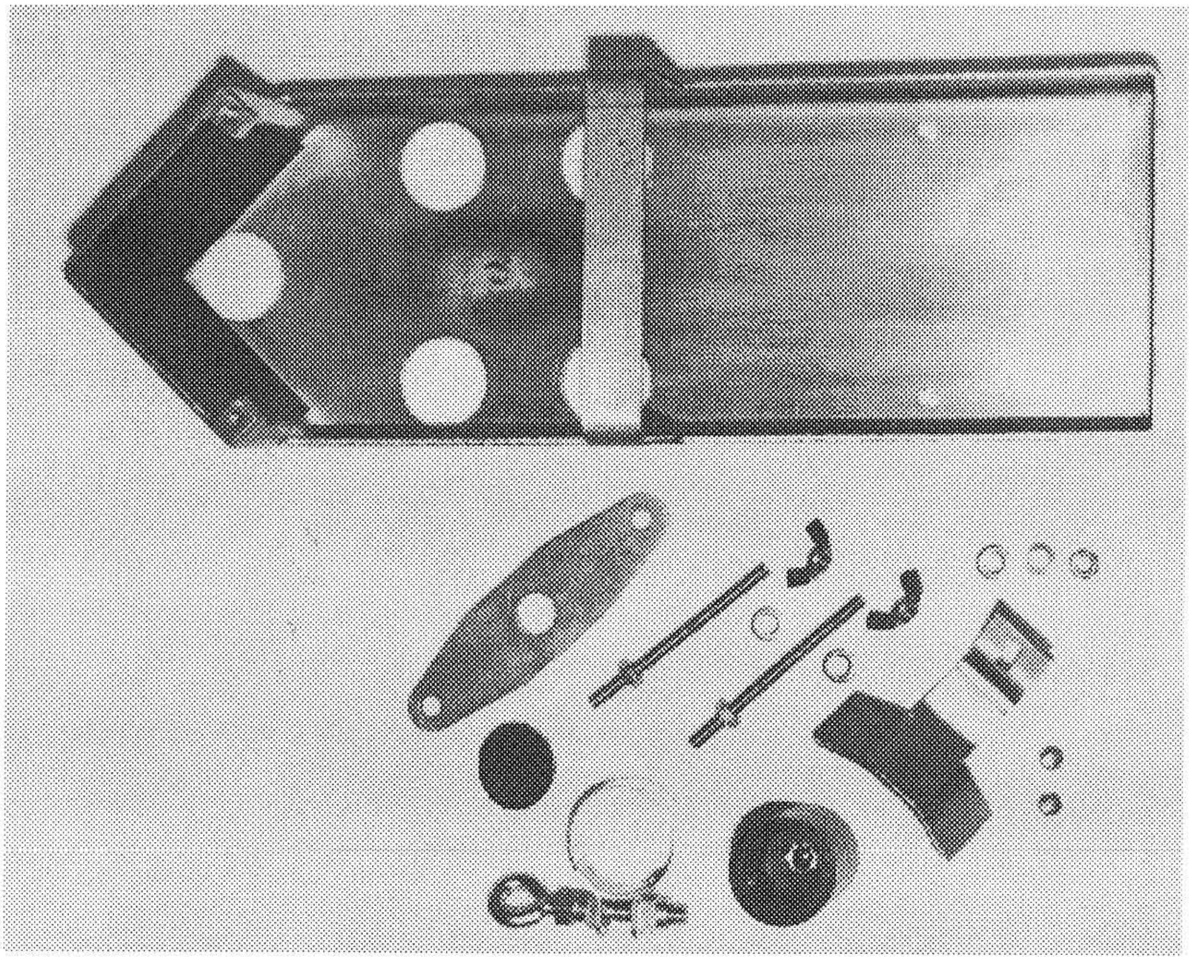

Figure 4.11 Photograph of the Frame and Accessories.

4.4.3 Battery Charger

The battery charger operates on a constant voltage-, constant current principle. This is a standard recommended charge principle which is supplied by the NI-CAD battery manufacturer. Figure 4.12 shows a simplified block diagram of the battery charger which will provide the cells with the necessary charge.

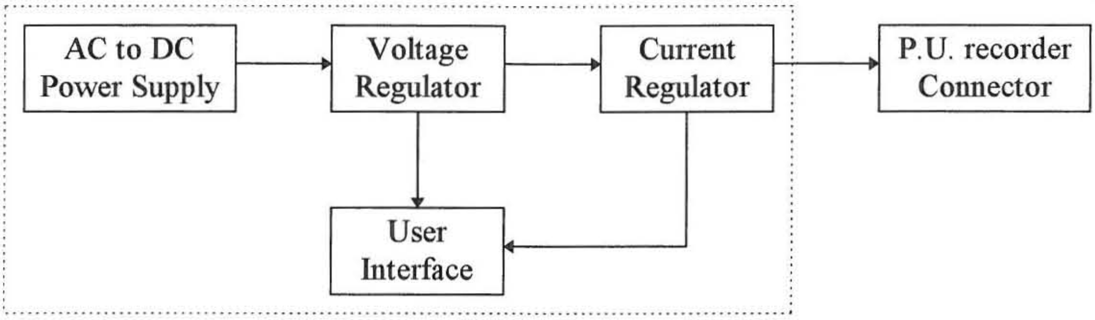

Figure 4.12 Block Diagram of the Battery Charger.

The AC to DC power supply will provide the regulators with the necessary electrical current to ensure proper operation. The voltage regulator will ensure that the charge voltage will not exceed a maximum of 6.8V, while the current regulator ensures that the maximum charge current does not exceed 850mA. When the batteries are low, the charge current will be maximum. As they approach full condition, the current will decrease to a trickle charge current of approximately 15mA. This is a safe trickle charge and would not damage the cells if they are fully charged.

4.5 Summary

This chapter described the design of the data logging instrument. Paragraph 4.2 described the development of the instrument hardware in terms of the printed circuit board, the temperature probe interface and the design of the user interfaces. The design and development of the instrument processor software was described in paragraph 4.3. This paragraph also included the discussion of the computer program flow-charts. The integration of the system into a factory instrument is done through the development of a packaging enclosure for the electronic hardware. The design of this enclosure and an accompanying frame for fitting the beer container was detailed in paragraph 4.4.

CHAPTER 5

EVALUATION OF THE SYSTEM

5.1 Introduction

Chapter 4 described the development of the data logging instrument. In evaluating the final design of the instrument, which has to be used in the factory, a number of experiments will be conducted and described in this chapter. These experiments are aimed at evaluating the instrument components in terms of each respective specification.

5.2 Evaluation Criteria

Chapter 3 described a set of technical specifications for the data logging instrument. Most of these specifications were met in the design phase by choosing components that are within the desired specifications. For example, the environmental specifications were met by using stainless steel material and 4mm glass in the enclosure design, while temperature probes were constructed to provide the desired measurement accuracy.

However, parameters such as the **temperature accuracy** and **battery durability** might show temporal and dynamic variations in repeated experiments as well as variations in environmental conditions. In order to evaluate the **repeatability** and **environmental stability** of these parameter measurements and their accuracy with respect to the design specifications, three experiments will be conducted. In these experiments, the results are compared to the technical design- and user- specifications detailed in Chapter 3. These specifications were used as the experimental evaluation criteria.

5.3 Evaluation Experiments

The accuracy of the data which is logged, depends on two components namely, the temperature probe and the instrument electronics. They must be isolated from one another in order to determine their variations independently. **Experiment 1** is described in Paragraph 5.3.1 to determine the stability of the instrument electronics on varying enclosure environmental conditions, as found in the pasteurizer, by simulating the temperature probe input, by using a very accurate dummy load. The stability and repeatability of the temperature sensing probes are evaluated in **Experiment 2** in Paragraph 5.3.2, by using a large number of probes in an isolated area where the environmental conditions are varied under controlled laboratory conditions. **Experiment 3**, detailed in Paragraph 5.3.3, is aimed at determining the battery life and the level of the supply voltage, under extreme instrument environmental conditions.

5.3.1 Experiment 1: Temperature Stability

5.3.1.1 Aim

The aim of this experiment is to determine the temperature stability of the recorder under varying environmental conditions as typically found inside the beer pasteurizer. The temperature conditions inside the pasteurizer varies between 25°C to 65°C which is the temperature range in which the experiment will be conducted.

5.3.1.2 Method

The temperature sensing probe basically provides a resistance input to the instrument electronics. In order to isolate the influence of the probe from the instrument, a fixed resistor is used as a dummy input to the sensing amplifier in the electronics. Since the critical temperature measurements of the instrument inside the pasteurizer are taking place at a temperature of 60°C, a decade resistor box is used to simulate a PT100 temperature probe. It is set to 123.24Ω to simulate 60°C very accurately. The decade box is connected to the recorder with the same length and type of cable that is used for the PT100 sensor in the probe. This decade box is kept at 25°C at all times to ensure its stability.

The P.U. recorder which is now at room temperature of 25°C and is measuring 60°C, is switched to recording mode in order to start the data logging process. It is then submerged in a controlled temperature water bath with the temperature inside the bath set at 65°C. The instrument is submerged for 20 minutes to ensure that the ambient temperature of the electronics reaches the bath temperature. The sampling rate of the recorder is fixed at 5 second intervals, which mean that a total of 240 readings are taken throughout the experiment. The data is then downloaded to a Windows spread sheet display program where the results are analyzed. Since the electronic drift is a slow process, data is selected at 1 minute intervals and displayed on a graph in Figure 5.1.

5.3.1.3 Results

The graph in Figure 5.1 shows the temperature and time curve of the results achieved in this experiment. The graph shows the upper and lower limits according to the technical specifications, which are 60.2°C and 59.8°C respectively. These specifications are discussed in Paragraph 3.2.4. The recorded data starts at 60°C as set on the decade box, and slowly decreases to 59.9°C over a period of 17 minutes.

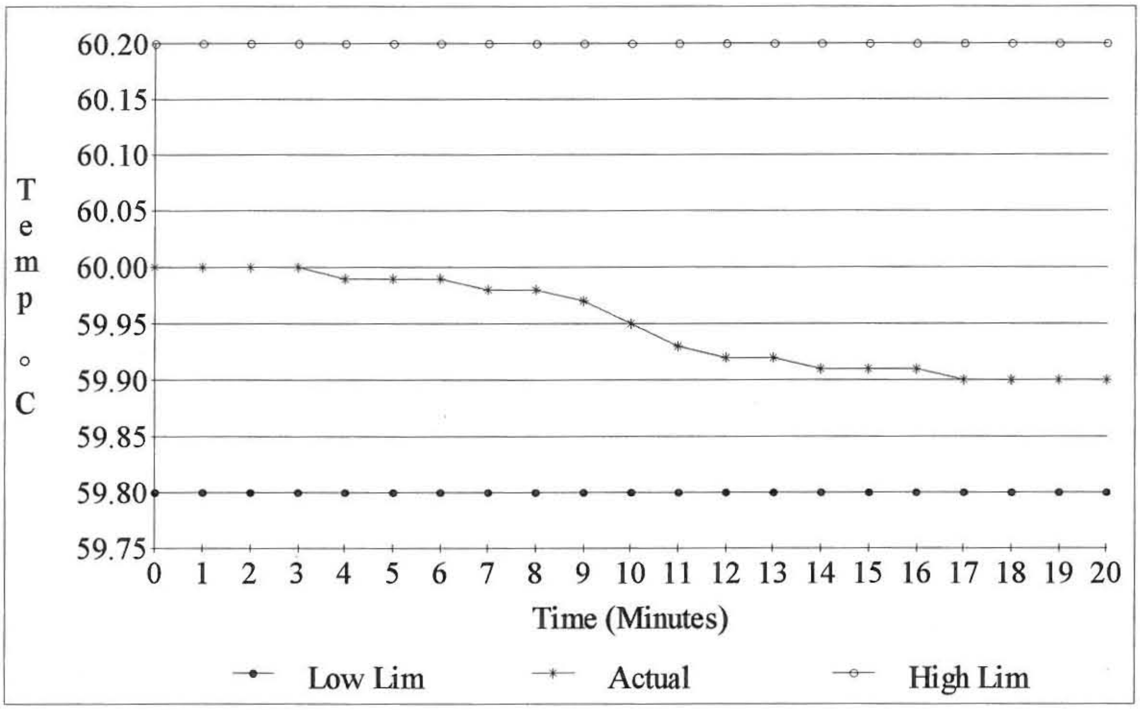

Figure 5.1 Temperature Stability of the P.U. Recorder Electronics.

The graph shows that the temperature logged during the 20 minutes was stable for the first 3 minutes. After 3 minutes, the measured temperature slowly drifted negatively by a maximum 0.04°C/minute and stabilized at a temperature of 59.9°C after a period of 17 minutes. After this period, from 17 to 20 minutes, no temperature variation occurred. The measured drift is shown to be within the boundaries of 0.2°C (positive and negative) which is defined as the specification of the instrument.

From the graph it is also clear that the transfer of heat from the hot water to the instrument and through the instrument housing to the electronics operating environment, is delayed by a period of approximately 3 minutes for this experiment, due to the heat transfer characteristics of the instrument housing material. Once the electronics are subjected to a higher temperature, the measured temperature drifts by a maximum of 0.1°C before it stabilizes. This drift, which occurs due to the processes involved in manufacturing electronic components, falls within the specifications of the instrument.

5.3.1.4 Conclusion

The temperature variation is within the specification for the instrument. The assumption is made that the temperature measurements deviate to the same extent, should other resistor values be used to simulate other measured temperatures. However, this assumption is not critical since the critical pasteurizing temperature is around 60°C.

5.3.2 Experiment 2: Temperature Probe Reliability

5.3.2.1 Aim

The aim of the experiment is to determine the accuracy and the repeatability of the temperature probes, which may vary due to the manufacturing of these probes. The operating temperature of the probes in the pasteurizer varies between 5°C and 65°C which is the minimum temperature inside the beer containers, and the maximum temperature inside the pasteurizer. Since pasteurization is logarithmic, the critical temperature will be at the high limit. This means that lethal rate increases with higher temperatures which requires less time for the same amount of pasteurization. These probes are tested at 60°C which is the recommended pasteurization holding temperature.

5.3.2.2 Method

A total of fifteen temperature probes with different lengths are submerged in a controlled temperature water bath with the temperature inside the bath at 60°C. The probes are tied together to keep conditions as close as possible. After 5 minutes, each probe is measured with a high resolution PT100 digital thermometer. This instrument will give a temperature readout with two decimal point resolution. The data is logged and then the bath temperature is decreased to 50°C for 5 minutes. It is then increased back to 60°C for 5 minutes, and then the probes are measured again. The same procedure is repeated to 70°C and down to 60°C again. A total of 45 samples are taken. The data is then processed and analyzed by using a frequency polygon.

5.3.2.3 Results

The probe data was sorted into groups of the same value, and then placed under specific intervals. Table 5.1 shows all the intervals under which these probes were sorted. It also indicates the number of probes which fall under each interval. Lastly, the cumulative frequency of the number of data samples taken, are shown.

Table 5.1 Frequency of Occurrence of Data Measured by the Temperature Probes.

Interval °C	Boundaries °C	Frequency	Cumulative Frequency
59.25	59.125 - 59.375	1	1
59.50	59.375 - 59.625	3	4
59.75	59.625 - 59.875	9	13
60.00	59.875 - 60.125	13	26
60.25	60.125 - 60.375	11	37
60.50	60.375 - 60.625	5	42
60.75	60.625 - 60.875	2	44
61.00	60.875 - 61.125	1	45

When this data is displayed as a frequency polygon as shown in Figure 5.2, it clearly indicates the number of samples which fall in the same temperature interval. This is useful to determine the accuracy and the repeatability of the probes.

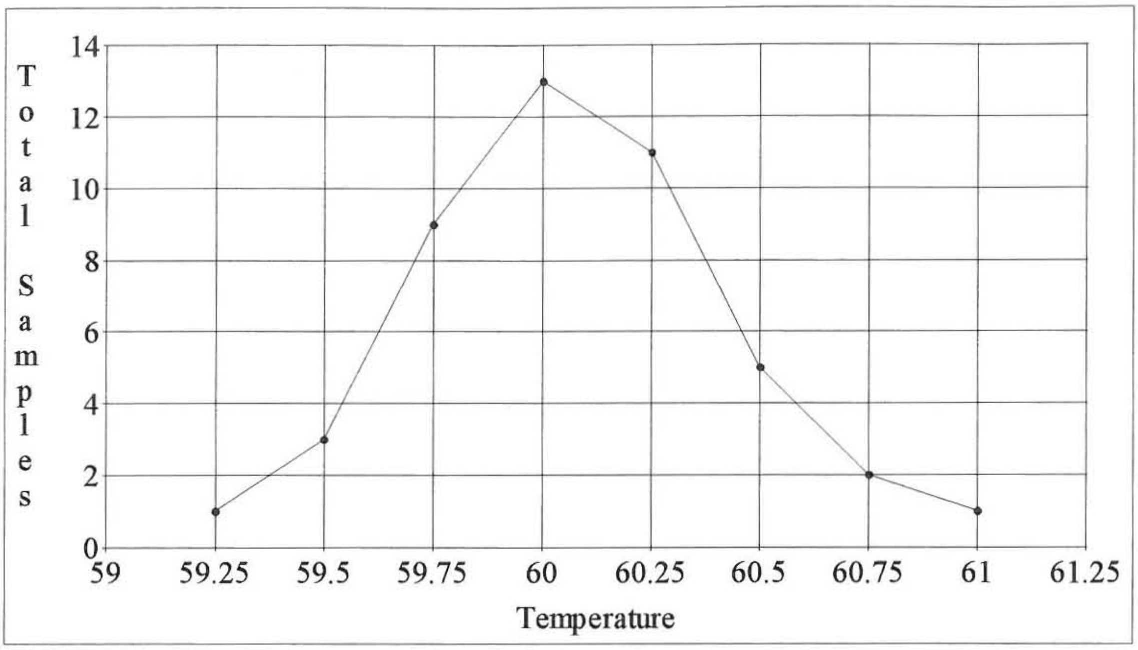

Figure 5.2 Frequency Polygon of Data from the Temperature Probes.

The largest number of probes fall slightly to the right of the center axis which is 60°C. This can be attributed to the added resistance of the probe lead wires. All the probes fall within the specifications as stipulated in Paragraph 3.2.4.

5.3.2.4 Conclusion

The results indicate that the complete probes, as they are manufactured, are within specifications of ±1°C. The assumption is again made that the measurements deviate to the same extent should other temperatures be used for this experiment. However, this assumption is not critical since the critical pasteurizing temperature is around 60°C.

5.3.3 Experiment 3: Instrument Battery Operational Test

5.3.3.1 Aim

The aim of this experiment is to determine the charge duration and voltage level of the rechargeable batteries, due to varying instrument environmental conditions typically found inside the beer pasteurizer. This experiment has to be conducted since NI-CAD rechargeable batteries are known to loose capacity due to heat and high temperature operating conditions.

5.3.3.2 Method

The instrument is connected to the battery charger, described in Paragraph 4.4.3, for a period of 10 hours to ensure that the batteries are fully charged before the experiment is conducted. A digital voltmeter is then connected to the batteries inside the instrument enclosure, through the MIL spec interface connector. The instrument is then switched to recording mode (operational condition) and submerged in a controlled temperature water bath, where the temperature is kept constant at 25°C until the batteries are drained. The battery voltage level is logged every 15 minutes. This experiment is then repeated at 65°C. Both results are then plotted on a graph for evaluation.

5.3.3.3 Results

Figure 5.3 indicates the battery duration under a constant temperature of 25°C and 65°C in terms of the battery voltage against time in hours. The graph clearly show that the voltage level remains above 6V before collapsing to an empty state. As discussed in Paragraph 4.2.1.7, the electronic circuitry requires a minimum of 5.4 volts battery level in order to operate correctly. It is clearly visible that the cells, at 65°C, do not last as long as room temperature. At 65°C, the batteries last approximately 14 hours while at 25°C the batteries last up to 16 hours. The battery life is shortened by approximately 13%, which will not severely affect the operational time of the recorder, as the technical requirement discussed in Paragraph 3.2.4 states a minimum of 10 hours battery life.

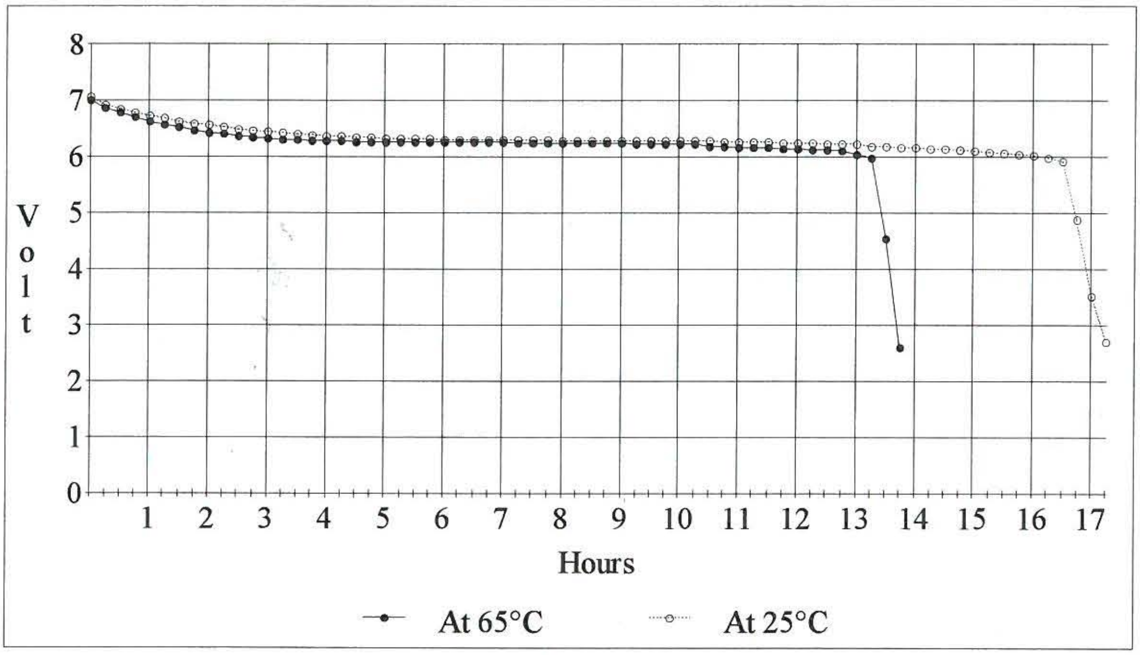

Figure 5.3 Battery Duration of the Instrument.

The voltage level at a high temperature drops at a maximum of 0.2V under the level at room temperature which is approximately 3.5%. This will not affect the operation of the recorder as the voltage is still above 5.4V. From this experiment, it is clear that the operating voltage of the batteries is not severely influenced at an operating temperature of 65°C. When the batteries reach an empty condition, the voltage rapidly decreases which indicates that recharging is required.

5.3.3.4 Conclusion

Battery voltage and durability are fairly constant over the time period of 14 hours at 65°C. This is a worst-case scenario as the recorder is exposed to these conditions for only short intervals. Battery duration is still approximately 140% of the required specification.

Before the recording menu can be entered, the battery voltage will be measured by the micro processor and reflected to the operator. According to these experiments, the battery indication for a medium condition is chosen to be within 6.15V to 6.2V when the recording menu is entered. This will allow the operator to do one more pasteurization test before the batteries need to be recharged.

The P.U. recorder is guaranteed to operate for a period of 10 hours before the batteries need to be recharged.

5.4 Summary and Conclusion

This chapter described the evaluation of the P.U. recorder, developed in Chapter 4, in terms of the technical specifications detailed in Chapter 3. Experiment 1 described the evaluation of the stability of temperature measurements in terms of varying temporal and environmental conditions. This experiment showed that the average temperature deviation at the normal operating temperature of the recorder (25°C to 65°C) is less than 0.2 °C (or 2%).

In Experiment 2, an evaluation was made of the reliability and the repeatability of the temperature probes as received from the manufacturer. The experiment showed that numerous readings taken from these probes were within 1°C (positive or negative), which comply with the technical specifications discussed in Chapter 3.

Experiment 3 evaluated the battery operation under extreme environmental conditions. The result of this experiment showed that the batteries charged life decreased by 13%, which is still more than 40% longer than required by the specifications in Chapter 3.

CHAPTER 6

SUMMARY AND DIRECTIONS FOR FUTURE RESEARCH

6.1 Project Summary

This developmental research study described the development of a customized P.U. recorder that is used for quality control in brewing pasteurization.

Recent market research has shown that a need arose for new pasteurizing measuring equipment that is more dedicated to the beer brewing industry. New standards in product quality forced brewers around the world to optimize pasteurizing processes. The current equipment, which measures these processes, has fulfilled the need up to a few years ago, but does not meet the latest standards.

In this study, a new P.U. recorder has been developed for measuring pasteurization, which is calculated from temperature conditions during the brewing pasteurization process. The instrument or recorder has been developed in four phases, namely:

- Feasibility study concerning the development of the product.
- Literature study concerning the brewing pasteurization process.
- User requirement analysis.
- Design and implementation.

The design was basically done in three components. Firstly, the hardware circuit design, in which the Intel 8051 family of micro processors, formed the central component of the design with interfacing to the temperature probes and RS232 computer interfacing. The software development, both for the instrument processor control and the PC, formed the second part of the design. The third component of the design was concerned with the development of the mechanical housing for the electronic circuits which were completed in order to comply with the user requirements.

Experimental results on the stability, repeatability and accuracy of the instrument formed part of this study. These tests have shown that the instrument development in this study is superior to the current imported commercial instrument in terms of accuracy and measurement stability. Secondary advantages of the product are the cost effectiveness and user friendliness.

6.2 Directions for Future Research

While developing this instrument or P.U. recorder, a few ideas for new developments arose and were listed as the project progressed. One opportunity lies in the fact that the developed instrument can analyze the pasteurization process but not the pasteurizer equipment itself. Whilst the logger measured the spray temperature that gave a good indication of the operational condition of the pasteurizer, a need arose to analyze some other criteria. These criteria could be derived from existing printouts but require a fair number of calculations and time.

In order to optimize a pasteurizer, one needs to know the bottle constant of a certain package. Since the bottle manufacturers change their manufacturing specifications according to new molding techniques and forms, these constants change accordingly. If an instrument can measure these constants, pasteurizers could be setup more accurately. This would inflict on the quality of the product and is thus of utmost importance. The instrument must be intelligent in order to allow operation by relatively unskilled operators since not many people would be able to derive these complex formulas.

Such modifications to the instrument will also support the analysis of the pasteurizer according to setup parameters. It must also be able to provide warning with regards to dirty sprays in the pasteurizer and to forecast when maintenance is required. It must indicate when the pasteurizer stopped in order to predict a valid pasteurization test.

As far as is known, there is at present, no such instrument on the commercial market.

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APPENDIX A

PRINTOUT AND DATA DISPLAY OF A PASTEURIZATION TEST

PUR-600 DATA LOGGER

TECHNICIAN________________________

UNIT : 5
POSITION : TOP DECK MIDDLE
PACKSIZE : 750ml
TIME : 11:44
DATE : 12/07/96
TRANSIT TIME : 51.5 Minutes

PROBE 1

P.U. VALUE : 12.5 P.U.s
MAX. TEMP : 60.5°C
BEER OUT T. : 34.5°C
TIME ABOVE 59.9°C : 5.10 Min.Sec
P.U. ABOVE 59.9°C : 5.6 P.U.s

PROBE 2

MAX. TEMP : 64.8°C

FULL REVIEW LISTING

TIME	PR1(°C)	PU(PR1)	PR2(°C)
0.0	4.0	0.0	23.4
0.5	4.0	0.0	28.3
1.0	5.5	0.0	29.0
1.5	7.2	0.0	29.1
2.0	9.4	0.0	29.3
2.5	11.3	0.0	29.6
3.0	12.5	0.0	29.7
3.5	14.1	0.0	29.8
4.0	15.0	0.0	29.8
4.5	16.6	0.0	30.0
5.0	17.7	0.0	30.0
5.5	18.7	0.0	32.7
6.0	20.1	0.0	34.9
6.5	21.2	0.0	34.9
7.0	22.6	0.0	34.9
7.5	23.4	0.0	34.9
8.0	24.4	0.0	35.0
8.5	25.3	0.0	35.1
9.0	26.3	0.0	35.1
9.5	26.9	0.0	35.2
10.0	27.7	0.0	35.2
10.5	28.2	0.0	40.4
11.0	29.2	0.0	41.9
11.5	30.7	0.0	42.1
12.0	31.8	0.0	42.1
12.5	32.6	0.0	42.4
13.0	33.5	0.0	42.8
13.5	34.3	0.0	43.0
14.0	35.0	0.0	42.4
14.5	35.5	0.0	42.8

15.0	36.6	0.0	54.8
15.5	38.6	0.0	56.8
16.0	40.5	0.0	57.4
16.5	42.1	0.0	57.3
17.0	43.6	0.0	57.4
17.5	44.8	0.0	57.2
18.0	46.0	0.0	56.9
18.5	46.9	0.0	56.8
19.0	47.4	0.0	55.4
19.5	47.9	0.0	61.4
20.0	49.3	0.0	63.6
20.5	50.6	0.0	63.9
21.0	51.7	0.0	64.2
21.5	52.8	0.0	64.0
22.0	53.7	0.0	63.4
22.5	54.6	0.0	63.5
23.0	55.4	0.1	64.2
23.5	56.2	0.1	64.6
24.0	56.7	0.1	64.7
24.5	57.5	0.2	64.8
25.0	58.0	0.2	64.8
25.5	58.5	0.3	64.6
26.0	59.1	0.3	64.4
26.5	59.4	0.4	63.3
27.0	59.6	0.4	61.2
27.5	59.7	0.4	61.3
28.0	59.8	0.4	61.3
28.5	59.9	0.4	61.2
29.0	60.0	0.5	61.2
29.5	60.1	0.5	61.2
30.0	60.1	0.5	61.2
30.5	60.3	0.5	61.1
31.0	60.3	0.5	61.0
31.5	60.4	0.5	61.0
32.0	60.4	0.5	60.4
32.5	60.4	0.5	58.8
33.0	60.4	0.5	55.0
33.5	60.1	0.5	53.6
34.0	59.8	0.4	53.1
34.5	59.4	0.4	53.1
35.0	58.9	0.3	53.1
35.5	58.5	0.3	53.2
36.0	58.2	0.2	53.3
36.5	57.8	0.2	53.1
37.0	57.5	0.2	52.4
37.5	57.2	0.2	47.6
38.0	56.6	0.1	40.1
38.5	55.6	0.1	39.9
39.0	54.5	0.0	39.9
39.5	53.4	0.0	39.8
40.0	52.4	0.0	39.4
40.5	51.5	0.0	39.8
41.0	50.6	0.0	39.9
41.5	49.6	0.0	39.1
42.0	48.8	0.0	33.5

42.5	47.8	0.0	33.3
43.0	46.7	0.0	33.2
43.5	45.7	0.0	33.1
44.0	44.9	0.0	33.1
44.5	44.0	0.0	33.1
45.0	43.2	0.0	33.1
45.5	42.5	0.0	33.1
46.0	41.8	0.0	33.1
46.5	41.2	0.0	30.4
47.0	40.5	0.0	28.3
47.5	39.5	0.0	28.0
48.0	38.7	0.0	28.0
48.5	38.0	0.0	27.9
49.0	37.3	0.0	27.8
49.5	36.6	0.0	27.8
50.0	36.0	0.0	27.8
50.5	35.4	0.0	27.8
51.0	34.9	0.0	27.8

REVIEW LISTING ABOVE 59.9°C

TIME(SEC)	PR1(°C)	PU(PR1)
00	60.0	0.08
05	60.0	0.08
10	60.0	0.08
15	60.0	0.08
20	60.0	0.08
25	60.0	0.08
30	60.0	0.08
35	60.0	0.08
40	60.1	0.08
45	60.1	0.08
50	60.1	0.08
55	60.1	0.08
60	60.1	0.08
65	60.1	0.08
70	60.1	0.08
75	60.1	0.08
80	60.1	0.08
85	60.2	0.08
90	60.2	0.08
95	60.2	0.08
100	60.2	0.08
105	60.3	0.09
110	60.3	0.09
115	60.3	0.09
120	60.3	0.09
125	60.3	0.09
130	60.3	0.09
135	60.3	0.09
140	60.3	0.09
145	60.3	0.09
150	60.3	0.09
155	60.3	0.09
160	60.4	0.09
165	60.4	0.09

170	60.4	0.09
175	60.4	0.09
180	60.4	0.09
185	60.4	0.09
190	60.4	0.09
195	60.4	0.09
200	60.4	0.09
205	60.4	0.09
210	60.4	0.09
215	60.5	0.09
220	60.5	0.09
225	60.5	0.09
230	60.4	0.09
235	60.4	0.09
240	60.4	0.09
245	60.4	0.09
250	60.4	0.09
255	60.4	0.09
260	60.4	0.09
265	60.4	0.09
270	60.3	0.09
275	60.3	0.09
280	60.3	0.09
285	60.2	0.08
290	60.1	0.08
295	60.1	0.08
300	60.0	0.08
305	60.0	0.08

GRAPHICAL REVIEW BEER

```
TIME/TEMP       20   25   30   35   40   45   50   55   60   65   70   75   80
                |****|****|****|****|****|****|****|****|****|****|****|****|
0.0     4.0
0.5     4.0
1.0     5.5
1.5     7.2
2.0     9.4
2.5     11.3
3.0     12.5
3.5     14.1
4.0     15.0
4.5     16.6
5.0     17.7
5.5     18.7
6.0     20.1    *
6.5     21.2    **
7.0     22.6    ****
7.5     23.4    ****
8.0     24.4    *****
8.5     25.3    ******
9.0     26.3    *******
9.5     26.9    ********
10.0    27.7    *********
10.5    28.2    *********
11.0    29.2    **********
```

11.5	30.7	************
12.0	31.8	*************
12.5	32.6	**************
13.0	33.5	***************
13.5	34.3	***************
14.0	35.0	****************
14.5	35.5	*****************
15.0	36.6	******************
15.5	38.6	********************
16.0	40.5	**********************
16.5	42.1	***********************
17.0	43.6	*************************
17.5	44.8	**************************
18.0	46.0	***************************
18.5	46.9	****************************
19.0	47.4	****************************
19.5	47.9	*****************************
20.0	49.3	******************************
20.5	50.6	********************************
21.0	51.7	*********************************
21.5	52.8	**********************************
22.0	53.7	***********************************
22.5	54.6	************************************
23.0	55.4	************************************
23.5	56.2	*************************************
24.0	56.7	**************************************
24.5	57.5	***************************************
25.0	58.0	***************************************
25.5	58.5	**
26.0	59.1	**
26.5	59.4	**
27.0	59.6	***
27.5	59.7	***
28.0	59.8	***
28.5	59.9	***
29.0	60.0	***
29.5	60.1	***
30.0	60.1	***
30.5	60.3	***
31.0	60.3	***
31.5	60.4	***
32.0	60.4	***
32.5	60.4	***
33.0	60.4	***
33.5	60.1	***
34.0	59.8	***
34.5	59.4	**
35.0	58.9	**
35.5	58.5	**
36.0	58.2	***************************************
36.5	57.8	***************************************
37.0	57.5	***************************************
37.5	57.2	**************************************
38.0	56.6	**************************************
38.5	55.6	*************************************

```
39.0    54.5    ************************************
39.5    53.4    **********************************
40.0    52.4    *********************************
40.5    51.5    *********************************
41.0    50.6    ********************************
41.5    49.6    *******************************
42.0    48.8    ******************************
42.5    47.8    *****************************
43.0    46.7    ****************************
43.5    45.7    ***************************
44.0    44.9    **************************
44.5    44.0    *************************
45.0    43.2    ************************
45.5    42.5    ************************
46.0    41.8    ***********************
46.5    41.2    **********************
47.0    40.5    **********************
47.5    39.5    *********************
48.0    38.7    ********************
48.5    38.0    *******************
49.0    37.3    ******************
49.5    36.6    ******************
50.0    36.0    *****************
50.5    35.4    ****************
51.0    34.9    ****************
```

GRAPHICAL REVIEW SPRAY

```
TIME  TEMP    20   25   30   35   40   45   50   55   60   65   70   75   80
              |****|****|****|****|****|****|****|****|****|****|****|****|
0.0     23.4    ****
0.5     28.3    *********
1.0     29.0    **********
1.5     29.1    **********
2.0     29.3    **********
2.5     29.6    ***********
3.0     29.7    ***********
3.5     29.8    ***********
4.0     29.8    ***********
4.5     30.0    ***********
5.0     30.0    ***********
5.5     32.7    **************
6.0     34.9    ****************
6.5     34.9    ****************
7.0     34.9    ****************
7.5     34.9    ****************
8.0     35.0    ****************
8.5     35.1    ****************
9.0     35.1    ****************
9.5     35.2    ****************
10.0    35.2    ****************
10.5    40.4    *********************
11.0    41.9    ***********************
11.5    42.1    ***********************
12.0    42.1    ***********************
12.5    42.4    ***********************
```

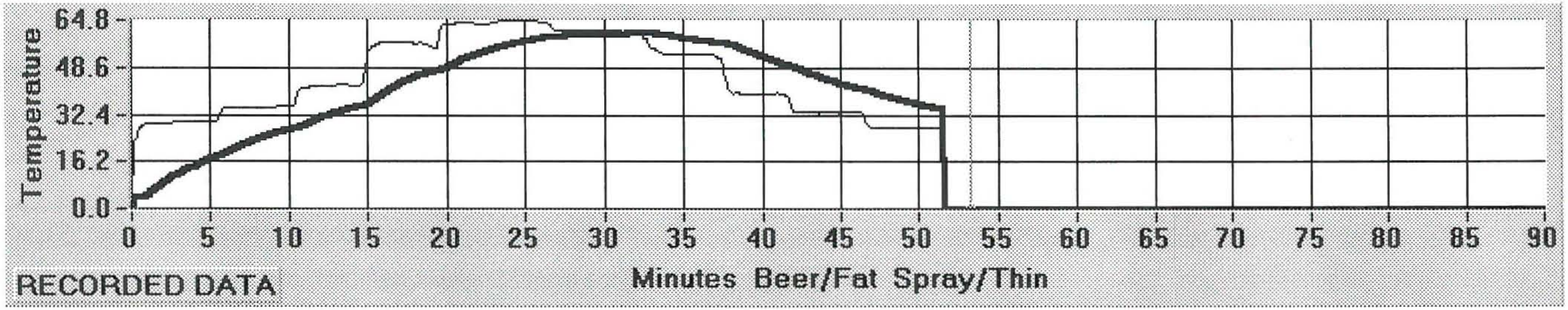
13.0	42.8	************************
13.5	43.0	************************
14.0	42.4	***********************
14.5	42.8	************************
15.0	54.8	************************************
15.5	56.8	**************************************
16.0	57.4	**************************************
16.5	57.3	**************************************
17.0	57.4	**************************************
17.5	57.2	**************************************
18.0	56.9	**************************************
18.5	56.8	**************************************
19.0	55.4	************************************
19.5	61.4	**
20.0	63.6	***
20.5	63.9	***
21.0	64.2	***
21.5	64.0	***
22.0	63.4	**
22.5	63.5	***
23.0	64.2	***
23.5	64.6	**
24.0	64.7	**
24.5	64.8	**
25.0	64.8	**
25.5	64.6	**
26.0	64.4	***
26.5	63.3	**
27.0	61.2	**
27.5	61.3	**
28.0	61.3	**
28.5	61.2	**
29.0	61.2	**
29.5	61.2	**
30.0	61.2	**
30.5	61.1	**
31.0	61.0	**
31.5	61.0	**
32.0	60.4	***
32.5	58.8	**
33.0	55.0	************************************
33.5	53.6	***********************************
34.0	53.1	**********************************
34.5	53.1	**********************************
35.0	53.1	**********************************
35.5	53.2	**********************************
36.0	53.3	**********************************
36.5	53.1	**********************************
37.0	52.4	*********************************
37.5	47.6	*****************************
38.0	40.1	*********************
38.5	39.9	*********************
39.0	39.9	*********************
39.5	39.8	*********************
40.0	39.4	********************

16.0	57.4	**************************************
16.5	57.3	**************************************
17.0	57.4	**************************************
17.5	57.2	**************************************
18.0	56.9	**************************************
18.5	56.8	**************************************
19.0	55.4	************************************
19.5	61.4	**
20.0	63.6	***
20.5	63.9	***
21.0	64.2	***
21.5	64.0	***
22.0	63.4	**
22.5	63.5	***
23.0	64.2	***
23.5	64.6	**
24.0	64.7	**
24.5	64.8	**
25.0	64.8	**
25.5	64.6	**
26.0	64.4	***
26.5	63.3	**
27.0	61.2	**
27.5	61.3	**
28.0	61.3	**
28.5	61.2	**
29.0	61.2	**
29.5	61.2	**
30.0	61.2	**
30.5	61.1	**
31.0	61.0	**
31.5	61.0	**
32.0	60.4	***
32.5	58.8	**
33.0	55.0	************************************
33.5	53.6	***********************************
34.0	53.1	**********************************
34.5	53.1	**********************************
35.0	53.1	**********************************
35.5	53.2	**********************************
36.0	53.3	**********************************
36.5	53.1	**********************************
37.0	52.4	*********************************
37.5	47.6	*****************************
38.0	40.1	*********************
38.5	39.9	*********************
39.0	39.9	*********************
39.5	39.8	*********************
40.0	39.4	********************
40.5	39.8	*********************
41.0	39.9	*********************
41.5	39.1	********************
42.0	33.5	***************
42.5	33.3	**************
43.0	33.2	**************
43.5	33.1	**************

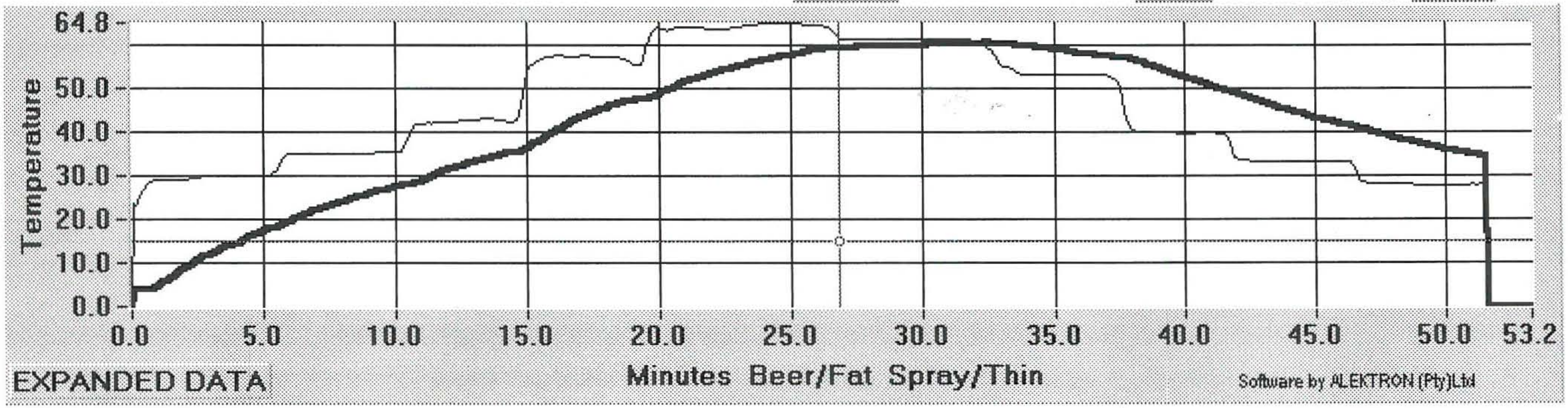
Unit	Position		Packsize	F … r	Time	Date	Transit Time
5	TOP DECK	MIDDLE	750 ml	PR48-B6-S2 0071	11:44	12/07/96	51.5 min

Total PU's	Beer Max	Beer Time Above		Beer PU's Above		Beer out	Spray Max
12.5 P.U's	60.5 °C	59.9 °C=	5.10 min	59.9 °C=	5.6 P.U's	34.5 °C	64.8 °C

Technician PC Pelser | Status PRINTING | QUIT | COM | LOAD | SAVE | PRINT | READ



Time 26.8 min | Beer 59.5 °C | Spray 62.2 °C



APPENDIX B

SCHEMATIC DIAGRAM OF THE SENSOR AMPLIFIER

Description of the Schematic Diagram

The schematic diagram shows a small important part of the electronic design of the processor control PCB. This is the analog circuitry with communication between the micro processor and the A/D converter.

The LT1290DCN A/D converter requires four I/O pins from the micro processor for the serial communication process. It also requires that the Analog Clock (ACLK) of the A/D converter be connected to the Address Latch Enable (ALE) of the micro processor. This signal is used as a clock signal for the internal circuitry within the A/D converter. It does not require any programming in the instrument software. The Serial Clock (SCLK) signal is an output from the micro processor, and is used to clock data to and from the A/D converter. The data to the A/D converter is done via the Data In (DIN) line, which is an output from the micro processor. The data from the A/D converter is done via the Data Out (DOUT) line which is an input to the micro processor. The Chip Select (CS) line is used to enable or disable the A/D converter. The A/D converter uses less power in the disable mode.

As shown in the schematic, the sensor is connected in a Wheatstone bridge with R1, R2 and R3, to compensate for a resistance offset. The offset is the result of the sensor resistance at 0°C, which is 100Ω. The bridge is set to be in balance at 0°C temperature on the sensor. Any out-of-balance signal on the bridge, due to the resistance increase of the temperature sensor, is amplified by the op-amp. The amplification is determined by resistors R5 and R4. R6 is for internal compensation in the op-amp and is the same value as R5. R7, R8, C1, C3, and C4 form part of the filtering circuitry to eliminate noise on the analog signal. The amplified signal from the op-amp is connected to a dual input on the A/D converter. The A/D converter will only convert the voltage difference between the two signals into a digital signal.

The micro processor will do all the calculations to measure this analog temperature signal as accurately as required by the end user.

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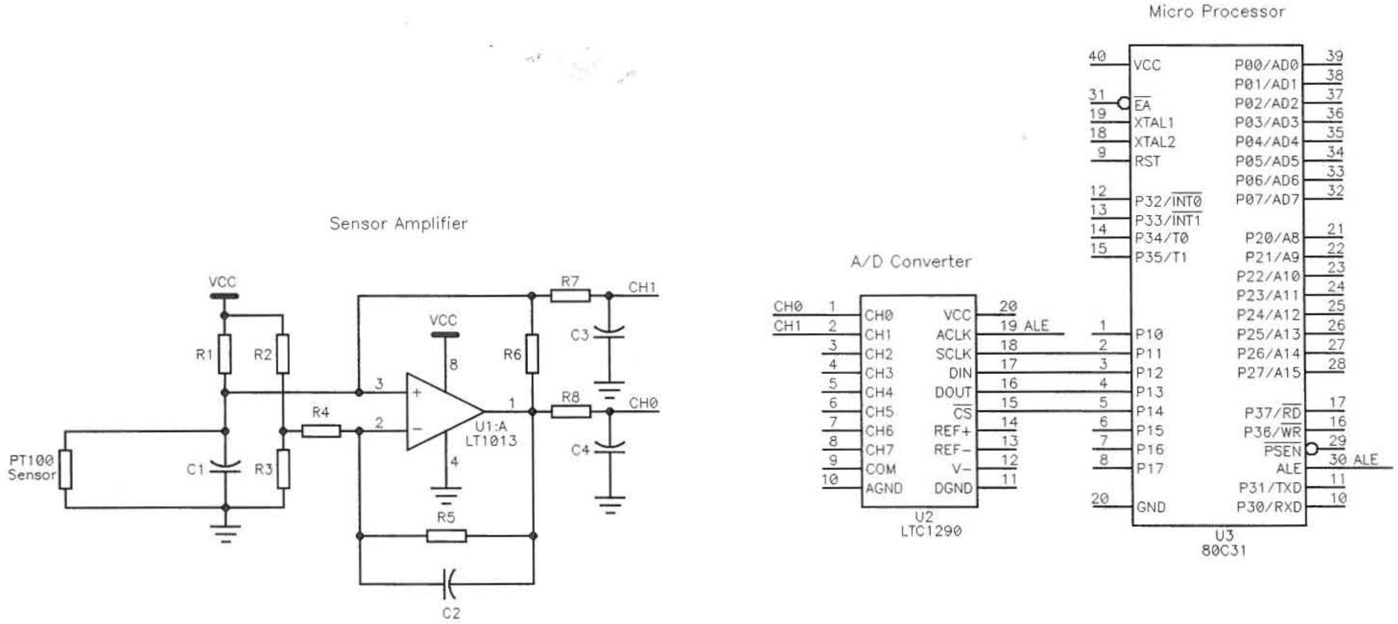

	PC Pelser
Title	PU – RECORDER
Doc.No	PUR0101.S01

APPENDIX C

SOFTWARE LISTING FOR THE ANALOG CIRCUITRY

Part 1.

```
/*DECLARE REGISTERS*/

DECLARE
        LCD_COMMAND     BYTE EXTERNAL AUXILIARY,
        LCD_DATA        BYTE EXTERNAL AUXILIARY,
        ACLK            BIT AT (090H) REGISTER,
        ADI             BIT AT (091H) REGISTER,
        ADO             BIT AT (092H) REGISTER,
        ACS             BIT AT (093H) REGISTER,
        VOLTAGE         WORD PUBLIC AUXILIARY;
```

Part 2.

```
/*PROCEDURES*/

/*PROCEDURE THAT MOVE DATA TO AND FROM THE A/D CONVERTER*/
READ : PROCEDURE PUBLIC;
DECLARE I BYTE;
VOLTAGE=0;
ACS=0;
DO I=0 TO 7;
 VOLTAGE=VOLTAGE + EXPAND(ADO);
 VOLTAGE=ROL(VOLTAGE,1);
 ADI=0;
 IF (CONF AND (10000000B)) > 0 THEN ADI=1;
 CONF = ROL(CONF,1);
 ACLK=1;
 ACLK=0;
END;
DO I=0 TO 3;
 VOLTAGE=VOLTAGE + EXPAND(ADO);
 VOLTAGE=ROL(VOLTAGE,1);
 ACLK=1;
 ACLK=0;
END;
ACS=1;
VOLTAGE=VOLTAGE/2;
END READ;
```

```
/*PROCEDURE THAT CONVERT THE DIGITAL DATA OF THE A/D CONVERTER
INTO A TEMPERATURE READOUT*/
READP1 : PROCEDURE PUBLIC;
DECLARE TEMP WORD;
DECLARE TOTAL WORD;
CONF=00001110B;
CALL READ;
TOTAL=0;
DO I=0 TO 9;
  CONF=00001110B;
  CALL READ;
  TOTAL=TOTAL+VOLTAGE;
END;
COUNT(0)=TOTAL/10;
TEMP=(COUNT(0)-OFFSET1);
TEMP=TEMP-(ERRTABLE(TEMP/(DIVITION1/100)));
COUNT(1)=TEMP/DIVITION1*10;
TEMP=TEMP MOD DIVITION1 *10;
COUNT(1)=(COUNT(1)+(TEMP/DIVITION1))*10;
TEMP=TEMP MOD DIVITION1 *10;
COUNT(1)=(COUNT(1)+(TEMP/DIVITION1))*10;
TEMP=TEMP MOD DIVITION1 *10;
COUNT(1)=COUNT(1)+(TEMP/DIVITION1);
COUNT(1)=COUNT(1)+PROBESET1;
CONF=11001110B;
CALL READ;
CONF=11001110B;
CALL READ;
IF VOLTAGE=4095 THEN COUNT(0)=4095;
END READP1;
```

Part 3.

```
/*SETUP VALUES*/

ACS=1;
ACLK=0;
CONF=00001110B;
CALL READ;
```

Part 4.

```
/*MAIN PROGRAM*/

DO WHILE 1;

/*PROGRAM ROUTINE TO DISPLAY THE TEMPERATURES ONTO THE LCD
DISPLAY*/
IF MODE=7 THEN DO;
IF STEP=0 THEN DO;
 CALL LCD_PRINT(.('  THERMOMETER   '));
 STEP=1;
END;

IF STEP=2 THEN DO;
 CALL READP1;
 IF COUNT(0) < 4095 THEN DO;
 IF COUNT(1) > 800 THEN COUNT(1)=800;
 ANADATA=COUNT(1);
 CALL LCDSUM;
  LCD(0) =ANA(1);
  LCD(1) =ANA(2);
  LCD(2) ='.';
  LCD(3) =ANA(3);
  LCD(4) =223;
  LCD(5) ='C';
  LCD(6) =' ';
  LCD(7) =' ';
  END;
  ELSE DO;
  LCD(0) ='P';
  LCD(1) ='1';
  LCD(2) =' ';
  LCD(3) ='E';
  LCD(4) ='R';
  LCD(5) ='R';
  LCD(6) =' ';
  LCD(7) =' ';
  END;
CALL READP2;
IF COUNT(2) < 4095 THEN DO;
IF COUNT(3) > 800 THEN COUNT(3)=800;
ANADATA=COUNT(3);
CALL LCDSUM;
 LCD(8) =' ';
 LCD(9) =' ';
```

```
  LCD(10) =ANA(1);
  LCD(11) =ANA(2);
  LCD(12)='.';
  LCD(13)=ANA(3);
  LCD(14)=223;
  LCD(15)='C';
  CALL LCD_PRINT1;
  END;
  ELSE DO;
  LCD(8) =' ';
  LCD(9) ='P';
  LCD(10)='2';
  LCD(11)=' ';
  LCD(12)='E';
  LCD(13)='R';
  LCD(14)='R';
  LCD(15)=' ';
  CALL LCD_PRINT1;
  END;
END;

END;
```