DESIGN OF A KNOWLEDGE-BASED SYSTEM INTERFACING WITH AN EXTRUSION COOKING PROCESS

by

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CHAPTER 1

INTRODUCTION

1.1 Objective

The objective of this report is to present a possible design for an automated control system composed of a knowledge based system (KBS), personal computer (PC) with appropriate software, and the necessary instrumentation. The function of this system is to detect and diagnose the appropriate process parameters and then control an extrusion cooking process in an automated fashion.

1.2 Design Topics Addressed

The design topics addressed in this report are given below.

1. Development of KBS software.
2. Development of PC software.
3. Design of electronic-sensing transducer circuitry.
4. Design of electronic control circuitry.
5. Determination of the necessary and appropriate transducer specifications.
6. Determination of the necessary and appropriate

control signal processing.

1.3 Background

With recent developments in high technology, computers have become a part of our everyday lives. We can see their operation in banks, department stores, fast-food restaurants, modern food-processing plants, warehouse management, airline terminals, and many other applications. In most of these uses, computers have been installed and utilized to take advantage of their enormous computational capability to process data. Computers for process control in the food industry will enable significant advances in the level of automation in many manufacturing plants. A successful design of the control strategy goes beyond the selection of hardware depending on knowledge of the process and an understanding of the capabilities of advance control tools. This can be accomplished by food industry personnel, based on applying available control components even without specialized control expertise. A great diversity of products and manufacturing plants in food processing operations exists nowadays that requires these high technology computational capabilities.

The following points, however, are critical to any automation program:

1. A firm must be established to assure consistent process operation before higher level automation is considered;
2. While the computer can be used to collect process data, knowledge of the process is required before such data can be used for control;
3. A top-down control strategy is required that defines overall short- and long-term objectives and implications of the control system.

For a food engineer or a food practitioner, the most crucial decisions are whether or not to use any optimization procedure, how to formulate the objective function to represent the process, and what quantity is to be maximized or minimized. It is very important to choose an appropriate software package. Generally, the decision of which package to use must be judged based on its potential in accelerating the process rather than its sophistication. Obviously, each application should be weighed individually according to the time, money, labor, and effort required.

For example, automatic control of the extrusion cooking process has become very important in recent years. The diversity of these manufacturing plants is reflected in the large range of instrumentation and control equipment which is utilized. Also in food processing, high product quality imposes requirements for accurate and reliable measurement processes and good performance from an automatic control system. The most important function of the instrumentation and control equipment is data collection from the outside world. The process parameters, such as temperature, water flow rate, steam pressure, etc., will affect the entire control system. The data collected by this equipment are then used for subsequent analysis.

In order to automatically control an extrusion cooking process, it is necessary to measure product temperature, flow rate, level, and many other parameters. Sensors and transducers are used to monitor the values of these parameters. The vast majority of these sensors produce an output in the form of a voltage or current signal. The electrical output is an analog signal representing the value of the parameter being measured. Since these signals are transmitted to a microcomputer system where appropriate control decisions are made and since the microprocessor can only accept discrete digital data in the form of a collection of bits, it is necessary to convert the analog signals to digital signals. On the other hand, most actuators or controllers being controlled by the microcomputer system can only operate on continuous analog output signals. Thus in a process control system, it is necessary to convert analog to digital signals, and vice versa.

Carefully selecting the microprocessor system and its required peripheral equipment is the first step in interfacing a microcomputer to external devices. This peripheral equipment includes sensors, transducers, amplifiers, sample-and-hold devices, multiplexers, analog-to-digital converters, digital-to-analog converters, demultiplexers, actuators, computer software, display, and related peripherals [1]. Sensors are required for a very large number of tasks. Presenting a possible interface design of twenty different sensors/transducers with a host computer is a major effort of this report.

In order to control the entire extrusion cooking system, every parameter affecting the process has to be carefully controlled. These parameters and their ranges can be stored in an expert system knowledge base in the microcomputer software. The knowledge base is the primary part of the expert system that makes the control decisions. Thus it is very important to design an intelligent computer program that uses an expert system knowledge base and inference procedures to implement the control process.

Figure 1.1 shows the configuration of the process to be controlled and the automatic control system. The top of the block diagram is the extrusion cooking process from meal input to product output. The controllers and transducers, which control and sense during the process, are also

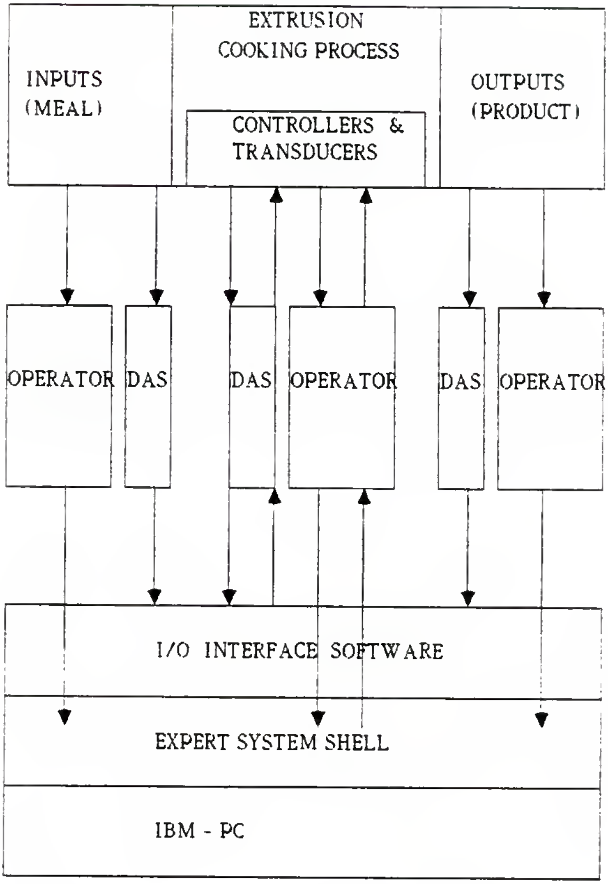


Figure 1.1 Block Diagram of an Automatic Extrusion Control Process

included. The middle of the block diagram includes the operator and data acquisition system (DAS). Both execute sensing and control functions. The bottom of the block diagram represents the microcomputer hardware and software of the control system. It includes the input and output interface software, expert system shell, and computer itself. The arrows represent the flow of process control signals between the blocks. For instance, when the raw material is fed into the process, the operator can control the quantity of the meal input. Next, the operator may manually input data to the computer system concerning the input meal status. Simultaneously, the DAS can sense the input meal status and transmit that data to the computer through the input/output (I/O) interface software. There are several different kinds of sensors in the block diagram. They take the process values, such as temperature, water flow rate, meal level, steam pressure, etc. and transmit these data to the computer through the DAS. The operator can also manually input the desired process values to the computer. When the computer receives the data, the expert system analyzes these data and makes control decisions. The decisions are transformed to analog signals for actuating the controllers through the DAS. The controllers control and adjust the physical equipment values, such as the water flow rate in the cooling jackets of the extruder, to control the extrusion cooking process. The I/O interface software block is responsible for making the data signals of the DAS and expert system compatible with one another. A well developed expert system shell, Personal Consultant-Plus (PC +)*, is used to develop the control expert system and then to diagnose and control the extrusion cooking process within the expert system shell block.

Chapter 2 describes the material and methods which can be used in an automatically controlled extrusion cooking process. The location of sensors and equipment are also included. Hardware specifications, including sensors, transducers, data acquisition, and gas chromatography, will be discussed in Chapter 3. Chapter 4 discusses the locations and hardware specifications for the control signals. The last chapter presents the computer interface control and expert system shell.

* Personal Consultant-Plus (PC+) is a trademark of Texas Instruments, Incorporated.

CHAPTER 2

MATERIAL AND METHODS

2.0 Introduction

Chapter 2 describes the extrusion cooking process. Then it presents the materials and methods which will be used for the automatic control of the extrusion cooking process. This chapter will discuss the following pertinent questions concerning automatic process control.

1. What process parameters must be measured?
2. What are the ranges of these parameters?
3. What kinds of sensors/transducers can be chosen?
4. Where should the sensors/transducers be located?
5. How does the data acquisition system work?
6. How does gas chromatography work?
7. How does the expert system make control decisions about the automatic cooking process system?
8. How do the sensors/transducers interface with the computer?

Figure 2.1 illustrates the general diagram of the equipment used in an extrusion cooking process starting at the mixer distributor. The equipment includes a mixer

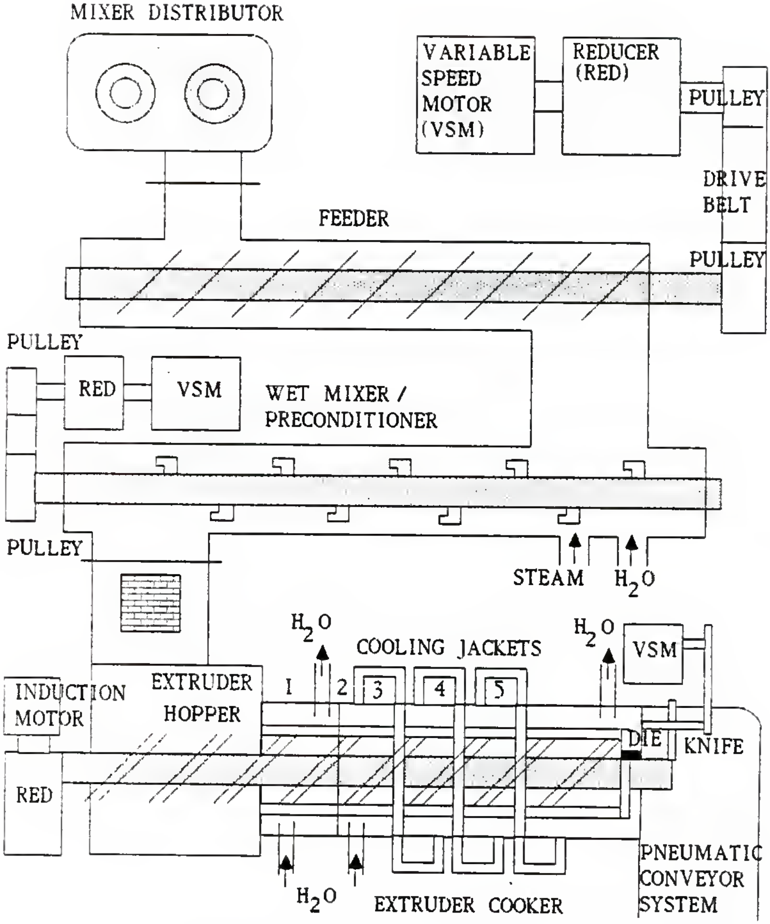


Figure 2.1 General Diagram of an Extrusion Cooking process System

distributor, a feeder driven by a DC variable speed motor (VSM) through a reducer (RED) gear box, a preconditioner also driven by a VSM through a RED, an induction motor that drives the extruder cooker screw through a RED, a water cooling system for the extruder cooker body, a knife driven by a VSM for cutting the extruder rope coming from the extruder die, and a pneumatic conveyor system. Some accessories, i.e., variable speed motor (VSM), reducer (RED), ammeter, and induction motor, are also included.

2.1 Extrusion Cooking Process

Extruders have been used for many years in the preparation of pasta, and the method is being used more widely for manufacturing other products such as breakfast cereals, noodles, snack foods, and dog foods [2]. A block diagram of an extrusion cooking process used by a national food processing company is shown in Figure 2.2. The functions of the components in this figure and the processes are described below.

Hammer Mills

1. The hammers will grind up the corn which is the raw material of the product.
2. The ground corn will be conveyed to mixer.

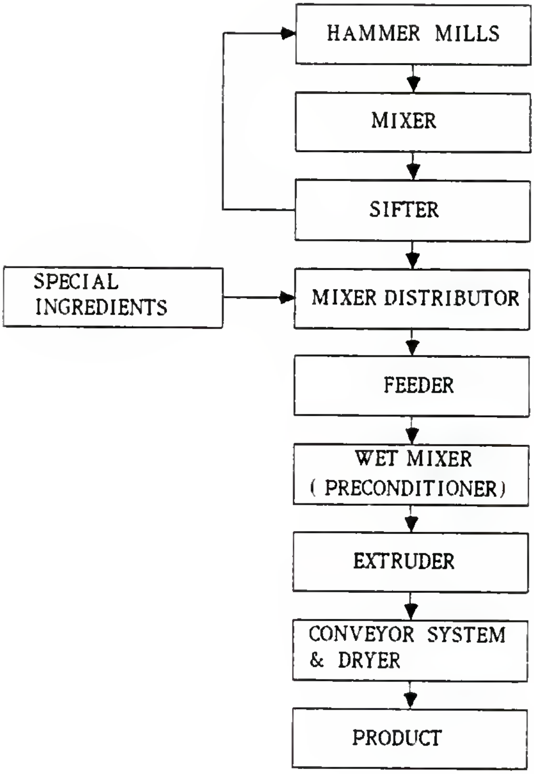


Figure 2.2 Block Diagram of an Extrusion Cooking Process System

Mixer

1. The mixer is used to stir the ground corn.
2. The stirred material will pass through a sifter.

Sifter

1. The sifter returns to the hammer mills meal that is too large and lets meal that is small enough continue being processed.

Mixer Distributor

1. The mixer distributor provides constant meal supply to the feeder and can also be used for the addition of other special ingredients and liquids.

Feeder

1. The feeder controls the meal feed rate at its output so as to maintain a steady flow of meal being fed to the preconditioner.
2. The variable speed drive motor drives a volumetric screw feeder thereby adjusting the flow rate of the feed. The speed depends upon the extruder capacity, feed condition, i.e., the density of product in the feeder.

Preconditioner

1. The preconditioner has a single paddle shaft used to mix meal with water and steam.

2. Process water and steam are fed to precondition the dry meal to increase the moisture, temperature, and homogeneity.

Extruder

1. The induction motor drives the extruder screw and is rated at 125 hp while drawing 140 amperes.
2. There are five water jackets used to control the temperature of the extrusion process.
3. The cooling jackets and die size control the amount of product cooking resulting from the mechanical forces of the screw.
4. The die controls the shape and size of product.
5. The product is the output.

Conveyor System & Dryer

1. The conveyor system moves the product from the extruder to the dryer pneumatically.
2. The dryer uses heat to dry the product.

The raw material is forced through a jacketed barrel by a helical screw and discharged through a die. The temperature required for production during the extrusion cooking control is a very important factor that has to be addressed. Cold water is circulated in the jackets of the barrel to diminish the heat generated by the mechanical work of compressing the material. Automatic control of water addition before extrusion can now be implemented, using sensors to measure the product moisture content either before or after the addition of water [2,3].

Extruders are designed with smoothly varying pitch and diameter ratios of the feed screw. The pitch and diameter ratios are calculated to achieve the required pressure for particular types of products. The pressure during the extrusion process, which can be measured in front of the die, is regulated by varying the screw drive speed. The extruder temperature during the extrusion process is important to monitor. It is controlled by adjusting the flow rate of the water circulating in different sections of the barrel jacket. This is a very critical control parameter of the entire process [2,3].

2.2 Sensor / Transducer Location & Function

Sensors or transducers are required to monitor physical parameters of a product or some process variables of interest so that this information can be input into the microcomputer system and, subsequently, appropriate control decisions can be made. The vast majority of transducers used in this report produce an output signal in the form of a low voltage or small current. This electrical output signal is an analog representation of the measured parameter. The electrical output signal has to be conditioned to the appropriate form before it is connected to the microcomputer.

Most available transducers in the industrial market exhibit nonlinear relationships. This problem can be overcome by calibrating the sensor. Any non-linearity between the input and output values can be corrected by the microcomputer software program. The monitoring and recording of the physical parameters demand that the measurements carried out by the sensors must be repeatable.

The sensors used should have the following desirable characteristics [3].

(1) Repeatability of measurements.

(2) Reliability over long periods of time.

(3) Ability to withstand hostile environments.

(4) A high electrical output signal value thereby avoiding the need to use amplifiers.

Transducers and sensors discussed in this report are used for monitoring physical parameters of the product and process which include pressure, temperature, flow rate, moisture, rotational speed, level and aroma/odor.

The location of each sensor is shown in Figure 2.3. The function of each sensor/transducer is described below and the hardware specifications can be found in Chapter 3,

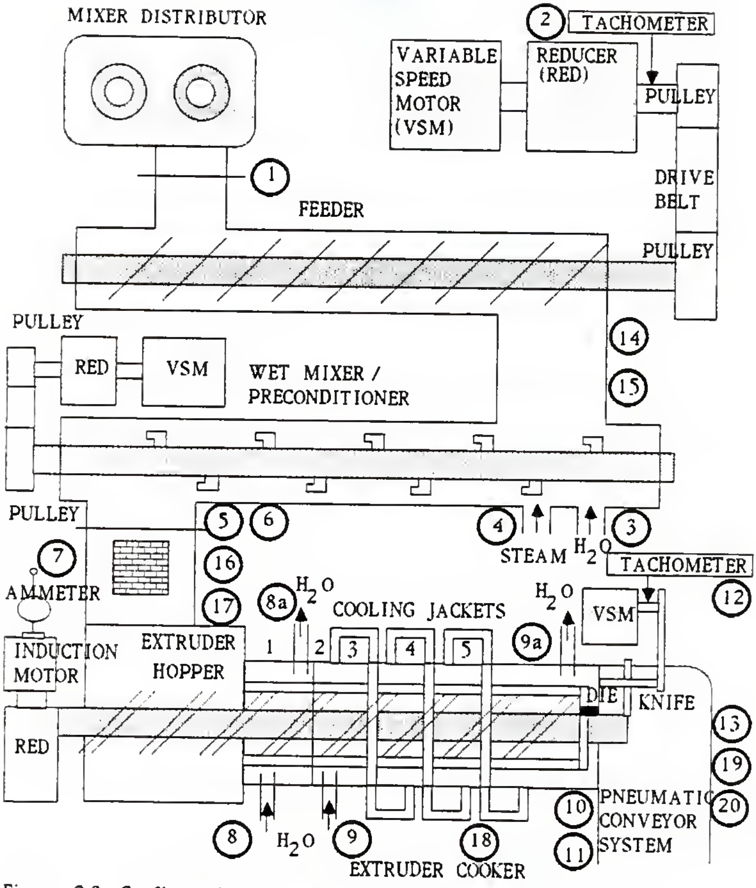


Figure 2.3 Configuration of Sensor Locations in an Extrusion Process

paragraph 3.1.

(1) Dry Meal Level Detector

The level detector is located in a vertical channel at the output of the mixer distributor. It is used to measure the progress of dry meal from the distributor to the feeder. Some important level scenarios that must be considered are given below.

1. No meal is in the vertical channel.
2. The level of meal flow rate is less than the minimum trigger value.
3. The level of meal flow rate is in the proper range.
4. The level of meal flow rate is higher than the maximum trigger value.
5. The feeder is not taking any more meal stock since the feeder is stopped or plugged up.

The output of the level detector is an electrical output signal in the form of a voltage or current. The amplitude of the output signal is dependent on the level of the meal flow rate detected. The output data goes into the microcomputer via the data acquisition system and is then processed by the expert system resident on the microcomputer.

(2) Feeder Tachometer

The feeder tachometer is used to measure the DC variable speed motor (VSM) which controls the speed of the feeder. The typical speed of the feeder is approximately 30 rpm (revolutions per minute) and its range is between 0 and 50 rpm.

Increasing the feeder speed will increase the dry meal flow to the extruder causing the induction motor amperes to increase, the production rate to increase, the meal to become drier, and the product density to decrease. All of the above has a tendency to bleach or burn the product.

Decreasing the feeder speed will decrease the dry meal flow rate to the extruder. The meal will become more moist, the amperes of the main drive induction motor will be reduced, and the production rate will decrease. There will be an increased tendency for an undercooked or sloppy and sticky product with increased density.

(3) Water Flow Rate Sensor

The water flow rate sensor monitors the process water that flows into the wet mixer.

Increasing the process water flow causes the moisture of the meal to increase, the product density to increase, the product to have a greater tendency to be undercooked and sloppy or sticky, and the amperes on the extruder drive to drop.

Decreasing the process water flow causes the moisture of the meal to decrease, the product density to decrease, the product to have a greater tendency to be overcooked, bleached, or burnt, and the amperes on the extruder drive to increase.

(4) Steam Pressure Sensor

The steam pressure sensor is located at the preconditioner to measure the steam input into the wet mixer.

Increasing the steam pressure increases the temperature of the meal, increases the moisture of the meal slightly, and causes the extruder motor amperes to drop slightly.

Decreasing the steam pressure decreases the temperature of the meal to the extruder, decreases the moisture of the meal slightly, and causes the extruder motor amperes to increase slightly.

Decreasing the temperature of the meal by decreasing the steam input by a wide margin leads to an undercooked product, a lower production rate, and much higher amperes for the extruder motor.

(5) Wet Meal Temperature Sensor

The temperature sensor located at the output of the wet mixer should indicate a temperature of the wet meal within the range of 200°F to 210°F.

(6) Wet Meal Level Sensor

The wet meal level sensor, located in the vertical channel between the preconditioner and the extruder, senses the wet meal flow rate. The principle and function of this sensor are similar to those of the dry meal level sensor.

(7) Extruder Induction Motor Ammeter

This ammeter detects the extruder induction motor current. The induction motor current is only used as a sensed input parameter for controlling the extrusion cooking process.

(8) & (8a) Water Flow Rate and Temperature Sensor
-- Jacket #1

The water flow rate and temperature sensors detect the input cooling water flow rate and output cooling water temperature for cooling jacket #1 of the extruder.

Increasing the cooling water flow rate to the first jacket will improve the flow of meal into the extruder hopper and reduce meal back-ups at the hopper.

Decreasing the cooling water flow rate to the first jacket may contribute to back-up problems.

(9) & (9a) Water Flow Rate and Temperature Sensor -- Jackets #2 to #5

The water flow rate and temperature sensors detect the input cooling water flow rate and output cooling water temperature for cooling jackets #2 through #5 of the extruder. The process function of these sensors is the same as those for cooling jacket #1.

(10) Die Pressure Sensor

The pressure sensor detects the pressure under which the cooked product is being extruded through the die.

(11) Die Temperature Sensor

The temperature sensor detects the temperature of the cooked product rope being extruded through the die.

(12) Cut-Off Knife Tachometer

The cut-off knife tachometer detects the rotational speed at which the knife cuts the cooked product rope into shaped pieces that have a desired length.

Increasing the speed of the cut-off knife will decrease the length of the cooked product pieces. Decreasing the speed will increase the length.

(13) Cooked Product Moisture Sensor

This sensor detects the relative moisture content of the cooked product pieces entering the pneumatic conveyor system.

(14) Meal Optical Sensor

In order to grade the meal based on its color and shape, an optical sensor should be used here. Since optically sensed data is analyzed using complicated image processing techniques, it will not be discussed in any detail in this report.

(15) Dry Meal Moisture Sensor

The dry meal moisture sensor is located in the vertical channel between the feeder and wet mixer. It detects the moisture content of the dry meal.

(16) Steam Optical Sensor

The steam optical sensor detects the density of the steam being vented between the wet mixer and the extruder hopper. The steam density indicates the amount of "preconditioning" of the wet meal before it enters the extruder. This optical sensor will not be discussed in any detail in this report.

(17) Aroma Sensor/Gas Chromatograph

The aroma sensor detects the compounds of the aroma in the steam being vented between the wet mixer and the extruder hopper. A gas collection system commonly employed in gas chromatography can be appropriately used here. The principle of gas chromatography is discussed in Chapter 2, Paragraph 6.

(18) Audio Sensor

The audio sensor is placed on the barrel of the extruder to detect the acoustic signals being generated by the mechanical action of the extruder. A microphone is the basic component of this sensor.

(19) Aroma Sensor/Gas Chromatograph

This aroma sensor detects the aromatic compounds of the cooked product leaving the extruder die.

(20) Cooked & Shaped Product Optical Sensor

This optical sensor detects the quality of the cooked and shaped product as it enters the pneumatic conveyor system. The product quality depends on its color and shape. This optical sensor will not be discussed in any detail in this report.

2.3 Expert System Process Control Concept

Expert systems (ES) are being developed to assist managers plan and schedule complex tasks, to help medical personnel diagnose diseases, and aid mechanics in troubleshooting problems. An expert system is an implementation of certain artificial intelligence (AI) techniques that enable intelligent computer programs to assist people in analyzing problems and making decisions in a very narrow knowledge domain. An intelligent computer program uses knowledge and inference procedures to solve problems which are difficult enough to require significant human expertise for their solution.

To develop an expert system, the following steps must be implemented [5].

1. Select a tool and implicitly commit oneself to a particular consultation paradigm.
2. Identify the problem and analyze the knowledge to be included in the system.
3. Design the system. Initially, this involves describing the system on paper. It typically involves generating decision flow-diagrams and drafting basic rules.
4. Develop a prototype of the system using the tool.

This involves actually creating the knowledge base and testing it by simulating a number of consultations.

5. Expand, test, and revise the system until satisfactory results are achieved.
6. Maintain and update the system as needed.

The most important characteristic of an expert system is that it makes decisions in a manner similar to the decision making process used by humans. To build the ES process control systems, "experts" who have accumulated through years of experience the essential knowledge in food process system are needed. To facilitate an expert system interaction, its reasoning has to be explained and new knowledge must be acquired, as well as modification of old knowledge.

Interfacing the knowledge base, which is programmed in the computer, with the outside instrumentation is very important in the automatic food processing control. The computer gets the signals from the transducers or sensors, and then builds a data file which can interface with an expert system that contains a knowledge base. The knowledge base has to be built by experts who are familiar with the extrusion control process. The knowledge base should include the rule base which the inference engine uses to make proper control decisions.

2.4 Equipment and Product Parameters

The equipment adjustments and product values of the extrusion cooking process are used as input parameters for the ES knowledge base. A list of the equipment adjustments, the product process results, their corresponding value ranges, and typical values are given below. This information is for an extrusion cooking process used by a national food processing company.

Equipment Adjustments	Range of Values
1. Feeder Speed	0 - 50 rpm (Typical: 30 rpm)
2. Process Water Flow	0 - 25 ppm or 0 - 2 gpm (Typical: 1.5 gpm)
3. Cut-off Knife Speed	0 - 4000 rpm (Typical: 2500 rpm)
4. Steam Pressure	0 - 50 psi (Typical: 30 psi)
5. Jacket Water Temperature	175 - 200° F (Typical: 190° F)
6. Cooling Water Supply Temperature	50 - 100° F (Typical: 65° F)
7. Induction Motor Load	0 - 200 amp (Typical: 140 amp)
8. Restriction Plate	large, small, none
9. Extruder Drive Amperes	under load, normal range 125 - 140, overload, max
10. Knife Aligned	yes, no
11. Shroud Obstruction	yes, no

12. Die Plugged	yes, no
13. Die Cap Properly Installed	yes, no
14. Leaking Jackets	yes, no
15. Leaking Liners	yes, no
16. Screw Wear	yes, no
17. Liner Wear	yes, no
18. Extruder Restriction	yes, no
19. Extruder Back Up	yes, no
20. Die Cap Wear	yes, no
21. Extruder Screw Build Up	yes, no
22. Extruder Screw Diameter	within tolerance, out of tolerance
23. Extruder Screw Flight Edges	sharp, rounded
24. Ammeter Calibration	yes, no
25. Screw Warped	yes, no
26. Process Water Fluctuations	yes, no
27. Steam Flow Fluctuations	yes, no
28. Feeder Surge	yes, no
29. Wet Mixer Build Up	yes, no
30. Mixer Paddles	out of line, missing
31. Mixer Distributor Flow Rate	okay, not okay
32. Jacket #1 Temperature	high, normal,low
33. Jacket #2 to #5 Temperature	high, normal, low
34. Adequate Air Flow	yes, no
35. Wet Mixer Retention Time	high, normal, low

36. Bin Control	okay, not okay
37. Delivery Control	okay, not okay
38. Mixer Distributor Level	okay, not okay

Product Process Results	Range of Values
1. Bushel Weight	high, target high, target, target low, low
2. Wet Product Size	large, normal, small
3. Wet Product Shape	normal, out of type
4. Wet Meal Moisture	high, normal, low
5. Wet Meal Temperature	normal 200 - 210^{o}F, high > 210^{o}F, low < 200^{o}F
6. Product Rate	high, low, fluctuating, standard 5000 - 6300 lb.
7. Wet Product Sticky	yes, no
8. Product Moisture	high, normal, low
9. Product Cook	overcook, burnt, just right, undercook
10. Wet Product Moisture	high, normal, low
11. Raw Meal Condition	scorched, normal

2.5 Data Acquisition

A data acquisition system is a computer interface system that allows one to feed data from the real world to a computer. It takes the analog signals produced by temperature sensors, pressure transducers, flowmeters, etc., and converts them into a digital form that the computer can comprehend. With an acquisition system, one can use a computer to gather, monitor, display, and analyze the data. If the acquisition system has digital to analog converter (DAC) output capabilities, one can also use the computer to control the entire process [2,6].

Data acquisition systems are used to acquire process operating data and store it on secondary storage devices such as magnetic tapes, floppy diskettes, and hard disks for future analysis. It is often necessary to design special-purpose data acquisition systems and interfaces to acquire values from the real world process. Microcomputer-controlled data acquisition facilitates the scanning of a large number of sensors. Figure 2.4 illustrates how the sensors interface with a microcomputer. The scanning rate is dependent upon the signal dynamics. This effectively means that some channels must be scanned at very high speeds in order to avoid aliasing errors while there is little loss of information by scanning other channels at slower speeds.

Analog data must be converted into a digital format before it is recorded and processed and requires the use of suitable analog-to-digital converters (ADC). The characteristics of the ADC will define the resolution that may be achieved and the rate at which the various channels

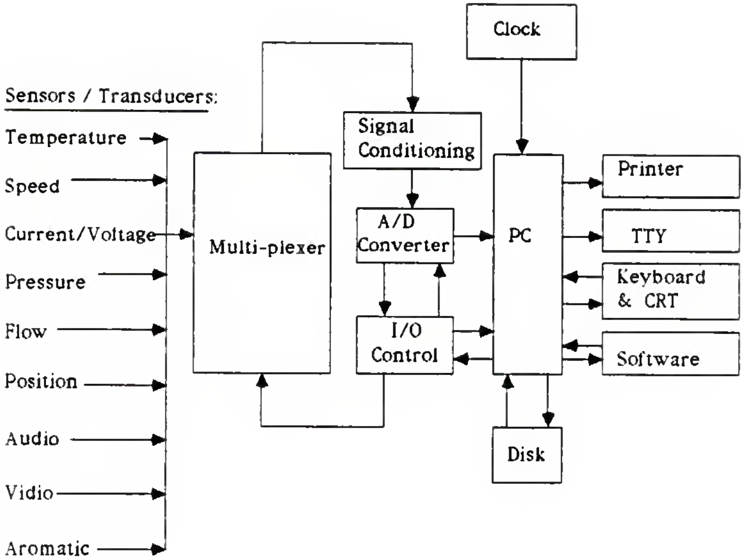


Figure 2.4 Interface Configuration Between Sensors and PC

can be sampled. The equipment for testing ADC is more difficult than for testing DAC. This is due to the fact that an ADC has as its input a continuous range of analog values [3].

Sensors/transducers can take data from the real world and put them into the computer through a data acquisition and computer interface system. Figure 2.5 shows another block diagram for sensing and controlling a physical process with a microcomputer-based system.

Data acquisition software works with the hardware interface equipment to take advantage of the computer system. A standard microcomputer serial communications port can be chosen for interfacing convenience. One has to consider some factors before selecting an appropriate interface system such as resolution, accuracy, types of input, etc.

Very often the signals presented to the inputs of the DAS are not in a form appropriate for conversion, and so they must be preconditioned. To interface those sensors with the DAS in this report, a voltage follower is always necessary in the path for input and output protection. Figure 2.6 illustrates a block diagram of a sensor/transducer output signal that has been conditioned into a standard form to be interfaced with the DAS. Chapter 3, Paragraph 1 will discuss this further. The signal

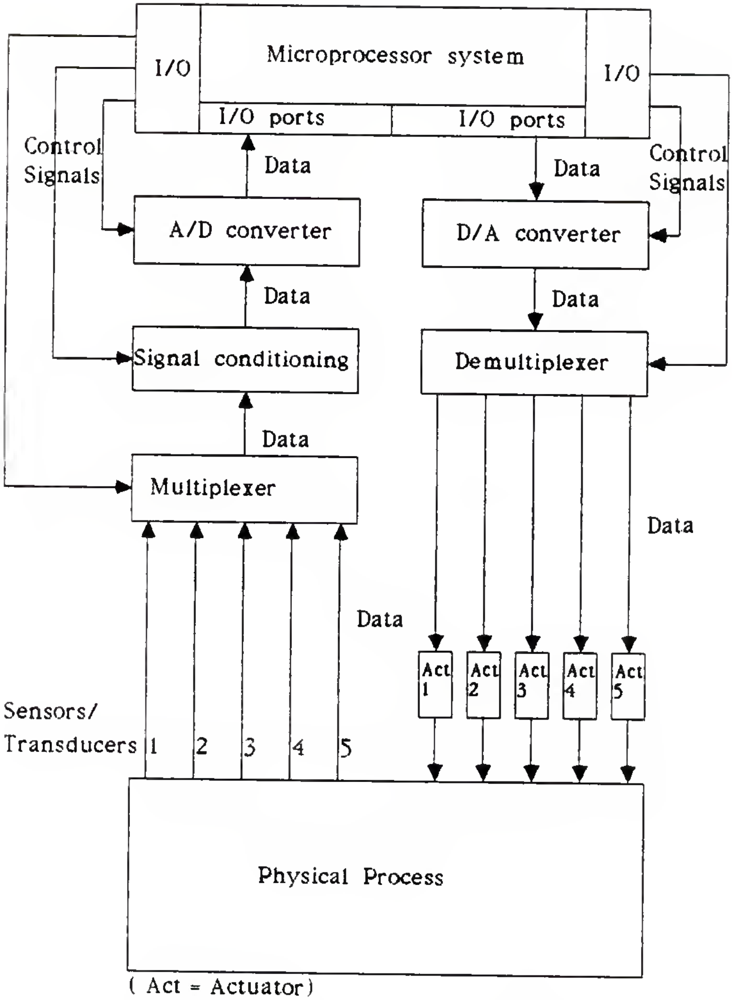


Figure 2.5 Block Diagram of Multiple Input - Multiple Output Microprocessor Based System

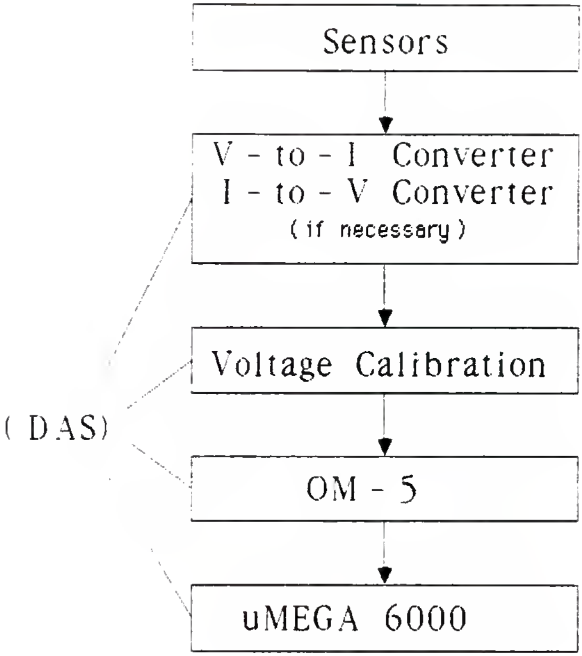


Figure 2.6 Block Diagram of Sensors Interfacing with DAS

conditioning and multiplexer is found in the OMEGA OM-5 Series Modular Signal Conditioner [10] (see Chapter 3, Paragraph 2). This series of signal conditioners is appropriate for use with the uMEGA 6000 Model [10] which contains the ADC, DAC, and digital/analog I/O control (see Chapter 3, Paragraph 2). The DAS is composed of the OMEGA OM-5 and uMEGA 6000. Note that the DAS will accept inputs from other sensors in the system as well. The outputs of this DAS will be inputted into the IBM-PC host computer, which will analyze these signals and control the process accordingly through a feedback network.

2.6 Gas Chromatography (GC)

The sensor/transducers #17 and #19 in Figure 2.3 are used to measure the aroma of the material and product. A complex chemical technology called gas chromatography can be appropriately used here.

Chromatography is a collective name of all separation processes where the separation of the compounds is effected by their partition (different absorption) between a stationary (fixed) phase with a large surface and a moving phase which flows first. Chromatographic methods have been developed for analytical purposes to study certain complex natural and synthetic substances. Besides their analytical applications, chromatographic methods have gained increasing importance in the solution of other problems, such as the preparation of pure substances, determination of chemical constants, reaction kinetic studies, investigation of molecular structures, and etc. [7].

In general, every gas chromatography technique consists essentially of six components:

1. Carrier gas system
2. Sampling device
3. Column
4. Oven
5. Detector
6. Recording and evaluating system.

Figure 2.7 illustrates the block diagram of a gas chromatography system. The operation of the apparatus can be summed up briefly as follows.

A gas stream, the so-called carrier gas, is fed into the column at a constant rate. The sample under investigation is injected into the carrier gas stream and reaches the column together with the carrier gas. In the column the components of the sample travel in the direction of the gas flow with different velocities depending on their binding to the stationary phase. If the velocities of each compound differ enough for the sample being tested and the

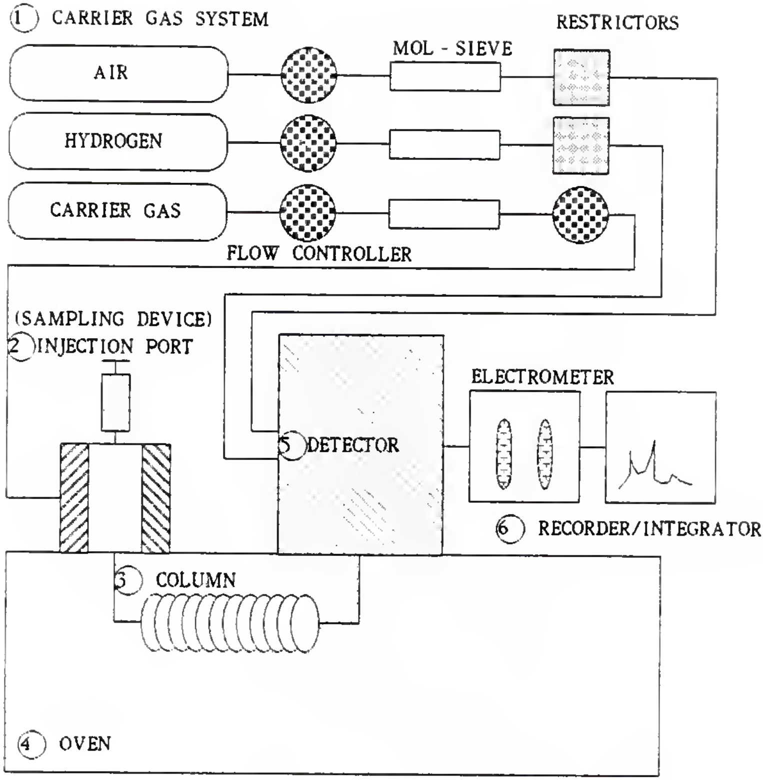


Figure 2.7 Block Diagram of a Gas Chromatography System

column is sufficiently long, the components of the sample will be completely separated and will appear in succession in the emerging carrier gas. The carrier gas emerging from the column is fed through the detector which produces a signal proportional to the quantity of each component within the original sample. By plotting or by electronically recording the signals from the detector, a chromatogram characteristic of the actual sample separation is obtained.

This simple separation of a mixture containing volatile materials is achieved as the compounds, which are contained in a tube, are partitioned between a stationary solvent that is coated on a fixed surface and a continuously flowing carrier gas. When the system is at a temperature such that the materials to be separated are in the vapor phase, molecular activity is very rapid and high resolution separation can be achieved. The carrier gas should not be inert, like nitrogen, helium, hydrogen, or argon. The sample may be introduced as either a liquid or a gas. Most often in a laboratory setting, samples are introduced through a rubber septum with a hypodermic needle [7].

The heart of the GC system is the chromatographic column. The two most widely used columns are the packed and the capillary kinds. The stationary solvents are used for particular separations. Solvents should be chemically inert. It is very important that they do not react with or alter either the sample or solvent. They should have a relatively high boiling point and be stable at the operational temperatures.

Temperature is a critical parameter for chromatographic separation. A slight change in column temperature will alter the retention time or the time necessary for a separation. The oven must be carefully controlled and monitored. Separation on the column is of little value unless the effluent from the column can be monitored. The most widely used detector today is the flame ionization detector (FID). The FID detects organic compounds in either N_2 or He gas streams from the column by burning the compound in a H_2 flame. This produces thermal ionization which can be measured by collecting the ions on a grid, converting, and amplifying that small electrical signal to drive a millivolt recorder. The FID is sensitive over a wide range of concentrations.

Most modern GC instruments have data processing capabilities such as: peak areas, heights, area percentage, concentrations from internal standard curve data, etc. Below are several methods used to identify GC peaks:

(1) Retention time - not very reliable;

(2) Plot retention time vs. number of carbons in a homologous series -- on semilog paper. There is a linear relationship;

(3) Subtractive techniques -- selective reagents can react with and alter retention times;

(4) Mass spectrometry -- an elegant but expensive method;

(5) Infra-red or spectral analyses of separated compounds;

(6) Separation on more than one column.

A (differential) chromatogram can be considered as the plot of the concentration of a substance in the effluent against the time that has elapsed since the introduction of that substance into the column. The differential plot is represented by the total amount response (mV vs. time).

CHAPTER 3

HARDWARE SPECIFICATIONS

3.0 Introduction

This chapter discusses the following points:

1. The hardware specification of each sensor/transducer used in the report;
2. Interfacing the output of sensors/transducers to the host computer;
3. The hardware specification of the data acquisition system;
4. The hardware specification of gas chromatography.

The number associated with each of the sensors/transducers below are the same as those used in Figure 2.3.

3.1 Sensor / Transducer

(1) Level Detector

The level detector discussed in Chapter 2, Paragraph 5 is located at the output of the mixer distributor. The proper mounting location should allow the measured material to flow freely both to and away from the level indicator paddle and shaft. The LV-1000 Series dry-level switch [8] has been selected as an appropriate level detector for this purpose.

The physical specifications of this level detector are as follows:

Electrical Motor: 110 VAC, 50/60 Hz, 4 amps.;

Relays: DPDT, 20 amps at 120/240 VAC, 10 amps @ 480/600 VAC;

Power Consumption: 4 Watts;

Ambient Operating Temperature: -30°F to 160°F;

Characteristics:

- High and low level control;
- Top and side mount models available for most dry material level applications;
- Fail-safe operation and alarm;
- Available with weatherproof or explosion proof enclosure construction;
- Units available with rugged 110V or 220V motors.

Price Range: From $220.00 to $257.00;

Figure 3.1 shows the block diagram of the data acquisition system required to detect and measure the outputs of the level detector and to condition these signals so that they will be appropriate for analysis by the host computer. The electro-mechanical interface is required since the output of the level detector is a relay (DPDT, rated at 20 amps @ 120/240 VAC). This interface outputs

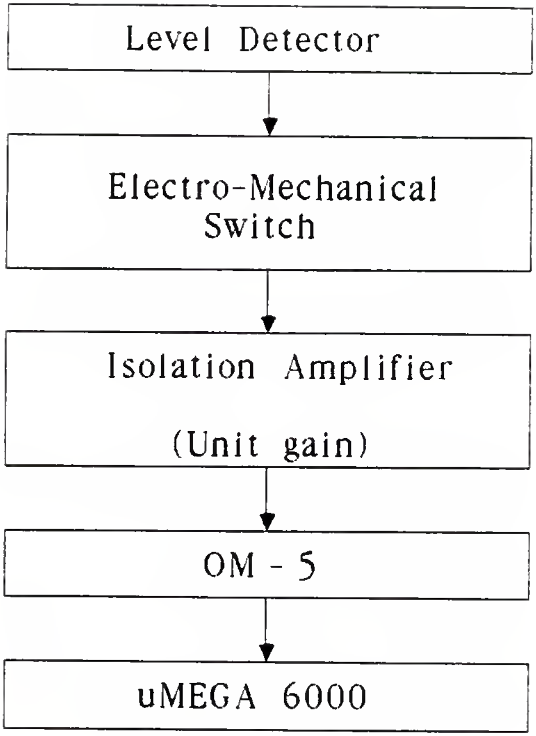


Figure 3.1 Block Diagram of Level Detector Interface

either a high signal (+5 VDC) or a low signal (ground) depending on the relay position.

That is, when the level of the dry meal reaches or exceeds the trigger level of the detector, the DPDT relay switch output will go "high", because the meal stops the paddle and shaft from rotating thereby causing the capacitor to discharge and relay coil to become deenergized. This causes the spring to pull the mechanical switch to the +5 VDC position (see Figure 3.2). This signifies a high output to the unit gain isolation amplifier connected to the interface. When the dry meal is below the trigger level, then the DPDT relay switch output will be "low" because the capacitor remains charged and the relay coil pulls the switch to electrical ground. The unit gain amplifier will recognize this low output as 0 V.

The subsequent work for interfacing the signal from the voltage follower to signal conditional OM-5 has been discussed in Chapter 2, Paragraph 5.

(2) Feeder Tachometer Meter

The tachometer is used to measure the meal flow rate of the feeder. The typical speed of the feeder is around 30 rpm and its range is between 0 and 50 rpm. The analog tachometer, which is offered by Renco Corporation (Rencotach

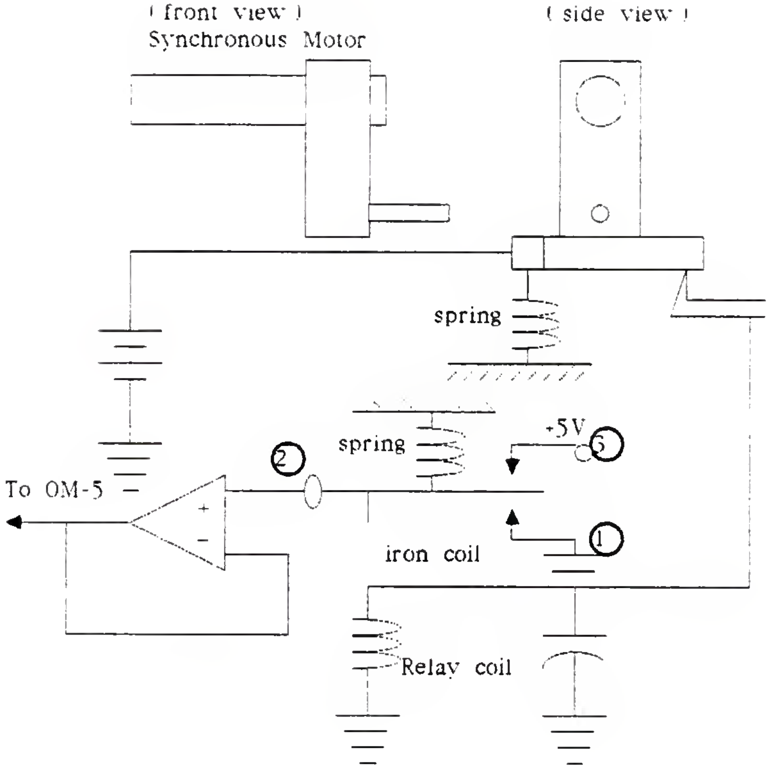


Figure 3.2 The Electromechanical Switch Interface

I) [9], can be used here. Its specifications are listed below:

Mechanical

Height: 2.50 inches maximum;

Moment of Inertia: 5×10^{-4} oz-in-sec^2 minimum;

Electrical

Analog Output: +10 VDC maximum;

Output Gradient: 1 V/1K rpm to 10 V/1K rpm;

Ripple: < 10 mV @ 8 KHz;

Linearity: +1%;

Input Power: +15 V @ 150 mA, -15 V @ 30 mA;

Environmental

Operating temp.: 0^{o}C to $+50^{o}$C;

Storage temp.: -30^{o} C to $+90^{o}$C:

Humidity: 90% relative, noncondensing;

Figure 3.3 shows the block diagram of the data acquisition system required to detect and measure the output of the feeder tachometer and to condition this signal so that it will be appropriate for analysis by the host computer. The maximum output of the tachometer meter is +10 VDC. It matches the range of operation of the sample and hold OM-5 [10] (see Chapter 3, Paragraph 2). The peak detector or voltage divider is not required for the data acquisition system.

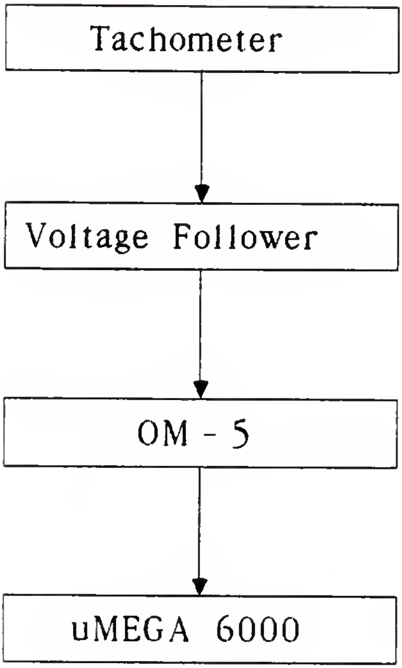


Figure 3.3 Block Diagram of Tachometer Interface

(3) Water Flow Rate Sensor (Input Wet Mixer)

The water flow rate sensor monitors the water that flows into the wet mixer. The OMEGA FP-5300 Series [8] industrial flowmeter is appropriate for this application. It is an electromechanical volumetric flow transducer which generates a sine-wave voltage output with frequency and amplitude linearly proportional to the rotor rotational velocity. Liquid flow rotates four permanent magnets past a coil, inducing an AC voltage proportional to this rotational rate. The sensor's specifications are:

Output Signal: Sine wave, 1 V (peak-to-peak) per ft/sec;

Output Frequency: 5-6 Hz per ft/sec;

Source Impedance: 8 Kohms;

Range: 1 - 50 FPS;

linearity: ± full scale;

Accuracy: ±1% full scale;

Repeatability: ±0.5% full scale;

Maximum Pressure: 200 PSIG max at 68°F (20°C);

Maximum Temperature: Polyvinyl Chloride (PVC) 140°F max @ 25 PSIG;

Maximum Percentage of Solids: 1% of fluid volume;

Pressure Drop: Equal to 8 ft straight pipe;

Material: Transducer Housing: glass-filled polypropylene;

O-Rings: Viton;

Shaft: Titanium; PVDF opt.

Rotor: PVDF;

Cable Length: 25 ft can be extended with copper wire to 200 ft;

Price: $160.00.

Characteristics:

- For liquids;
- Low pressure drop;
- Range: 1 to 50 FPS;
- Inert to most acids and bases;
- ±1% sensor accuracy;
- Easy to install and maintain;
- All plastic design available.

Figure 3.4 shows the block diagram of the data acquisition system required to detect and measure the output of the flow meter and to condition this signal so that it will be appropriate for analysis by the host computer. The voltage followers present before and after the voltage divider serve as input and output protection against subsequent circuit loading. Since the maximum water flow range is 2 GPM, we may get the corresponding output voltage. The maximum voltage output of the flow meter is calculated

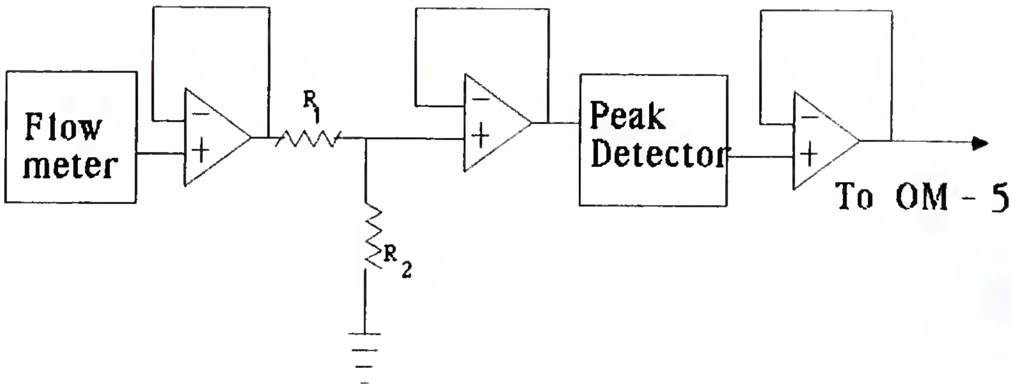


Figure 3.4 Block Diagram of Flowmeter Interface

to be 39.216 V and the range of operation of the sample-and-hold (S/H) circuitry is ±10 V (see Chapter 3, Paragraph 2), the voltage divider is required to "step-down" the output voltage to the appropriate range. The range of R_1 can be chosen to be $3R_2$ for this purpose.

The peak detector is required to: (1) detect the peak amplitudes of the flow meter output, and (2) to change this output signal, which is AC, to DC. The circuit schematics for the peak detector is shown in Figure 3.5.

The ADC and multiplexer are the same as those found in Paragraph 3.1, the OM-5 signal conditioner is also equipped with the S/H circuitry required here.

(4) Steam Pressure Sensor (Input Wet Mixer)

The OMEGA PX880 Series [12] can be used to monitor the steam pressure. Its specifications are listed below:

Excitation: 12 to 48 VDC with reverse polarity protection;

Output: 4 to 20 mA;

Loop Resistance: 600 ohms /24 VDC;

Accuracy: ±0.5% of calibrated span (includes linearity, hysteresis, and repeatability);

Response Time: 20 ms;

Turndown: 5:1 ratio;

Stability: ±0.5% of upper range limit for six months;

Compensated Temperature Range: -20^{o} to 180^{o}F;

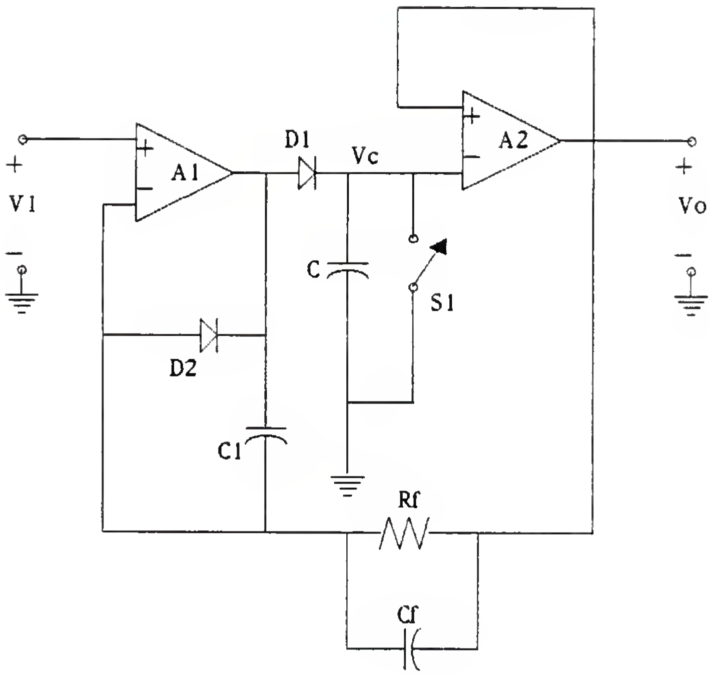


Figure 3.5 Schematic Circuitry of Peak Detector

Operable Temperature Range: -40° to $212^{\circ}F$;

Storage Temperature: -40° to $212^{\circ}F$;

Overrange: 200% upper range limit;

Humidity Limit: 0 to 100% relative humidity (RH);

Process Connection: 1/2 national pipe thread (NPT) female;

Electrical Connection: 1/2 NPT female;

Body Material: 316 stainless steel (SS);

Wetted Parts: 316 SS;

Fill Fluid: DC 200 silicone oil;

Weight: 1.67 lb.

Price Range: From $466.00 to $495.00.

Figure 3.6 shows the block diagram of the data acquisition system required to detect and measure the output of the steam pressure sensor and to condition this signal so that it will be appropriate for analysis by the host computer. Since the output range of this steam pressure transducer is from 4 to 20 mA, it should be converted to the voltage level that the DAS can use appropriately. A current-to-voltage converter can be used here. Figure 3.7 shows a good way to convert current to voltage while holding the input strictly at ground. This particular circuit has an output of 1 volt per milliampere of input current. The range of this converter output should be from 4 V to 20 V. The voltage divider is required to

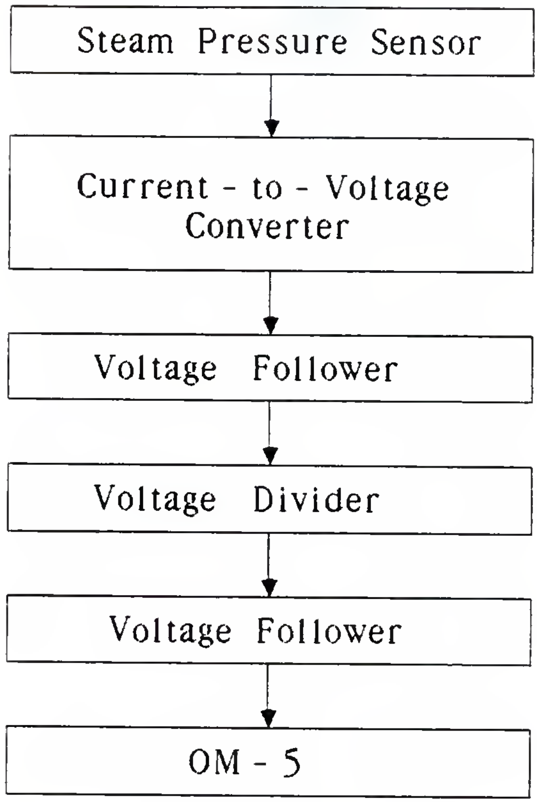


Figure 3.6 Block Diagram of Steam Pressure Sensor Interface

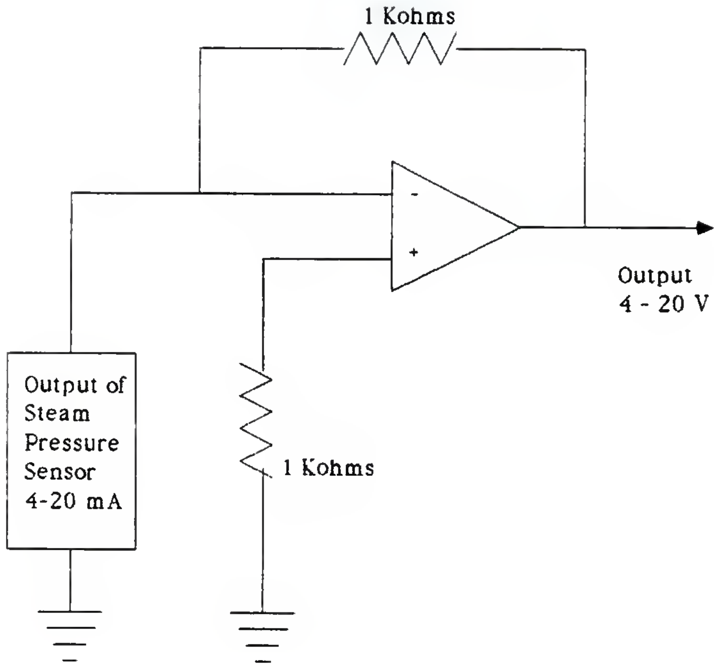


Figure 3.7 Schematic Circuitry of Current-to-Voltage Converter

step down the output voltage to the appropriate range ($\pm$ 10 V). The value of R_1 can be chosen to be the same as R_2 to get the proper range. The voltage followers are also needed before and after the voltage divider to serve as input and output protection against subsequent circuit loading.

(5) Wet Meal Temperature Sensor

The temperature sensor is located at the output of the wet mixer. The temperature at this point in the process should be controlled between 200^{o}F and 210^{o}F. The OMEGA 88000 Series probes [13] are normally supplied with a retractable sensor cable with lengths ranging from 1 to 5 ft. These cables are rated to 220^{o}F. The 6 ft. FEP Teflon coated lead wires, rated to 500^{o}F, are also available. The Series 88000 probes are offered in the thermocouple calibrations K (Chromel-Alumel) and E (Chromel-Constantan).

<u>Price Range</u>: From $110.00 to $200.00.

<u>Thermocouple Output Voltage</u>

K Type: 3.819 mV @ 200^{o}F;
4.049 mV @ 210^{o}F;

E Type: 5.869 mV @ 200^{o}F;
6.242 mV @ 210^{o}F;

Figure 3.8 shows the block diagram of the data

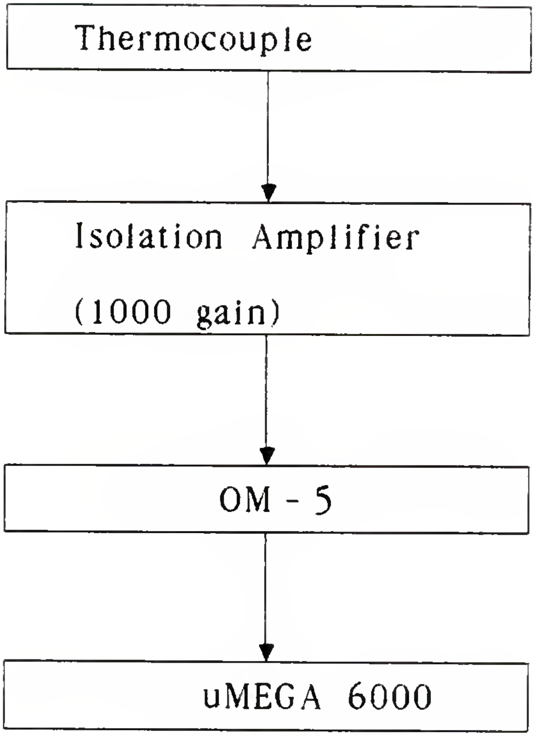


Figure 3.8 Block Diagram of Thermocouple Interface

acquisition system required to detect and measure the output of the thermocouple and to condition this signal so that it will be appropriate for analysis by the host computer. The maximum output of the thermocouple is less than 7 mV. In order to get more accurate results, the high gain (around 1000 gain) isolation amplifier is necessary here. Figure 3.9 shows a noninverting amplifier. The input impedance is infinite (with a 741 op amp integrated circuit chip it would be hundreds of megohms). The op amp's output impedance is between 50 and 500 ohms.

(6) Wet Meal Level Sensor

This level sensor listed in (1) may also be used for this purpose. The method for interface is also the same as sensor #1.

(7) Extruder Induction Motor Current Sensor (Read Only)

A current sensor can be set to detect the magnitude of the current. The Series MV - Lightweight Shunts MVB 170 - 50 (parts no.: 91587-1) [9] offered by Electronic Precision Components can be appropriately used here.

Figure 3.10 shows the block diagram of the data acquisition system required to detect and measure the output of the current sensor and to condition this signal so that it will be appropriate for analysis by the host

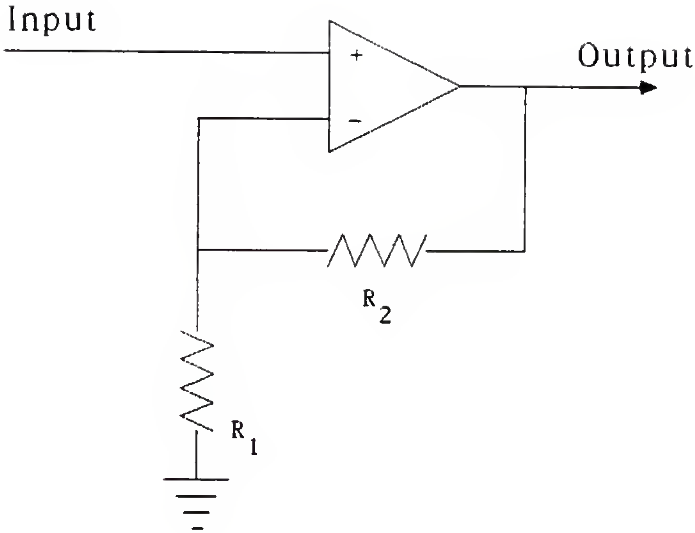


Figure 3.9 Schematic Diagram of Non-inverting Amplifier

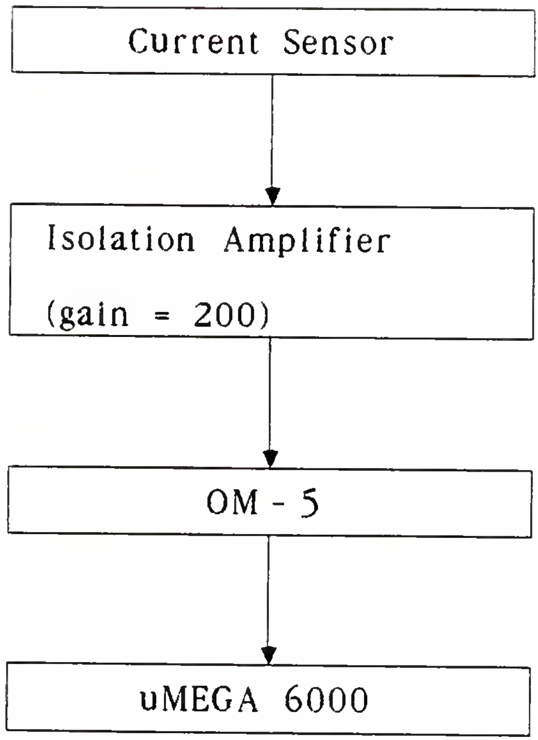


Figure 3.10 Block Diagram of Current Sensor Interface

computer. The maximum output of the current sensor is 50 mV corresponding to the maximum input 170 A. In order to get more accurate results, a high-gain (around 200 gain) isolation amplifier is necessary here. The noninverting amplifier circuitry is similar to Figure 3.9.

(8) Water Flow-Rate and Temperature Sensor

This temperature sensor should be put on jacket #1 to detect the temperature at this location. The temperature range to be measured is between 80° and 90°F. This temperature sensor could be the same as the one which was discussed in (5). The interface method is the same as for sensor #5.

Thermocouple Output Voltage

K Type: 1.068 mV at 80°F;
1.294 mV at 90°F;

E Type: 1.597 mV at 80°F;
1.937 mV at 90°F;

The flowmeter sensor used to detect the water flow rate here could be the same as the one in (3) which is the OMEGA FP-5300 Series. The interface method would also be the same as before.

(9) Water Flow-Rate and Temperature Sensor

This temperature sensor should be put on jackets #2 through #5 to detect the temperature at these locations.

The temperature range encountered is between 140° and 175°F. This sensor could be the same as (8). The interface method would be the same as before.

<u>Thermocouple Output Voltage</u>

K Type: 2.436 mV at 140°F;

3.243 mV at 175°F;

E Type: 3.683 mV at 140°F;

4.947 mV at 175°F;

The flowmeter sensor and its interface method could be the same as (8).

(10) Die Pressure Cooked-Product Transducers

This pressure sensor is located at the output of the extruder to measure the product pressure at the die. The OMEGA PX620 Series High Accuracy Pressure Sensors [12] chosen incorporate an optical means of detecting the effective pressure of an elastic member. There is no physical contact between the strained member and the portion that produces the electrical signal. This unique pressure sensor offers extreme accuracy and repeatability. Specifications for the PX620 Series are:

<u>Excitation</u>: 12 to 40 VDC, reverse polarity protected;

<u>Output</u>: 4 to 20 mA;

Sensitivity: Better than 0.005% of span;

Accuracy: Model PX621: ±0.15% of span, including linearity, sensitivity, hysteresis, and repeatability at 73°F; Model PX623: ±0.10% of span;

Response Time: 3 msec;

Repeatability: Better than 0.005% of span;

Compensated: Model PX621: 0° to 150°F, Model PX623: 0 to 180°F;

Temperature Effect: Model PX621: ±0.02% of span/°F over temp. compensated range; Model PX623; ±0.004% of span/°F over temperature compensated range;

Overpressure Limit: 100% of span to 500 PSI; 30% of span to 7,500 PSI; 20% of span to 10,000 PSI;

Pressure Sensor: Non-contacting optical pressure sensor measuring motion of diaphragm or Bourdon tube element;

Process Connection: 1/4" NPT female - 1/2" NPT male combination for pressure ranges through 5,000 psi;

Electronic housing: Aluminum cover, epoxy finish with circular electrical connector. Mating connector included;

Wetted Parts: Element-Inconel 718 Optional-403 Ss or 410 SS;

Other Wetted Parts: 316 SS;

Price: $520.00.

Figure 3.11 shows the block diagram of the data acquisition system required to detect and measure the output of the cooked product die pressure transducer and to condition this signal so that it will be appropriate for analysis by the host computer. The output range of this transducer is from 4 to 20 mA. This is the same as sensor #4 that was discussed before. The subsequent design of the interface would be the same as before.

(11) Cooked-Product Die Temperature Sensor

This temperature sensor is located at the die to measure the temperature of the cooked product. Omega's rugged Spring-Loaded Bayonet and Compression-Fitting (CF) Thermocouples [13] are ideally suited for measuring machinery temperatures at the crosshead, die, and barrel. The maximum length for armored cable is 40 feet (5 feet is standard). The CF series thermocouples are available in four thermocouple calibrations: J (Copper-Nickel); K (Chromel-Alumel); T (Copper-Constantan); and E (Chromel-Constantan).

Price Range: Thermocouples, from $21.00 to $25.00; Thermocouple Extension Cable Assemblies, $17.00.

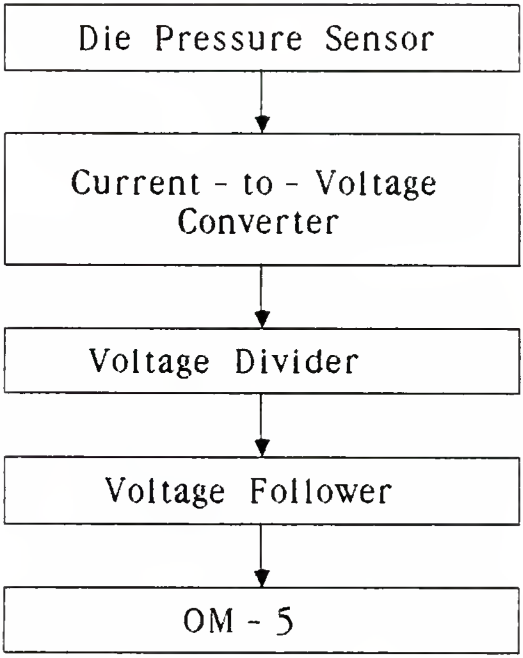


Figure 3.11 Block Diagram of Die Pressure Sensor Interface

The temperature range or output product is from 250^{o}F to 300^{o}F. The interface design would be the same as for sensor #5. Since the maximum voltage output of this thermocouple is still less than 10 mV, the high gain isolation amplifier which has been discussed in (5) also can be used here.

<u>Thermocouple Output Voltage</u>

J Type: 6.420 mV at 250^{o}F;
        7.947 mV at 300^{o}F;

k Type: 4.964 mV at 250^{o}F;
        6.092 mV at 300^{o}F;

T Type: 5.281 mV at 250^{o}F;
        6.647 mV at 300^{o}F;

E Type: 7.760 mV at 250^{o}F;
        9.708 mV at 300^{o}F;

(12) Cut-off Knife Tachometer

This tachometer is used to measure the speed of the knife that cuts the rope being extruded from the die. The typical rotational speed of this knife is around 2500 rpm. Its rotational speed can be varied between 0 to 4000 rpm. As such, the tachometer used in (2) cannot be used here. Instead, the analog tachometer, offered by Renco Corporation (Rencotach I), should be used. Its specifications are listed below:

Mechanical

Height: .84 inches maximum;

Moment of Inertia: 3.2 x 10^{-5} oz-in-sec^2 minimum;

Electrical

Analog Output: 1 VDC/1K rpm; .05 - 10 VDC;

Digital Output: 60 PPR, 15 V square wave output @ 4.7 Kohms impedance;

Ripple: 20 mV @ 1 KHz;

Linearity: +0.1%;

Input Power: +15 V @ 15 mA, -15 V @ 10 mA;

Environmental

Operating temp.: 0^oC to $+70^oC$;

Storage temp.: -30^oC to $+90^oC$;

Humidity: 95% relative, noncondensing;

Though the tachometer meter used here is different from sensor #2, the analog output of the two is the same. The interface design which was discussed in (2) should also be used here. It should be interfaced to the OM-5 Series directly.

(13) Product / Moisture Sensor

This sensor is used to detect the relative humidity of the product. The probe RH-30 Series [13] offered by OMEGA can be used for this application. This ultra-sensitive composite sensor element is composed of temperature/humidity sensors formed into a single unit. The built-in digital display is accurate to $\pm 0.3^\circ F$ ($0.6^\circ F$) and $\pm 3\%$ RH. The following are its specifications:

Range: 0 to 99.9% RH; -10 to $60^\circ C$ (14° to $140^\circ F$);

Accuracy: $\pm 3\%$ RH at $25^\circ C$ ($77^\circ F$); 0 to 90% RH; $\pm 0.3^\circ C$ ($\pm 0.6^\circ F$) at 18° to $28^\circ C$ ambient temperature; $\pm 0.5^\circ C$ at other temperatures;

Temperature Sensor: platinum resistance thermometer (RTD);

Humidity Sensor:electrostatic capacitance type polymer-film;

Resolution: $0.1^\circ C$ ($0.1^\circ F$); 0.1% RH;

Price Range: From $210.00 to $336.00.

The probes of the OMEGA RH-30 Humidity Series are completely interchangeable through a connector base and cover a board range of applications in grains. The electrical output of these probes is either a current or a voltage which can be measured. In general, the electrical output signal is very low. A voltage follower is necessary to get enough gain.

(14) Meal / Optical Sensor

In order to grade the meal based on its color, an image processor could be used. The series 151 Image Processor, produced by Imaging Technology Inc., provides a complete image processing system for applications requiring real-time image operations. Please see Appendix A for its specification.

A video signal multiplexer on the ADI-151 module allows the Series 150 the capacity to acquire and process image data from up to four different video sources or sensing devices. Thus, this sensor can also be used on (16) and (20).

The image processor has its own central processing unit (CPU) because image processing is data processing intensive. Therefore it may not be feasible to interface this processor with the computer which controls the entire process.

(15) Dry Meal / Moisture Sensor

This sensor is located before the preconditioner and is used to detect the humidity of the dry meal. The sensor for this purpose could be the same as the one used in (13). The interface design would be the same as before.

(16) Steam Optical Sensor

This steam optical sensor is located between the preconditioner and the extruder to detect steam leakage. This sensor measures the steam density and/or the moisture content in the air. The suggested image processor in (13) could be used here.

(17) Aroma / Gas Chromatograph

The aroma detector is located at the same location as (16) to measure the components of the aroma there. A gas chromatography process can be used here. The principle of gas chromatography was discussed in Chapter 2, Paragraph 6.

Rather than connecting to a recorder or an integrator, the analog signal coming out of the GC oven can be connected to the host computer through a data acquisition system. The assumption is that the standard data has been collected and stored in the host computer. When the new data is fed into the host computer, they should be compared with the standard data.

The analog output voltage range of the GC oven is from 0 to 1 V. This can be interfaced to the OM-5 Series directly through a unit gain isolation amplifier.

(18) Audio

The audio sensor is used to detect the grinding noise emanating from the extruder barrel. The audio sensor signal of the grinding noise is passed through a low-pass filter with a cut-off frequency of 10 KHz. Thus frequencies of this signal above 10 KHz are suppressed. It is assumed that the grinding noise signal frequencies that pass through the low-pass filter have a Gaussian distribution. Then to get a root-mean-square (rms) voltage of this Gaussian noise signal, multiply this rms value by 1.13. Figure 3.12 shows the block diagram of the data acquisition system required to detect and quantify the audio signal presented at the extruder and to condition this signal so that it will be appropriate for analysis by the host computer.

The basic component of this sensor is a microphone. An omni-directional type of microphone produced by H & R Corporation, product number TM24K330, can be used. The microphone's specifications are:

Sensitivity: 66 dB $\pm$3 dB;

Frequency Response: 50 Hz to 13 kHz;

Signal to Noise Ratio: > 40 dB;

Maximum SPL: 130 dB;

Impedance: 150 ohms;

Operating Voltage: 1.5 - 10 VDC; 0.7 mA;

Price: $2.75;

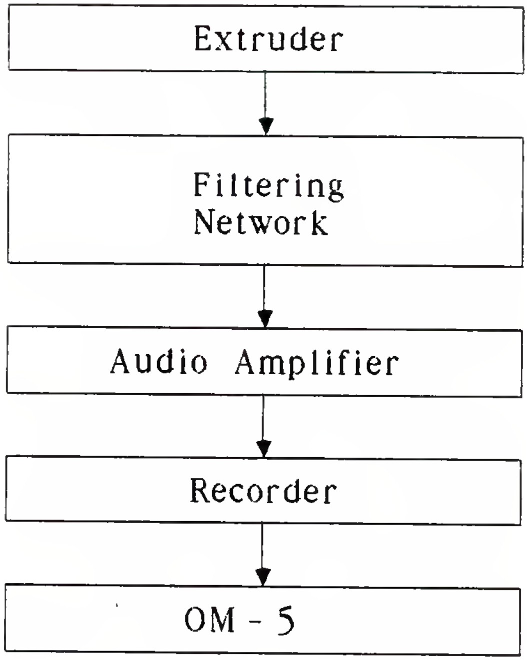


Figure 3.12 Block Diagram of Audio Sensor Interface

The microphone selected is a miniature electrical condenser style, model number TM24K329, manufactured by H & R Corporation, Philadephia, PA. Though this microphone offers high sensitivity, it still needs to be placed in close proximity to the extruder for best reception of the grinding noise.

The audio amplifier is required to amplify the audio signals detected by the microphone so they will be recognized by the S/H and the ADC. The S/H, ADC, and the multiplexer are of the same system discussed in Chapter 3, Paragraph 2. The filtering network is necessary to block or screen out undesirable ambient acoustical components of the detected sound.

(19) Aroma / Gas Chromatograph

The aroma sensor is used to detect the aroma of output product. It is located at the output of the die. A gas chromatography process can be used here. Please see Chapter 3, Gas Chromatography paragraph, for more detail. The method and principle are the same as for sensor #17.

(20) Product / Optical Sensor

This optical sensor is located at the output of the die to be used to grade the product quality. The product's quality depends on its color and shape. The suggested image processor in (13) would also be used here. The products color and shape will need to be analyzed separately.

3.2 Data Acquisition System

The uMEGA 6000 Data Acquisition Model is designed to be very flexible and field expandable [10]. It can be used as a stand-alone system in communication with an operator console, or as a data acquisition system working with a host computer. Each analog input/output module can be removed and changed with a single screw, without upsetting any wiring interface. The uMEGA 6000 is programmable in either BASIC or C. This model combines the ease-of-use of the BASIC language with powerful procedures and functions, keywords for all I/O functions and interrupt servicing for real time response. The C language provides high performance, fast speed, and utilizes a standard programming language with special functions for the uMEGA 6000. The following are the specifications for the uMEGA 6000:

CPU

Microprocessor: Intel 80188, 16 bit, 8 MHz;

RAM: 256 Kbytes, battery backup;

Rom: 196 Kbytes total; 64 K user (in BASIC), 128 K (in C);

EPROM: 1 Kbytes system, 1 Kbytes user:

Clock: 30 sec/month accuracy, battery backup;

Battery Life: 6 months, continuous;

Analog-to-Digital Converter Resolution: 0.006% (14-bit);

Analog-to-Digital Converter Accuracy: 0.02% (12bit);

A/D Conversion Time: 35 us (12-bit); 220 us (14-bit); software add approx. 1ms in uMegabasic;

Digital-to-Analog Conversion Resolution: 0.006%;

Communication Ports: dual RS-232-C, single RS-422/485, single IEEE-488.

ENVIRONMENTAL

Operating Temperature: 32° to 140° F (0° to 60° C);

Storage Temperature: $-13^{\circ}$to 185°F (-20° to 85° C);

Relative Humidity: 5 to 95%, noncondensing.

POWER

Input power Voltage: 5 VDC, -3 to +5%;

CPU: 8.0 W consumption;

Analog Input Modules: 0.2 W consumption, typical;

Analog Output Modules: 0.7 W consumption, typical;

Solid State Relay Modules: 0.25 W consumption, typical.

ANALOG/DIGITAL OUTPUT

Number of Channels: 24; 56 with expander;

Isolation: 1500 V, input to output; 6000-ASBP limits to 750 V channel to channel; 6000-AMUX supports the full 1500 V;

Accuracy: 0.05% of range;

Drift: 1 uV/°C;

Common Mode Rejection: 160 dB;

Normal Mode Rejection: 60 dB;

Differential Input Protection: 220 Vrms, continuous;

Input Resistance: 15 Megaohms;

Output Transient Protection: IEEE-472 (SWC);

Output Compliance: +5 VDC.

DIGITAL I/O

Number of Channels: 48, basic configuration; 256, expanded;

Signal Levels: TTL, inverted;

Solid State Relays; 4 channels per module;

SSR Isolation: 4000 V, input to output;

SSR Input Types: 10-32 VDC, 120 or 240 VAC, or 120/240 VAC, 5-60 VDC;

SSR Output Types: 120/240 VAC, 50 - 60 VDC;

SSR Output Current: 3 Amps;

Low speed Counter: 16 channels; 0 to 25 Hz speed, debounced; 0 to 4,294,967,296 count;

High Speed Counters: 2 channels; 0 to 1 MHz speed; 0 to

4,294,967,296 count; direct connection only; fast SSR limited to approx. 5kHz;

Frequency Inputs: 7 channels; 2 Hz to 1 MHz speed, auto-ranging; direct connection only; fast SSR limited to approx. 5 kHz;

Interrupts: 2 channels;

Time Proportional Outputs: 2 channels.

Price Range: From $3,000.00 to $3,500.00.

The uMEGA 6000 features full flexibility for both analog and digital inputs and outputs. In the report, there are at least 20 inputs and 7 control outputs to be used. A uMEGA 6000 can be configured in many ways to meet the needs of different applications. The basic system supports 24 channels of analog I/O, and can be expanded to 56 channels with an optional expansion backplane. Real-world interfacing is provided by OM-5 signal conditioning modules, which plug onto the backplane for both analog input (thermocouple, voltage, current) and output. The output current range of the OM-5 Series is from 0 to 20 mA or from 4 to 20 mA. The output voltage range of OM-5 is from -5 to +5 VDC. The specifications of OM5 series are listed below:

INPUT MODULES:

Input Types: Thermocouple, voltage;

Voltage Output: 0 to +5 VDC or -5 to +5 VDc;

Accuracy: ±0.05% of span;

Nonlinearity: ±0.02% of span;

Common Mode Voltage,Input to Output: ±1500V peak continuous;

Transient Protection: Meets IEEE-Std 472 (swc);

Common Mode Rejection @50 or 60 Hz: 160 dB;

Normal Mode Rejection @50 or 60 Hz: 60 dB;

Bandwidth: 4 Hz, normal; 10 K Hz, wideband;

Power consumption: 0.15 W (30 mA).

OUTPUT MODULES:

Input: 0 to +5 VDC or -5 to +5 VDC;

Output: 4 to 20 mA or 0 to 20 mA;

Load Resistance: 750 ohms at 4.95 V;

Accuracy: ±0.05% of span;

Nonlinearity: ±0.02% of span;

Common Mode Voltage,Input to Output: ±1500V peak continuous;

Current Output Protection, Transient: Meets IEEE-Std 4721;

Common Mode Rejection: 90 dB;

Input Resistance: 10 Megaohms;

power Consumption: 0.85 W (170 mA);

Bandwidth: 400 Hz.

MECHANICAL AND ENVIRONMENTAL:

Module Dimensions: 2.25" x 0.6';

Temperature Range, Rated Performance: -13° to 185° F;

Storage Temperature Range: -40° to 185° F;

RFI Susceptibility: $\pm$0.5% span error, 5 W @ 400 MHz @ 3 ft.

Price: $150.00 each;

Characteristics:

- rugged, compact, economical signal conditioning;
- Modular design for mix and match capability;
- Analog input Modules for sensors and analog voltage and current;
- $\pm$0.05% accuracy;
- Convenient connection to user equipment.

The uMEGA 6000 has advanced communications capabilities, with flexibility for a variety of configurations. Dual RS-232-C ports can be used for local peripheral interfacing, with an RS-422/485 high speed serial port available for multidrop communications, long distances, or electrically noisy environments. There is also an IEEE-488 parallel bus which can be used for communications to host computers or expansion processors and programmable instruments.

3.3 Gas Chromatograph

The HP 5890A is a gas chromatographic system manufactured by the Hewlett Packard Company. The general specification for the HP 5890A Gas Chromatograph is listed below:

Power Requirement:

Voltages: 120/200/220/240 VAC;

Range: +5, -10% each;

Frequency: 47.5 - 66 Hz;

Consumption: 2200 VA max.;

Output: 7500 BTU/hr max.

Environmental:

Operating range: 10^{o} - 40^{o} C ambient, 5 - 95% humidity;

Heated Device: Up to 4 heated zones;

Detectors: 2 maximum;

Inlets: 2 maximum.

Flow Sensor:

Range: 0-100sccm;

Accuracy: ±3 sccm for He and H_2;

±5 sccm for N_2 and $ArCH_4$;

Extended Range: 100 - 150 sccm;

Accuracy: ±15 sccm

[sccm = standard cc per minute].

Characteristics:

- Three-ramp temperature programmable oven;
- Two channels of baseline single column compensation;
- Power fail memory protection;
- Single analog output (-10 to 1 mV and 0 to 1 V);
- Control of four heated zones (injection ports, detectors and valves);
- Stopwatch function;
- Built-in diagnostics and comprehensive self-tests;
- 120 VAC, 50/60 Hz power supply with 20 amp line cord;
- Functional keyboard with alphanumeric display.

Price:

5890A Gas Chromatograph Mainframe: $5,300.00;

IRD detector: $420.00;

FID detector: $1,480.00;

Injection port: from $70.00 to $1,430.00;

RS-232-C interface board: $510.00;

Flow controller: $250.00 ($400.00 for two);

CHAPTER 4

CONTROL SIGNAL

4.0 Introduction

This chapter discusses the parameters that need to be controlled in the extrusion cooking process. In order to get good performance for the entire control system, these parameters must be monitored all the time. There are seven controllers used in this report and they will be discussed later.

The electrical signal outputs by the OM-5 Series are lower than 5 V. Thus, they cannot be used to implement the required control actions directly. The voltage output may not be suitable for operating the actuator and must be converted into a suitable energy form. External devices are therefore required to achieve the necessary conversions.

4.1 Equipment Location

In order to accurately control the process without extensive operator involvement, a controller is required. Any microcomputer-based control system requires that the data input from the process sensors be compared with the desired process corrective actions should be taken if the actual process output values are different from the desired ones. Thus, it might be necessary to close/open a valve, or decrease/increase the speed of a DC motor. Actuators are required to implement the necessary control action. A wide range of actuators is used in the automatic control industry.

To choose an appropriate controller, the main considerations include the necessary precision of control and the type of the control as discussed below.

The controllers presented in this report are used for controlling physical parameters. The locations of these controllers are shown in Figure 4.1. The various controllers and their applications are listed below.

(1) Field winding voltage controller -- meal flow rate;

(2) Water flow rate valve controller (input wet mixer);

(3) Steam valve controller (input wet mixer);

(4) Drive motor controller;

(5) Water flow rate valve controller -- jacket #1;

(6) Water flow rate valve controller -- jackets #2 - #5;

(7) Cut-off knife tachometer controller.

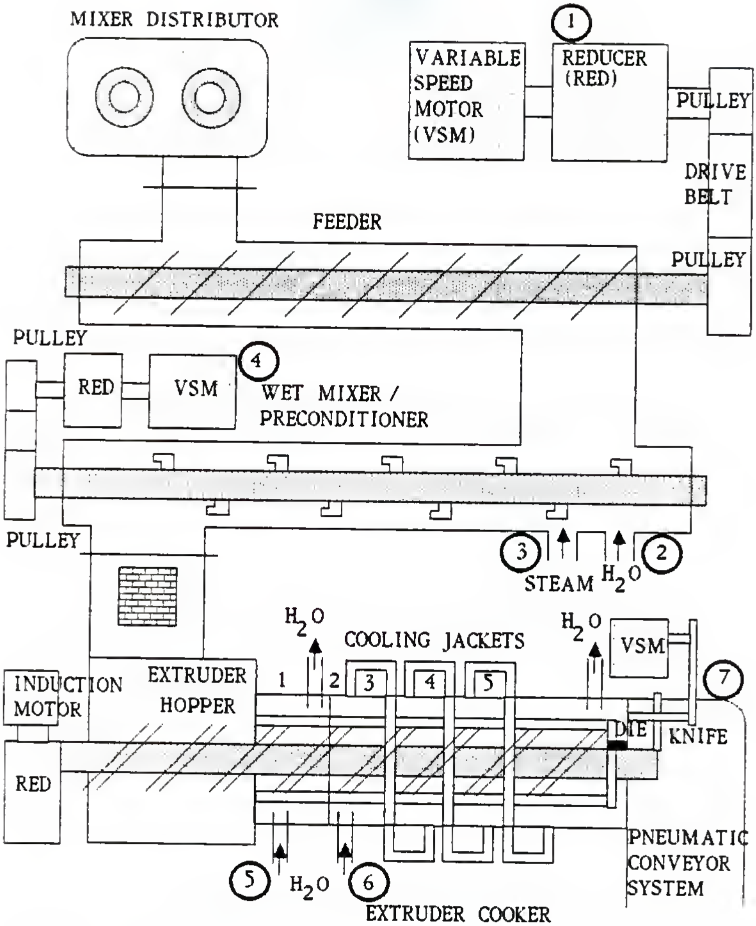


Figure 4.1 Configuration of Controller Locations in an Extrusion Process

4.2 Hardware Specification

(1) Field Winding Voltage Controller -- meal flow rate;

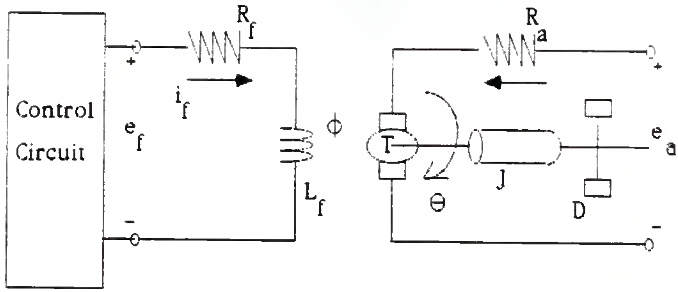
The DC motor linear model is shown in Figure 4.2. Figure 4.3 shows the block diagram of the control circuitry and the DC motor field winding which is the controller (actuator).

For a field-controlled motor, when e_f changes, i_f must change. If we restrict i_a to be a constant, then;

$$T = K_1 \, i_f; \ (K_1 \text{ is a constant})$$

Since the torque (T) of the DC motor is proportional to the field current (i_f), then so is the angular displacement of the motor shaft (Θ). Since a change in the field-winding voltage (e_f) or the field-winding current (i_f) controls the angular displacement of the motor shaft (Θ), the control circuitry design must control the field voltage of the DC motor.

Since the output voltage range of the OM-5 Series that was selected for the de-multiplexer output channel is from -5 V to 5 V, the DC power amplifier in Figure 4.3 is necessary to amplify the power of the control signal.



R_f : Field - Winding Resistance

L_f : Field - Winding Inductance

i_f : Field - Winding Current

e_f : Applied Field Voltage

R_a : Armature Resistance

i_a : Armature Current

e_a : Armature Voltage

T : Torque Developed by Motor
Φ : Air Gap Flux
Θ : Angular Displacement (OUTPUT)
J : Moment of Inertia of Motor and Load
D : Viscous Friction of Motor and Load

Figure 4.2 The DC Motor Linear Model

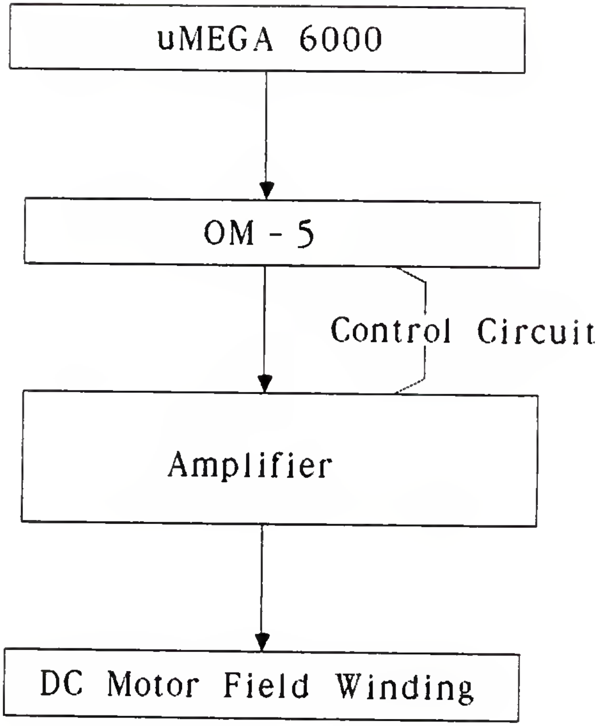


Figure 4.3 Block Diagram of the Control Circuit and the DC Motor Field Winding

(2) Water Flow Rate Valve Controller (input wet mixer)

The electric actuator, product number 253 offered by Jamesbury Company, can be used to control the water flow rate here. Figure 4.4 shows the block diagram of the data acquisition system required to control the water flow rate valve. The electric actuator can be controlled either by voltage or by current. Recall that the output voltage range of the OM-5 Series is from -5 V to +5 V. There are three trigger levels for controlling the valve. When the output of the OM-5 is +5 V, it will actuate the valve to fully open. When the output is -5 V, it will move the valve to completely closed. When the output is zero, it will stop the valve control. In order to attain enough power to actuate the actuator, a power amplifier is also necessary.

(3) Steam Valve Controller (input wet mixer)

The electric actuator selected in (2) can also be used here to control the steam valve. The principle and method are also the same.

(4) Drive Motor Controllers

This one is also a DC motor. The circuitry can be the same as the one shown in (1).

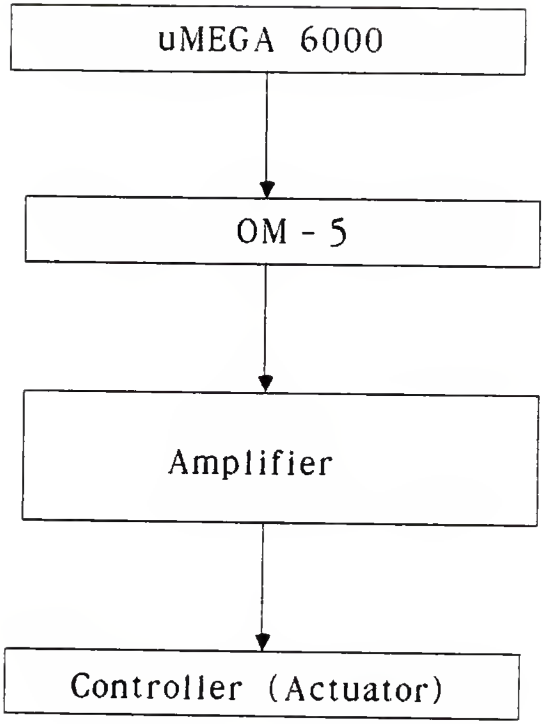


Figure 4.4 Block Diagram of the Controller Interface

(5) Water Flow Rate Valve Controller -- jacket #1

The water flow rate valve controller is used to handle the jacket #1 water flow for cooling. This controller could be the same as the one used in (2).

(6) Water Flow Rate Valve Controller -- jacket #2 To #5

The water flow rate valve controller is used to handle the jackets #2 through jacket #5 water flow for cooling. This controller could be the same as the one used in (2).

(7) Cut-off Knife Controller

This one is also a DC motor. The circuitry can be the same as the one discussed in (1).

CHAPTER 5

COMPUTER SOFTWARE

5.0 Introduction

Most conventional control systems simply consist of specialized hardware which is used to implement the required control actions usually based on the application of analog control techniques. These systems are necessarily restricted and inflexible.

The development of real-time data acquisition and control software is more demanding than the development of software used for routine data processing application. This chapter will introduce the interface control and the expert system shell.

5.1 Interface Control

The major concern with the interfacing issue is that different microprocessors have different timing and control signals. The address bus, the control bus, and the data bus are used for internal communication in a computer system. Any peripherals and memory interfaced to the microprocessor must have similar characteristics. This is accomplished by using additional circuitry for communication between the microprocessor and a standardized data communication system or bus. The use of standard buses also means that a wider variety of boards will be available which can be interfaced with the bus. There are two kinds of standard buses available, serial and parallel (2).

The interfaces required in the industrial environment will vary depending upon the type of sensors and actuators used. The following devices are commonly used for interfacing sensors and actuators to the microcomputer:

(1) Analog-to-digital converters (ADC);

(2) Digital-to-analog converters (DAC);

(3) Multiplexers and demultiplexers;

(4) Sample-and-hold circuits;

(5) Amplifiers.

In real-time process data acquisition systems, the sensors used to detect the process parameters of a process have to be interfaced directly to the microcomputer. Then, the microcomputer will give a voltage or current output signal to operate the actuators through amplification. In this report, there are twenty sensors and seven controllers that have to be processed. It is necessary to use a multiplexer which transfers data from these sensors into one (communication) line for connecting to the microcomputer input port. Similarly, a de-multiplexer is necessary for transferring the data from one output port to a number of lines connected to actuators. To accomplish the above described requirements, the uMEGA 6000 Series is chosen. It combines the functions of both the multiplexer and the demultiplexer.

5.2 Expert Systems and Their Shells

An expert system is the closest that one can get to cloning an expert's decision making processes in a specific task domain. Expert systems can be used to advise, analyze, categorize, communicate, consult, design, diagnose, tutor, train, etc. Expert systems are usually developed with the help of human experts who solve specific problems and reveal their thought processes as they proceed. Expert system shells are written in many programming languages and programming environments. LISP, PROLOG, FORTRAN, PASCAL, INTERLISP, C, and OPS5 are proramming languages; and PERSONAL CONSULTANT PLUS, KEE, LOOPS, M.1, EMYCIN, RULEMASTER, and EXPERT-EASE are programming tools (13,14). To develop an expert system, one must first demonstrate that the idea works. This often consists of a feasibility study. Next one should proceed to a prototype which has experimental use on a real-life problem. The protype then leads into a testable system which is controlled by field personnel. Finally, one can produce a commercial product which is likely to include: a user interface, documentation, training, customer support, and on-going development.

One popular expert system shell, Personal Consultant Plus [16], was developed by Texas Instruments. It is a LISP-based expert system shell written in PC Scheme LISP. It offers frame-based representation, forward and backward chaining, meta-knowledge control, graphics display, and a broad interface to Scheme LISP. PCPlus lets applications users ask the system why information is being requested, how a conclusion was arrived at, and what the user's responses were. It can also interact with dBASE II, dBASE III, and dBASE III Plus (the databases which are written in LISP) during a consultation. For this purpose, PCPlus provides several functions that allow one to use a knowledge system as either a front-end (gathering and maintaining information) or a back-end (accessing information) to the database, or as both. An important limitation of the dBASE function in PCPlus is that it recognizes only numeric and character data types and not any others. One may specify the amount of memory allocated for dBASE by adding to the knowledge base the user-defined property. Each dBASE filename includes the extension ".DBF". One may update a database for his own records. If one wishes to keep a record of the conclusions of his knowledge base, he could create a database of conclusions. A dBASE function could be included in the 'THEN' clause of the rule that determines the conclusion. The dBASE function would then add each conclusion to the database. There are many commands to interact with a dBASE file.

5.3 Expert System Parameters

All of the extrusion cooking process control parameters as well as their possible values, used in the ES knowledge base of this report are given below.

PARAMETER		POSSIBLE INPUT VALUES
BUSHELWEIGHT	:	HIGH, TARGETHIGH, TARGET, TARGETLOW, LOW
EXTRUDERDRIVEAMPS	:	UNDERLOAD, INSPECS 125-140, OVERLOAD, MAX
WETPRODUCTSIZE	:	LARGE, INSPECS, SMALL
WETPRODUCTSHAPE	:	INSPECS, OUTSPECS
WETMEALMOISTURE	:	HIGH, INSPECS, LOW
WETMEALTEMPERATURE	:	INSPEC 200-210, HIGH > 210, LOW < 200
JACKET1TEMPERATURE	:	HIGH, INSPECS, LOW, ADEQUATE
JACKET2_5TEMPERATURE	:	HIGH, INSPECS 185-200, LOW < 140, ADEQUATE < 175
PRODUCTIONRATE	:	HIGH, STANDARD 5000 - 6300 lb., LOW, FLUCTUATING

RESTRICTIONPLATE : LARGE, SMALL, NONE

WETPRODUCTSTICKY : Y/N

WETPRODUCTBALLEDUP : Y/N

PRODUCTMOISTURE : HIGH, INSPECS, LOW

KNIFEALIGNED : Y/N

SHROUDOBSTRUCTION : Y/N

ADEQUATEAIRFLOW : Y/N

SHROUDSEALLEAKAGE : Y/N

DIEPLUGGED : Y/N

DIECAPPROPERLYINSTALLED: Y/N

PRODUCTCOOK : OVERCOOKED, BURNT, JUSTRIGHT, UNDERCOOKED

WETPRODUCTMOISTURE : HIGH, INSPECS, LOW

WETMIXERRETENTIONTIME: HIGH, INSPECS, LOW < 20 sec.

RAWMEALCONDITION : SCORCHED, NORMAL

LEAKINGJACKETS : Y/N

LEAKINGLINERS : Y/N

SCREWWEAR : Y/N

LINERSWEAR : Y/N

EXTRUDERRESTRICTIONS: Y/N

EXTRUDERBACKUP : Y/N

DIECAPWEAR : Y/N

EXTRUDERSCREWBUILDUP: Y/N

EXTRUDERSCREWDIAMETER: WITHIN TOLERANCE, OUT OF TOLERANCE

EXTRUDERSCREWFLIGHTEDGES: SHARP, ROUNDED

AMMETERCALIBRATION : Y/N

SCREWWARPED : Y/N

PROCESSWATERFLUCTUATING: Y/N

STEAMFLOWFLUCTUATION: Y/N

FEEDERSURGE : Y/N

WETMIXERBUILDUP : Y/N

WETMIXERPADDLES : OUT OF LINE, MISSING

MIXERDISTRIBUTORFLOWRATE: OK, NOT OK

BINCONTROL : OK, NOT OK

DELIVERYCONTROL : OK, NOT OK

MIXERDISTRIBUTORLEVEL: OK, NOT OK

CHAPTER 6

CONCLUSIONS

The design of the extrusion cooking control process consists three major components; hardware equipment, process, and control system. A successful design of the control strategy goes beyond the selection of hardware. Successful design also depends on knowledge of the process and an understanding of the capabilities of advance control tools. This understanding must include knowledge of the large range of instrumentation and control equipment which is utilized as well as the requirements for accurate and reliable measurement process and good performance from an automatic control system.

To support the statements above, several major tasks were accomplished. They are given below.

1. The parameters that must be measured in an automatic extrusion control system were defined.
2. The different types of industrial/commercial sensors/transducers available were discussed.
3. The interface between sensors and actuators and a host computer were discussed.
4. Commercially available expert system software

packages that can be used to implement an automatic extrusion control system were presented.

5. The necessary and appropriate control signals have been determined.
6. The necessary circuitry for the various electric-sensing transducers has been designed.

A processing plant is a complex entity with entirely different operating characteristics from those encountered in a laboratory process. To implement this automated control of extrusion cooking in industry, one needs to consider more factors such as; cost, precision of the system required, degree of automation, time, etc. However these are topics for future research efforts.

CHAPTER 7

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APPENDIX A

Hardware Specification of Series 151 (Image Processor)

The Series 151 image processor, produced by Imaging Technology Inc., is a family of modules designed to provide a complete image processing system for applications requiring real-time image operations. It can be interfaced with an IBM PC. The 151 system and its PC interface allow control of a module, high-performance, real-time image processor form a PC.

There are four modules in the 151 Series from which an image processing system can be built around. Analog/digital converters provides and interface to cameras and monitors. A frame buffer module provides the image storage required in the system. A pipeline processor is an general-purpose image processor that performs many commonly used image processing functions and performs a significant amount of conditional processing. The real-time convolver is an accelerator used for performing convolutions on stored images in real time with user-defined kernels up to 4 x 4 or 16 x 1.

The followings are the specifications of these four modules:

1. ADI-151 (Analog/Digital Interface)

Video Input

- Accepts RS-170, RS-330, or 50 Hz CCIR (European) Video standard;
- Four software-selectable video input sources;
- DC restoration of input video signal;
- 4.2 MHz anti-aliasing filter;
- Montonic 8-bit flash A/D converter with 10 MHz sampling rate;
- Programmable gain and offset, 256 steps each;
- Sixteen 256-byte programmable look-up tables are available for point processing of input video data and feedback;

Video Output

- Video is output in RS-170 or CCIR standards;
- Three channels of D/A output, each with sixteen 256-byte programmable transformation tables (LUTs) for pseudocolor applications;
- RGB video (synchronization on green optional);
- Composite sync or horizontal and vertical sync;
- Each of the three LUT data paths may be driven from separate data sources under software control;

Timing and Synchronization

- Sync stripper extracts composite sync from input composite video;

- Sync separator extracts vertical sync;
- Dual phase-locked loops (PLLS) provide stable horizontal lock to unstable video sources such as commercial videocassette recorders (VCR);
- System clock source is software-selectable to be PLL- or crystal-generated;
- On-board logic automatically switches to crystal-generated timing if external sync is lost, ensuring an uninterrupted RS-170/CCIR timebase;
- Provides synchronization required for operation in area-of-interest mode;
- Jitter less than 20 nanoseconds;

2. FB-150 (Frame Buffer)
   - Frame memory size - 512 x 512 pixels, with a total of 32 bit-planes;
   - Organized as two independent 512 x 512 x 8 frame stores plus a full 16-bit 512 x 512 image accumulator for storing precise results;
   - Multiple frame buffer modules (up to four) can be used in one system, functioning as independent memory banks.

Data Transfer

- Entire memory can be mapped to system address space;

- Indirect addressing via X and Y pointer registers;
- Index addressing also possible using X and Y pointer registers;
- Independent auto-increment or decrement of X and Y pointer registers following pixel data read or write in either addressing mode;
- Single pixel access times:
  - typically: 1.2 microseconds;
  - worst case: 1.5 microseconds;
- Burst mode pixel access time: 100 nanoseconds (up to eight consecutive pixels).

Host Memory Access

- Transparent dual-port access for host CPU and video bus input/output;
- Individual bit-plane write-protect (separate from video bus write-protect register);
- Fast block moves using on-board Pixel Buffer;
- X-mode and Z-mode data transfers;
- Pixel access on arbitrary memory boundary;
- Frame memory interface: A24:D16.

Video Memory Access

- Independent pan and scroll for 16-bit image accumulator and 8-bit image stores;
- Zoom factors of 2 or 4 available in hardware;

- Individual bit plane write-protect mark;
- Automatic spin compensation;
- ADI processing is supported; area-of-interest defined as M x N pixel frame;
- ADI non-interlaced frame access.

3. <u>ALU 150 SPECIFICATIONS</u>

<u>Input Select</u>

-Input selector multiplexes the four video bus input channels onto four internal buses;

- Each internal bus can receive data from any of the four input channels;

-Each maximum output can be individually tri-stated and a register constant selected.

<u>input multiplier</u>

- Two of the internal buses drive an 8 x 8 multiplier; two others form a 16-bit input to the ALU;

-The product of the 8 x 8 multiplier is used as the other 16-bit input to the ALU;

- The input multiplier can be optionally bypassed.

<u>ALU Section</u>

-Provides sixteen different arithmetic and logical operations on the two 16-bit inputs;

- Mask register allows logical operations to occur only on specified bit planes;
- Seven status bits generated to provide relative magnitude information on 16-bit inputs and overflow/carry-out for arithmetic operation;
- Overflow and carry-out bits are fed forward to the barrel shifter section to provide conditional output jamming capability;
- Status bits are fed to the conditional LUT to provide selection of output LUTs;
- An interrupt can be generated on ALU overflow;
- Absolute value of ALU output can be calculated before being passed to the barrel shifter.

<u>Barrel Shifter</u>

- Provides scaling or shifting of ALU results;
- 16-bit and 17-bit modes of operation;
- Can provide maximum positive or maximum negative output jamming on ALU overflow or underflow;
- Separate unsigned two's complement select;
- Output of barrel shifter section is monitored for min/max comparison and detection allowing, further conditional processing capability.

- Byte-swap circuitry is on-board to allow interchange of the barrel shifter outputs;

Output LUTs

- Sixteen 256-byte LUTs allow point processing of image data prior to output on the pipeline bus;
- Least significant and most significant bytes of the 16-bit output can each be transformed by a separate LUT selected by either the host CUP or conditionally by either the ALU section status bits, sign bit, or the min/max comparison bits;
- Conditional LUT selection allows functions such as positive/negative clipping, addition an/or subtraction of an 8-bit constant, or full 16-bit thresholding or windowing to be performed;
- The LUT output is sent over the pipeline bus to either the frame buffer or to another pipeline module for further processing;

4. RTC-150-SPECIFICATIONS

- Four on-board Digital Signal Processors (DSPs) provide number crunching power;
- Ability to compute at a rate of 340 MOPS (Million Operations Per Second);

- Real-time performance for kernels as large as 4 x 4 pixels or 16 x 1 pixels;
- Larger kernels can also take advantage of the convolution accelerator;
- Area-or-interest convolution processing supported for increased system throughout; multiple convolution passes can be performed on an AOI in one time frame (1/3 sec).

Price: $11,495.00.

DESIGN OF A KNOWLEDGE-BASED SYSTEM INTERFACING WITH AN EXTRUSION COOKING PROCESS

by

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1979

AN ABSTRACT OF A MASTER'S REPORT

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ABSTRACT

Automatic control systems are used widely in industry. This report presents a design of such an automated system for extrusion cooking control. The proposed control system is designed to acquire and analyze the input signals first. Then the expert system's knowledge base, stored in a microcomputer, makes appropriate control decisions. Finally these control decisions are translated into actuator control signals that are transmitted to the control actuators. The major efforts of this report are: determination of the necessary and appropriate transducer specifications; determination of the necessary and appropriate control signal processing; design of electronic-sensing transducer circuitry; design of electric control circuitry; development of knowledge base software; and, development of PC software. The design consists of three major components; equipment, process, and control system. The sensors/transducers used in this report have been selected based on a market survey and analysis of their functions and performance.