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Master Thesis

SCADA Online Product Quality Control

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صفحة نتيجة الحكم على البحث (نتيجة الحكم من قبل لجنة المناقشة)

ABSTRACT

Controlling the quality of the product during the manufacturing phase is the process of analysis, control, management of factors and variables that affect the quality of the final product. Integrating the computer in the industrial manufacturing control will ensure the quality of the product, as well as to provide the necessary data for the production process progress, the ingredients ratio used in each production batch and statistical data of the changes that may occur in the composition of the product. Traditional methods to control the quality of the product are inadequate and inappropriate; they need to be changed to keep pace with the huge development in the field of industrial automation, control systems, industrial quality and computer technology used in various industries as well as clear development in the field of industrial sensors

This study falls into three-research area: integration of SPC and EPC, SCADA batch processes monitoring and control, and concrete batching plant. The objectives of this study are (a) To design a SCADA system for batch process monitoring and quality management, (b) To establish an integrated SPC/EPC methodology for a batch process, and (c) to illustrate the proposed approach with an application of the analysis and monitoring of an industrial concrete batching plant .

The concrete batching plant has different batch processing subsystems, but the aggregate batching process has the greatest impact on product quality, unfortunately, this industrial process is poorly automated, in most plants in Gaza strip. The traditional control or even the manual control is still common which leads to uneven mixtures and inconsistent product quality subject to several disturbances. A complete PLC system is designed for full-automated concrete plant, with new aggregate weighing and batching algorithm implemented for adaptive flow rate and feeding speed control.

Through this study ,the implemented algorithm and SCADA system , process engineers at the industrial plants are now able to use a valuable decision making tool when the production process is affected by certain disruptions, with obvious consequences on product quality, productivity and competitiveness.

Keywords: SPC, EPC, APC, PLC, SCADA, Batching, Modeling, Simulation, Quality, MATLAB/Simulink,

ملخص

التحكم المباشر في جودة الإنتاج بإستخدام نظام سكادا

إن إدارة و مراقبة جودة المنتج أثناء عملية التصنيع هي عملية التحليل و التحكم وإدارة العوامل و المتغيرات التي تؤثر على جودة المنتج النهائي, لذا فإن إستخدام وتطبيق الطرق التي تعتمد على الحاسوب تضمن المحافظة على جودة المنتج ,بالإضافة لتوفير البيانات اللازمة عن سير عملية الإنتاج و المكونات المستخدمة في كل دفعة انتاج و البيانات الإحصائية للتغييرات التي قد تحدث في تركيب المنتج. إن الطرق التقليدية للتحكم في جودة المنتج هي غير كافية و غير ملائمة و تحتاج للتغيير لتواكب التطور الكبير في مجال الأتمتة الصناعية و أنظمة التحكم في الجودة الصناعية و تكنولوجيا الحاسوب المستخدمة في الصناعات المختلفة بالإضافة إلى التطور الواضح في مجال المجسات الصناعية.

هذه الدراسة تشمل ثلاثة مجالات مختلفة من البحوث: دمج SPC و EPC و عمليات التحكم ومراقبة الإنتاج باستخدام SCADA ، وتصميم نظام تحكم لمصنع انتاج الخرسانة. أهداف هذه الدراسة هي: (أ) تصميم نظام للتحكم و مراقبة وإدارة الجودة باستخدام SCADA ، (ب) وضع منهجية لدمج SPC / EPC للتحكم في العملية الصناعية، و (ج) لتوضيح النهج المقترح مع تطبيق و تحليل و تحكم في مصنع خلط الخرسانة.

يتكون مصنع إنتاج الخرسانة من العديد من الأنظمة الفرعية للتحكم في الإنتاج ، ولكن عملية توزين و خلط الركام لها أكبر تأثير على جودة المنتج. لسوء الحظ، فإن هذه العملية الصناعية غير مؤتمتة بالشكل المطلوب، حيث تعمل معظم مصانع الخرسانة في قطاع غزة على أنظمة التحكم التقليدية أو حتى الأنظمة اليدوية, مما يؤدي إلى منتج بنسب متفاوتة، وجودة غير متناسقة تخضع لعدة اضطرابات. تم تصميم نظام PLC كامل لمصنع الخرسانة الآلي ، مع تطوير خوارزمية للتحكم في معدل تدفق التعبئة للمواد و سرعة التغذية.

يسمح نظام SCADA من خلال هذه الدراسة وتطبيقها, بالإضافة لخوارزمية التعبئة للركام المهندسين و العاملين في مصانع الخرسانة بالتحكم بالحصول على معلومات مهمة عن عملية الإنتاج تساعدهم في إتخاذ القرارات التي تحسن من جودة الإنتاج.

This thesis is dedicated

To the soul of my Father, the first to teach me, I feel he is always with me supporting and guiding.

To my beloved Mother, for her constant prayers, her support, encouragement, and constant love have sustained me throughout my life., and for her confidence in me.

To my Wife, for her relentless care and support. Her understanding have lightened up my spirit to finish this thesis.

And to my Children, Malak, Ibrahim and Ahmed with hope for a bright future.

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At the very outset, all my prayers and thankfulness are to Allah the almighty for facilitating this work and for granting me the opportunity to be surrounded by great and helpful people at IUGAZA and PTCDB.

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To my father’s Soul, who encouraged me to be the best I can be, to have high expectations and to fight hard for what I believe. The man to whom I will be grateful, for the rest of my life. I pray his soul may rest in perfect peace under the mercy of Allah,

The warm heart, my mother, deserves all the credit here; she has been a source of inspiration to me for years. I would never forget her continuous prayer for the sake of my success.

No acknowledgement would be complete without expressing my appreciation and thankfulness for my wife; I can't refute her long lasting patience and support which she showed during this work and which was essential to accomplish it.

Finally, My appreciation goes to all colleagues and friends for their suggestions and encouragement during the writing of this thesis. A very sincere appreciation to my dear friends, Eng. Ahmed Harb, Eng. Mohammed Abu Qasem ,and Eng. Marwan Abu Shughaiba, for helping me to complete this work.

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ABBREVIATIONS

APC	*Automatic Process Control*
ARL	*Average run length*
ARMA	*Autoregressive Moving Average*
CpK	*Process Capability Index*
CUSUM	*the cumulative sum*
DCS	*Distributed Control System*
EPC	*Engineering Process Control*
EWMA	*exponentially weighted moving average*
FDC	*Fault detection & Classification*
HMI	*Human-Machine Interface*
HVAC	*heating, ventilation, and air conditioning systems*
IED	*Intelligent Electronic Devices*
LCL	*lower control limit*
MMSE	*minimum mean squared error*
MPC	*model predictive control*
MV	*manipulated variable*
PC	*Personal Computer*
PLC	*Programmable Logic Controller*
PV	*Present Value*
R2R	*Run to run*
RTU.	*Remote Terminal Unit*
SCADA	*Supervisory and Data Acquisition*
SP	*set point*
SPC	*Statistical Process Control*
UCL	*upper control limit*
AFR	*Aggregate Flow Rate*
AFW	*Aggregate Filling Weight*

NOMENCLATURE

μ	*Process Mean*
σ	*Standard deviation*
e_t	*process output*
X_t	*process input*
ρ_b	*Aggregate bulk density (kg/m3)*
V	*feeding speed*
W	*Material Weight*
W_{all}	Batching weight
T_{all}	Weighting time
T_w	*Weight duration pulse*
W_{er}	*Weight Error*
T_g	*Gate total open Time*
$MRfr$	*Mass real flow rate*
$MCfr$	*Mass Calculated flow rate*
$u(k)$	*Process input*

CHAPTER 1 INTRODUCTION

1.1 Background

Improving product quality is the most preoccupation of industrial managers and engineers. This objective becomes more critical in various industries. Essentially, because of the lack and the increasing prices of raw materials and energy require today a decrease of production costs for large technical processes. In fact, a continuing processes control in manufacturing systems becomes more and more necessary. Particularly, innovative monitoring and control techniques of the batch process operations are strongly needed in the process control field. Since, batch and semi-batch processes play a significant role in the production and processing of high-value-added materials and products, or when the quality of the final product, of great importance for safety. Examples include the production of pharmaceutical and food manufactures biochemical reactors, ready mix concrete, the processing of materials by injection molding and etching processes.

Typically, the manufacturing of a batch involves charging ingredients to a specific processing unit, processing them under controlled conditions, and discharging the final product. A batch operation is considered successful if the values of the process variables remain within acceptable limits while following the recipe prescribed for the process, resulting in a uniform, high-quality product. Batch processes are “simple” in terms of equipment and operation design, but are often quite complicated in terms of product quality monitoring and of production scheduling and organization.

To achieve the required quality measures for ready-mix concrete, a suitable control method must be selected, such as batch process immediate control methodology, which is concerned with instant action to control the quality of the concrete being produced, which depends on the ingredients weighing process.

1.2 Problem Statement

The batching and weighting process in a manufacturing plant suffers from severe changing of industrial environment or material specifications, this implies that it is very difficult to control by conventional control methods.

A closed loop batching control system is illustrated in Figure 1.1. Unlike the conventional batching control system, the feeding speed, is calculated from the weight instrument and fed back to batching controller. The feeding mechanism is an electromagnetic device regulated by power amplitude or pulse duration and frequency. Some parameters, have to be tuned manually. In the conventional control system, e.g., the amplitude decrease of feeding speed, setting value of feeding speed, *Vset*, increment of control variable, $u(k)$, threshold of shutting down the electromagnetic mechanism in advance, threshold of shutting down valve, to predict the material remaining in air, and dropping into the collecting box later, initial values of amplitude and frequency of electromagnetic mechanism $u(0)$,etc.

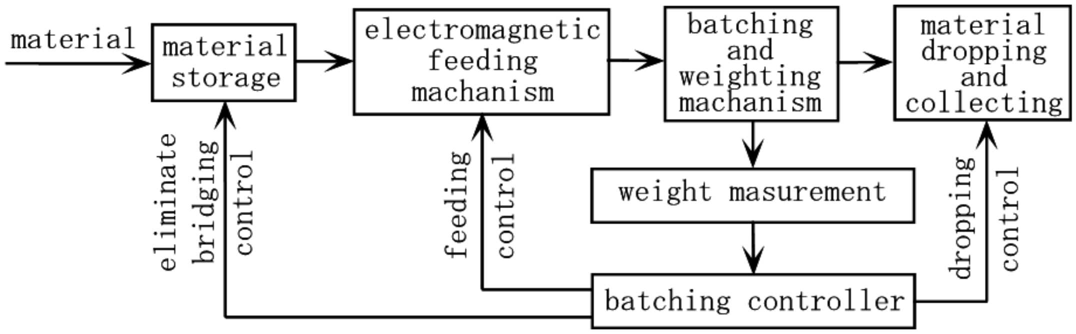
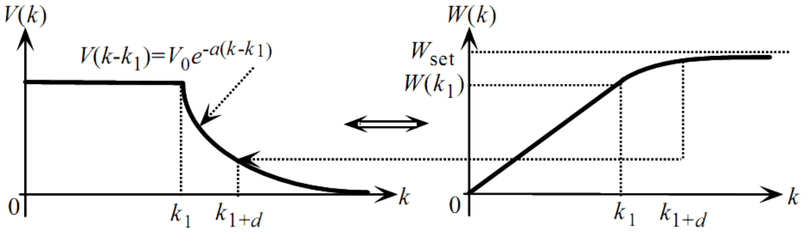


Figure (1.1): Diagram of Closed Loop Batching System.

An ideal technical speed curve to match feeding speed with material weight is shown in Figure 1.2(a). At the beginning stage of the batching operation, the feeding speed is fixed at speed V_0. When the batching weigh approaches to the setting value, i.e., after instant $k= k_1$, the feeding speed is decreased at slow exponential rate. In open loop system, where the information of material weight is just used as a logic control signal rather than a control variable used for closed-loop directly, the weight cannot be kept in accordance with the speed as shown in Figure 1.2(a) and 1.2(b) due to the fluctuation of the real feeding speed around the ideal technical speed curve. Especially after the instant $k=k_1$, the real feeding speed curve cannot achieve the exponential function, as a result, it cannot obtain the accurate batching weight finally even the designed servo system can track the setting speed promptly.

To solve this issue we need a new closed-loop control scheme where the system parameters are monitored and controlled online by a SCADA system, which can track the flow of the production process and compare the current system states with the required set points to achieve the required product quality.



(a) Curve model of feeding speed (b) Weight of feeding material

Figure (1.2): Relation Between Feeding Speed and Weight Under Ideal Situation.[1]

1.3 System Overview

The rapid development of computer technology, sensor technology, and process measurement technology provide favorable conditions for the implementation of process quality control. The key to process quality control is the acquisition of process quality data and the adjustment of process parameters, which are to collect process information and product information, and transfer them into computer via data interface after the signal preprocessing. Then, the controller finishes the adjustment of process parameters via executive (Actuator) units to achieve process quality control. The block diagram of the system is shown in Figure. 1.3 Process quality data acquisition and controlling contents include the monitoring of parameters process product quality testing. Process parameters monitoring is realized by measuring the relevant parameters on product quality characteristics. Process product quality testing is achieved by testing products' quality feature in the machining processes or machining process interval. Common processing measurement parameters include cutting force, temperature, the spindle motor current changes, vibration and noise signals. Process quality control should establish the correlation between process parameters and the final product quality characteristics, and ensure the quality of the final product by the adjustment to parameters.

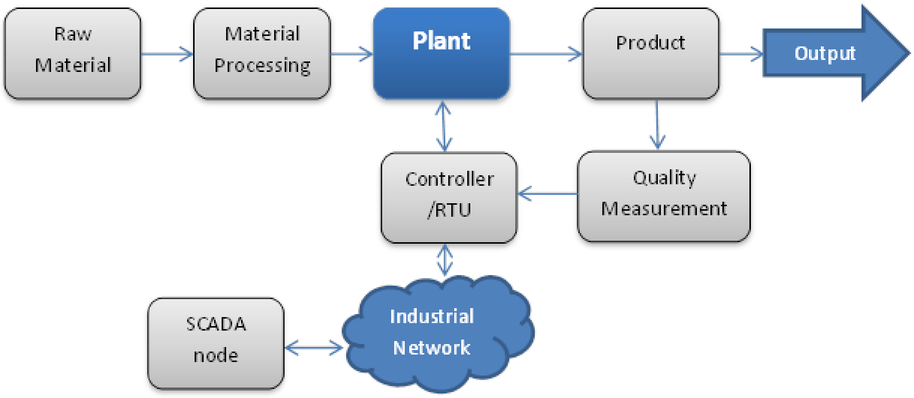


Figure (1.3): System Block Diagram.

Process quality control system is a novel computer-aided process quality control system, which integrate hardware and software. The system could realize quality data collection, transmission, storage, quality monitoring and quality statistical analysis for spare parts production process. It could accomplish the collection and monitoring of quality data automatically in field. Once the production process has problems, it can give an alarm and begin to analyze, providing a basis for process quality control. Furthermore, it can also carry out offline quality statistical analysis of the quality data derived from the machining field, guaranteeing after-process control of processing quality.

1.4 Literature Review

Despite that the topic of product quality control in industrial plants is a very important issue, there is a lack of documented research in this area Industrial companies work in this field will not disclose their products and solutions that deal with this issue. A few researchers tackled this issue from different points of view,

Tao and Gaoshan [2] discussed SPC (Statistical Process Control) technology which is the principal method used in process quality control and then analyzes the feasibility of combining computer technology with mathematical statistics theories like SPC. It also pointed out the management contents of process quality control system.

Bailin, et al. [1] proposed an adaptive Control Scheme to tune the parameters of the Industrial Batching and Weighting Controller.

Cheek and Self [3] conducted a case study on paper mill plant and they showed how simple statistical techniques can be used to determine which variables in an on-line monitoring process require adjustment. A method for tuning the variables is suggested. While the calculations are relatively simple, they require a considerable amount of computing power to deal with the large amount of data and its organization and manipulation.

Velasquez and D'Souza [4] reviewed the evolution of quality control solutions in a manufacturing plant and presented how the modern automation techniques can be utilized to improve Quality Control in manufacturing plant.

Aumi, et al. [5] addressed the problem of driving a batch process to a specified product quality using model predictive control (MPC) with data-driven models. They proposed a predictive control design for batch systems designed to drive the batch to a specified quality by batch termination, the linear quality model predicted the quality, more accurately. This, in turn, led to more effective control action.

Hachicha., et al. [6] proposed a new integrated SPC/EPC system that applied in batch process. The integration is performed continually in two successive phases: (1) Active SPC for the batch making advance, and (2)run to run (RTR) control action between batches.

Wang [7] investigated the possibilities and benefits of a SPC monitoring model of time delay feedback controlled process. They compared the monitoring of the process output and the control action of minimum mean squared error (MMSE) controlled time delay processes for detecting unanticipated mean shifts. For a MMSE controlled process, the control action should be more effective to monitoring mean shifts when there is time delay in process adjustment.

Yu, et al. [8] presented a new SPC model that can overcome the shortness of current SPC methods which they expect to be a complementary for EPC and process monitoring. The model expected features emphasized on the quality-oriented process control model that quantitatively specifies what a desired process is and how to assure it. It’s also a flexible and dynamic control model based on designated quality target and the known or estimated (capability process) *Cp* value of relative process, also it’s an on-line process measuring and monitoring system and information-based manufacturing environment are desired technical support condition to this new SPC approach.

1.5 Objectives

The overall objective is to design, simulate and implement a SCADA based automation system with improved online quality control. This system will read product quality related data from the PLC, and analyze this data to tune the controller parameters to achieve optimized process control for better quality standards. This objective is divided into smaller tasks:

- ☒ Analyze the main factors that affect the accuracy of the automation system output.
- ☒ Derive and present the system model of the batching process.
- ☒ Study different approaches track and identify the error between the required o/p and real o/p.
- ☒ Simulate the industrial batch process system model using Matlab.
- ☒ Design a SCADA system to monitor and control the selected process.

☒ Develop a prototype for the designed system with one or more RTUs.

1.6 Motivation

The motivation for this project comes from the following:

- A personal interest in automation systems, with the challenges of high product quality. I hope to make the process of designing online SCADA production lines with high quality standards for the production lines available in our local industry.
- The local industry in Gaza Strip will benefit from a product quality control system that can increase the production quality within the bounds of production speed, different local industries like food production lines, concrete batching, flourmills, product filling and packing that all have different batching systems, depend on old techniques, which does not solve the problem.
- There is no clearly defined or rigorous method to approach (solve) such problems especially in the hardware realization implementation. Designers often end up plugging numbers and do not develop any intuition and rely on old low performance techniques or trial and error methods.

1.7 Methodology

Different methods, techniques and algorithms related to the quality of products in automation lines were reviewed and a performance criterion was formulated to select the suitable solution, the project was divided into different phase’s which:-

- Build a PLC controlled batching systems with variable parameters, which will be tuned, based on the change of the product flow.
- Design a SCADA system to access the PLC memory map registers to extract and change the product quality control variables.
- Write the industrial protocol that will link the SCADA system with the PLC network.
- Design a database system that will be used to store all the production process variables and construct a history log for all the operation phases.
- Design the algorithm, which will tune the quality control variables based on the database log.

1.8 Thesis Contribution

- Design and implement an aggregate filling algorithm to improve the weighing process accuracy and product quality.
- Providing a practical mechanism for production quality control and generating statistical data and charts for any production process has been implemented.
- Integrating industrial automation system, quality management and supervisory control in one practical platform.

- Service the community through providing the customers with a good quality products maintained by the computerized control system
- Upgrading the local industry by providing the necessary regulations for excellent products, as well as to increase the volume of production within the limits of the required quality.
- The development of many industries including the food industry, production lines, grinders, packing systems and construction industries.

1.9 Thesis Outline

This thesis structured in the following way: chapter 2 provides theoretical background, which describes the basics of industrial automation and control systems, and presents the different methods for process control. Chapter 3 discusses the statistical process control methods to improve the quality of the manufactured products. Chapter 4 introduces the supervisory control and data acquisition system and its role in quality improvement. Chapter 5 covers the concrete batching plant, which is taken as a case study. Chapter 6 presents the design of the control and quality software implemented to improve the quality of the products. Chapter 7 shows the results of testing the developed system are presented and discussed. Finally, a general conclusion is provided as well as recommendations and perspectives for future work are presented in chapter 8.

CHAPTER 2 INDUSTRIAL CONTROL AND AUTOMATION

2.1 Introduction

Industrial control system (ICS) is a general term that encompasses several types of control systems used in industrial production, including supervisory control and data acquisition (SCADA) systems, distributed control systems (DCS), and other smaller control system configurations such as programmable logic controllers (PLC) often found in the industrial sectors and critical infrastructures. Industrial Automation is a discipline that includes knowledge and expertise from various branches of engineering including electrical, electronics, chemical, mechanical, communications and more recently computer and software engineering.

Automation is the use of control systems (such as numerical control, programmable logic control, and other industrial control systems), in concert with other applications of information technology (such as computer-aided technologies [CAD, CAM, CAx]), to control industrial machinery and processes, reducing the need for human intervention. In the scope of industrialization, automation is a step beyond mechanization. Whereas mechanization provided human operators with machinery to assist them with the muscular requirements of work, automation greatly reduces the need for human sensory and mental requirements as well. Processes and systems can also be automated.

In the absence of process automation, plant operators have to physically monitor performance values and the quality of outputs to determine the best settings on which to run the production equipment. Maintenance is carried out at set intervals. This generally results in operational inefficiency and unsafe operating conditions. Process automation simplifies this with the help of sensors at thousands of spots around the plant that collect data on temperatures, pressures, flows and so on. The information is stored and analyzed on a computer and the entire plant and each piece of production equipment can be monitored on a large screen in a control room. Plant operating settings are then automatically adjusted to achieve the optimum production. Plant operators can manually override the process automation systems when necessary.

2.2 Process Control

Process control is a statistics and engineering discipline that deals with architectures, mechanisms and algorithms for maintaining the output of a specific process within a desired range. Process control is extensively used in industry and enables mass production of continuous processes such as concrete batching, paper manufacturing, chemicals, power plants and many other industries. Process control enables automation, with which a small staff of operating personnel can operate a complex process from a central control room.

A commonly used control device called a programmable logic controller, or a PLC, is used to read a set of digital and analog inputs, apply a set of logic statements, and generate a set of analog and digital outputs. For example to control a room temperature using a PLC, the room temperature would be an input to the PLC. The logical statements would compare the set point to the input temperature and determine whether more or less heating was necessary to keep the temperature constant. A PLC output would either then open or close the heating element, an incremental amount, depending on whether more or less heat was needed. Larger more complex systems can be controlled by a Distributed Control System (DCS) or SCADA system.

Most basic process control systems consist of a control loop as shown in Figure 2.1.

The system has four main components, which are:

- A measurement of the state or condition of a process.
- A controller calculating an action based on this measured value against a pre-set or desired value (set point)
- An output signal resulting from the controller calculation which is used to manipulate the process action through some form of actuator
- The process itself reacting to this signal, and changing its state or condition.

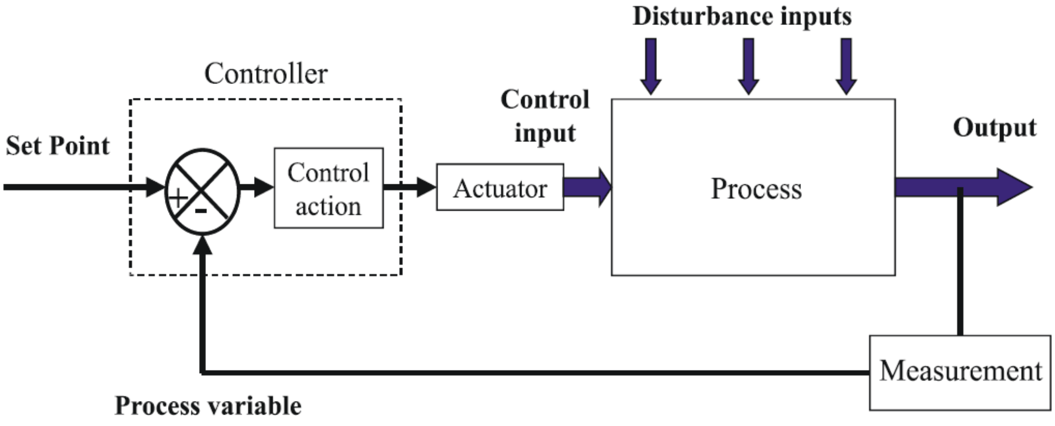


Figure (2.1): Block Diagram Showing the Elements of a Process Control Loop.

Two of the most important signals used in process control are called

- Process Variable or *PV*
- Manipulated Variable or *MV*

In industrial process control, the Process Variable or PV is measured by an instrument in the field and acts as an input to an automatic controller which takes action based on the value of it. Alternatively, the PV can be an input to a data display so that the operator can use the reading to adjust the process through manual control and supervision.

The variable to be manipulated, in order to have control over the *PV*, is called the Manipulated Variable *MV*. If we control a particular flow for instance, we manipulate a valve to control the flow. Here, the valve position is called the Manipulated Variable and the measured flow becomes the Process Variable.

2.2.1. Types of Process Control Systems

In practice, process control systems can be characterized as one or more of the following forms:

Discrete – Found in many manufacturing, motion and packaging applications. Robotic assembly, such as that found in automotive production, can be characterized as discrete process control. Most discrete manufacturing involves the production of discrete pieces of product, such as metal stamping.

Batch – Some applications require that specific quantities of raw materials be combined in specific ways for particular durations to produce an intermediate or end result. One example is the production of adhesives and glues, which normally require the mixing of raw materials in a heated vessel for a period to form a quantity of product. Other important examples are the production of food, beverages and medicine. Batch processes are generally used to produce a relatively low to intermediate quantity of product per year (a few kgs to millions of kgs).

Continuous – Often, a physical system is represented through variables that are smooth and uninterrupted in time. The control of the water temperature in a heating jacket, for example, is an example of continuous process control. Some important continuous processes are the production of fuels, chemicals and plastics. Continuous processes in manufacturing are used to produce very large quantities of product per year (millions to billions of kgs).

Applications having elements of discrete, batch and continuous process control are often called hybrid applications.

2.2.2. Principles of Process Control System

The process plant is represented by an input/output block as shown in Figure 2. 2.

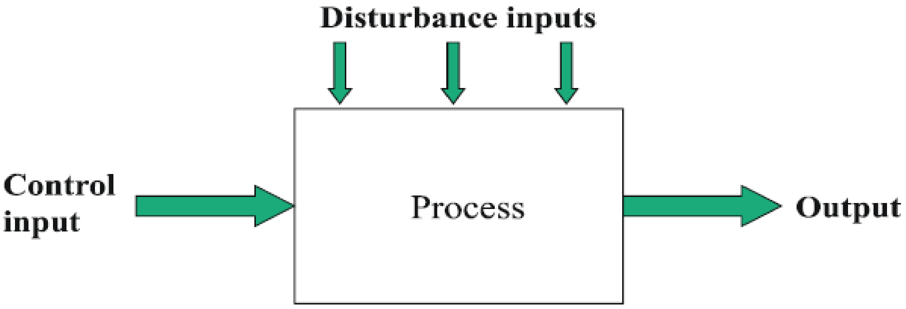


Figure (2.2): Basic Block Diagram for the Process Being Controlled.

In Figure (2.2), we see a controller signal that will operate on an input to the process, known as the ‘manipulated variable’. We try to drive the output of the process to a particular value or set point by changing the input. The output may also be affected by other conditions in the process or by external actions such as changes in supply pressures or in the quality of materials being used in the process. These are all regarded as ‘disturbance inputs’ and our control action will need to overcome their influences as well as possible. The challenge for the process control designer is to maintain the controlled process variable at the target value or change it to meet production needs whilst compensating for the disturbances that may arise from other inputs. So for example, if we want to keep the level of water in a tank at a constant height while others are drawing off from it, we will manipulate the input flow to keep the level steady. The value of a process model is that it provides a means of showing the way the output will respond to the input actions. This is done by having a mathematical model based on the physical and chemical laws affecting the process. For example in Figure 2.3, an open tank with cross sectional area A is supplied with an inflow of water $Q1$ that can be controlled or manipulated. The outflow from the tank passes through a valve with a resistance R to the output flow Q_2. The level of water or pressure head in the tank is denoted as H. We know that Q_2 will increase as H increases and when Q_2 equals Q_1 the level will become steady. The block diagram of this process is shown in Figure 2.4

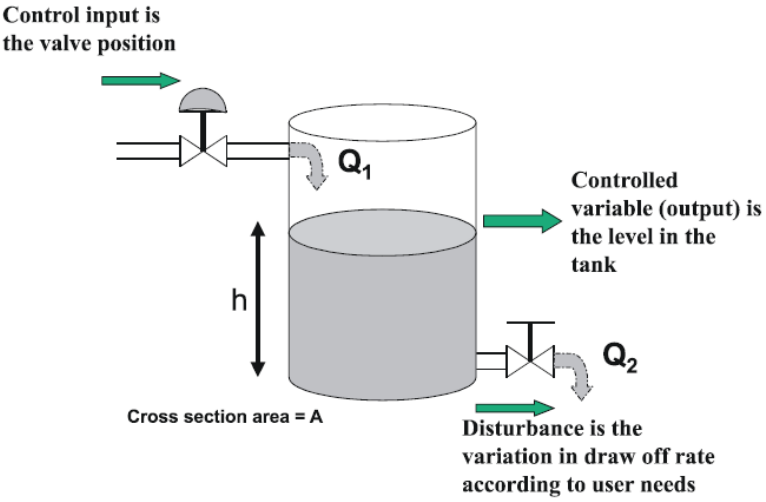


Figure (2.3): Example of a Water Tank With Controlled Inflow.

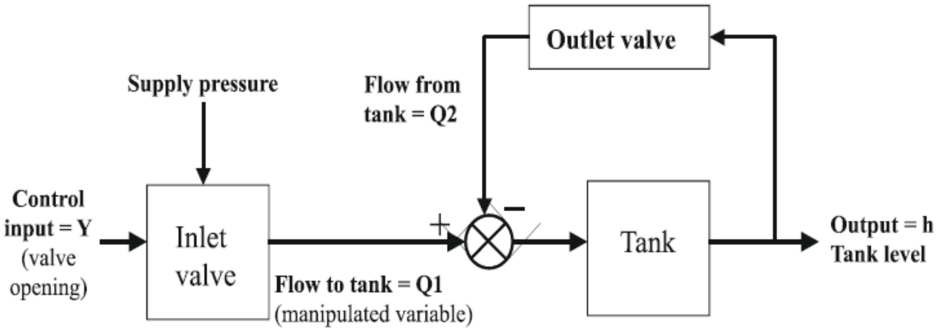


Figure (2.4): Elementary Block Diagram of Tank Process.

2.2.3. Process Control Modes

There are five basic forms of control available in Process Control:

- On-Off
- Modulating
- Open Loop
- Feed Forward
- Closed loop

On-Off control: The oldest strategy for control is to use a switch giving simple on-off control, as illustrated in Figure 2. 5. This is a discontinuous form of control action, and is also referred to as two-position control. A perfect on-off controller is 'on' when the measurement is below the set point (SP) and the manipulated variable (MV) is at its maximum value. Above the SP, the controller is 'off' and the MV is at a minimum.

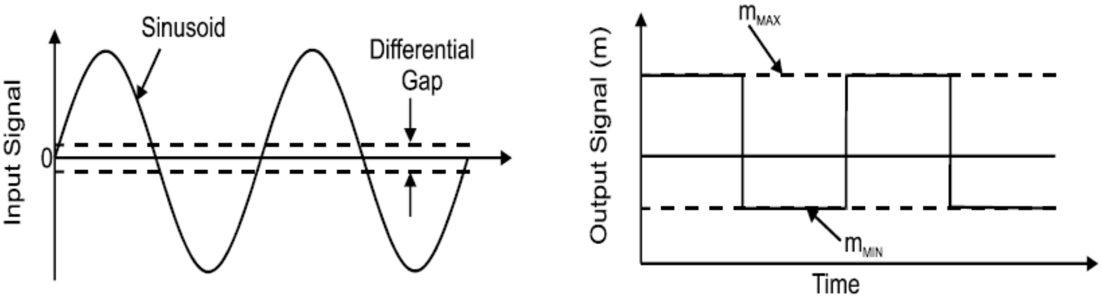


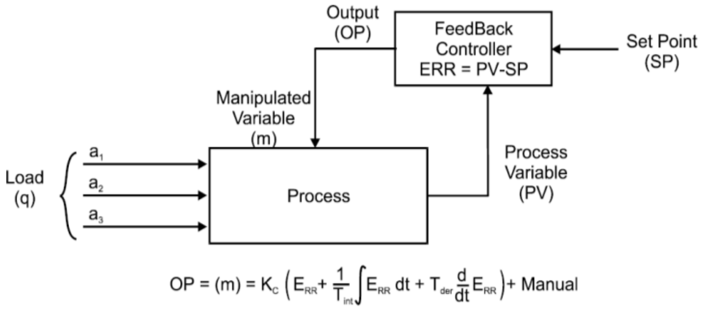
Figure (2.5): Response of a Two Positional Controller to a Sinusoidal Input.

Modulating control: If the output of a controller can move through a range of values, this is modulating control. Modulation Control takes place within a defined operating range only. That is, it must have upper and lower limits. Modulating control is a smoother form of control than step control. It can be used in both open loop and closed loop control systems.

Open loop control: The control action (Controller Output Signal OP) is not a function of the PV (Process Variable) or load changes. The open loop control does not self-correct, when these PV's drift.

Feed forward control: Feed forward control is a form of control based on anticipating the correct manipulated variables required to deliver the required output variable. It is seen as a form of open loop control as the PV is not used directly in the control action.

Closed loop or feedback control: If the PV, the objective of control, is used to determine the control action, it is called closed loop control system. The principle is shown below in Figure 2. 6.



$$OP = (m) = K_C \left(E_{RR} + \frac{1}{T_{int}} \int E_{RR}\, dt + T_{der} \frac{d}{dt} E_{RR} \right) + \text{Manual}$$

Figure (2.6): The Feedback Control Loop.

The idea of closed loop control is to measure the PV (Process Variable); compare this with the SP (Set Point), which is the desired, or target value; and determine a control action which results in a change of the OP (Output) value of an automatic controller. In most cases, the ERROR (ERR) term is used to calculate the OP value.

$$ERR = PV - SP$$

If ERR = SP - PV has to be used, the controller has to be set for REVERSE control action.

2.2.4. Process Dead Time

Overcoming the dead time in a feedback control loop can present one of the most difficult problems to the designer of a control system. This is especially true if the dead time is greater than 20% of the total time taken for the PV to settle to its new value after a change to the SP value of a system.

If the time from a change in the manipulated variable (controller output) and a detected change in the PV occurs, any attempt to manipulate the process variable before the dead time has elapsed will inevitably cause unstable operation of the control loop. Figure 2. 7 illustrates various dead times and their relationship to the PV reaction time.

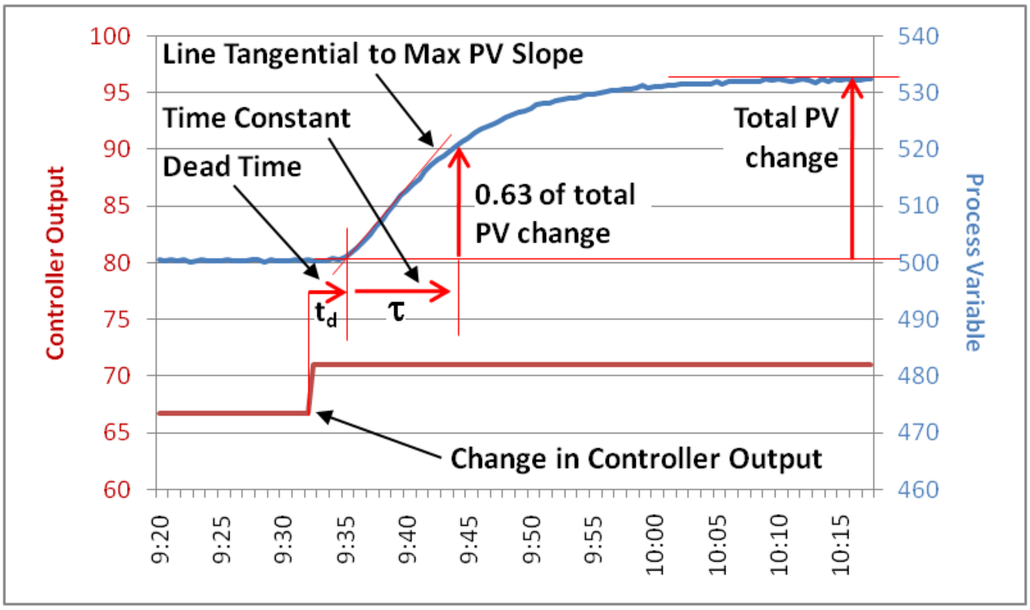


Figure (2.7): Process Dead Time and Time Constant.

Conveyor Belt weighing scale with hopper feeder is an example of a controlled system with dead time, the adjustment of conveying quantity for conveyor belt (Figure. 2.8). If the bulk material quantity fed to the conveyor belt is increased via slide gate, a change in the material quantity arriving at the discharge end of the belt (sensor location) is only noticed after a certain time, hence the process deadtime is the time taken from when the material leaves the hopper until it reaches the measurement transmitter..

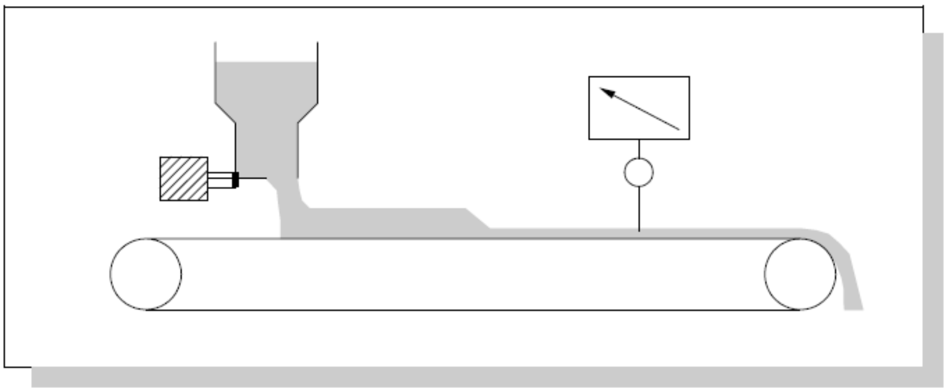


Figure (2.8): Controlled System with Dead Time.

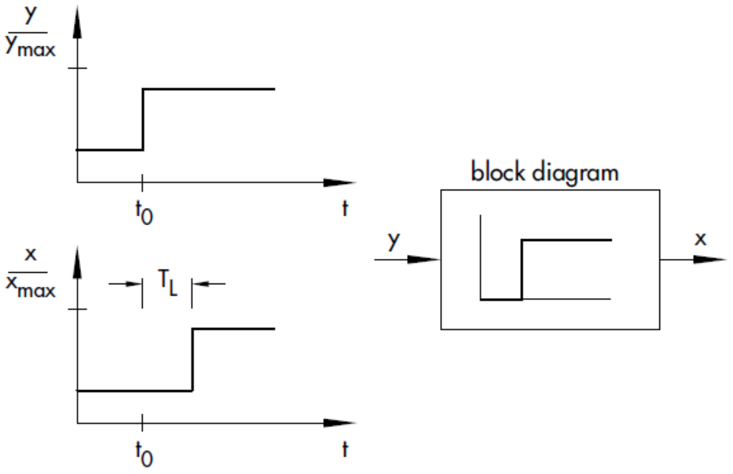


Figure (2.9): Dynamic Behavior Of A Controlled System With Dead Time

In Figure 2.9 we can observe the dynamic behavior of the conveyor belt weigher with hopper feeder where *y* represents the slide gate position; and *x* is the conveyor quantity.

2.3 Advanced Process Control

Advanced process control (APC) is a broad term within the control theory. It is composed of different kinds of process control tools, for example, model predictive control (MPC), statistical process control (SPC), Run2Run (R2R), fault detection and classification (FDC), sensor control and feedback systems. APC is often used for solving multivariable control problems or discrete control problems.

2.3.1. Predictive Control

Predictive control, or model predictive control (MPC), is one of only a few advanced control methods used successfully in industrial control applications. The essence of predictive control is based on three key elements:

- Predictive model,
- Optimization in range of a temporal window, and
- Feedback correction.

These three steps are usually carried on continuously by computer programs online. Predictive control is a control algorithm based on the predictive model of the process. The model is used to predict the future output based on the historical information of the process as well as the future input. It emphasizes the function of the model, not the structure of the model.

Predictive control is an algorithm of optimal control. It calculates future control actions based on a penalty function or performance function. The optimization of predictive control is limited to a moving time interval and is carried on continuously online. The moving time interval is sometimes called a temporal window. This is the key difference compared to traditional optimal control that uses a performance function to judge global optimization

Predictive control is also an algorithm of feedback control. If there is a mismatch between the model and process, or if there is a control performance problem caused by the system uncertainties, the predictive control could compensate for the error or adjust the model parameters based on on-line identification.

2.3.2. Model Predictive Control (MPC)

Model predictive control, or MPC, is an advanced method of process control. Model predictive controllers rely on dynamic models of the process, most often-linear empirical models obtained by system identification. The models are used to predict the behavior of dependent variables (i.e, outputs) of a dynamical system with respect to changes in the process independent variables (i.e., inputs). In chemical processes, independent variables are most often set points of regulatory controllers that govern valve movement (e.g. valve positioners with or without flow, temperature or pressure controller cascades), while dependent variables are most often constraints in the process (e.g. product purity, equipment safe operating limits). The model predictive controller uses the models and current plant measurements to calculate future moves in the independent variables that will result in an operation that honors all independent and dependent variable constraints. The MPC then sends this set of independent variable moves to the corresponding regulatory controller set points to be implemented in the process.

CHAPTER 3 PROCESS CONTROL FOR QUALITY IMPROVEMENT

3.1 Introduction

The goal of a manufacturing system is to produce multiple copies of the same product, each having attributes within specified tolerances. Variation reduction is one of the major techniques for achieving process stability and requires increasing amounts of process and equipment control at various levels of manufacturing systems. In particular, controlling complicated processes to produce smaller feature sizes is inherently difficult in semiconductor manufacturing. Some researchers attribute this difficulty to an insufficient number of sensors and actuators at each manufacturing process step for establishing a desired level of concurrent control over process parameters. Moreover, mathematical models incorporated into the control scheme rely on empirical data and are consequently imprecise.

Two categories of research and applications have been developed independently to achieve process control. Engineering process control (EPC) uses measurements to prescribe changes and adjust the process inputs with the intention of bringing the process outputs closer to targets. It employs feedback/feedforward controllers for process regulation and has gained a lot of popularity in continuous process industries. Statistical process control (SPC) uses measurements to monitor a process and look for major changes in order to eliminate the root causes of the changes. It has found widespread applications in discrete parts industries for process improvement, process parameter estimation, and process capability determination. Although both techniques aim at the same objective of reducing process variation, they have different origins and have used different implementation strategies for decades.

Practitioners of SPC argue that because of the complexity of manufacturing processes, EPC methods can very likely over control a process and increase process variability rather than decrease it. Moreover, important quality events may be masked by frequent adjustments and become difficult to detect and remove for ultimate quality improvement. On the other hand, practitioners of EPC criticize SPC methods for excluding the opportunities for reducing the variability in the process output. Owing to the stochastic nature of manufacturing processes, traditional SPC methods always generate too many false alarms and fail to discriminate quality deterioration from the in-control state defined by SPC rules. Recently, an integration of EPC and SPC methods has emerged in semiconductor manufacturing and has resulted in a tremendous improvement of industrial efficiency Sachs, et al. [9] .

The EPC/SPC integration employs an EPC control rule to regulate the system and superimposes SPC charts on the EPC system to detect process departures from the system model. Both academic research and industrial practice have shown the effectiveness of the EPC/SPC integration model when the process is subjected to both systematic variations and special-cause variations. To avoid confusion, we may refer to EPC activities as process adjustment and to SPC activities as process monitoring.

3.2 Engineering Process Control

Engineering process control is a popular strategy for process optimization and improvement. It describes the manufacturing process as an input–output system where the input variables (recipes) can be manipulated (or adjusted) to counteract the uncontrollable disturbances to maintain the process target. The output of the process can be measurements of the final product or critical in-process variables that need to be controlled. In general, without any control actions (adjustment of inputs), the output may shift or drift away from the desired quality target owing to disturbance. These disturbances often are not white noise but exhibit a dependence on past values. It is thus possible to anticipate the process behavior based on past observations and to control the process by adjusting the input variables.

Engineering process control requires a process model. A simple but useful process model that describes a linear relationship between process inputs and outputs is,

$$e_t = gX_{t-1} + D_t \ , \tag{3.1}$$

where et and X_t represent the process output and input (control) deviations from target, D_t the process disturbances that pass through part of the system and continue to affect the output, and g the process gain that measures the impact of input control to process outputs. To simplify our discussion, we assume that the process gain is unity, i.e., g = -1. When no process control is involved, the process output is simply the disturbance, and the variance of the output is obtained as σ_D^2 . The objective of process control is to reduce process variations by adjusting inputs at the beginning of each run, i.e, $\sigma_e^2 < \sigma_D^2$ where σ_e^2 is the variance of the controlled output.

Theoretically, only predictable deviations can be quantified by EPC methods. Modeling errors due to process changes are generally hard to capture in real time and to compensate for with EPC schemes. Various adaptive EPC schemes that dynamically adjust control parameters have been investigated. Recently, an adaptive framework has been proposed in semiconductor manufacturing (by superimposing) an SPC scheme to monitor modeling errors and revise the process models Sachs, et al. [9].

3.3 Statistical Process Control (SPC)

If a product is to meet or exceed customer expectations, generally it should be produced by a process that is stable or repeatable. More precisely, the process must be capable of operating with little variability around the target or nominal dimensions of the product's quality characteristics. Statistical process control (SPC) is a powerful collection of problem-solving tools useful in achieving process stability and improving capability through the reduction of variability.

SPC is one of the greatest technological developments of the twentieth century because it is based on sound underlying principles, is easy to use, has significant impact, and can be applied to any process. Its seven major tools are

1. Histogram or stem-and-leaf plot
2. Check sheet
3. Pareto chart
4. Cause-and-effect diagram

5. Defect concentration diagram
6. Scatter diagram
7. Shewhart Control chart

Of the seven tools, the Shewhart control chart is probably the most technically sophisticated. It was developed in the 1920s by Walter A. Shewhart of the Bell Telephone Laboratories. Montgomery [10]

3.3.1. Basic Principles

A typical control chart is shown in Figure. 2.10. The control chart is a graphical display of a quality characteristic that has been measured or computed from a sample versus the sample number or time. The chart contains a centerline that represents the average value of the quality characteristic corresponding to the in-control state. (That is, only chance causes are present.) Two other horizontal lines, called the upper control limit (UCL) and the lower control limit (LCL), are also shown on the chart. These control limits are chosen so that if the process is in control, nearly all of the sample points will fall between them. As long as the points plot within the control limits, the process is assumed to be in control, and no action is necessary. However, a point that plots outside of the control limits is interpreted as evidence that the process is out of control, and investigation and corrective action are required to find and eliminate the assignable cause or causes responsible for this behavior. It is customary to connect the sample points on the control chart with straight-line segments, so that it is easier to visualize how the sequence of points has evolved over time.

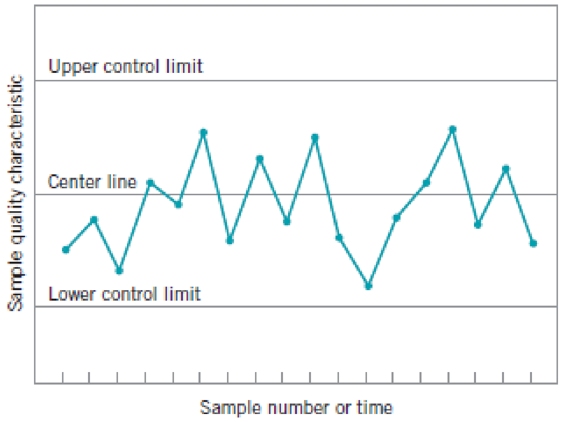


Figure (3.1): A typical Control Chart.

3.3.2. Common-Cause Variations

Common-cause variations are the basic assumption on which the SPC methods are based. This assumes that the sample comes from a known probability distribution, and the process is classified as “statistically” in control. In other words, “the future behavior can be predicted within probability limits determined by the common-cause system”. This kind of variation, from a management point of view, is inherent in the process and is difficult or impossible to eliminate.

3.3.3. Special-Cause Variations

Based on Shewhart's classification, Deming [11] argues that a special cause of variations is "something special, not part of the system of common causes," and should be identified and removed at the root. That is, the process output should be consistent with the postulated stable behavior or the common-cause model when the process is statistically in control, and whenever any deviation occurs from the common- cause model, one should look for it and try to eliminate it.

Statistical control charts essentially mimic a sequential hypothesis test to discriminate special causes of variations from the common-cause variation model. For example, a basic mathematical model behind monitoring process mean changes is

$$e_t = \eta_t + X_t \quad , \tag{3.2}$$

where e_t is the measurement of the process variable at time t, and η_t is the process mean at that time. Here, X_t represents variations from the common-cause system and is inherent in the process. In some applications, X_t is or can be treated as an independently and identically distributed (i.i.d.) process. With few exceptions, the mean of the process is constant except for occasional abrupt changes, i.e.,

$$\eta_t = \eta + \mu_t \, , \tag{3.3}$$

where η is the mean target, and μ_t is zero for $t < t_0$ and has nonzero values for $t > t_0$. For example, if the special cause is a step-like change, μ_t is a constant μ after t_0. The goal of SPC charts is to detect the change point t_0 as quickly as possible so that corrective actions can be taken before quality deteriorates and defective units are produced. Among many others, the Shewhart chart, the exponentially weighted moving average (EWMA) chart, and the cumulative sum (CUSUM) chart are three important and widely used control charts.Montgomery [10]

In typical applications of SPC charts, a fundamental assumption is that the common-cause variation is free of serial correlation. Unfortunately, the assumption of independence is often invalid in many manufacturing processes. For example, in discrete parts industries, the development of sensing and measurement technology has made it possible to measure critical dimensions on every unit produced, and in continuous process industry, the presence of inertial elements, such as tanks, reactors, and recycle streams, results in significant serial correlation in measurement variables. Serial correlations call for EPC techniques to reduce variations and present new challenges and opportunities to SPC for quality improvement.

3.3.4. Conventional SPC

SPC has been traditionally achieved by successive plotting and comparing a statistical measure of the variable with some user defined 'control' limits. If the plotted statistic exceeds these limits, the process is considered to be out of statistical control. Corrective action is then applied in the form of identification, elimination or compensation for the 'assignable' causes of variation. The most common charts used are the Shewhart, Exponential Moving Average (EWMA), range and Cumulative Sum (CuSum) charts.

3.3.5. Algorithmic SPC:

Conventional SPC is an off-line technique. Whilst there are many reports of successful cases in the parts manufacturing sector, this 'passive' control strategy does not suit continuous systems. Here, in addition to keeping products within specifications, there is a requirement to keep the process operating. Depending on the complexity of the process, the time taken to identify, eliminate and compensate for assignable causes of variation may not be acceptable. Nevertheless, the aim of both automatic process control and SPC is to increase plant profitability. Thus, it is reasonable to expect that the merger of these two apparently dichotomous methodologies could yield strategies that inherit the benefits associated with the parent approaches. This has been a subject of recent investigations where SPC is used to monitor the performances of automatic control loops. Such a strategy is sometimes called 'Algorithmic SPC' (ASPC), referring to the integrated use of algorithmic model based controllers and SPC techniques. Note, though, that the process is still being controlled by an automatic controller that is the process is being controlled all the time.

3.3.6. Active SPC:

Another way to integrate the two control approaches is to provide on-line SPC. Statistical models are used not only to define control limits, but also to develop control laws that suggest the degree of manipulation to maintain the process under statistical control. Thus, in applications to continuous processes, the need for an algorithmic automatic controller is avoided, leading to a direct or 'active' SPC strategy. Indeed, the technique is designed specifically for continuous systems. In contrast to ASPC, manipulations are made only when necessary, as indicated by detecting violation of control limits. As a result, compared to automatic control and ASPC, savings in the use of raw materials and utilities can be achieved using active SPC.

3.3.7. Process Improvement using Control Charts

The most important use of a control chart is to improve the process. Generally, most processes do not operate in a state of statistical control, and consequently, the routine and attentive use of control charts will identify assignable causes. If these causes can be eliminated from the process, variability will be reduced and the process will be improved. This process improvement activity using the control chart is illustrated in Figure. 3.2. We note that the control chart will only detect assignable causes. Management, operator, and engineering action will usually be necessary to eliminate the assignable causes. In identifying and eliminating assignable causes, it is important to find the root cause of the problem and to attack it. A cosmetic solution will not result in any real, long-term process improvement. Developing an effective system for corrective action is an essential component of an effective SPC implementation.

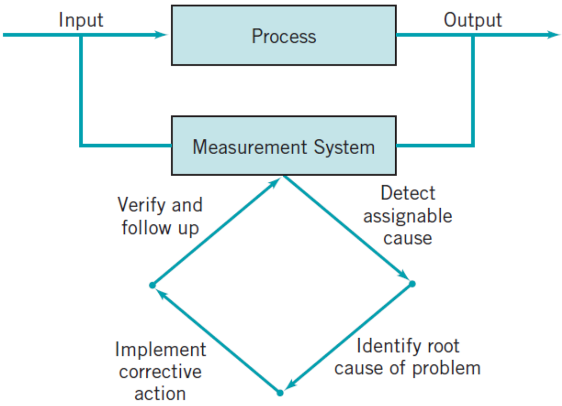


Figure (3.2): Process Improvement using The Control Chart.

3.3.8. Integration of EPC/SPC Run-to-Run Control

Engineering process control and SPC are two complementary strategies developed in different industries for quality improvement. There is a corresponding relationship between them through prediction.

The relationship between EPC and SPC through prediction has been recently explored in many industrial applications. To make an appropriate selection between the two approaches in practice, it is important to identify disturbance structures and strengths of the two control methods to influence the process. There are four categories of ongoing research and applications of the two quality-control approaches.

- If a process is not correlated, there is no need to employ EPC schemes. Traditional SPC control charts should be used for identifying assignable cause variations.
- When data are correlated, the possibility of employing EPC techniques should be examined. SPC control charts are called for to monitor autocorrelated processes if no feasible EPC controller exists.
- If appropriate controllers are available, EPC control schemes can be employed to compensate for the autocorrelated disturbance. However, no single EPC controller system can compensate for all kinds of potential variations.
- To identify and understand the cause of process changes, a unified control framework should be applied to regulate a process using feedback control while using the diagnostic capability of SPC to detect sudden shift disturbances to the process.

The integration of EPC/SPC looks for the best opportunities of quality improvement by integrating and combining the strengths of EPC and SPC among the various levels of control that may be incorporated into a manufacturing system. Run-to-run (R2R) or sequential optimization and control is a typical realization of EPC/SPC integration in semiconductor manufacturing. The R2R controller is a model-based process control system in which the controller provides recipes (inputs) based on post-process measurements at the beginning of each run, updates the process model according to the measurements at the end of the run, and provides new recipes for the next run of the process. It generally does not modify recipes during a run because obtaining real-time information is usually very expensive in a semiconductor process and because frequent changes of inputs to the process may increase the variability of the process's outputs and possibly even make the process unstable. A block diagram of such an R2R controller is shown in Figure 3.3.

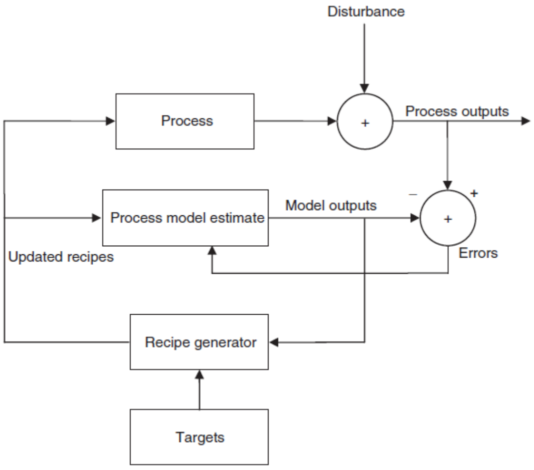


Figure (3.3): Structure of Run-to-Run Controller.

A good R2R controller should be able to compensate for various disturbances, such as process drifts, process shifts due to maintenance or other factors, model or sensor errors, etc. Moreover, it should be able to deal with the limitations, bounds, cost requirements, multiple targets, and time delays that are often encountered in real processes. The initial R2R process control model can be derived from former experiments using statistical methods such as the response surface model (RSM). When the controller is employed online, the model within the controller is updated according to the new measurements from run to run. A typical R2R system consists of three components: diagnosis module, gradual module, and rapid module.

Diagnosis module. It is a generalized SPC to distinguish between slow drifts and rapid shifts and decide if the process is running in accordance with the current process model. Since the inputs experience small changes, it is generally impossible to apply standard control charts to monitor the outputs.

Gradual module. This module uses historical data to linearly update process models by giving less weight to old data. A pure I control is typically employed when the process can be well approximated by linear models.

Rapid module. This module quickly updates the process model based on changes detected by the diagnosis module. It must accomplish tasks such as estimating the magnitude and location of the disturbance, assessing sequentially the probability that a change actually took place given new available data, and using estimations of the disturbance to prescribe control actions. Sachs, et al. [9]

CHAPTER 4 SCADA (SUPERVISORY CONTROL AND DATA ACQUISITION)

In "IEEE Standard for SCADA and Automation Systems" 2008 [9], the requirements for SCADA and automation systems in substations are defined. This standard defines the process of substation integration as the design process that is the foundation for substation automation. Functional and environmental requirements are provided for all IEDs located in the system.

According to these standards, SCADA (supervisory control and data acquisition) is defined as a type of industrial control system (ICS). Industrial control systems are computer controlled systems that monitor and control industrial processes that exist in the physical world. SCADA systems historically distinguish themselves from other ICS systems by being large-scale processes that can include multiple sites, and large distances. These processes include industrial, infrastructure, and facility-based processes, as described below:

Industrial Processes: include those of manufacturing, production, power generation, fabrication, and refining, and may run in continuous, batch, repetitive, or discrete modes.

Infrastructure Processes: may be public or private, and include water treatment and distribution, wastewater collection and treatment, oil and gas pipelines, electrical power transmission and distribution, wind farms, civil defense siren systems, and large communication systems.

Facility Processes: occur both in public facilities and private ones, including buildings, airports, ships, and space stations. They monitor and control heating, ventilation, and air conditioning systems (HVAC), access, and energy consumption.

4.1 Common System Components

A SCADA system usually consists of the following major control components:

- **Control Server.** The control server hosts the DCS or PLC supervisory control software that is designed to communicate with lower-level control devices. The control server accesses subordinate control modules over an ICS network.
- **SCADA Server or Master Terminal Unit (MTU).** The SCADA Server is the device that acts as the master in a SCADA system. Remote terminal units and PLC devices (as described below) located at remote field sites usually act as slaves.
- **Remote Terminal Unit (RTU).** The RTU, also called a remote telemetry unit, is special purpose data acquisition and control unit designed to support SCADA remote stations. RTUs are field devices often equipped with wireless radio interfaces to support remote situations where wire-based communications are unavailable. Sometimes PLCs are implemented as field devices to serve as RTUs; in this case, the PLC is often referred to as an RTU.
- **Programmable Logic Controller (PLC).** The PLC is a small industrial computer originally designed to perform the logic functions executed by electrical hardware (relays, drum switches, and mechanical timer/counters).

PLCs have evolved into controllers with the capability of controlling complex processes, and they are used substantially in SCADA systems and DCSs. Other controllers used at the field level are process controllers and RTUs; they provide the same control as PLCs but are designed for specific control applications. In SCADA environments, PLCs are often used as field devices because they are more economical, versatile, flexible, and configurable than special-purpose RTUs.

- **Intelligent Electronic Devices (IED).** An IED is a “smart” sensor/actuator containing the intelligence required to acquire data, communicate to other devices, and perform local processing and control. An IED could combine an analog input sensor, analog output, low-level control capabilities, a communication system, and program memory in one device. The use of IEDs in SCADA and DCS systems allows for automatic control at the local level.
- **Human-Machine Interface (HMI).** The HMI is software and hardware that allows human operators to monitor the state of a process under control, modify control settings to change the control objective, and manually override automatic control operations in the event of an emergency. The HMI also allows a control engineer or operator to configure set points or control algorithms and parameters in the controller. The HMI also displays process status information, historical information, reports, and other information to operators, administrators, managers, business partners, and other authorized users. The location, platform, and interface may vary a great deal. For example, an HMI could be a dedicated platform in the control center, a laptop on a wireless LAN, or a browser on any system connected to the Internet.
- **Data Historian.** The data historian is a centralized database for logging all process information within an ICS. Information stored in this database can be accessed to support various analyses, from statistical process control to enterprise level planning.
- **Input/Output (IO) Server.** The IO server is a control component responsible for collecting, buffering and providing access to process information from control sub-components such as PLCs, RTUs and IEDs. An IO server can reside on the control server or on a separate computer platform. IO servers are also used for interfacing third-party control components, such as an HMI and a control server.

4.2 Network Components

There are different network characteristics for each layer within a control system hierarchy. Network topologies across different ICS implementations vary with modern systems using Internet-based IT and enterprise integration strategies. Control networks have merged with corporate networks to allow engineers to monitor and control systems from outside of the control system network. The connection may also allow enterprise-level decision-makers to obtain access to process data. The following is a list of the major components of an ICS network, regardless of the network topologies in use:

- **Fieldbus Network.** The fieldbus network links sensors and other devices to a PLC or other controller. Use of fieldbus technologies eliminates the need for point-to-point wiring between the controller and each device. The sensors communicate with the fieldbus controller using a specific protocol. The messages sent between the sensors and the controller uniquely identify each of the sensors.

- **Control Network.** The control network connects the supervisory control level to lower-level control modules.
- **Communications Routers.** A router is a communications device that transfers messages between two networks. Common uses for routers include connecting a LAN to a WAN, and connecting MTUs and RTUs to a long-distance network medium for SCADA communication.
- **Firewall.** A firewall protects devices on a network by monitoring and controlling communication packets using predefined filtering policies. Firewalls are also useful in managing ICS network segregation strategies.
- **Modems.** A modem is a device used to convert between serial digital data and a signal suitable for transmission over a telephone line to allow devices to communicate. Modems are often used in SCADA systems to enable long-distance serial communications between MTUs and remote field devices. They are also used in both SCADA systems, DCSs and PLCs for gaining remote access for operational functions such as entering command or modifying parameters, and diagnostic purposes.
- **Remote Access Points.** Remote access points are distinct devices, areas and locations of a control network for remotely configuring control systems and accessing process data. Examples include using a personal digital assistant (PDA) to access data over a LAN through a wireless access point, and using a laptop and modem connection to remotely access an ICS system.

4.3 Systems Concepts

The term SCADA usually refers to centralized systems which monitor and control entire sites, or complexes of systems spread out over large areas (anything from an industrial plant to a nation). Most control actions are performed automatically by RTUs or by PLCs. Host control functions are usually restricted to basic overriding or supervisory level intervention. For example, a PLC may control the flow of cooling water through part of an industrial process, but the SCADA system may allow operators to change the set points for the flow, and enable alarm conditions, such as loss of flow and high temperature, to be displayed and recorded. The feedback control loop passes through the RTU or PLC, while the SCADA system monitors the overall performance of the loop.

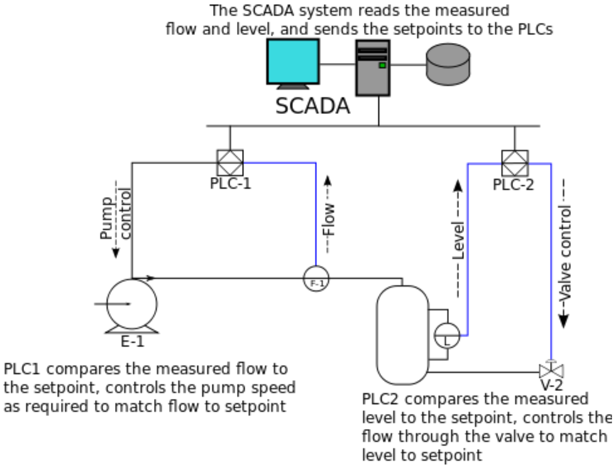


Figure (4.1): SCADA's Schematic Overview. [12]

Data acquisition begins at the RTU or PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to an Historian, often built on a commodity Database Management System, to allow trending and other analytical auditing.

SCADA systems typically implement a distributed database, commonly referred to as a tag database, which contains data elements called tags or points. A point represents a single input or output value monitored or controlled by the system. Points can be either "hard" or "soft". A hard point represents an actual input or output within the system, while a soft point results from logic and math operations applied to other points. (Most implementations conceptually remove the distinction by making every property a "soft" point expression, which may, in the simplest case, equal a single hard point.) Points are normally stored as value-timestamp pairs: a value, and the timestamp when it was recorded or calculated. A series of value-timestamp pairs gives the history of that point. It is also common to store additional metadata with tags, such as the path to a field device or PLC register, design time comments, and alarm information.

4.4 SCADA, Integrated Industrial Control System ICS

The key components of SCADA integrated ICS include the following

- **Control Loop.** A control loop consists of sensors for measurement, controller hardware such as PLCs, actuators such as control valves, breakers, switches and motors, and the communication of variables. Controlled variables are transmitted to the controller from the sensors. The controller interprets the signals and generates corresponding manipulated variables, based on set points, which it transmits to the actuators. Process changes from disturbances result in new sensor signals, identifying the state of the process, to again be transmitted to the controller.
- **Human-Machine Interface (HMI).** Operators and engineers use HMIs to configure set points, control algorithms, and adjust and establish parameters in the controller. The HMI also displays process status information and historical information.

- **Remote Diagnostics and Maintenance Utilities.** Diagnostics and maintenance utilities are used to prevent, identify and recover from failures.

A typical SCADA integrated ICS Figure 4.2 contains a proliferation of control loops, HMIs, and remote diagnostics and maintenance tools built using an array of network protocols on layered network architectures. Sometimes these control loops are nested and/or cascading –whereby the set point for one loop is based on the process variable determined by another loop. Supervisory-level loops and lower-level loops operate continuously over the duration of a process with cycle times ranging on the order of milliseconds to minutes.

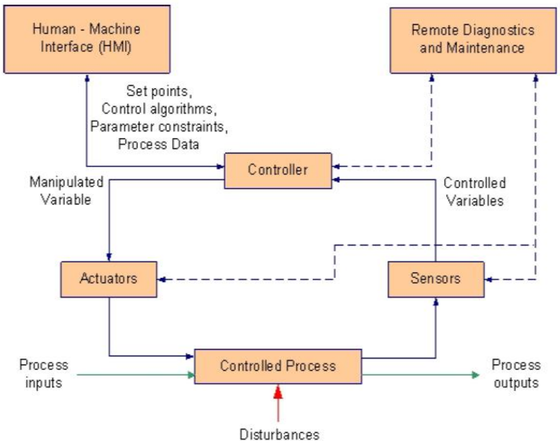


Figure (4.2): SCADA Integrated ICS.

4.5 Role of SCADA in Quality Management

A production process includes the quality assurance testing of samples from each product lot. The test data is used to produce a certificate of conformance Report for such a lot. The data is being collected from test equipment, then sometimes manually entered into a customized database form, and then formatted to produce the Certificate of Conformance. Manual data entry is time-consuming, error-prone, and repetitive. Here is the challenge to introduce a supervisory control system to automate that process and integrate data collection with its other manufacturing systems. With the automation of the quality assurance process by electronically collecting data from the measurement tools, the operator does not need to write test measurements into a form and then into a computerized spreadsheet. Dozens of samples with up to hundreds of measurements are displayed; with manual work, the system can only handle a limited number of measurements. In being automated, it can be upgraded to manage much more. After data collection, a system can retrieve the expected measurement values from database for the samples of that lot.

A summary screen might he immediately displayed to the operator indicating, for each sample, whether all measurements were within control limits, Within specification limits, or outside specification limits. The operator can also view details about each sample and adjust the data manually. Any data modifications are stored in an audit trail, and the initial raw data is kept for historical records. When the operator is satisfied that the data is correct, the system sends this validated data to its database, and it is possible to produce the Certificate of Conformance. Time saving for these procedures is significant: it could easily take an operator longer to record the measurement data than it takes the tool to create it. A supervisory control system brings the time for the whole process, from measurement to a report, down to a matter of seconds.

In order to stay on top of a competitive market, companies have to keep their production costs as low as possible. One element of their strategy is to collect production and control data, analyze it to find improvements, and incorporate those improvements in each new plant. To be profitable, these plants must run 24 hours a day, 7 days a week, If a machine has a wrong setting, it reduces production or creates a waste product. If a company has to track process and product information, offline quality testing results, and data from tens of thousands of I/O points, the communication link used may not respond quickly enough, or reliably enough, to handle these requirements. The role of including quality control with its other control systems may lie in the automating the control and information flow of plants, in integrating processing machines, the Manufacturing Execution Systems (MES) that monitor the processes, and in the data-based Enterprise Resource Planning (ERP) system that provides decision support.

The complete system block diagram in Figure 4.3 presents the role of the SCADA system , the quality measurement data is collected from the final product and stored in special registers inside the Controller/ RTU which in this case the programmable logic controller PLC, this data is transferred to the SCADA node using industrial network which could be local or remote network, this data is analyzed and a control decision to tune the controller if necessary to ensure that the product is within the bounds of required quality.

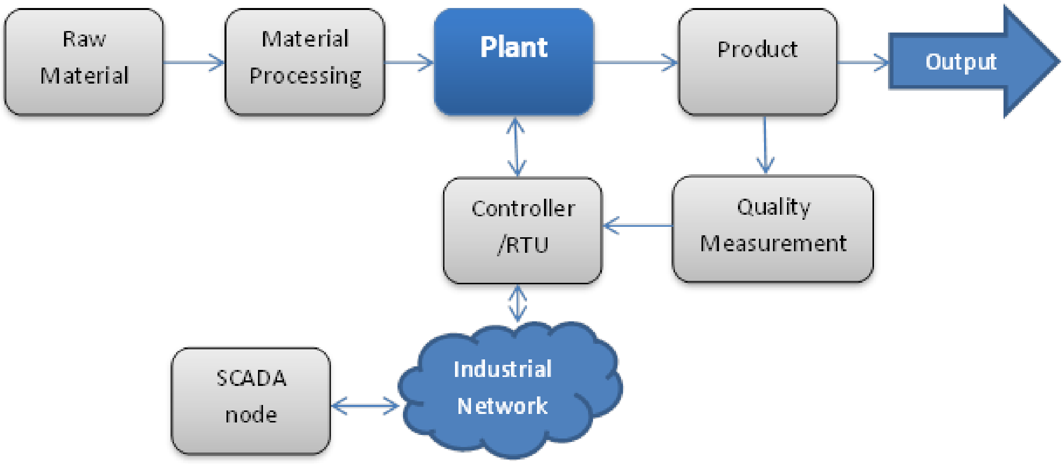


Figure (4.3): Complete System Block Diagram.

CHAPTER 5 CONCRETE PLANT AUTOMATION

5.1 Introduction

A concrete plant, also known as a batch plant, is a complex device that combines various raw ingredients to form concrete. Some of these inputs include sand, water, aggregate (rocks, gravel, etc.), chemical additives, and cement. There are two types of concrete plants: ready mix plants and central mix plants. A concrete plant can have a variety of parts and accessories, including but not limited to: mixers (either tilt-up or horizontal or in some cases both), cement batchers, aggregate batchers, conveyors, radial stackers, aggregate bins, cement bins, cement silos, and batch plant controls.

The center of the concrete batching plant is the mixer. There are three types of mixers: Tilt, pan, and twin shaft mixer. The twin shaft mixer can ensure an even mixture of concrete and large output, while the tilt mixer offers a consistent mix with much less maintenance labor and cost.

All concrete plants have similar operations despite that may vary in the types of components and level of automation. Their main function is to proportion the various components in the exact quantities, which will make the specified concrete.

There are more than 50 concrete batching plants in Gaza Strip, of which only 16 plants are certified from the engineering syndicate.

There are less than five automated concrete plants in Gaza Strip; none of these plants has any quality management functions during the batching process.

5.2 Plant Types

A ready mix plant combines all ingredients except for water at the concrete plant. This mixture is then discharged into a ready mix truck (also known as a concrete transport truck). Water is then added to the mix in the truck and mixed during transport to the job site.

A central mix plant combines some or all of the above ingredients (including water) at a central location. The final product is then transported to the job site. Central mix plants differ from ready mix plants in that they offer the end user a much more consistent product, since all the ingredient mixing is done in a central location and is computer-assisted to ensure uniformity of product. A temporary batch plant can be constructed on a large job site. A concrete plant becomes central mix with the addition of a concrete mixer. The only available concrete batching plants in Gaza Strip are the ready mix plant type.

5.3 Batch Plant Layout and Operation

Concrete mixing plant is mainly composed of material weighing systems, material-handling systems, material storage system and control system and other ancillary facilities. The batching unit, aggregate conveying unit, water supplying and additive agent supplying system, scaling system, mixing system, electrical control system and pneumatic system are centralized in one location.

A complete layout diagram of a typical ready mix concrete batching plant is shown in Figure 5.1, and will be covered in our study.

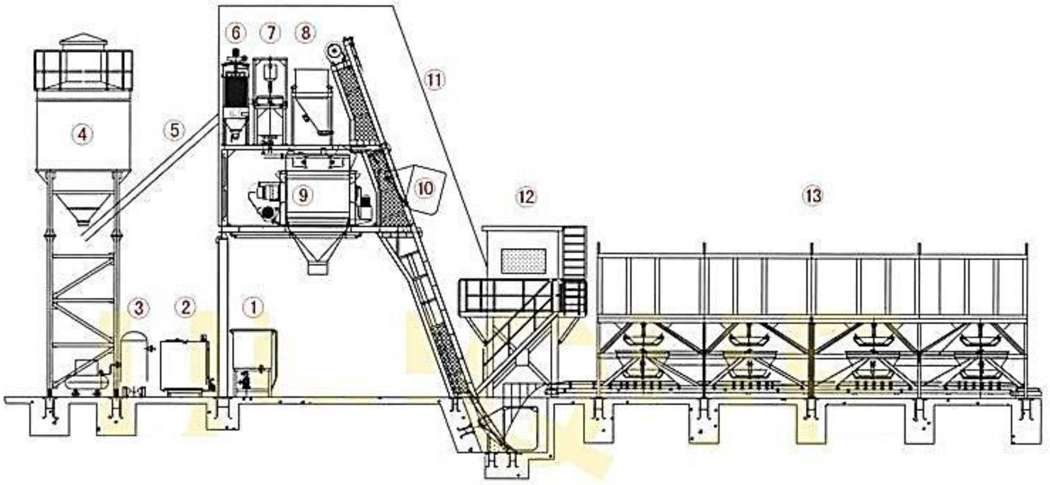


Figure (5.1): Concrete Plant Layout

1. Water Supply system
2. Admixtures supply system
3. Compressed Air Supply system
4. Cement storage system
5. Cement screw conveyor
6. Cement batching system
7. Additives batching system
8. Water feeding system
9. Material bin mixer
10. Aggregate feeding system
11. Equipment protection cover
12. Control system
13. Aggregate storage system

Batching is the process of weighing and introducing into the mixer the ingredients for a batch of concrete. All raw materials, cement, aggregates, water and admixtures are weighted and batched, at the aggregate and cement weigh hoppers and at the admixtures weigh cylinder respectively. Our plant has five different types of aggregates each one stored in separate feeder bin. Cement powder is stored in silos. weigh hoppers have only one weigh conveyor and hence each type of aggregates is added consequently and not altogether. Admixtures, which are in liquid form, have only one storage tank. Water is controlled using a meter system measuring the volume required. Finally, the mixing process is carried out in the truck mixer during the transportation to the construction site, all the material must be mixed thoroughly until it is uniform in appearance and all ingredients are evenly distributed. The most crucial factor concerning concrete type and its mechanical and chemical properties is the materials proportion. Furthermore, other essential parameters such as material hierarchy regarding the input sequence in the mixer and the mixing time need to be considered in order to ensure the quality objective. All parameters regulated or not, are specified in the corresponding recipe specification sheet used for each concrete mix. A flowchart of the overall process is depicted in Figure. 5.2, where all the actions for batching and mixing are shown. When production starts, system operator has to choose the desired recipe and insert the wanted quantity of concrete through a SCADA graphic user interface. Then, the batching process starts for the three different kinds of materials (there is no need for batching water), and process continues to the next step, which is the mixing process, only when all ingredients are batched properly. Mixing process starts simultaneously with the material induction in the mixer. Induction hierarchy, as noted above, depends on the specific recipe chosen. After all ingredients are placed into the mixer, the mixing process starts while truck mixer is loaded with concrete. When truck loading ends and all the material weighers are empty, the production is completed and the system is ready for a new one.

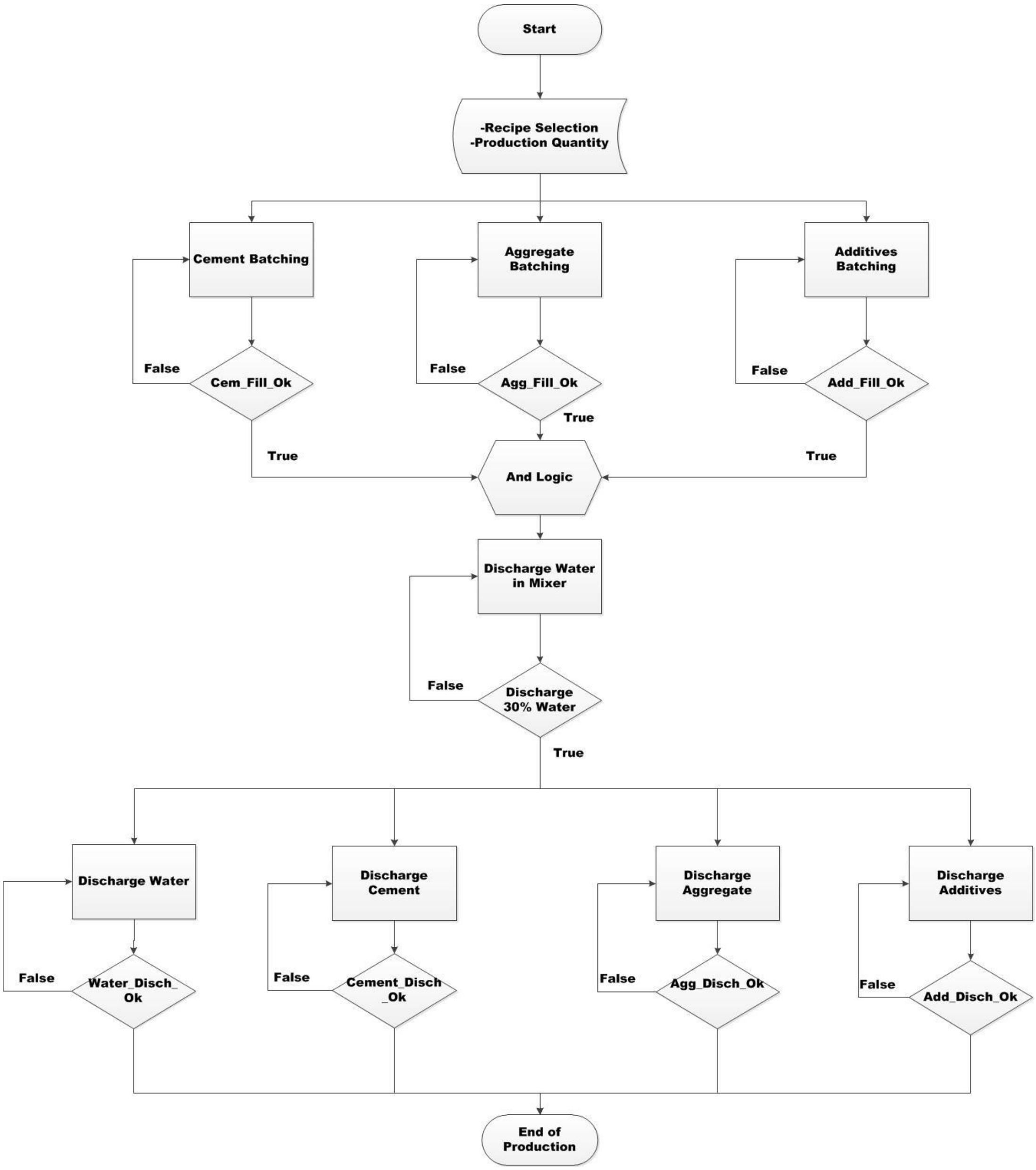


Figure (5.2): Batching and Mixing Process Flowchart.

5.4 Aggregate Batcher (Scale)

5.4.1. Discharge Gates

Aggregate batcher discharge gate(s) are operated by a pneumatic cylinder. The cylinder receives air from a double acting solenoid valve that operates from an electrical signal from the batch control.

To operate a double acting (inching) solenoid valve two signals are required an open and a closed, both signals need to be momentary. Flow controls are installed on the solenoid valve or cylinder that regulates the airflow to the cylinder. The flow controls are installed allowing the operator to regulate the speed at which the cylinders move to allow for precise control of the gates. During normal operation of the plant, the batch control will control the operation of the gates and the discharge rates. The batch control does need to be programmed properly to operate the gate efficiently. Below are some settings that may affect the operation of the gate. Note: These settings may be labeled differently depending on the manufacturer of the control.

Flow Rate (Minimum and Maximum)-Most batch controls try to obtain a flow rate when discharging; they will typically try to stay in a range and work off of a minimum and maximum setting. The settings for this need to be determined for each plant individually.

Initial Open-The initial open setting is used to get the gate opened at the start of discharge. Typically the initial open setting should get the gate ¼ - 1/3 of the way open with the first pulse or to get a good flow rate started.

Open and Close Pulse-After the discharge gate has been opened with the initial open pulse, the open and close pulse takes over for the remainder of discharge. If the batch control determines the flow rate needs to be adjusted, a pulse will be sent to the open or close the gate depending on if the discharge rate needs to increase or decrease. Each open or close pulse should move the cylinder 1/8 of its overall travel.

5.4.2. Discharge-Feed Interlock

The air cylinders that actuate the discharge gates of the aggregate batcher are equipped with a reed switch (limit switch) attached to a tie rod. The piston of the air cylinder has a magnetic strip on it that the reed switch senses. The reed switch is used to let the batch control know if the discharge gate or gates are closed. If the batch control does not see a closed signal from the reed switch, it will not allow material to be fed into the scale. Located on most batch control is an indicator light that verifies when the gate or gates are closed.

5.4.3. Vibrators

Aggregate batchers are equipped with a pneumatic vibrator. The vibrator receives air to operate from a single acting pneumatic valve. The electrical signal to the valve for the vibrator should be momentary. The vibrator for the aggregate batcher should be setup in the batch control to come on to help clean out the batcher at the end of each batch. The vibrator should be set up to come on when there is less than 500 Kgs of material in the scale. The vibrator can also be set up in most batch controls to activate if the flow of material drops below a certain rate (kgs/sec) or stops. The overuse or misuse of vibrator can cause damage to the batcher steel and vibrator mount.

5.4.4. Aggregate Feed Gates Operation

The aggregate feed gates are used to discharge material from the aggregate storage bins into the aggregate batcher. The gates are equipped with air cylinders that are operated by pneumatic valves as shown in Figure 5.3. The valves that operate these gates are single acting valves, which require a momentary button in the batch control. When the valve receives a signal from the batch control the gate will open, when the signal is removed the gate will close.

Each aggregate gate has an air cylinder that is equipped with a quick exhaust valve plumbed into the rod end port of the cylinder. The quick exhaust valve is installed to exhaust the air at the cylinder instead of it having to travel back to the valve to be exhausted. This allows the gate to close quickly and reduce the chance of over weighing.

Figure (5.3): Charging Hopper Feed Gates.

5.4.5. Belt scale system

In-motion belt scale systems are used for providing accurate weighing measurements of aggregate materials. A wide variety of belt scale systems are available to provide vital information for the effective management and efficient operation of a business. Most belt scale systems comprise three major elements: the weighbridge with load cell(s), the belt speed sensor and an electronic integrator. The weighbridge attaches to a conveyor's stringers and supports the weigh idler, while the load cell(s) measure the weight of material on the belt. The speed sensor is mechanically connected to the conveyor's tail pulley and generates a stream of pulses. Each pulse represents a unit of travel. The frequency of the pulse stream is proportional to belt speed. The electronics integrate the output signals from the load cell(s) and speed sensor to arrive at a rate of material flow and total material passed over the scale. The model chosen very much depends on the application. as shown in Figure 5.4 Some belt scales provide basic rate information and totalisation functions in processes involving non-critical or lower-value materials with an accuracy of ±1%. These are specifically designed for applications where economy and ease of installation are important considerations. as shown in Figure 5.5.

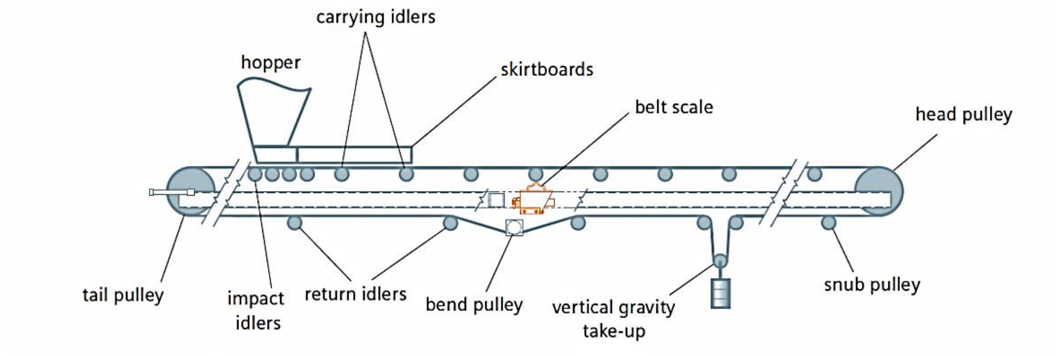


Figure (5.4): Belt Conveyor Terminology.

Figure (5.5): Aggregate bins and Belt Scale.

5.5 Cement Batchers (Scale)

5.5.1. Discharge Gates

The cement batcher discharge gate is operated by a pneumatic cylinder that actuates the gate. The cylinder receives air from a double acting solenoidthat receives an electrical signal from the batch control. To operate a double acting (inching) solenoid valve two signals are required an open and a closed, both signals need to be momentary. Flow controls are installed on the solenoid valve or cylinder that regulates the air flow to the cylinder. The flow controls are installed allowing the operator to regulate the speed at which the cylinder moves to allow for precise control of the gate.

During normal operation of the plant, the batch control will control the operation of the gate and the discharge rate. The batch control does need to be programmed properly to operate the gate efficiently. Below are some settings that may affect the operation of the gate. Note: These settings may be labeled differently depending on the manufacture of control.

Flow Rate (Minimum and Maximum)-Most batch controls try to obtain a flow rate when discharging; they will typically try to stay in a range and work off of a minimum and maximum setting. The settings for this need to be determined for each plant individually.

Initial Open-The initial open setting is used to get the gate opened at the start of discharge. Typically the initial open setting should get the open 1/4 -1/3 of the way open with the first pulse.

Open and Close Pulse-After the discharge gate has been opened with the initial open pulse the open and close pulse take over for the remainder of discharge. If the batch control determines the flow rate needs to be adjusted a pulse will be sent to the open or close depending on if the discharge rate needs to increase or decrease. Each open or close pulse should move the cylinder 1/8 of its overall travel.

5.5.2. Discharge-Feed Interlock

The air cylinder that actuates the discharge gate of the cement batcher is equipped with a reed switch (limit switch) attached to the tie rod. The piston of the air cylinder has a magnetic strip that the reed switch senses. The reed switch is used to let the batch control know if the discharge gate is closed, the reed switch should be adjusted so when the gate is closed a signal is sent to the batch control. If the batch control does not see a closed signal from the reed switch it will not allow material to be fed into the scale. Located on most batch control is an indicator light that verifies when the gate is closed.

5.5.3. Vibrators

Cement batchers are equipped with a pneumatic vibrator. The vibrator receives air to operate from a single acting pneumatic valve. The electrical signal to the valve for the vibrator should be a momentary button. On the cement batcher the vibrator should be set up in the batch control to come on to help clean out the batcher at the end of each batch. The vibrator should be set up to come on when there is less than 50 Kgs of material in the scale. The vibrator can also be set up in most batch controls to activate if the flow of material drops below a certain rate (Kgs/sec) or stops. Caution: The overuse or misuse of vibrator can cause damage to the batcher steel and vibrator mount.

During the initial use of the cement batcher, the batcher will hold some material that will remain in the scale; this material fills in all the corners and crevices. It is important that this material is zeroed off the scale and left in the scale; failure to do this will result in increased batch time and damage to the scale through over vibration.

5.5.4. Aeration

Gravity cement batchers are equipped with aeration pads in the batcher. The aeration pads receive their air from a single acting solenoid valve, the electrical signal for this valve should be a maintain button. Aeration for the scale should be activated by the batch control at the start of the weigh up process and remain on until the scale is empty at the end of discharge. A regulator will be located along with the solenoid valve for aeration; approximately 8 PSI is required for the aeration. It is important when dealing with high-pressure air being used for aeration that the air is non-lubricated, dry and filtered. Using lubricated and moist air for aeration will decrease the life of the air pads and reduce discharge speed.

5.5.5. Cement Feed Gates Operation

Cement feed gates are used to discharge material from the cement silos into the cement batcher. The gates are equipped with air cylinders that are operated by pneumatic valves. The valves that operate these gates are single acting valves, which require a momentary button in the batch control. When the valve receives a signal from the batch control the gate will open, when the signal is removed the gate will close.

The air cylinders on the cement gates have a quick exhaust valve plumbed into the butt end port on the cylinder. The quick exhaust valves are installed to exhaust the air at the cylinder instead of it having to travel to the valve to be exhausted. This allows for the gate to close quickly and reduce the chance of over weighing.

5.5.6. Cement Feeder Screw (Screw Conveyors)

Screw conveyors may be used on some plants to convey material from a silo to a weigh batcher. A momentary signal will be needed to operate a screw that is feeding material to a batcher. Butterfly valve will be installed between the silo/bin feeding the conveyor, the valve and screw should work in conjunction with each other, the valve should open when the screw starts the screw conveyer shown in Figure 5.6.

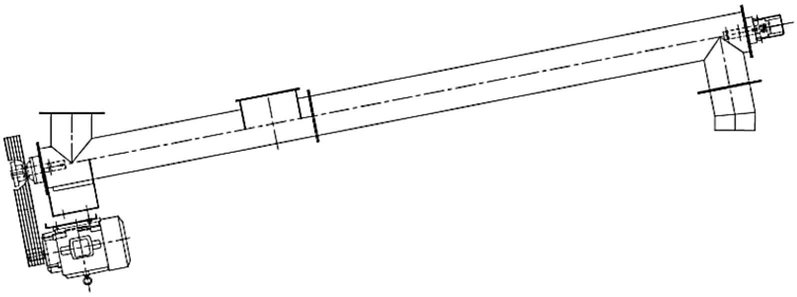


Figure (5.6): Cement Screw Conveyor.

When dealing with a screw conveyor it is important that the operator does not jog the screw conveyor, jogging the screw may cause material to pack in the screw not allowing it to start or damage the machinery. Jogging is sending a quick start signal to the screw causing it to turn on briefly. It is recommended when needing small quantities of material out of a screw conveyor that the conveyor is allowed to run a minimum of 3-5 seconds.

5.6 Water System

5.6.1. Water Meters

Water meter (turbine type) is used to meter water. The meter will produce an output of one pulse for every 10 liters of water that passes through the meter. A turbo meter should be equipped with a strainer before the meter to prevent contaminate from entering the meter and damaging it. the water meter shown in Figure 5.7.

Figure (5.7): Water Meter With Pulse Output.

5.6.2. Water Batcher (Scale)

Water batchers are equipped with a butterfly valve located in the bottom of the batcher to discharge the water. An air cylinder is used to actuate the butterfly valve and it receives air from a single acting pneumatic valve, which requires a momentary button to operate it.

Since rating of water during discharge is not common, the valve will open completely during discharge. If it is required that the water discharge rate needs to be slowed a gate stop is provided on the air cylinder to reduce the amount the valve can open thus reducing the flow rate.

5.6.3. Discharge-Feed Interlock

The air cylinder that actuates the discharge gate of the water batcher is equipped with a reed switch (limit switch) attached to the tie rod. The piston of the air cylinder has a magnetic strip that the reed switch senses. The reed switch is used to let the batch control know if the discharge gate is closed, the reed switch should be adjusted so when the gate is closed a signal is sent to the batch control. If the batch control does not see a closed signal from the reed switch, it will not allow water to be fed into the scale. Located on most batch control is an indicator light that verifies when the gate is closed.

5.6.4. Water Holding Tanks

Water holding tanks are used to pre-meter a batch of water in advanced of the batch being discharged. Instead of discharging the batch, water directly into the truck the water is metered into a holding tank in advance. When the load is ready to be discharged into the truck the water is discharged from the tank. Water holding tanks are equipped with a butterfly valve located in the bottom of the tank to discharge the water. An air cylinder is used to actuate the butterfly valve and it receives air from a single acting pneumatic valve, which requires a momentary button to operate it. Since rating of the water is not possible, the valve will open completely during discharge. If it is required that the water discharge rate needs to be slowed a gate stop is provided on the air cylinder to reduce the amount the valve can open thus reducing the flow rate.

The holding tank will be equipped with an empty probe, the empty probe is needed so the batch control knows when the tank is empty and the valve needs to be closed. A capacitance probe is used as the empty probe, when water hits the probe, it is grounded thus producing a signal that there is water against the probe.

When used on a transit mix plant the head water should be metered into the holding tank prior to the batch being discharged. This allows the water to be meter up ahead of time and be in the hold tank. After the head water is discharge the tail water will be metered into the tank in preparation of discharge at the end of the load.

5.6.5. Water Feed Valve

For water feed valves that do not come directly out of a surge tank and are located is a water line a butterfly valve will be used which will be actuated by a rack and pinion actuator. Also these feed valves are used to feed holding tanks and surge tanks. The actuator will receive air from a single acting pneumatic valve; a momentary signal will be needed to activate the valve. When the valve is activated, the valve will open and when the signal is removed, the valve should close.

Flow controls are located between the solenoid valve and actuator to allow the operator to control the speed that the valve shuts at. In most cases the water feed line will be under pressure and closing the valve to fast will cause “water hammer” and damage piping. The flow control can be used to slow down the valve closing and reduce “water hammer”.

5.6.6. Water Pumps

When a water pump is used to feed water to a plant, the pump is usually setup to turn on when the water feed is activated. When this is the case no extra controls are needed from the batch control to run the water pump, the pump will turn on when the water feed is activated.

5.7 Solenoid Valves

Generally two different types of solenoid valves are installed on the batch plant, single acting solenoid valves and double acting (inching) solenoid valves.

Single acting valves: valve will have one coil when power is applied to the valve the component will open when power is removed, it will close. Single acting valves are typically found on the following components: aggregate, cement and water feeds, water batcher discharge, drip pans and vibrators.

Double acting (inching) valves: valve will have two coils, when power is applied to one coil the component will move in one direction as long as power is applied. When power is removed the component will stop, the component will not move again until power is applied to that coil or power is applied to the other coil to move it in the opposite direction. Double acting (inching) valves are typically found on the following components: aggregate and cement discharge and telescoping shrouds.

All solenoid valves are equipped with manual overrides; the manual override allows the solenoid valve to be operated directly at the valve without energizing the coil.

The manual override will either be a push button or a twist knob. On a single acting valve, there will be one manual override button and on a double acting valve, there will be two, one for each coil. Manual override buttons or knobs can be used to assist in the troubleshooting and help determine an air versus electrical problem and used in emergency situations when electricity is not available but compressed air is.

5.8 Weighing Systems

Weighing systems include aggregate weighing system, cement weighing system, water-weighing system (optional), additive weighing system; all depend on Load cells to ensure their weighing accuracy. Aggregate weighing system is realized by aggregate batching machine. In small concrete batching plant, because there is less volume aggregate for weighing, accumulative weighing is used by scaling every aggregate one by one.

Cement, water, additive are usually weighed in a container, the additive can be fed into water weighing container first, the additive and the water will mix quickly and homogeneously , then discharge together into the concrete mixer.

In addition, water-weighing system is optional, many plants use water metering instead.

5.9 Electrical System

Electrical power enters the batch plant through a Main Disconnect that is used to supply power to the Service Panels. The main disconnect should be used to lock out the electrical power prior to performing any maintenance or servicing any electrical components on the plant. The main disconnect provides three phase power to individual breakers in the plant service panel that power motors. Each motor will have a breaker and a motor starter that switches the three phase power to energize the motor.

Switch power provides power to electrical components on the plant that need a constant power supply such as: limit switches and bin signals. Switch power is also used to power the push button or switches in the batch control for each function on the plant.

5.10 Automation and Controls

The automation of Concrete Batching Plants can be provided by control board mounted in the operator cabinet, which should have a wide visual angle and is isolated from various climate conditions specially dust and humidity. In the Concrete Batching Plants, automatic or manual concrete production can be made by control board, which is equipped with PLC and a TOUCH PANEL or a normal monitor. The whole concrete production process can be followed using the synoptic diagram mounted on the control board, and the weighing of aggregate, water, cement and additive can be followed by the indicators on control board.

In the concrete batching plant Automation System, computer system is given as standard and it consists of PC, printer, UPS and concrete production software, which is developed according to customer request.

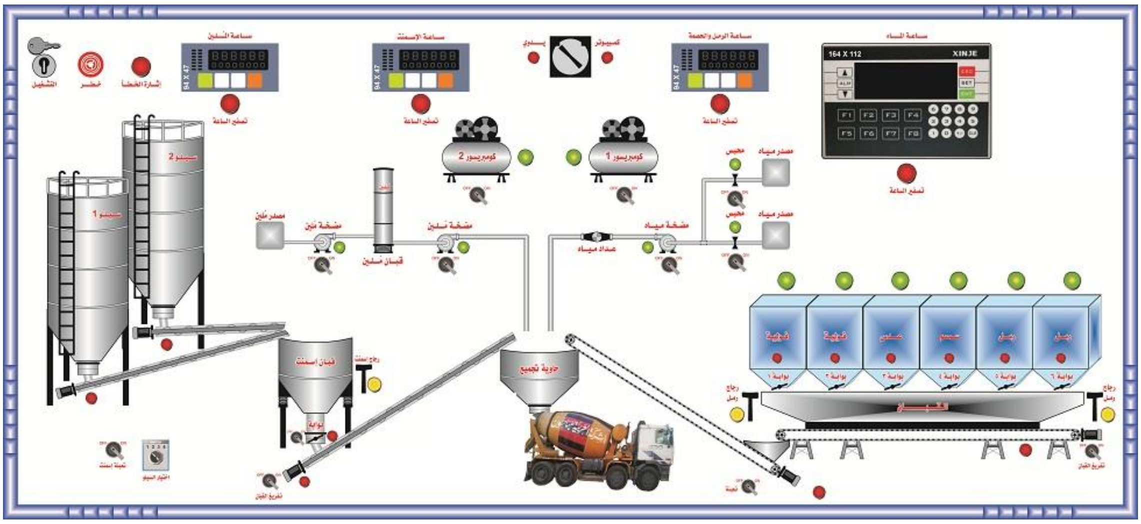


Figure (5.8): Concrete Plant Electrical Control Panel.

CHAPTER 6 SYSTEM MODELING AND CONTROL

6.1 Introduction

Weight batching is the core process in most industrial batching plants, there are different types of weight batching processes depending on the raw materials .In concrete batching plant there are generally four types of batching processes which are:-

- Water batching
- Aggregate batching
- Cement batching
- Admixture batching

These batching process have a suitable controller for each process, but they are very similar in the controller design.

In this chapter, we will formulate the necessary system models to study the different parameters that affect the final mixture product, and explain how the statistical process control methods can be used to tune the controller to manage the quality of the production.

6.2 Water Batching Process

The control variable of this loop is the water level in the tank (current value). The water level is measured by a sensor and supplied to the controller. Depending on which setpoint of the water level is given, the valve must be activated for a specific duration. The valve can only be opened or closed based on the pulse duration from the controller. The output of the controller delivers the manipulated time variable of the change of the valve as shown in Figure 6.1.

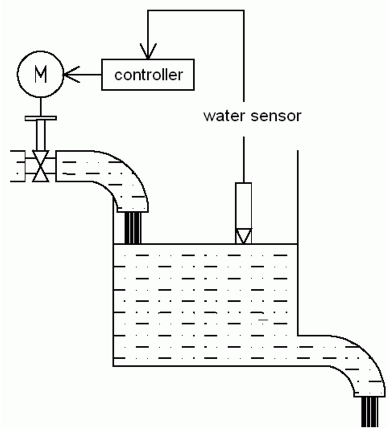


Figure (6.1): Water Tank Batching Process

The schematic in Figure 6.2 shows the block diagram of the used liquid level control system. The controller drives the pump, which fills the tank with water. The backward signal transfers the water level back to the input. The controller could be changed in its characteristics between proportional, integral, derivative, some of them and all together to change the properties of the control-process.

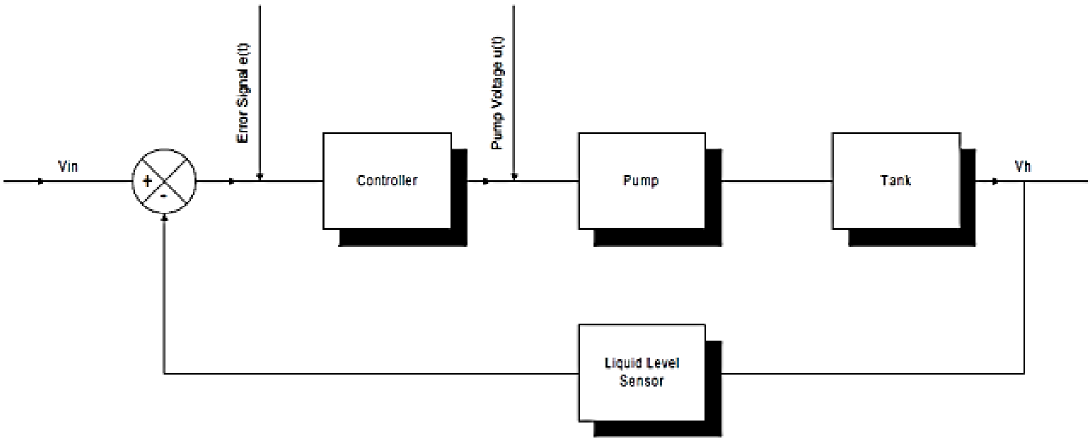


Figure (6.2): Water Batching Process Block Diagram.

6.2.1. Modeling of Liquid Filling System

In analyzing systems involving fluid flow, we find it necessary to divide flow regimes into laminar flow and turbulent flow, according to the magnitude of the Reynolds number (the Reynolds number Re is a dimensionless number that gives a measure of the ratio of inertial forces (Vρ) to viscous forces (μ / L) and, consequently, it quantifies the relative importance of these two types of forces for given flow conditions.)

If the Reynolds number is greater than about 3000 to 4000, then the flow is turbulent. The flow is laminar if the Reynolds number is less than about 2000. In the laminar case, fluid flow occurs in streamlines with no turbulence. Systems involving turbulent flow often have to be represented by nonlinear differential equations, while systems involving laminar flow may be represented by linear differential equations. (Industrial processes often involve flow of liquids through connecting pipes and tanks. The flow in such processes is often turbulent and not laminar.) In this section we shall derive mathematical models of liquid-level systems. By introducing the concept of resistance and capacitance for such liquid-level systems, it is possible to describe the dynamic characteristics of such systems in simple forms.

6.2.2. Resistance and Capacitance of Liquid-Level Systems

Consider the flow through a short pipe connecting two tanks. The resistance *R* for liquid flow in such a pipe or restriction is defined as the change in the level difference (the difference of the liquid levels of the two tanks) necessary to cause a unit change in flow rate; that is,

$$R = \frac{\text{change in level difference, m}}{\text{change in flow rate, m}^3\text{/sec}}$$

Since the relationship between the flow rate and level difference differs for the laminar flow and turbulent flow, we shall consider both cases in the following. Consider the liquid-level system shown in Figure 6.3(a). In this system the liquid spouts through the load valve in the side of the tank. If the flow through this restriction is laminar, the relationship between the steady-state flow rate and steady-state head at the level of the restriction is given by

$$Q = KH \tag{6.1}$$

where Q = steady-state liquid flow rate, m^3/sec
K coefficient, $m^2/$sec
H = steady-state head, m

Notice that the law governing laminar flow is analogous to Coulomb's law, which states that the current is directly proportional to the potential difference.

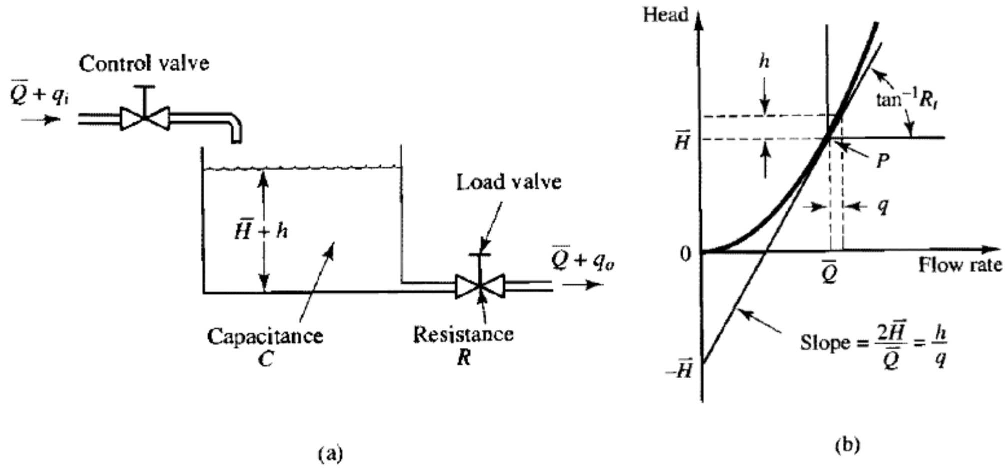


Figure (6.3): (a) Liquid-Level System;(b) Head Versus Flow Rate Curve.

For laminar flow, the resistance R_l is obtained as:-

$$R_l = \frac{dH}{dQ} = \frac{H}{Q} \tag{6.2}$$

The laminar-flow resistance is constant and is analogous to the electrical resistance. If the flow through the restriction is turbulent, the steady-state flow rate is given by:-

$$Q = k\sqrt{H} \tag{6.3}$$

where Q = steady-state liquid flow rate, m3/sec
K = coefficient, m2.5/sec
H = steady-state head, m

The resistance R_t for turbulent flow is obtained from

$$Rt = \frac{dH}{dQ} \tag{6.4}$$

From Equation (6.4), we obtain-

$$dQ = \frac{K}{2\sqrt{H}} dH \tag{6.5}$$

We have

$$\frac{dH}{dQ} = \frac{2\sqrt{H}}{K} = \frac{2\sqrt{H}\sqrt{H}}{Q} = \frac{2H}{Q} \tag{6.6}$$

Thus

$$R_t = \frac{2H}{Q} \tag{6.7}$$

The value of the turbulent-flow resistance R_t depends on the flow rate and the head. The value of R_t, however, may be considered constant if the changes in head and flow rate are small. By use of the turbulent-flow resistance, the relationship between Q and H can be given by

$$Q = \frac{2H}{R_t} \tag{6.8}$$

Such linearization is valid, provided that changes in the head and flow rate from their respective steady-state values are small. In many practical cases, the value of the coefficient K in Equation (6.4), which depends on the flow coefficient and the area of restriction, is not known. Then the resistance may be determined by plotting the head versus flow rate curve based on experimental data and measuring the slope of the curve at the operating condition. An example of such a plot is shown in Figure 6.3(b). In the figure, point P is the steady state operating point. The tangent line to the curve at point P intersects the ordinate at point ($-\overline{H}$,0). Thus, the slope of this tangent line is $2\overline{H}/\overline{Q}$. Since the resistance, R_t at the operating point P is given by $2\overline{H}/\overline{Q}$ the resistance R_t is the slope of the curve at the operating point.

Consider the operating condition in the neighborhood of point P. Define a small deviation of the head from the steady-state value as h and the corresponding small change of the flow rate as q. Then the slope of the curve at point P can be given by

Slope of curve at point $$P = \frac{h}{q} = \frac{2\overline{H}}{\overline{Q}} = R_t \tag{6.9}$$

The linear approximation is based on the fact that the actual curve does not differ much from its tangent line if the operating condition does not vary too much.

The capacitance C of a tank is defined to be the change in quantity of stored liquid necessary to cause a unit change in the potential (head). (The potential is the quantity that indicates the energy level of the system.)

$$C = \frac{\text{change in liquid stored, m}^3}{\text{change in head, m}} \tag{6.10}$$

It should be noted that the capacity (m^3) and the capacitance (m^2) are different. The capacitance of the tank is equal to its cross-sectional area. If this is constant, the capacitance is constant for any head.

6.2.3. Liquid-Level System.

Consider the system shown in Figure 6.3(a). The variables are defined as follows:

$\overline{Q}$ = steady-state flow rate (before any change has occurred), m^3/sec
q_i = small deviation of inflow rate from its steady-state value, m^3/sec
q_o = small deviation of outflow rate from its steady-state value, m^3/sec
$\overline{H}$ = steady-state head (before any change has occurred), m
h = small deviation of head from its steady-state value, m

As stated previously, a system can be considered linear if the flow is laminar. Even if the flow is turbulent, the system can be linearized if changes in the variables are kept small. Based on the assumption that the system is either linear or linearized, the differential equation of this system can be obtained as follows: Since the inflow minus outflow during the small time interval *dt* is equal to the additional amount stored in the tank, we see that

$$Cdh = (q_i - q_o)dt \tag{6.11}$$

From the definition of resistance, the relationship between q_o and h is given by

$$q_o = \frac{h}{R} \tag{6.12}$$

The differential equation for this system for a constant value of R becomes

$$RC\frac{dh}{dt} + h = Rq_i \tag{6.13}$$

Note that RC is the time constant of the system. Taking the Laplace transforms of both sides of Equation (6.14), assuming the zero initial condition, we obtain

$$(RCs+1)H(s) = RQ_i(s) \tag{6.14}$$

Where

$$H(s) = \mathcal{L}[h] \qquad \text{and} \qquad Q_i = \mathcal{L}[q_i]$$

If *qi* is considered the input and h the output, the transfer function of the system is

$$\frac{H(s)}{Q_i(s)} = \frac{R}{RCs+1} \tag{6.15}$$

If, however, q_o is taken as the output, the input being the same, then the transfer function is

$$\frac{Q_o(s)}{Q_i(s)} = \frac{1}{RCs+1} \tag{6.16}$$

where we have used the relationship

$$Q_o(s) = \frac{1}{R}H(s) \tag{6.17}$$

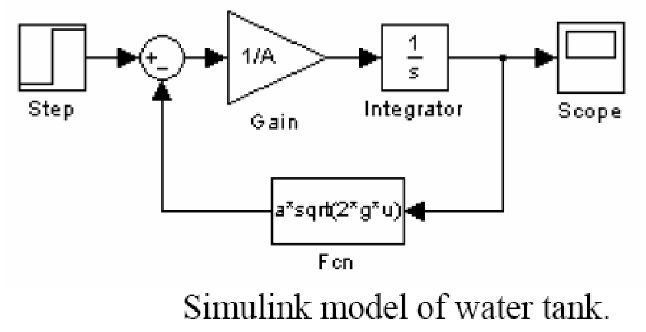


Figure (6.4): Water Tank Process Closed Loop Simulink Model.

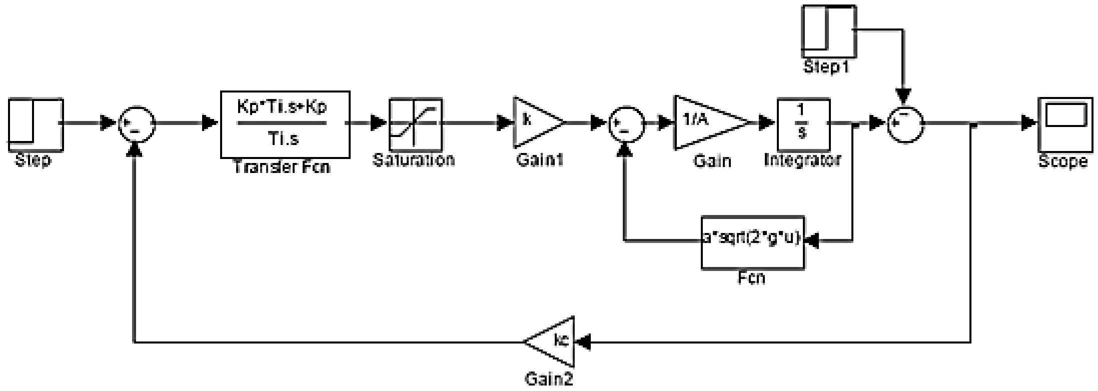


Figure (6.5): Water Tank Closed Loop Process Control Simulink Model.

6.3 Aggregate Batching Process

The aggregate batching process is very similar to the water batching process, we can use the resistor capacitor charge/fill model to describe the aggregate filling process, but we need to consider the difference in the density of granular raw materials and liquid materials, which introduces a new formula to calculate the flow rate of the aggregate.

The control of the aggregate batching is much more complex due to the nature of the dead time delay in the aggregate batching process.

6.3.1. Aggregate Flow Rate

In the aggregate batching process the controller of the active aggregate material with specific flow rate of the required aggregate type sends a variable duration pulse to control the gate of the aggregate bin, the duration of this pulse will specify the flow rate of the aggregate, in Figure 6.6 we notice the dead time delay of the process, as the flow rate of the aggregate increases after a delay time and reaches its maximum peak when the gate is full open , and then decreases when the gate starts to close.

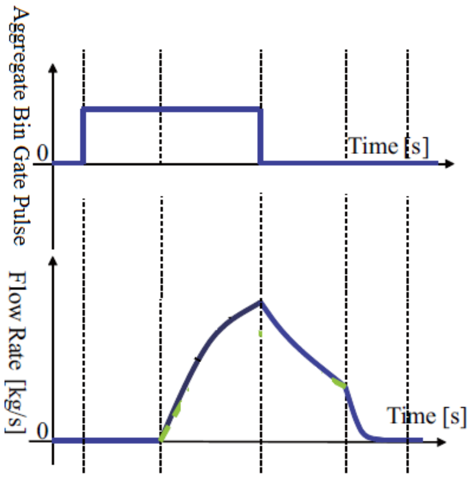


Figure (6.6): Time Series Data of Aggregate Batch Process

In the automatic batching system of the aggregate process, an input command is applied to the piston for opening the aggregate bin, and aggregate in the hopper is poured freely through the bin gate. The weight of the outflow aggregate is measured by the load-cell. The outflow aggregate is poured and accumulated over the weighing conveyor belt. The filling process is represented by the block diagram shown in Figure.6.7. P_f is a flow rate model representing from the angular opening velocity to flow rate of the outflow aggregate.

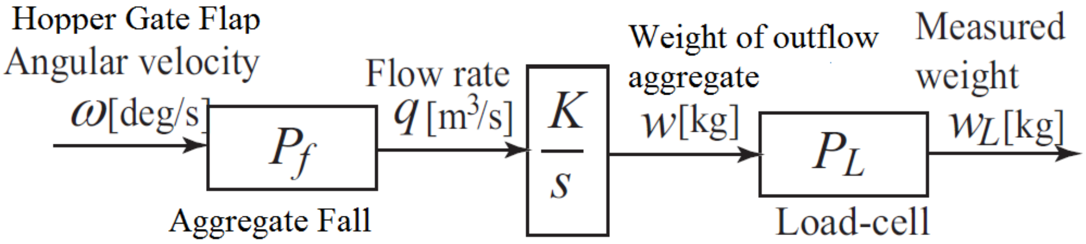


Figure (6.7): Block Diagram of Aggregate Filling Process. [13]

The flow rate of the aggregate can be calculated using Beverloo equation

$$W = 0.58\rho_b g^{0.5}(B - kd_p)^{2.5} \qquad (6.18)$$

where W is the discharge rate (kg/sec)

ρ_b is the bulk density (kg/m3)
g is the gravitational constant
B is the outlet size (m)
k is a constant (typically 1.4)
d_p is the particle size (m)

Note: Units must be SI.

The aggregate mix consists of four different granular solids each with different particle size, and with different flow rate factor, when the control system is installed for a certain plant, the flow rate of each aggregate bin material is obtained empirically , the controller (PLC), sends predefined pulses with known time duration to each aggregate bin gate piston, and after each pulse the weight obtained is stored in the memory, the flow rate is calculated using the following formula.

$$\text{Flow Rate} = \frac{\text{Weight}}{Time}$$

The same formula will be used by the controller to estimate the required time pulse based on the flow rate of certain aggregate

$$\text{Pulse Duration} = \frac{\text{Target Weight}}{\text{Raw Material Flow Rate}}$$

The flow rate is a very important factor in the weighing batch process; it affects directly the feeding speed of the aggregate, and the final weight accumulated on the belt scale, if the estimated flow rate is equal to the actual flow rate, the weighing process will take a single cycle to reach the target weight, with a very low error within the allowed tolerance as shown in Figure 6.8.

If the estimated flow rate is lower than the actual flow rate, the feeding speed will drop and it will take several cycles to reach the target weight depending on the difference between the estimated flow rate and the actual flow rate as shown in Figure 6.9.

If the the estimated flow rate is higher than the actual flow rate, the feeding speed will increase beyond the required value and the actual weight will pass the target weight causing an excess weight error which depends on the difference between actual and estimated flow rate as shown in Figure 6.10.

To solve this problem, a monitoring program must track the change in actual flow rate and adjust the system parameters to avoid the low speed filling or the overshoot problems.

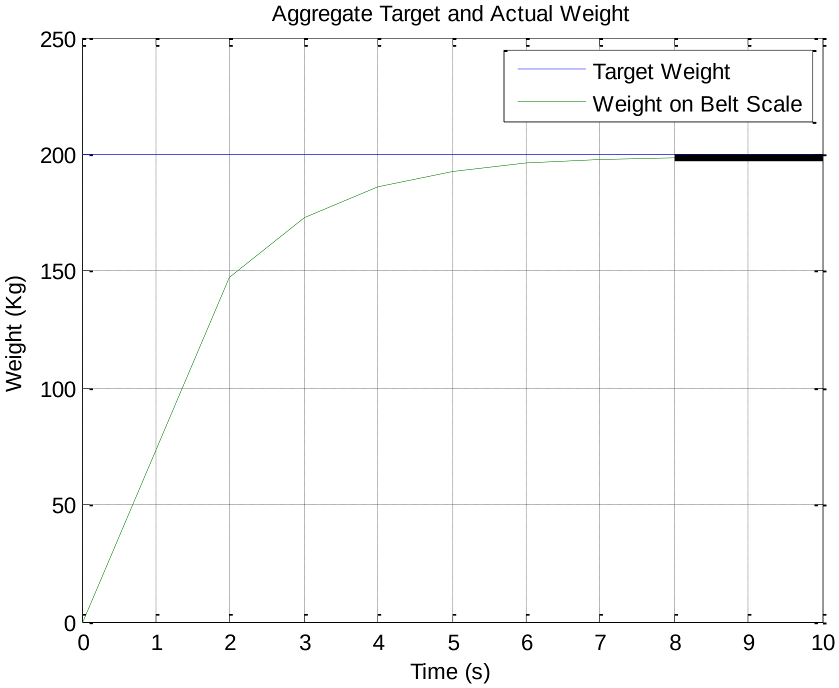


Figure (6.8): Aggregate Filling When Estimated Flow Rate = Actual Flow Rate.

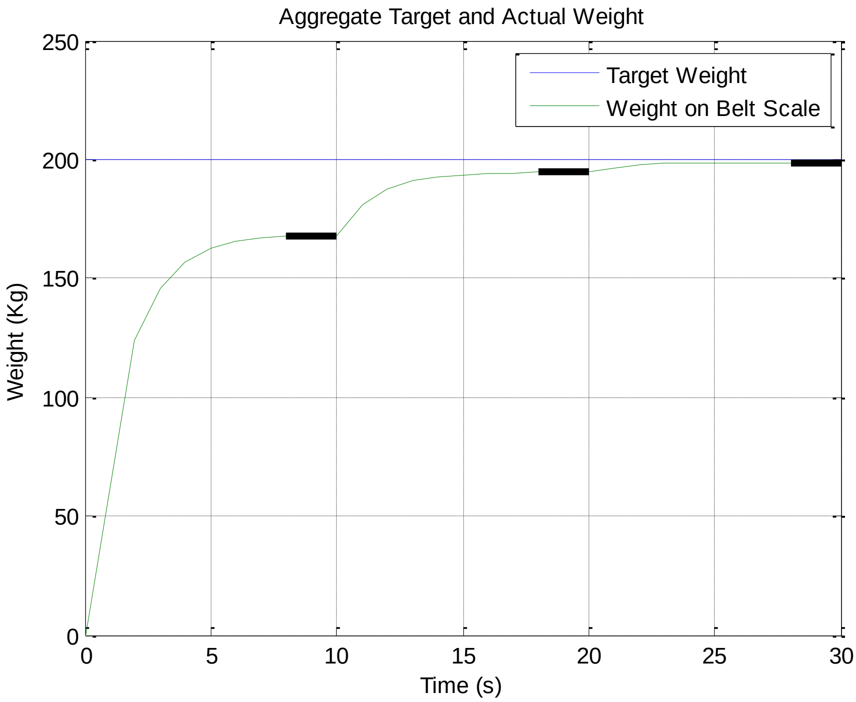


Figure (6.9): Aggregate Filling When Estimated Flow Rate > Actual Flow Rate.

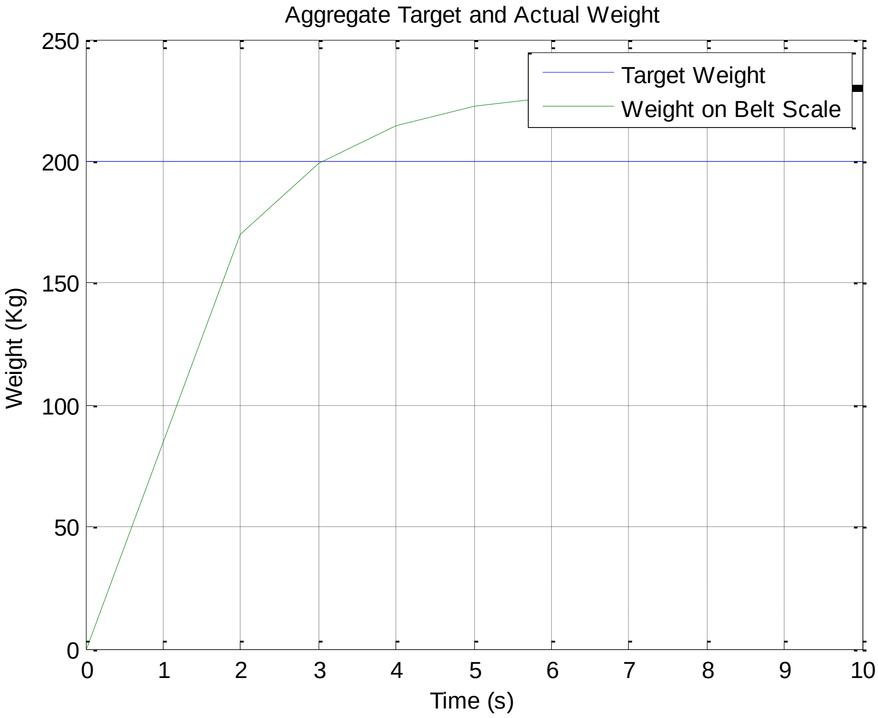


Figure (6.10): Aggregate Filling When Estimated Flow Rate < Actual Flow Rate.

6.3.2. Aggregate bin gates calibration

The only accurate way to set gates is by making a calibration chart for each gate, using the aggregate to be used in the mix. The gate flow rate (in kg/seconds) is plotted on the chart as the horizontal coordinate, and the weight of material (in kg) is the vertical coordinate. When the calibration chart is being prepared, the gate is set, usually at 25 percent or less of the total opening, and the feeder is started. When the feeder is running normally, the material is measured into a tare container and weighed at known time intervals (or number of revolutions). This gives one point on the calibration chart. The operation is repeated for three or more gate openings and the points connected on the chart Figure 6.11. after the gates have been calibrated and locked, minor adjustments may be necessary to assure uniform production. When the gates discharge on to the belt conveyer, their output may be checked by closing all of the gates except one, which is set at one of the calibration points. When the gates cannot be closed completely.

The flow rate calibration results of 3 different aggregate materials are presented in Figures 6.11, 6.12, 6.13

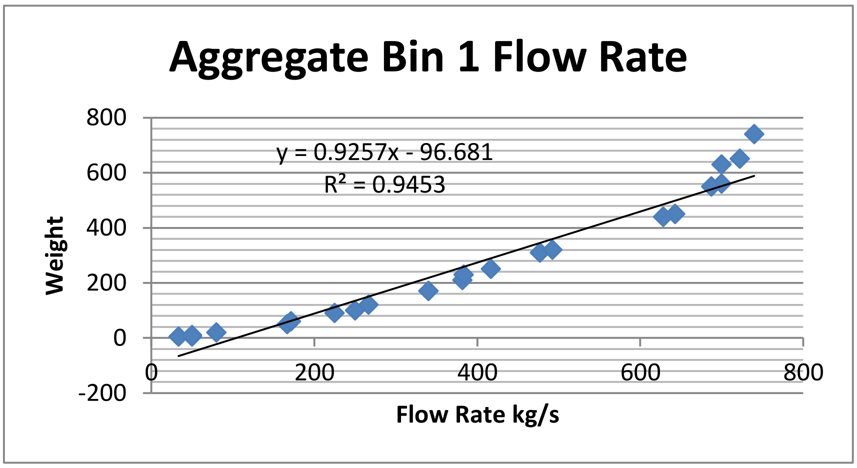


Figure (6.11): Aggregate bin 1 flow rate calibration

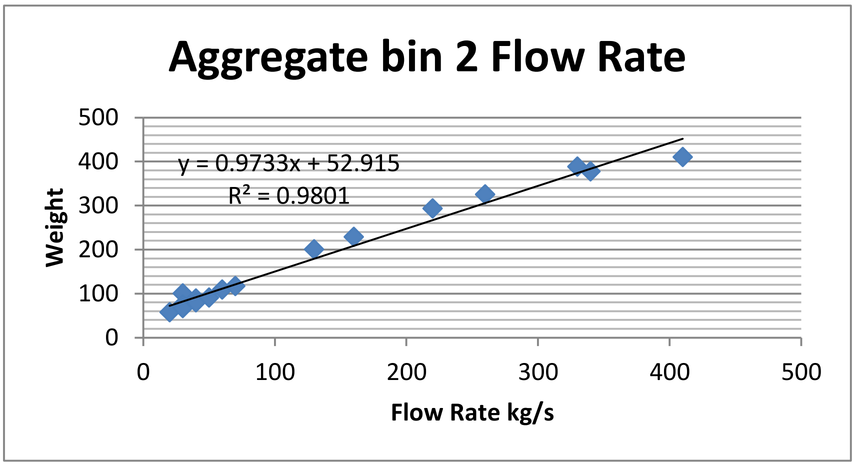


Figure (6.12): Aggregate bin 2 flow rate calibration

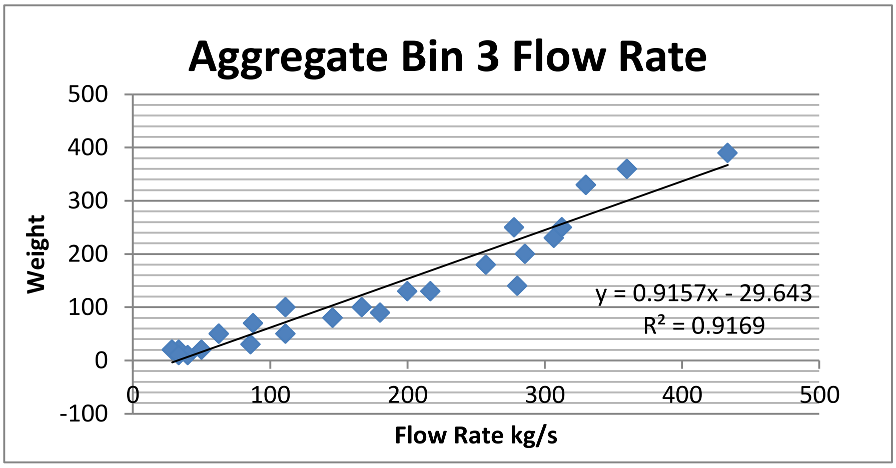


Figure (6.13): Aggregate bin 3 flow rate calibration

6.3.3. Aggregate batch controller

The aggregate batching control system is illustrated in Figure 6.11. The feeding mechanism is an electromagnetic/pneumatic device controlled by the batching controller. Some parameters have to be tuned manually in the conventional control system, e.g., the material flow rate or the setting value of feeding speed V_{set}, increment of control variable $\Delta u(k)$, threshold of shutting down the electromagnetic mechanism in advance, threshold of shutting down valve to predict the material remaining in air and dropping into the conveyor belt scale later, initial values of pulse duration and frequency of electromagnetic mechanism $u(0)$, etc.

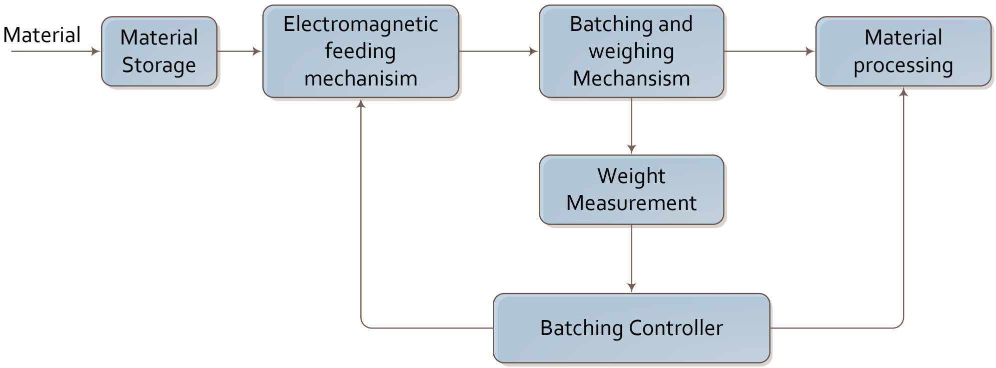


Figure (6.14): Diagram Of Aggregate Batching Control System

In the batching control scheme, the weight signal is used sufficiently to determine the speed setting value online.

6.3.4. Adaptive Tuning of Feeding Speed

The block diagram of the discrete-time control system is illustrated in Figure 6.12, where $G_c(z)$ indicates the transfer function of PI controller, $G_p(z)$ is the generalized transfer function of entire batching process containing electromagnetic/pneumatic bin gate control and belt scale transport device. $F_1(z)$, $F_2(z)$ and $F_3(z)$ are the computational function blocks, where $F_1(z) = (1 - z^{-1})/T$ is the differential element, T is the sampling interval, $F_2(z)$ and $F3(z)$ are the blocks of speed setting value and nonlinearity compensation ,respectively.

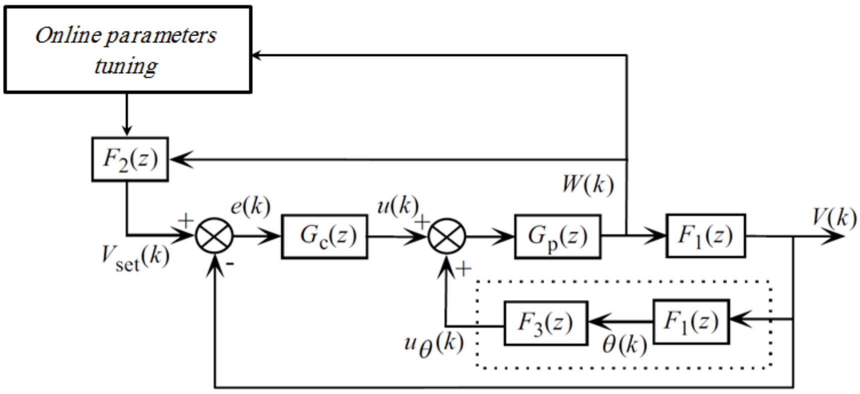


Figure (6.15): Adaptive Speed Setting Control System For Batching By Weight

In Figure 6.12 , $F_2(z)$ updates the next speed setting value $V_{set}(k)$ adaptively with respect to the weight at current instant by using the relation between feeding speed and material Weight. It is performed as follows. Firstly, the ideal feeding speed $V(k)$ is calculated from the weight $W(k)$. Let k_1 be a relative start instant, and the variable d be the shift of instant from k1, then the following expression holds

$$\begin{aligned} W(k) &= W(k1) + \int_0^d V_0 e^{-ax} dx \\ &= W(k1) + \frac{V_0}{a} - \frac{V_0}{a} e^{-ad} \end{aligned} \tag{6.19}$$

Then the ideal feeding speed V corresponding to weight W at any instant can be calculated by

$$\begin{gathered} V = V(d) = V_0 e^{-ad} \\ d = \left[-\ln\left[a\left(W(k_1) + \frac{V_0}{a} - W(k) \right) \Big/ V_0 \right] \Big/ a \right] \end{gathered} \tag{6.20}$$

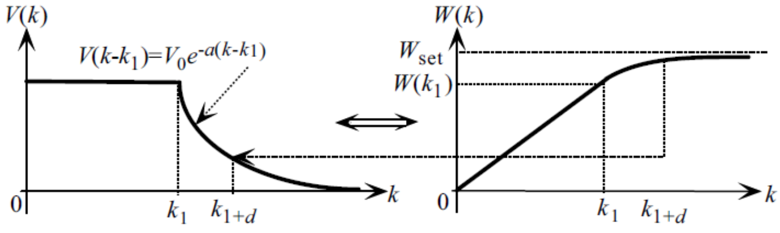
Moreover, (6.20) can be rewritten in

$$V_{set}(k) = a\left(W(k_1) + \frac{V_0}{a} - W(k) \right) \tag{6.21}$$

Then the input and output of the computational function block $F_2(z)$ are the weight $W(k)$ and the feeding speed setting value $V_{set}(k)$ at the next instant respectively. For the contrast, the setting value at the first operation is fixed by V_0. It is clear that the feeding speed given by (6.21) is in accordance with the current batching weight and can compensate the tracking error up to the current instant, so it can be considered as an optimal setting.

6.3.5. Parameter Tuning of Speed Curve

The performance of the batching and weighting system mainly depends on the setting of feeding speed and the design of control law, merely on the form of technical curve. It implies that the control law is feasible as long as the speed curve is operated from a considerable high level at first stage and is reduced later appropriately. Figure 6.10 (a) illustrates such a convenient technical curve used in practical control. In the new scheme, the setting speed can be calculated by (6.21) online adaptively, while the parameters of the technical speed curve can be designed very loosely.



(a) Curve model of feeding speed (b) Weight of feeding material

Figure (6.16): Relation between feeding speed and weight under ideal situation

For example, for the given batching weight W_{all} and weighting time T_{all}, it is possible to finish 80% of the work in the first 60% of time, and the remaining in the last 40%. Accordingly the parameter V_0 is set as follows

$$V_0 = \frac{0.8xW_{all}}{0.6xT_{all}} \tag{6.22}$$

The descent curve is determined by the exponential decaying coefficient

$$0.2W_{all} = \int_0^t V_0 e^{-ax} dx = \frac{V_0}{a} - \frac{V_0}{a} e^{-ax\,0.4T_{all}} \tag{6.23}$$

On the other hand, when the batching process approaches to the end, the feeding speed $V_0 e^{-ax\,0.4Tall}$ should be close to 0. So a can be given by

$$a = V_0 / 0.2W_{all} \tag{6.24}$$

Through letting $V_0 e^{-ax\,0.4Tall} \approx 0$ in (6.23)

6.4 Integrating EPC and SPC for effective APC, and improved quality

Statistical Process Control (SPC) aims at achieving process stability and improving process capability by reducing variation. A set of problem solving tools are used in SPC which range from a simple Histogram to sophisticated control charts. SPC is normally applied in the form of open-loop control for process monitoring. Coefficient of variance and/or Process Capability Index (CpK) may be used as SPC indicators. Shewhart X-bar and R charts are commonly used for process monitoring; Figure 6.14 illustrates the implementation of SPC on stationary process

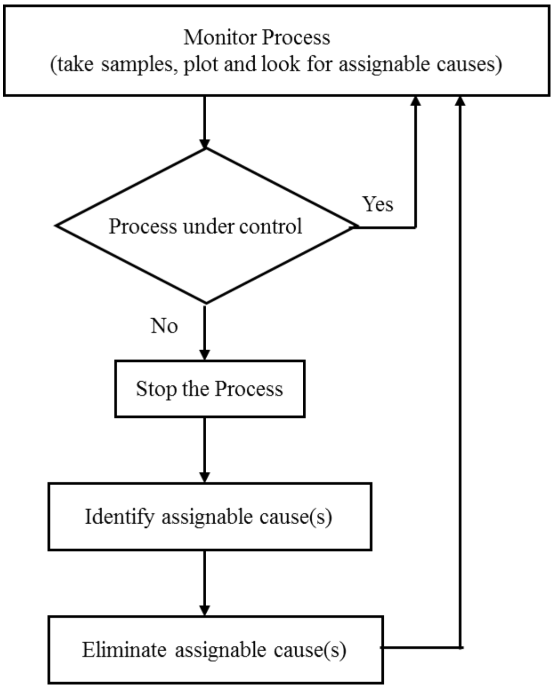


Figure (6.17): SPC suits stationary processes exhibiting no drift in process mean

Engineering Process Control (EPC) also aims at achieving process stability and improving process capability by reducing variation. EPC may be applied in the form of either open-loop or close-loop. The control mechanism could be either feedback, or feedforward or combination of both. SPC techniques are often used in combination with EPC. Coefficient of variance and/or Process Capability Index (CpK) may be used as APC indicators.In Figure 6.15 EPC is used to adjust process input in the feedback loop.

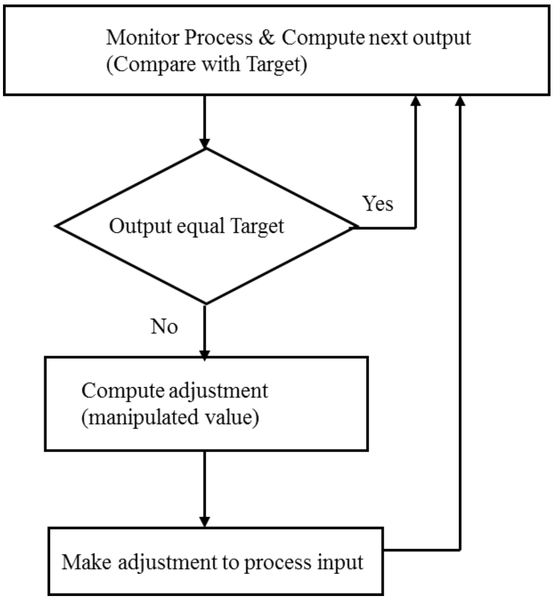


Figure (6.18): EPC process implementation

R2R control: Set of algorithms to be used for on-line process control with the goal to reduce output variability as measured by the mean squared deviation from target. The R2R controller Figure 6.16,responds to post-process and summarized in-process measurements by updating process models between runs and providing a new recipe for use in the next run

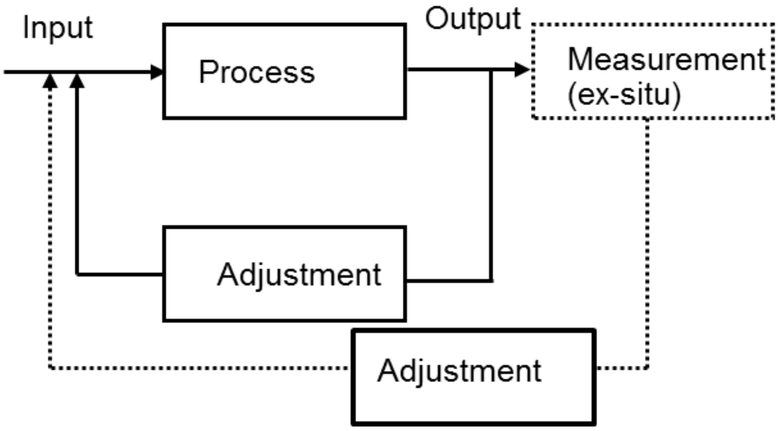


Figure (6.19): R2R control structure

Real-time control:,On-line control and instead of minutes or hours before action is taken, the machine is shut down automatically when a computer algorithm discovers that the process is non-normal or out of control. Machine parameters rather than process parameters are measured and monitored.

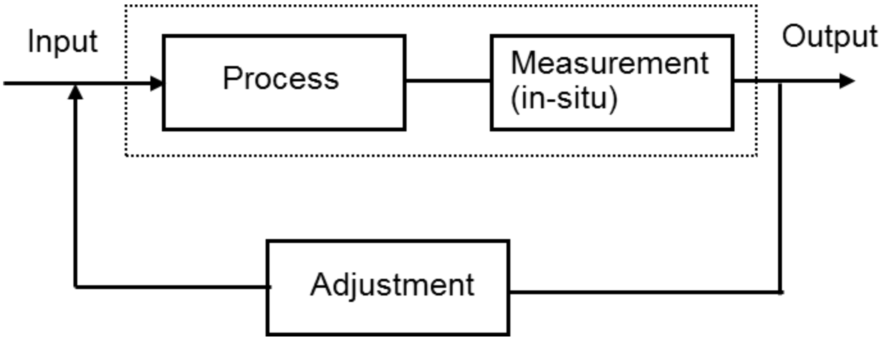


Figure (6.20): Real-time control of process

R2R in Figure 6.16, Real-time process control in Figure 6.17, and SPC fall under Fault detection & Classification (FDC) technique that can be used in open loop or close-loop mode to ensure that variation is identified and necessary action is applied.

6.4.2. Monitoring model of time delay feedback controlled process

In this study, Autoregressive Moving Average, *ARMA(1,1)* models are used to illustrate stationary processes:

$$Z_t - \mu_t = \phi(Z_{t-1} - \mu_{t-1}) + a_t - \theta_{at-1} \tag{6.25}$$

where, Z_t is the process output in time t .μ_t is the mean of the process output in time t . a_t represents a white noise variable with $a_t \sim N(0, \sigma_2^{a})$.$\varphi$ and θ are autoregressive and moving average parameters satisfying $|\varphi| < 1$ and $|\theta| < 1$. When the mean of the process output is unchangeable, the mean and deviation of Z_t could be given as follow:

$$\mu_Z - \mu_t = \mu, \sigma_Z^2 = \frac{(1-2\phi\theta+\theta^2)}{1-\theta^2}\sigma_a^2$$

And the output error can be described as follow:

$$e_t = Z_t + Y_t \tag{6.26}$$

The output of time delay adjustment process Y_t can be given:

$$Y_t = \sum_{i=1}^{n} b_i Y_{t-1} + \sum_{i=1}^{m} c_i X_{t-1} \tag{6.27}$$

where, η is the maximum delay time of adjustment process autocorrelation. m is the maximum delay time of feedback control action. b_i and c_i are autoregressive and moving average parameters satisfying $|b_i| < 1$ and $|c_i| < 1$. X_t is the feedback control action. For the ARMA(1,1) model, the MMSE PI controller is defined by

$$X_t = \phi X_{t-1} + (\theta - \phi) e_t \tag{6.28}$$

Then the SPC monitoring model of time delay MMSE controlled Process could be given as Figure

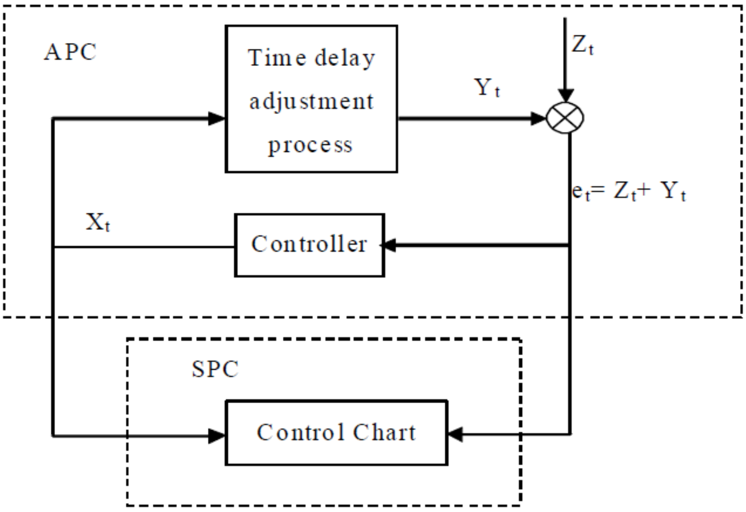


Figure (6.21): SPC monitoring model of time delay feedback controlled process

6.4.3. Statistical process control of feedback controlled processes

The mean of a stationary process is unchanged, $\mu = 0$. Under MMSE control policy of equation (6.28), it is not difficult to show mean and standard deviation of e_t and X_t as

$$\mu_e = 0, \sigma_e = \sigma a;$$

$$\mu_X = 0, \sigma_X = \frac{|\theta - \phi|}{\sqrt{1-\phi^2}}\sigma_a$$

If there is a shift in process, mean from time 0, the shift magnitude can be described as $d = l \cdot \sigma_Z$, and equation (6.28) can be rewrite as

$$X_t = \frac{\theta - \phi}{1 - \phi B} e_t$$

According to equation (6.25),(6.26) and (6.27), the output error and control action can be calculated as:

$$et = \frac{(1-\phi B)(1-\sum_{i=1}^{n} b_i B^i)}{(1-\phi B)(1-\sum_{i=1}^{n} b_i B^i) - (\theta - \phi)\sum_{i=1}^{m} c_i B^i}\mu_t + \frac{(1-\phi B)(1-\sum_{i=1}^{n} b_i B^i)}{(1-\phi B)(1-\sum_{i=1}^{n} b_i B^i) - (\theta - \phi)\sum_{i=1}^{m} c_i B_i} a_t \qquad (6.29)$$

$$= \sum_{i=0}^{t} p_i \mu_{t-1} + \frac{(1-\phi B)(1-\sum_{i=1}^{n} b_i B^i)}{(1-\phi B)(1-\sum_{i=1}^{n} b_i B^i) - (\theta - \phi)\sum_{i=1}^{m} c_i B_i} a_i$$

$$Xt = \frac{\theta - \phi}{1 - \phi B} e_t$$

$$= \frac{(\theta - \phi)(1-\phi B)(1-\sum_{i=1}^{n} b_i B^i)}{(1-\phi B)^2(1-\sum_{i=1}^{n} b_i B^i) - (1-\phi B)(\theta - \phi)(1-\sum_{i=1}^{m} c_i B^i)}\mu_t + \frac{(1-\sum_{i=1}^{n} b_i B^i)(1-\phi B)(\theta - \phi)}{(1-\phi B)^2(1-\sum_{i=1}^{n} b_i B^i) - (1-\phi B)(\theta - \phi)\sum_{i=1}^{m} c_i B_i} a_t$$

$$= \sum_{i=0}^{t} q_i \mu_{t-1} + \frac{(1-\sum_{i=1}^{n} b_i B^i)(1-\phi B)(\theta - \phi)}{(1-\phi B)(1-\sum_{i=1}^{n} b_i B^i) - (\theta - \phi)\sum_{i=1}^{m} c_i B_i} \qquad (6.30)$$

where, p_i and q_i are coefficients of the two sequence respectively.

From equation (6.29) and (6.30), the mean of output error e_t and the mean of control action X_t can be given as

$$\mu_e^{'} = \sum_{i=0}^{t} p_i d$$
$$\mu_X^{'} = \sum_{i=0}^{t} q_i d \qquad (6.31)$$

The standard deviations of e_t and X_t keep unchanged.

Hence, ARL of control chart using to monitoring the output error e_t and control action X_t can be given as follow:

$$ARL_e = 1/\left[1-\varphi(k-\frac{\mu_e^{'}}{\sigma_e})+\varphi(-k-\frac{\mu_e^{'}}{\sigma_e})\right] \tag{6.32}$$

$$ARL_X = 1/\left[1-\varphi(k-\frac{\mu_X^{'}}{\sigma_X})+\varphi(-k-\frac{\mu_X^{'}}{\sigma_X})\right]; \tag{6.33}$$

where k is control limits parameter of control chart and ϕ *()* is cumulated function normal distribution.

CHAPTER 7 SIMULATION AND RESULTS

This chapter presents simulations and results. Mathematical modeling and control analysis of concrete batching plants modules were carried out in this study. The mathematical models of the water and aggregate batching process were presented. This simulation will focus on the aggregate batching process due to the complexity of control and monitoring program of the aggregate batching process and its main role in the quality factor of the ready mix concrete. There are four types of aggregate materials used in the aggregate batching process, which are, sand(fine aggregate), and three different sizes of coarse aggregate, the batching process of each types is the same except for different flow rate of each material.

The batch hopper is mounted on load cells, which generate an analog signal proportional to the weight of the compounded ingredients in the batch hopper. This signal is digitized and supplied to the PLC, which controls feeding of the individual constituents from the supplied bins. Each constituent is fed from its supplied bin to the batch hopper at least two different feed rates, the feed rate for a constituent is decreased as feeding nears completion to prevent overfeeding of a material. However, the slowing down of the feed rate and finally the stopping of feeding is controlled in response to both the current weight of the constituent accumulated in the batch hopper and the product of the average feed rate and the response time of the feeder when feeding is interrupted. This differs from conventional systems in which control is responsive to the accumulated weight of the material in the batch hopper. By continuously monitoring feed rate, fast feeding may be maintained for a longer period than in prior conventional batch systems, thereby decreasing the time required to compound a batch. After a batch is compounded, it is mixed in a mixing hopper and delivered to a selected utilizing device. Figure 7.1 shows a batching process with three different aggregate materials.

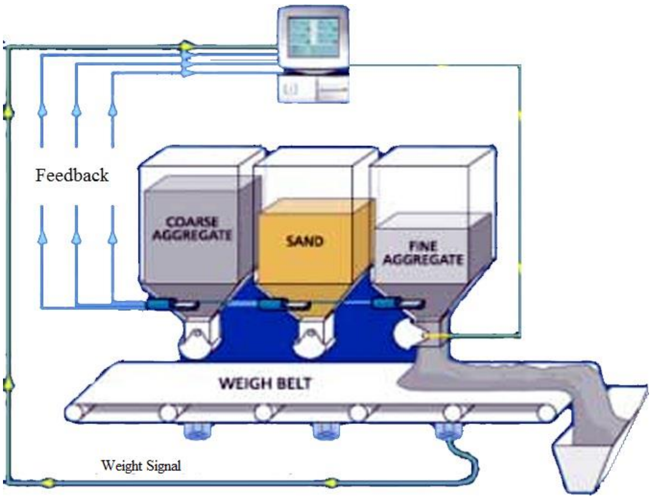


Figure (7.1): Batching System With 3 Different Aggregate Types

7.2 Aggregate Batching Program and Operation

The aggregate batching process starts by reading the target weight of the first aggregate material from the specified register of the PLC memory, this value is stored by the SCADA system, then it will find the difference between current weight and the selected set-point, this weight span value is divided by the estimated flow rate of the current aggregate material, to predict the time duration to open the aggregate bin gate , this time duration is added to the gate initial time .

The PLC opens the first aggregate bin and starts a timer (Gate Open Time), when this timers ends, the PLC closes the gate for a time duration (Gate Close Time), during this time the cycle repeats by finding the weight difference between the new weight on the belt scale and the target weight and so on. a flowchart of the batch process is illustrated in Figure 7.2

To better understand the operation of the batching algorithm, we will consider three scenarios.

Case 1: Estimated Aggregate Flow Rate = Actual Aggregate Flow Rate.
Case 2: Estimated Aggregate Flow Rate > Actual Aggregate Flow Rate.
Case 3: Estimated Aggregate Flow Rate < Actual Aggregate Flow Rate

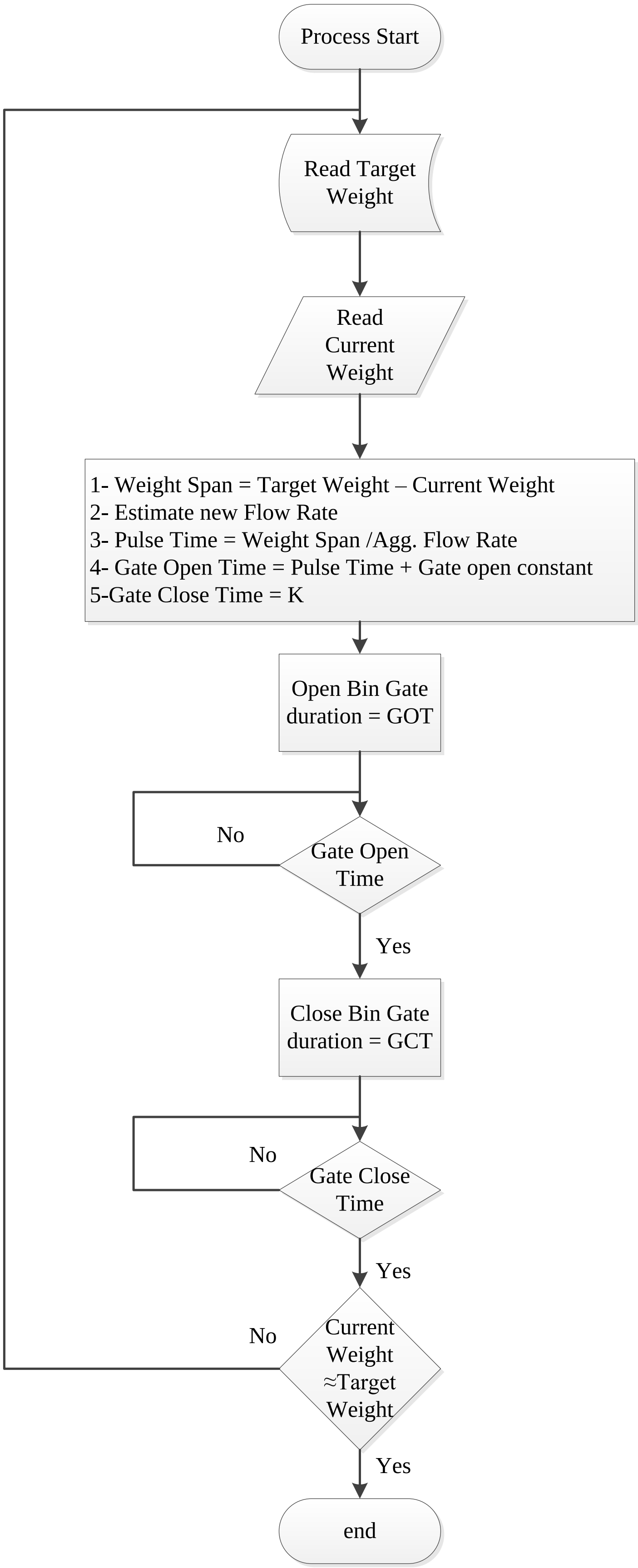


Figure (7.2): Aggregate Batch Weighing Process Flow Chart

Case I: (Estimated Aggregate Flow Rate = Actual Aggregate Flow Rate)

Target Weight = 1000 Kg.
Estimated Aggregate Flow Rate = 550 kg/s
Actual Flow Aggregate Flow Rate = 550 kg/s
Current weight on Scale = 0 kg

First cycle run

Select a set point 75% of target weight to avoid overfilling in case of wrong estimated overflow in first cycle.

```
Wer = (TargetWeight - w)*k; % Weight error = Target Weight - current Weight
   = (1000 - 0)*0.75;
   = 750 kg
```

Calculate the time required for the aggregate bin gate to discharge the first weight target W_{e1}

```
Tw = (Wer / MCfr); % Convert Weight to duration
  = 1363.636 ms
```

Add the initial time required for the gate actuator mechanism to respond

```
Tg = Tw + Ti;      % Gate open time = weight pulse + gate initial flow
   = 1563 ms
```

The PLC will send a control pulse of a time pulse ~ 1.5 seconds to the aggregate bin gate piston

After closing the gate , the PLC collects and calculates the following data:-

```
Actual Weight            =   746.92 kg
Weight Error             =   3.07 kg
Actual Flow Rate         =   5.47 kg/s
Flow Rate Correction     =   0.02 kg/s
Remaining Weight         =   253.07 kg
```

Second cycle run

```
Wer = (TargetWeight - w)*k; % Weight error = Target Weight - current Weight
   = (1000 - 746.92)*0.75;
   = 189.8 kg
```

```
Tw = (Wer / MCfr); % Convert Weight to duration
  = 345 ms
```

```
Actual Weight            = 935.95 kg
Weight Error             = 0.77   kg
Actual Flow Rate         = 5.47   kg/s
Flow Rate Correction     = 0.02   kg/s
Remaining Weight         = 64.04  kg
```

Third cycle run

```
Wer = (TargetWeight - w)*k; % Calculate Weight difference
    = (1000 - 936)*0.75;
    = 48 kg
Tw = (Wer / MCfr); % Convert Weight to duration
   = 87 ms
```

```
Actual Weight              = 983.78 kg
Weight Error               = 0.2    kg
Actual Flow Rate           = 5.47   kg/s
Flow Rate Correction       = 0.02   kg/s
Remaining Weight           = 16.02  kg
```

Fourth cycle run

```
Wer = (TargetWeight - w)*k; % Weight error = Target Weight - current
Weight
    = (1000 - 983.78)*0.75;
    = 12.12 kg
```

```
Tw = (Wer / MCfr); % Convert Weight to duration
   = 22 ms
```

```
Actual Weight              = 996   kg
Weight Error               = 0.05  kg
Actual Flow Rate           = 5.47  kg/s
Flow Rate Correction       = 0.02  kg/s
Remaining Weight           = 4     kg
```

In Figure 7.3 the simulation of the four cycle runs, from which we can see that the filling weight never crossed the target weight for each cycle. The results are also tabulated in Table 7.1

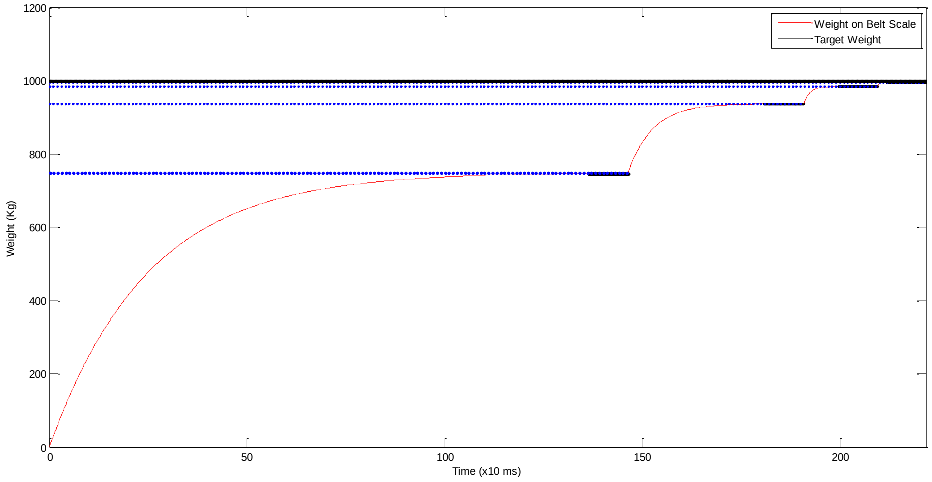


Figure (7.3): Simulation of four-cycle runs aggregate batching process with estimated flow rate =actual flow rate

Table (7.1): Case I: Cycle runs of filling 1000kg aggregate , estimated flow rate = actual flow rate

Cycle Run	Set Point (kg)	Actual Weight (kg)	Remaining Weight	Gate Open Time (ms)	Estimated Flow Rate (Kg/s)	Actual Flow Rate (kg/s)	Flow Rate Correction (kg/s)
1	750	747	253	1363	550	550	0.02
2	189	935	64	345	550	550	0.02
3	48	984	16	87	550	550	0.02
4	12	996	4	22	550	550	0.02

Case II: (Estimated Aggregate Flow Rate > Actual Aggregate Flow Rate)

Target Weight = 1000 Kg.
Estimated Aggregate Flow Rate = 550 kg/s
Actual Flow Aggregate Flow Rate = 450 kg/s
Current weight on Scale = 0 kg

First Cycle Run

```
Wer = (TargetWeight - w)*k; % Weight error = Target Weight - current
Weight
   = (1000 - 0)*0.75;
   = 750 kg
```

```
Tw = (Wer / MCfr); % Convert Weight to duration
  = 1363 ms
```

```
Actual Weight            = 606.8 kg
Weight Error             = 143.2 kg
Actual Flow Rate         = 4.45  kg/s
Flow Rate Correction     = -1.05  kg/s
Remaining Weight         = 393.2 kg
```

From the first cycle the PLC reads the weight accumulated on the scale and calculates the actual flow rate based on the last pulse duration, the algorithm detects that the flow rate is greater than required and needs to be decreased by 1.05 kg/s, the simulation run is shown in Figure 7.4 the data for all cycles are tabulated in Table 7.2

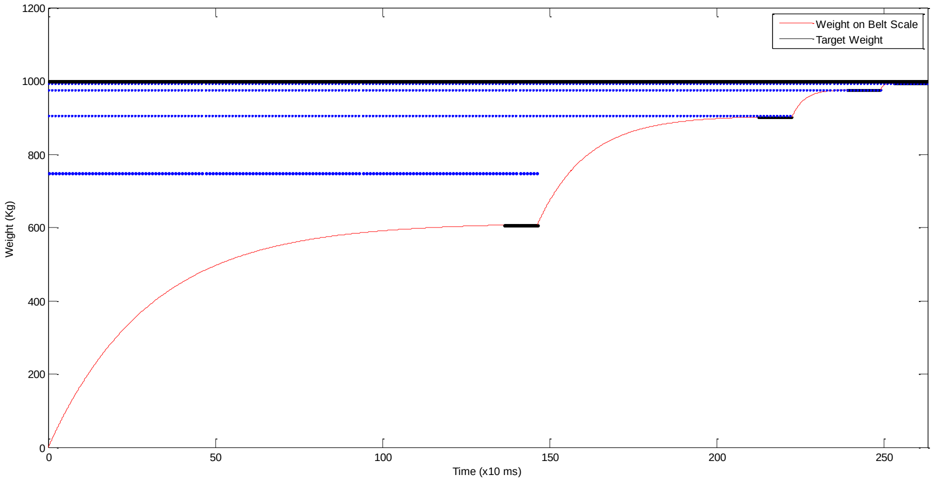


Figure (7.4): Simulation of four-cycle runs aggregate batching process with estimated flow rate > actual flow rate

Table (7.2): Case II: Cycle runs of filling 1000kg aggregate , estimated flow rate > actual flow rate

Cycle Run	Set Point (kg)	Actual Weight (kg)	Remaining Weight	Gate Open Time (ms)	Estimated Flow Rate (Kg/s)	Actual Flow Rate (kg/s)	Flow Rate Correction (kg/s)
1	750	606	253	1363	550	450	-1.05
2	295	935	64	663	448	450	-
3	73	984	16	165	448	450	-
4	18.5	996	4	41	448	450	-

Case III: (Estimated Aggregate Flow Rate < Actual Aggregate Flow Rate)

Target Weight = 1000 Kg.
Estimated Aggregate Flow Rate = 550 kg/s
Actual Flow Aggregate Flow Rate = 650 kg/s
Current weight on Scale = 0 kg

First Cycle Run

```
Wer = (TargetWeight - w)*k; % Weight error = Target Weight - current
Weight
   = (1000 - 0)*0.75;
   = 750 kg
```

```
Tw = (Wer / MCfr); % Convert Weight to duration
  = 1363 ms
```

```
Actual Weight           = 885  kg
Weight Error            = -135 kg
Actual Flow Rate        = 6.5  kg/s
Flow Rate Correction    = +0.99  kg/s
Remaining Weight        = 115 kg
```

From the first cycle the PLC reads the weight accumulated on the scale and calculates the actual flow rate based on the last pulse duration, the algorithm detects that the flow rate is lower than required and needs to be increased by 0.99 kg/s, the simulation run is shown in Figure 7.5 and the data for all cycles are tabulated in Table 7.3

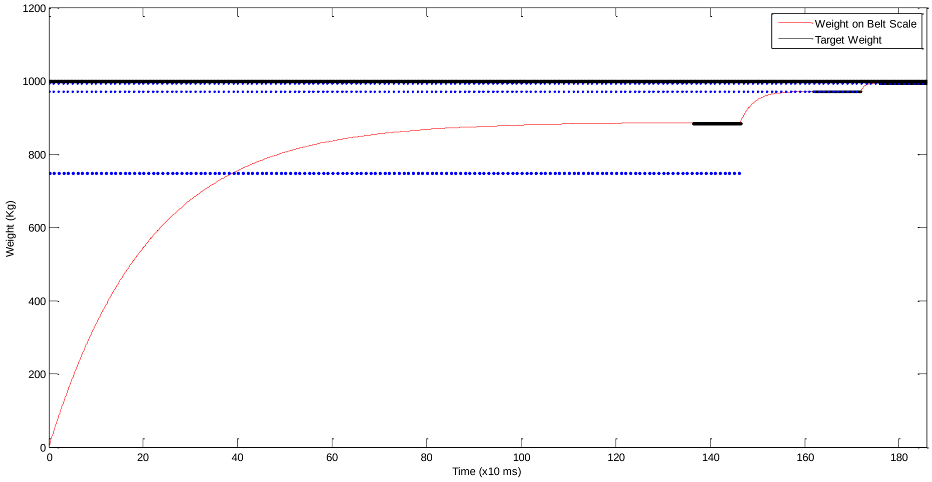


Figure (7.5): Simulation of four-cycle runs aggregate batching process with estimated flow rate < actual flow rate

Table (7.3): Case II: Cycle runs of filling 1000kg aggregate , estimated flow rate < actual flow rate

Cycle Run	Set Point (kg)	Actual Weight (kg)	Remaining Weight	Gate Open Time (ms)	Estimated Flow Rate (Kg/s)	Actual Flow Rate (kg/s)	Flow Rate Correction (kg/s)
1	750	885	115	1363	550	650	0.99
2	89	971	28	132	650	650	-
3	21	993	7	332	650	650	-
4	-	-	-	-	-	-	-

7.3 SPC control charts implementation.

Control Charts, also known as Shewhart charts or process-behaviour charts are the most common tool used under SPC. Standard control charts are produced by calculating an average result for a time series of data, plotting this as the central line, and then calculating control limits either side of this mean. These control limits are usually set at plus and minus three standard deviations from the central line. This range will account for approximately 99.7% of all natural, ‘common cause’, variation.

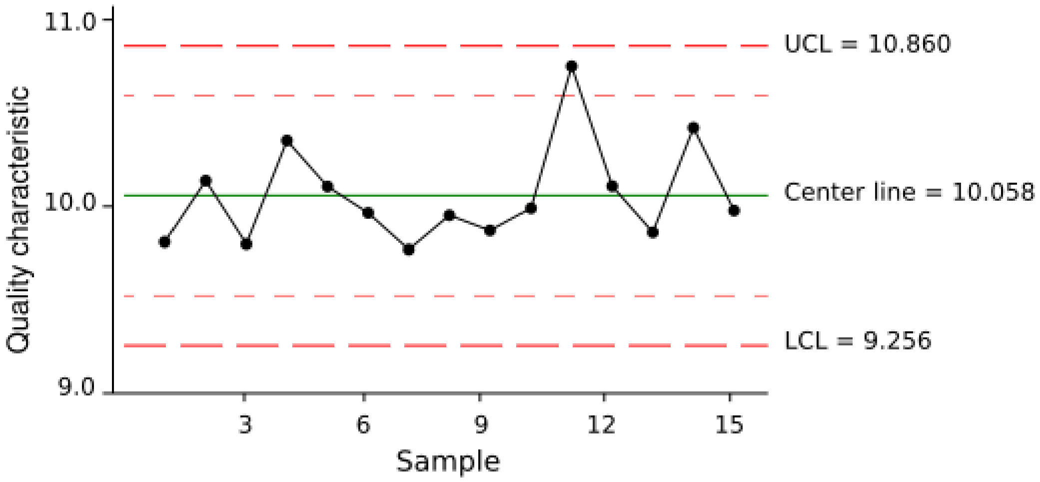


Figure (7.6): Control chart example

This control chart in Figure 7.6 shows a central line, upper and lower control limits and warning limits (the thin dashed red lines). Warning limits are usually set at plus and minus two standard deviations and indicate points where further investigation may be necessary, especially should a number of consecutive points fall between the warning and control limits.

7.3.2. Producing Control Charts

An important part of the control chart is obviously the setting of the limits used to identify points where the system is ‘out of control’. There are a number of formulae that are used to produce these limits, and each is dependent on the type of chart being used and certain characteristics of the data.

Below are some of the most commonly used formulae for calculating control limits:

$$Control\ Limits = \bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

Where: $\bar{p}$ = historical average proportion
n = number of opportunities

A "c-chart" control chart is produced for count data with n observations each with a constant 'area of opportunity'.

Where counts are involved , the following formula is used:

$$Control\ Limits = \bar{c} \pm 3\sqrt{\bar{c}}$$

Where: $\bar{c}$ = historical average count

This formula assumes that the data follows a Poisson distribution, as the standard deviation of a Poisson distribution can be estimated by the square root of the mean.

Where the data does not follow a Poisson distribution the following formula is used for counts:

$$Control\ Limits = \mu \pm 3\sigma$$

Where: μ = Mean value of the data
σ = Standard Deviation of the data

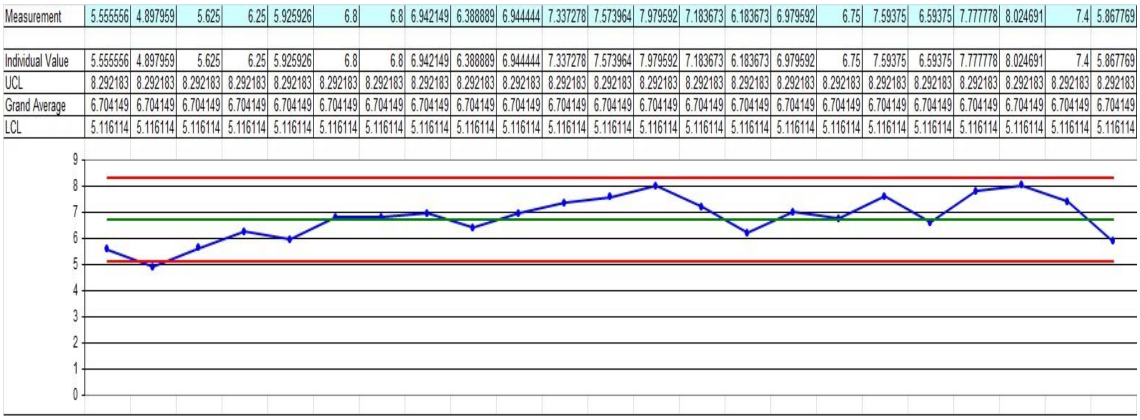
7.3.3. Identifying special cause variation using control charts

If the process is in a 'state of control' then the sample means will fall within the control limits about 299 times out of 300 (where three standard deviations have been used for the limits). Any points where the sample means fall outside the control limits should be investigated further, as something may be affecting the system and the quality of outputs may be affected.

7.3.4. Selecting the process characteristics and monitoring variables

In the aggregate batch process control, two key variables were used to determine the product quality, which are aggregate filling Weight (AFW), and aggregate flow rate (AFR). Their monitoring is done based on weight measurement samples, usually taken out at end of aggregate bin gate close, after the weight is stable on the belt conveyor.

The process is monitored online through these large number of process measurements. Samples are collected and plotted on control charts whose centerline and range were determined by the historical data, as shown in Figure 7.6



Measurement	5.555556	4.897959	5.625	6.25	5.925926	6.8	6.8	6.942149	6.388889	6.944444	7.337278	7.573964
Individual Value	5.555556	4.897959	5.625	6.25	5.925926	6.8	6.8	6.942149	6.388889	6.944444	7.337278	7.573964
UCL	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183
Grand Average	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149
LCL	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114

Measurement	7.979592	7.183673	6.183673	6.979592	6.75	7.59375	6.59375	7.777778	8.024691	7.4	5.867769
Individual Value	7.979592	7.183673	6.183673	6.979592	6.75	7.59375	6.59375	7.777778	8.024691	7.4	5.867769
UCL	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183	8.292183
Grand Average	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149	6.704149
LCL	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114	5.116114

Figure (7.7): SPC control chart of aggregate flow rate

A large measurement observations for a longer period can be seen in In Fig.7.7 and 7.8 which show control relative to the statistical limits and run tests for 100 filling runs which is considered a sufficient period of time .

The user can monitor these charts on their user interface screens, to see if the process is stable and within limits as it runs on the factory floor. If there are Special Cause variations in the operation. Appropriate actions can be taken based on these observations to correct out-of-limit operation. In addition, the effects of any process setpoint changes can also be observed and evaluated objectively. These continual improvement and optimization strategies are at the heart of practical implementation of Total Quality Management.

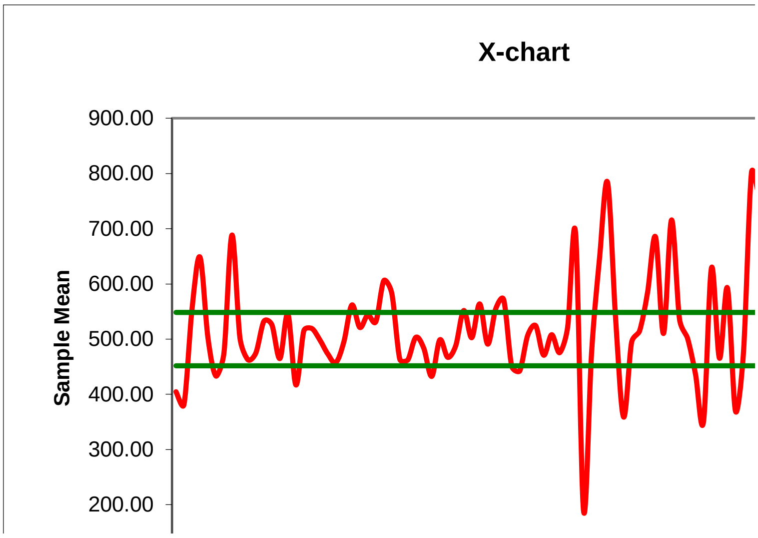


Figure (7.8): X-Chart for Controlling Process Variables (Flow Rate)

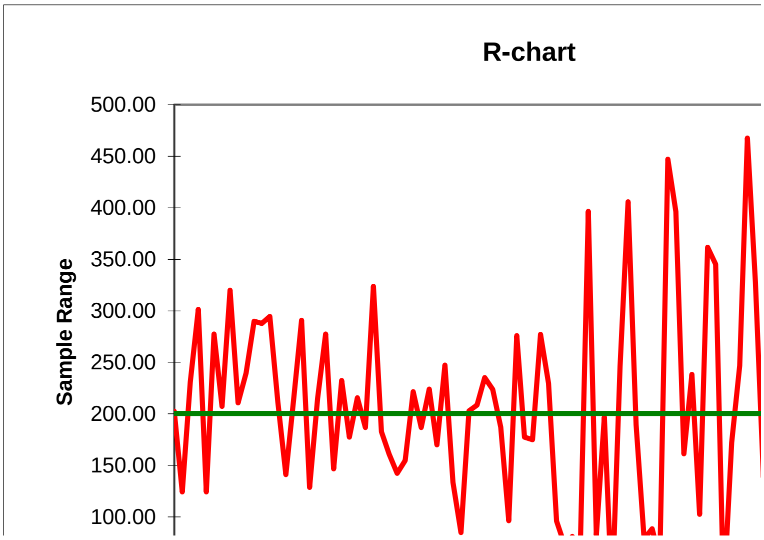


Figure (7.9): X-Chart for Controlling Process Variables (Flow Rate)

7.3.5. Fault detection and diagnosis based on SPC and EPC

There are different rules that can be applied on industrial batch process based on SPC control charts, some of these rules are presented in Table 7.4. For each control chart, there are two cases that arise: Exceeding the Upper Limit of Control (ULC) up or exceeding the Lower Control Limit (LCL) down.

Table (7.4): Extract from the EPC Rules According Control Charts Limits

Variable	Current value is less than LCL	Current value is greater than UCL
AFR	- increase air pressure - check pneumatic selector - Check gate piston - Adjust flow rate constant	- Decrease air pressure - Adjust filling parameters - Adjust flow rate constant

CHAPTER 8 CONCLUSION AND RECOMMENDATIONS

This thesis presented the design and development of industrial batching plant control and quality management using SCADA. The plant subsystem modules were modeled in this research. A complete mathematical model of aggregate batching process was developed, and a novel algorithm for aggregate batching process was developed and implemented in one of the largest readymix concrete batching plants in Gaza strip, the control system is based on PLC ladder logic and SFC. Different simulations of the process were performed using MATLAB software.

A SCADA based Graphical User Interface (GUI) of the software package was developed for controlling and monitoring the plant. An industrial communication protocol (Modbus) was implemented to link the SCADA system with the PLC.

The process and batching data were transferred from PLC memory to SCADA database for quality control, this data stored and exported in Ms Excel format.

The implemented system reduced the average error in a single batch from 7% of total weight batch to below 3%.

The developed system provides immediate, real-time feedback on the process. Program enables entering data, changing the view of data, reviewing alarms and assigning comments and causes to the SPC samples. This SPC program might be useful in the implementation of Total Quality Management strategies that call for continuous improvement of the process variability.

A future work can focus on detailed system modeling of pneumatic control devices to take into account the variation caused by change in air pressure. In addition, the moisture in the aggregate material can be measured using special sensors to compensate for water ratio in the mixture.

[14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [13], [34], [35]

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APPENDIX A: SCADA GUI

A.1. Main Screen

A complete functional SCADA system was developed and tested in a real concrete batching plant in Gaza, the software allow the operators to select the jobmix type, and other related information regarding the current batch, all the data along with process parameters are saved in database.

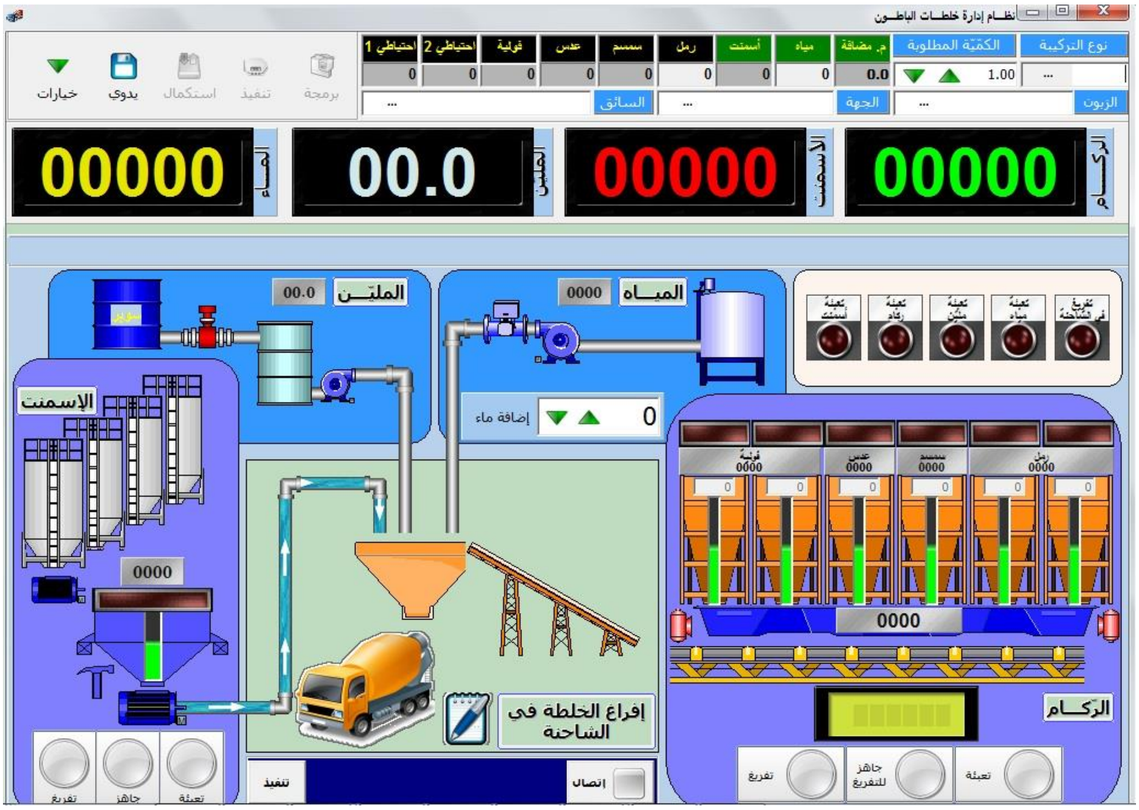

Figure (A.1) SCADA main screen

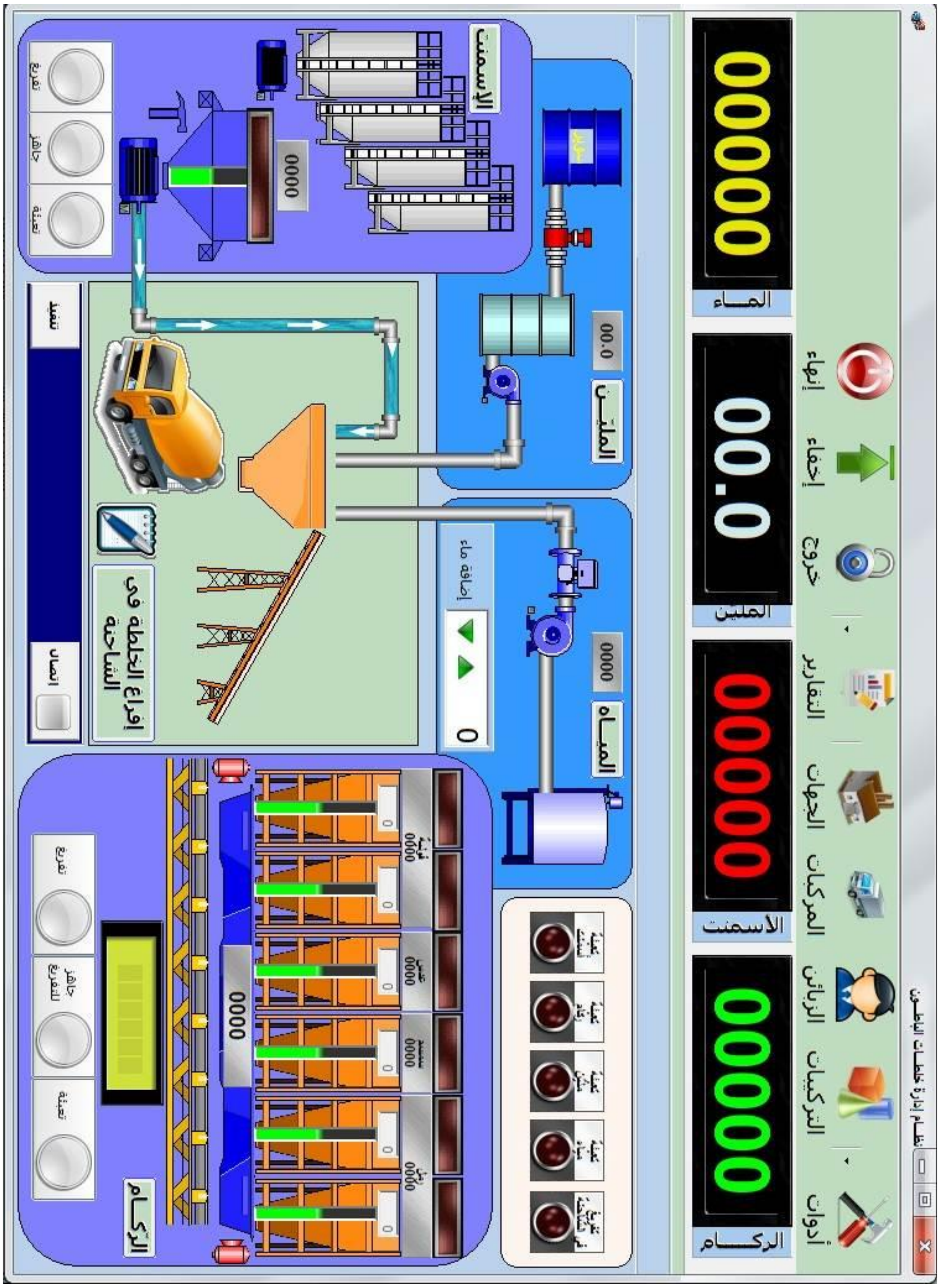

Figure (A.2) System Settings Toolbar

عرض تفـــاصيـــل الخلطة رقم:

رقم الخلطة: 1396

التركيبة: B250
الكميّة: 8.5
المركبة: 4
تاريخ التنفيذ: 16:35:07 22/12/2012

اسم الزبون: ناصر الحلو
الجهة: غزة
السائق: أسامة جابر حبيب

الملاحظات:

التصنيف	العنصر	ك. المطلوبة	ك. الحقيقية	الفرق
متفرقات	م. مضافة	12.75	12.75	0
متفرقات	مياه	1275	1275	0
متفرقات	أسمنت	2550	2594	44
ركــام	رمل	5950	5950	0
ركــام	سمسم	2125	2110	15-
ركــام	عدس	2125	2140	15
ركــام	فولية	5950	5950	0
ركــام	احتياطي 1	0	0	0

Figure (A.3) Single batch details

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إعدادات تعبئة الركام

	معدل تقطيع بطيء	معدل تقطيع سريع	معدل التدفق البطيئ	معدل التدفق السريع	زمن الفتح	زمن الإغلاق	وزن تفعيل البوابة 2
بوابة الفولية	0	0	0	0	0	0	0
بوابة العدس	0	0	0	0	0	0	
بوابة السمسم	0	0	0	0	0	0	
بوابة الرمل	0	0	0	0	0	0	0

إعدادات تعبئة الأسمنت

تعديل الوزن المطلوب 0

إعدادات التفريغ

	نقطة التفعيل	زمن البدء	فترة الإطفاء	فترة التشغيل
رجّاج تفريغ الركام	0	0	0	0
رجّاج تفريغ الأسمنت	0	0	0	0

Figure (A.4) System Calibration Screen

A.2. PLC Sequential Function Chart (SFC)

A complete control system for plant automation was implemented using PLC ladder logic and SFC as show in Figure A.5 The PLC SFC Control

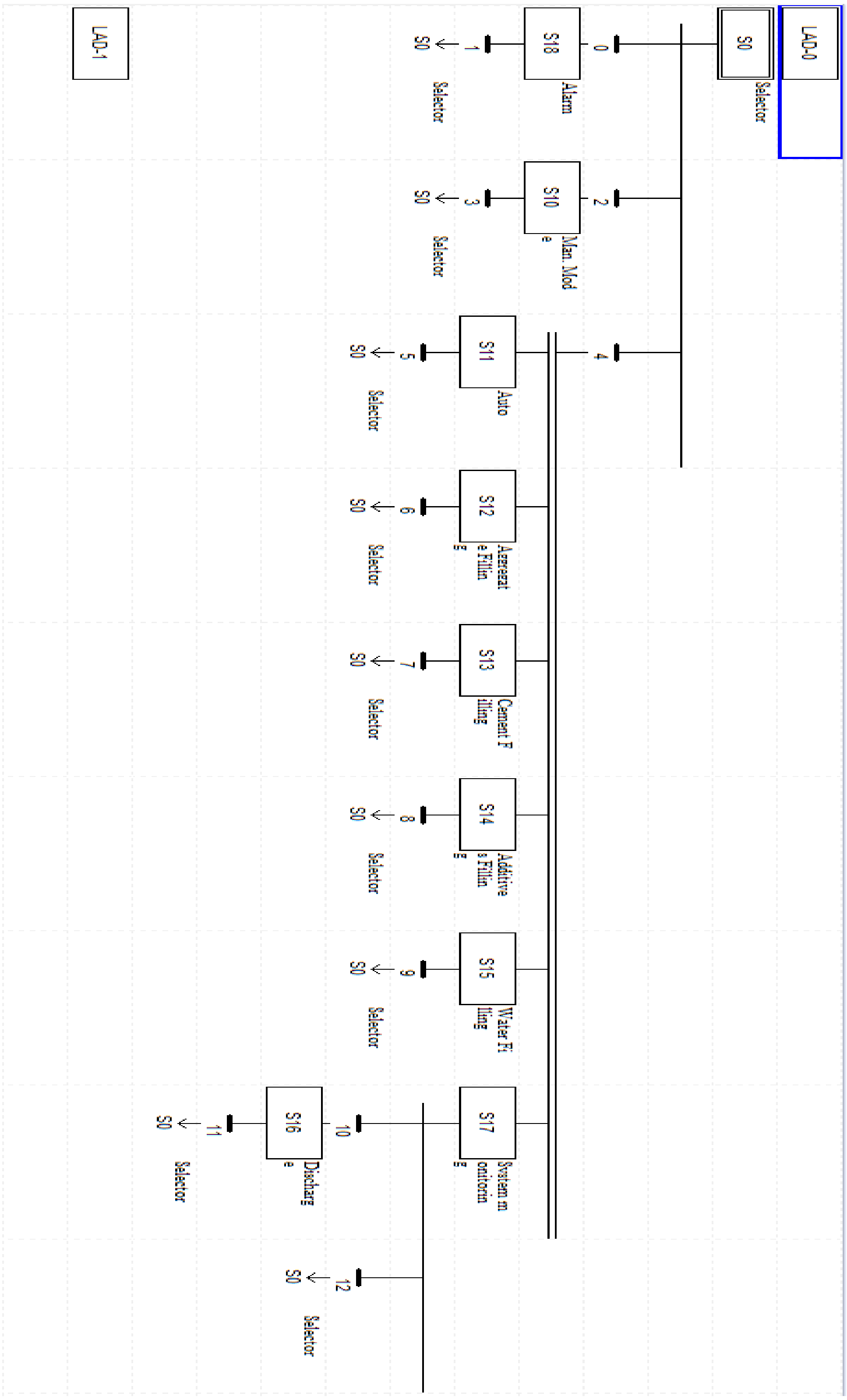

Figure (A.5) The PLC SFC Control