A SIMULATION STUDY OF PAPER MAKING PROCESS

A DISSERTATION
Submitted in partial fulfilment
of the requirements for the award of the Degree
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ELECTRICAL ENGINEERING
SYSTEM ENGINEERING AND OPERATIONS RESEARCH

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CERTIFICATE

Certified that the dissertation entitled A Simulation Study of Paper Making Process , which is being submitted by Rajendra Prasad in Partial fulfilment for the award of Degree of Master of Engineering in System Engineering and Operation Research of Electrical Engineering of the University of Roorkee, Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for a period of six months from January 1979 to June,1979, for preparing this dissertation at this university.

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RAJENDRA PRASAD

SYNOPSIS

The paper making industry requires intensive use of automatic control at various stages to implement the control of a paper machine even using on-line digital computer whenever possible. The work was undertaken to develop a linear model and then identifying the model parameters for a given subsystem. The different phases of the project are the following:

1. To suggest a state space discrete time model for a subsystem of paper making process.
2. To identify the parameters of the system.
3. To estimate the states of the process.
4. To investigate the effects of the new control variables on the states of the process.

All these points are covered in this work and the results obtained are found in close agreement with the experimental data.

CONTENTS

CHAPTER I

INTRODUCTION

The paper making is one of the most exciting process in which assembling of individual fibers is done to make a sheet of paper. On-line automatic controls should be adopted for the optimal preference of the process. Presently adaptive control schemes are used for increase in production.

The IInd chapter of this dissertation presents an introductory survey of the over all paper making process in descriptive form. The purpose being to present in one place the over all view of the paper making process.

In IIIrd chapter the emphasis is placed on major control items that are relevent to the model presented in this work. The problem of head box control and digester control is discussed in detail. The basis weight depends on the measurement of weight per unit area of the fiber at the dry end . More uniform quality of paper is obtained through reduction of variations in basis weight, moisture content and cross machine stretch. These variations are reduced by more efficient control of stock feed, wire and dryers. Variations in cross machine stretch are reduced, by better control of drag and velocity differences in the dryer section.

In Chapter IV the previous work done in the modelling of paper making process is revived.

Chapter V contains the actual work done in this thesis. The intent of the work being to present a state space model of a subsystem of paper making process. The following points are kept in mind for the development of the model.

1. Scope or boundary of the process under study
2. Depth of details
3. Physical and safety constraints
4. Steady state or dynamic control (frequency components in variables)
5. Accuracy required
6. State variables and available control variables
7. Disturbances and other control variables

It is presentation of a physical process in the form of a mathematical model. So intution, judgement and classical scientific method of observation is adopted using well known laws of physical and chemistry to describe the process in mathematical form. The key factors of the model are -

1. Development of the model in mathematical form
2. Identification of the variables of interest
3. Determination of extent of information from existing documents

In the paper making process particularly the complications arise due to difficulty in obtaining accurate measurements but such complications are however accurately handled by the linear stochastic control theáry. For the on-line control it is necessary that identification technique should also be on-line so that the identifier receives the information about the response of the system and feeds the identified values of the parameters to the controller continuously. On line identification is approximate because -

1. The process has time varying dynamics. The variations in dynamics is caused by such factors as changes in the wire drainage characteristics degradation of dryer felt, ambient air properties and changes of weight an composition from one grade of paper to another.
2. The accuracy with which the control parameters are selected for moisture content and basis weight has a strong influence on operating economy.
3. Selection of control parameters by trial and error methods is not practical because of the normally strong interaction between moisture content and basis weight and because of high disturbance level.

The modelling and identification problem has been considered initially by Beacher, Astrom Farmer, Hem, Sastry and Vetter etc. except for Astrom, others have not used basis weight undoubtedly the most important commercial variable, as the state variable. Even Astrom has not considered other commercially and physically important variables like moisture content as the state variable.

The model presented in this thesis is in state variable form. The states have been chosen carefully from physical and commercial considerations. An on-line identification technique based on Kalman -Filter theory has been suggested.

The problem is,

1. To obtain a stochastic, linear discrete time, time invariant state space model for an existing paper making process from (fan pump onwards)
2. To choose proper state and control variables.
3. To identify various noises in the system.
4. To obtain optimal estimates of unknown elements of plant matrix and control matrix, and covariances of noises using real data collected from an actual paper making process.

The correctness of the estimated parameters is judged by comparing the estimates of states with their measured values, and from the magnitude of elements of error covariance matrix. The proposed model is investigated with reference to the process at the Star Paper Mills, Saharanpur, (U.P.), India.

The study of the problem is started with a detailed analysis of the paper making process in general and a discussion of the specific process at Saharanpur in particular. The identification technique based on Kalman filtering theory and an adaptive suboptimal estimation algorithm of Sage and Husa are given in detail, final idenfification algorithm is stated in chapter V whereas the methodology of data collection and model testing is given in chapters VI and VII respectively. The data collected from Saharanpur plant are processed respectively for machine No. 2 and Machine No. 3. Chapter VIII gives the conclusion of the work and scope of the future work is also included. Results are given in the end.

All the data collected from the Star Paper Mills Saharanpur, is given in Appendix I. The flow chart of computer programme along with its listing is given in Appendix II.

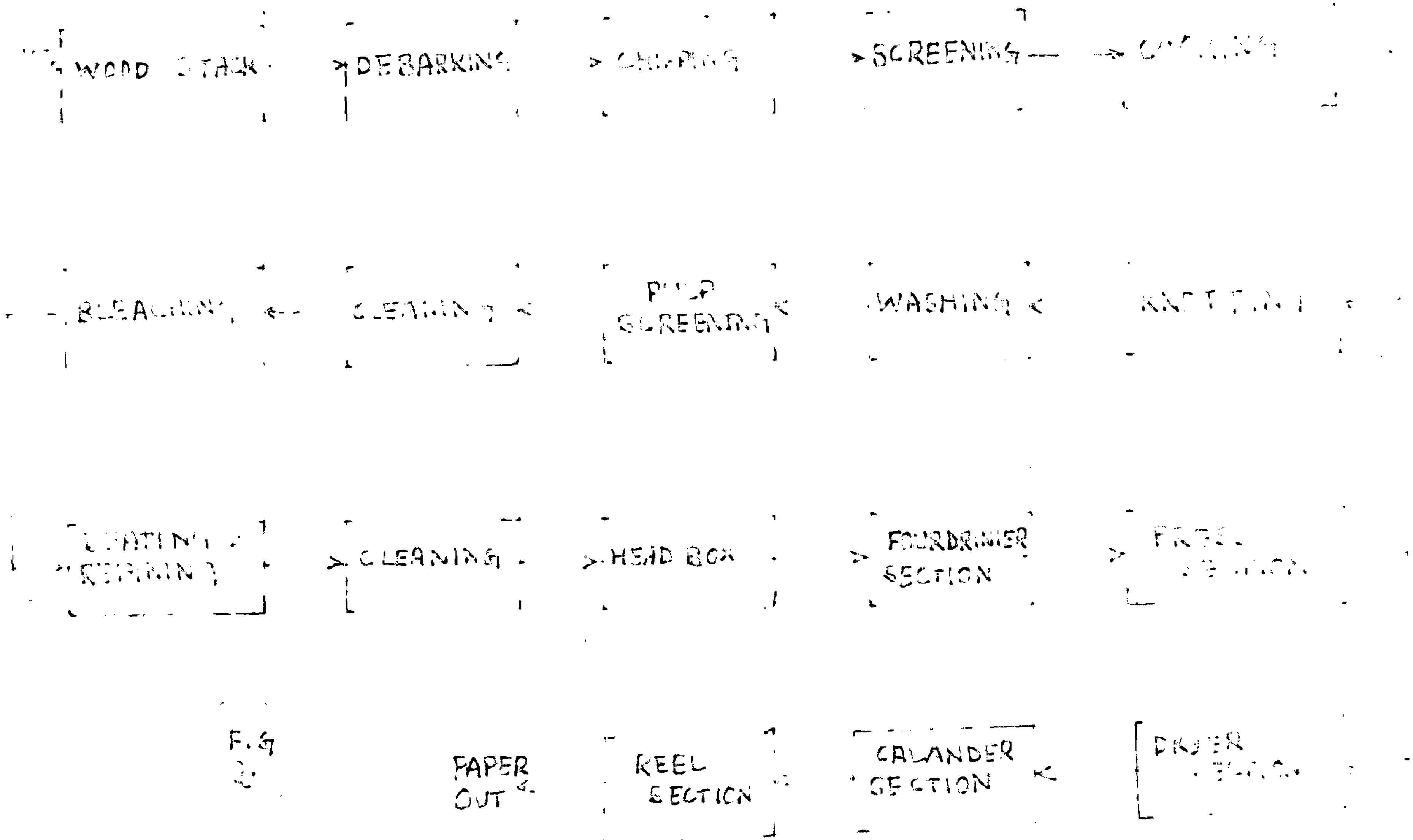
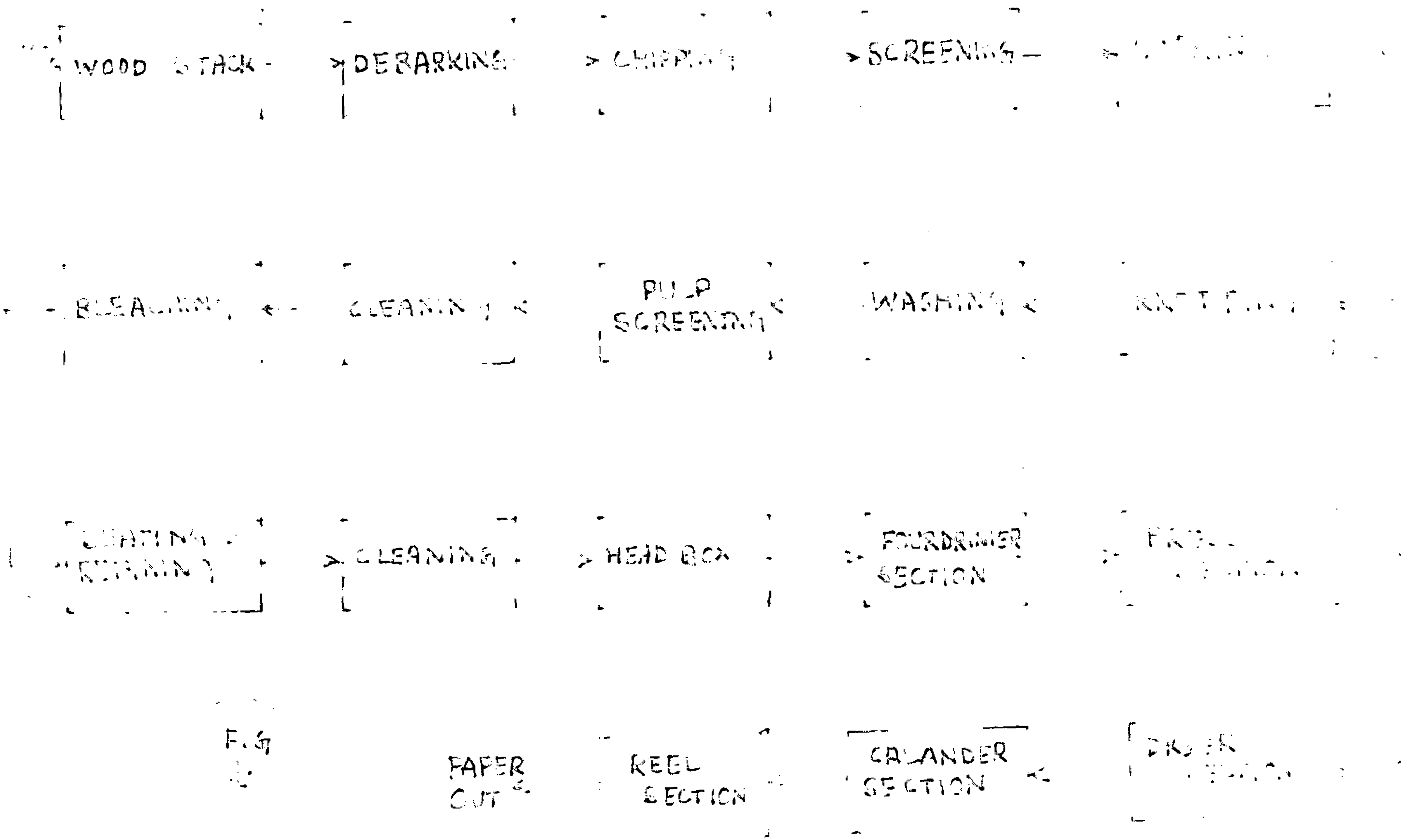


FIG 2

COMPLETE PAPER-MILL PROCESS



COMPLETE PAPER-MILL PROCESS

CHAPTER-II

PAPER MAKING PROCESS

2.1 WOOD PREPARATION

The wood is extremely hetrogeneous consisting of various wood species, in all cases with a certain individuality of each log. The felling transporting barking and chipping of wood are important preliminary steps to the pulping operation. After the wood is felled it is cut into lengths and shipped to the mill where it is kept in a wood pile near the pulp mill or stored under water. One of the most important operations in the wood preparation is therefore equalising of wood by mixing logs or chips, producing a homogenous wood mixture in the form of clean chips of the right size, preferably with a fairly constant water content.

2.2 TRANSPORTATION OF WOOD

The trees are cut to size 4 to 8 feet and some times even 10 to 60 feet in length and upto 40 inches in diameter depending on the capacity at barker and chippers. Trucks and rails are used for the transportation of these logs to pulp mill, water transportation can also be used if facility exists. The modern trend is somewhat different as the pulp mill is now constructed near the forest as near as possible on the bank of a river and then pulp is transported by trucks and rails to the paper mills.

2.3 BARKING OF WOOD

The bark and dirts are removed from the wood because it is very hard for cooking, does not contain cellulose and degrades the paper quality. Barking is easy if the pulp wood is stored under water. For the wood which is not stored under water, pre-heat treatment with hot water about 80°C or with saturated steam is essential to make barking easier. Wood soaked in hot water for about two hours will bark only in one fifth of the usual time with reduced power costs and wood losses.

We have two types of barkers

i) Hydraulic Barkers

ii) Mechanical Barkers

In the modern forestry barking is done primarily at the pulp mill, which will also facilitate the identification of various wood spices and a possible sorting out at interesting groups of wood spices. The barking is usually carried out either in single log m/c or preferably in barking drums where in with the rotation of drum the logs are tumbled against one another to loosen and rub off the bark that passes out between the openings in the drum sections. After retention time of 1/2 to 2 hours, the clean logs are continually forced out the end of the barker.

2.4 CHIPPING OF WOOD

The discharged logs from the barkers are usually received on a wide conveyor sometimes 5 feet wide. By the time of logs reach the chipper, they must be converged down to the width of chipper spout preferably during the transfer to the chipper feed conveyor.

There is a huge rotating disk with knives mounted in its pockets. The logs for chipping are taken on link chain conveyors from flume and are fed in to spout of a chipper. The logs are pulled in to the chipper due to gravity and the action of the knives on the log. The feeding of log depends on the speed of the belt conveyor system which is driven by a feed motor. Chips from the chipper are either blown to the storage or to the screening tank.

2.5 CHIP SCREENING

Occasionaly wide sections are discharged from the chipper along with fines and slivers of various sizes and lengths depending on knives level angle. As proper cooking requires chips of reasonably uniform size, all chips must be screened before entring to digesters. Chip screens can be installed either between chipper and storage or between storage and digester. The main advantage of the first arrangement is that oversized chips or cords, slivers, strips, fines and dust are kept out of storage bins. In most cases the screening rate is higher than the chipping rate so the chips through belt conveyor systems are taken to a big tanks from the chippers for screening. When the tank is full the screening starts. There are numerous designs of chip screens in use, e.g. vibrating, oscillating and gyratory. In all cases it is necessary to make out two seperations. The first takes out oversize chips, which goes to a rechipper. The second seprates the fines from accepted chips, the fines usually going into a refuse conveyer.

2.6 COOKING

The cooking is a treatment of the wood by chemicals at fairly high temprature to dissolve lignin and make it possible to librate the individual wood fibers after suitable mechanical treatment.

The chipped wood under suitable conditions of temprature and pressure is fed to digesters where different chemicals are added to it. Digester temprature and pressure are controlled to given an ideal cook. As shown in the fig. (3.9) has two main openings one at the top to receive the chips and other at the bottom to discharge the cooked material. Steam is passed wither directly or indirectly (intubes), to pre-heat the chips.

Lignin is one of the mazor substances present in the wood, occuring in amounts ranging from 17 to 32 % weight of the moisture free wood. Lignin is not evenly distributed throughout the wood. Different parts of the same wood may have lignin contents as different as 32 to 70 %.. It is a complex chemical insoluble in inert solvents. The cooking result can be judged fairly accurately from pulp lignin content determinations such as kapa number. The KAPPA NUMBER which is proportional to lignin content can be considered as the determining variable (degree of dilig-nification). Cooking process is sometimes called as delignification of the wood.

2.7 WASHING

The cooked wood goes to washers, which use series back washing principle for washing the wood, through knotters. The knotters remove uncooked and oversize wood from the cooked wood and the washers remove the chemicals used during cooking as these chemicals are soluble in hot water. The flow of hot water at the last washing stage is controlled here to have a concentrated black liquor for the better recovery efficiency.

2.8 PULP SCREENING

The next process to pulp screening and cleaning which is followed by bleaching. During screening and cleaning the oversize wood and the impurities from the cooked wood are removed. There are many types of materials introduced (or created) that are considered to be undesirable by the paper maker. The equipment available to seperate wanted from unwanted material is called screen. Screens have a feed chamber to contain the total material fed to the screen in liquid suspension this chamber is seperated from accept chamber by the screen plate. The accept chamber collects the material passing through the screen plate and discharges it by pressure or gravity to the next operation in the system. There is also the reject chamber or discharge point for clearing the screen of debris which has been separated from the good fibre by screen plate.

2.9 BLEACHING

The main object of the bleaching process is the removal of coloring materials in the fibres and the production of white pulp of satisfactory properties. During bleaching lignin is also removed as it is converted in to water soluble compounds. Both types of oxidising and reducing agents are used for bleaching. Commonly used are chlorine compounds e.g. hypochlorous acid sodium hypochlorite, calcium hypochlorite, chlorine dioxide and sodium chlorite etc. The other hydrogen peroxide sodium per oxide (oxidizing agents), sulfur dioxide, sodium bisulphite, sodium hydrosulphite and sodium borohydride (reducing agents) are also in use. Chlorine and its compounds containing available chlorine are commonly used for bleaching because of their low cost.

When chlorine gas is dissolved in water a molecule each of hypochlorous and hydrochloric acid is formed. The composition of a chlorine solution depends on PH. Below a PH of 7 hydrochloric acid is present in the solution and prolonged exposer of the fibres to hydrochloric acid will result in degradation and loss of strength of fiber. Thus the PH of the system is important factor. Free chlorine available also depends on the temprature of the bleaching tower hence bleaching rate is governed by temprature of tower as well. So adequate temprature regulation is a necessity for the efficient use of the bleaching agent and the production of a uniform product. Conditions of temprature, pulp consistancy, PH and concentration of bleaching agent must be controlled to give the desired degree of purification and brightness with a minimum attach on the fiber constituents considering the above factors a multistage bleaching process is used. A single stage bleaching process can also be used producing a poor quality of paper for rough use. In the single stage process variables which are to be controlled mainly depends on the quality of the pulp required. PH and temprature are in general controlled.

2.10 PULPING

The main objective of pulp making process is to seperate wood into its individual fibers of cellulose under such conditions as to obtain the commercially desirable properties in the fibre. The most important properties from the paper making point of view are (1) fibre morphology (2) The amount of distribution of chemical constituents of pulp fibre (3) The shape, size, distribution and physical conditions of the pulp fibres.

The raw material used as well as the type of pulping process, influences the first two properties whereas third property is influenced by the fibre treatment process i.e. the stock prepration also in addition to above two factors. The classification of paper making processes is done on the basis of the manner in which the pulp is obtained. Thus we get three broad classifications, mechanical, chemical and semichemical.

Mechanical pulp is obtained by grinding log or black of wood against revolving abrasive stone in presence of water. Mechanical wood pulp is practically identical with wood in composition.

In the chemical pulping the barked logs are passed through a chipper, a huge rotating disk carrying some knives. After screening process which remove oversize and undersize chips, the chips are carried to the digesters, where these are cooked under pressure in a chemical solution which removes unwanted constituents of wood and leaves the separated cellulose fibres - a pulp. There are three main chemical process as: (1) soda process (2) sulphite process (3) sulphate process. In soda process, the chips are digested in caustic soda at high temprature. In sulphite process wood chips are cooked with sulphurous acid and a base of either calcium, sodium, magnesium or ammonium. In case of sulphate process wood chips are digested in sodium sulphide along with sodium hydroxide. Though the name of the process is sulphate process sodium sulphide is used for cooking.

In semi chemical process mechanical and chemical methods are used to make the pulp. Any of the common pulping chemicals like sulfurous acid or bisulphite and conventional cooking processes can be used for making the semichemical pulp by reducing greatly chemical to wood ratio with lesser cooking time, or the temprature of the cooking. By rubbing and grinding action semichemical pulp is obtained. It is similar to chemical pulp. The result of the pulping stage is a mixture of wood fibres and water with a consistancy (fibre concentration)of 3 to 6 per cent.

2.11 STOCK PREPARATION

This comes after pulping. The stock preparation stage starts at the beaters and refiners where the pulp is subjected to additional mechanical treatment and in some cases chemical treatment by the use of additives, and made ready for forming into a sheet on paper machine. The beating and refining changes the length and the structure of the fibres and influences the strength properties of the paper by bruising and internal loosening of the fibre, as well as by cutting action. The fibres are subjected to much more mechanical treatment in refining.

Beating and refining serve two objects (1) Blending of various paper making materials and (2) imparting th them such a properties that they will form into sheets having the desired characteristics.

Beating is probably the most fundamentally important process in paper making. Well beaten fibres can be readily formed into a uniform sheet of paper of high density whereas unbeaten fibres cannot be formed.

Beating effects are primarily physical. Among the most important ones are fracture and partial removal of wall of cellulose fibre, decrease in fibre length, inceease in fibre flexibility, formation of fibriles and increase in external specific surface paper. After refining the pulp is diluted so that consistancy in the head box of the paper m/c is 0.2 to 1.0 percent.

2.12 PAPER MACHINE

The last stage of the paper mill is the paper machine. The paper machine consists of a wire supported by table rolls with suction boxes and couch roll, presses, dryers, calanders mouch and wire pit and pope reel. The purpose of the paper m/c is to separate the fibres from the water and to form a sheet of paper from the fibres. The pulp flows out of the head box through a slice on to the wire in a jet. The velocity of jet is determined by the headbox level and is normally chosen so as to mach the wire speed. The amount of water removed on the wire is determined by the properties of the pulp, the size and number of table rolls, the pressure of suction boxes etc.

Two standard types of paper machines are used to manufacture many and varied grades of paper.

1) The fourdriener machine
2) The cylinder machine

The simplified diagram of a kraft paper machine of fourdriener is shown in the fig. no. (3.10).

The fibres from the very low consistancy aqueous suspension deposit on to a relatively free woven screen. Over 95 percent of water is removed by drainage through wire. This drained water is commonly called as white water which is generally reused. (White water is life blood of the paper m/c and its use in all possible places to achieve the absolute maximum recovery of fibres, heat and chemicals must be properly engineered and closely gaurded). The paper web from the fourdrinier wire is taken to press and then to dryers to produce a paper of 90 to 95 percent solid. After passing through dryers the paper is smoothed in the calender and rolled up on the pope reel.

2.13 FIBRE FLOCCULATION

In the manufacture of commercial varieties of cylinder paper board the stock fed to the multicylinder m/c is largly composed of cellulose fibres. These fibres are flexible elongated particles with large length to diameter ratio forming loose three dimensional network structure, within a suspension at all consistancies greater than a particular very low value called Critical Consistancy or concentration. (0.05-0.2 percent) moreover the specific gravity, of cellulose fibres of varying purity can be assumed as 1. This fact suggest that once the fibres are thoroughly dispersed in water, they will not remain in this condition for a prolonged period of time. Actually fibre dispersion in water remains complete for only a few seconds, after which the forces existing in such a system starts moving the fibres towards one another to create fibre flocculation commonly called floccing. This entanglement of fibre occurs above the critical consistancy.

The rate at which the flocculation of fibres occurs.

1. Increases with increasing temprature
2. Increases with increasing consistancy
3. Increases with lower velocity of the liquid flow through the various components
4. Increases with low stock freeness
5. Increases with length of fibres
6. Decreases, if the surface of the fibres coated by such chemical additives which reduce the frictional forces between the fibres.

The value of consistancy of diluted pulp in head box is always more than critical consistancy, this forming a paper sheet on the wire.

The basic functions performed by the paper m/c wet end or the sheet section are written below it is that section where the greatest complications arise and the need for speedy control lies.

1. Dilute the incomming fibre stocks to a consistancy low enough to permit easy relative motion between fibres, hence high degree of uniformity of fibre suspension. The uniformity of dilution directly influences the uniformity of the basis weight in machine direction.

2. Distribute the diluted fibre suspension uniformly on the forming wire screen, while maintaining the fibres uniformly dispersed.

3. Deposite the individual fibres uniformly on to the forming wire screen as suspending water drains away from the wire.

4. Compact the fibre mat while it is in plastic condition to obtain close fibre to fibre contact and closing up the pore structure of the web.

5. Remove as much of the entraped water as possible before transferring the web to the wet press section.

The water removed from the wire depends on the properties of pulp (fibre length distribution fibre structure temprature etc), the number of table rolls and their dimensions, the pressure in the suction boxes under the wire etc. When the paper leaves the wire: The consistancy is about 20 to 25 percent. Water removal in the process depends on the forces that keep the press rolls together, felt conditions, and the temprature of the paper sheet. The consistancy after presses is 40 to 60 percent.

2.14 DRYING PROCESS

As the paper leaves the press section it contain from 35 to 40 percent solids. The dryers consists of a sequence of steam heated cylinders, and the water removal is given by the steam pressure which is set separately for different groups at drying cylinders, and the ventilation of the dryer section

The steam pressure required for drying the sheet depends on the type and grade of the paper, the number of drying cylinders, the speed of the machine and the efficiency of the ventilating system. Apart from the pressure and temprature of the steam the efficiency of dryer depends on the efficiency to remove condensate from the drying cylinder. Bibre content after drying section is about 90 to 95 per cent and the moisture content is about 5 to 10 percemtg After passing through dryers the paper is smoothened in calender, with the application of pressure and some degree of friction, and rolled upon the pope reel.

CHAPTER -III

MAJOR CONTROL ITEMS

(Quality Control of Paper)

Paper quality is controlled at different sections. Firstly it depends on the quality of raw material used, secondly on cooking process. The paper quality also depend upon the degree of bleaching beating refining and cleaning during bleaching and stock prepration stage. At paper machine section the paper weight per unit area (grade) and moisture are controlled. In this chapter the discussion will be restricted to that part of the paper m/c control which improves the paper quality. The mainfactors which improve the paper quality are basis weight control, moisture control and tension control. Tension is controlled after dryers as up to that section paper runs on felts. Tension control also increases the rate of production.

3.1 BASIS WEIGHT CONTROL

The oldest method of controlling the basis weight (wt/m^2) is to weight samples of paper taken from the reel and then by manually or remotely adjusting a stuff gate or valve and the head box slice lip to correct variations from the weight specified in order, obviously, considerable off weight paper could be produced in the interval between the prepration and testing of the samples and the corrective action.

At present development of the β gauge has resulted in the direct measurement of the basis weight by means of a radioactive source material. The principle of the operation is based on β ray absorption. Low energy rays rediated from a weak radio active source strikes the paper as it passes the gauge, some of these rays are absorbed by the sheet from the source. Variations in the weight of the sheet will vary the amount of absorption and thus by measuring head basis weight can be directly determined. When the sourse and measuring head are on the same side of the sheet, the method is termed as Back Scattering.

A β gauge consists of an holder for the ray source, a means for holding and positioning the source holder and head, and the necessary recording and controlling instrument. The measuring head is essentially an ionization chamber supplied with constant voltage. As the amount of radiation reaching the head varies, the amount of current through the chamber varies. This measurement is amplified and picked up by the associated recording and controlling instrument, which position a stuff gate or control valve. Traversing gauges are available for scanning the entire width of the sheet. Anxilary equipment is available to indicate tolerance limits and to actuate audible or visual signals if thier limits are exceeded moisture measuring and recording gauges are also attached to the scanning mechanism.

3.2 MOISTURE CONTROL

Moisture in the paper sheet is measured by measuring the different related variables since it is difficult to measure moisture directly. Some of the related variables include, conductivity, dielectric properties absorption of radio activity and temprature difference between a dryer and the sheet leaving. Moisture in the paper sheet can be accurately controlled by utilising the dielectric properties of the paper. Changes in moisture of sheet change its dielectric constant. Since electrical capacitance is directly proportional to the dielectric constant of the material in the field of a capacitor, the sheet itself is used as the dielectric. The measuring head constitues the plates of a condenser. The system using an electronic controller which resets the dryer temprature controller to correct the deviation resting of temprature controller produce a trouble when there is gradient change in temprature throughout the whole dryer system, as temprature of all dryer cylinders will have to be reset. Considering this it is suggested that the pressure of the heating stream should be changed.

One more scheme which can be much more fruitful and convenient for controlling the moisture in paper sheet is proposed here. For evaporation of water from the sheet flow of [illegible] dryer should also be used. Evaporation of water from the sheet will depend on the dryer cylinder temprature and flow of air as well. It would be easier to vary the flow of air to the dryer system to control the moisture contents in the paper sheet instead of changing the temprature of each cylinder. In this scheme the moisture in the paper sheet can be controlled by controlling the water evaporation rate through regulated flow of air, keeping the same temprature gradient of the dryers cylinders system.

3.3 SHEET DRAG MEASUREMENT

A fourdrinier wire travelling faster than the velocity of stock leaving the head box, the term used for this condition is termed as drag. By connecting the output of the slice velocity square root computer and the wire speed transducer to the low and high pressure sides respectively of a differential pressure relay, it is possible to measure this drag. The output signal from the relay is connected to a recording receiver the chart of which may have a 50-0-50 scale to be read in feet per minute values above 0 indicate drag, values below zero are the result of the reverse difference between the two relay outputs and would repeat the reverse condition or rushing of the stock on the wire.

In some installations slice velocity and m/c speed are measured either electronically or pneumatically and the two measurements are recorded in to single chart.

3.4 PH CONTROL

The PH of the stock to the paper m/c is usually controlled by admitting acid to the suction of the fan pump, using the pH electrode in a sample line from pump discharge.

Save all water from which essentially all fibres have been removed by strainers is sometimes used for scalling water on pumps. If this water is excessively acid, corrosion may become a problem in which case it will be necessary to correct the pH. This is accomplished by a control similar to above, which ejects soda ash or some other alkaline corrective in to the line supplying the seals.

3.5 COUCH PIT AND SAVE ALL CONTROLS

It is customary to control the couch pit level by positioning a control valve in the discharge of the couch pit pump. When the valve closes due to low level in the couch pit, a pressure switch stops the pump, restarting on level rise. As the level rises and the valve begins to open the pressure switch automatically restarts the pump.

The white water from the pit is pumped to the savealls, where usable fibres are recovered and discharged by gravity to a wet box chest while filtrate is drained to the white water chest. There are several methods of controlling the savealls. A common method is a variable speed drive from level in the vat. Increasing level will speed up the drive, decreasing level will slow it down. Automatic interlocks can be made to start the saveall drive and turn on the white water showers. Whenever there is sufficient level in the saveall drive and turn on the white water showers, whenever there is sufficent level in the saveall, and to shut down the equipment and the showers if the saveall level below a predetermined minimum.

3.6 SLICE VELOCITY WIRE SPEED (Eff[illegible] Ratio)

The slice is essentially a slot or rectangular orifice, at the front of the head box which allows the stock in the head box to flowout on to the fourdriner wire. Its primary purpose is to take the relatively slow moving stock in the headbox at a high static head and dischagge it in to the atmosphere at a velocity close to the wire speed.

The jet velocity at vena contracta is

$v = C_v\sqrt{2gh}$ where

h = head box level

C_v = is unity for most of the slices

The jet at vena contracta is contracted the area A_u at this point (of jet crossection) is related As to the slice opening by

$A_u = C_a A_s$

C_a: coefficient of contraction

Therefore the flow from the slice Q is given by the relationship $Q = A_u V$

$$Q = C_a C_u A_s \sqrt{2gh}$$

$$Q = C_q A_s \sqrt{2gh}$$

C_q = coefficient of volume discharge.

Slice velocity is recorded by measuring pressure at the slice and translating the reading in to velocity units. The high pressure side of a pneumatic pressure transmitter is connected to the lower part of the headbox. In this way the instrument measures the total head of the liquid of the stock, plus the air, pressure if any on the headbox.

The output of the transmitter is connected to a computing instrument which automatically extracts the square root of the measurement and produces a linear output pressure, that is proportional to velocity. This pressure is then fed to one side of a pressure differential relay, and is opposed on the other side by a manually regulated air pressure. The output of the relay is received by a recorder on which a chart reads directly in feet/minutes. The manual regulator permits the shifting the range span upward or downward on the recorder chart to match the velocity range of various furnishes.

One method of measuring wire speed is to equip the couch roll with a special gear, using an electronic device which produces an electric impulse as each tooth of the gear passes the device. The higher the speed of the gear the higher will be freq. of impulses. These impulses are fed on electronic tachometer, which translate the input impulses into a linear electric output signal, the signal is then transduced in to a linear pneumatic signal, which is connected to high pressure side of a differential relay. The pneumatic output of the relay is then received by a second recording pen in the slice velocity recorder and is read on the same chart in feet per minutes. The output of the manual regulator previously mentioned is connected to the low pressure chamber of the relay to permit the shifting of instrument range up or down to suit varying wire speed ranges.

3.7 CONSISTANCY CONTROL

One of the most important process variable in the pulp and paper industry is consistancy of the pulp and paper stack. Consistancy is measured and regulated in practically every phase of the process to achieve uniform operation. In pulp manufacturing consistancy control is used in such areas as:

1. Continuous digesters
2. Screening
3. Brown stack washing
4. Bleach plants

In paper mill operations it is applied in

1. Refining
2. Stock blending
3. Repulping
4. Saveall operations
5. Wet end of the paper machine

Consistancy is defined as the percentage by weight of dry fibrous material in any combination of pulp and water or stock (pulp and additives) and water, it is calculated by the following formula,

$$C = \frac{F}{W} \times 100$$

C = consistancy of pulp or stock slurry expressed in percent

W = the total weight of a particular amount of pulp or stock slurry and

F = the weight of fibrous material in that amount of pulp or stack slurry

Basic determination of consistancy in a laboratory procedure. A measured sample of slurry is weighed, the total solids are separately dried and weighed, and the weight of fibrous material is then expressed as a percentage of measured sample. Consistancies of less than 1 percent are usually considered low those greater than 6 percent high.

3.8 CLAY CONTENT OF FINAL SHEET

There is as yet no on line instrument for measuring clay concentration in the final sheet in the meantime however to control this the computer works on the assumption that a constant clay/fibre ratio in the final sheet requires a constant, but different clay/fibre ratio in the flow box. The later ratio is computed as part of the flow box consistancy calculations, and the clay flow rate is automatically adjusted to maintain this ratio constant at the required value. Thus each time an adjustment to thick stock is made a corresponding adjustment to clay flow made. It is perhaps important to emphasise that the ratio between these two adjustments is not constant and simple ratio control would be incorrect.

Periodic laboratory measurements are carried out on clay concentration in the final sheet and the results fed in to the computer. If the means deviates from the required value, the computer calculates a new figure for the required clay/fibre ratio in the flow box and starts to control to this new figuro.

3.9 TENSION CONTROL

To enable the elimination of frequent breakage of paper the tension is measured and controlled at those positions of the paper machine where web is strong enough to support a reasonable tension i.e. after the dryer section. Because before the dryer section the paper web is wet and it is supported by felts so there is little probability of paper breakage. Furthermore slipage of fibres also prevents paper breaking at paper sheet can expand at that stage.

The actual tension in a running paper web can be measured as the resulting force with which the paper web acts on a paper web guide roll. This resulting force can be measured with a suitable installation of load cells. Since the signal representing the web tension is to be used in an

electronic control system, the output signal from the load cell should be preferably be electrical. To achieve this control it is necessary that rolls must be properly aligned and appropriate roll Crowns are needed for rolls under heavy pressure.

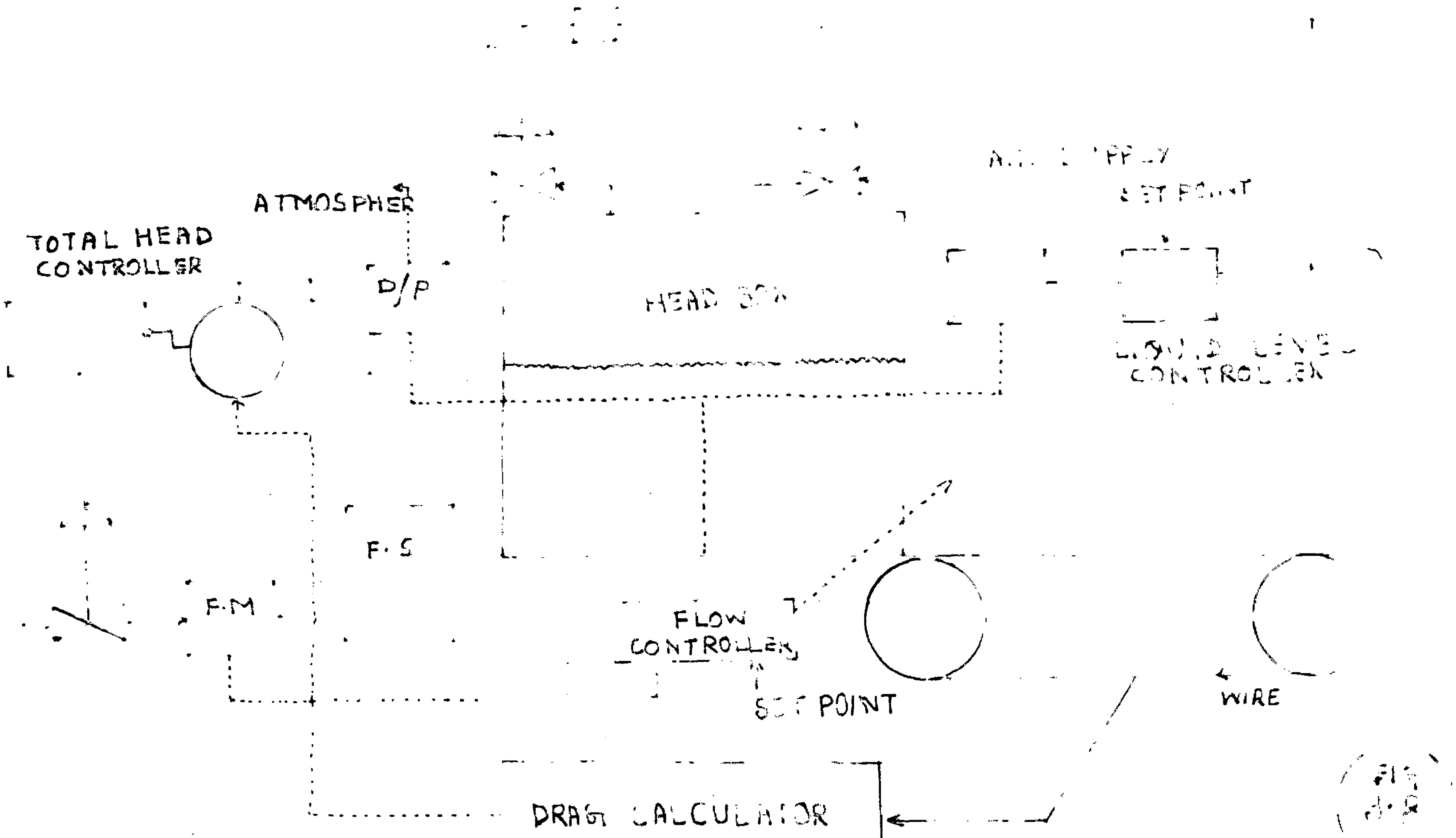
The pressductor load cell is a pressure transducer for measuring force and weight. It works on the magnetoelastic effect, that is the fact that the permeability of a magnetic material is changed by mechanical stress. The load cell is in principle like a transformer. With primary and secondary as shown in fig. (3.90). In the unloaded state, the magnetic field from the current feed primary winding is completely Symmetrical. As a result of the symmetrical arrangement of the winding no voltage is induced in the secondry winding. With an applied load and a certain amount of stress in the pressductor load cell material the magnetic field is distorted and a voltage is induced in secondry winding. This induced voltage is linearly dependent on, and is taken as a measure of the applied force on weight. The voltage output of the pressductor is directly proportional to tension, this voltage is compared with a reference voltage and the error is given to a controller which control the speed of the machine and hence tension.

3.10 HEAD BOX CONTROL

The key part of the paper making process is the wet end of the paper m/c where the web of the paper is actually formed and where greatest complications arise. The head box should be accurately controlled through reliable equipments. The control of head box is largely a matter of control of the velocity and volume rate of flow to the sheet forming apparatus (fourdrinier wire). The control of basis weight occurs through adjustment of the solid input rate to the paper machine system, in response to direct measurement of the basis weight of the dry sheet.

For an optimum control system for a head box the following five factors should be considered and controlled:

1. A constant liquid level must be maintained in the head box.
2. Total head within the box must be controlled to close tolerance to ensure that a constant dray between wire speed and jet velocity is maintained, despite changes in the wire speed.
3. A constant jet escape angle should be maintained to achieve delivery of stock to the fourdrinier wire in a controlled manner.
4. Turbulence within the head box must be controlled closely to ensure the stock delivered to the slice and formed into a sheet shows good formation as well as stable strength and optical properties.

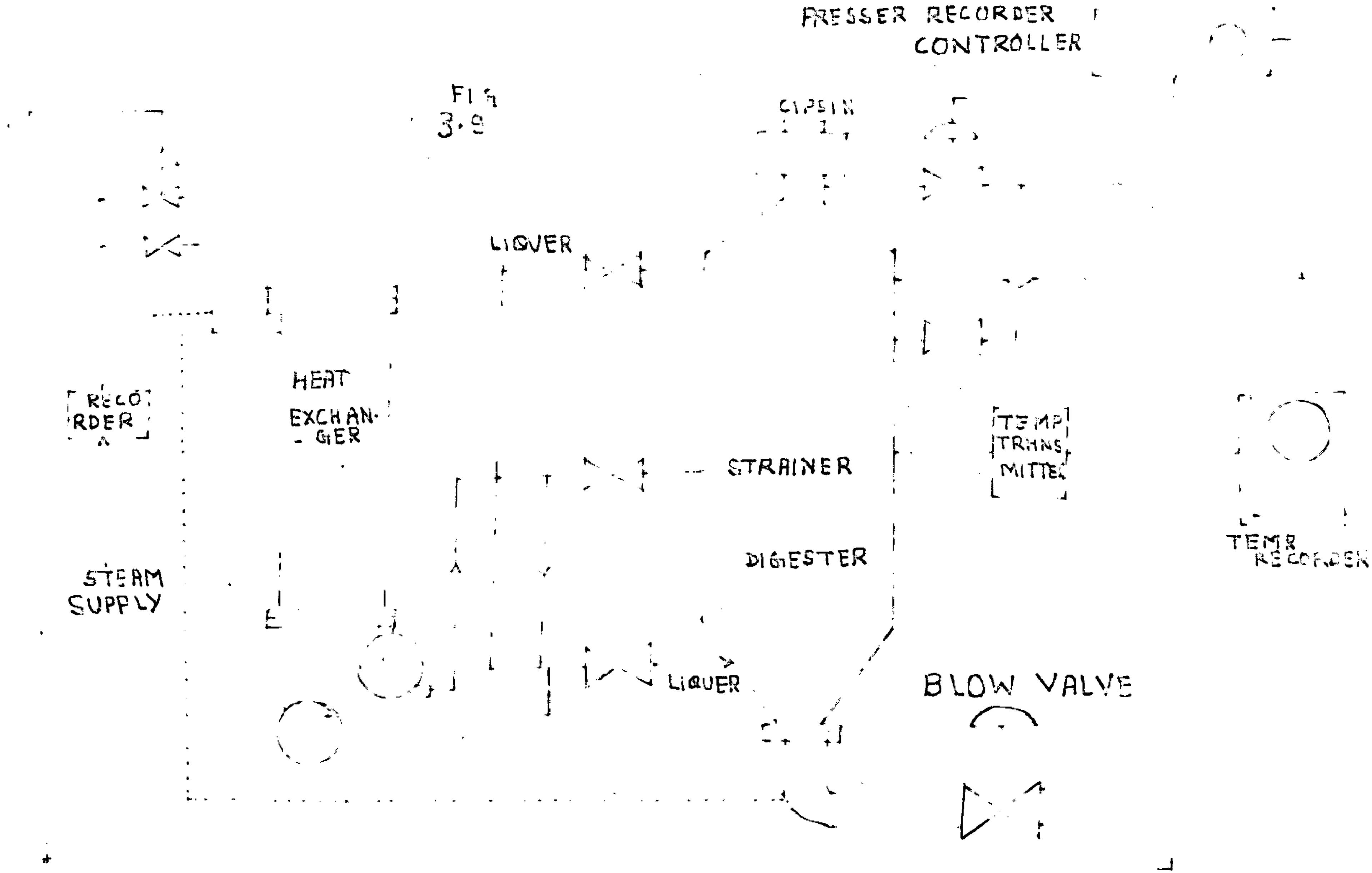


HEAD BOX CONTROL

The last variable is controlled by the use of proper flow spreaders as discussed earlier in this chapter. The control of escape angle is practically very difficult as there are no good means for measurement and to control it accurately. So it is proposed to maintain it at a constant value and to control the first three variables which are easy to control for any change in the system. For controlling these three variables in a head box system, manipulated variables such as air valve stem position water valve stem position, and slice opening are controlled. Unfortunately, the adjustment of any one of these variables causes a change in all three controlled variables (liquid level, total head, and liquid flow).

The controlled variables in the head box system are sensed at the head box fig. No. (3.8). The variables, head box liquid level and head box total head are essentially pressure measurement made with the aid of differential pressure (D.P.) cells equiped with a diaphram, the position of which is sensed by a level system that inturn converts mechanical movement into a pneumatic signal by a flapper-nozzle arrangement. In the case of a liquid level, the variable is sensed by attaching one side of a cell to a top in the bottom of the head box and the other side to a tap connected to the air pad of the box. Total head on the other hand, is sensed by connecting one side of the cell to the atmosphere and other to another tap located at the bottom of the head box liquid level is controlled by pheumatic or electronic controllers with proportional-integral action. The modulated variables are the positions of the supply and blowing values for the air pad. Total head is generally controlled by

FIG 3.9



DIGESTER CONTROL SYSTEM

electronic controllers with proportional-integral action. The prime function of a total head controller is to maintained a constant drag on the wire. As a result total head set point is a function of wire speed and it is necessary to adjust it when changes in speed occurs. This requires a system that sense wire speed, takes note of drag set point and calculates an appropriate total head set point (Hr). This can be accomplished via either analog or digital computer. This calculated total head is compared with the existing total head and the resulting error forms the actuating signal through a P.I. controller.

Flow through the head box is measured by a magnetic flow meter located just upstream of the box. The variable manipulated by flow controller cause upsets in total head that are compensated for by adjustments in the position of the valve controlling flow to the box.

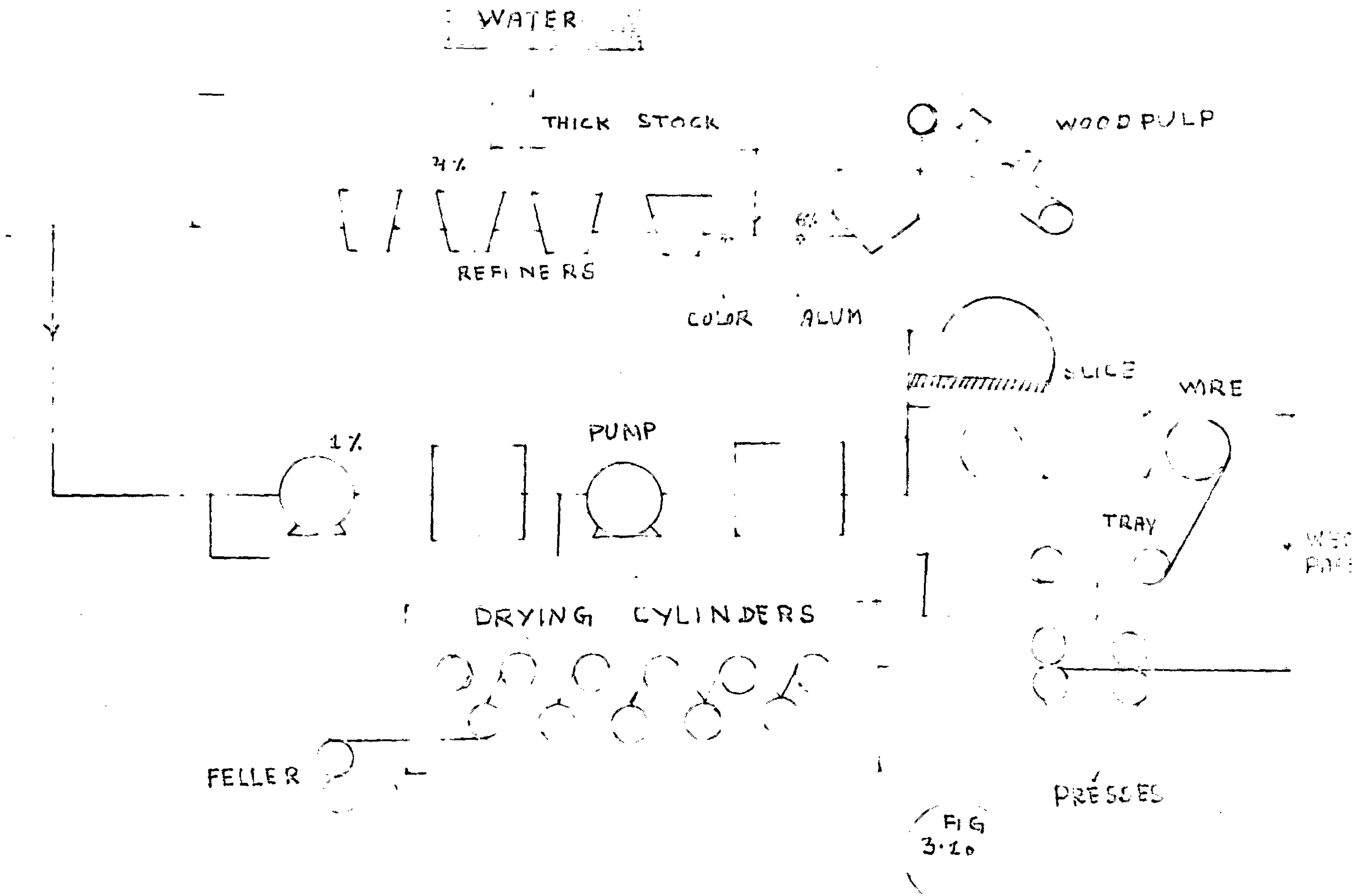
3.11 DIGESTER CONTROL

Digesters are big vessels in which cooking is done at high pressuure and temprature with acids and bases. As shown in the fig. (3.9) digester has two main openings one at the top to receive the chips and other at the bottom to discharge the cooked material to blow pit. Apart from these there are a few side openings for temprature and pressure measurements, control and for circulating the cooking liquor.

Pulp mills normally have parallel arrangement of digesters for easy and convenient handling of chips from storage and the discharge of cooked pulp from the digesters. After closing the blow valve at the bottom the wood chips are allowed to flow into the top opening of digester. When the digester is filled the top digester cover is lowered in to place and bolted.

Steam is passed, either directly or indirectly in tubes to preheat the chips. Now a predetermined quantity of hot liquor from a high pressure accumulator tank is pumped into the digester depending on the quantity of chips and the concentration of the liquor. The digesters can also be charged with a proposed automatic system. During this charging and preheating process the air and other uncondensable gases go out through a valve which is at the top of digester.

When the digester is filled with the liquor, heating of the contents is started either by direct injection of steam or by forced circulation through a heat exchanger. The pressure and temprature for an ideal cook should follow a predetermined schedule, either automatically or manually controlled. Depending on the types of chips maximum pressure is in between 90 to 135 psi and maximum temprature from 125° to 160°C and the total time of cook from 6 to 12 hours with 2 to 3 hours primary time for attainment of maximum temprature. In the preliminary phase of the cook, the temprature is raised gradually to about 138°C with a pressure of about 85 psi to permit complete penetration of liquor in to the chips. The progress of the cook is followed by testing of liquor of the side relief. When one to one and half hour of cooking time remains, the heating is discontinued and



WATER
THICK STOCK
4%
WOOD PULP
6%
REFINERS
COLOR
ALUM
SLICE
WIRE
1%
PUMP
TRAY
DRYING CYLINDERS
FELLER
PRESSES

FIG 3.10

the pressure gradually reduced. When the pressure in digester is about 20 psi then blow out valve is opened, and pulp is discharged to blow pit.

Once the digester attains the maximum temprature it is required to maintain it fairly constant at that value for 2 to 4 hours depending on the process. The digester temprature can be controlled by controlling the steam flow either to digester or to heat exchanger in direct heating or indirect heating as the case may be. Transducers are used to convert variations in temprature in to corresponding variations in power which further give signal to electromechanical device that controls the steam to the digesters.

3.12 COMPUTER CONTROL OF PAPER MAKING PLANT

In the modern paper industries for controlling the different variables computers can be used for high speed production of better quality paper with greater flexibility to meet the changing requirements. Because most of the variables on a paper machine are inter-related to several others. This means that a change in one variable will cause a change in several other variables. Unless these interactions are taken into account by control systems a control level change in one variable will cause disturbances in several other variables and may cause the entire process to oscillate for a longer period.

Fig.(3.10) shows the flow diagram of the process in operation. The major raw material is cellulose in the form of wood pulp. This is pulped with water in a hydropulper to give a homogeneous suspension of fibre in water at a concentration (consistancy) of about 6 percent. Additives are included as necessary and after further dilution the stock is refined. This operation cuts and fibrillates the fibres to prepare the stock for the paper machine. Further dilution brings the consistancy down to 3 percent at which stage it is reffered to as thick stock. The thick stock is diluted with back water from the paper machine and size solution and clay suspension are added. Clay is important as a filter to give a smooth sheet for printing. The stock is now called thin stock and has a consistancy about 0.7 percent it passes through cleaners and screens to remove lumps and then into the flow box.

The purpose of the flow box is to distribute the thin stock uniformly as it passes through a long thin orifice, called the slice on to a moving wire mesh, which is the main feature of the fourdrinier paper machine. The flow box is pressurised and the pressure is adjusted to control the speed at which the stock flows through the slice. Most of the water and some of the solids are drained through the wire, to form the back water, and a self supporting continuous web of wet paper is taken of the wire at the opposite end of the flow box. The paper web is pressed on felt toremove further moisture continuously dried on large, steam filled rotating cylinders and finally reeled as finished paper with a small moisture content.

The key part of the process is the wet end of the paper machine where the web of the paper is actually formed on the wire. It is in this area that the greatest complications arise and the need for speedy control action lies.

The basis weight (weight per unit area) is a particularly important measurement. This is obtained using a beta ray gauge mounted at the dry end of the machine. This gauge must be properly set up for each grade of paper being run and to obviate mistakes. It is set up automatically by the computer at each grade change.

The main functions of the computer are concerned with -

1. Quality control of the product
2. Overall production rate
3. Grade changes

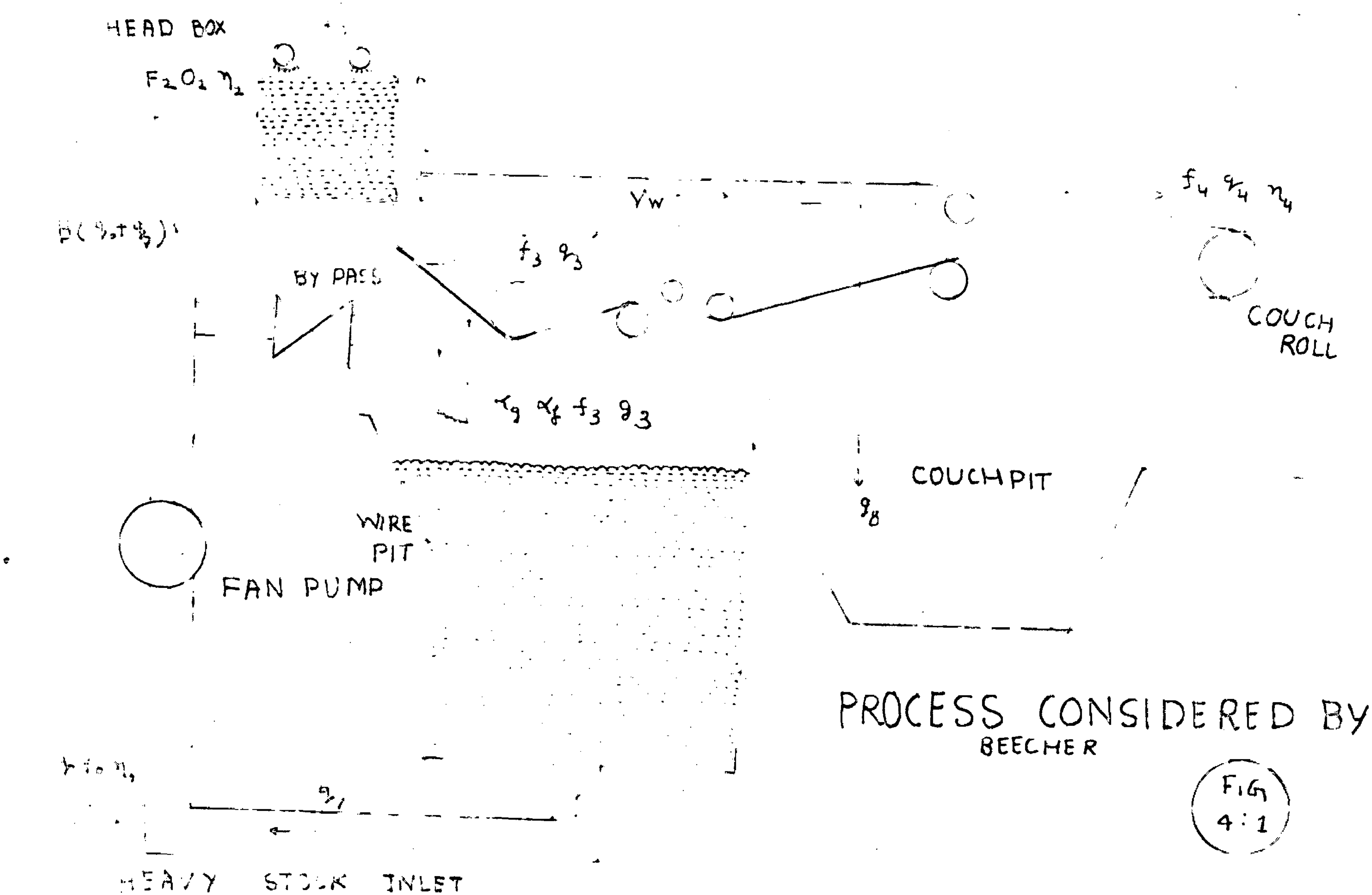
The computer controls the quality (basis weight) by first setting up standard running conditions for the grade being run and then trimming these by feedback from the β gauge. The feed back control is important feature of the system.

The formation of a sheet of paper has an important bearing on the printability and numerous other properties. The control system provide the operator with the ready means of altering formation by making controlled adjustments for efflux ratio and flow box consistancy. The computer control the efflux ratio to the required value for each grade by measuring the wire speed and then computing and setting the correct pressure in the flow box.

If the operator decides that he requires a change in consistancy or efflux ratio in order to improve the formation he instruct the computer to perform the change, which it then does by making all necessary adjustments to flows slice gap, and flow box pressure in the correct time relationship, in such a manner so as not to produce a disturbance in basis weight.

The most important factor determining the over all production rate is of course the speed at which the paper machine is run. In the past an operator has been happy to run the machine at a steady safe speed, because of the risk of poor paper quality or a paper break if he attempts to increase the speed. Now he is able to call for an increase in speed with the knowledge that the computer will do this for him at the same time making all adjustments to the other process variables in the correct time sequence. He can now therefore sail closer to the wind by running his machine faster without loss of quality and thus achieve an overall increase in production.

In the mill a wide range of different grades of paper has to be made, which require different machine speeds, different consistancies different control parameters etc. and several grade changes may be required during the course of one day. Without computer control grade changes tend to be trouble some and lengthy But with computer control of process become systematic and is speeded up considerably. The computer does this by storing standar running conditions for all grades and setting up the required new conditions automatically and in the proper manner when a grade change is required.



PROCESS CONSIDERED BY BEECHER

FIG 4:1

CHAPTER IV

REVIEW OF PREVIOUS WORK IN MODELLING OF PAPER MAKING PROCESS

The past decade has witnessed a major advance in the use of process control systems by the paper industry. Increasing attention has been paid to mathematical modelling of the paper making process. Earlier attempts in this field are due to Beecher Astrom, Farmer, Hem, Sastry and Veter. These models are being reviewed here.

4.1 ALFRED E. BEECHER'S MODEL

He considered the problem of control of machine direction basis weight on a standard fourdrienier wire starting from incomming heavy stock to the fan pump. The system will include the wire pit, the fourdrinier wire the head box, the suction boxes suction couch and the seal box shown in the fig. (2.1) schematically. The couch pit savealls machine chest etc. have all been ommitted for simplicity.

Let us start to the stock feed at the fan pump. The stock will flow at a rate q_o g.p.m. with consistancy η_o. This consistancy is weight ratio of dry solid to total water. While usually the consistancy is defined as the weight ratio of solids to water plus solids. Theamount of fibres in the stock line depends on flow rate q_o and consistancy η_o.

f_o is hypothetical quantity of pulp it is analogus to flow rate of pulp if it were similar to water (gallons of pulp per minute).

The heavy stock is mixed with white water at the fan pump. The white water flows wire pit at a rate of g_r g.p.m. with consistancy of n_7. The effulent from the fan pump flows partially to the headbox and the remainder to the wire pit. Let β is the fraction flowing to the headbox so that $(1-\beta)$ is returned to the wire pit. The head box have a head of h feet. Therefore the volume in the head box Q_2 will depend upon head h and the dimensions of the head box.

n_2 = Head box consistancy

F_2 = Quantity of fibres in the head box (F_2 gal)

A defoam spray provides a flow of g_h g.p.m. of water. There will be an effluent from the head box through the slice of g_3 g.p.m. of water and f_3 g.p.m. of fibre.

The slice opening is x_s inch.

The wire is moving with a linear velocity of V_w f.p.m. There are g_4 g.p.p.m. of water, f_u g.p.m. of fibre in the sheet flowing over the couch roll with consistancy n_4.

A fraction a_g of water, a_f of fibre flows through the wire to the wire pit. The sealbox will considered synonymous with the wire pit. A wire spray provides g_a g.p.m. to the wire pit. The wire pit contains Q_6 gal of water and F_b gal of fibre at a consistancy of n_7. A flow g_8 g.p.m. of water runs from the wire pit to the couch pit maintaining a constant volume Q_6.

The model is derived using components and energy balances together with a few definitions. The rate of change of water, Q_2 in the head box depends on incomming and outgoing flows.

$$\frac{dQ_2}{dt} = \beta(g_o + g_7) + g_h - g_3 \quad \text{------------(4.1.1)}$$

The head is determined by Q_2

$$h = K_1 Q_2 \quad \text{------------(4.1.2)}$$

By definition $f_o = n_o\ g_o$ ------------ (4.1.3)

so that the fibre balance may be written about headbox

$$\frac{dF_2}{dt} = \beta(f_o + n_7\ g_7) - f_3 \quad \text{------------(4.1.4)}$$

Also if the headbox is perfectly mixed

$$f_3 = n_2\ g_3 \quad \text{------------ (4.1.5)}$$

The energy balance is uded to obtain g_3 from the head and opening of the slice. For an open head box

$$g_3 = K_2 \times \sqrt{h} \quad \text{------------ (4.1.6)}$$

K_2 depends upon machine dimensions

At steady state

$$\frac{dQ_2}{dt} = \frac{dF_2}{dt} = 0 \quad \text{------------(4.1.7)}$$

$\frac{dQ_2}{dt}$ and $\frac{dF_2}{dt}$ are non zero only when the conditions are changing. The presence of these deviations cause the model to take a dynamic nature.

Proceeding to wire phenomina

$$f_4 = (1 - \alpha_g)\ f_3 \quad \text{------------ (4.1.8)}$$

$$g_4 = (1 - \alpha_g)\ g_3 \quad \text{------------ (4.1.9)}$$

$$n_4 = \frac{f_4}{g_4} \quad \text{------------ (4.1.10)}$$

The basis weight depends on f_4 and machine speed

$$BW = \frac{K_3 f_4}{v_w} \quad \text{------------} \quad (4.1.11)$$

Finally we may consider water and fibre balance at the wire pit.

$$\frac{dF_6}{dt} = \alpha_f f_3 + f_o (1-\beta) - n_7 g_7 - n_7 g_8 \quad \text{----}(4.1.12)$$

Q_6 is the constant so the water balance becomes

$$g_8 = g_4 + a_g g_3 + (1-\beta) g_o - g_7 \quad \text{-------}(4.1.13)$$

$$n_7 = \frac{F_6}{Q_6} \quad \text{------------} \quad (4.1.14)$$

In considering the remainder of the system, one more derivative has been arisen giving a total of there time derivatives. Consiquently we may say that this is a third order system.

The system has in equations so we may define in dependent variables. These are BW, f_4, F_6, Q_2, n_7, g_8, g_3, h, g_4, F_2, f_3, and f_o. The independent variables include β, α_g, α_f, g_o, x_s, V_w, g_h, g_o, n_o, g_7, k_1, k_2, k_3 and Q_6. F_2, Q_2, F_6 are called state variables.

4.2 FARMER'S MODEL

The Farmer's and the Beacher's model have the same approach except that no diferential equations are encountered in the former. This model has been used for analog, computer control of paper machine with the following control objectives:

BOUNDRY FOR FIBRE BALANCE

PROCESS CONSIDERED BY FARMERR

FIG 4.2

1. To maintain by means of close loop control the basis weight of a given grade of paper within the limits of ± 1.5 percent
2. To provide the operator with facilities for independent control of machine speed, basis weight, breast box consistancy Q efflux ratio.
3. Automatic grade change that is the ability to change from initial speed basis weight breast box consistancy and efflux ratio to a completely new set of conditions demanded by the operator.

He derived the model on the basis of steady state material balance equations.

The picture of the model is shown schematically in the fig. No. (4.2)

When the stock flows from the slice on to the wire, a proportion of the fibres form in to paper to be drawn off the couch, but the remainder drop through the wire in to the trays and the back water silo. If the flow from the slice is F_s and the consistancy (amount of fibres/unit volume) is C_s then the fibre flowing on to the wire is F_sC_s.

The through factor t is defined as the proportion of fibre lost through the wire, therefore the quantity of fibres leaving the wire as paper is given by F_sC_s (1-t). This equals basis weight x machine width X wire speed i.e.

$$S \times \text{width} \times V_w = F_sC_s\,(1-t) \qquad \text{------- (4.2.1)}$$

where V_w = wire speed

S = substance or basis weight

G_s = effective slice gap

$= G_{sa}$ x machine width x slice jet velocity

Therefore

$S \times width \times V_w = G_{sa} \times width \times V_s \times C_s(1-t)$ ------ (4.2.2.)

$\therefore S = q\, G_{sa}\, C_s(1-t)$ -------- (4.2.3)

where q, the efflux ratio $= \dfrac{\text{slice jet velocity } V_s}{\text{wire speed } V_w}$

Fibre and flow balance in the wet end

For the values:

F_t: Thick stock flow

C_t: Thick stock consistancy

F_b: back water flow

C_b: back water consistancy

Fibre flow in to wet end = fibre flow from slice

That is

$F_tC_t + F_bC_b = F_sC_s$ -------- (4.2.4)

but $F_b + F_t = F_s$ -------- (4.2.5)

Elimination of the flow terms is possible if thick stock flow is made proportional to slice flow.

that is

$F_t = rF_s$ ------------ (4.2.6)

Then $F_b = F_s - F_t = F_s(1-r)$ ------------ (4.2.7)

and $V\, F_sC_t + (1-r)\, F_sC_b = F_sC_s$ ----------- (4.2.8)

to a very close approximation the back water consistancy $C_b = t\, C_s$.

$$\therefore \quad C_s = \frac{r\,C_t}{(1-t+rt)} \qquad (4.2.9)$$

$$\text{or } C_s(1-t) = rC_t - rtC_s \qquad (4.2.10)$$

The term rtC_s is small compared to rG and is a correction for fibre loss in the back water system.

Machine through put: Equation (4.2.1) and (4.2.2) may be combined to give machine throughput.

Thick stock fibre flow in = fibre made in to paper + losses. eliminating $C_t(1-t)$ from (4.2.3) and (4.2.9)

$$\frac{S}{q\,G_{sa}} = rG - rtC_s \qquad (4.2.11)$$

$$\therefore \quad C_t = \frac{S}{vq\,G_{sa}} + \frac{S}{q\,G_{sa}} \times \frac{t}{(1-t)} \qquad (4.2.12)$$

4.3 HEMS MODEL

The paper making process comprises a certain number of basic operations such as the transport of fibre and additives between tanks and chest where mixing takes another important feature is the comming together at a point of several streams of stock with different consistancies, then emerging as one stream. Thus the basic concepts fundamental to he process are

1. Transport delays
2. Mixing in chest and tanks
3. mixing at a point
4. flow dynamics

Some of these are non linear in character. Out of the above four processes Hem considered only the dynamic behaviour of the system in the neighbourhood of some specified operating level and proposed a linear state space model (discrete time model) on the basis of following assumptions:

1. Simplified fluid flow equations in the form of a direct analogy between fluid flow and electric current in networks is considered to be adequate.
2. Perfect mixing takes place in the head box and wire pit.
3. The delays are time invariant and independent of the state variables.
4. Changes in the fraction of the fibre and additives that filter through the wire is taken to be proportional but of apposite sign to the changes in the initial basis weight on the wire.

Water is used as a vehicle to transport fibres in a network of pipes and tanks, hence lags will occur with respect to changes both inflow and in concentrations. It will be necessary to consider the past states of the system, as well as the present states owing to transport delays that effect the concentration of fibre and additives. Finally the interactions between flow and concentration dynamics must be considered as these determine the distribution of fibre concentrations throughout the system.

The object of the modelling problem is to evaluate these functions and determine the resultant dynamic behaviour of the plant.

Since we are interested mainly in the dynamic behaviour in the neighbourhood of a fixed operating point. The total hydroulic pressure at the slice opening is of particular interest and this together with the stock level, form the variables of the simultaneous differential equations that describe the head box flow dynamics.

Let

C_1, C_2 = Hydroulic capacitance, of headbox air space and stock volume respectively.

C_1, C_o = Consistancies before and after mixing.

P_1, P_2 = Hydraulic pressure at the slice and pressure attributable to headbox stock level alone.

r = Number of converging streams before mixing.

q_{ai}, q_{ao} = Air flow in and out of the headbox.

V = Volume of stock in mixing tanks.

The following equations can be written to describe the headbox flow dynamics:

$$C_1 \frac{dP_1}{dt} = q_{ai} - q_{ao} + (C_1 + C_2) \frac{dP_2}{dt} \qquad (4.3.1)$$

$$C_2 \frac{dP_2}{dt} = q_i - q_o \qquad (4.3.2)$$

The input and output concentrations in the mixing tanks, headbox and wire pit are assumed to be related by the first order differential equations.

$$\frac{dV}{dt} = - q_o + \sum_{j=1}^{r} (q_i)_j \qquad (4.3.3)$$

$$\frac{d(C_oV)}{dt} = -C_o q_o + \sum_{j=1}^{r} (C_i)_j (q_i)_j \qquad (4.3.4)$$

The thick flow, the recirculation flow and the wire pit flow converge immediately before the mixing pump . The output concentration from the pump can be derived as a special case of equations (4.3.3) and (4.3.4) by putting $v = 0$ and $r = 3$.

The basic equations (4.3.1) and (4.3.4) are linearised about a chosen operating level.

In order to obtain a discrete model, it was assumed that the informations of the state variables only at periodic intervals of time (every 10s) and the forcing functions were to be held constant throughout the interval (10s) and changed in a step manner at the sampling instants. The model is sought in the following form:

$$X(n+1) = \sum_{i=0}^{n} F_i \, x\,(n-i) + EU(n) + d \qquad \text{------------------} \quad (4.3.5)$$

where n is independent discrete time variable, X is (mxl) state vector of the paper machine, U is (Sxl) control vector and d is mxl plant noise vector. F and E are mxn and mxs transition and input matrices respectively.

In order to account for delays, a modified version of a method described by Tou was used to form difference equations of the linear continuous equations. This yield the complete deterministic model in discrete form given by equation (1) now $g = 3$, $m = 5$, $s = 4$

$$x(n+1) = \sum_{i=0}^{3} F_i \, x(n-i) + EU(n) \qquad \text{-------------} \quad (4.3.6)$$

The system is characterised by five state variables and four control variables. Thus the transition matrices and control matrices are (5x5) and (5x4) respectively.
where

x_1 = Hydraulic pressure at the slice

x_2 = Stock level in the head box

x_3 = Consistancy immediately after the mixing pump

x_4 = Head box consistancy

U_1 = Head box air flow

U_2 = Thin stock flow

U_4 = Machine speed

The model represents the plant behaviour sufficiently well in order to devise practical control schemes.

4.4 ASTROM'S MODEL

Astrom has presented a linear stochastic state variable model for the paper making process. The drawback of model based on the physical considerations as pointed out by him is that, the assumption is always made that the fibre flow through the wire is always proportional to the fibre flow through the head box. A slightly refined model is obtained by having a Coefficient of proportionality dependent upon the average basis weight on the wire. But all the same the average value of the fibre going into the wire pit, is difficult to estimate.

A general linear model of the system is sought in the form,

$$X(t+1) = \phi X(t) + U(t) + e(t) \quad \text{------------} \quad (4.4.1)$$

$$y(t) = \phi(t) X(t) + Y(t) \quad \text{------------} \quad (4.4.2)$$

Where

X(t) defines the state vector having as its components the physical quantities. Like the first component $X_1(t)$ is the basis weight of the reel. The other components of X(t) represents the dynamics of the wire, headbox and white water system, the delay in the dryer section the dynamics of the disturbances, fluctuations in input consistancy and the measurement errors, for example $X_5(t)$ can be calibration error and the drift of the instrument and $X_6(t)$, the high frequency component of the measurement error. As the system is stationery in normal.

4.5 SASTRY AND VETTERS MODEL

In Sastry and Vetters model the process is conveniently divided into pipe section head box and wire section.

Pipe section consists of fan pump, primary and secondary cleaners, screens and tapered header. The fibre concentration changes in accordance with the flow rate and concentractions of the constituent feeds and outflows, namely thick stock white water, diluted stock to head box and and cleaner rejects. From this one get a differential equation giving rate of increase of headbox consistancy. In head box section we get two differential equations. One giving rate of change of head box air pad pressure level. In this approach instead of using the, theoretical relationship between head box total head and slice i.e. $C_{sL}-C_dH\sqrt{2gH_t}$

Where, C_{sL} is slice flow

Cd: Coefficient of discharge

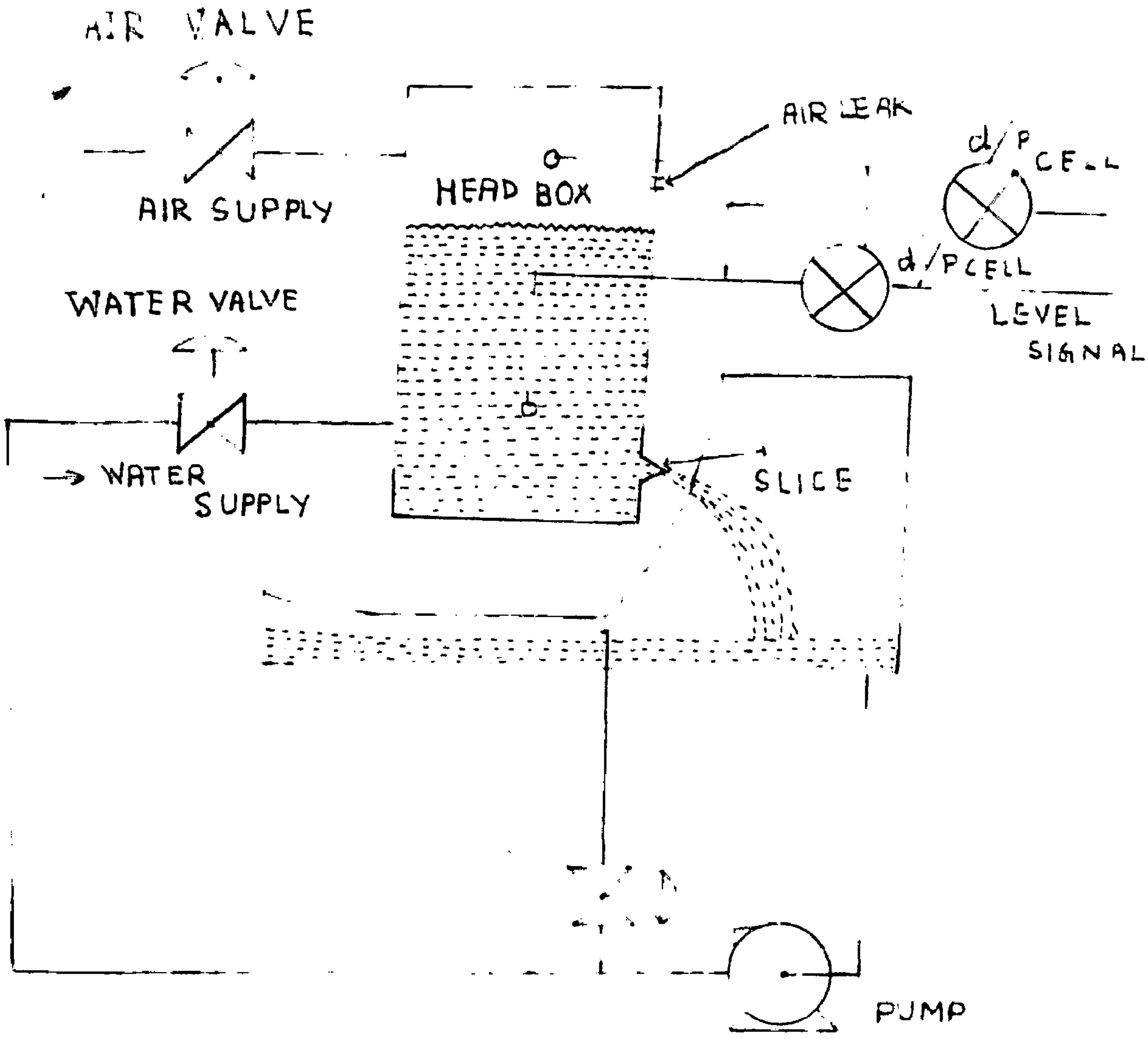

AIR VALVE
AIR LEAK
d/P CELL
AIR SUPPLY
HEAD BOX
d/P CELL
LEVEL SIGNAL
WATER VALVE
WATER SUPPLY
SLICE
PUMP

FIG 4.6

At Slice opening area

H_t: total head, we use an empirical relationship which may be more accurate description of pressure flow interaction.

For wire section, drainage rate and fibre retension on wire depends on many factors. For the purpose of parameter identification data was collected over a fifteen minutes interval with a sampling period of two seconds. Parameters were determined by iterative regression line and by kalman filtering.

4.6 STOCHASTIC STATE VARIABLE MODEL FOR A PAPER MACHINE HEADBOX

(by S.K. Sud, K.K. Biswas and A.K. Sinha)

The headbox is of central importance to the paper maker for with he generates the thin jet of stock subsequently deposited. On the fourdrinier wire and formed into paper. As the stock moves water is drained out, leaving a thin sheet of fibres, which is later processed dried and converted into paper. For smoothness and uniformity of paper production it is essential that the total pressure head and height of stock inside the head box remain constant. This is achieved by controlling the stock input and the air supply to the headbox. The headbox thus represents a two input two output system with air valve setting and stock valve setting as two inputs and measured pressure head and stock height as two outputs. The schematic diagram for the above is shown in the fig:

For the design of a proper control system for the above process it is essential to have the dynamic model of the system. Earlier attempts have been made to construct transfer function models from the freq. response data, and then design controllers. Such models are obtained using graphical plots and are approximate. Moreover it is always not possible to carryout frequency response tests in an actual plant efforts must therefore be developed towards time domain models from usual operating input output data. Since the process happens to be of an interactive multivariable type, a direct application of a minimum variance type control algorithms based on simple input output model may not be possible without first decoupling the system. Another way of tackling the problem is to go for state variable feedback control algorithms. This would invalve forming a state variable model for the process.

A state variable stochastic model is developed here for the head box based on input and output data. The model includes effect of plant disturbances and errors in measurement. An important feature of the proposed method is the on line identification scheme which is an essential requirement for adaptive control of the process. The model structure is as follow

Model Structure: The head box is essentially a two input and two output system. At the input and output of the headbox actuators and transducers are connected for controlling the water level and air pressure. The water is fed by a pump into the headbdx via a control valve, and supply of pressurised air is fed into the top of the headbox through a small control valve. A small hole provides an outlet for the air so that pressure in the box can be controlled. The water and air valves are both electropneumatically actuated. Two differential pressure cells are used to measure the pressure head and height of water inthe box. A complete block diagram of a head box with the actuators (A_1 and A_2) and transducers (T_1 and T_2) is shown in the fig. (2).

The physical equations governing the dynamics of the headbox are basically non linear. These equations have been linearised about the steady state operating point to obtain a linear model. Taking the pressure head H and the water level L in the head box as the two states of the system the following state model for the head box is assumed:

$$\begin{bmatrix} H \\ L \end{bmatrix} = \begin{bmatrix} a_1 & a_2 \\ a_3 & a_4 \end{bmatrix} \begin{bmatrix} H \\ L \end{bmatrix} + \begin{bmatrix} b_1 & b_2 \\ b_3 & b_4 \end{bmatrix} \begin{bmatrix} CV_1 \\ CV_2 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \end{bmatrix}$$

Where a and b are unknown elements of the state transition and input transition matrices respectively. w_1 and w_2 are state noise representing the plant disturbance and modelling error. These are to be asumed zero mean white gaussian process with constant variances q_1 and q_2 respectively.

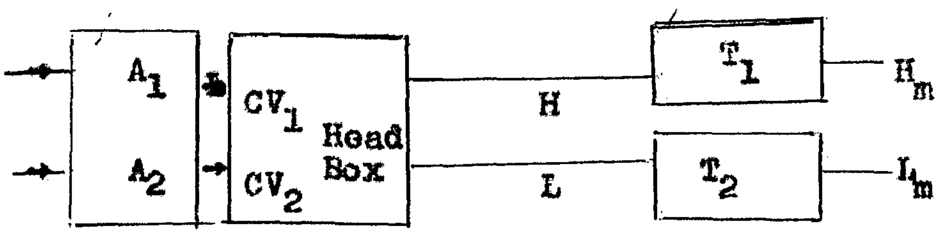


FIG2

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} a_1 & a_2 \\ a_3 & a_n \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} b_1 & b_2 \\ b_3 & b_4 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \end{bmatrix}$$

CHAPTER- V

THE MODEL PRESENTED IN THIS THESIS

5.1 SETTING UP OF THE PROPOSED MODEL

In this chapter an attempt is being made to present a mathematical model describing the dynamics of physically and commercially important quantities involved in the paper making process. These quantities are termed as (state variables) of the system. Beecher has shown from physical considerations that the process to be modelled should be at least third order system. Moreover a higher order model needs large memory and more computation time it is decided to make a third order model.

Three state variables are therefore defined here. Like Astrom's model the first and most important state variable is basis weight (weight per square meter) of the finished product which is a measure of goodness and quality of paper. Since it is desired to make a model for process starting from fan pump onwards (complete wet end including presses and dryers) it would be desirable to select next state variable which will with other things also reflect dryer dynamics. Therefore moisture content may be choosen as the second state variable. The head box consistancy is taken as the third state variable.

We next consider the control variables. At the mill the basis weight change is made by changing the thick stock flow rate hence this is taken as the first control variable. Since the production rate is directly controlled by wire speed so wire speed is taken as the second control variable. At the mill wire speed change is affected only for change of production rate, head box level is also varied but this variation is always related to wire speed hence the head box level cannot be taken as an independent control variable. Because to obtain good quality paper wire speed must be same as the speed of the jet of pulp comming out of slice and velocity of jet is physically related to the head box pulp level (Since the head box used in the mill do not have additional air pad pressure which is used in mills abroad which run at the speed of several thousand feet/min). The approximate equality between jet velocity and wire velocity is not a physical constraint built in the system but a constraint on the operating staff). The ratio of (jet velocity/wire speed) is termed as efflux ratio.

It is also important to note that wheather the head box pulp level can be included as a state variable. Because head box pulps storage with wire pit are two storing tanks which make transition of state from one instant to another instant possible when input is cut off. But another factor going into consideration isthat since head box height is manually controlled to match the proper wire speed, head box height becomes a dependent control variable and hence it should not be taken as state variable.

There are certain other independent variables like steam pressure in drying cylinders suction pressure in suction boxes, pressure between presses etc. which have some control over the states of the system, but they are either indirect or can be assumed constant, hence excluded from the dynamic model.

Head box height of the pulp is controlled by a level controller for small adjustments by value v_1 shown in figure, In case of major changes, the height is controlled manually by chaging the total in comming flow by value v_2. The thick stock flow rate is controlled by Kalle level controller or flow controller.

The approach adopted by Sastry and Vetter that a model based on physical considerations be made and identification technique should be used only for identification of parameters thrown up by physical considerations has been discarded here. In the proposed model, physical considerations have applied only for choosing the state and control variables and elimination of physically insignificant parameters.

The model is represented by the following linear discrete time state equation:

$$X(k+1) = A\,x(k) + BU(k) + W(k) \qquad (5.1.1)$$

X(k) is the state vector

U(k) is two dimensional control vector

W(k) is three dimensional noise vector.

i.e.

$$\begin{bmatrix} X_1(K+1) \\ X_2(K+1) \\ X_3(K+1) \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & a_3 \\ a_5 & a_4 & a_6 \\ a_7 & a_8 & a_9 \end{bmatrix} \begin{bmatrix} X_1(K) \\ X_2(K) \\ X_3(K) \end{bmatrix} + \begin{bmatrix} b_1 & b_4 \\ b_2 & b_5 \\ b_3 & b_6 \end{bmatrix} \begin{bmatrix} U_1(K) \\ U_2(K) \end{bmatrix} + \begin{bmatrix} W_1(K) \\ W_2(K) \\ W_3(K) \end{bmatrix} \quad (5.$$

where

$X_1(K)$= is the avg. basis weight of the finished product in gms/cm^2

$X_2(K)$= is the moisture content of the paper in percentage.

$X_3(K)$= is the consistancy at headbox in gms/liter.

$U_1(K)$= is the thick stock flow rate in m^3/min.

$U_2(K)$= is the wire speed in meters/minutes

$W_1(K)$= is the plant noise in basis weight in gms/cm^2

$W_2(K)$= is the plant noise in moisture content in percentage.

$W_3(K)$= is the plant noise in consistancy in gms/liter.

a_1, a_2 .... a_9 and b_1, b_2, ... b_6 are unknown parameters (asumed constant) of the system. The physical significance of these parameters is shown below

The coefficient

a_1: Accounts for the change in basis weight due to decrease in flow with fall of the head box level.

a_2: Takes in to account the effect of changed drying condition on basis weight (the quality of material handled is changed and the steam applied to dryers is assumed to be constant)

a_3: takes in to account miscellaneous factors relating to head box consistancy like the fact that the pulp of head box will not have same consistancy throughout due to the non-newtonian nature of fluid containing fibers.

The effect of X_1 and X_3 on the state X_2 is negligible hence the coefficeints a_5 and a_6 can be assumed to be zero. This assumption helps in reducing the number of unknown parametees to be estimated similarly a_7 and a_8 are also assumed to be zero. Though the level of the head box falls with time, the fluid is considered to be properly mixed to a large extent and the consistancy therefore can be assumed to remain more or less constant. For this reason the coefficient a_9 can be taken as unity.

The elements of the B matrix are considered next. In case of b_1 and b_4, it is known that if thick stock flow is more the basis weight increases and if wire speed is more basis weight decreases. (because the same amount of pulp is spread over a larger surface area) therefore, coefficients b_1 and b_4 have some non zero value. Similarly moisture is affected both by thick stock flow rate (if flow is less moisture is more) and by wire speed (if the speed is more moisture is more because less time is required for the drainage of water down the wire) therefore b_2 and b_5 are also non zero quantities. Since head box consistancy is totally independent of wire speed b_6 can be assumed to be zero. This is not true for b_3

since the consistancy will depend upon thick stock flow rate (greater the flow rate greater the consistancy).

W(K) is considered to be zero mean Gaussion, white noise with a covariance Q(K), which is used to take care of plant noise and also of the modelling wrrors etc. the covariance Q(K) is also unknown and is one of the parameters to be estimated.

So finally the model is reduced to -

$$\begin{bmatrix} X_1(K+1) \\ X_2(K+1) \\ X_3(K+1) \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & a_3 \\ 0 & a_4 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_1(K) \\ X_2(K) \\ X_3(K) \end{bmatrix} + \begin{bmatrix} b_1 & b_4 \\ b_2 & b_5 \\ b_3 & 0 \end{bmatrix} \begin{bmatrix} U_1(K) \\ U_2(K) \end{bmatrix} + \begin{bmatrix} W_1(K) \\ W_2(K) \\ W_3(K) \end{bmatrix} \quad (5.1.2)$$

All the three states of the system model can be directly measured. The measurement or the output model is therefore given by -

$$Z(K) = H\, x\, (K) + V(K) \quad \text{------------------------} \quad (5.1.3.)$$

where

Z(K) = is the three dimensional output vector.

X(K) = is three dimensional state vector.

H = is 3x3 identity matrix, and

V(K) = is the measurement noise sequence, which again for convenience is assumed to be zero mean white Gaussion with constant but unknown covariance.

i.e.

$$\begin{bmatrix} Z_1(K+1) \\ Z_2(K+1) \\ Z_3(K+1) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_1(K+1) \\ X_2(K+1) \\ X_3(K+1) \end{bmatrix} + \begin{bmatrix} V_1(K+1) \\ V_2(K+1) \\ V_3(K+1) \end{bmatrix} \quad \text{---}(5.1.3.$$

where

Z_1: is the measured basis weight in gms/sqm.

Z_2: is the measured moisture content in percentage.

Z_3: is measured consistancy in gms/liter.

V : is the observation noise vector assumed to be zero mean white gaussion with covariance R.

In this model all the states are observed, also from physical process it is known that all the states are controlable by the two control variables. As an approximation the parameters have been assumed to be constant so that a time invariant model could be proposed. Even if the parameters are slowly time varying, this model is expected to work. In the model the average basis weight has been taken as the most important state and is one of the measured quantities.

5.2 MODEL PARAMETER IDENTIFICATION

With the structure of the model formulated above it now remains to evalugte the unknown parameters of matrices A and B i.e. a_1, a_2, a_3, b_1, b_2, b_3, b_4, b_5 and the noise covariance Q(K) and R(K) of the state and output noise sequence respectively, in a recursive manner on the basis of record of measurements Z(K) and U(K) $\forall$ K = 1,2 ---- A number of parameter estimation algorithm are available to identify parameters of such models using normal input output data. Two such algorithms are described in the following section:-

5.2.1 EXTENDED KALMAN FILTER

The solution of the problem is divided in two steps firstly a method to obtain the estimates of the elements of A and B matrices based on Kalman filtering theory is being discussed. Determination of noise covariances R(K) and Q(K) will be discussed subsequently.

1. This filter requires a dynamic model for the parameters. A parameter vector can be constructed which contain all the unknown elements of matrices A and B * Since these elements are assumed constant, the following relationship holds.

$$^{*}P^T = (a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4, b_5) \quad \text{------} \quad (5.2.1)$$

$$P(K+1) = P(K) \quad \text{------} \quad (5.2.2)$$

The next step is to combine above equation (5.2.2) with the state equation (5.1.2) to obtain the following higher dimensional augumented state equation.

$$X(K+1) = f(X(K), U(K) + W(K) \quad \text{------} \quad (5.2.3)$$

where

$$X(K) = [x^T(K) \; P^T(K)]^T$$

$$= \begin{bmatrix} x(K) \\ P(K) \end{bmatrix}$$

is a 12 dimensional augumented state vector and f[.] is a non linear vector function whose components are given below.

$$f(X(K),U(K)) = \begin{bmatrix} a_1x_1(K) + a_2x_2(K) + a_3x_3(K) + b_1U_1(K) + b_4U_2(K) \\ a_4x_2(K) + b_2U_1(K) + b_5U_2(K) \\ x_3(K) + b_3U_1(K) \\ a_1(K) \\ a_2(K) \\ a_3(K) \\ a_4(K) \\ b_1(K) \\ b_2(K) \\ b_3(K) \\ b_4(K) \\ b_5(K) \end{bmatrix}$$

$$W(K)^T = [W_1(K),\ W_2(K),\ W_3(K)\ \ 000\ 000\ 000\ ]$$

is a 12 dimensional augumented state noise vector with zero mean and noise covariance $Q_1(K)$ given by ,

$$Q\ (K) = \begin{bmatrix} \underset{3x3}{Q_1(K)} & \vdots & \underset{3x3}{0} \\ \cdots & \cdots & \cdots \\ \underset{9x3}{0} & \vdots & \underset{9x9}{0} \end{bmatrix} = E\ [W(K)\ W^T(K)\ ]$$

The output equation (4.1.3) can be rewritten in terms of the augumented state vector X as -

$$Z(K) = H_1(K)\ X(K) + V(K) \qquad \text{———— } (5.2.4)$$

where

$H_2(K) = [H(K) : 0\ 3x9]$ is a 3 x 12

matrix.

$$H = \begin{bmatrix} 100 & 000 & 000 & 000 \\ 010 & 000 & 000 & 000 \\ 001 & 000 & 000 & 000 \end{bmatrix}$$

The problem of parameter identification is now reduced to a non linear filtering problem with the covariance of noise sequence unknown.

Application of Kalman filter algorithms is not possible unless the equations are properly linearised. The linearisation procedure is shown below by tailor series expansion.

Let X^o with a given $X^o(0)$ be a refrence (nominal) deterministic tragectory which satisfies the following system equation.

$X(K+1) = f(X(K) - X^o(K)$ as the deviation or perturbation from the reference trajectory.

[$\delta X(K)$) is then a stochastic process satisfying the differance equation.

$$\delta X(K+1) = f(X(K),U(K)) - f(X^o(K),U(K))+W(K) \qquad \text{------ } (5.2.5)$$

with

$\delta X(0) \approx H(X(0) - X^o(0), P(0))$

If the deviation from the reference trajectory are small (say in the mean square sense). Then a first order tailor series expansion gives,

$$\{ F(xy) = F_0(y) + \sum_{j=1}^{M} x \frac{\partial F}{\partial x_j}(0,y) \}$$

$$f(X(K),U(K) = f(X^0(K),U(K) + \frac{\partial f_i}{\partial x_j}(X^0(K),U(K))X(K)$$

$$= f(X^0(K),U(K) + F[X^0(K),U(K)]\, X(K)$$

or. $f(X(K), U(K) - f(X^0(K), U(K))$

$$= F(X^0(K), U(K))\, X(K) \qquad \text{-------- (5.2.6)}$$

where

$$F(X^0(K), U(K)) = \frac{\partial f_i}{\partial x_j}(X(K), U(K)$$

$i = 1, 2, 3$ ------------ 12

$j = 1, 2, 3$ ------------ 12

is the jacobian matrix calculated along the reference trajectory, (X^0,U). Thus an approximate linear equation (also called the perturbation or variational equation) is obtained from (5.2.5) and (5.2.6) as -

$$\delta X(K+1) = F(X^0(K), U(K))\, X(K) + W(K) \qquad \text{------- (5.2.7)}$$

Defining nominal measurements as -

$$Z^0(K+1) = HX^0(K+1) \qquad \text{-------- (5.2.8)}$$

and $\delta Z(K+1) = Z(K+1) - Z^0(K+1)$ -------- (5.2.9) and performing the similar linearization, the linearized measurement equation is obtained as -

$$Z(K+1) = HX(K+1) + V(K+1) \qquad \text{--------(5.2.10)}$$

equations (5.2.7)and (5.2.10) constitute linear state and measurement equations where the state is the deviation X(K) and measurement is the deviation Z(K). This linear state model is now quite suitable for the application of the Kalman filter algorithm in order to obtain the estimates of the state deviations. The real problem is still unsolved since it is required to estimate the states and not the deviations. It is now shown that the filtered estimates of the augmented state X(K) can also be obtained using the same deviation model (5.2.7) and (5.2.10).

If X(K) is conditional probability function then under requirements of symmetry and convexity of the conditional probability distribution function the optimal estimate is the conditional expectation i.e.

$$\hat{X}(K/K) \triangleq E\,[X(K) \mid Z(0), Z(1), \text{-------} Z(K)]$$

Then from the definition of state deviation

$$\hat{X}(K|K) = X^{o}(K) + \delta\hat{X}(K|K)$$

Let the error in the estimate be given by $\tilde{X}(K|K)$ then $\tilde{X}(K|K) = \hat{X}(K) - \hat{X}(K|K)$

$$= \delta X(K) - \delta \hat{X}(K|K)$$
$$= \delta \widetilde{X}(K|K) \quad \text{---------- (5.2.11)}$$

The error covariance of the filtered estimates is defined as

$$P(K|K) \stackrel{\Delta}{=} E\{\widetilde{X}(K|K)\,\widetilde{X}^T(K|K)\}$$
$$= E\{\delta\widetilde{X}(K|K)\,\delta\widetilde{X}^T(K|K)\} \quad \text{---------- (5.2.12)}$$

The initial choice of reference trajectory is made with $X^0(0) = \hat{X}(0|0)$. Then $\delta X(0) = (0, P(0)$. It is evident from (5.2.7) that expectation $E[\delta X(K)] = 0$ for all K. It is desired to use a linear filter secursive structure. The relinearization is done about each new estimate as new estimate becomes available. This procedure goes as follows as K = 0, linearise about $\hat{X}(0|0)$. Once Z(1) is processed re-linearise about $\hat{X}(1|1)$ and so on. The reason is to use a better referencetrajectory as soon as one is available. Because of re-linearization large initial estimation errors are not allowed to propogate through time and hence linearity assumptions are less likely to be violated.

As a consequence of above linearization procedure $\delta X(0|0) = 0$. Taking the expectation from both sides of the equation (5.2.7) given observations up to Z(K),

$$\delta\hat{X}((K+1)|K) = F(X^0(K), U(K))\,\delta\hat{X}(K|K)$$

This gives $\delta X(1|0) = 0$. Since the subsequent relinearization is done about X (1|1), $\delta X(1|1) = 0$.

Hence again $\delta \hat{X}(2/1) = 0$ and in general

$\delta \hat{X}(K+1|K) = 0$ for all K.

As a result between the observation the best estimate of the state is the reference state and accoringly

$$\hat{X}(K+1|K) = f(X^0(K), U(K)) = f(\hat{X}(K|K), U(K)) \text{ ----} \quad (5.3.13)$$

using the Kalman filter algorithm, the estimate for the deviation $\delta X(K+1)$ for observations up to $Z(K+1)$ is given by -

$$\delta \hat{X}(K+1|K+1) = \delta \hat{X}(K+1|K) + K(K+1)(\delta Z(K+1) - H\delta \hat{X}(K+1|K)$$

where $K(K+1)$ is the Kalman filter gain matrix

Since $\delta \hat{X}(K+1|K+1) = \hat{X}(K+1|K+1) - \hat{X}(K+1|K)$

and also $\delta \hat{X}((K+1)|K) = 0$

$$\hat{X}(K+1|K+1 = \hat{X}(K+1|K) + K(K+1)(\delta Z(K+1)$$

$$= \hat{X}(K+1|K) + K(K+1)(Z(K+1) - H\hat{X}(K+1|K)) \text{ ----} \quad (5.2.14)$$

using the model (5.2.7) and (5.2.9), the Kalman gain matrix $K(K+1)$ is given by -

$$K(K+1) = P(K+1|K)\, H^T [HP(K+1|K)\, H^T + R(K+1)]^{-1} \text{ ----} (5.2.15)$$

where $P(K+1|K)$ is the prediction error covariance for the state deviation $\delta X(K)$ and hence for the state $X(K)$ from equation 4.2.1. This is given by the following:

$$P((K+1)|K) = F(K)\, P(K|K)\, F^T(K) + Q(K) \quad \text{--------} \quad (5.2.16)$$

where F(K) is the jacobian matrix already defined.

The filter error covariance is given by -

$$P(K+1|K+1) = (I-K(K+1)H)\, P(K+1|K) \quad \text{--------} \quad (5.2.17)$$

where I is the Identity matrix.

Equation (5.2.13) through (5.2.17) solved recursively give the filtered estimate of the augumented state X(K+1), for observations up to Z(K+1) for the non linear state model (5.2.2). This procedure is an extension of Kalman filtering theory to non linear models and is known as the extended Kalman filtering theory. This solves the above equation a choice of initial conditions of X (0|0) and P (0|0) have to be made.

5.2.2 ADAPTIVE ESTIMATION OF NOISE COVARIANCES

The following recursive algorithm due to Sage and Husa is directly applicable for obtaining the covariances of the state noise W(K) and measurement noise V(K).

$$\hat{R}(K+1|K) = \frac{1}{K}\left((K-1)\,\hat{R}(K|K-1) + \tilde{Z}(K)\,\tilde{Z}^T(K) - HP(K|K-1)H^T\right) \quad \text{-} (5.2.18)$$

$$\hat{Q}(K+1|K+1) = \frac{1}{K+1}\Big(H\hat{Q}(K|K) + K(K+1)[\tilde{Z}(K+1)Z^T(K+1))K^T(K+1)$$

$$+ P(K+1|K+1) - F(K)\, P(K|K)\, F^T(K) \quad \text{------} \quad (5.2.19)$$

$$\text{where } \tilde{Z}(K) = Z(K) - H\hat{X}(K|K-1) \quad \text{------} \quad (5.2.20)$$

These equations have to be processed along with above Kalman filter equations. The initial choise of (R(1|0), Q(0|0) have also to be made. Thus section (5.2.1) and (5.2.2) explain the technique for identification of all unknown parameters of the model presented in section (5.1.1).

The apparent disadvantage of the above technique is that the dimension of the model is increased considerably. Also the augmented system is non linear. It has been observed that unless the initial conditions are choosen properly this filter often fails to converge to any sets of consistant estimates.

CHAPTER VI

6.1 METHODOLOGY OF DATA COLLECTION

The model presented in the previous section has been tested and the parameters identified using real data collected from star paper mills Saharanpur. (U.P.) There are at present four machines in operation. The paper machine No. 1 is used for producing white or coloured writing paper, while all other three machines are producing brown kraft paper. Datas were collected only for machines No. 2 and 3 because it was not possible to collect the data from machine No. 1 and 4 due to some practical reasons.

Following data were collected for both the machines:

1. Basis weight of the finished product.
2. Per cent moisture content of the finished product just produced.
3. Consistancy of head box pulp.
4. Consistancy of the regulating box pulp.
5. Machine speed (it is same as that of wire speed).
6. Head box level.
7. Thickness of the finished paper.
8. Thick stock flow rate.

Data were collected on both the machines at one hourly interval simultaneously. This is so because it was not practicable to tear the paper for taking sample at an interval less than one hour. Also because of non availability of any on line recorder, it was not possible to take the readings at any shorter interval. Thirty minutes are required for collecting the above data for one machine and since it was decided to collect from both the machines simultaneously it was not at all possible to collect the data within shorter interval.

The basis weight was measured by cutting of a fresh sample from the reel, making it template size (25 x 40") and weighing this on the electric balance of the Star Paper Mills, Saharanpur. For the measurement of the dry basis weight, all samples were kept in an electric oven over night and weighed next morning. Difference between the two weights gives the moisture content.

Consistancy of head box and regulating box pulp was measured in the following way:

Taking pulp from head box and regulating box respectively at an hourly interval and 500 ml of head box pulp 100 ml of regulating box pulp respectively was made in to paper sheet (by the machine) in the laboratory. The paper sheets were dried in oven and weighed next day. The consistancy is expressed in gpl it was converted in to percentage by dividing the above figure by 10.

Consistancy in gpl may be obtained directly by taking samples of one litre pulp, but was avoided because thicker sheet of the paper take more time for drying.

Thickness of the paper was measured by a special instrument which gives the accuracy of 10^{-6} metres.

The Kalle level controller setting was related to the thick stock flow rate but unfortunately it was not functioning well. Therefore thick stock flow rate was calculated on the basis of material balance equations.

Let the speed of machine = x m/min.

Length of sheet of paper comming out of reel = y meters

Basis weight of the paper = Z gm/m^2

∴ Wet paper comming out per minute = xyz gms.

Gross Dry paper weight comming out per minute = xyz - w percent

where w percent is moisture content in percentage. It is assumed that 2 percent of the paper is lost in breakage etc.

∴ net dry paper comming out per minute = xyz-w percent + 2 percent

(This is the total fiber going in to machine per minute)

Consistancy of thick stock = p gms/liter

∴ Volume of the fiber going in to machine per minute =

$$\frac{(xyz - w \text{ percent} + 2 \text{ percent})}{p} \text{ litres/min.}$$

CHAPTER VII

MODEL TESTING AND IDENTIFICATION USING REAL DATA

METHODOLOGY OF DATA PROCESSING

A computer programme based on the identification algorithm given in the previous section was devised and run on IBM 1620 at S.E.R.C. Roorkee. This was done for m/c No. 2 and m/c No. 3 respectively.

Initial value of 12 dimensional state vector X were chosen in the following manner. First the values of elements of A matrix (a_1, a_2, a_3 and a_4) were selected on the basis of physical considerations. Using the measured value of states, input and the assumed values of elements of A matrix, the elements of B matrix (b_1 .... b_5) were obtained. The first set of measured states were taken as the initial states. This procedure provides the set of 12 initial values which is expected to be quite close to the real values. Q(0), the initial plant noise covariance matrix was taken as null matrix while P(0) was taken as diagonal matrix with all elements of value 10, arbitrarily taken for both machines separately.

The variables were normalised for better numerical accuracy. Thick stock flow rate was normalised by dividing 200, wire speed was similarly normalised by dividing it by 160 for m/c No. 3 and for m/c No. 2 $U_1(K)$ by and $U_2(K)$ by 300. Similarly normalisation was done for states also.

The sub estimation algorithm for R matrix has not been used, instead, its value has been assumed known equal to a constant diagonal matrix on the basis of approximately 10 per cent measurement error. This assumption is valid only if the error involved in the measurement is properly guessed. As a result of assumption the computational burden is also reduced.

In the adaptive algorithm of Q matrix the correction term in the algorithm viz,

$$K(K+1)\bar{\bar{z}}(K+1)\tilde{z}^{T}(K+1)\ K^{T}(K+1)+P(K+1/K+1)-F(K)\ P(K/K)F^{T}(K)$$

is tested for first three diagonal entries and added to the rest of the term only if it is non negative. The negative correction terms is neglected because it implies that no correction is necessary. Also the first 3 diagonal terms of matrix are estimated. From 4th to 12th (the entties corresponding to parameters) the diagonal terms in Q continue to be zero as the process is stationary.

RESULTS

The computer programme was run for the data collected for machine Nos. 2 and 3 separately. For machine No. 2 the results are given in tabular as well as in graphical form and ror machine No. 3 the results are given in tabular form, in the end, starting from Table No. 1 to Table No. 10.

CHAPTER VIII

CONCLUSIONS

In the mathematical model of paper making process presented in the previous chapters it was intended to study the effect of thick stock flow rate and wire speed (the two control variables) on the states of the process, A quite good closeness has been found between the measured values of the variables and those actually estimated. The small errors between measured and estimated values of the parameters indicates that the states of the process and hence the plant can be very well controlled to a large extent by using these two controls. From the plots of the elements of P matrix and the parameters given in the results, it is clear that after some iterations the P matrix continuous to increase and the estimates of the parameters tends to become constant. Estimates of some parameters viz b_5, b_2 and a_4 are fairly constant. The parameters a_2, a_3, a, showing increasing or decreasing tendency within a specific spectrum of values, or some parameters eq. b_4 become constant after some iterations. A large variation is found in the value of parameter b_3, and the b_1 parameter become constant after decreasing to some iterations.

At the first iterations Q was assumed to be zero. As shown in the fig. Q increases exponentially upto some iterations and afterwords decreases quite fast to reach a small stable value. By increasing a number of iterations a seems to become converging.

The values of P goes on decreasing gradually as K increases.

The identification technique requires that there should not be a sudden jump which will invalidate linearisation about operating points. There should not be abrupt change in the values of the variables with the change of the order. If it happens then the linearization become invalid about operating point. Which further causes high errors. This can be avoided by taking the reading at shorter intervals (few seconds), although it is impracticable because of non availability of on line recorders.

Some of the errors are introduced because of the shortcomming in the data collution. Since all the data are collected in an off line manner from a commercially operated plant, it was not possible to collect the data at exact time interval required. The sampling errors can be reduced considerably if the instrument can be installed that can measure the property of interest in an on-line faishon for example β ray gauge is suggested to measure the basis weight on line.

Within the specified period at Star Paper Mills it was possible to collect the fifty samples. Moreover the sampling was stopped at the time when there was abrupt change in the grade of the paper. Better results could be found if more samples would have been collected.

For better results the job of the present day engineers is to have the on-line recorders. Further improvements in the model can be obtained by assuming the time varying parameters. For example the head box consistancy in this particular model is assumed constant, but it is varying from point to point. Scope of the future work in this field is formulation of the mathematical model of the proposed type and then application of on-line digital computers for identifying and correcting the disturbances for the final quality control of paper. In India there is no mill having on-line computer control and on-line recording facilities.

The extended Kalman filter technique has been used for the identification purposes in the present work. An apparant disadvantage of the above technique is that the dimension of the model is increased considerably. Also the augumented system is non linear. It has been observed that unless the initial conditions are chosen properly this filter often fails to converge to any sets of consistant estimates.

In the wes (Sweden etc) on line computer control for paper making process has already been done. A study of similar type is carried out on a pilot plant at UMIST, Manchester and England.

FIG
2

START

READ

M, X(I), H(I,J), P(I,J), R(I,J), Z_1(K), Z_2(K)

[illegible](K), V1(K), [illegible](K), V22(K), K=1,M

[illegible] A, [illegible] NORMALISE

[illegible](K), [illegible](K), Z1(K), Z2(K), Z_3(K)

k = 1

[illegible], [illegible](K), [illegible](K), Z1(K), Z2(K)
Z3(K)

[illegible]RM A

[illegible] = [illegible](K,K)A^T + [illegible](K,K)

K(K+1) = P(K+1,K) H^T[HP(K+1,K)H^T
+ R(K+1)$]^{-1}$

P(K+1|K+1) = [I - K(K+1)H]P(K+1|K)

[illegible]

X (K+1/K+1) = X (K+1/K) + K (K+1)
[Z (K+1) - H X (K+1/K)]

Z (K+1) = Z (K+1) - HX (K+1/K)

AD = K(K+1) Z (K+1) / Z (K+1) ...
+ P (K+1 / K) ... A H (K, K) A

AD < 0 ... YES

IF AD < 0 ... NO ... Q (K, K) = (K-1) Q (K-1/K-1) + AD / K

PUNCH, K, X(I)
P(I,I), Q(I,I)

IF K = 50 ... NO ... YES ... STOP

APPENDIX I

(ii)

LISTING OF COMPUTER PROGRAMME

```
C  C  COMP PROGRAM FOR M/C 2,3 BY R-P SHARMA S E O R
      DIMENSION X(12),H(3,12),P(12,12),R(3,3),ZI(50),Z2(50),
      Z3(50)
     1LU1(50),U2(50),A(12,12),HT(12,3),D(12,3),G(12,3),F(3,3),
      X1(12,1)
     2RK(3),GT(3,12),E(12,12),YT(3),,Y(3,1),XX1(12,1),RKK(12,1),
      XX(12,1)
     3X(12,1),AD(12,12)
      RLAD11,M
   11 FORMAT(I2)
      READ12,(X(I),I=1,12)
      READ12,((H(I,J),J=1,12),I=1,3)
      READ12,((P(I,J),J=1,12),I=1,12)
      READ12,((R(I,J),J=1,31,I=1,3)
      READ12,(Z1(K),K=1,M)
      READ12,(Z2(K),K=1,M)
      READ12,(Z3(K),K= 1,M)
      READ12,(UI(K),K=1,M)
      READ12,(U2(K),K=1,M)
   12 FORMAT (8F10,5)
      DO31I=1,12
       DO31J=1,12
      Q(I,J)=0.0
   31 A(I,J)=0.0
      DO14I=3.12
   14 A(I,I)=1.0
      Z2(K)=(Z1(K)-Z2(K))*10.0/Z1(K)
      Z1(K)=Z1(K)/16.0
      Z3(K)=Z3(K)/10.0
      U1(K)=U1(K)/200.
      U2(K)=U2(K)/60.
      DO100K=1,M
      PRINT 30,U1(K),U2(K),Z1(K),Z2(K),Z3(K)
   30 FORMAT(5F10.5)
      IF(K-50)2,1,3
      A(1,1)=X(4)
      A(1,2)=X(5)
      A(1,3)=X(6)
      A(1,4)=X(1)
      A(1,5)=X(2)
      A1,6)=X(3)
      A(1,8)=U1(K)
      A(1,11)=U2(K)
      A(2,2)=X(7)
      A(2,7)=x(2)
      A(2,9)=U1(K)
      A(2,12)=U2(K)
      A(3,10)=U1(K)
    1 DO17I=1,12
      DO17J=1,12
```

```
17    AT(I,J)=A(J,I)
      DO201N=1,12
      DO201L=1,12
      B(L,N)=0.0
      DO201I=1,12
      B(L,N)=B(L,N)+A(L,I)*P(I,N)
201   CONTINUE
      DO202N=1,12
      DO202L=1,12
      C(L,N)=0.0
      DO202I=1,12
202   C(L,N)=C(L,N)+B(L,I)*AT(I,N)
      DO18I=1,12
      DO18J=1,12
18    B(I,J)=C(I,J)+Q(I.J)
      DO15I=1,12
      DO15J=1,3
15    HT(I,J)=H(J,I)
      DO203N=1,3
      DO203L=1,12
      D(L,N)=0.0
      DO203I=1,12
203   D(L,N)=D(L,N)+B(L,I)*HT(I,N)
      DO204N=1,3
      DO204L=1,3
      E(L,N)=0.0
      DO204I,1,12
204   E(L,N)=E(L,N)+H(L,I)*D(I,N)
      DO19I=1,3
      DO19J=1,3
19    E(I,J)=E(I,J)+R(I.J)
      DI=(E(1,1)*E(2,2)*E(3,3)-E(3,2)*E(2,3)*E(1,1))
      D2=(E(1,2)*E(3,1)*E(2,3)-E(2,1)*E(3,3)*E(1,2))
      D3=(E(1,3)*E(2,1)*E(3,2)-E(3,1)*E(2,2)*E(1,3))
      DET=D1+D2+D3
      EI=E(2,2)*E(3,3)-E(3,2*E(2,3)
      E4=E(3,1)*E(2,3)-E(2,1)*E(3,3)
      E7=E(2,1)*E(3,2)-E(3,1)*E(2,2)
      E2=E(3,2)*E(1,3)-E(1,2)*E(3,3)
      E5=E(1,1)*E(3,3)-E(3,1)*E(1,3)
      E8=E(3,1)*E(1,2)-E(1,1)*E(3,2)
      E9=E(1,1)*E(2,2)-E(2,1)*E(1,2)
      E8=E(1,2)*E(2,3)-E(2,2)*E(1,3)
      E6=E(2,1)*E(1,3)-E(1,1)*E(2,3)
      F(1,1)=E1/DET
      F(1,2)=E2/DET
      F(1,3)=E3/DET
      F(2,1)=E4/DET
      F(2,2)=E5/DET
      F(2,3)=E6/DET
      F(3,1)=E7/DET
      F(3,2)=E8/DET
      F(3,3)=E9/DET
      DO205I=1,3
```

D1 = E(1,1)* E(2,2)*E(3,3)
— E(1,1

```
205   G(L,N)=G(L,N)+D(L,I)*F(I,N)
      DO206N=1,12
      DO206L=1,12
      S(L,N)=0.0
      DO206I=1,3
206   S(L,N)=S(L,N)+G(L,I)*H(I,N)
      DO201=1,12
20    S(1,1)=S(1,1)-1.0
      DO211=1,12
      DO21J=1,12
21    S(I,J)=-S(I,J)
      DO207L=1,12
      DO207N=1,12
      P(L,N)=0.0
      DO207I=1,12
207   P(L,N)=P(L,N)+S(L,I)*B(I,N)
      XI(I)=X(4)*X(1)+X(5)*X(2)+X(6)*X(3)+X(8)*U1(K)+X(11)*U2(K)
      X1(2)=X(7)*X(2)+X(9)*U1(K)+X12*U2(K)
      X-(3)=X(3)+X(10)*U1(K)
      X1(4)=X(4)
      X1(5)=X(5)
      X1(6)=X(6)
      X1(7)=X(7)
      X1(8)=X(8)
      X1(9)=X(9)
      X1(10)=X(10)
      X1(11)=X(11)
      X1(12)=X(12)
      DO221=1,12
22    XX(1,1)=X1(1)
      DO208L=1,3
      Y(L,1)=0.0
      DO2081=1,12
208   Y(L,1)=Y(L,1)+H(L,I)*XX(1,1)
      DO23I=1,3
23    YT(I)=Y(I,I)
      RK(1)=Z1(K)-YT(1)
      RK(2)=Z2(K)-YT(2)
      RK(3)=Z3(K)-YT(3)
      DO91=1,3
9     RKK(1,1)=RK(1)
      DO209L=1,12
      X2(L,1)=0.0
      DO209I=1,3
209   X2(L,1)=X2(L,1)+G(L,1)*RKK(1,1)
      DO261=1,12
26    XX1(1,1)=XX(1,1)+X2(1,1)
      DO1191=1,12
```

```
119   X(I)=XXI(1,1)
      DO27I=1,3
      DO27J=1,3
27    E(I,J)=RK(I)*RK(J)
      DO28I=1,3
28    GT(I,J)=G(J,I)
      DO307N=1,3
      DO307L=1,12
      D(L,N)=0.0
      DO307I=1,3
307   D(L,N)=D(L,N)+G(L,I)*E(I,N)
      DO308N=1,12
      DO308L=1,12
      B(L,N)=0.0
      DO308I=1,3
308   B(L,N)=B(L,N)+D(L,I)*GT(I,N)
      DO29I=1,12
      DO29J=1,12
      AK1=K-1
      AK=K
      AD(I,J)=B(I,J)+D(I,J)-C(I,J)
      IF(AD(I,J))32,29,29
32    AD(I,J)=0.0
29    Q(I,J)=(AK1*Q(I,J)+AD(I,J))/AK
      PRINT 41
41    FORMAT(2X,1HK,14X,6HP(I,I*,16X,4HX)I*,14X6HQ)I,I*)
      DO8I=1,12
      KKL=I
IF(KKL-3)4,4,5
      PRINT 802,K,P(I,I),X(I)
      GOTO8
      PRINT801,K,P(I,I),X(I),G(KKL,KKL)
8     CONTINUE
801   FORMAT(13,3F20.6)
802   FORMAT(13,2F20.6)
      ER1=(Z1(K)-X(1))/Z1(K)
      ER2=(Z2(K)-X(2))/Z2(K)
      ER3=(Z3(K)-X(3))/Z3(K)
      PRINT99,ER1,ER2,ER3
99    FORMAT(3F10.6)
100   CONTINUE
3     STOP
      END
```

APPENDIX -II

(1) A BRIEF DESCRIPTION OF THE STAR PAPER MILL SAHARANPUR (U.P.)

The Star Paper Mill at Saharanpur (U.P.) have at present four paper machines in operation. Paper machine No(1) is used for producing white or coloured writing paper. The basis weight is of the order of 40 to 80 gms. The paper production is about 30 tons a day. Consistancy is changed by changing the flow box level. Head box height is controlled by white water by pass valve. Whereas the wire speed is controlled independently. The capacity of this machine is small because capacity of dryer section is small.

Paper Machine No. 2 is used for the production of Brown craft paper of heavier variety (50 to 200 gms/m^2). The production capacity is about 50 tons per day approximately.

Paper Machine No. 3 is also used for Brown Craft Paper of light variety (30 - 50 gms). The production capacity is about 25 tons per day.

Paper machine No. 4 is used for the production of tissue paper (cigarette paper) or brown craft paper of light variety (10 to 40 gms). It-s production capacity is about 25 tons per day.

Here consistancy is controlled by Kalle level controller. Head box height is controlled by white water by pass valve whereas wire speed is controlled independtly.

Sl. No.	Wet Sample wt gms	Dry Sample wt gms	Head Box Level mm	M/C speed m/min U_2	Thickness in microns	Consistancy in gpl R	Consistancy in gpl H Z_3	Moisture content in gms	Moisture content % Z_2	Basis wt gm/m^2 Z_1	Thick stock slow rate lit/min U_1
1	7.868	7.434	375	185	175.00	24.76	5.148	0.434	5.516	74.34	2034.79
2	7.778	7.391	440	170	127.67	28.99	5.188	0.387	4.9755	73.91	1597.60
3	7.991	7.902	422	185	133.34	27.73	4.988	0.389	4.8429	79.02	1944.45
4	8.244	8.042	423	187	155.00	28.54	5.282	0.202	4.8429	80.42	1943.50
5	7.897	7.437	420	190	136.67	27.64	5.458	0.459	5.8130	74.37	1866.58
6	7.784	7.352	470	185	126.67	28.91	4.986	0.432	5.549	73.52	1722.50
7	7.742	7.440	465	184	143.2	30.03	4.598	0.302	3.900	74.40	1669.02
8	8.264	7.244	370	160	133.34	22.59	3.464	1.02	12.34	72.44	1809.7
9	8.229	7.692	370	160	133.34	24.06	3.714	0.537	6.5257	76.92	1853.38
10	8.009	7.501	365	162	126	28.52	4.598	0.508	6.3428	75.01	1546.75
11	6.389	5.786	570	220	120	25.45	4.094	0.603	9.438	57.86	1755.82
12	6.138	5.775	580	210	105	30.08	3.612	0.383	6.2398	57.75	1465.34
13	6.202	5.844	580	210	106.67	29.51	5.616	0.358	5.772	58.44	1518.91
14	6.001	5.611	578	210	103.34	27.91	3.588	0.390	6.4989	56.11	1530.17
15	6.065	5.703	580	210	110.00	31.31	3.626	0.362	5.968	57.03	1394.23

17	5.731	4.458	580	210	94	29.62	3.688	1.273	22.16	44.58	1198.23
18	6.008	5.697	578	212	100.00	29.62	3.688	0.311	5.176	56.97	1498.74
19	6.243	5.810	572	212	98.00	29.60	3.626	0.433	6.939	58.10	1501.11
20	6.002	5.731	575	212	97.34	29.10	3.626	0.271	4.515	57.31	1545.22
21	5.859	5.687	585	210	113.34	27.95	3.628	0.172	2.935	56.87	1607.55
22	6.101	5.898	582	210	105	30.74	3.574	0.203	3.328	58.98	1509.74
23	6.587	6.301	590	210	121.34	30.08	3.700	0.286	4.392	63.01	1630.18
24	6.006	5.645	585	207	103.34	32.34	3.896	0.361	6.011	56.45	1316.31
25	5.869	5.706	575	210	151.67	25.64	3.596	0.163	2.777	57.06	1761.23
26	5.828	5.714	585	210	100.00	28.70	3.702	0.122	2.093	57.14	1586.67
27	6.144	5.961	585	215	99.67	28.24	2.568	0.183	2.978	59.61	1697.044
28	6.251	5.991	585	215	119.72	34.21	2.522	0.260	4.16	59.91	1398.67
29	5.892	5.491	585	215	100.00	35.21	3.721	0.367	3.25	58.34	1400.00
30	6.246	5.952	585	215	102.24	34.05	4.007	0.435	3.895	56.78	1493.33
31	5.819	5.508	600	200	93.34	30.77	3.456	.3182	5.468	55.08	1311.77
32	6.350	6.054	600	200	86.67	31.98	4.112	.296	4.66	60.54	1399.1132
33	5.912	5.854	600	210	96.67	35.97	3.626	.158	2.67	58.54	1289.32
34	6.298	6.114	590	214	103.34	30.03	3.226	.184	2.92	61.14	1639.44
35	6.352	6.042	595	210	98.67	33.27	3.902	.310	4.88	60.42	1406.05

36	6.40	6.003	600	210	100.00	39.87	3.514	.397	6.203	60.03	1149.18
37	5.941	5.000	600	210	98.00	34.47	3.802	.941	15.70	50.00	995.312
38	5.910	5.001	595	210	100	34.56	3.76	.989	16.51	50.01	984.64
39	5.985	5.003	595	210	107.76	33.73	3.56	0.456	2.89	53.01	1411.50
40	6.212	5.892	595	210	106.75	32.46	3.50	0.543	7.45	52.01	1326.53
41	6.436	5.024	625	210	111.67	33.79	2.05	1.414	2.197	50.24	944.33
42	6.042	5.926	595	205	96.67	34.65	2.884	0.116	1.919	59.26	1098.14
43	6.075	5.979	595	210.	111.67	34.65	2.014	0.096	1.580	59.79	1182.60
44	5.807	5.610	580	205	100.00	37.80	3.82	0.197	3.392	56.10	1139.28
45	5.872	5.641	585	210	106.67	33.01	3.80	0.231	3.935	56.41	1336.28
46	6.500	5.801	585	210	100.00	34.21	2.522	0.699	10.75	58.01	1231.85
47	6.431	5.005	585	210	130.01	42.00	3.602	1.426	2.27	50.05	1079.01
48	6.490	5.00	580	205	112.34	42.50	3.562	1.49	7.55	50.00	864.22
49	6.990	5.340	575	210	108.76	39.26	3.37	1.45	6.43	53.40	1035.93
50	6.900	5.391	585	210	109.00	33.84	2.07	1.509	7.376	53.91	1201.1402

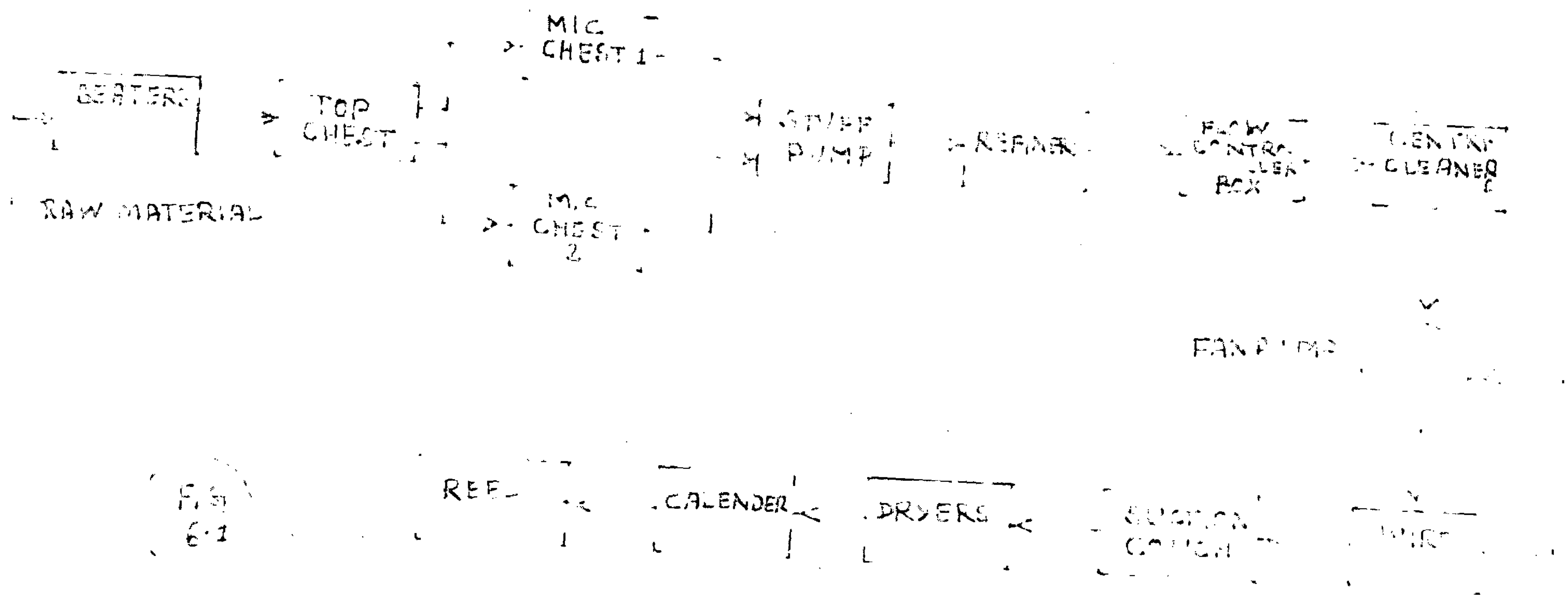
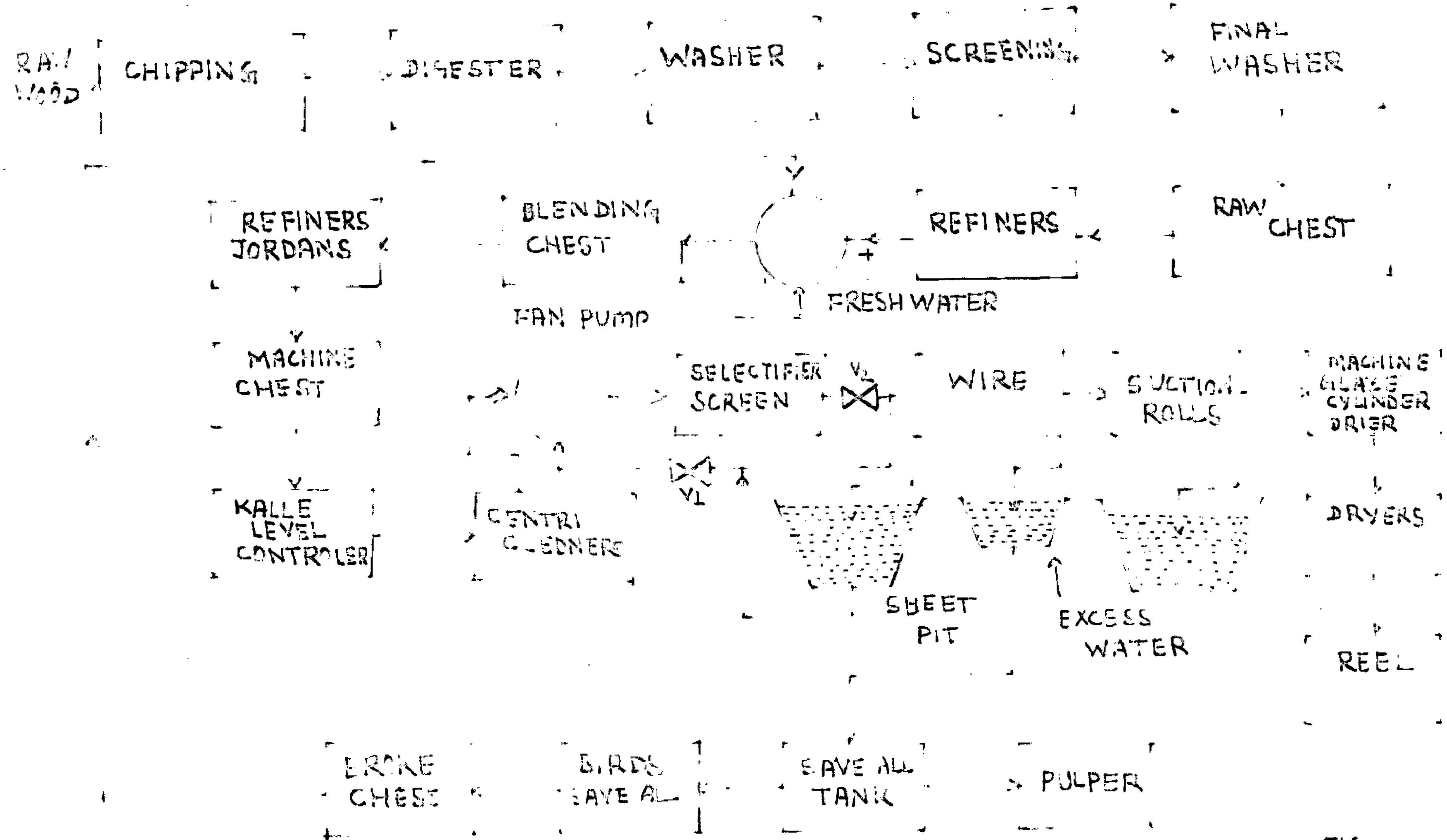


FIG 6·1

F... DIAGRAM FOR PAPER MIC NO 1



FLOW DIAGRAM FOR MACHINE 2 AND 3

FIG. 6.23

S.No.	Wet Sample gms	Dry Sample gms	Head Box level in "	M/C speed m/min U_2	Consistancy R in gpl	Consistancy H Z_3	Moisture (gms)	Moisture content % Z_2	Basis wt gm/m^2 Z	thick stock flow rate lit/m U_1
1.	4.141	3.951	10	135.0	30.63	2.848	0.19	4.588	39.51	643.992
2.	4.126	3.250	10.25	135.0	35.00	2.882	0.366	6.8831	32.50	442.961
3.	4.243	3.082	9.75	130.0	23.60	2.794	0.261	6.151	30.82	617.56
4.	4.301	3.088	10.12	135.0	25.82	3.01	0.213	4.952	30.88	594.82
5.	4.067	3.821	10.20	134.0	24.65	2.722	0.246	6.048	38.21	756.469
6.	4.008	3.754	10.00	135.0	20.05	2.66	0.250	6.262	37.54	918.37
7.	4.515	4.381	10.25	135.0	30.07	3.368	0.134	2.971	43.81	739.7132
8.	5.005	4.797	10.25	135.0	20.09	3.248	0.208	4.155	47.97	797.56
9.	4.658	4.477	10.25	134.0	30.56	3.238	0.181	3.885	44.77	731.299
10.	4.62	4.452	10.25	135.0	30.50	3.200	0.168	3.636	44.52	736.062
11.	4.334	4.001	12.25	130.0	27.31	3.224	0.333	7.683	40.01	681.48
12.	4.300	4.001	12.5	135.0	32.49	3.028	0.299	6.953	40.01	599.58
13.	4.172	3.919	12.5	135.0	41.57	2.776	0.253	6.064	39.19	629.71
14.	5.199	3.909	12.5	134.0	30.59	3.628	0.29	6.906	39.09	617.86
15.	4.297	4.009	12.5	133.0	30.05	2.796	0.288	6.702	40.09	641.65

16.	4.208	3.953	12.5	135.0	35.21	2.754	0.255	6.059	39.53	551.87
17.	4.172	3.919	12.4	135.0	35.00	2.740	0.253	6.064	39.19	550.37
18.	4.204	3.890	12.25	135.0	34.92	2.738	0.314	7.469	38.90	539.36
19.	4.222	3.910	12.25	135.0	32.49	3.008	0.312	7.389	39.10	583.18
20.	4.213	3.991	12.25	135.0	36.90	2.798	0.222	5.269	39.91	536.12
21.	4.154	3.908	12	140.0	40.90	3.292	0.246	5.922	39.08	487.788
22.	4.226	3.931	12	140.0	36.44	3.442	0.295	6.980	39.31	544.518
23.	4.209	3.009	12	140.0	30.05	3.122	0.209	4.965	30.09	516.38
24.	3.869	3.622	12.4	140.0	40.09	3.182	0.247	6.384	36.22	458.97
25.	4.155	4.002	12.4	140.0	26.73	3.256	0.153	3.682	40.02	782.53
26.	4.002	3.895	12	140.0	28.88	3.072	0.107	2.625	38.95	712.63
27.	3.861	3.722	12.5	135.0	28.24	3.568	0.139	3.600	37.22	664.82
28.	4.201	3.890	12.5	135.0	38.44	3.62	0.311	7.402	38.90	490.33
29.	4.356	3.981	12.5	135.0	34.44	3.915	0.412	6.582	34.12	546.36
30.	5.618	4.128	12.5	135.0	35.98	3.425	0.398	5.981	32.73	580.58
31.	4.241	4.007	11.5	78.34	33.54	2.822	0.234	5.5175	40.07	342.748
32.	4.102	3.901	11.5	68.34	30.60	2.67	0.201	4.900	39.01	321.13
33.	3.803	3.761	11.2	75.34	30.60	3.068	0.242	6.373	37.61	336.096
34.	4.184	4.002	11.4	73.34	31.59	3.304	0.182	4.349	40.02	345.3693
35.	4.200	3.940	13	75.00	31.24	3.422	0.76	6.190	39.40	343.937

36.	4.213	3.941	13	76.67	30.06	3.482	0.272	6.456	39.41	364.477
37.	4.005	3.900	13	76.60	29.63	2.722	0.105	2.621	39.00	380.55
38.	4.012	3.092	12.5	76.00	33.10	2.700	0.320	7.801	30.92	253.712
39.	4.256	3.800	12.5	78.00	31.12	3.126	0.345	6.891	35.72	318.72
40.	4.124	3.512	12.5	77.77	33.34	3.256	0.324	5.829	37.89	328.12
41.	4.0265	3.909	11.0	135	27.53	3.500	0.1175	2.91	39.09	613.23
42.	4.619	3.042	11.5	135	29.34	3.118	0.559	12.12	30.42	531.0196
43.	4.169	3.060	11.5	137	30.61	2.56	.109	2.62	30.60	513.88
44.	4.102	3.071	11.2	135	30.59	2.062	.131	3.193	30.71	508.55
45.	4.200	3.712	11.5	135	35.60	2.258	.129	3.07	37.12	528.85
46.	4.121	3.691	11.5	135	34.22	3.062	0.43	4.43	36.91	539.39
47.	4.026	3.129	11.5	130	36.90	2.518	0.897	21.77	31.29	418.00
48.	4.350	3.241	11.5	135	32.56	2.692	.109	2.505	32.41	507.80
49.	4.424	3.291	11.5	135	38.00	3.342	.133	3.07	32.91	439.25
50.	4.625	3.698	11.5	125	37.86	3.532	0.927	3.89	36.98	454.82

TABLE NO. 1

Estimate of original states and their filtering error covariances for paper machine 2

k	x_1	x_2	x_3	P_{11}	P_{22}	P_{33}
1	0.71342	0.60350	0.36393	0.00250	0.01000	0.00120
2	0.71139	0.54991	0.35146	0.00249	0.01000	0.00120
3	0.72420	0.50990	0.36454	0.00203	0.01000	0.00100
4	0.79339	0.44724	0.36147	0.00236	0.01000	0.00080
5	0.72858	0.49352	0.36175	0.00243	0.01000	0.00069
6	0.77855	0.41234	0.36215	0.00235	0.01000	0.00059
7	0.72670	0.61659	0.36758	0.00237	0.01000	0.00053
8.	0.70889	0.58434	0.37508	0.00228	0.01000	0.00048
9.	0.70679	0.58730	0.37577	0.00224	0.01000	0.00044
10	0.72670	0.44720	0.37769	0.00222	0.01000	0.00040
11	0.71854	0.49663	0.38208	0.00226	0.01000	0.00037
12	0.70634	0.41828	0.37702	0.00217	0.01000	0.00035
13	0.69313	0.47104	0.37362	0.00223	0.01000	0.00032
14	0.72614	0.65275	0.37209	0.00222	0.01000	0.00031
15	0.72469	0.56750	0.37330	0.00220	0.01000	0.00029
16	0.72884	0.60864	0.37463	0.00196	0.01000	0.00027
17	0.70711	0.63905	0.37539	0.00191	0.01000	0.00026
18	0.72226	0.47810	0.37847	0.00199	0.01000	0.00025
19	0.73471	0.42185	0.38031	0.00188	0.01000	0.00023
20	0.73229	0.42585	0.38021	0.00193	0.01000	0.00022
21	0.70227	0.58501	0.37560	0.00180	0.01000	0.00021
22	0.72082	0.63380	0.37180	0.00180	0.01000	0.00020
23	0.75086	0.63935	0.36649	0.00186	0.01000	0.00019

24	075049	0.58946	0.36351	0.00210	0.01000	0.00018
25	0.73456	0.44299	0.36219	0.00183	0.01000	0.00018
26	0.70107	0.44781	0.35918	0.00171	0.01000	0.00017
27	0.72794	0.44019	0.35911	0.00165	0.01000	0.00016
28	0.72554	0.63291	0.36014	0.00159	0.01000	0.00016
29	0.66816	0.65076	0.36157	0.00176	0.01000	0.00015
30	0.72111	0.71324	0.36207	0.00177	0.01000	0.00015
31	0.70410	0.56551	0.36277	0.00173	0.01000	0.00014
32	0.73041	0.52877	0.36345	0.00140	0.01000	0.00014
33	0.73770	0.45323	0.36521	0.00138	0.0.000	0.00013
34	0.74444	0.53585	0.36634	0.00145	0.01000	0.00013
35	0.68901	0.71316	0.36619	0.00150	0.01000	0.00013
36	0.69936	0.74916	0.36718	0.00150	0.01000	0.00012
37	0.75929	0.55401	0.36881	0.00152	0.01000	0.00012
38	0.72303	0.51175	0.36912	0.00153	0.01000	0.00012
39	0.73302	0.53355	0.37049	0.00129	0.01000	0.00012
40	0.70753	0.40706	0.36967	0.00129	0.01000	0.00011
41	0.72394	0.37505	0.36941	0.00138	0.01000	0.00011
42	0.88980	0.62730	0.37082	0.00189	0.01000	0.00011
43	0.90057	0.51811	0.37214	0.00199	0.01000	0.00011
44	0.82407	0.43163	0.37510	0.00178	0.01000	0.00010
45	0.85407	0.48892	0.37850	0.00139	0.01000	0.00010
46	0.81503	0.34251	0.38212	0.00133	0.01000	0.00010
47	0.70362	0.53683	0.37949	0.00154	0.01000	0.00010
48	0.69781	0.43172	0.37465	0.00126	0.01000	0.00009
49	0.74877	0.56550	0.37225	0.00125	0.01000	0.00009
50	0.70944	0.47599	0.37036	0.00120	0.01000	0.00009

TABLE NO. 2

Measurements of Original States and
Plant Noise covariances

k	z_1	z_2	z_3	Q_{11}	Q_{22}	Q_{33}
1	0.71330	0.60423	0.36390	0.00000	127.42254	0.00000
2	0.71140	0.55103	0.35140	0.00000	193.28027	0.00000
3	0.77390	0.51040	0.37240	0.01213	158.67017	0.00000
4	0.79950	0.44778	0.36380	0.00910	136.24.55	0.00000
5	0.73300	0.49386	0.36460	0.00728	111.20414	0.00000
6	0.78990	0.41271	0.37080	0.00606	93.38160	0000000
7	0.72610	0.61699	0.37340	0.00520	81.02294	0.00000
8	0.74230	0.58467	0.38780	0.00920	70.89507	0.00000
9	0.71260	0.58799	0.37830	0.00818	65.19976	0.00000
10	0.73700	0.44776	0.37960	0.00736	59.35876	0.00000
11	0.71850	0.49687	0.38700	0.00669	53.96251	0.00000
12	0.70960	0.41855	0.35850	0.00613	29.46563	0.00000
13	0.69230	0.47089	0.36040	0.00566	45.66059	0.00000
14	0.72580	0.65307	0.36480	0.00526	42.39911	0.00000
15	0.73840	0.56744	0.37580	0.00491	39.57251	0.00000
16	0.73600	0.60870	0.37780	0.00460	39.57251	0.00000
17	0.70540	0.63935	0.37520	0.00433	34.91692	0.00000
18	0.73230	0.47795	0.38820	0.00409	32.97709	0.00000
19	0.72930	0.42232	0.38300	0.00387	31.24145	0.00000
20	0.73890	0.42496	0.37630	0.00368	30.00611	0.00000
21	0.69510	0.58553	0.34820	0.00350	28.58611	0.00000
22	0.73420	0.63470	0.35380	0.00335	27.49116	0.00000
23	0.77410	0.63945	0.33980	0.00331	26.29589	0.00000

24	0.74620	0.59233	0.34720	0.00318	27.99954	0.00000
25	0.73820	0.44297	0.35690	0.00305	26.87756	0.00000
26	0.68460	0.44844	0.34040	0.00295	25.89209	0.00000
27	0.72950	0.44140	0.36230	0.00284	25.27483	0.00000
28	0.73630	0.63289	0.37080	0.00276	24.37216	0.00000
29	0.66230	0.64925	0.37420	0.00266	24.00373	0.00000
30	0.75020	0.71181	0.36760	0.00269	23.61765	0.00000
31	0.70790	0.56364	0.36980	0.00260	23.54071	0.00000
32	0.74130	0.52880	0.37040	0.00255	22.80507	0.00000
33	0.75000	0.45333	0.38080	0.00251	22.11400	0.00000
34	0.76130	0.53593	0.37730	0.00246	21.46359	0.00000
35	0.67570	0.71185	0.36480	0.00241	21.06762	0.00000
36	0.69320	0.74870	0.37620	0.00235	20.48241	0.00000
37	0.77900	0.55456	0.38530	0.00225	19.68745	0.00000
38	0.72070	0.51339	0.37160	0.00225	19.68745	0.00000
39	0.74070	0.53463	0.38360	0.00222	19.28151	0.00000
40	0.70350	0.40654	0.36080	0.00218	18.79947	0.00000
41	0.73450	0.37577	0.36720	0.00215	18.35843	0.00000
42	0.90690	0.63513	0.38720	0.00210	23.79974	0.00000
43	0.91220	0.52182	0.38620	0.00205	25.21695	0.00000
44	0.79830	0.43522	0.39840	0.00205	26.65297	0.00000
45	0.85450	0.49269	0.41220	0.00201	28.49111	0.00000
46	0.81980	0.34399	0.41780	0.00198	28.26452	0.00000
47	0.69890	0.53513	0.34520	0.00194	28.17301	0.00000
48	0.67010	0.43128	0.31280	0.00192	27.60174	0.00000
49	0.75300	0.56574	0.34320	0.00190	27.03844	0.00000
50	0.66950	0.47498	0.33940	0.00190	26.64064	0.00000

TABLE NO. 3

Estimates of Some Parameters and Noise
Error Covariances

	a_1	a_2	a_3	P_{44}	P_{55}	P_{66}
1	-0.28806	-0.14552	-0.19403	7.80198	9.60090	9.45049
2	-0.29285	-0.12859	-0.19602	7.14053	1.39969	9.33612
3	-0.35627	-1.54082	-2.80131	6.92638	1.02420	8.05250
4	-0.17289	-1.54309	-2.51371	6.80213	1.02357	7.74736
5	-0.24332	-1.47082	-2.59005	3.85616	1.00485	7.72221
6	-0.16214	-1.48042	-2.09850	3.82548	1.00485	7.43544
7	-0.17276	-1.47526	-2.08554	3.41839	0.99155	7.42884
8	-0.56257	-0.72509	-1.33486	3.14204	0.67710	7.13005
9	0.64101	-0.63895	-1.10278	3.08784	0.62120	6.72310
10	0.42277	-0.59531	-0.50843	2.95371	0.61479	5.77997
11	0.43096	-0.58904	-0.49548	2.59543	0.47897	4.64604
12	0.36319	-0.62199	-0.39591	2.51183	0.46836	3.90098
13	0.39069	-0.61523	-0.45271	2.09487	0.38420	3.61143
14	0.40652	-0.61371	-0.47100	1.42083	0.32829	3.59317
15	0.39715	-0.36274	-0.58005	1.42042	0.22840	3.56988
16	0.36830	-0.33335	-0.61717	1.41247	0.21974	3.55018
17	0.36943	-0.34264	-0.61404	1.41166	0.20300	3.54522
18	0.23758	-0.28023	-0.57412	1.33287	0.18499	3.53967
19	0.30149	-0.24362	-0.57854	1.23746	0.15750	3.53835
20	0.30750	-0.28106	-0.59299	1.23618	0.13946	3.53542
21	0.28223	-0.26170	-0.72626	1.19867	0.13464	3.37254
22	0.30671	-0.20980	-0.42331	1.19763	0.12448	2.96958
23	0.59878	-0.04590	-0.31573	1.11043	0.09211	2.94148

24	0.48496	-0.07369	-0.35813	0.76606	0.07773	2.93411
25	0.54698	-0.06464	-0.42614	0.58105	0.07274	2.74439
26	0.40591	-0.02421	-0.21830	0.52104	0.06720	2.59205
27	0.40399	-0.02915	-0.22673	0.51857	0.05765	2.56433
28	0.09924	-0.04929	-0.32121	0.49458	0.05425	2.48429
29	0.41840	-0.06820	-0.25588	0.45953	0.04571	2.41412
30	0.23583	0.03407	-0.07705	0.42096	0.03674	2.38772
31	0.24946	0.03709	-0.08980	0.41992	0.02922	2.37008
32	0.23229	0.05177	-0.11564	0.41720	0.02803	2.36241
33	0.26111	0.04918	-0.18643	0.41099	0.02797	2.31949
34	0.31928	0.03020	-0.29463	0.39841	0.02661	2.27339
35	0.24154	0.03106	-0.24174	0.36394	0.02661	2.25858
36	0.25974	0.02018	-0.27557	0.35619	0.02342	2.22363
37	0.20757	0.05784	-0.21009	0.34920	0.01992	2.21363
38	0.19323	0.05716	-0.22374	0.30870	0.01977	2.18785
39	0.19529	0.05461	-0.18769	0.00867	0.01957	2.16311
40	0.18928	0.05491	-0.20256	0.30642	0.01954	2.14940
41	0.16110	0.04119	-0.12556	0.29820	0.01765	2.08794
42	0.07162	0.00822	-0.25672	0.28031	0.01526	2.05392
43	0.26427	0.01769	-0.63283	0.14095	0.01494	1.51965
44	0.05384	0.02597	-0.28960	0.09562	0.01487	1.39985
45	0.05990	0.02604	-0.29852	0.09479	0.01435	1.39324
46	0.07861	0.02429	-0.31607	0.08594	0.01415	1.38807
47	0.05854	0.03081	-0.31095	0.07659	0.01222	1.38779
48	0.07503	0.03639	-0.48057	0.07538	0.01217	1.33228
49	0.06312	0.03373	-0.47291	0.07106	0.01162	1.33073
50	0.06167	0.03147	-0.22384	0.07104	0.01162	1.28221

TABLE NO. 4

Estimates of some Parameters and Noise Error Covariances

k	b_4	b_1	b_2	P_{77}	P_{88}	P_{99}
1	5.22095	7.51215	-149.25928	9.96679	6.52623	9.62680
2	5.87014	7.51220	-148.22317	9.74262	6.52615	9.05579
3	6.08503	5.89567	-147.84656	9.65011	6.03210	8.77368
4	6.28284	5.77056	-147.46967	9.57291	5.97280	8.49357
5	6.37681	5.19571	-147.25842	9.52228	4.84831	8.23868
6	6.48291	4.62881	-147.05858	9.45240	4.47639	7.98795
7	6.56013	4.61083	-147.85225	9.41836	4.38586	7.74382
8	6.67264	2.92473	-146.72486	9.27684	2.88658	7.54361
9	6.86600	2.71100	-146.65509	9.17566	2.53297	7.34669
10	7.00335	2.40184	-146.26530	9.08855	2.25885	7.18143
11	7.02745	2.38070	-146.18811	9.07380	2.20583	7.02918
12	7.06132	2.39944	-146.11895	9.04329	2.11961	6.90307
13	7.05391	2.43790	-146.15492	9.03857	2.10977	6.78939
14	7.07950	2.45150	-146.07728	9.02638	2.07475	6.67836
15	7.05856	1.83620	-146.09471	8.91313	1.47793	6.61047
16	7.06262	1.71909	-146.08886	Σ.87415	1.34265	6.54101
17	7.11018	1.74161	-146.04015	8.81818	1.25168	6.48219
18	7.08017	1.58989	-146.06431	8.75096	1.16710	6.43874
19	7.08378	1.56623	-145.99028	8.75080	1.14437	6.37494
20	7.11555	1.51102	-146.10803	8.74716	1.10181	6.32755
21	7.10695	1.54688	-146.03960	8.74639	1.09960	6.27894
22	7.21407	1.50596	-145.95801	8.69807	1.08620	6.25059
23	7.21888	1.16781	-145.95600	8.62065	0.93185	6.23377

24	7.67679	1.19693	-145.69753	8.53401	0.92849	6.20610
25	7.67383	1.15870	-145.69964	8.50554	0.83755	6.19074
26	7.64725	1.15624	-145.63471	8.50042	0.83602	6.15774
27	7.60540	1.16942	-145.51645	8.49607	0.76670	6.12335
28	7.60692	1.15070	-145.51899	8.49225	0.76505	6.10074
29	7.40312	1.23315	-145.55470	8.42201	0.58855	6.09854
30	7.18706	0.94275	-145.58544	8.34290	0.51713	6.09718
31	6.83691	0.89894	-145.59048	8.20869	0.43134	6.09715
32	6.83783	0.88668	-145.58953	8.20120	0.43027	6.07481
33	6.83914	0.86519	-145.58456	8.20073	0.42797	6.07481
34	6.83691	0.82851	-145.58121	8.18895	0.42363	6.05630
35	6.80325	0.91343	-145.62342	8.18615	0.38311	6.05165
36	6.72701	0.92305	-145.62568	8.06080	0.37922	6.05152
37	6.82416	0.94300	-145.62090	7.91098	0.37767	6.05115
38	6.87352	0.94237	-145.54109	7.90671	0.37761	6.03999
39	6.85711	0.94723	-145.48306	7.90558	0.37630	6.02600
40	6.85459	0.95864	-145.50156	7.90547	0.36940	6.01981
41	6.78574	0.96648	-145.45436	7.85798	0.36881	5.99721
42	5.55657	1.23849	-144.40281	7.73550	0.21180	5.90737
43	5.74654	1.28649	-144.17630	7.72490	0.20286	5.89256
44	5.62347	1.25770	-143.89067	7.72048	0.20206	5.86838
45	5.24287	1.25844	-143.52336	7.68390	0.19264	5.83429
46	5.17421	1.25335	-143.43225	7.67658	0.19146	5.82149
47	5.41501	1.28045	-143.50998	7.60829	0.16042	5.81440
48	5.40756	1.27571	-143.51891	7.60722	0.16034	5.81268
49	5.39079	1.28062	-143.50736	7.58924	0.15924	5.80426
50	5.36400	1.33634	-143.52136	7.58657	0.15673	5.80354

TABLE NO. 5

Estimates of some parameters and noise error

k	b_3	b_4	b_5	$P_{10,10}$	$P_{11,11}$	$P_{12,12}$
1.	0.23054	-6.48508	130.73562	0.97181	6.56559	9.63103
2.	-0.01231	-6.48503	131.76673	0.00237	6.56551	9.06648
3.	0.00222	-2.26384	132.5583	0.00060	3.19664	8.76579
4.	0.00047	-2.37128	132.607	0.00024	3.15275	8.46555
5.	0.00046	-2.47246	132.77393	0.00012	3.11747	8.16929
6.	0.00051	-2.13218	132.98947	0.00007	2.97776	7.87762
7.	0.00171	-2.11453	133.21226	0.00004	2.85827	7.59298
8.	0.00237	-1.65528	133.35035	0.00003	2.84673	7.35841
9.	0.00239	-1.62883	133.62669	0.00002	2.84029	7.15145
10.	0.00228	-1.40011	133.82387	0.00002	2.70092	6.97292
11.	0.00261	-1.39317	133.90916	0.00001	2.50141	6.78649
12.	0.00157	-1.38016	133.98478	0.00001	2.44741	6.63644
13.	0.00096	-1.42142	133.94260	0.00001	2.20569	6.48029
14.	0.00068	-1.44060	134.02757	0.00001	1.94682	6.34736
15.	0.00069	-0.997558	134.00846	0.0000	1.52834	6.26054
16.	0.00075	-0.79154	134.01510	0.0000	1.34921	6.17286
17.	0.00075	-0.81080	134.06671	0.0000	1.27998	6.10683
18.	0.00096	-0.62600	134.03925	0.0000	1.13053	6.04937
19.	0.00103	-0.65851	134.11778	0.0000	1.10147	5.97836
20.	0.00094	-0.58778	133.95948	0.0000	1.01601	5.89197
21.	0.00054	-0.56377	134.03209	0.0000	0.97326	5.83744
22.	-0.00020	-0.68260	134.10710	0.000	0.93799	5.79565
23.	-0.00037	-0.60128	134.20429	0.0000	0.73299	5.79175

24.	-0.00037	-0.60128	134.20429	0.00000	0.73299	5.79175
25.	-0.00044	-0.58836	134.20198	0.00000	0.72146	5.77315
26.	-0.00057	-0.58661	134.26853	0.00000	0.72104	5.73893
27.	-0.00055	-0.59186	134.37469	0.00000	0.71131	5.71117
28.	-0.00047	-0.56648	134.37161	0.00000	0.70726	5.67924
29.	-0.00036	-0.63032	134.29065	0.00000	0.60563	5.66812
30.	-0.00033	-0.33812	134.21844	0.00000	0.53278	5.65963
31.	-0.00028	-0.30789	134.15554	0.00000	0.39071	5.65530
32.	-0.00024	-0.27587	134.15657	0.00000	0.48178	5.64318
33.	-0.00015	-0.24743	134.16198	0.00000	0.47667	5.62809
34.	-0.00010	-0.202651	134.16581	0.00000	0.46972	5.60291
35.	-0.00009	-0.24856	134.08595	0.00000	0.45796	5.58639
36.	-0.00005	-0.25287	134.08182	0.00000	0.45706	5.58601
37.	-0.00002	-0.27731	134.07856	0.00000	0.45518	5.58585
38.	0.00004	-0.26130	134.12479	0.00000	0.41230	5.58210
39.	0.00009	-0.27849	134.17352	0.00000	0.40518	5.57219
40.	0.00005	-0.28010	134.14836	0.00000	0.40518	5.56080
41.	0.00004	-0.28713	134.19687	0.00000	0.40464	5.53681
42.	0.00008	-0.41382	134.51420	0.00000	0.37081	5.52859
43.	0.000012	-0.46485	134.50207	0.00000	0.36091	5.52853
44.	0.00023	-0.41674	134.57134	0.00000	0.35858	5.52706
45.	0.00033	-0.41837	134.70358	0.00000	0.35373	5.52263
46.	0.00044	-0.41927	134.75892	0.00000	0.35372	5.51786
47.	0.00034	-0.43647	134.59408	0.00000	0.33976	5.48582
48.	0.00018	-0.38698	134.58005	0.00000	0.33567	5.48170
49.	0.00010	-0.38438	134.59284	0.00000	0.33541	5.547121
50.	0.00004	-0.52826	134.55662	0.00000	0.31841	5.46639

TABLE NO. 6

Estimates of Original States and
their Filtering Error

	x_1	x_2	x_3	P_{11}	P_{22}	P_{33}
1	0.67879	0.59964	0.83333	0.00250	0.00100	21.37778
2	0.70089	0.58786	1.65690	0.00250	0.00100	43.77852
3	0.73517	0.67959	0.49677	0.00250	0.00100	60.57687
4	0.71525	0.56477	-0.13078	0.00250	0.00100	3.40714
5	0.69253	0.55295	0.50804	0.00248	0.00100	0.26664
6	0.73387	0.56383	0.20711	0.00243	0.00100	0.36650
7	0.68429	0.51157	-0.25836	0.00198	0.00100	0.38548
8	0.72313	0.60633	-0.53803	0.00115	0.00100	0.56023
9	0.75128	0.64220	-0.50632	0.00163	0.00100	0.72958
10	0.78392	0.63189	-0.41275	0.00139	0.00100	0.58150
11	0.72489	0.55033	-0.46600	0.00194	0.00100	0.65823
12	0.74924	0.52680	-0.24976	0.00194	0.00100	0.45061
13	0.74169	0.49264	0.34382	0.00225	0.00100	0.34950
14	0.73979	0.50141	0.42609	0.00188	0.00100	0.34023
15	0.49271	0.69596	-0.54488	0.00242	0.00100	0.26617
16	0.52166	0.65362	-0.12000	0.00245	0.00100	0.25916
17	0.50864	0.87517	-0.04479	0.00241	0.00100	0.30778
18	0.51614	0.66503	-0.22776	0.00242	0.00100	0.35133
19	0.52561	0.51007	-0.30590	0.00239	0.00100	0.38773
20	0.49191	0.52064	-0.29082	0.00239	0.00100	0.41218
21	0.54220	0.47717	-0.23341	0.00238	0.0100	0.41218
22	0.50192	0.59107	-0.24361	0.00238	0.00100	0.42364
23	0.54757	0.60541	-0.30214	0.00237	0.00100	0.41766

24	0.52783	0.63164	-0.36385	0.00236	0.00100	0.40861
25	0.52468	0.53989	-0.38993	0.00236	0.00100	0.40904
26	0.53248	0.37905	-0.37653	0.00235	0.00100	0.40323
27	0.53055	0.44041	-0.33233	0.00236	0.00100	0.40697
28	0.54398	0.43240	-0.35967	0.00234	0.00100	0.41503
29	0.66261	0.08484	-0.11050	0.00235	0.00100	0.35468
30	0.66561	0.57858	-0.30453	0.00237	0.00100	0.29141
31	0.60406	0.47008	-0.29403	0.00233	0.00100	0.26285
32	0.61642	0.48971	-0.25921	0.00233	0.00100	0.26088
33	0.62738	0.47786	-0.30278	0.00232	0.00100	0.26726
34	0.67515	0.68106	-0.34443	0.00231	0.00100	0.25627
35	0.62408	0.59818	-0.43423	0.00232	0.00100	0.24525
36	0.60841	0.51499	-0.39800	0.00230	0.00100	0.24785
37	0.63324	0.46684	-0.33267	0.00230	0.00100	0.23687
38	0.61664	0.37766	-0.33002	0.00230	0.00100	0.23675
39	0.63058	0.35918	-0.34470	0.00229	0.00100	0.24665
40	0.76860	0.35918	-0.47622	0.00230	0.00100	0.22229
41	0.56879	0.48351	-0.56785	0.00229	0.00100	0.23045
42	0.65335	0.50318	-0.32043	0.00230	0.00100	0.21153
43	0.66229	0.53770	-0.31995	0.00228	0.00100	0.21239
44	0.69574	0.52765	-0.31232	0.00228	0.00100	0.19289
45	0.64239	0.46098	-0.33756	0.00227	0.00100	0.20166
46	0.49521	0.47118	-0.39397	0.00228	0.00100	0.22871
47	0.52666	0.45333	-0.25263	0.00228	0.00100	0.23459
48	0.51586	0.48369	-0.10286	0.00226	0.00100	0.23929
49	0.49791	0.45409	-0.04008	0.00226	0.00100	0.23262
50	0.50352	0.49235	0.04584	0.00226	0.00100	0.23876

TABLE NO. 7

Measured States and Plant Noise Covariances Results

k	z_1	z_2	Q_{11}	Q_{22}	Q_{33}
1	0.67860	0.59976	0.00000	812.25973	0.00000
2	0.70080	0.58790	0.00000	1045.35188	0.00000
3	0.73570	0.67962	0.00000	1036.57167	0.00000
4	0.71530	0.56480	0.00000	1046.36995	0.00000
5	0.69080	0.55298	0.00000	1052.38904	0.00000
6	0.73600	0.56386	0.00000	1016.22307	0.00000
7	0.67240	0.51160	0.00000	977.94581	0.00000
8	0.72730	0.60635	0.00000	939.90987	0.00000
9	0.71470	0.64223	0.00019	914.77940	0.00369
10	0.76750	0.63192	0.00017	896.48234	0.00333
11	0.71590	0.55036	0.00015	876.88657	0.00302
12	0.71560	0.52683	0.00071	860.83808	0.03482
13	0.73680	0.49267	0.00065	851.26567	0.03214
14	0.72990	0.50144	0.00061	842.16572	0.02985
15	0.51440	0.69596	0.02655	786.02134	0.07935
16	0.51100	0.65362	0.03487	736.89500	0.08783
17	0.50390	0.87517	0.03282	693.54824	0.08538
18	0.52180	0.66501	0.03100	664.58463	0.08364
19	0.52740	0.51005	0.02937	636.51225	0.08070
20	0.48980	0.52062	0.02790	609.76195	0.07728
21	0.53860	0.47716	0.02657	582.26561	0.07368
22	0.50080	0.59105	0.02536	560.21380	0.07036
23	0.54840	0.60540	0.02426	539.35360	0.06730

24	0.52880	0.63162	0.2325	520.13029	0.06450
25	0.52420	0.53987	0.2232	503.39070	0.06192
26	0.53030	0.37903	0.02146	486.60800	0.05954
27	0.52680	0.44039	0.02066	470.35811	0.05733
28	0.54350	0.43238	0.01993	456.83735	0.05528
29	0.65290	0.84084	0.01946	444.12429	0.05368
30	0.67060	0.57859	0.01881	429.42314	0.05190
31	0.60200	0.47010	0.01821	416.74927	0.05022
32	0.61260	0.48971	0.1764	413.94187	0.04865
33	0.62780	0.47786	0.01710	391.70021	0.04718
34	0.67540	0.68108	0.01680	380.82531	0.04579
35	0.62690	0.59818	0.01613	369.04459	0.04448
36	0.60390	0.51399	0.01508	359.66835	0.04325
37	0.62770	0.46686	0.01526	350.45536	0.042208
38	0.61430	0.37767	0.01485	341.33285	0.03097
39	0.62920	0.35419	0.01447	332.48329	0.03993
40	0.77370	0.56353	0.01411	328.05000	0.03894
41	0.57290	0.48350	0.01377	320.04878	0.03804
42	0.63990	0.50321	0.01387	314.44638	0.03832
43	1.66020	0.53772	0.01355	307.28774	0.03743
44	0.69360	0.52768	0.01324	302.49084	0.03658
45	0.64210	0.46099	0.01295	295.76882	0.035577
46	0.49880	0.47113	0.01267	294.81470	0.03543
47	0.51400	0.45331	0.01253	289.58407	0.03521
48	0.50240	0.48368	0.01242	283.88250	0.03502
49	0.48670	0.45408	0.01222	278.09635	0.03454
50	0.50170	0.48233	0.01197	273.53512	0.03385

TABLE NO. 8

Estimates of Some Parameters and Their Filtering Error Covariances.

k	a_1	a_2	a_3	P_{44}	P_{55}	P_{66}
1	-0.42695	-0.30112	-0.22584	8.26993	9.43312	9.68113
2	-0.39798	-0.36225	-0.41243	8.11761	8.78160	3.61246
3	-0.25257	-0.97067	-0.27870	7.91192	5.18055	3.43848
4	-0.24821	-0.91203	-0.36124	7.90290	3.54559	0.20022
5	0.18833	-0.26997	-0.20847	6.66071	0.85855	0.04811
6	-0.19945	-0.21111	-0.16128	4.21520	0.80219	0.01189
7	-1.02163	0.03868	-0.16959	1.71454	0.57136	0.01163
8	-1.09089	00.04983	-0.17443	1.34214	0.56169	0.00982
9	-1.33352	-0.29331	-0.19212	1.30403	0.48590	0.00962
10	-1.18044	-0.34605	-0.20969	1.20731	0.47398	0.00834
11	-1.36447	-0.31201	-0.22359	0.97365	0.46598	0.00701
12	-0.73797	-0.42481	-0.27349	0.77769	0.45963	0.00577
13	-0.78621	-0.39335	-0.29138	0.75382	0.44948	0.00249
14	-0.73332	-0.40150	-0.29661	0.73594	0.44005	0.00231
15	-1.71647	0.42808	-0.[illegible]	0.57763	0.33636	0.00231
16	-0.80607	-0.23782	-0.30464	0.19500	0.13165	0.00229
17	-0.70829	-0.30677	-0.30713	0.15623	0.11277	0.00227
18	-0.80807	-0.19387	-0.30495	0.13236	0.08258	0.00226
19	-0.81625	-0.19100	-0.30502	0.13004	0.08229	0.00226
20	-0.81469	-0.18324	-0.30483	0.12998	0.08076	0.00225
21	-0.80137	-0.17979	-0.30562	0.12835	0.08066	0.00225
22	-0.80201	-0.17661	-0.30568	0.12831	0.07966	0.00225
23	-0.80494	-0.17406	-0.30545	0.12669	0.07843	0.00224

24	-0.80511	-0.17254	-0.30534	0.12669	0.07810	0.00224
25	-0.80321	-0.170358	-0.30540	0.12613	0.07744	0.00223
26	-0.80321	-0.17080	-0.30569	0.12610	0.007720	0.00223
27	-0.80889	-0.14991	-0.30603	0.12577	0.07272	0.00223
28	0.80853	-0.14937	-0.30612	0.12568	0.07252	0.00222
29	0.78370	-0.14177	-0.31176	0.12472	0.07243	0.00217
30	-0.79090	-0.09097	-0.30887	0.12445	0.05910	0.00213
31	-0.79795	-0.08767	-0.30911	0.1251	0.05867	0.00213
32	-0.79556	-0.07911	-0.30995	0.12244	0.05780	0.00212
33	-0.79582	-0.07954	-0.30987	0.12238	0.05761	0.00212
34	-0.79583	-0.07972	-0.30982	0.12238	0.05751	0.00211.
35	-0.79624	-0.06904	-0.30954	0.12237	0.05488	0.00211
36	-0.78653	-0.07244	-0.31013	0.12145	0.05476	0.00210
37	-0.77921	-0.06868	-0.31157	0.12112	0.05468	0.00209
38	-0.78000	-0.06499	-0.31202	0.12110	0.05417	0.00208
39	-0.77970	-0.06146	-0.31226	0.12109	0.05282	0.00208
40	-0.77436	-0.06833	-0.31080	0.12087	0.05245	0.00206
41	-0.75649	-0.06271	-0.31164	0.11694	0.05206	0.00205
42	-0.64992	-0.09186	-0.31856	0.10727	0.04134	0.00202
43	-0.64677	-0.09270	-0.31820	0.10676	0.05130	0.00200
44	-0.64425	-0.09566	-0.31891	0.10645	0.05087	0.00197
45	-0.64415	-0.09565	-0.31895	0.10642	0.05087	0.00197
46	-0.64492	-0.09765	-0.10641	0.05080	0.00197	0.00197
47	-0.55715	-0.12078	-0.32318	0.09581	-0.05007	0100195
48	-0.51026	-0.12327	-0.32784	0.09293	0.05006	0.00192
49	-0.47473	-0.13661	-0.33266	0.09056	0.04973	0.00187
50	-0.47033	-0.13723	-0.33334	0.08915	0.04970	0.00184

TABLE NO. 9

Estimates of Some Parameters and Their Filtering Error Covariances

k	a_4	b_1	b_2	P_{77}	P_{88}	P_{99}
1.	5.48374	7.19702	-148.71004	9.94125	5.96886	9.58220
2.	5.72800	7.31757	-.48.27483	9.90296	5.89525	9.46065
3.	5.89067	7.16269	-147.98029	0.87583	5.86594	9.37170
4.	6.08406	7.16842	-147.68219	9.83976	5.85040	9.28601
5.	6.23677	6.74633	-147.39155	9.81709	4.68900	9.20387
6.	6.36490	6.89680	-147.14160	9.79650	4.32083	9.12554
7.	6.49132	7.18848	-146.90422	9.77496	4.00609	9.04958
8.	6.60119	7.14875	-146.68406	9.75758	3.38355	8.97976
9.	6.74256	7.30525	-146.44890	9.73152	3.86767	8.90763
10.	6.89672	6.88502	-146.20993	9.70194	3.13879	8.83659
11	7.04329	6.69693	-145.98306	9.67384	2.89468	8.76926
12	7.16716	5.76467	-145.75364	9.65427	2.46078	8.70212
13	7.28858	5.50160	-145.51469	9.63708	1.75125	8.63556
14	7.39783	5.44234	-145.27864	9.62309	1.72889	8.57024
15	7.40005	2.43472	-145.27467	0.60867	0.24770	8.52885
16	7.39376	2.28277	-145.28201	9.57335	0.23697	8.47424
17	7.39090	2.29122	-145.28562	9.54263	0.23665	8.42500
18	7.25736	2.24722	-145.38552	9.47560	0.12200	0.38898
19	7.17306	2.24104	-145.47452	9.44242	0.23068	Σ.35031
20	7.12067	2.24518	-145.55941	9.42681	0.23025	8.30933
21	7.08619	2.23458	-145.61625	9.41040	0.22922	8.26472
22	7.03857	2.23608	-145.70617	9.39809	0.22899	8.22085
23	6.97594	2.23776	-145.78733	9.37345	0.22846	8.18026

24	6.90971	2.23827	-145.86833	9.34715	0.22842	8.14018
25	6.83029	2.23791	-145.95966	9.31769	0.22835	8.10122
26	6.77829	2.23372	-146.03817	9.29993	0.22780	8.06075
27	6.75608	2.22736	-146.11015	9.29573	0.22738	8.01667
28	6.71473	2.22706	-146.20443	9.28771	0.22732	7.97494
29	6.75201	2.10202	-146.09117	9.28116	0.20310	7.91453
30	6.8[illegible]	2.12457	-146.04942	9.21509	0.20047	7.86797
31	6.84860	2.11753	-145.97695	9.19455	0.18854	7.81882
32	6.86701	2.10801	-145.93230	9.18606	0.19745	7.76881
33	6.86665	2.10800	-145.93309	9.17648	0.19745	7.72125
34	6.89205	2.10884	-145.87043	9.16777	0.19543	7.67146
35	6.90320	2.10778	-145.85945	9.13252	0.19540	7.63173
36	6.90543	2.10344	-145.85632	9.11150	0.19522	7.59042
37	6.93459	2.08096	-145.79843	9.10018	0.19206	7.54582
38	6.94602	2.07831	-145.76897	9.09361	0.19179	7.50219
39	6.94788	2.07728	-145.75785	9.09235	0.19168	7.45761
40	6.97122	2.11102	-145.60497	9.09122	0.18281	7.40373
41	6.95713	2.08792	-145.62515	9.07465	0.17625	7.37471
42	7.00364	1.97610	-145.51362	9.06698	0.16560	7.33063
43	7.02269	1.97485	-145.46950	9.05916	0.16552	7.28869
44	7.08543	1.96589	-145.35070	9.04725	0.16[illegible]61	7.24597
45	7.09020	1.96641	-145.34089	9.0[illegible]	0.16087	7.20803
46	7.02597	1.94091	-145.47799	9.03344	0.14978	7.18605
47	6.99413	1.90913	-145.54715	9.02796	0.14839	7.16024
48	6.97844	1.87911	-145.59556	9.02481	0.14721	7.13005
49	6.96683	1.84304	-145.62289	9.01947	0.14477	7.10060
50	6.94161	1.84150	-145.69454	9.01628	0.14460	7.07494

TABLE NO. 10

Estimates of Some Parameters and Their Filtering Error Covariances

k	b_3	b_4	b_5	$P_{10,10}$	$P_{11,11}$	$P_{12,12}$
1.	0.50000	-6.72770	131.16903	10.00000	6.68927	9.65686
2.	0.58838	-6.69232	131.54371	8.63848	6.47110	9.56677
3.	-0.05420	-6.55881	131.80370	4.62175	6.29771	9.49747
4	-0.15103	-6.56483	132.06163	0.16432	6.28048	9.43332
5	-0.15598	-6.75630	132.31312	0.16416	6.04154	9.37181
6	-0.24976	-6.64188	132.53621	0.02114	5.82864	9.30842
7	-0.26236	-6.56545	132.74903	0.02055	5.80703	9.24836
8	-0.26137	-6.47675	132.94644	0.02047	5.19652	9.19222
9	-0.20794	-6.26824	133.15460	0.01862	5.16837	9.13570
10	-0.16812	-5.85085	133.36369	0.01208	4.44933	9.08132
11	-0.15181	-5.51826	133.56195	0.01024	3.68616	9.02990
12	-0.05564	-4.82700	133.76245	0.00563	3.44760	8.97862
13	-0.03847	-4.50728	133.96832	0.00260	2.39953	8.92921
14	-0.03054	-4.47242	134.17171	0.00220	2.39180	8.88072
15	-0.08214	-0.89183	134.17616	0.00177	0.29249	8.81858
16	-0.04409	-0.98021	134.16776	0.00110	0.28889	8.75680
17	-0.03893	-0.02017	134.16365	0.00099	0.28241	8.69306
18	-0.04386	-0.97028	134.03466	0.00093	0.27644	8.63053
19	-0.04428	-0.95893	133.91601	0.00092	0.27198	8.56480
20	-0.04409	-0.97012	133.80615	0.00092	0.26880	8.49615
21	-0.04295	-0.97113	133.73610	0.00091	0.26879	8.42840
22	-0.04285	-0.97448	133.61950	0.00091	0.26768	9.35462
23.	-0.04314	-0.97587	133.51531	0.00090	0.26731	8.28773

24	-0.04332	-0.97749	133.41125	0.00089	0.26693	8.22159
25	-0.04322	-0.97710	133.29200	0.00088	0.26684	8.15518
26	-0.04282	-0.97493	133.19153	0.00088	0.26669	8.08888
27	-0.04253	-0.97769	133.10005	0.00088	0.26661	8.01769
28	-0.04245	-0.97800	132.97668	0.00087	0.26655	7.94566
29	-0.03722	-0.86153	133.09004	0.00083	0.24553	7.88460
30	-0.03990	-0.91787	133.13361	0.00079	0.22913	7.83389
31	-0.03958	-0.90617	133.20743	0.00079	0.22379	7.78290
32	-0.03881	-0.90319	133.25533	0.00078	0.22369	7.72535
33	-0.03887	-0.90268	133.25442	0.00078	0.22342	7.66345
34	-0.03893	-0.90350	133.32007	0.00077	0.22145	7.60830
35	-0.03948	-0.90985	133.33216	0.00076	0.22052	7.56057
36	0.03855	-0.91022	133.33568	0.00075	0.22052	7.50836
37	0.03706	-0.89292	133.39574	0.00074	0.21865	7.46035
38	-0.03688	-0.89174	133.42779	0.00073	0.21860	7.40869
39	-0.03648	-0.89326	133.44035	0.00073	0.21835	7.35186
40	-0.03787	-0.93173	133.57983	0.00071	0.20682	7.31118
41	-0.03760	-0.92455	133.55610	0.00071	0.20618	7.26412
42	-0.03056	-0.863621	133.55167	0.0067	0.20302	7.22462
43	-0.03009	-0.86416	133.70845	0.00066	0.20301	7.17748
44	-0.02944	-0.85380	133.81815	0.00064	0.19778	7.14106
45	-0.02941	-0.85448	133.82910	0.00064	0.19549	7.09369
46	-0.02940	-0.82385	133.60708	0.00064	0.18048	7.03604
47	-0.02503	-0.84276	133.51407	0.00061	0.17998	6.98934
48	-0.02141	-0.84531	133.45255	0.00059	0.17998	6.94078
49	-0.01786	-0.82358	133.41958	0.00057	0.17909	6.89771
50	-0.01742	-0.82494	133.32227	0.00056	0.17895	6.85023

BIBLIOGRAPGY

1. Stochastic optimal linear estimation and control J.S. Meditch M.C. Graw Hill, 1969.
2. Adaptive filtering with unknown priory statistics - Sage Andrew and Husa, G.W.J.A. C.C. Proceedings August, 5-7,1969.
3. A.E. Beecher, Dynamic Modelling Techniques in Paper Industry TAPPI Vol. 46, pp. 117-120 (1963).
4. V.A. Sastry and W.J. Vetter, A paper making wet end dynamics model and parameter identification by iterative filtering, conference on Industrial Applications of dynamic modelling 16-18 Sept.1969, IEE Conf. Pub. No.-57.
5. S. Hem, Computer control of a paper machine using a linear state space model, paper making systems and their control Vols. I and II Transection of Symp. at Oxford in Sept.1969 Eddited by Francis and Bolam, by Technical Section of B.P. BM.A. 1970.
6. Statistical Simulation of paper making R.R. Narkheda, M.E. Thesis 1975,University of Roorkee, Roorkee.
7. Case studies in system control, Sponsored by IEE Professional group on Automatic Control 70C-50-A.C.
8. Modelling of paper making, Dr. A.K. Mahalanibis, Dr. A.K. Sinha, and M.M. Godbole, Paper presented at Symposium dn controls system, Bangalore 1974.

9. K.J. Astrom, Control problems in paper making proceedings of the I.B.M. Scientific computing symposium on Control theory and applications, October, 19-21,1974.

10. Eykhoff, P. (1963) Some fundamental espects of process parameter estimation IEE trans. Automatic Control, AC-8, 347-357.

11. Astrom, M and Eykhuff, P. (1971) System identification Automatica 7, March 1971 (1)

12. Tou, J, Modern Control theory MacGraw Hill, 1973.

13. Pulp and Paper Technology by Britt Velt and II.

14. Stochastic State Variable model for a paper machine head box, S.K. Sud M.E., K.K. Biswas, M.Tech., Ph.D., and A.K. Sinha, B.Sc. (Eng) M.Tech. Ph.D., Control and Science Record including automation, Education and Management. Dec. 1977, I.E.E. Transactions.

15. Computer Process Control (Modelling and Optimization) by T.H.LEE, G.E. Adams and W.M. Gaines Willey.