Chapter 2
THE PRESS PROBLEM
An introduction to process description and control systems analysis.

A simple pressing problem has been used for some time as the introduction to the GEMS approach to process analysis. Here, we will use the same process to introduce the approach of a Control Engineer to a new process. First, consider the following extract from the GEMS manual concerning this process.

THE DESIGNER’S VIEW
Consider a system consisting of a tank for mixing pulp and dilution liquor to form a pulp consistency of 2%, followed by a press with 30% outlet consistency. The water used for dilution is a mixture of pressate and fresh water added to the pressate tank (5 cubic meters per ton of pulp). The residual pressate is sewer. See Figure 1 for a flow sheet of this process. Notice that the pulp production rate is 10 ton/hr entering at 8% consistency and 60°C with 5% dissolved solids in the liquor. The temperature of the fresh water is 20°C.

The above operation can be simulated given blocks (models) to represent simple splitting and mixing operations or a combination of both. Assume that SPLIT, MIXER, and DILUTE blocks are available. DILUTE is simply a block that decides how much liquor needs to be split off to dilute pulp to a given consistency and then mixes it with the pulp. The flow diagram of Figure 1 is represented by GEMS block diagram shown in Figure 2. Here, the blocks and streams have been numbered for easy reference.

The process above which is extracted from the GEMS manual is presented in typical "design" terms. We might use our GEMS balance to size pipes and pumps. It is a rather cut-and-dried situation.

THE OPERATOR OR CONTROL ENGINEER’S VIEW
What would it look like in operational terms? It would be something like the design situation, but just enough different to make life interesting. For example, the production rate would vary—sometimes at 10 tons per hour, but just as likely 12: processes are routinely run above their design capacity. Similarly, the consistency and dissolved solids in the feed would vary and there is a high likelihood we would not always know when they changed.

Regardless of the rate or condition of the feed, we would be expected to process it and produce some specific results. In this process, the goal might well be to keep the solids on the high consistency pulp below some upper limit to avoid incurring costs or bad performance in the next process. All processes have built into them adjustments which make it possible to meet the specifications even if the feed conditions are different than the designers contemplated. In this process, it is likely that the fresh water makeup rate and the recycle flow rate of dilution liquor would be adjustable. The operator would use these to compensate for variations in the feed conditions or the press performance.
While many processes run above design conditions routinely, there are usually limits that either cannot be exceeded or ones which if exceeded, put the operation at risk of possible shutdown or other bad situation. In the present process, for example, there might be a feeling that the total flow to the press must stay below some upper limit. Different operators might have different ideas about what the limiting value is.

When there is more than one way to meet specifications, such as a high recycle rate and low makeup rate or vice versa, it may be possible to show that there is a cost or value difference which would make the choice clear. We call the formula which estimates that cost the "objective function". One of the benefits of using simulation in an operational situation is that it is possible to calculate costs and profits and focus the attention of process operators on these, leading to economically better operation.

At this point, we have discussed the process in terms closer to those which the Control Engineer would use.

**INSTRUMENTATION**

The Process and Instrument Diagram is the most widely used tool for describing control situations. Such diagrams are colloquially referred to as "P&I diagrams". A plausible P&I diagram for the press process is shown in Figure 3. It will be seen to be an embellished version of the process diagram shown in Figure 1. The embellishments are the instrumentation "bubbles" and control valves shown, some with interconnections that show details of the basic control scheme supplied with the process.

Before reviewing the instrumentation, it is well to point out here that we will routinely distinguish between basic instrumentation and advanced controls. Our goal is to learn how to develop advanced controls, controls which go beyond merely the question of operating the plant and address the issue of operating it so as to automatically achieve business goals. With basic instrumentation, the job of running the unit to meet business goals is left to the process operator. Advanced controls automate part of the operator's job while usually leaving the total workload largely unchanged. Advanced control is a question of achieving most of the time a quality of operation that only the best operators achieve on their better days. It is not a simple matter to develop successful advanced controls and many processes still operate with basic control only, even in this age when all the controls are achieved with digital control systems.

Figure 3 shows that we measure the consistency and flow rate of the incoming pulp stream. On the right hand side we see that the flow rate of the fresh water to the process is measured and controlled. Also, the flow rate of the recycle stream is measured and controlled (center of the diagram). The flow rate of the sewered stream is measured. All the foregoing instrumentation is strictly basic, although one may well find processes of this sort in actual papermills with rather less instrumentation than that shown in the Figure.

There is one more instrument shown in the diagram: a conductivity measurement on the stream of liquor leaving the press. This provides a way to gauge the amount of dissolved solids left on the pulp, since the liquor with the pulp will have the same dissolved solids
concentration as that in the pressate. Such an instrument is more costly and requires more maintenance than the other instruments on the P&I diagram. It also is less directly related to the quantity we are really interested in than such things as flow meters. Clearly, the relationship between conductivity and solids on pulp would be affected by variations in the chemical makeup of the dissolved solids themselves, for example the ratio of organics to inorganics.

ORGANIZING INFORMATION IN A PROCESS CONTROL SITUATION

In the Chapter 2 appendix an outline to organize information in process control situations is presented. It can be used in the design process or in reviews of existing designs. Here we will assume we are considering a control system design for this situation with the added benefit that we are free to propose some of the process answers that would normally be obtained by interviewing the process supervisors and operators. You should review the outline in the Appendix before reading the discussion below.

MANIPULATED VARIABLES

Step one is to list the manipulated variables of the process. The outline describes the meaning of this term. Given the P&I diagram we are in a position to state that the manipulated variables of an advanced control system would be the setpoints of the fresh water flow controller and the recycle flow controller. With basic control, these are the controls used by the operator, and they could be automated if we understood how.

SPECIAL SENSORS

From the description in the outline and the discussion about the process operation we suspect that the conductivity sensor in the pressate line is a "special sensor".

CONVENTIONAL SENSORS

All the rest of the sensors in our P&I diagram qualify as conventional sensors, but in a more general situation, we will want to be sure to only include sensors that we think will play a role in an advanced control system. Here we count: pulp consistency, pulp flow rate, recycle flow rate, fresh water flow rate, sewer flow rate, for a total of 5 conventional sensors.

LABORATORY DATA INPUTS

Here we must pretend we are the process supervisor and describe any lab tests that are performed routinely by the operators. We would not normally include the once per day or once per week tests run by the technical department in such a list. The reason for leaving those out is that we are considering here using some test as part of a routine control decision, much as we will use the conventional and special sensors. The infrequent rate of
tech department samples and the delay time until the results are available usually preclude their use in routine control decisions. Instead, they are used for longer term process planning.

In our discussion of this process we hinted at a serious interest in the amount of dissolved solids left on the pulp because of the effect it has on the downstream process. Taking that lead, we might conclude that the operators will be grabbing a hand sample of the high consistency pulp at two hour intervals and running some relatively fast lab analysis on it. Their test will probably include both consistency and dissolved solids on pulp. They will use this along with the reading of the conductivity sensor to make decisions regarding the settings on fresh water and recycle flow.

We thus conclude that there are two lab test, product consistency and dissolved solids on pulp, run at two hour intervals in this situation.

DISTURBANCE AND UPSET CONDITIONS

In many ways this is the most difficult aspect of the outline to complete. It usually takes a great deal of familiarity with the process to get a good representation of disturbances and upsets. Our operational description above gave some likely clues. The pulp flow rate and consistency are both subject to variations due to the operation of upstream equipment. Our process is expected to handle what it gets. These are clear disturbances in this situation.

On a longer time scale, a process like this might be subject to variations in its operation as the elements of the press wear out or go out of alignment. This is also a clear disturbance.

As an example of an upset condition, we may learn from the supervisor that "every now and then" the reading on the conductivity sensor "goes wild". Such a response would bear much additional investigation. Here, we may speculate that the incoming pulp has a very unusual solids composition associated with it or it contains some species that the sensor is not able to handle correctly. The issue of upset conditions is too vague to be included effectively without more real information.

We thus conclude that there are three disturbances: pulp flow rate and consistency which can be expected to vary with a period of from one to several hours, and press performance which may vary over a period of one to several weeks.

OPERATOR SETPOINTS

Here we are told in the outline to look for two lists: one before the advanced control is added and one afterward. The before list usually is closely aligned with the manipulated variables; this is the case here. Before advanced control, the operator setpoints are the setpoints of the recycle and fresh water flow controllers.

The choice of setpoints, once the advanced control is installed, is really a key decision in the control systems design. Based on the discussion of process operation above, we can see that a very useful control for this process would have the operator enter the desired
solids on pulp, with the control system itself setting the fresh water or recycle flow setpoints. It is always so that the number of setpoints in the advanced control is identical to the number in the basic control. However, sometimes, the control system contains one or more setpoints that are not visible to the operator. In fact, these are set by management decision.

Here, let us visualize a situation where the operator gets to set the solids on pulp setpoint and management sets a goal of minimum cost of operation at that setpoint. This would constitute a nontrivial control system.

CONTROL STRATEGIES

This is, of course, the subject of the course. In a design situation, the description of the control strategy will get longer as the design proceeds. Here we will provide only the bare bones sketch.

The control will use both feedforward control and feedback control. The feedback will be based on the reading of the conductivity sensor and the laboratory estimate of solids on pulp. The feedforward information will be the pulp flow rate and possibly the pulp consistency if the sensor proves reliable enough. The controller will set the fresh water flow rate and the recycle flow rate.

Such a verbal description should be augmented with functional diagrams of the control system as soon as possible.

CONTROL EQUIPMENT

Nowadays, advanced controls are often implemented directly in the DCS, the Digital Control System used for all control and instrumentation. If the strategy gets elaborate, parts of the advanced control may be implemented on a computer attached to the DCS. This might be an integral part of the DCS, such as the "multifunction module" in a Bailey system or the Applications module in a Honeywell, or an attached micro or minicomputer carrying out a host of advanced functions. Here, we expect to implement the control directly on the DCS.

GOALS

Frequently, I am advised to move the "goals" section of the outline to the top of the outline. While I admit that it could be higher than the bottom, I feel that the goals cannot be stated in sufficiently precise terms until all the first five items in the outline are well established. If goals are "do-able" in the first position, it is because at least that much information has already been reviewed and decided.

Here, the goals are fairly clear. The control system is to reduce the variability in solids on pulp leaving the unit. We should try to quantify how much reduction we will achieve or what tolerance we will hold to in the completed control system. Second, the control
system is to minimize the cost of operation. Again, a quantitative statement will be needed if the cost of the control development is at all high.

For the moment, we will leave it at the two specific goals: reduced variation in solids on pulp; reduced cost of operation.

PROCESS TESTING

The design of a control system nearly always includes a phase in which the characteristics of the process are determined by actual testing on the unit. In this process, we need quantitative information on the effect on solids on pulp of changes in the fresh water and recycle flow rates. The method of testing and the way in which data are interpreted is a prime topic in the course. The simplest tests attempt to characterize the response in terms of "influence coefficients". To gain some familiarity with the approach, a simulation of this process has been developed and is available for testing. The simulation properly represents the nonlinear behavior of this process so the accuracy issues that arise with the influence coefficient approach can be quantitatively assessed.

The screen presented on the spreadsheet emulates a simple screen from the process. However, there is more information presented on the screen than would be routinely available on the process. In any case, the model provides a way to elicit process information much like that which would be obtained by plant testing, although the effort per "data point" is considerably reduced, owing to the speed of response of the model compared to that of the process.

The screen is divided with the left part being used for "manipulated variables". This is a misnomer; the variables are independent variables of the process; only the recycle flow and fresh water flow are true manipulated variables of the process; however all may be considered manipulated variables of the simulation.

The right side of the screen is labeled "responses" and the results of tests will be recorded here.

<table>
<thead>
<tr>
<th>MANIPULATED VARIABLES</th>
<th>RESPONSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulp feed rate (tons/day)</td>
<td>200</td>
</tr>
<tr>
<td>Feed consistency (%)</td>
<td>8</td>
</tr>
<tr>
<td>Feed dis. solids (%)</td>
<td>5.5</td>
</tr>
<tr>
<td>Outlet consistency (%)</td>
<td>30</td>
</tr>
<tr>
<td>Fresh water (ton/ton pulp)</td>
<td>6.831</td>
</tr>
<tr>
<td>Dilution consistency (%)</td>
<td>2</td>
</tr>
<tr>
<td>Flow to press (mt/hr)</td>
<td>408.3334</td>
</tr>
<tr>
<td>Cons. to press (%)</td>
<td>2</td>
</tr>
<tr>
<td>Solids on pulp (kg/ton)</td>
<td>90.51285</td>
</tr>
<tr>
<td>Recycle flow (mt/hr)</td>
<td>445.8139</td>
</tr>
<tr>
<td>Spent liq. flow (mt/hr)</td>
<td>133.3139</td>
</tr>
<tr>
<td>Spent liq. solids (%)</td>
<td>3.382053</td>
</tr>
</tbody>
</table>

We may take the results above to represent the "nominal operating point of the plant". Then, to learn something about the response of solids on pulp to the disturbance variable outlet consistency, we would enter a different value than 30% in the outlet consistency (simulating a press that is not running as stable as it should) and record the change in solids on pulp. The following screen illustrates this.
Here, the consistency has been reduced by 5% (a big change for sure) and the solids on pulp went up to 115.9 from its nominal value of 90.5. We are in a position to estimate the influence coefficient between the disturbance variable outlet consistency and the variable to be controlled, solids on pulp. We obtain

\[
\frac{\text{solids on pulp}}{\text{pulp rate}} = \frac{(115.9 - 90.5)}{(25 - 30)} = -5.08
\]

If, for example, the specification on solids on pulp is that it must be below 100, we realize that some control action will be required whenever the consistency goes below about 28%.
Figure 1. Process diagram of washer press

Figure 2. GEMS diagram of washer press
Figure 3. P&I diagram of the washer press
Chapter 2 Appendix

OUTLINE FOR ANALYZING CONTROL SYSTEMS

A one page assessment of a control system using this outline provides a concise summary. For careful work, the individual items should be expanded upon, using one or more pages per item to lead to a full system description.

1. MANIPULATED VARIABLES of the control system.

List the key flows, valves, speeds, etc. which are set by the advanced features of the control system.

Manipulated variables are listed first because there are usually only a small number of them and they are the clearest indication of the scope of the control system.

2. SPECIAL SENSORS

Usually analytical instruments, e.g., pulp brightness. Colloquially, special sensors cost a lot and don't work too well.

3. CONVENTIONAL SENSORS

By conventional sensors we mean flows, pressures, temperatures, levels, and the like. Find all that are closely tied into the advanced control strategies. NAME THE SPECIFIC POINTS OF APPLICATION, e.g., "stock flow rate", "headbox level".

Typically, there are three or fewer conventional sensors playing a role in a well designed control system per manipulated variable.

4. LABORATORY DATA INPUTS

These are necessary to supplement special sensor inputs. List the key items; assess how frequently they are run and how closely they are tied into the control strategy.

5. DISTURBANCES AND UPSET CONDITIONS.

Disturbances are the causes of variation in the uncontrolled process. Upset conditions are modes of process behavior that make the process difficult to operate.

6. OPERATOR SETPOINTS.

Two lists should be prepared: one corresponding to the operator setpoints before the advanced control system is installed; the second corresponding to conditions after the advanced control is in place. A good advanced control system leads to simpler and more goal oriented setpoints for the operator with the control system handling the details. Comparison of the two lists helps determine if this has really happened.

7. CONTROL STRATEGIES.

First list the control strategies, then develop the details, preferably using P&I diagrams, functional diagrams, block diagrams, flow charts, etc. Try to avoid vague statements which imply more than the control system can actually deliver. In a serious study or design application of the "outline" this item can grow to considerable length.
8. CONTROL EQUIPMENT.
Computers, displays, operator consoles, software, and special aspects of the installation can be covered here.

9. GOALS (especially ECONOMIC).
Process objectives can be briefly reviewed and the way the control system helps to achieve these presented. Usually the control system serves to reduce variability in the process: state where and how much. Show how this translates into ECONOMIC TERMS and make a quantitative estimate of cost savings.

Some people think that "goals" should be listed first in an outline. The concept here is that all too frequently, goals are stated in vague "mom and apple pie" terms. By putting them last, one has set forth the actual resources available to the control system (manipulated variables, special sensors, control strategies, etc.). These are sobering realities; there is more tendency to state achievable goals.