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Title: SIXTH QUARTERLY REPORT - THREE PHASE CENTRIFUGE CONTROL SYSTEM

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Los Alamos
NATIONAL LABORATORY

Sixth Quarterly Report – Three-Phase Centrifuge Control System

By

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Review

Los Alamos National Laboratory has been asked to build an intelligent setup and control system for a three-phase centrifuge that was designed and is operated by Centech Inc. of Casper Wyoming. The Los Alamos work is an effort to make it possible for non-experts to operate the Centech machine. The reason for the intelligent control system is that only Neal Miller, the inventor of the centrifuge, can operate it in an optimal manner. Without the control system this "one operator" limitation reduces the potential impact that this centrifuge technology will have on US oil field and refinery environmental problems. The three-phase centrifuge is a portable device that is used for cleaning up oil field and refinery wastes. It is also being considered for in-line processing for both refinery and oil field operations. The centrifuge, in addition to supplying clean up services, recovers pipeline grade oil from the wastes. Therefore it has the potential to help the US, somewhat, with oil supply problems.

Accomplishments —first quarter-- FY01.

This is actually the sixth quarter of the project.

This quarter we were only able to spend two weeks in the field with Centech Inc. One week was spent in Edgerton Wyoming just North of Casper and last week (December 11-15) in Evanston Wyoming. Each job had it's own unique problems.

Even though, we thought that we had all our equipment problems solved last quarter, we continued to be plagued with spurious measurements. This time we did find some serious damage to the feed BS&W meter that has been corrected and also a bad coaxial cable to the flow meter that has been corrected. Everything looks good now. One problem that we have with the sensors is that the entire feed-forward system is not running yet. Therefore Neal isn't observing the conditions constantly. This is because he is not really using the meters. The test runs that Los Alamos makes is where the problems show up, under constant heavy use. Another problem seems to be that these sensors were probably not designed to take the abuse that comes with moving the centrifuge from place to place and running under extreme temperature conditions. In spite of this things seem to be working ok now. We were set to test our systems when we went to Evanston last week, but Neal was having a hard time splitting the very heavy, " dead" (no light ends), paraffinic oil in very cold weather. The centrifuge was up and down and we didn't have any runs long enough, the entire week, to test our control system.

We have had some bad luck in testing our control system, but we have accomplished quite a bit in building it. It is very frustrating, not to be able to test and tune it. Here is a list of the good things that have happened this quarter:

- We have expanded the fuzzy soft sensor to include feed temperature. This means three times as many rules.
- We have expanded the neural-net soft sensor to include feed temperature as well. (We need to compare these two soft sensors in some actual runs to determine which one is best, or if a combination of the two works even better.)
- We have completed a physical based model of the feed system. (This model is designed to enhance or fill in any "holes" in Neal's knowledge. Neal has a very good experience based knowledge of a myriad of situations, but the soft sensor now has 135 rules which is a little bit too much knowledge to extract from one human. This is another reason for re-introducing the neural net program.)
- We have developed a "Fuzzy- statistical process control (SPC) technique" for combining the new feed-forward controller with the existing feedback control system.

Figure 1 shows the new modified Soft-Sensor-Control-System.

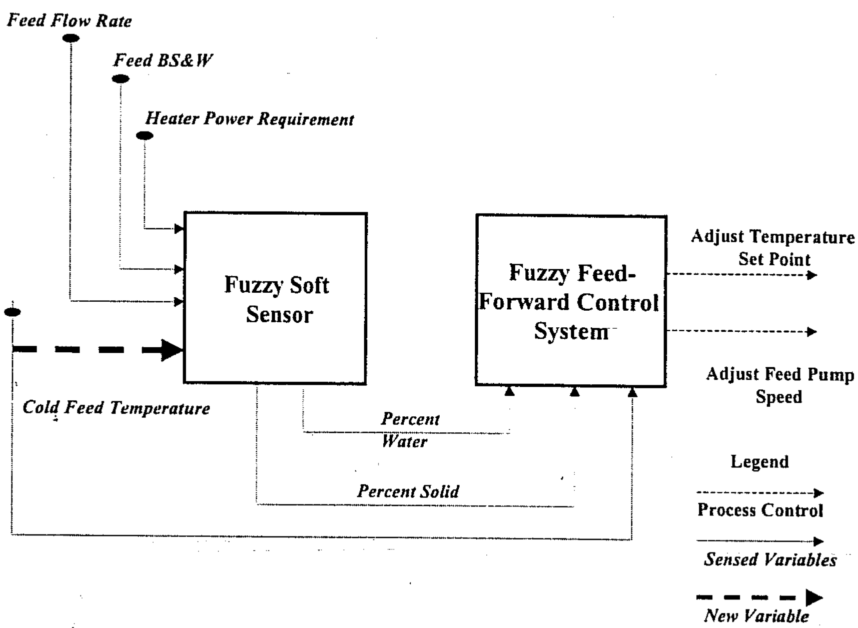

Figure 1. Updated diagram for the fuzzy feed-forward control system and fuzzy soft sensor (with new temperature measurement to the soft sensor.)

Figure 2 shows the block flow diagram for the combined feed-forward and feedback control systems. This system includes the "fuzzy-statistical process control (SPC) filter" and the conflict resolution program. The feed-forward controller is used to detect large changes in the feed that require process control adjustments before a major problem is encountered with the centrifuge. This is very important for many of Centech's operations, like stratified layers of material in the feed tanks or ponds. The fuzzy-SPC filter is required because the feed signals are quite "noisy" and we don't want to make changes in advance unless they are truly required. The feedback control system is continually working, making adjustments to the process after a product change has been detected. The conflict resolution portion of the controller makes sure that corrections to the process due to both feedback and feed-forward conditions are compatible with the goals of both controllers. This is usually dominated by the feed-forward portion because this is an event that is in the future, not in the past, and only significant changes are allowed because of the filter. However, some weight must be given to current action governed by the feedback controller.

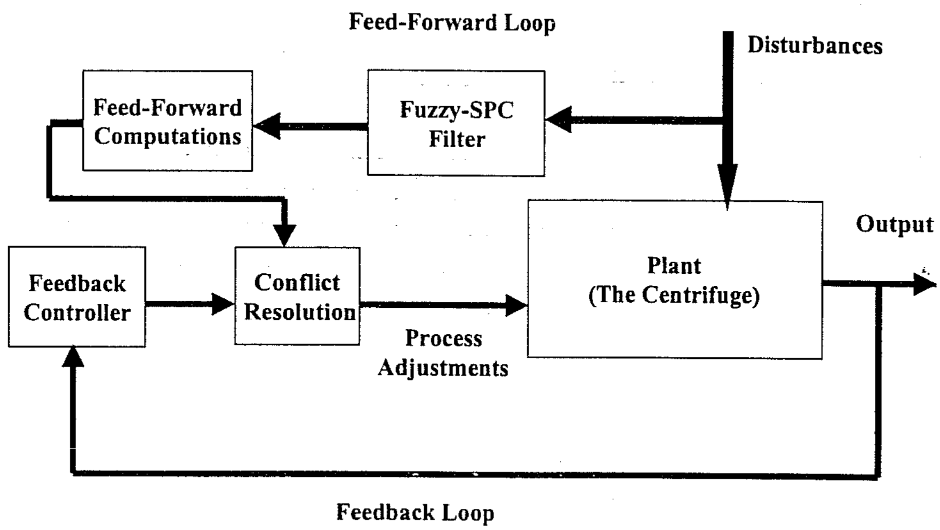

Figure 2. Block flow diagram for the combined feed-forward and feedback control systems.

The fuzzy-SPC filter is a rather unique trick to filter out the sensor noise, but it is quite appropriate for the centrifuge since the system time constant is in the order of minutes rather than seconds. The technique is compute intensive and probably would be too slow for something like an airplane control system. The idea is based on the principle of the

SPC X bar-R chart. It uses fuzzy logic because several variables are treated rather than one. Examples of X bar and R charts are given in figures 3 and 4 respectively.

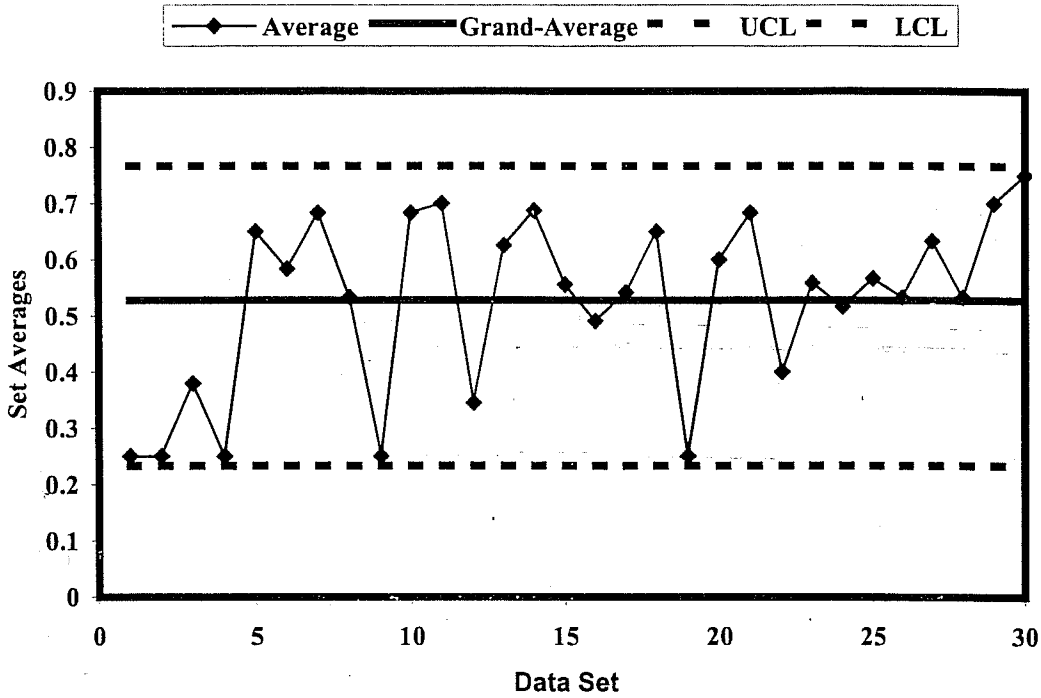

Figure 3. The X bar chart for the fuzzy SPC filter.

The X bar chart works like this:

- Data sets consisting of five points are taken 10 seconds apart of a quantity called "feed-change-magnitude" (Explained shortly).
- The average and range of each set are computed.
- After thirty sets (five minutes), the average-average or grand average and average range are computed.
- The upper and lower control limits are computed from statistical tables for both the X bar and R charts (figures 3 and 4.) These control limits are essentially three standard deviations above and below the mean lines.
- If X bar (average set) data stray beyond the control limits, the "feed-change-magnitude" is significant and the fuzzy soft sensor and feed-forward control is implemented.
- If the range data go beyond the control limits, it usually means that sensor difficulties are coming into play.

The X bar and R charts for this report were generated with the physical model of the feed system that we have just completed, a random number generator, and our fuzzy system for the fuzzy SPC filter. Figure 3 shows that the model feed has not changed significantly, but the last data point is heading for the upper control limit. Figure 4, the range chart needs some work because many of the data points are hanging at the upper control limit. Since we are not using real sensors in the simulation, this doesn't mean too much. But we will look harder at this chart to make sure the calculations are correct.

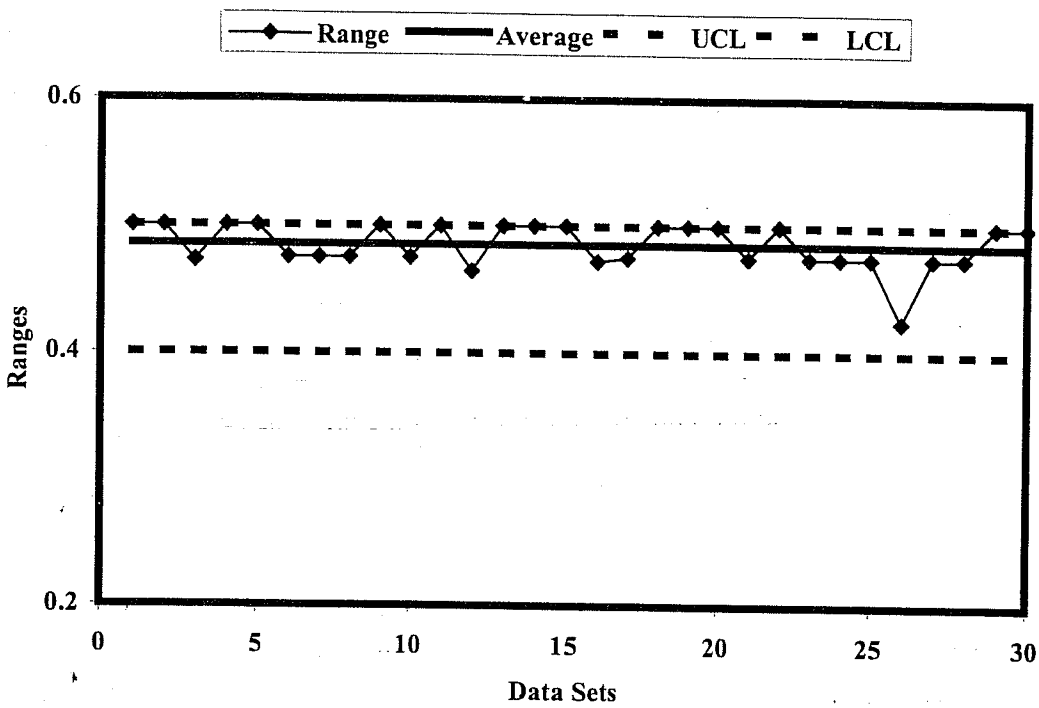

Figure 4. The R chart for the fuzzy SPC filter.

The "feed–change-magnitude" is computed with a fuzzy rule based system. If we look at figure 1, we see that four input variables are used in the soft sensor to compute two output variables, percent change in water and percent change in solid. All four of those variables, cold feed temperature, feed flow rate, feed BS&W, and feed heater requirements have measured random noise in them and they are not independent. This became quite apparent with the new physical model and the cold feed temperature and that is why that variable had to be added to the soft sensor rule base. So a change in say feed temperature might cause a change in flow rate that is not caused by a physical property change and therefore no change in the water or solid content. Our rule base takes this into account. There are sixteen rules, four input variables, eight input membership functions, one output variable and five output membership functions. The rules are of the form:

If **Cold Feed Temperature Change is...**and **Feed Flow Rate Change is...** and **Feed BS&W Change is...** and **Feed Heater Requirement Change is...** Then **Feed-Change-Magnitude is...**

All of the input membership functions are binary—**Positive** and **Negative Changes.** They are normalized between –1 and 1. The output has five membership functions **Large Positive, Small Positive, Zero, Small Negative, and Large Negative.** These membership functions are normalized between zero and 1 as can be seen in figure 3. The range 0 to 1 on the output is a prejudice of the authors for liking to use only positive numbers for output functions.

Other techniques are available for filtering the input and sensor noise. We feel this one is the best. It provides us with a technique for withholding a significant process change unless it is really needed. It provides us with a means to determine if the process feed is changing significantly, because we are making new control charts every five minutes. If the average sample mean or grand average continues to change over a period of time we need to know this and we can determine this from the charts. If the changes are slow enough they can be handled with the feedback system entirely. More abrupt changes will require the feed-forward system intervention. We can also determine changes in sensor noise and hopefully determine in advance if we are having sensor problems. (Which we have had plenty of in the past.) Note that once the initial control chart has be constructed (five minutes into the run), we can sample and control as much as we want. The continuing control chart upgrade goes on in the background.

On paper, with the simulation, this fuzzy SPC filter works great. It has been constructed with the physical model and data that have been collected while working on the centrifuge system. But this system like all of the rest needs to be tested and modified using real data when the centrifuge is running correctly and the sensors are functioning correctly. Hopefully this will happen in our next trip to Wyoming.

One problem that we may run into when we are working with the real system is some auto-correlation, since the system is essentially continuous. This means that some changes will have to be made possibly in time between samples or even sample size.

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Dear John:

Enclosed, please find our Sixth Quarterly Report—Three-Phase Centrifuge Control System. I am sorry that we are again late. I hope things are going well for you.

Sincerely,

Jerry

W. J. Parkinson