A SAMPLED-DATA JUICE FLOW CONTROLLER FOR A TWO-TANDEM MILL

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ABSTRACT

Use of batch scales to weigh incoming mixed juice introduces flow pulsations into the system which complicate subsequent control of juice pH and temperature and degrades clarifier operation. Dead-band control of the receiving tank level is only a partial cure for the problem. Control of the juice flow from two milling tandems is particularly difficult because intervals between scale and tank dumps from the two tandems can vary widely causing large fluctuations in flow.

A sampled-data control system for a two-tandem mill was developed by the authors which largely avoids the disturbing effect of two scale tanks dumping in rapid succession. When the interval is less than a pre-specified minimum, the controller simply ignores the level change resulting from the second dump, maintaining flow rate at the level established by the previous dump. The controller utilizes solid-state operational amplifiers and discrete logic elements of the CMOS type to perform the control functions. It has now been in service at a Hawaiian sugar factory for over a year and has resulted in a substantial improvement in juice flow uniformity with attendant improvements in pH control.

INTRODUCTION

A uniform flow of mixed juice from the milling train to the boiling house greatly simplifies control of juice pH and temperature and results in better juice clarification. Obtaining a uniform juice flow when cane flow is well regulated and juice flow is measured with a continuous flow meter (or not at all) is not particularly difficult. When the incoming juice is measured in batch scale tanks, however, the flow is disturbed by the filling and discharging of the scale tanks. The level of the receiving tank assumes a saw-tooth shape (Fig. 1); and any attempt to control itConventionally propagates the flow irregularities through the heater and clarifier.
In the Hawaiian sugar industry, mixed juice rather than cane is the starting point in the factory balance. Because batch scales are used in all factories, continuous flow meters not being considered sufficiently accurate for balance purposes, fluctuating juice flow is a situation common to all factories. A proportional plus integral (PI), “deadband” level control system which allows some variability in level, has often been employed to reduce these flow fluctuations. With integral (reset) action, however, reset “windup” cause overshoot in tank level after a mill shutdown; in extreme cases the juice receiving tank may overflow before control is reestablished.

Since the flow pattern is intermittent, it seems logical that an intermittent system of measurement and control would be a better solution to the problem than a continuous system.

In 1971, Lui developed a sampled-data control system for mixed juice flow for a single-tandem mill having one or two scale tanks (Lui1). In this system, the level of the receiving tank was sampled at each dump of one or the other of the scale tanks. The level at that moment was then used to establish the controller output (proportional mode only) until the next scale dump occurred. Factory tests of this system proved it to be highly successful in smoothing out the irregularities in flow.

Control of a two-tandem mill with each tandem delivering juice to two scale tanks presents a more complicated control problem. It would only be coincidence if the two mills were to deliver juice at exactly the same rate for any length of time. Inasmuch as the rates are different, the intervals between dumps from the scale tanks for the two tandems mill have a beat frequency similar to that for any two processes occurring at different frequencies. Thus, at times, the interval between the discharge of a tank from one tandem and
When a tank from the other will be 0 or almost so, followed by a long interval in which no dumping at all occurs. At other times, the intervals will be longer and more uniformly spaced. The control system, to be successful, must be able to recognize these differences in dumping patterns and not be misled by the large changes in receiving tank level that occur when two scale tanks are dumped at the same or almost the same time.

This paper describes a two-tandem flow control system designed and built at the Hawaiian Sugar Planters' Association (HSPA) and the results obtained with this system in factory installation.

DESCRIPTION OF CONTROL SYSTEM

General comments

The two-tandem flow controller is a hybrid, essentially solid-state system, hybrid in that both analog and digital elements are used in performing the control functions, essentially solid-state in that integrated circuits are used for all of the computational elements and most of the digital logic. A few of the switching functions, such as the inputs from the scale-dump switches, are handled by conventional electromagnetic relays.

Schematic diagrams of the juice weighing system and of the controllers are shown in Fig. 2 and 3. The actual factory sampled-data controller installation is shown in Fig. 4, while Fig. 5 and 6 show typical juice flows with the HSPA deadband and controllers in operation, respectively.

Operation of juice weighing system

The mixed juice weighing system, shown in Fig. 2, consists of two holding tanks, four batch scale tanks, a receiving tank, two juice pumps, and a pneumatically operated control valve. The control equipment for this system includes: (1) the HSPA two-tandem controller, (2) a relay box which acts as an interface between the controller and the various switch and microswitch inputs from the scale tanks and mill tandems, (3) pressure-to-voltage and voltage-to-pressure transducers to convert signals entering and leaving the controller respectively, (4) a liquid level detector consisting of a bubbler and differential pressure transmitter, and (5) a pneumatic recorder to record the output of the controller.

Juice from the A-tandem is pumped to one of the holding tanks, and that from the B-tandem to the other. Each holding tank supplies two scale tanks which fill and discharge alternately into the receiving tank. A micro-switch on each scale tank closes when that tank starts dumping, actuating a relay in the controller input circuit.

The receiving tank provides surge capacity between the scale tanks and the juice heaters and clarifiers. Either one or both of the pumps can be used to pump the juice through the juice heaters to the clarifier. The liquid
Mixed juice from A tandem
Mixed juice from B tandem
Signal from A + B tandems

Holding tank
Holding tank

Relays and Switches

HSPA controller

DB
P/ET

Differential pressure transmitter
Pneumatic to electrical transducer

MSW
Electrical to pneumatic

E/P
Pneumatic to electrical

U
Pneumatic line

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Juice flow

Legend:
JB - Junction box
D/PT - Differential pressure transmitter
P/ET - Pneumatic to electrical transducer
MSW - Microswitch
E/P - Electrical to pneumatic
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Pneumatic line
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Electrical line

FIGURE 2. Proposed mixed juice flow control system
FIGURE 3. Block diagram of two-tandem juice flow controller

Notes:
1. Timer is reset each time a scale tank dumps.
2. Controller update signal generated only when output of dump interval timer exceeds minimum interval setting.
3. Output bias is halved when either tandem stops.
level in the receiving tank is sensed by the bubbler. The level signal, generated by the differential pressure transmitter connected to the bubbler, is converted into a voltage signal for input to the controller. The voltage output of the controller is then converted back to a pneumatic signal for transmission to the control valve and recorder.

**Operation of controller**

The function of the controller is to minimize the disturbances in flow from the receiving tank caused by the fluctuations in tank level that occur each time one or more of the scale tanks are dumped. This must be accomplished of course, without either overflowing the receiving tank, or running it dry.

**Generation of error signal.** Referring to Fig. 3, the level signal from the receiving tank is compared with the set point value (usually set around 50% of tank height), and the error signal generated is transmitted either to a proportional control element, or to an integrator, depending on whether the controller is set in the proportional or in the integral mode. (In the proportional mode the error is multiplied by a constant; in the integral mode, it is multiplied by a constant and integrated with respect to time.)

**Generation of controller output.** The output from whichever element in use is transmitted to a track-and-hold circuit which is in the "hold" mode most of the time, but which is periodically switched to the sampling mode by a dump-interval comparator described in the next paragraph. The output of the track-and-hold circuit represents the most recent correction signal to the controller output. It is transmitted to the output which is provided with adjustments for both controller gain and bias. Gain is adjustable from the controller panel; output bias is controlled by the number of mill tandems in operation, being halved when either tandem stops. The output from this unit is transmitted to the voltage-to-air transducer for conversion into the pneumatic signal which will control the valve position.

**Operation of dump interval comparator.** As mentioned previously, the track-and-hold unit is controlled by a dump interval comparator. The dump signals which are generated when any of the scale tanks begin dumping into the receiving tank are transmitted to the controller through the relay box. Any one of these signals starts the scale tank interval timer. If the interval timer output reaches a pre-set value (the minimum dump interval), a switching circuit is latched in readiness for operation when the next scale dump actually occurs. The controller output is then updated when the next scale dump occurs by switching the track-and-hold circuit from "hold" to "track" long enough to pick up the latest correction signal. (The integrator is also reset if the controller is in the integral mode).

If the next scale dump occurs before this minimum dump interval is reached, however, the switching circuit is not latched and no update of controller output occurs. The dump interval timer is then reset and starts anew to measure the next dump interval.
The purpose of the scale tank dump interval timer and the minimum dump interval setting is to identify scale dumps that occur within a short time of each other and ignore the effect that these closely spaced dumps would have upon the controller output if they were used to update the output. Without this ability, juice flow would be unnecessarily disturbed by the large change in receiving tank level that occurs when dumps are closely spaced. It is essential, of course, that the minimum dump interval settings be matched to the physical characteristics of the system (flow rates, tank sizes, etc.) so that they are long enough to ignore dumps closely spaced but not too long to ignore all the dumps.

Function of output bias. The output bias is a voltage which is added to the level correction signal to provide the controller output signal. The bias is field-adjustable and is sized to be roughly equivalent to the average juice flow expected from the two mill tandems. When one or the other of the tandems stops, the flow, of course, is cut approximately in half and less bias is required than before. While one could allow the feedback loop in the controller to sense the change in flow and make the appropriate changes in the controller output, better control is obtained by using a bias shifting circuit to transmit the effect of the reduced inflow to the controller output as soon as this change occurs.* Some of the change in outflow thus occurs immediately.

Controller hardware

The analog portion of the controller consists of three model 142501, and two model 142101 Teledyne-Philbrick operational amplifiers and a Teledyne-Philbrick model 4856 sample-and-hold amplifier. The digital circuit elements include AND and OR gates, NOR latches, and a decimal counter. MEKO-type 56-H24-30 solid state relays driven by inverting buffers are used to carry on the actual switching operations, a Schmidt trigger is used to eliminate contact bounce in resetting the controller at the start of operations. All digital integrated circuit elements are of the complementary metallic oxide semiconductor (CMOS) type.

The entire controller circuit is mounted on a one 4½-inch x 6½-inch circuit board with the direct current power supply mounted on a second board. The controller enclosure is sealed with a silicone “rubber” material to minimize the entry of dust and dirt into the unit.

RESULTS

The controller was installed at the factory of The Lihue Plantation Company, in July, 1977. After a few initial startup problems, it has been on-line ever since except for a period when the power supply board worked loose from the connector. This problem has since been corrected.

* Actually, control action could be further improved by interposing an RC circuit between the bias signal and the controller to obtain a gradual change in the controller output. This was not tried, however.
The two controller output charts shown in Fig. 5 and 6 represent approximate juice flows with the deadband controller and with the HSPA controller, respectively. The flow indications were reversed in the sense that the closer the line was to the center of the chart, the higher the flow (a result of the valve being reverse-acting).

In the deadband system (Fig. 5) flow fluctuated widely as a result of mill stops and the beat frequency effects from the different flow rates for the two tandems.

The improvement in flow uniformity with the sampled-data control system was quite dramatic. Factory personnel have reported that as a result of the improved flow, pH and temperature control of the juice entering the clarifier were improved. Steam flow to the juice heaters was also more uniform.

CONCLUSIONS

A sampled-data controller is inherently more suitable for controlling juice flow from a batch weighing system than a continuous controller.

When a two-tandem system is to be controlled, it is essential to eliminate the wide swings in flow that occur when the scale tank discharges from the two tandems are in step.

A sampled-data controller with provisions for ignoring those scale dumps that occur too close together works quite well in controlling flow from a two-tandem system.

REFERENCE

1. Lui, E. J. Private communication.

1 Since flow is not exactly proportional to control valve pressure because of the effect of receiving tank level; however, this effect is relatively small.
UN CONTRALOR DE DERRAME DE JUGO DE DATOS COMO MUESTRA PARA EL MOLINO TWO-TANDEM*

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RESUMEN

Uso de basculas para pesar en cantidad los entrantes jugos mixtos introduce pulsaciones de fluir al sistema que complica el control subsiguiente del jugo, pH y temperatura y degrada la operacion de clarificar. El control “deadband” del nivel del tanque recibidor es solo una cura parcial para el problema. Control del fluir del jugo de dos molinos en combinación (tandems) es particularmente dificil porque intervalos entre la escala de tanques de descargue de los dos “tandems” pueden variar mucho causando grandes fluctuaciones en el derrame o fluir del jugo.

Una muestra del sistema de control de datos para molinos en combinaciones de dos (tandem) fue desarrollado por los autores que evita mucho los efectos molestos de la escala de dos tanques descargando en rapid sucesion. Cuando el intervalo es menos que el minimo pre-especificado, el contralor simplemente ignora el cambio del nivel, resultando en un segundo descargue, manteniendo el tranco de fluir (rate flow) al nivel establecido por el descargue anterior. El contralor utiliza “solid-state” amplificadores operacionales y elementos logicos separado del tipo CMOS para hacer las funciones del control. Ya hace un año que esta en servicio en una fabrica de azúcar Hawailiana y ha resultado en un mejoramiento substancial en la uniformidad del derrame del jugo con acompañado mejoramiento en el pH y como en el control.

* Publicado con permiso del Director como papel No. 000 en el “Journal Series” de la Estación de Experimentos de la Asociación de Arrendadores de Azúcar Hawailiana. 1934