Condensate Clean Up Control System with Distributed DDC

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ABSTRACT

In the operation of Condensate Clean Up System in BWR plants, regeneration intervals of the demineralizer are not equal and there is no base to determine the interval which is usually decided by operator's experience. Regeneration of resin is, therefore, sometimes performed too early remaining much capacity of resin unused.

In order to improve such operation mode, following approach was made

(1) to equalize the operating time difference of sequential two demineralizers (t1-t0, t2-t1, ..., in Fig. 2) which is called as operating intervals in this paper.

(2) to control initial flow for newly connected demineralizer as new one has less flow, resulting higher flow which makes further unbalance in flow between new and old demineralizers in parallel operation

The economic and efficient operation of this system, along with the reduction of radioactive resins, and safety supervisory function, can be achieved by the distributed DDC with microprocessor in the direction of above approaches.

1. INTRODUCTION

The current Condensate Clean Up System in BWR plants consists of multi-demineralizers as shown in Fig. 1.
The system is not controlled in the flows of demineralizers and their operating intervals are decided by operator's experience. Unequal flows is resulted as new demineralizer has higher flow than the old ones.
If their operating intervals are very short, the operator regenerates the demineralizer by manual control in order to continue its operation, so they are regenerated with remained capacity.

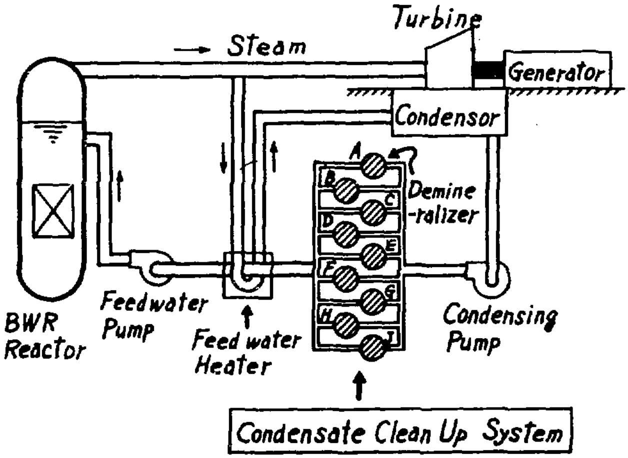


Fig. 1 Condensate Clean Up System

In addition, its system is usually operated with one spare of demineralizer for regeneration to decide the termination at which the first demineralizer should be switched to spare for regeneration and for this purpose, and the operator calculates the ion exchange quantity [difined as the product of conductivity difference ($\mu\mho$/cm) between inlet and outlet of the demineralizer and flow (ton)] by himself which is considered to be troublesome and exhausting work for the operator.

The current operating condition of demineralizers (8 normally in operation, 1 standby) is shown in Fig. 2. The each operating interval of them, (t1-t0, t2-t1,..., t8-t7), is not equal.

As each intervals is not controlled, the effect of increase or decrease in their flows and inlet conductivities, that is, the distribution of their ion exchange quantities cannot be equalized by this operation mode. Therefore, except the random average disturbance, operating intervals of demineralizers are not equal. If any interval of two sequential demineralizes was very short, the latter demineralizer should reach the end point before the former has finished off its regeneration. In such a case, conductivity of clean up water returned to the reactor becomes higher which will give unfavorable effect to the plant operation.

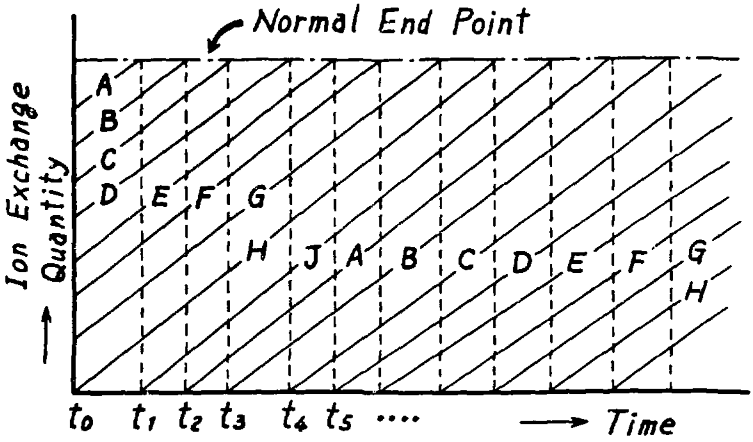


Fig. 2 Time VS Ion Exchange Quantity

In order to avoid such condition, it is best that each of their intervals at the end point should be controlled to be equal.

Then, the system will be safety operated with higher end point by making use of their remained capacities within the limit of its outlet conductivity than the current operation mode.

The ion exchange quantity, M(t), is defined as

$$M(t) = \int_{t_0}^{t} [D_I(\tau) - D_O(\tau)] \times Q(\tau)dt \text{ ———————— } (1)$$

where,

t : time
t_0 : time beginning to connect with Condensate Clean Up System
$D_I(\tau)$: inlet conductivity of demineralizers
$D_O(\tau)$: outlet conductivity of demineralizers
$Q(t)$: flow of demineralizers

In case that the ion density of the water at the inlet of demineralizer is increased, it is difficult to decide whether its effect is due to the increase of flow or inlet conductivity. It is not easy, therefore, to prove the effect in practice of the flow control on the equalizing operating intervals. Then, the concept shown in Fig. 3 has been adopted instead of operation mode shown in Fig. 2.

The lines, a, b, ... h, show the integral flows of 8 demineralizers.

Here, they should be normally regenerated at the end point, Q(t)=Qm. If $D_1(t)$ is increased stepwise, the end point, Qm, depended on the inlet conductivity, should be changed to the line (1) and (2) as shown in Fig. 3.

The gradient of lines, a, b, ..., h, shows the flows of demineralizers.

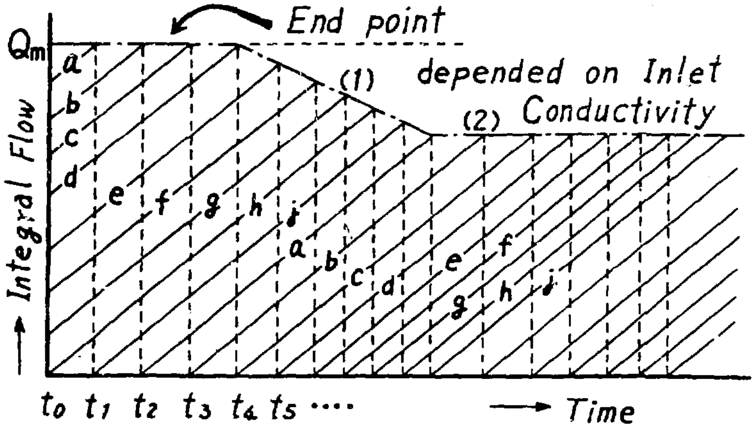


Fig. 3 Time vs Demineralizer's Flow

In this concept, we can express the two process variables, the conductivity (µ℧/cm) and integral flow (ton), separated. Therefore, the following analysis can be made in sample manner.

2. SYSTEM ANALYSIS

Even in the case that the inlet conductivity of demineralizers was increase, their outlet conductivities are practically constant. From equation (1)

$$M = (D_I - D_O)Q = [D_I - D_O(M)]Q$$

$$\left.\frac{dM}{dt} = -QP_O(M) + F\right\} \text{—(2)}$$

where, $F = Q_I \cdot Q$

By the numerical analysis of the equation (2), M(t), Characteristics of Time vs Ion Exchange Quantity in Fig. 4 are obtained.

We can consider that the actual characteristics are nearly equivalent to the straight line.

So, we can set the assumption as follows.

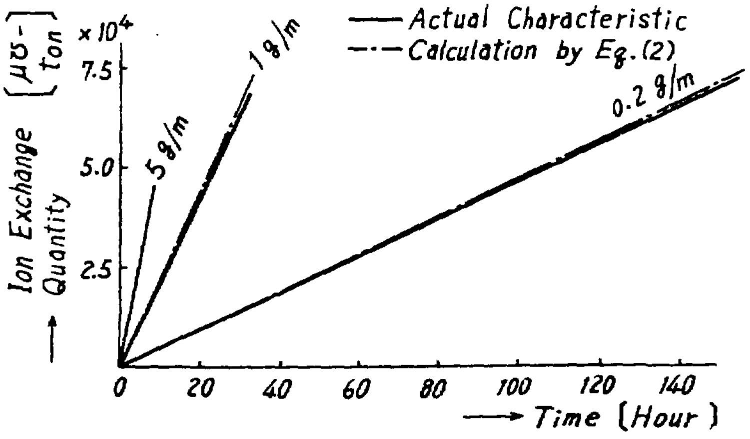


Fig. 4 Characteristics of Time vs Ion Exchange Quantity

THE OUTLET CONDUCTIVITY IS CONSTANT IN CHARACTERISTICS OF ION EXCHANGE QUANTITY

Under this assumption, as the right side of equation (2) is constant, Characteristics of Ion Exchange Quantity respect of time is the straight line in the domain which the regeneration is possible, except the large scale leakage of sea water. Therefore, Time vs Ion Exchange Quantity is equivalent to Time vs Integral flow.

Considering above correlation of Time vs Integral Flow, control of the flow of the demineralizers is the most appropriate for efficient operation of the system. Concept for this operation is that:

(1) for the demineralizer closer to the end point of its capacity should have a maximum possible flow.

(2) for the demineralizer which has much capacity remained should have a lower initial flow to give wider flow control range.

So we adopt the control approaches as follows.

i) Minimize initial flow for newly connected demineralizer

ii) Maximize the flow of other demineralizers

This operating intervals for all demineralizers.

General Theory

Nomenclatures used in this paper are as follows.

M: Life of a demineralizer (constant)

a: initial flow
b: Maximum flow
T: Operating interval of demineralizers

i: Operating interval number of demineralizer

K: Number for a group of 8 demineralizers.

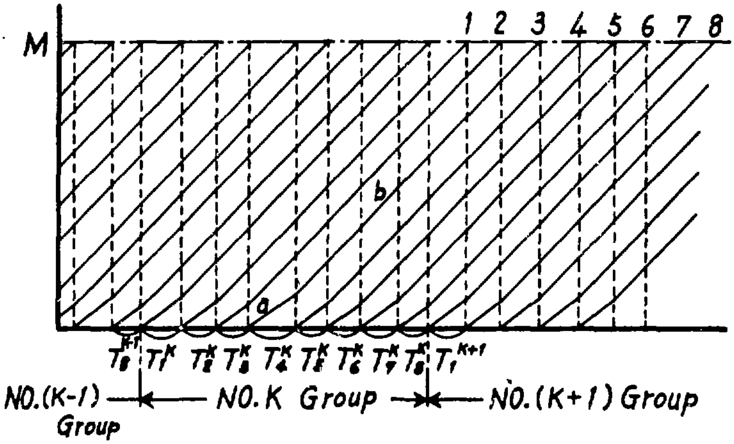


Fig. 5 General Analysis Configulation

For the characteristics of first demineralizer in the group K, we obtain

$$aT_1^k + b\left(\sum_{i=2}^{8} T_i^k\right) = M \quad (3)$$

For the characteristics of the second one,

$$aT_2^k + b\left(\sum_{i=3}^{8} T_i^k + T_1^{k+1}\right) = M \quad (4)$$

from equation (3) and (4),

$$T_1^{k+1} = \frac{a}{b}\, T_1^k + \left(1 - \frac{a}{b}\right) T_2^k \quad (5)$$

The some procedure will be applied for other demineralizers and similar seven equations will be obtained as follows.

$$\left.\begin{aligned} T_2^{k+1} &= \frac{a}{b}\, T_2^k + \left(1 - \frac{a}{b}\right) T_3^k \\ T_8^{k+1} &= \frac{a}{b}\, T_8^k + \left(1 - \frac{a}{b}\right) T_1^{k+1} \end{aligned}\right\} \text{———} (6)$$

By defining $X_1^k = T_2^k - T_1^k$

from equation (5) and (6)

$$X_1^{k+1} = \frac{a}{b}\, X_1^k + \left(1 - \frac{a}{b}\right) X_2^k$$

$$X_7^{k+1} = \frac{a}{b}\, X_7^k + \left(1 - \frac{a}{b}\right) X_8^k$$

$$X_8^{k+1} = \frac{a}{b}\left(1 - \frac{a}{b}\right) X_1^k + \left(1 - \frac{a}{b}\right)^2 X_2^k + \frac{a}{b}\, X_8^k$$

Also, by defining $X^k = (X_1^k, X_2^k, \ldots, X_8^k)^T$ and by expressing $a/b=g$, following time invariant discrete equation is obtained.

$$X^{k+1} = \begin{bmatrix} g & 1-g & 0 & \cdots & \cdots & 0 \\ 0 & g & & \ddots & & \vdots \\ \vdots & 0 & \ddots & & \ddots & 0 \\ \vdots & \vdots & & \ddots & & \vdots \\ \vdots & 0 & & & g & 1-g \\ g(1-g), & (1-g)^2 & 0 & \cdots & 0 & g \end{bmatrix} X^k \equiv AX^k \text{——} (7)$$

The constant operating interval of 8 demineralizers on steady state is equivalent to the condition that X^k converge to zero.

If the eigenvalue is shown by λ , following relation may be obtained.

$$|\lambda| < 1 \text{ ———————} (8)$$

Therefore, the characteristic equation of A is obtained as

$$(\lambda - g)^8 - \lambda (1-g)^8 = 0 \tag{9}$$

For example: from equation (a) for g=0.5, the eigenvalues, λ , are

$$\left.\begin{array}{l} 0.45 \pm 0.47j \\ 0.85 \pm 0.37j \\ 1 \\ 0.16 \pm 0.26j \\ 0.12 \end{array}\right| \tag{10}$$

For simplicity, we consider the example of 3 demineralizers instead of obtaining the initial value for λ =1 in equation (7).

$$X^{k+1} = \begin{pmatrix} g & 1-g & 0 \\ 0 & g & 1-g \\ g(1-g) & (1-g)^2 & g \end{pmatrix} X^k \tag{11}$$

$$\text{Here } gX_1^0 + X_2^0 \, x \, X_3^0 = 0 \tag{12}$$

Their eigenvalues are $\lambda =1, \frac{1}{2} \left\{ (3g-1) \pm (1-g) \sqrt{4g-1}\, j \right\}$

where $g \leq 1$.

Therefore, $|\lambda| \leq 1$ on $g \leq 1$

The equation (11) is made diagonal by variable transformation, X=PZ, and

$$Z^{k+1} = P^{-1}APZ^k \tag{13}$$

is obtained. Looking for P, we obtain,

$$Z^{k+1} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \alpha & -\beta \\ 0 & \beta & \alpha \end{pmatrix} Z^k$$

By defining

$$P^{-1} = \frac{1}{\det P} \begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix}$$

We transfer the initial value satisfying equation (12) to Z^0 by $Z^0 = P^{-1}X^0$.

$$Z_1^0 = \frac{1}{\det P} (P_{11} X_1^0 + P_{12} X_2^0 + P_{13} X_3^0) = \frac{1}{\det P} \left| \frac{\sqrt{4g-1}}{2g} (gX_1^0 + X_2^0 + X_3^0) = 0 \right.$$

is obtained. It is clear that initial value for eigenvalue, λ =1, is usually zero.

Therefore, it will be assumed that THIS CONTROL SYSTEM IS OPARATED TO EQUALIZE THEIR OPERATING INTERVALS.

3. COMPUTER SIMULATION RESULTS

The result of system analysis shows that the uncontrolled operating intervals are gradually averaged by controlling the demineralizer's flow. Then, in order to prove the analysis results of 8 demineralizers, the following computer simulations were tried on the above-mentioned control approach.

Simulation [1] ... Time vs Ion Exchange for random disturbance.

◉Input conditions

(1) Normal inlet conductivity: 0.12 µ℧/cm
(2) Change value of inlet conductivity: ± 0.06, -0.03 µ℧/cm
(3) Change mode of inlet conductivity: random mode
(4) Outlet conductivity: 0.07 µ℧/cm
(5) Ratio of the control flow ($g=\frac{a}{b}$): 0.867 ($a < b$)

◉Result → **We cannot of find which cause on flow or inlet conductivity is there in Fig. 6.**

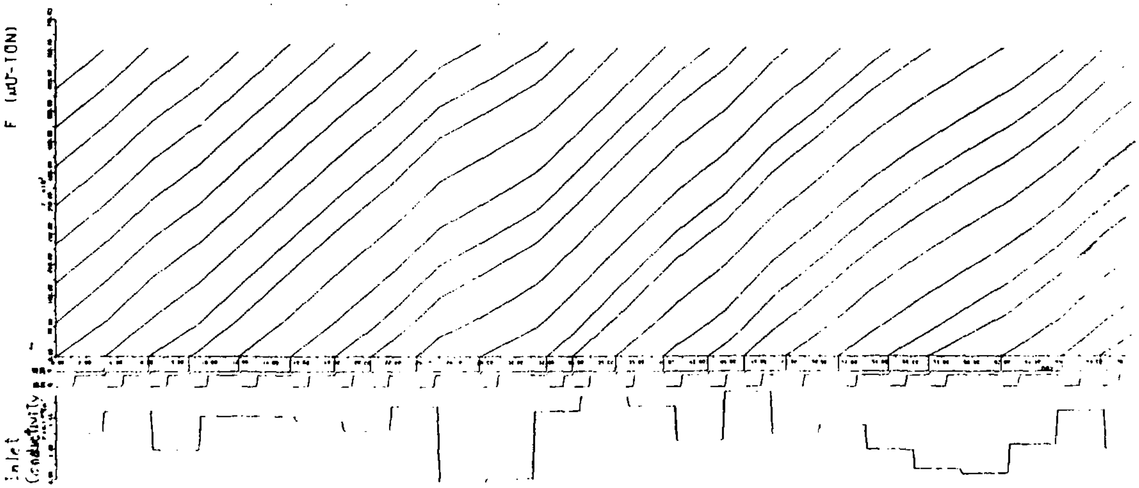


Fig. 6 Time vs Ion Exchange Quantity for Random Disturbance

Simulation [2] ... Time vs Integral Flow for random disturbance

◉ Input conditions are the same as Simulation [1].

◉Result → **We can express the cause on flow as the gradient of their characteristics and the cause on inlet conductivity as their end point in Fig. 7.**

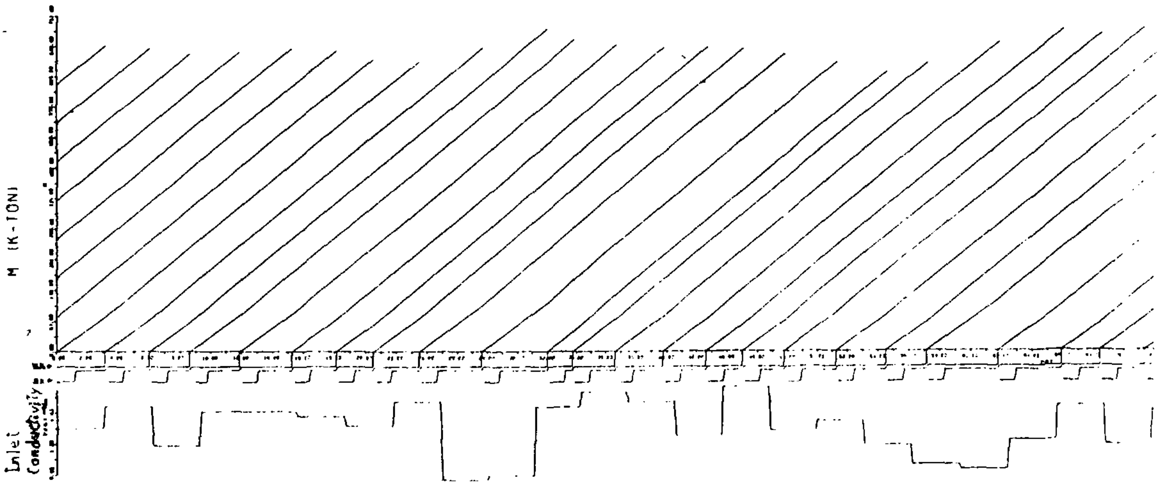


Fig. 7 Time vs Integral Flow for Random Disturbance

Simulation [3] ... All equal controlled flow on each demineralizer.

◉ Input conditions

(1) Normal inlet conductivity: 0.12 $\mu℧$/cm
(2) Change value of inlet conductivity: none
(3) Change mode of inlet conductivity: none
(4) Outlet conductivity: 0.07 $\mu℧$/cm
(5) Ratio of controlled flow (g=a/b): 1 All equal flow

◉ Result ➔ Its previous distribution in operating intervals is not averaged in Fig. 8.

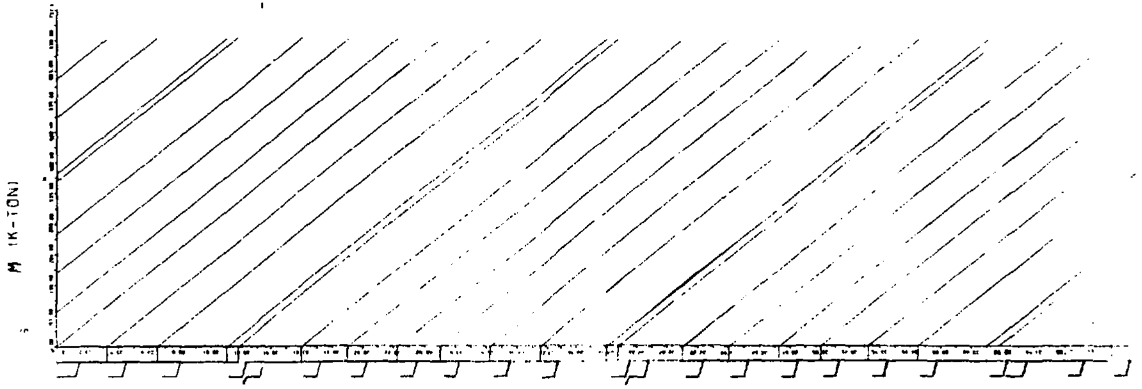


Fig. 8 Time vs Integral Flow in case of All Equal Controlled Flow

Simulation [4]

◉ Input conditions
The same as Simulation [3] except ratio of control flow

(5) Ratio of control flow (g=a/b): 0.867 (a < b)

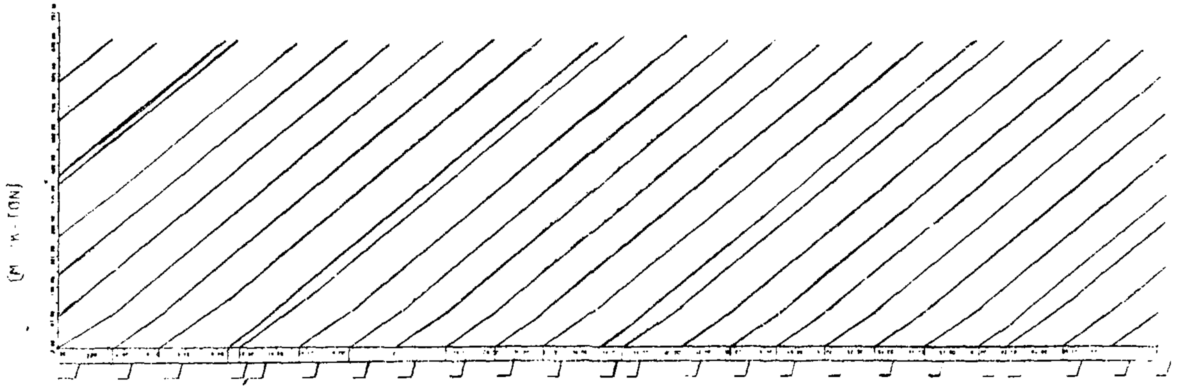


Fig. 9 Time vs Integral Flow in such flow as a <b

◉Result → Initial distribution of operating intervals is gradually averaged by the effect of input condition (5)

4. CONTROL METHOD

From system analysis and computer simulation, even if there is increase of their inlet conductivity, eg, leakage of sea water into turbine's condensor and so on, their operating intervals should be equalized as much as possible.

It has been considered that two approaches will equalize their operating intervals:

(1) predict control approach settle the end point to equalize their intervals within limit of outlet conductivity of demineralizers.
(2) ratio control of initial flow for newly connected demineralizer to Condensate Clean Up System and flows of other demineralizers.

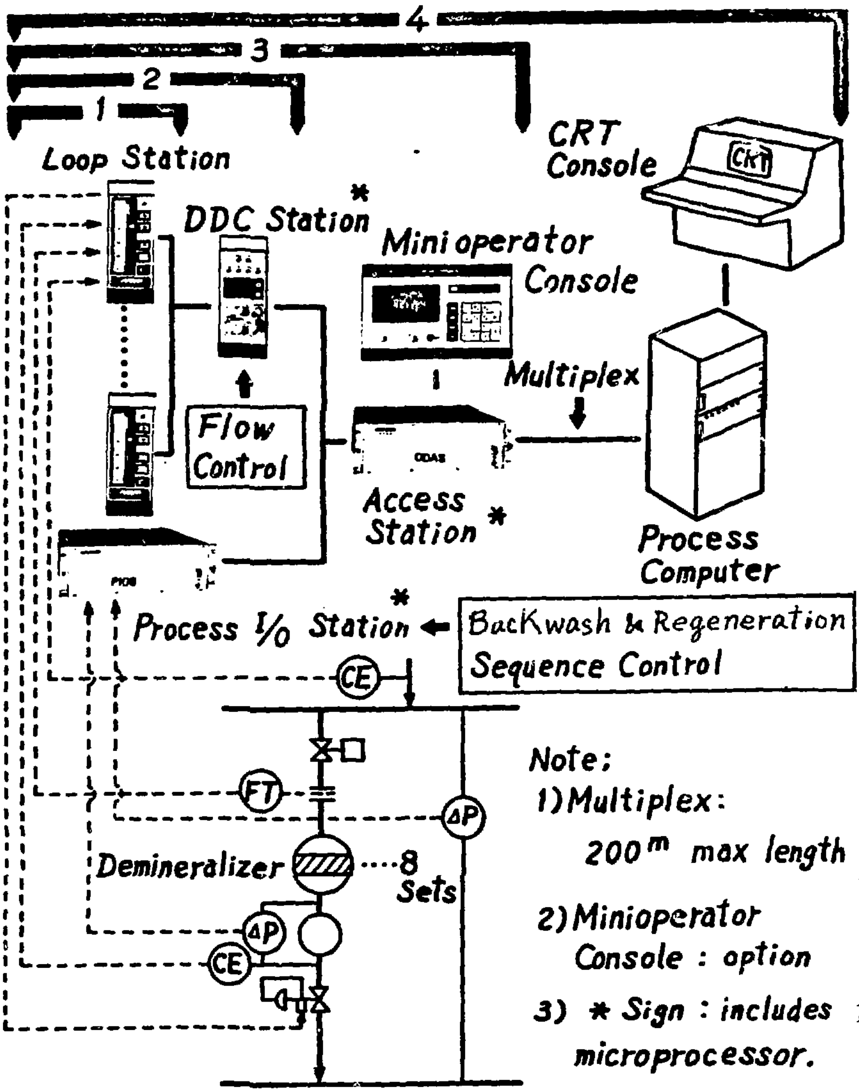
The former is more complex and needs more memory capacity than the latter.

The deviations of Ion Exchange Quantities at the end point are very small because of their averaging intervals in the control (2).

Considering above results, it is concluded that ratio control method is the most favorable and these controls can be performed by DDC Station, a sort of unit in the Toshiba Digital Instrumentation and Control System "TOSDIC". These distributed DDC System is able to control their flow, but also backwash and regeneration sequence control in Process I/O Station. The both stations are connected to the digital bus via Access Station in TOSDIC system.

TOSDIC hardwares basically consist of three sort of stations, Loop Station [DDLS], DDC Station [DDCS] and Access Station [DDAS] with Minioperator console [POC], although they can be a easily expanded up to a large scale over all instrumentation and control system which may employ a CRT display unit.

The distributed DDC system will be applied to the Condensate Clean Up System in a concept shown in Fig. 10.



Note:

1) Multiplex: 200^{m} max length

2) Minioperator Console : option

3) * Sign : includes microprocessor.

Fig. 10 Condensate Clean Up Control System Configulation with Distributed DDC

Process Computer System:
Provide information processing and high-level SSC for an entire system. Complete with CRT display intended for a one-man control system.

Multiplex:
is provided for an overall production system.

Access Station (DDAS):
A data transmission unit for concentrated management of the TOSDIC System.

DDC Station (DDCS) with the built-in microprocessor up to 8 loops can be controlled.

Process I/O Station (PIOS):
Process noncontrol variables.

Loop Station (DDLS) Capable of effecting the same operation and monitoring as those by conventional analog controller.

Notation

1: Manual operation

2: Instrumentation control panel level

3: Local console-concentrated level
(Medium-scaled instrumentation)

4: Computer hierarachy control level
(Overall instrumentation control system)

5. CONCLUSION

The features of the control system discussed in this paper are as follows:

1. More Economical Operation for Condensate Clean Up System

   As the end point for regeneration can be extended by the control method described in this paper, average operating intervals for demineralizers will be longer than the current uncontrolled system.

   If the maximum flow of demineralizers were designed to handle excess flow due to the flow decrease for newly connected demineralizer, number of operating demineralizer could be reduced or could have more operating capacity than current system.

2. Decrease of Radioactive Waste

   The regenerative operation will be decreased on the same reason as above. The consumption of acid and alkaline for regeneration is also decreased as compared with the current operation mode. In addition, this radioactive waste is ordinarily send to the R/W equipments, so it is easily controlled.

3. Improve Operability of the System

   Operators obtain the ion exchange quantities by calculating from the flow and conductivity difference between the inlet and outlet of demineralizer in the current system, but their quantities will be directly indicated by the distributed microprocessor in the improved system. In addition the operators can remotely supervise the operating conditions by multiplex transmission and watch concentrately informations combined together with other technical informations by a CRT display unit.

4. Safe Supervisory Function

   Advantage of digital processing is fully utilized by distributed microprocessor system "TOSDIC" for various safety control steps which formerly were not practically obtainable from analog instrumentation. The added safely management includes a functional check by validity of sensors, upper/lower alarm limits, rate of change alarm and deviation alarm.

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3) Reference Manual of TOSHIBA DIGITAL INSTRUMENTATION AND CONTROL SYSTEM