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Retention control system for the wet-end section in a paper machine.

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Abstract : We introduced a retention control system for the wet-end section of a paper machine using two intelligent pulp and filler(ash) low consistency sensors. When we tried to control the white water(WW) total consistency by the retention aid dosage using the "Proportional plus Integral(PI) feedback controller", we experienced a strong interaction with the existing paper ash content control of the QCS(quality control system). To alleviate this interaction problem, we utilized a "decoupling controller" together with the "PI feed-back controller".

Keywords : *paper machine, wet-end section, retention control, interaction, PI control (proportional plus integral control), decoupling control.*

1. INTRODUCTION

Some advanced paper machines use an "automatic retention control system[1)]" in the wet-end section along with the "retention monitoring sensor". The aim of the "retention control" is to stabilize the retention (total materials include pulp and ash components) and the filtration conditions of the wet-end section of a paper machine, and stabilize its operation and the quality of the paper products.

We also tried to introduce a "retention control system" in a paper machine at the *Kure Mill* using two intelligent pulp and filler(ash) low consistency sensors on the thin stock supply line(Fig.1:F2-*line*) of the head box(HB) and the white water (WW) filtrate line(F4-*line*) of the wet-end section. The paper machine to which we applied this retention control system has a 5,800 mm wire width, and a fourdrinier with an on-top wire part. It is a very high speed machine, – maximum:1,200m/min. –, produces "neutral paper" and "acid paper" twice a month by rotation. The production rate, the basis weight and the web ash content ranges are about 500 ton/day, 45–160 g/m^2 and 8–20 %, respectively.

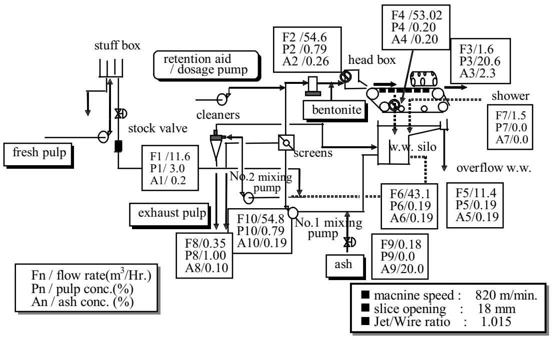

Fig.1. Paper machine wet section and material balance.

Fig.1 shows a diagram of the wet section flow of the paper machine. From this figure, we can determine the material balanced pattern of the individual flow lines for a 820 m/minute machine speed. In this figure, the notation "Fn" denotes the flow quantity, and "Pn" and "An" are the pulp and the filler(ash) consistency values, respectively.

The retention aid system using in this paper machine is a dual components system which consists of a dissolved cationic polymer and a suspended bentonite(Fig.1). The polymer is added before (or after) the machine screen and the bentonite is added just before the head box. The polymer dosage ratio is about 200 ppm against the thick stock(fresh pulp) quantity of the feed line, and the polymer controls the filtration conditions of the wire part.

Incidentally, the retention values(R_i) are approximately calculated using Eq.(1) with the two position's measured consistencies of "F2-*line*" and "F4 -*line*". The subscript "i" separately indicates the kinds of consistency, total(pulp+ash), pulp and ash. When this paper machine produces "neutral paper", the retention values are approximately $R_{total} \approx 60$ %, $R_{pulp} \approx 70$ %, $R_{ash} \approx 40$% on average.

$$R_i(\%) \approx \left\{ 1 - \left(\frac{C_{WW,\,i}}{C_{HB,\,i}} \right) \right\} \cdot 100 \quad \ldots\ldots \quad (1)$$

R : retention (%) C : consistency(%)
HB : head box line WW : white water line
i : total(pulp+ash), pulp, ash

2. RETENTION CONTROL

The method of "automatic retention control" in common use was disclosed[1)2)] by ***MetsoAutomation***, etc. Following their concept, we tried to apply it to

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our paper machine with the same strategy. At that time, we paid attention to the fact that in this "retention control system", the control target is used with the "WW total consistency($C_{WW,total}$ or "P4+A4" in Fig.1)", not with the "retention value (R_i)". The "WW total consistency" is controlled by the chemicals(polymer) in order to maintain it at the desired constant value. The reason to stabilize the WW total consistency is understood from the following explanations.[2]

First, from the material flow balance of Fig.1, we know the fact that those material amounts, which come from the short circulation line of the WW recovery line (F4~F6-*line*), and finally supplied to the head box(HB) line (F2-*line*) are considerably larger quantities than expected. It occupies about 41% of the pulp+ash components and up to 58% of the ash component. (Table.1).

Table 1. Material balance (summary of Fig.1).

	(1) HB Line. (Ton/Hr.)	(2)WW circulation Line. (Ton/Hr.)	{(2)/(1)}·100 ratio (%)
Pulp	43.1	8.2	19 %
Ash	14.2	8.2	58 %
Pulp+Ash	57.3	16.4	41 %

Based on these figures, we can recognize the importance of controlling and stabilizing the WW consistency, the pulp, the filler(ash), and in the end, the total consistency of the WW filtrate line, because the fluctuation of the filler(ash) and the total consistency will have a significant impact on the stability of the paper ash content and the produced paper quality. In this case, the movement mode of the HB and the WW consistencies are quite similar, and the ratio ($C_{WW,i}$ /$C_{HB,i}$) term of Eq.(1) will be maintained nearly equal at the same time. In fact, such a situation will happen, because the WW consistency is always dependent on the HB consistency. Therefore, even if the retention value(R_i) is constantly controlled, the possibility of an oscillating and fluctuating WW total consistency accompanied by the HB consistency may periodically occur. To avoid such a situation, the strategy to preferentially stabilize the WW total consistency is recommended in the "retention control system".

3. LOW CONSISTENCY SENSOR [3]

It has been said that measuring the consistencies and controlling the wet-end process of the paper machine continuously is difficult. Because the stock consistency of the pulp slurry is quite thin(below 1.0 %) and the wet-end process changes slowly accompanied by the long dead-time and the long time-delay because of the big volume of the WW silo and the long WW circulation flow line. Especially when measuring the ash(filler) consistency by the hand analysis, it needs about 1–2 day's time delay from sampling for the troublesome firing treatment, and even the analyzing the total consistency it needs about 2–3 hours delay time at the soonest. In actual, filtrating the content of the pulp slurry and weigh on a scale has been a time consuming work. So we have had almost no online information from the wet-end section before, until this intelligent low consistency pulp and filler(ash) sensor is developed about 10 years ago by ***Metso Automation*** (former ***Kajaani Automation: Finland***) for the first time. Now, we have been able to know the consistencies continuously. Fig.2. shows the structure of the ***Kajaani***'s online consistency sensor that provides individual measurements for the filler (ash) and total solids contents of the pulp. This sensor measures 14 kinds of signals in total simultaneously based on five kinds of optical principals, that is, light scattering, absorption, reflection, transmission and depolarization.

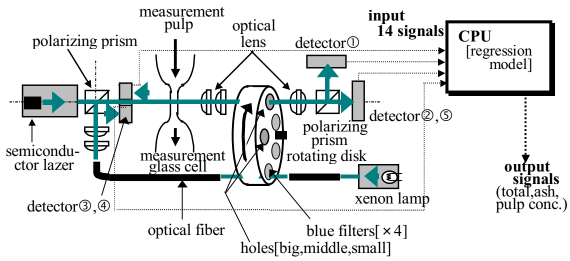

Fig.2. Low consistency pulp and ash sensor. (*Metso Automation*: *Finland*)

Filler(ash) and total consistency are mainly calculated based on the measurement of light absorption and depolarization. The light sources for the sensor are a semiconductor laser and a xenon lamp. Light from the laser is polarized before passing through the measurement cell. The transmitted light is collected with a lens and directed through a rotating aperture disc. The filtered light is again collimated with a lens and directed to a second polarizer, which divides it into two beams that are detected by photodiodes. Different wavelengths of light are rotated different amounts. For example, cellulose composed of pulp and sugar in solution, are known to exhibit the effect. Plane-polarized light entering a crystal along the optic axis is decomposed into two circularly polarized vibrations rotating in opposite directions with the same frequency. In the meantime, the light from the xenon lamp is absorbed by a lignin component that include in the pulp fiber specifically when passing through the measurement cell.

The sensor calibration is done comparing with the 14 sensor signals and the measured sample's consistencies by the hand analysis in the laboratory. We made multi-regression models for the total consistency and ash consistency by the statistic analysis. Selecting five or so useful high correlation signals among 14 signals, we decide the coefficients of multi-regression model statistically to fit, and estimate the consistencies by CPU calculation.

In the end, four regression models for the total and filler(ash) consistencies of head box line and WW line are obtained, here. After the propriety of the multi-regression models were checked during several months, we proceed to the following "retention control system" constructing work utilizing this intelligent consistency sensor.

4. PREPARATION FOR CONTROL

We used the previous ***Metso Automation(Kajaani)*:"*RMi*"** intelligent sensor as the retention monitoring system in this paper machine. Mentioned above, the sensor consists of two optical consistency sensor units and CPU units. Each optical sensor can separately and continuously measure the low consistency of the total(pulp+ash) and the ash consistency. The measuring range is less than 1.5 % for the total consistency and less than 0.8 % for the ash consistency. The pulp consistency can then be calculated from the equation of pulp = (total – ash). As the sensor system is a very expensive one to introduce, we need to make more effective use of it not only as a monitoring sensor but also as a control sensor.

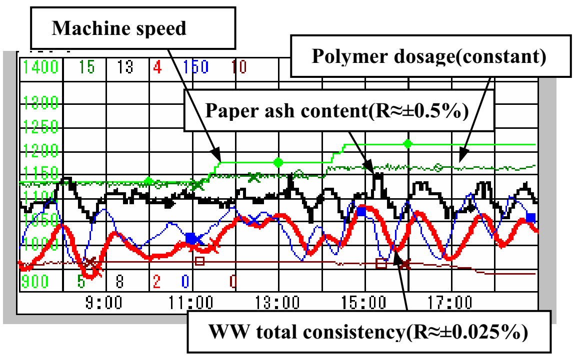

Fig.3. No Retention control.

Fig.3 shows the process conditions before the introduction of the retention control. The fluctuation of the WW total consistency and the paper ash content are relatively high and could not be stabilized because of the tuning limit of the paper ash content control using the old "QCS(quality control system)".This is due to the fact that, the tuning parameter available for the ash content control is restricted to only one parameter in this QCS in spite of producing many kinds of "neutral papers" and "acid papers". In fact, the process response significantly varies depending on the type of produced paper.

5. RETENTION CONTROL UTILIZING PI FEEDBACK CONTROL

As mentioned above, this retention control system is aimed to regulate the WW total consistency, and it is controlled by the retention aid chemical (polymer) dosage. The WW total consistency can slightly vary by the change in the dosage of the retention aid (polymer) in the pulp slurry(thin stock), although the degree of change is very small. The response speed for the effect to appears in the WW consistency and the retention value are very slow because of the big volume of the WW silo and the long WW circulation flow line.

For the implementing method of the "retention control", it has been recommended to use the conventional simple "Proportional and Integral(PI) feedback controller". Fig.4 shows the PI control loop and the retention monitoring sensor(consists of two consistency sensors) configuration in the wet-end section.

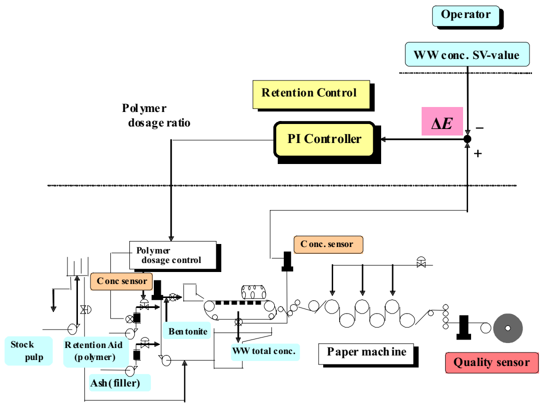

Fig.4. PI feedback control by retention aid.

Next, carrying out with the "step response test" to examine the relationship between the polymer dosage and the WW total consistency, we obtained the following test data for the neutral paper production. That is, for the increased action of about 10 % of polymer(increase 1 liter/minute when the polymer dosage is 10 liter/minute), the WW total consistency decreased about 0.01 %, and the total retention increased about 1.8 %. Therefore, the "steady-state response gain(WW total consistency vs. polymer)" is about K= – 0.01(%/liter). We also concluded that the "dead-time" is about 3.2 minutes(192 seconds) and the "time-constant" is 19.4 minutes(1,164 seconds). Therefore, the transfer function, "G", of this process response can describe the next approximate expression when we use the "dead-time plus first order lag model" for simplicity.

$$G = \frac{K \cdot e^{-192 \cdot S}}{1 + 1164 \cdot S}$$

Next, from these data and using Ziegler-Nichols's step response method, etc., we estimated the "proportional gain: Kp" and "integral time: Ti" for the "PI feedback controller". We then repeatedly tuned these controller parameters to suitably fit the actual process through the production run.

6. INTERACTION PROBLEM

However, when we tried to integrate this retention control system using the "PI controller" into the DCS system, we experienced a strong interaction with the paper ash content control of the existing traditional scanning QCS(quality control system), as indicated in Fig.5, and we could not control it as well prior to its installation.

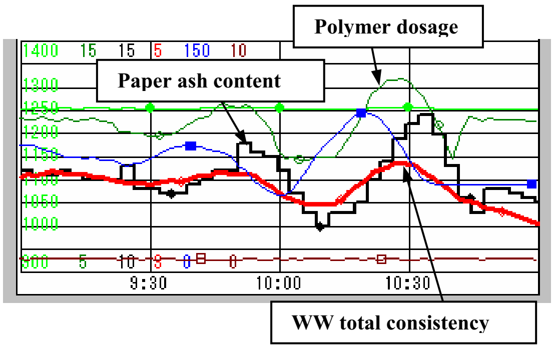

Fig.5. Control result of PI feedback control.

When we tried to control the WW total consistency by the retention aid polymer, the ash retention of the wet-end section changes at the same time, and the paper ash content fluctuates against the product specification. However, although the scanning QCS controller begins to automatically correct this ash content by the filler(ash) flow, it works in the opposite direction against the retention control.
Therefore, both the paper ash content and the WW total consistency gradually begin to violently oscillate and became impossible to control(Fig.5). Fig.6 shows the relation of the two controllers' configuretion that produces the interaction problem in this paper machine system.

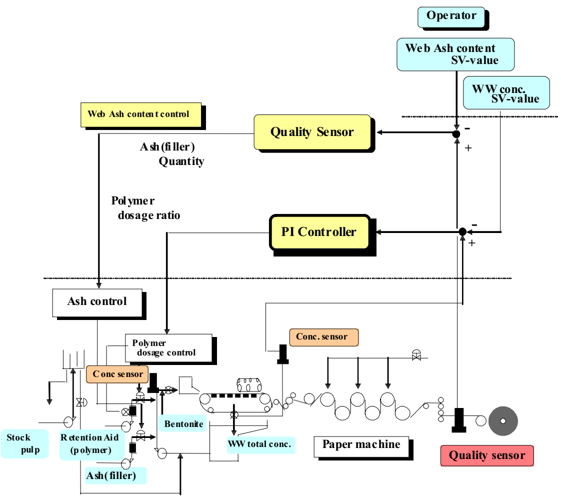

Fig.6. Interaction with PI feedback control.

Furthermore, because of the frequently carried out grade changes, the inevitable changes in the composition of the coated dry-broke pulp, and the use of the de-inked pulp from recycled newsprint and magazine papers, the filler(ash) content of the pulp flow is apt to widely vary in this paper machine. These factors work as triggers of the process disturbances. Similar interaction problems are also discussed in ***Metso Automation***[4] and ***Invensys***[5] in other cases, and they solved this problem by using the modern new "Model Predictive Control(MPC)" system. However, in our trial process, because the DCS and the QCS were old (introduced about 15 years ago), we needed to solve the control interaction problem by a simple and more reasonable method.

7. STEP RESPONSE TESTS

To begin with, we examined a series of "process transfer functions(steady-state gain, time-constant, dead-time)" correlated with this interaction phenomenon from some actual step response tests and usual operation data. Using these data, we could apply the simple "dead-time plus first order lag model" to all the process response models here.
In general, as the response results were not very clear due to the process disturbances, the system identification used to judge the "transfer functions" was difficult.

Table 2. Transfer functions of process.

	Quality Sensor control Ash content	WW total consistency
Ash quantity	$G_{11} = \dfrac{+K_{11} \cdot e^{-126 \cdot S}}{1 + 75 \cdot S}$	$G_{21} = \dfrac{+K_{21} \cdot e^{-90 \cdot S}}{1 + 780 \cdot S}$
Polymer dosage	$G_{12} = \dfrac{+K_{12} \cdot e^{-174 \cdot S}}{1 + 828 \cdot S}$	$G_{22} = \dfrac{-K_{22} \cdot e^{-192 \cdot S}}{1 + 1164 \cdot S}$

Table.2 shows the four representative "transfer functions(G_{nn})". Although the steady-state gain values are omitted here, the plus or minus signs of "K_{nn}" represent the response direction of the process.

8. DECOUPLING CONTROL [6]

Finally, to prevent the occurrence of the interaction problem, we introduced the traditional "decoupling control elements" between the "retention control system" of the "PI feedback controller" and the "filler(ash) flow control" system of the QCS as shown in Fig.7. At that time, it is well known, that the decoupling control elements "C1" and "C2" are designed using Eq.s (2) and (3), and the parameter data could be used from Table.2. Fig.8 shows the diagram of the decoupling control configuration that was built for this paper machine system.

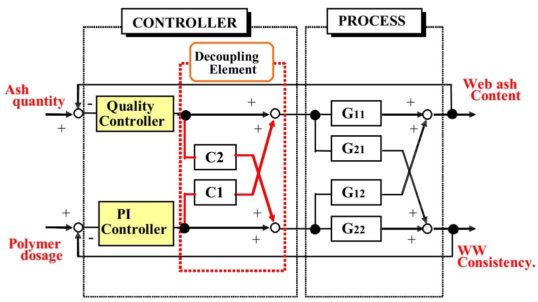

Fig.7. Decoupling control.

$$C1 = -\frac{G_{12}}{G_{11}} = -\frac{+K_{12} \cdot (1 + 75 \cdot S)}{+K_{11} \cdot (1 + 828 \cdot S)} \cdot e^{-48 \cdot S} \quad \ldots\ldots \quad (2)$$

$$C2 = -\frac{G_{21}}{G_{22}} = -\frac{+K_{21} \cdot (1 + 1164 \cdot S)}{-K_{22} \cdot (1 + 780 \cdot S)} \cdot e^{+102 \cdot S} \quad \ldots\ldots \quad (3)$$

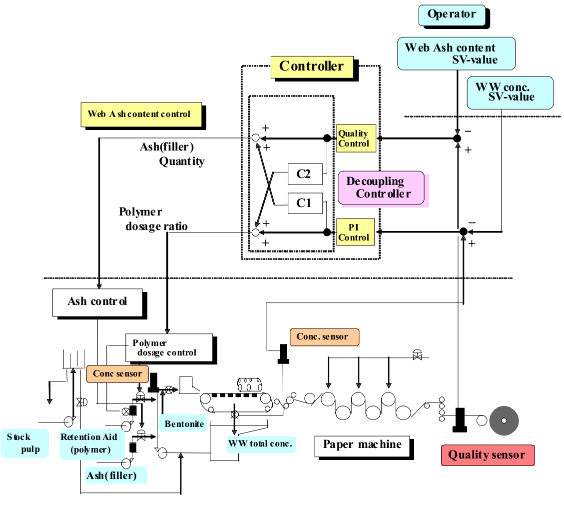

Fig.8. PI Control plus Decoupling control.

9. DECOUPLING CONTROL STRATEGY [7]

As mentioned above, as the DCS and the QCS in this paper machine system were old, we could not integrate the complex "C1 and C2" form as is. Therefore, for the decision of the decoupling control elements "C1" and "C2", we used the "steady-state and partial decoupling controller" for simplification. At first, although the "C2" of Eq.(3) includes the prediction term of "$e^{+102\cdot S}$" in it, it is impossible to physically achieve it. Therefore, by neglecting this prediction term, the "C2" of Eq.(3) was transformed into Eq.(4).

$$C2 \approx -\frac{+K_{21}\cdot(1+1164\cdot S)}{-K_{22}\cdot(1+780\cdot S)} \quad \ldots\ldots \quad (4)$$
$$\approx -\frac{+K_{21}}{-K_{22}} = +\text{constant.}$$

Furthermore, in this case, the dynamic characteristics of the "G_{12}" and the "G_{22}" are very similar, consequently the numerator and the denominator of Eq.(4) are roughly canceled. Finally, we may select "C2" as a steady-state constant value for simplification. It is known that one of the strategies to "robust" the decoupling controller is to introduce the "steady-state decoupling element" to avoid the harmful effect of the modeling errors.
Besides, the effect of the term (K_{21}/K_{22}) of "C2" is stronger than the other term (K_{12}/K_{11}) of "C1" ($|(K_{21}/K_{22})| >> |(K_{12}/K_{11})|$) in this wet-end process response, so we set "C1=0" here by adopting the "partial decoupling" for added simplification.

$$C1 = -\left(\frac{+K_{12}}{+K_{11}}\right)\cdot\frac{(1+75\cdot S)}{(1+828\cdot S)}\cdot e^{-48\cdot S} \approx -0$$

According to the strategy mentioned above, we repeatedly tuned the "C2" (and the "C1") parameter values in the actual production run. It was very convenient for us to be able to set the "C1" and "C2" controller elements in such a simple style for the old DCS. The adequacy of the controller robustness has been confirmed by long running tests.

10. CONTROL RESULT

Fig.9 shows the control result of the "decoupling controller" accompanied by the "PI feedback controller". We managed to successfully apply the automatic retention control system to this paper machine, and we could use the decoupling control as a reliable method. The right side trend of Fig.10 shows the middle length period's control result compared with the no control period(left side trend). We will now be able to clearly understand the effectiveness of the control.

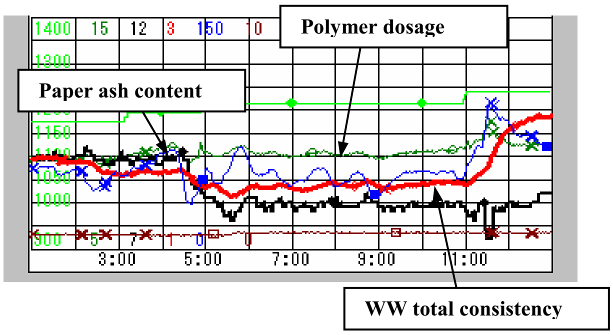

Fig.9. PI Control plus Decoupling control.

Table.3 shows the analysis result of the stability improvement (1sigma standard deviation) of the WW consistency, the paper ash content and the ash flow variations from long running data. They are compared with the conditions before and after the control.

Table 3. Control result (1sigma standard deviation).

	before	after	reduction (%)
WW consistency(%)	0.015	0.006	▼59 %
Paper ash content (%)	0.13	0.10	▼21 %
Ash flow (liter/min.)	9.49	7.56	▼20 %

Furthermore, the contribution to the reduction of the fluctuation width of the "couch vacuum" of the press section has been reported based on the on-site observations(Fig.10). It shows that it is equivalent with the stability of the web drainage condition in the wire section.
In addition, many grades of paper are produced in this paper machine and grade changes are frequently carried out. Therefore, we are confused about determining the optimal target value(SV) of the WW consistency when we use this new retention control system because the balanced WW total consistency changes for each case[8)9)]. Therefore we simply adopted the "PV value" of the WW total consistency as the "SV target value" at first, when we started this retention control. After that, we manually changed the target value little by little along with checking the process conditions.

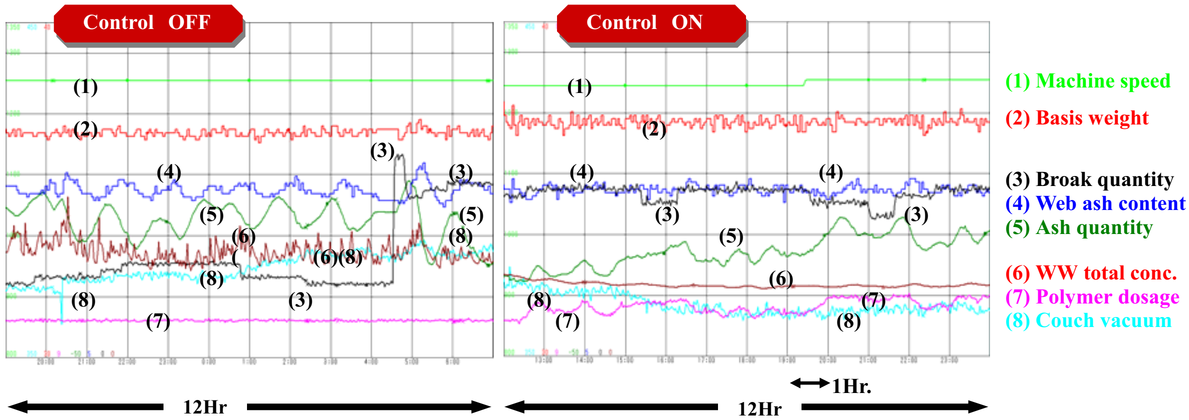

Fig.10. PI control plus Decoupling control (neutral paper).

11. CONCLUSION

By using the "decoupling controller" together with the "PI feedback controller", we could manage to apply the "automatic retention control system" to this paper machine. We could also successfully improve not only the stability of the WW consistency(total, pulp, ash), but also the paper ash content and the ash flow, which is difficult to control using only the old QCS capabilities. At the threshold of this trial, the anticipated fluctuation in the "web formation" that could have taken place from the frequent changes in the retention aid dosage did not occur at the present time. Setting a restriction on the bound pair limit of the polymer dosage will hardly prevent the problem. In addition, a "charge sensor system" in the wet-end section was added to this paper machine, and, as another activity, the "charge control system" regulates the "cationic demand" of the broke chest flow line based on the coagulant.

As another problem, when this retention control system is used, – although it doesn't reach the quality problem level –, a small high frequency fluctuation of the "basis weight" has been recognized when compared with the no control period. Therefore, we begin a counter plan to stabilize it by expanding the decoupling controller from a two to three-interaction element problem that includes the stock flow.

Through these trials, we restudied the importance of paying attention to some other interaction concerns in the machine operations. Although we could keep the WW total consistency within the desired value range by this "retention control system" which was combined with the "decoupling controller", with difficulty, we would like to evaluate what merits can be obtained from the long-range operations from now on.

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