RECENT FEATURES OF FUJI ELECTROSTATIC PRECIPITATOR

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Fuji Denki Seizo K. K. has recently succeeded in the development of a fundamentally new system which is very effective in precipitation and rapping, the two most fundamental processes of the electrostatic precipitator.

One of the advantages is the improved spark-suppression control which does away with the necessity of circuit-breaking and facilitates automatic voltage return due to complete suppression of the short current when spark discharge occurs between the electrodes and reduction of arc quenching time to within a very short duration of 0.03 second.

The other advantage is the unique electric rapping system which constantly maintains a high sparking voltage and readily dislodges pile of cohesive dust which heretofore was not possible by any mechanical rapping system.

This new system is readily adoptable to small precipitators for manufacture of sulphuric acid as well as large precipitators for pulverized-coal-fired-power boiler plants. The outline of the new system is as follows:

I. OVERALL EFFICIENCY AND ADVANTAGES OF THE NEW SYSTEM

A precipitator must be evaluated on the basis of overall efficiency based on precipitation efficiency and rate of operation. To raise the overall efficiency, the following requirements must be met:

1) Improved precipitation

Stable operation at constantly high voltage to increase the electrically precipitating force.

2) Improved rate of operation

Operating stability to prevent shut-down or circuit-breaking of power supply in spite of high voltage operation.

The operating characteristics and the precipitating field have been measured in numerous precipitators in operation by the Fuji Denki Seizo K. K. and the requirements to increase the overall operating efficiency have been surveyed in detail. As a result, we have adopted the following new system to maintain high degree of stability and precipitating efficiency.

1. Power supply control system based on a saturable reactor

Since the control system utilizing the saturable reactor made by this company has a complete current limiting action, the spark current is under full control even when high voltage is applied and sparks occur frequently and a very stable operation is possible without circuit-breaking in power supply. In the induction voltage regulator system heretofore employed, power supply circuit-breaking was performed whenever sparking occurred. Since the use of this saturable reactor makes possible operation without interruption in power supply even when sparking occurs, higher voltage than heretofore may be applied and much more stable operation is possible.

2. Joint use of rapping system utilizing condensers

The condenser inserted in parallel between the electrodes discharges the stored energy momentarily during sparking to break up cohesive piles of dust. It was very difficult to attain complete rapping action with the normal mechanical rapping systems used heretofore and it was impossible to avoid pile of dust after two to three months of operation. Since this electric rapping system completely removes the dust which is the direct cause of sparking, it draws the high voltage operation without sparking and troubles leading to stoppage hardly occur.

In the operation test of our new control system utilizing jointly the saturable reactor and the condenser, the corona discharge current was doubled and the operating voltage increased 20 per cent over the IVR system used heretofore, making possible approximately 50 per cent reduction in the size of the precipitating chamber.

II. SATURABLE REACTOR CONTROL SYSTEM

To increase the precipitating force of the electrostatic precipitator, the corona discharge current and the supply voltage must be increased. In systems utilizing the induction voltage regulator, the power had to be cut off whenever sparks occurred and this increase in voltage was impossible.

Our precipitating chamber utilizes the saturable reactor control system which immediately quenches the spark whenever it occurs and returns the voltage. Since the adoption of this system, it has been possible to increase the corona discharge current and the operating voltage, with additional advantage of a very stable operation.

1. The theory of the saturable reactor and spark suppression

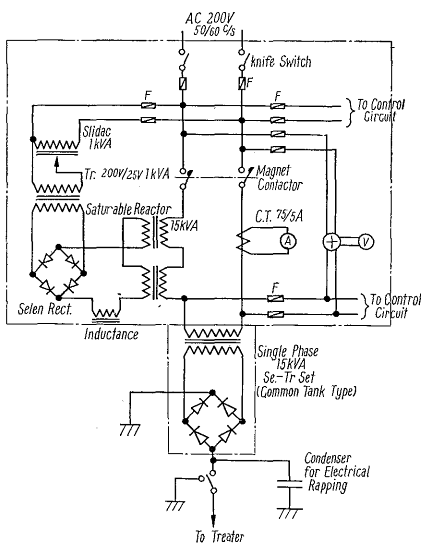

Fig. 1. Connection diagram of Fuji standard saturable reactor system

Fig. 1 shows the standard saturable reactor control diagram. As is well known, the saturable reactor consists of two cores with rectangular hysterisis loop, each with a-c and d-c coils respectively coupled in series for opposing polarity. Our standard product is specially built with a large inductance in the d-c control circuit to keep control current constant even against load fluctuation. For this reason, this saturable reactor functions as the so called constrained state (Fig. 2 and Fig. 3). In other words, as the reactor is sufficiently saturated when the load current is small, the supply voltage is applied to the load intact but when the load current increases and reaches to a higher level than the control AT, the reactor is released from its saturated state to serve as a high impedance, and the flow of current higher than the control AT is impossible. Consequently, the wave form of the load current is nearly rectangular to constitute the so called "Law of equal ampere turn".

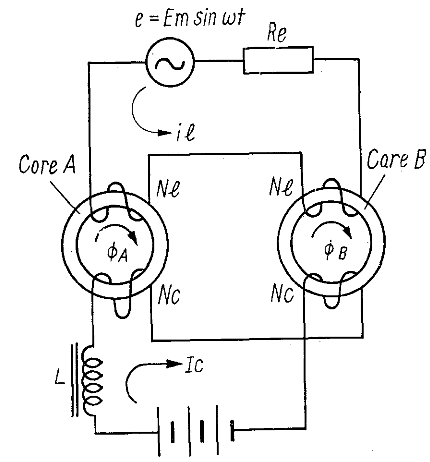

Fig. 2. Principle of standard saturable reactor

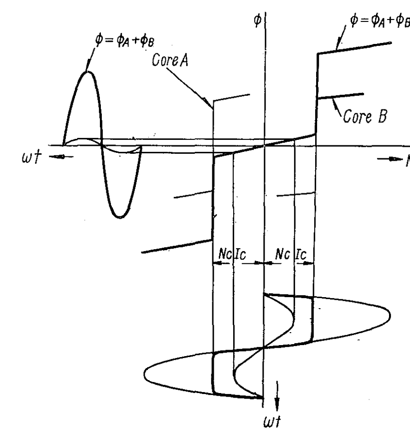

Fig. 3. Magnetic flux of saturable reactor

$$I_C \cdot N_C = I_L \cdot N_L \qquad (1)$$

I_C : control current
N_C : number of turns of control winding
I_L : load current
N_L : number of turns of load winding

Inasmuch as the load current changes with the control current on the basis of equation (1), this saturable reactor can be used as a control device for the load current and hence the load voltage.

The greatest advantage in the use of this saturable reactor in controlling the power supply of the electrostatic precipitator is in its ability to function as a complete momentary supressor of spark dischage current. Since the control current of the reactor does not change even when load is momentarily shorted, the load current does not change. The voltage under load is switched to the reactor simultaneously with the short, and the prescribed constant current is maintained. In contrast, the shorting current five to ten times normal, flows in the form of arc discharge whenever sparking occurs in the induction voltage regulator system used heretofore, necessitating the suspension of power supply.

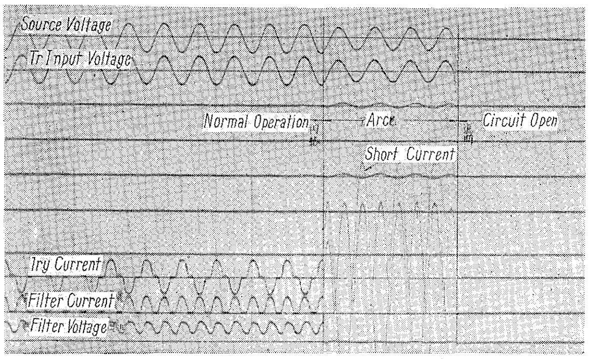

Fig. 4. Oscillogram of IVR system

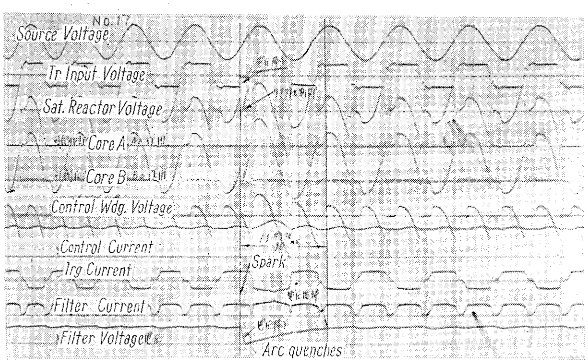

Fig. 5. Oscillogram of standard saturable reactor control

Fig. 4 and Fig. 5 are oscillograms made under actual operation. Fig. 4 shows occurrence of arc discharge simultaneous with sparking and stoppage within several cycles in the induction voltage regulator system. In contrast, Fig. 5 shows the results when the saturable reactor is used in conjunction with the condenser in electrical rapping. The same figure shows the momentary load current being controlled at zero and no change in the corona discharge current even when the spark discharge occurs. The voltage return after arc quenching requires only 1.5 c/s (30 ms). Continuous stable operation is possible even under adverse conditions when sparks occur repeatedly.

Furthermore, under this system, the electrostatic precipitator voltage wave pattern under normal condition is flat and the effective sparking voltage is high. This is due to the effects of inductance in the control circuit to maintain the load current and voltage of the reactor in nearly a rectangular wave pattern. The precipitator voltage in the oscillogram in Fig. 5 is entirely flat.

2. Operating stability and constant current system

As is well known, the electrostatic precipitator functions by means of steady d-c corona discharge, but is usually unstable since the characteristics of this corona discharge varies greatly with the conditions of gas, dust and rapping at the electrode within the precipitator, and a small fluctuation in the power supply voltage greatly affects the corona discharge current.

Our saturable reactor control system has a perfectly constant current characteristic capable of maintaining a prescribed current by means of a control current regardless of load conditions, and this characteristic greatly stabilizes the operation of corona discharge.

For example, when the gas temperature rises or when the humidity of the gas is reduced, the corona characteristic changes and the filter resistance and the sparking voltage are reduced in the precipitator as shown in Fig. 6. The corona current immediately, prior to the shorting is nearly the same or only somewhat less as also shown in the Figure. In the IVR system, when operation is conducted at voltage slightly less than the sparking voltage (Point A Fig. 6), sparking occurs immediately when the gas temperature rises or the gas humidity falls, and operation is interrupted.

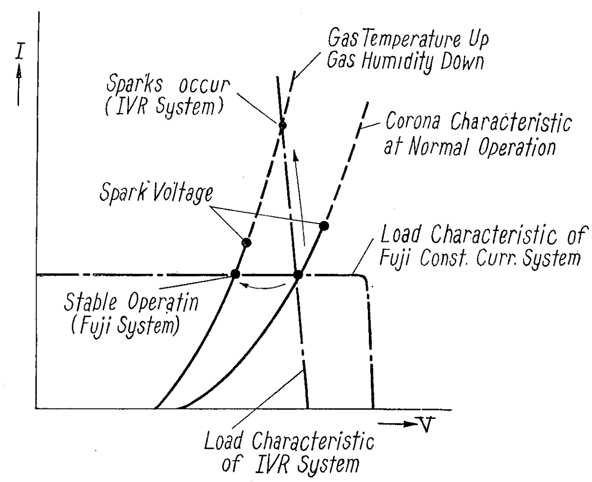

Fig. 6. Stability for fluctuation of gas condition

In contrast, our standard system is rational and permits uninterrupted operation just below the shorting voltage under such temperature fluctuation since constant current control functions as shown in the figure.

Furthermore, this system has the additional advantage of not being affected greatly by the fluctuation of source voltage.

The corona characteristics shown in Fig. 7 is greatly affected by the fluctuation of the source voltage when a power source having constant voltage characteristics of the IVR system is used.

For example, with ± 10 per cent fluctuation of source voltage, the fluctuation of corona current becomes as high as ± 40 per cent with corresponding change in operating conditions. On the other hand, with the constant current control by the saturable reactor, the corona current fluctuates ± 10

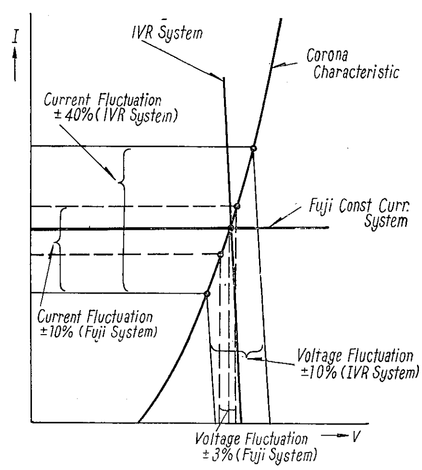

Fig. 7. Stability for voltage fluctuation of ±10%

per cent and the load voltage only ±3 per cent. The fluctuation of the precipitation rate is a very small ±1 per cent and is nearly within the tolerance of precipitation efficiency measurement. Consequently, a very stable operation is possible.

III. THE PRINCIPLES AND EFFECTIVENESS OF ELECTRIC RAPPING

1. Principles of electric rapping

In the electrostatic precipitator, the function of efficiently dislodging the pile of precipitated dust into the hopper, i.e. rapping, is an important function along with the function of separating dust particles from gas and collecting them on the surface of the precipitating electrodes. It was also necessary in the systems used heretofore to prevent decrease in sparking voltage and the consequent stoppage of operation due to piling of dust. However, actually, the dust collected and adhering to certain parts of the electrode became impossible to remove after one or two months of operation in the ordinary mechanical rapping system and the operation had to be suspended for internal cleaning after 4 to 6 months. As a result, operation rate of greater than 98 per cent was, in reality, difficult to attain.

Electric rapping refers to the system of removing the dust directly adhering to the electrodes by the destructive power of stored energy released during a very short interval from the condensers inserted in parallel between the electrodes. It is the system entirely different from the systems heretofore used and has been originated by our Company. In this system, spark is induced at a point within the precipitating chamber most likely to discharge spark to remove dust at that point, followed by inducing sparks at a point next most likely to discharge spark to remove dust at that point, etc. Thus, dust is removed and cleaned constantly from the points having poor electrical characteristic to restore high sparking voltage. Let us assume that a precipitator is operating at a certain voltage, and sparks occur at a point incapable of withstanding the operating voltage due to collection of dust on the surface of the precipitator electrode over a period of time. Simultaneously, dust is removed from that part by means of electric rapping and the operation is continued for a while. The process is repeated at another point and the operating voltage is maintained constantly at a predetermined level. Electric rapping is very effective since it is capable of selecting automatically the point and the time requiring rapping. Even when a small amount of dust is collected, precipitating action seldom suffers as long as the amount is not sufficient to induce spark or does not require electric rapping. Since the spark discharge in systems used heretofore produced a chain reaction in the frequency and the scope of troubles, they were operated at an extremely low voltage to prevent spark discharge as much as possible or were frequently stopped for internal cleaning and were considered bottlenecks to improvement in overall operating efficiency. In contrast, the new system of electric rapping in conjunction with complete current control by the saturable reactor utilizes the spark discharges as a means to improve the overall operating efficiency, increase the applied voltage to the point where spark discharge occurs to conduct effective rapping and continue to operate for long periods while drawing high voltage.

2. Effectiveness of electric rapping

The mechanical rapping systems used heretofore employed heavy weights or electromagnets to apply shock to a single electrode or a section of a block of scores of electrodes to remove dust piles from the electrodes by means of mechanical shock vibration. In these system, the following fundamental faults cannot be avoided:

1) Since the shock is applied to a section of a group of electrodes, impulsive vibration is not uniformly applied and dust adheres easily at the point of weakest vibration.

2) When the strength of the electrode plates are considered, the amount of rapping shock has a limit beyond which it cannot be increased.

3) No force can be applied to the dust itself due to structural consideration, and the efficiency in removing it is very poor.

Due to the above factors, problems frequently occurred when somewhat cohesive dust were involved.

In contrast, since the new system of electric rapping applies electric shock directly to the pile of dust to remove it by destruction, there is a great difference from shaking off the dust by transmitted vibration by rapping on the end of the electrodes. This problem will be more easily understood when an attempt is made to remove dust, not removed by normal rapping in routine cleaning, by light rapping with a stick. Fig. 8 is a photograph of electric rapping being conducted on fly ash and cement projections which also effectively illustrates the direct action of the electric rapping in dust removal.

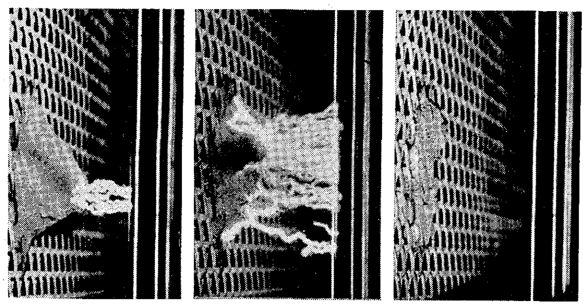

Fig. 8. Dislodging action by electrical rapping

Furthermore, since the energy of the heavy weight is distributed over the entire group in normal mechanical rapping as uniform impulsive vibration to all parts, only a small fraction of the entire energy of the weight is directed towards a certain segment of the dust pile which is the cause of the sparking. Nearly all of the remaining energy is expended in removing dust which does not require direct rapping, and the waste of energy is excessive for removal of dust that actually requires it. In contrast, since the energy from the condensers is concentrated at a point requiring rapping the most, the effectiveness is extremely great. Furthermore, the point of rapping is changed to meet the condition of dust collection and the dust removal is effected successively from points requiring it the most.

Moreover, in mechanical rapping since only the most easily removed dust adhering to the surface of the electrodes and the most bulky dust piles are released, possibilities are great that such dust will be carried out with the gas flow. The poor precipitation factor of the system utilizing continuous rapping compared to the system utilizing intermittent rapping is well known. In electric rapping, the decrease in effectiveness due to reentrainment when rapping is conducted at considerable interval is hardly a problem. Since electric rapping is conducted in one locality at a time, not only is the amount of reentrainment very small, but even when reentrainment occurs, it is immediately precipitated again.

The strength of the shock in the electric rapping is governed by the energy stored in the condensers $cv^2/2$ and the operating current. This strength is several ten times that of a normal mechanical system and is adequate for complete destruction and removal of normal dust, i.e. comparable to that adhering to talc. On the other hand, it has hardly any destructive force against metal such as the discharge wire. For example, even after 10^5 times continuous rapping, only surface deterioration due to heat as shown in Fig. 9 was observed and there is absolutely no danger of frequent trouble of broken those wire as commonly thought.

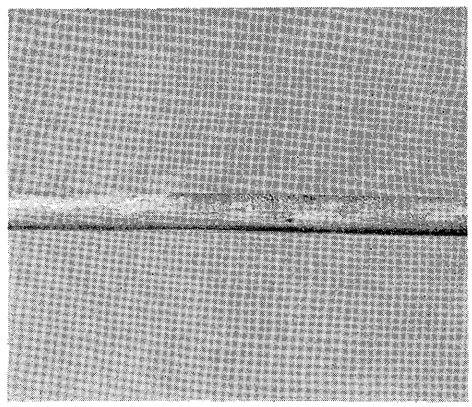

Fig. 9. Discharge electrode after 10^5 blows

3. Spark suppressing operation

The standard system employed by our firm is the electrical rapping method by means of both mechanical rapping and condenser backed by a power source control system equipped with a saturable reactor. Since at the outset of operation sparking voltage is sufficiently high, this equipment ordinarily can operate while removing a large quantity of dust by means of mechanical rapping only. With the lapse of operating time, dust pile which will cause the lowering of sparking voltage will most likely begin to accumulate. In the system used heretofore, it would then be necessary to suspend operations and clean the interior. In the electrical rapping system, however, sparking removes the dust pile and restores high voltage thus permitting continued stable operation. Through this means, the originally established operating condition is constantly maintained, so continuous operation is performed at high precipitating efficiency.

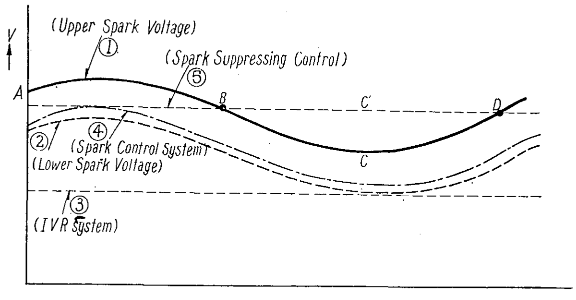

Fig. 10. Diagram of operation

Let us now compare the state of operation with that of other systems.

Fig. 10 shows a time record of the operational variations of the precipitator. Line ① represents the upper spark voltage (the voltage at which sparking will occur continuously) of the precipitator. Dotted line ② represents the lower spark voltage (the voltage below which sparking will not occur). Let us assume that these lines represent the variations in the precipitator.

When the supplied voltage exceeds the lower spark voltage and becomes higher, spark discharge begins to occur and when the upper spark voltage is attained, continuous sparking results. At an intermediate voltage, there is a tendency of an increase in sparking frequency along with the rise in ordinary voltage. In the former IVR system the circuit had to be broken when sparking occured so operating voltage must unavoidably be established below the lower spark voltage. In a system in which the voltage is regulated automatically while observing the sparking voltage so that sparking always occurs at a fixed frequency, the results may be as represented by ④. Such a system is referred to as "spark control operation."

On the other hand, in this system, stable operation is possible even when sparking occurs and it possesses the means to eliminate the cause of lowering of the spark voltage. Accordingly operation, for instance, would be as shown by ⑤. Operation is possible between A～B with occasional sparking. Between B～D, operation was usually impossible. But in this case, since effective sparking voltage can be increased through rapping by means of a condenser, stable operation of B～C′～D with high voltage is possible. In this way, while operation would ordinarily be done by lowering the voltage, sparking is suppressed through electrical rapping by means of the condenser and operation is performed with high impressed voltage. This is called "spark suppressing operation."

Table 1. shows the actual difference between ① and ⑤. In other words, it shows the results of operation indicating the effect of spark suppressing operation.

Table 1. Comparison of operation

	Operating voltage	Discharge current	Precipitating efficiency
IVR System	41.4 kV	40 mA/chamber	85%
Fuji System	52.3 kV	95 mA/chamber	95%

Note: Fuji standard single phase full-wave 10 kVA power was used for both systems.

IV. CONCLUSION

In the electrical precipitator, it is a known fact, the precipitating force of the particle strengthens in proportion to roughly the square of the strength of the electric field in the precipitating space under certain conditions. We are therefore striving to impress a slightly higher voltage in order to increase the precipitation efficiency. Our efforts have resulted in the development of the following two automatic systems replacing the former IVR voltage regulating system.

1. Automatic regulation of voltage while observing the sparking voltage so that the precipitator will operate near the sparking voltage.

2. Automatic regulation of voltage while eliminating the cause of any lowering of sparking voltage so that the precipitator will always operate at maximum efficiency.

Along with the automation recently becoming widespread in all fields, various experiments are finally being conducted on precipitators which can be classified under 1 above. Very little, however, is known about those falling under 2. In the case of electrical precipitators, however, it is believed that those falling under 2 are more basically and effectively automatic. We are confident that the saturable reactor control system and the electrical rapping system with the use of condenser both introduced previously and the only one classified under 2, are positive systems which will contribute toward the future development of precipitators.