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PUMP MOTOR CONTROL FOR WATER AND SEWAGE WORKS

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I. INTRODUCTION

Recently, water and sewage works are being designed and operated for optimum conditions in regards to both water quality and quantity because of the increases in water demand and the water pollution. Variable speed motors for pump operation play an important role in the development of water and sewage works.

Currently, variable speed motors are used in the following applications:

1) Water works

(1) Intake pumps

Intake pumps will be controlled when the capacity of the pump well or the river is small so that the water level of the pump well keep constant. By smoothing the amount of intake water, the water treatment equipment after the water accumulation well can be used efficiently.

(2) Distribution and transport pumps

Since distribution pumps are connectted directly with customers, the discharge pressure is controlled at a constant value so that the water supply pressure is kept within the specified value range. When the distribution piping is extended in the long distance, it is necessary pressure drops in the pipes and the terminal pressure is controlled at a constant value.

In order to keep the changes with time in the water demand uniform, water is supplied from the reservoir (pondage) in the pumping station during the daytime peak. The distribution pump in this case is called a peak pump and the constant flow control or flow program setting control will be applied.

When there is a distributing reservoir at the demand terminal, the amount of water transported is controlled by the water level of the distributing reservoir. The pump in this case is called a transport pump.

(3) Pressure booster pumps

When it is not feasible to transport the water with a one-stage pumping station at a certain feed distance, a booster pumping station is provided. The control of the booster pump is constant terminal pressure control, which controls so that the suction pipe pressure does not fail.

(4) Chemical feed pumps

The feed pump is controlled so that chemicals are injected in accordance with the quality and flow of the raw water. They are mainly small capacity devices.

2) Sewage works

(1) Waste water pumps

The influent waste water to the treatment plant must have differences in water levels so that it can flow by gravity down into the various treatment facilities. Therefore, the water is lifted to the pre-aeration tank by the inflow waste water pumps. Since the capacity of the dirty water pumping equipment is designed taking account of the future, there are many cases where the flow is small in comparison with equipment capacity at the initial

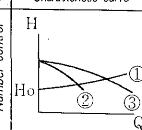
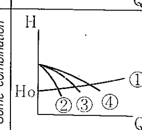
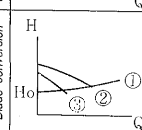
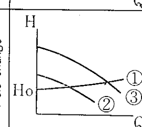
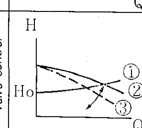
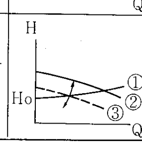
Item	Method		Characteristic curve	Symbol explanation	Remarks
1	Set speed	Number control		H_0 actual lift ① Piping characteristics ② 1-unit operation ③ 2-unit operation	Since flow rate is changed in stages, level changes in pump well are large. Difficult to handle at small flow rates.
2	Set speed	Some combination		H_0 actual lift ① Piping characteristics ② 1 small unit drive ③ 1 large unit drive ④ 2-unit drive	By combining pumps, flow can be fine controlled in steps. Combination sequence is complex.
3	Stepwise speed	Blade conversion		H_0 actual lift ① Piping characteristics ② Small capacity blade ③ Large capacity blade	Ideal for capacity increases in long-term planning. Time required for blade conversion operations.
4	Stepwise speed	Pole change		H_0 actual lift ① Piping characteristics ② Low speed operation ③ High speed operation	Small space occupied by pumps. High and low speed rates are high.
5	Continuous control	Valve control		H_0 actual lift ① Piping characteristics ② Pump characteristics ③ Characteristics at valve control	Continuous control is possible. Efficiency deteriorates due to valve loss. Faults easily develop due to garbage, etc.
6	Continuous control	Variable speed		H_0 actual lift ① Piping characteristics ② Pump characteristics ③ Characteristics during speed changes	Continuous control is possible. Efficiency is better than valve control. Price of motor control equipment is high.

Fig. 1 Flow control method of pump sets

construction stage. The various methods are as shown in *Fig. 1.* Recently, the variable speed motor has been used very frequently.

(2) Rainwater pumps

Since the maximum amount of rain water becomes more than 10 times the amount of waste water, the rainwater reservoirs are larger and the pump equipment capacity is smaller because of accumulation. For change of the amount of rainwater inflow, various diameter of pumps are used and they can be combined in various ways. The trend in recent years has been to use large capacity pumps of the same diameters and keep the numbers small through efficient utilization of the sedimentation basins. When the pump capacity is large, the water level changes in the pump wells become great and there is very frequent start-stop. Therefore, the flow is limited by speed control.

When large capacity rainwater pumps are operated when there is little rainfall or at the start or end of the rainfall, the flow rate in the sedimentation basins becomes fast and foreign mater is removed. Under such conditions, good results can also be obtained by pump flow control.

(3) Booster pumps

Booster pumps are controlled in accordance with the water levels in the final treatment plants or the water level when the beam is open.

II. PUMP SPEED CONTROL

Up to the 1950's, all pumps were of the constant speed type but since the 1960's, pump speed control has been performed by variable speed motors. The advantages of using variable speed motors are as follows:

1) Savings in energy

By means of speed control, the pump discharge pressure can be kept as low as required. Therefore, it not necessary to limit the pressure in the piping or at the outlet. The loss due to the piping is proportional to approximately the cube of the flow. Therefore, the energy loss due to the piping can be kept small by transporting the water at a uniform flow rate with time. By speed control, the pump can be operated at near maximum efficiency which means a savings in electric power.

2) Overall equipment improvements

Because the flow control range per pump is great, the number of pumps can be kept to a minimum by using large capacity pumps of the same diameters. Therefore, total construction costs are cheaper, the control circuits are simple and operation and maintenance are easy.

Through the use of speed control systems with good response and continuity, operation can be con-

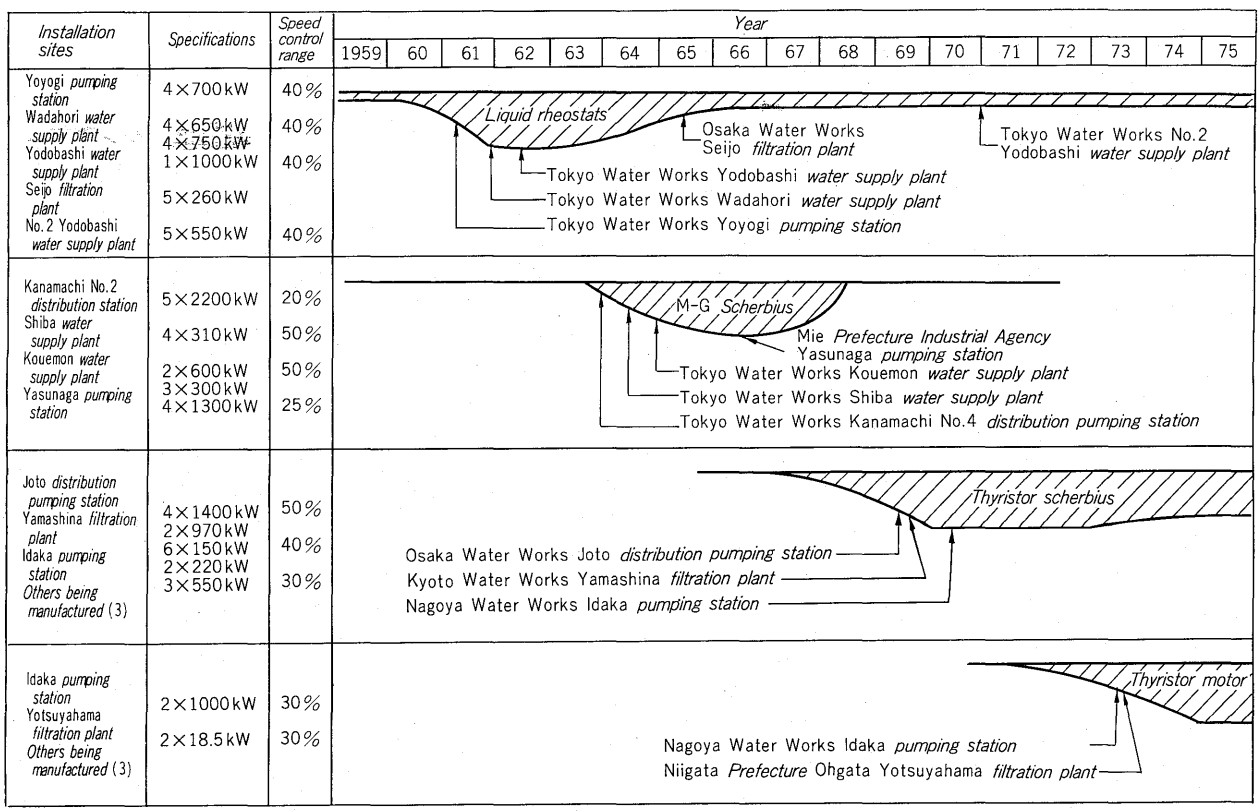


Fig. 2 Trend in speed control methods

trolled with no problems even when the pump well or pondage is small and there can be suitable responses to changes in demands by the distribution pumps, etc.

Variable speed motors have changed with the progress in basic thchnology and the demands of the times as shown in *Fig. 2*.

The requirements of variable speed motors are as follows:

1) Good efficiency

Because of the recent energy resources problem and the increase in unit power costs, higher equipment efficiencies have gradually come to be more appreciated.

The power loss of motors and control equipment is 4～25% of the rated output. In secondary resistance control and KS motors, the sliding power all becomes heat and efficiency deteriorates. However, the energy loss is still smaller than in the case of valve control. The efficiency is good in the case of thyristor motors and DC devices which control the primary power and the Scherbius and Kraemer systems which return the secondary slip power.

2) Easy maintenance

DC motors are not suitable for use in water or sewage works because of wear of the rectifier brushes and the trouble involved in replacements. If the shaft lubricating oil and the wound induction motor brushes must be replaced, this is permissible since replacement is easy and need only be performed 1～2 times a year.

3) Low construction costs

The equipment must be economical in respect to construction costs, operating power fees, maintenance costs, reliability and safety.

4) Others

Variable speed motors also require reliability, safety, simplicity, easy expansion and flexibility. Response and control accuracy presents almost no problem in loop control.

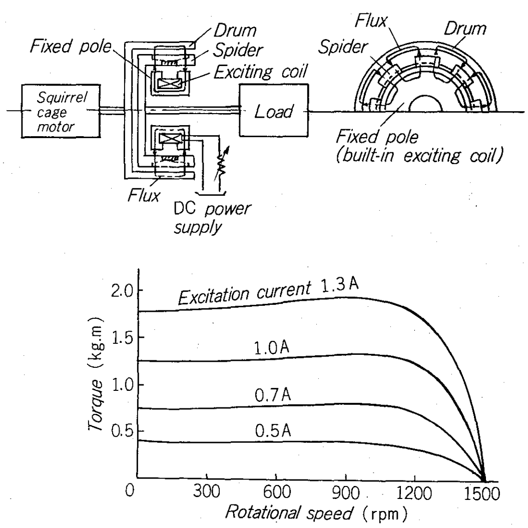


Fig. 3 Principle of KS motor

III. VARIABLE SPEED MOTORS FOR PUMPS

1) KS motors

Fig. 3 shows the principle of KS motors. By means of the regulation of the excitation current, the relative speeds of the drum and the spider can be changed. The efficiency deteriorates in proportion to the speed.

However, since the pump drive power decreases in proportion to the cube of the speed, the heat loss does not become so large. A disadvantage is that the KS coupling is larger than that of the main motor. Maintenance and inspection are easy and the control equipment is small and inexpensive.

Therefore, this motor is ideal for small capacity equipment and is often used for chemical injection pumps in filtration plants. The control circuit is shown in *Fig. 4* and *Fig. 5* shows an actual application.

2) PS motor

The PS motor circuit construction is shown in *Fig. 6*. This motor has an especially high rotor resistance and it employs a squirrel cage induction motor with a high slip. Since a large amount of heat is generated by the rotor, special consideration must be given to cooling system. The thyristor controls the voltage applied to the motor winding. The motor torque changes in proportion to the square of the applied voltage and the speed becomes balanced with the load torque.

The PS motor is larger than usual motors but it is smaller than the KS motor. Therefore, it is

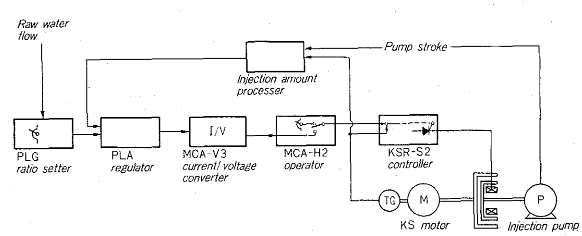


Fig. 4 Control flow diagram of chemical feed pump driven by KS motor

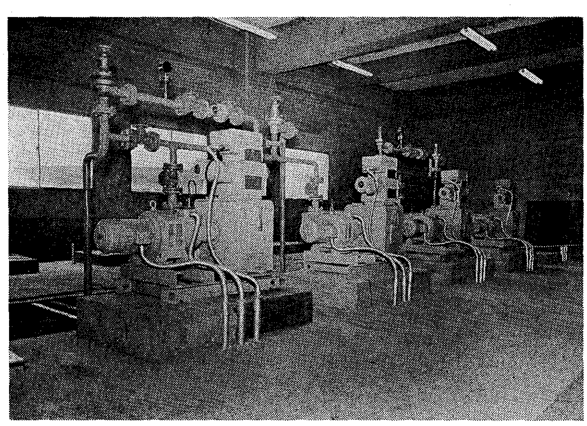


Fig. 5 KS motor and chemical feed pump

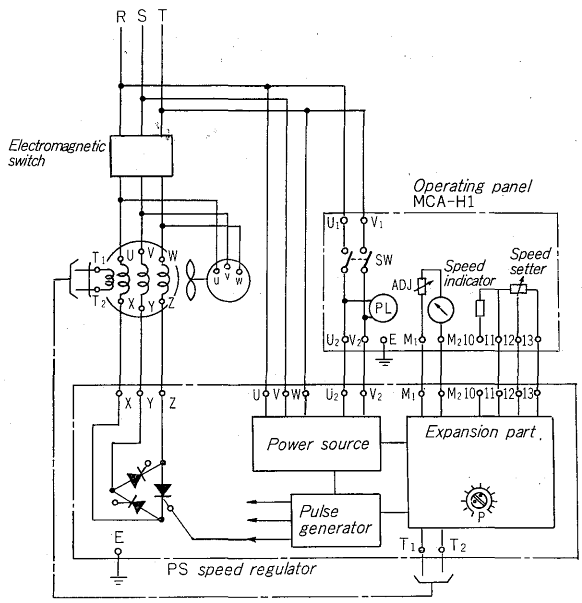


Fig. 6 Circuit diagram of PS motor

suitable for low capacity pump loads and is used for chemical injection pumps in filtration plants, etc. The disadvantages are a bad power factor, a large motor current, harmonic components in the current and the necessity of considerable care for the power supply when several motors are used together.

3) Secondary resistance control of a wound induction motor

This system was widely used before the establishment of semiconductor techniques. Liquid rheostats are used up to about 1,000 kW and metal resistors are used for under 200 kW. A motor operated cam type controller is used for notch short circuit control but it frequently requires large numbers of electromagnetic contactors. The efficiency of secondary resistance control is better than that of the previous two systems but a rather large amount of heat is generated in the secondary resistor. Therefore, this system is not used much in cases when the capacity is over 300 kW and the operating time rate is above 30%. It is suitable for sewage rainwater pumps and peak pumps with low usage rate. *Fig. 7* shows an example of the application of liquid rheostats.

4) Scherbius control

Scherbius control returns the secondary slip power consumed by the above secondary resistor to the

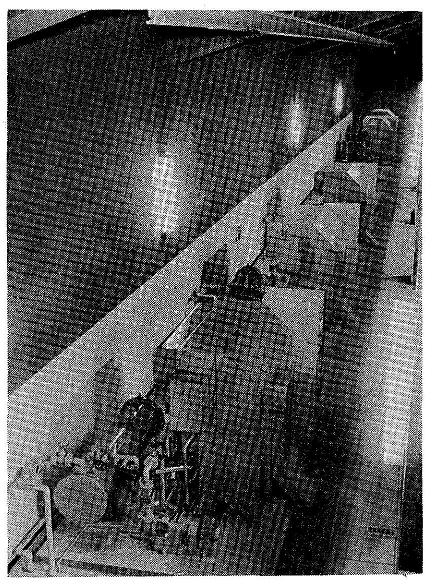


Fig. 7 Liquid rheostat for 550kW motor speed control

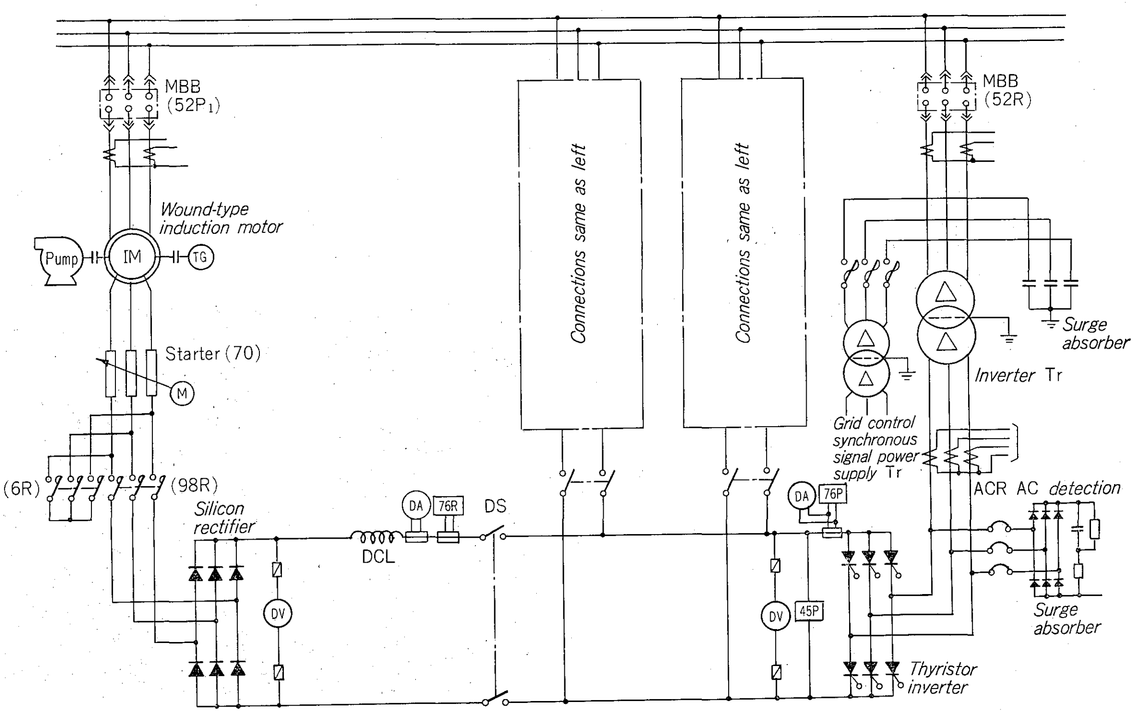


Fig. 8 Single line diagram of SCR Scherbius system

power supply side. The secondary slip power is rectified into direct current by a silicon diode. The M-G Scherbius system using a DC motor and a squirrel cage induction motor is employed in the initial stage as the equipment of feeding back the power from DC to the power supply. However, when large capacity thyristors are used thereafter, the thyristor-Scherbius system with a separately excited inverter is employed. The reason is the big problem of maintenance of DC motors.

The thyristor-Scherbius system is shown in *Fig. 8*. Efficiency is good, everything is completely static except for the main motor and maintenance is easy. The motor is an ordinary wound induction motor and since the capacity of the power feed back equipment is smaller than the motor primary input power, the equipment costs are less than those for other thyristor motors. The main disadvantage is the separately excited inverter but there is considerable instability beause of disturbances such as momentary power supply interruptions and commutation loss can easily occur. It is possible to use a Scherbius circuit as a partial measure against momentary power supply interruptions. *Fig. 9* shows an actual application of thyristor Scherbius equipment.

5) Thyristor motor

The thysistor motor has the rectifier of a DC motor replaced by a thyristor circuit. It has excellent characteristics from low to high capacity equipment. Since the sliding part in the main motor is the bearing only maintenance is easy, efficiency is good, the speed control range is wide with no relation to the price and it is easy to take measures against momentary power interruptions. The disadvantage is not so economical.

Therefore, the thyristor motor is ideal when reliability is required, the operating time rate is high, the speed control range is wide and the syetem is to be used for distribution pumps for urban water supply.

6) Inverter motor

The speed control system by the voltage and frequency control of a squirrel cage induction motor has been known for a long time. By reducing the cost using thyristors, it is possible to manufacture variable frequency power supply equipment at a suitable price.

In the event that the starting torque of the pump is low, the inverter motor can be easily employed. Currently, the motors have been standardized up to 200 kW and the small capacity motors are more economical than the thysistor motors. In the future, it is expected that this system will be employed even in high capacity cases.

Fig. 10 shows a standard circuit (FRENIC–200 type).

4) Other types

Other systems include the DC motor, rectifier motor and liquid joint.

The DC motor has been standardized in the Leonard equipment and is easy to use but brush maintenance is difficult and it is rarely employed

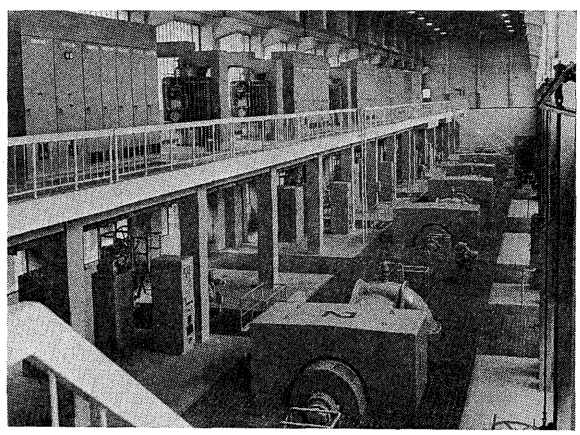


Fig. 9 1,400kW SCR Scherbius system

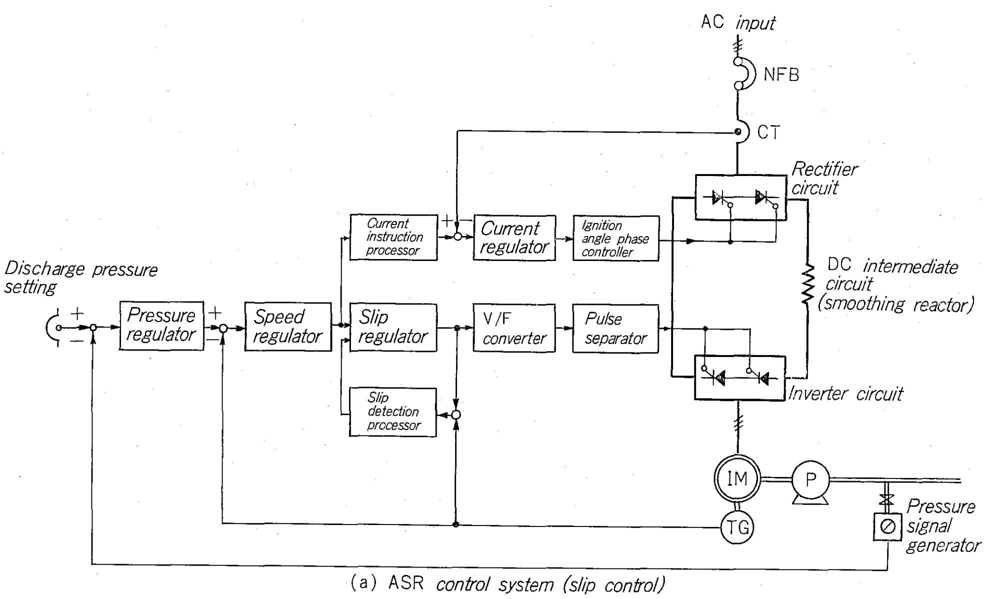


Fig. 10 Diagram of inverter motor (FRENIC–2000)

in water or sewage works.

The commutator motor has more difficult in the brush maintenance than the DC motor and is manufactured very little at present.

The liquid joint can be controlled entirely by mechanicaly, so it is suitable for the case of and electrical equipment being difficult to employ.

IV. MEASURES AGAINST MOMENTARY POWER SUPPLY INTERRUPTIONS IN THYRISTOR SCHERBIUS EQUIPMENT

1) Necessity of measures against momentary power supply interruptions

The following are the example of the actual voltage drop times in super high voltage receiving systems:

~0.1 sec.	2.3%
0.1~0.5 sec.	84%
0.5~1 sec.	9.2%
1~ sec.	4.5%

The number of cases per substation annually is 1~7 with an average of 2.9 per year.

Conventional thyristor Scherbius equipment is subject to commutation loss due to momentary power supply interruptions and the blowing of fuses to protect semiconductors leads to accidents. Even in cases when fuses did not blow, large capacity pumps require some time to restart once they are stopped and this presents a major difficulty for distribution pumping equipment which is related to public utilities. Thyristor motors are used to solve this problem but the high construction costs are a disadvantage.

The conventional thyristor Scherbius circuit was followed and it became possible to develop measures against momentary power supply interruptions. This has been provisionally called the improved Scherbius system.

2) Improved Scherbius with measures against temporary power interruptions

Fig. 11 shows the circuit of the improved Scherbius. Basically, it is the same as the conventional system but an auxiliary thyristor has been added in parallel with the momentary interruption detection processor and the DC reactor.

When the power supply voltage drops below the normal value for more than approximately 2 msec, an abnormality in the power supply voltage is detected. At the same time as this detection, the auxiliary thyristor is fired and the DC reactor is short circuited. The ignition phase of the main thyristor inverter is shifted and the reverse voltage becomes large. In this way, the DC intermediate circuit current can be momentarily at zero. If the current becomes zero and the power supply voltage drops, the thyristor ignition pulse is completely stopped. If the power supply voltage recovers, it is automatically restarted with confirming of the voltage.

Fig. 12 shows the chart of automatic restarting flow. When there is a long-term power interruption, the main motor is stopped. This time is determined by the pump distribution system conditions. When restarting is possible and the main motor rotational

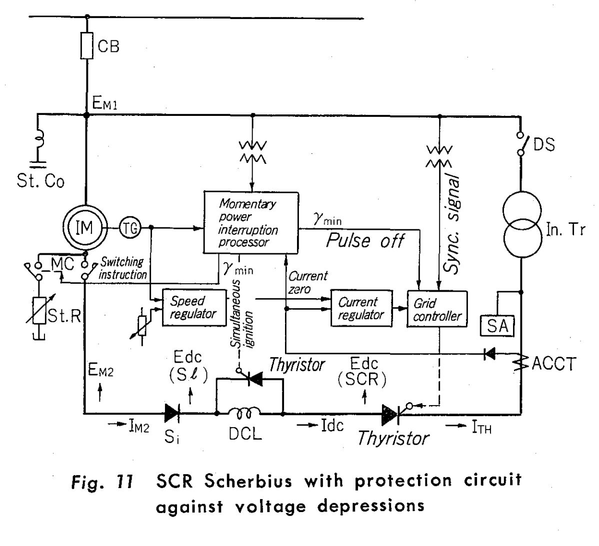


Fig. 11 SCR Scherbius with protection circuit against voltage depressions

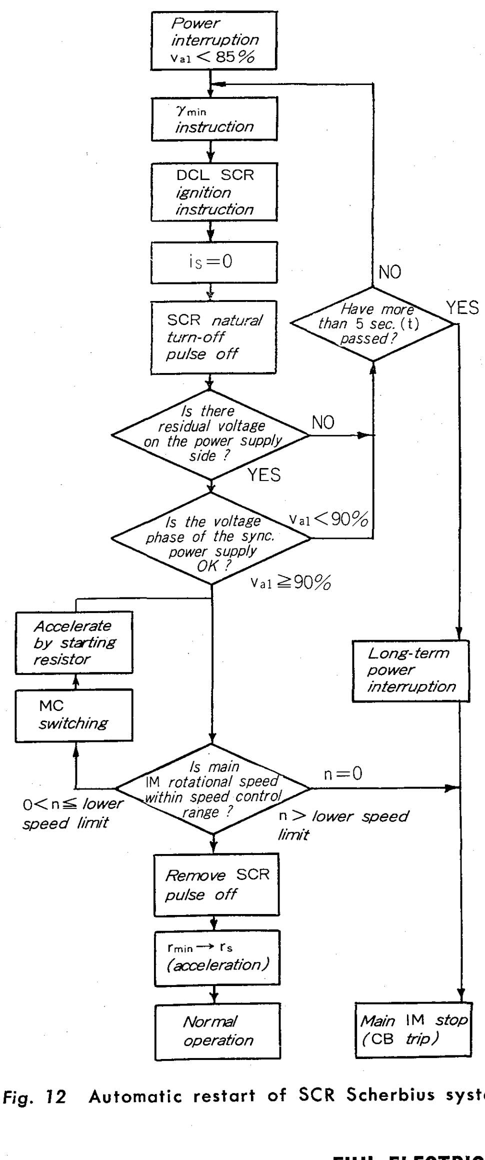


Fig. 12 Automatic restart of SCR Scherbius system

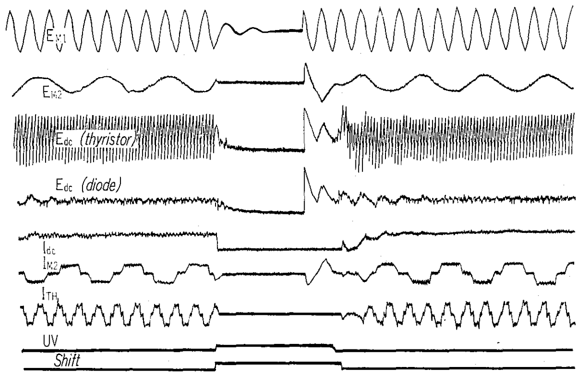


Fig. 13 Oscillogram of SCR Scherbius circuit wave forms in case of voltage depression

speed has dropped below the Scherbius control range, there is acceleration by the starting resistor. Scherbius operation begins when the rotational speed increases. *Fig. 13* shows the oscillogram of the various waveforms during momentary power supply interruptions.

V. PUMP CONTROL SYSTEMS

1) Automatic operation

(1) Water level control (when pump intake side capacity is small)

When the pump well is small, there are considerable changes in the water level when the pump is started or stopped. These water level changes can be decreased and the pump starting frequency can also be lowered by using pump speed control or valve opening control.

Fig. 14 explains the control system. When there is constant water level control by means of a regulator with integral elements, the overshoot in the transient speed change phenomena becomes large or ON/OFF control occurs. Therefore under such conditions, stable control is possible by cascade setting by means of the water level.

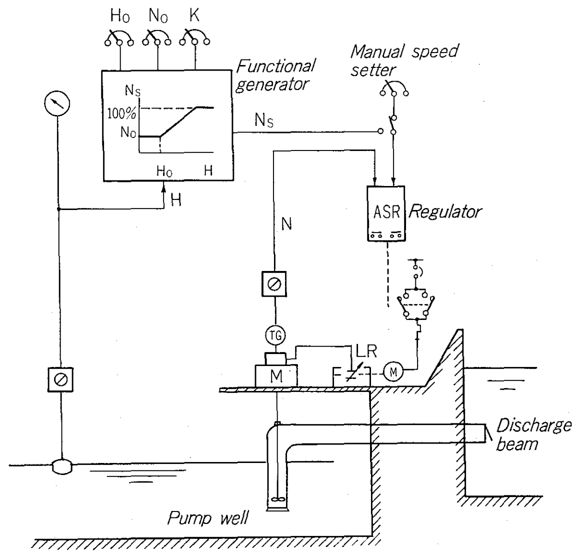
This system is often used for rainwater pump control in sewage pumping stations.

(2) Water level control (when water level of discharge side pondage tank is to be constant)

When the capacity of the pondage tank is small, the method mentioned above is effective. When the capacity of the pondage tank is medium, the number control system according to the water level can be used. When the pondage tank has a large capacity, uniform pump operation is difficult by water level control alone. It is desirable that the pump discharge flow be controlled so that the amount is corrected by the water level discrepancy in the pondage outflow. The control system in this case is as shown in *Fig. 15*.

This system is often used for water works distribution and transport pumps.

(3) Pressure control



H_0 : Standard water level (lower limit)
N_0 : Standard speed (lower limit)
K : roportional degree
N_S : Set speed
N : Speed (measured value)
ASR : Speed regulator
TG : Tachogenerator

Fig. 14 Block diagram of pump well level

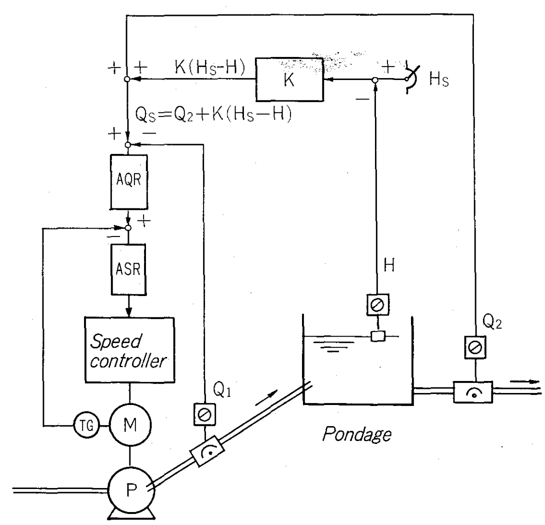


Fig. 15 Water level control of reservoir with large capacity

When the water transport and distribution piping resistance is large, the pressure at the terminals changes in accordance with the water demand. Constant terminal pressure control is performed to maintain the terminal pressure at an appropriate value. The control system is shown in *Fig. 16*.

(4) Flow control

When water transport is planned, flow control by a 24-hour program setter is applicable. This system is often used for water works peak pump control.

(5) Number control

In the above pressure controls, etc., automatic

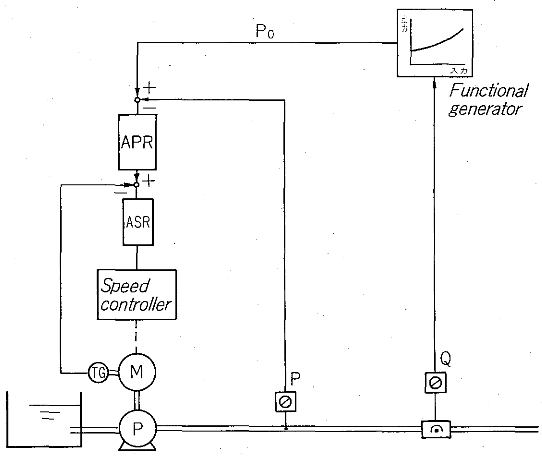


Fig. 16 Terminal point pressure control

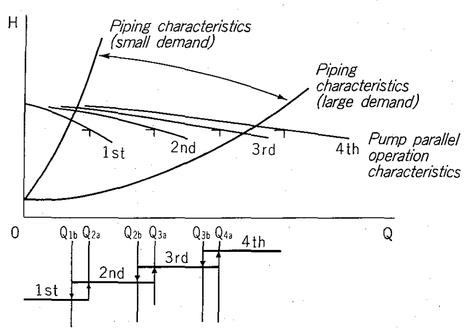


Fig. 17 Number control of constant speed pumps

number control by means of flow is often used concurrently. When the pump is operated at a constant speed, number conversion by flow alone as shown in *Fig. 17* is sufficient but in the case of speed control, the possible operating range is changed in accordance with the speed so that the pressure factor is added. When the number of pumps is changed as in *Fig. 18*, highly efficient operation is possible. Such control is simple if a mini-computer is used.

2) Pump protection

(1) Cavitation protection

The range in which pump cavitation occurs is given by the following equation:

$$H_a+h_S-h_v-h_s \leqq \left[\frac{N\sqrt{Q}}{S}\right]^{4/3}$$

where H_a: atmospheric pressure
h_s: actual suction lift
h_v: saturated steam pressure
h_t: suction pipe loss head
Q: discharge
S: suction ratio speed (constant)
N: rotational speed

With a constant speed pump, the cavitation limit when the suction side pressure is above the planned value is determined only by the discharge flow. When the pump speed is controlled, the cavitation limit is changed by the rotational speed. In this

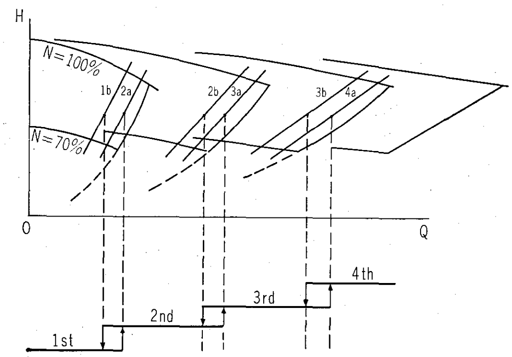


Fig. 18 Number control of variable speed pumps

case, protection by the same characteristic curves as those shown in *Fig. 18* is necessary.

(2) Piping abnormality detection

When there is a burst in the piping, a sudden change in the flow and an increase in the fault occurs.

a) Detection by flow changes

Detection is by determining the changes with time of the discharge flow $Q(t)$.

$$\frac{Q(t)}{dt} > K \qquad K\text{: set value}$$

Detection is by the above equation but when control is by a mini-computer:

$$\frac{Q(t)-Q(t-\Delta t)}{\Delta t} < K$$

Δt: sampling time

Detection can be easily performed.

b) Detection by flow increases

There is inherent resistance in the piping on the pump discharge side and normally, the corresponding total lift does not drop below this. Therefore, piping abnormalities can be detected from the relation between the flow and the pressure.

$$H < RQ^n + H_0$$

where H: discharge pressure
R: piping resistance
Q: discharge flow
n: constant (1.85～2)
H_0: actual lift

VI. CONCLUSION

The above article has outlined the basic concepts and methods of pump control. Recently, small capacity mini-computers have been used in various fields and they are also very effective in pump control.

Considerable progress has been made over the last 10 years in pump control in relation to energy savings and maintenance but there will be greater emphasis in the future on total plant economy and reliability.