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COMPUTER CONTROL SYSTEM FOR WATER AND SEWAGE WORKS

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I. INTRODUCTION

In recent years, in order to effectively utilize limited water resources, operate water works economically and rationally and supply users with appropriate amounts of good quality water, wide ranging water control systems including forecasting functions have become necessary as an advancement from the conventional filtration plant control systems.

On the other hand, sewage works have greatly expanded from the standpoints of the maintenance of living environments and the prevention of water contamination. Facilities are tending to become larger, more complex and handling wider areas and the control systems are also becoming more efficient and appropriate. With the introduction of computer control systems, there have been remarkable technical advances to systems which perform total control of all sewage in a river basin. Fuji Electric is the leader in the industry in the supply of computer control systems for water and sewage works and a wide range of technology has been accumulated on the basis of this experience. This article introduces mainly the application software for total process control systems for water and sewage works.

II. COMPUTER CONTROL IN WATER AND SEWAGE WORKS

1. Wide Ranging Total Water Works Control System

1) Processing system

A wide ranging water works processing system consists of several dams and rivers as water sources, a group of filtration plants for water treatment; pumping stations, distributing basins and pondage for intake and distribution of the water as well as the conduits and piping to connect these facilities and the piping leading to users' houses as can be seen in *Fig. 1*. From the dams, the water is discharged in accordance with the amount of water in the reservoirs, the rainfall, the river conditions and the demand conditions. The water is taken in by the pumping stations in keeping with water concessions and demands and conducted to the various filtration plants. After filtration, the water is distributed to the users via the distributing basins and pondage.

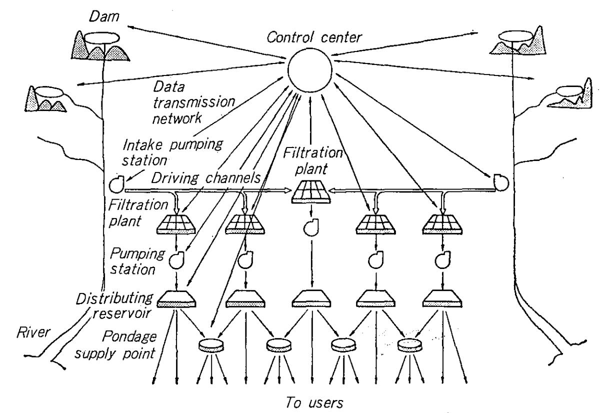


Fig. 1 Systematic diagram of wide area water supply system

The total control system performs all operations rationally from intake to the end of distribution by forecasting possible intake amounts and demands, evaluating the treatment possibilities in the filtration and distribution facilities and securing optimum operation of all facilities.

2) Composition of the total control system

(1) Control center system construction

The control center in the wide area water supply total control system is the core of the system and it must be provided with the following basic functions:

(a) Large scale data transmission and processing and data banking
(b) On-line real time data processing and control
(c) INQ (inquiry) function
(d) Remote batch function
(e) System development and analysis functions
(f) Function to raise level of the system

The control center is equipped with a large-scale computer and peripheral equipment as shown in the sample system construction in *Fig. 2*. As the man/machine interface, there are monitoring panels, television display and typewriter equipment, operator console, etc. There is also communication control equipment to perform an exchange of communi-

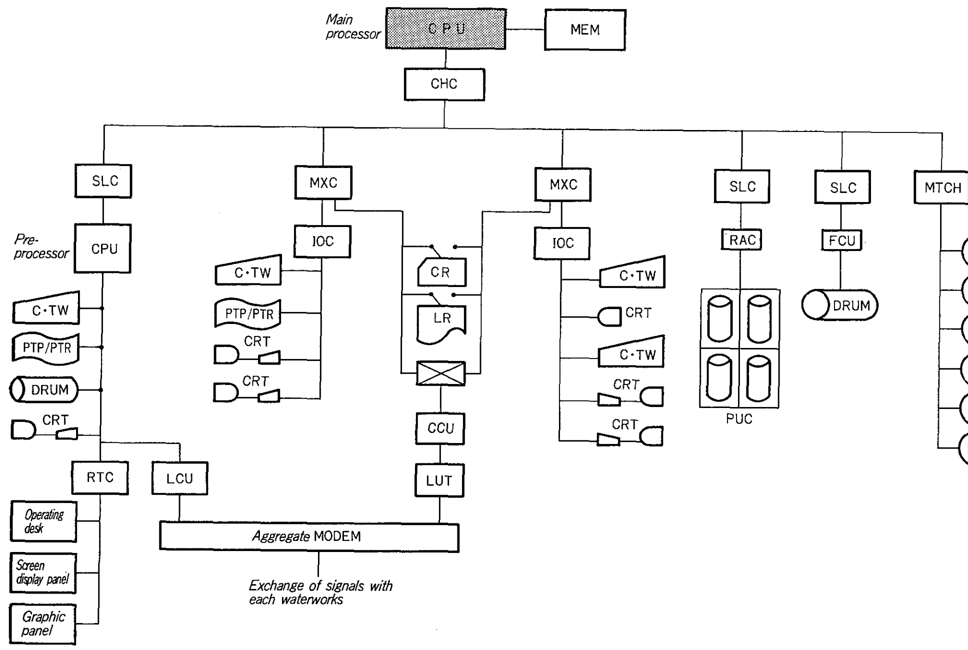


Fig. 2 System construction diagram of control center

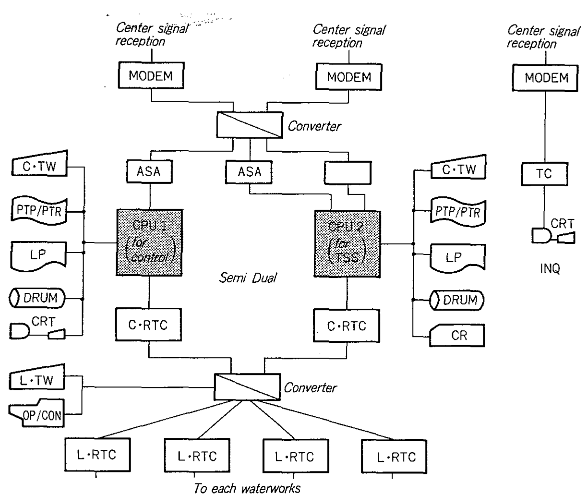


Fig. 3 System construction diagram of filtration plant

cations with the water works treatment facilities.

(2) Construction of filtration plant system

The role of the filtration plant control system in the wide area total water works system is to control water filtration and distribution on the basis of instructions from the control center, to control data from the pumping stations and supply points (distributing basins) and data relaying.

The construction of the filtration plant control system consists of a control computer, TSS terminals, peripheral equipment, INQ terminals, process input/output equipment (RTC) and data transmission equipment.

For the man/machine interface, there are monitoring panels, television display and typewriter equipment, operator console, etc. The control center computer can be widely utilized from the INQ and TSS terminals via circuitry. In addition, telemeter and telecontrol equipment is necessary to obtain data from the pumping stations and supply centers.

(3) Data transmission

Data transmitted between the control center and the various treatment facilities include information sent from the facilities to the center, instruction requests and control instructions from the center to the facilities and responses to the requests. The transmission circuits between the center and the various facilities are special private lines, public telephone lines, multi-directional multiple radio lines and uni-directional (1:1) radio lines which are used in accordance with the conditions.

Control and operation instruction signals from the control center are transmitted to each of the facilities as set time instructions and emergency instructions.

However, the data from the facilities such as measurement results and equipment operating condition data are transferred to the control center at set times or in emergencies. The transmission period for these data is 5 minutes, 1 hour, 1 day, 1 week, etc. depending on the data contents.

The transmission speed is normally 1,200 BPS or 2,400 BPS.

3) Functions of total control system center computer

(1) Control functions

The processes in a wide area water supply system are characterized by a large transmission lag—the idle time is large compared with the process time constants. The control system must be sufficient to perform effciently for the whole system such operations as the intake pumps, valve control, dam discharge amount control, estimations of amounts remaining in the water sources, etc. on the basis of appropriate water distribution instructions to the entire system ; to produce water which meets the standard in respect to both guantity and quality ;

to supply water to the various supply points encompassing the distributing basins and complex piping networks ; and forecast demand.

Therefore, normal plant operation must have countermeasures against idle time and forecast control on the basis of demand forecasts but the control algorithm requires optimum control to minimize operating costs and ensure stable utilization of the equipment.

For abnormal plant opertion—when there is an accident in the plant, when there is a level abnormality caused by a plant accident or a forecast error, when the quality of the water from the source is abnormal or when there is a combinations of any of these—the number of control objects increases remarkably and the corresponding control becomes more complex.

Therefore, appropriate classification of abnormalities and corresponding processing patterns must be performed by decision tables, etc. and there must also be a rapid return to normal operation by means of operating instructions requested by the start of the processing program. From the standpoint of the amount of water, the processes controlled form a wide ranging network connected by branches (open water conduits, piping) with unit buffers as nodes (storage facilities such as filtration basins, distributing basins, etc.). The objects for control can be specified for each buffer level and the corresponding operation can be specified for inflow and outflow amounts to the buffers.

The approaches from the optimum control are of various types ranging from theoretical items such as LP, DP and MP to trial and error items for estimated water level variations in specified patterns.

From the standpoint of water quality, there are various types of control such as control of injection of cohesion agents in the filtration plants, related control around the settling basins, control chemical injection rate setting related to water quality control concerning turbidity, alkalinity, etc. at the outlets of the settling and purification basins, control around the filter basins, and control related to water transport, desludging, etc. However, the job of the center should be to give out control instructions calculated on the basis of the optimum control algorithms and the corresponding local control loops should operate by site SPC or DDC level application programs.

(2) Management functions

(a) Total control system

The center system when viewed from the standpoint of control is connected radially to the various terminals in the filtration plants and pumping stations.

The results of data exchanges and data sent from the site are accomodated in files provided for each function after processing such as checking or deducting. These data can be given out for logging of daily and monthly reports, etc. or can be referred to from the operator console, CRT, etc.

The measurement data are used for the required control processing in the various control jobs for intake, distribution, water quality, etc. in the wide area water supply system. Manual setting instructions are added, the control instruction filts are edited and control instructions are transmitted.

(b) Reliability

To prevent blind operation of the entire system when the control center computer is down, the system must have a data bank function in the preprocesser and independent operation of the filtration plants and pumping stations must be possible when they are separated from the center to increase the reliability of the system in the filtration plants and pumping stations.

Therefore, the fail-safe construction must be used for the hardware components (dual, duplex) and for the software, a fail-soft function must be provided in the various control jobs to achieve the optimum security control items.

(c) Expandability

If kept within the range of the maximum structure decided when the system was edited, expansion of auxiliary memory equipment is easy. Software expandability is also very important. For example, it is necessary to give sufficient consideration to easy compilation, addition to, correction and erasing of files—compiler levels and utility levels aid in this—and also to easy functional improvements of the core operation programs, etc.

(d) Aids to control system operation

The control center has various data not at the sites. These data can be referred to at the various sites and can assist site plant operation.

The right to utilize the center computer which has a higher functional level and a larger scale than the filtration plant total control system computer can be opened to the sites (TSS).

In on-line job intervals, simulation for process model identification, control system analysis, etc. and operation of the plant structural design, management and clerical control systems is possible.

2. Filtration Plant Total Control System

1) Type of total control system

The construction of the filtration plant total control systems differs in accordance with size and type of equipment in the filtration plants. The equipment components and control items must be decided depending on the control and management systems at the design stage.

(1) Filtration plant independent computer control system

In this system, one computer is provided in each filtration plant and monitoring control is performed independently (there are no connections to other computers).

This is the standard system when monitoring and control of the chemical injection, settling basin, etc. are performed in the plant.

(2) Hierarchy computer control system

When the connections of the various facilities in the filtration plant with it high processing capacity are complex, the hierarchy computer control system is generally used.

With this system, the jobs are clearly divided between the upper and lower level computer functions. The upper level computer performs operations for all of the filtration plants such as high level sequence processing and operations between the filtration plants as well as overall system development of off-line jobs, etc. It is a large scale computer. The lower level computer performs control and monitoring in the filtration plants.

(3) Scattered type computer control system

Recently, highly advanced micro-computers have come into use and various types of data which were formerly collected in centers are now collected in micro-computers located at the sites. These computers perform local control. Many devices in each facility are controlled per function by each computer. A computer (medium size or over) for overall control is located in the center and connections are made with the local micro-computers by means of data transmission equipment such as the data highway.

2) Total control system functions

There are three types of filtration plant total control systems as described above on the basis of construction.

The functions for each system can be shown by the classification in *Table 1* (in the filtration plant independent computer control system, the items related to the center, i. e. b), e), j) and k) are not applicable).

Table 1 Classification of main application software

a) Filtration plant data collection
b) Data transmission to control center
c) Data checking
d) Condition monitoring
Condition display on display panels
Data display by color video display
e) Recpetion of instructions from control center
f) Filtration plant control
i) For intake
ii) For driving
Water level control, flow control, diversion well level control, raw water flow control
iii) For pretreatment with chemicals
Sulfuric acid band ratio injection control, sodium hydroxide injection control, preliminary chlorine ratio injection control
iv) For settling basins
Settling basin speed control, desluding control
v) For filter basins
Filter basin flow control, prior and after washing flow control
Filtration tank water level control and lift pump automatic operation
Automatic filtration equipment
vi) For after-treatment with chemicals
After-treatment chlorine ratio injection control
vii) For supply and drainage water
Supply water flow control and distributing reservoir water level control
Waste water reservoir water level control and waste water pump automatic operation
viii) Supply water measurement control
Distribution plant measurement control
ix) For water quality
Turbidity control
pH, alkalinity and conductivity control
g) Data collection from pumping stations and supply points
h) Control of pumping stations and supply points
i) Data processing control
Compilation of daily reports
j) INQ with control center
k) TSS with control center

3. Application Software

The apllication software for the wide area water supply total control system is divided into blocks for each type of job with the connections between them as shown in *Fig. 4*. The main items are described below.

1) Wide ranging distribution control

When showing the processes to be controlled in a wide area water supply system by means of the signal flow of the nodes and branches (*Fig. 5*), the water distribution amounts can be decided if one returns in sequence from the terminal nodes to the trunk nodes.

In this case, control principles are applied to unit buffers as the various nodes. At this time, the output of the terminal node nearest to the user is estimated on the basis of the forecast model.

There are various types of estimation methods including (1) the method of least squares+exponent levelling, (2) shift averaging, (3) self regression analysis and (4) the Karman filter. The forecast width is mainly a short-term forecast of about one day from the idle time each hour.

The inflow amount to the terminal node is calculated on the basis of this estimated outflow. The water levels of the control amounts for each buffer are as follows:

$$H_{n+1}=H_n+\frac{Q_{\mathrm{IN}_n}-Q_{\mathrm{OUT}_n}}{A} \quad \text{..............(1)}$$

$$\underline{H}_n \leq H_n \leq \overline{H}_n \quad \text{..............(2)}$$

where Q_{IN} : inflow amount, Q_{OUT} : estimated outflow amount, A : basin area.

When the evaluation standards are set in relation to H and Q_{IN}, the operating amount Q_{IN} can be decided by *LP* or *DP*.

The simulation type trial and error method in which the limits in equation (2) are satisfied and the changes in Q_{IN} are kept small can also be used.

In this case also, for example for the system shown in *Fig. 5*, the operating flow amount can be determined from 2 types of algorithms of the forecast control mode and the abnormality treatment

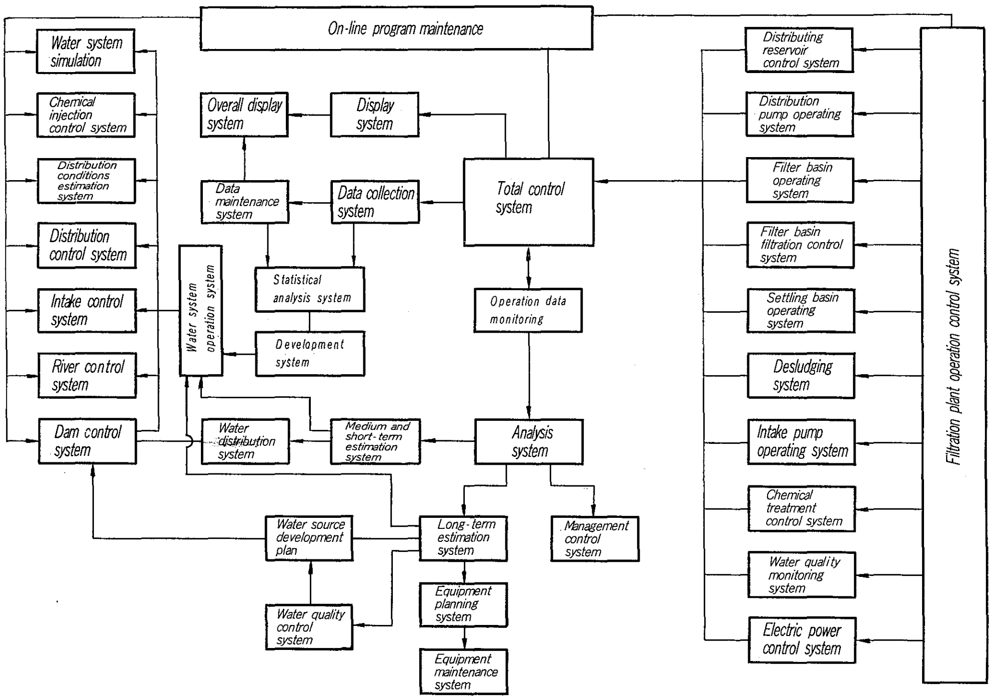


Fig. 4 **Application software block diagram of total control system**

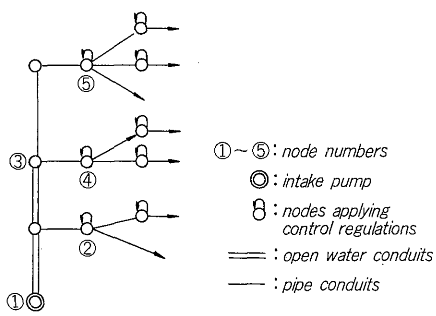


Fig. 5 **Signal flow diagram**

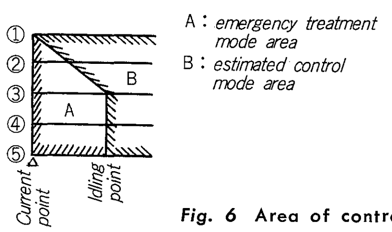


Fig. 6 **Area of control mode**

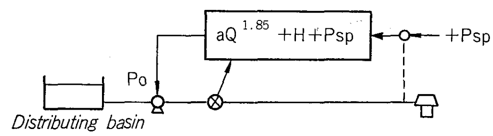


Fig. 7 **Setting control of pumping pressure**

mode at the boundry of the idle time of the tunnel between nodes ①~② and ① and ③.

When the *LP* is used, dynamic scheduling is also possible but the probability that no answer will be obtained increase in accordance with the value of the subscript "*n*" of the time band.

When *DP* is applied to the individual nodes, the computing time and the roughness of the changes in the operating amount of the answer obtained are not compatible and therefore, the aplicability for on-line jobs deteriorates.

2) Narrow area distribution control

(1) Distribution condition forecast

The flow rates and energy levels (total of position, pressure and head speed) in the conduits at the various supply points are estimated by the piping calculation program (the estimation is naturally not necessary if there is a sensor).

The piping calculation is performed in two ways: by obtaining the loop flow rate such that the totals of the head losses in each loop are zero (Hardicross method) and by obtaining the energy level so that the total flow in and out of each node is zero.

In both cases an unstable factor for numerical analysis (when solved as non-linear hypercomplex simultaneous equations, convergence can not be confirmed) is included and this point must be carefully considered when on-line jobs are connected.

(2) Distribution control

(a) Using the standard pipe end pressure setting value

The pump discharge pressure instruction value P_0 required to satisfy the specified value P_{SP} of the pipe end residual pressure is shown as follows:

$$P_0 = aQ^{1.85} + H + P_{SP} \qquad \text{..............(3)}$$

where H: standard difference between pump and standard pipe end, Q: flow rate.

Therefore, the control system for the pump pressure setting in this case is as shown in *Fig. 7*.

(b) Control by actual pipe end pressure

The pump discharge pressure instruction value P_0 is as shown in equation (4).

$$P_{0n} = P_{0n-1} + \alpha(P_{SP} - P) \qquad \text{..............(4)}$$

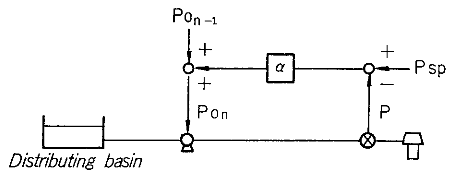


Fig. 8 **Setting control of pumping pressure**

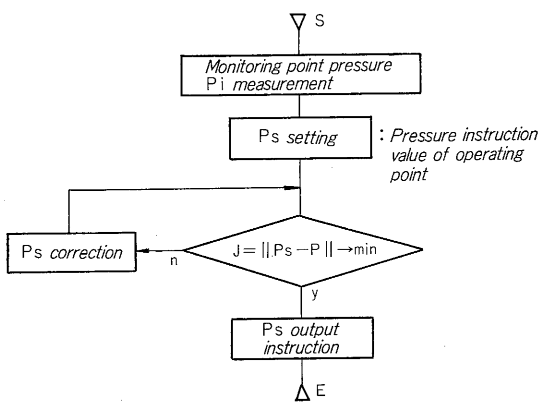


Fig. 9 **General flow chart of pressure control**

where P_{0n-1}: previous discharge pressure set value
P_{SP}: standard pipe end pressure setting
P: actual pipe end pressure

A block diagram of this case is shown in *Fig. 8*.

(c) Using functions of several variables

When there are many control points, there are several methods which can be considered including calculation of the optimum operating pressnre by trial and error with the piping calculation program as the basis (*Fig. 9*) but in all cases, there is still room for improvements and expansion in respect to algorithms.

3) Demand forecasts

Short-term demand forecasts are utilized in distribution forecasts, distributing basin operation, etc. Medium-term demand forecasts are used for distribution and storage planning. Long-term demand forecasts are used for dam storage and equipment investment planning.

4) Intake pump intake amount

The intake values for each pumping station are alloted and set on the basis of the set intake values for each filtration plant. The allotment of the intake amounts is decided so that the intake cost and chemical treatment cost total is a minimum in consideration of the pumping station operating rates. When the intake amounts are decided, such factors as the possible intake amounts for each pumping station, the water intake rights and the responsible discharge amounts are considered. When pressureless tunnels are included in the crude water transport system, the intake instruction timing is decided in consideration of the required transport time.

5) Filtration plant intake amounts

The total intake amount of each filtration plant is decided by the total amount of water distributed and the operating methods used for each distributing basin. The allotment of the intake amount for each filtration plant is determined by the LP method, etc. from the coordinated transport of water to each distributing reservoir, the filtration plant treatment costs, the water transport costs, the operating rates, the permissible range in treatment amount variations, etc.

6) Optimum operation instruction items of filtration plants

(1) Injection rate of cohesion agent

The injection rate of the cohesion agent consists of an injection rate decided by such feed-forward factors as crude water turbidity, crude water alkalinity, alkali injection rate, preliminary chlorine injection rate, pH and water temperature and an injection rate correction value decided by feedback factors. The feedback factors include the treated water turbidity as a criterion of the cohesion settling conditions, the Zeta potential, the conductivity and filter basin operating data.

(2) Alkali injection rate

The alkali injection rate is determined from the cohesion agent injection rate, the preliminary chlorine injection rate, the crude water alkalinity, etc.

(3) Preliminary chlorine injection rate

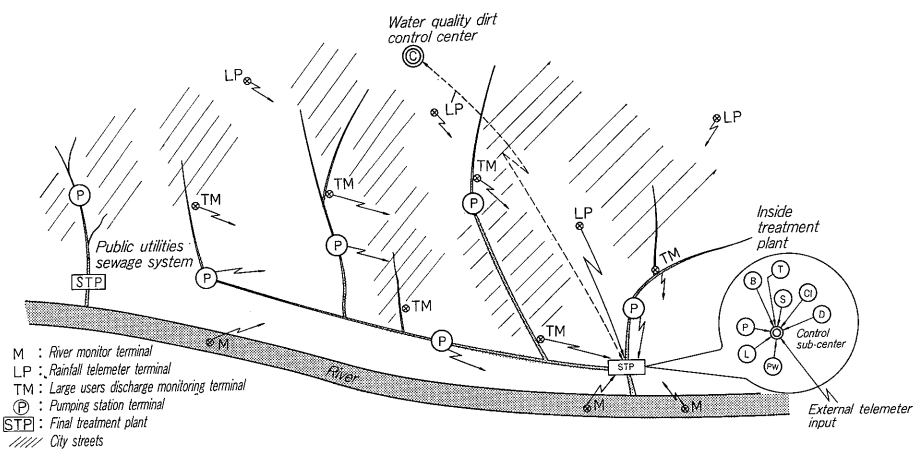


Fig. 10
Schematic diagram of information signals of basin-wide sewage

The preliminary chlorine injection rate is an injection rate determined from the concentration of such chlorine consumption products as ammonia nitrogen and manganese in the crude water, the water temperature and pH, etc. and it is corrected by the feedback of the residual chlorine in the treated water. The concentration of the chloring consumption products is controlled by an in-line system.

Since there is a large time delay in preliminary chlorine injection control, the feedback correction

***Table 2* Classification of main application program**

System name	Nomenclature	Contents and level division	System I	System II	System III	System IV
Total operation control system	Data collection (including checking)	Data collection 1 (analog pulse input), data collection 2 (digital input)	○	○	○	○
		Data collection 3 (frequency input), data collection 4 (telemeter input)	○	○	○	○
		Data collection 5 (irregular input, water quality input), data collection 6 (time series data collection)	○	○		
	Data transmission	Data transmission 1 (no-control, call response)	○	○	○	○
		Data transmission 2 (polling selection system)	○	○		
		Others (file cross-call, multi-processor)	○			
	Abnormality diagnosis	Upper/lower limits, variation rate, sequence faults, control delays, hardware faults, program irregularities, water quality meter monitoring	○	○	○	○
	Operator console	Setting, display, interrupting	○	○	○	○
	Reporting	Alarm print-out, daily and monthly reports (including initial processing)	○	○	○	○
	Scheduling	Plant operation planning (tertiary treatment, sludge treatment)	○	○		
	Batch processing	FORTRAN utilization (statistical analysis, technical calculations)	○	○		
	Data bank, data retrieval		○	○	○	
	CRT display	No. 1 (data display, setting display, alarm display, skeleton display data retrieval, operator guide)	○	○	○	○
		No. 2 (estimation display, control data display, simulation display)	○	○		
Inflow sewage control system	Estimation of amount of sewage inflow and sewage quality	Flow telemeter system, relay pumping station telemeter system	○	○	○	
		Rainfall telemeter system, operator setting system	○	○		
	Relay pumping station control		○	○		
	Inflow sewage measurement		○	○	○	○
	Rainfall calculation		○	○		
	Rainfall variation estimation		○	○	○	○
Sewage treatment control	Inflow gate operation, settling basin cyclic sequence control		○	○	○	○
	Pump control		○	○	○	○
	High level treatment control (including removal of excess sludge)	Flow control (amounts of air and transmitted sludge)	○	○	○	○
		Program control	○	○	○	
		On-line water quality simulation	○	○		
		On-line water quality control	○			
	High level sequence treatment control		○	○		
	Initial sludge removal control		○	○	○	
	Chlorine injection		○	○	○	○
Sludge treatment control	Dehydrater control		○	○	○	○
	Furnace control		○	○	○	
	Digestion tank control	Sequence control	○	○	○	○
		Optimum control	○	○		
	Dehydration pretreatment control		○	○	○	○
	Heat treatment control		○	○		
Receiving and transformer power control	Control demand control		○	○	○	
	Automatic power factor regulation		○	○	○	
	Bus line load monitoring		○	○	○	○
	Power failure load distribution guide		○	○	○	

is in the form of sampling control.

(4) Later chlorine injection rate

The later chlorine injection rate is an injection rate determined by such feed-forward items as residual chlorine in the filtered water, water temperature, pH and anticipated stagnation time and it is corrected by feedback of the residual chlorine at the filtration plant basin outlet. The feedback correction is by sampling control.

(5) Settling basin operation control

Settling basin operating instructions include floccuater speed setting and desludging instructions.

The floccuator speed is determined from the shaking speed, speed gradient, stagnation time, etc.

The desludging instruction is given in accordance with estimations or detections of flock settling conditions. Estimation of the settling conditions is performed from the impurity removal rate, the flock formation rate, the treatment flow rate, etc. A sludge level switch is used in the detection of settling conditions.

(6) Filter basin operating instructions

The filter basin operating instructions consist of filter rate setting and filtration instructions.

The filter rate is the optimum rate and the number of filterings is decided from the filter rate.

The filtration instruction is determined in accordance with the filter resistance, the continuous filter time and the filter operation plan as well as the cohesion agent used, the cohesion settling conditions, the purity of the treated water, the purity of the filtered water, the water temperature, etc.

(7) Return water flow rate

In principle, the return water flow rate is injected constantly in proportion to the crude water but there are equipment and operational limitations on the capacity of the drainage basins, drain water filtration conditions, etc. and it is necessary to alter this injection proportion in respect to the crude water and return water quantities.

III. COMPUTER CONTROL OF SEWAGE SYSTEMS

1. Total Sewage Control System

1) Sewage works and data transmission system

In systems to prevent rive basin contamination in consideration of the basin total sewage control system and the discharge after treatment, the widening of the areas covered has brought about more complex data transmission routes. *Fig. 10* shows the data transmission system.

2) Terminal treatment station sub-centers

The sub-centers in large scale treatment stations collect data from the following places:

Ⓟⓦ : high voltage receiving and transformer station electrical rooms,

Ⓟ : settling basin pump equipment electrical rooms,

Ⓢ : dirty water treatment electrical rooms (2~6 places),

Ⓣ : high level treatment electrical rooms,

Ⓓ : sludge treatment electrical rooms (or control rooms),

Ⓑ : blower electrical rooms and

Ⓛ : water quality testing laboratories.

Table 3 **System construction of system I~IV**

Name		Specification components				Remarks
		System I	System II	System III	System IV	
Central processing unit (CPU)	Main memory	64kw over	32kw over	24kw over	12kw over	Specifications after expansion
Magnetic drums	Auxiliary memory	512kw over	512kw over	256kw over	128kw over	Specifications after expansion
Magnetic disks	Auxiliary memory	512kw over	128kw over			Specifications after expansion
Magnetic tapes		○	○	○		"○" means recommended
System typewriter		○	○	○	○	"○" means necessary
Line printer		○	○			"○" means necessary
Paper tape puncher		○	○	○	○	"○" means necessary
Paper tape reader (card reader)		○	○	○	○	"○" means necessary
CRT display	640 character color	○	○	○	○	"○" means necessary
	4,000 character color	○	○			"○" means recommended
Typewriter		○	○	○	○	"○" means necessary (however, unnecessary when there are two or more LP's in system I and II)
Real time controller		○	○	○	○	"○" means necessary
Relay panel		○	○	○	○	"○" means necessary
Operator consol		○	○	○	○	"○" means necessary

3) Total control system job items and hardware components

The jobs for the total control system are normally as given in *Table 2*.

For the types of main application programs, the programs are classified into system I to system IV depending on system functions.

Systems I to IV have the hardware components shown in *Table 3*. However, the job classification is not always so strict and there is some system flexibility.

2. Application Software

The tatal sewage control system has as its major component the control computer system and there is a tendency to shift from rational operation to optimum operation. The main application software for the sewage treatment system is described below.

1) Sewage inflow estimation

There are four estimation methods based on the data collection method.

(1) Inflow telemeter method

This system is used in the final treatment stations of urban sewage systems. The telemeter terminal is located at some positions in the main line and water flow rate and quality data sent from it are collected and the amount to flow into the terminal treatment station is estimated. With this system, only comparatively short-term estimations are possible but correct estimates can be made.

(2) Rainfall telemeter method

This method uses a weather observation telemeter terminal and the amount to flow into the terminal treatment station is estimated from the river basin covered by this terminal and the flow out time on the basis of the amount of rainfall. It is used for large basins in river basin sewage systems, etc. Comparatively long-term estimations can be made but long-term data collection is required before accurate estimations can be made.

(3) Relay pumping station telemeter method

In this system, relay pumping stations are located in the trunk lines and estimations are made from the pump discharge pressures or the number of pumps operating, etc.

(4) Setting system by operator

In this system, the operator in the control room manually makes settings from the operator console. The evaluation data in this case can be of various types from methods (1)~(3) above.

2) Sewage inlet quality estimation

As in the case of sewage inflow estimation, there are four methods for water quality estimations in accordance with the data collection system:

(1) Water quality telemeter system
(2) Rainfall telemeter system
(3) Relay pumping station telemeter system
(4) Setting system by operator

Of these, (2) estimates water quality changes when there is a shift from dirty water to rain water during rainfall but the estimation is made by weighted averages against standard changes during fair weather from the records for the last several days. Therefore, long-term statistical data is required.

3) Rainfall calculation

This calculation is basically the same as the rainfall telemeter system for sewage inflow estimation. However, while the changes in the amount of dirty water from the wide-ranging drainage area is stressed in the sewage estimation, the amount of rain water entering the normal urban sewage system is calculated in the rainfall calculation.

Data collection is by rainfall telemeter but there are four types according to the layout of the sewage equipment.

4) Rainfall variation estimation

Since the rainfall calculations cover a relatively long period, a variation estimation is performed without telemeter input from data set from the operator console and change rates of water inflow, etc.

5) Sewage inflow calculations

The calculation of sewage inflow is often difficult in treatment stations. Five systems are used depending on the data collection method.

(1) Partial fume method

In this system the water levels are measured and processed in a computer.

(2) Flow rate/water level method

In this system the flow rate is measured by a ultrasonic flowmeter, the area is calculated from the water level and the amount is then calculated. Since there is a large difference in levels when it is raining and when there is the normal dirty water, the flow rate is measured at several points and the constants used for the average flow calculation from the water level are changed according to the computer tables.

(3) Water level calculation method

In this method the flow rate is calculated by the ideal water formula from the water level.

(4) Lift pump Q–H covering formula

This method is used to calculate amount of lift from the pump Q–H characteristics and the water levels of the pump well and the distributing well.

(5) Lift pump discharge flow rate method

In this method, an ultrasonic flowmeter is attached on the pump discharge side and calculations are made by a computer.

6) Setting basin control

The settling basin control is confirmed to two point control: flow rate in the basins and water area load (or stagnation time). The water area load can determine the number of basins used in accordance with the flow and the control aim can be achieved by increasing the number of basins used. When there is no flow rate control mechanism such as a proportional dam or a partial flume, selection of the number of basins used and control of the

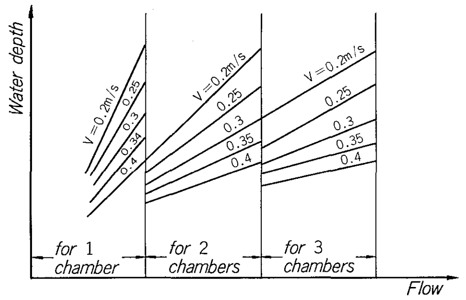


Fig. 11 Water level control of grid chamber

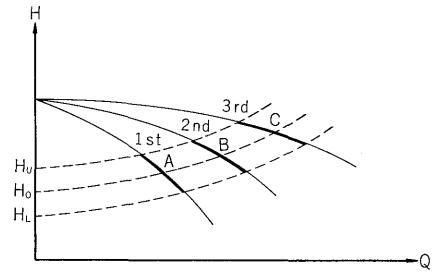


Fig. 12 Characteristics of pumps

water depth become very important in maintaining a suitable flow rate in the basins.

In facilities with a pump well connected near the downstream side of the setting basin, the water level of the pump well directly influences the settling basin water level so that mutual control is required.

Fig. 11 shows the water level control range and basin selection number in accordance with changes in the flow rate.

7) Relay pumping station control

Relay pumping station control is of various types but the following three methods are used if unmanned operation is a prerequisite.

(1) Pump number control method

Changeover of the number of pumps in use is controlled by a computer and auxiliary equipment, etc. is controlled by telecontrol operations.

(2) Pump number and speed control method

In this system, the number of pumps and their speeds is set from the center. Since the setting values are calculated from the flow rate, it is necessary to perform corrective operations by means of the pump well water level at the site. The auxiliary equipment, etc. is controlled by telecontrol operations.

(3) Pump control and auxiliary equipment control method

In this methods, auxiliary equipment sequence control is performed by a computer in addition the pump number and speed control. When the transmission equipment is loaded, sequencers can also be located at the sites.

8) Pump well water level control (pump operation control)

Pump operation control methods include pump number control and speed control. Pump number control results in the changing of a pump lift characteristics curve and an alteration in the operating points by means of changing the number of pumps in operation.

Since each pump is used at near the rated operating conditions, efficiency is good but the flow rate control range is not continuous (refer to *Fig. 12*).

In speed control, the pump lift characteristics curve is changed and the operating points are altered by means of changing the pump speeds. In this case, the Q–H characteristics are as follows with the speed N as parameter:

$$H(N)=\frac{H_0}{Q^2_0}\cdot\{Q(N)\}^2 \qquad \text{..............(5)}$$

where $H(N)$: head at speed N
$Q(N)$: flow at speed N
H_0: constant (head at 100% speed)
Q_0: constant (flow at 100% speed)

9) Method to determine initial settling basin sludge removal timing

There are three methods according to the input method.

(1) Sewage inflow SS setting method

In this method, the sewage input SS is fed in from the console the stagnation time is calculated from the flow rate and the amount of settling basin sludge is calculated from the normal settling characteristics.

(2) Sewage inflow SS measurement method

In this method, the SS of method (1) is measured.

(3) Sewage inflow and initial settling inlet SS measurement method

In this method, the amount of settling basin sludge is calculated from Σ [flow × (inflow SS − outflow SS)].

10) Air control

The following three methods are used to control the amount of air.

(1) Inflow/water quality ratio control method

In this method, the calculation is made by equation (6).

$$Q_{air}=Q_{in}\cdot f(S)+a \qquad \text{..............(6)}$$

where $f(S)$: function of water quality concentration (for example, TOD)
a: constant

(2) Aeration tank DO set value control method

(3) Water quality control method

In this method, control is performed for one operation value of the high level treatment water quality control described later.

11) High level treatment water quality control (No. 1)

For on-line control of high level treatment water quality control on-line simulation is performed and flow control settings are changed but after these results are obtained, the process is estimated on the basis of control and the operator performs evaluation from the display.

Simulation is classified into two types depending on the aim.

(1) Simulation of normal condition model

In this method, a calculation is made to find out what changes in operating conditions are suitable to maintain the desired outlet water quality when the inlet water quality and flow are changed at the current microfauna. There is no special consideration for transient conditions.

(2) Simulation by transient condition model (No. 1)

In this method, attention is focused on only load changes due to shock and calculations are made to determine what shifts are appropriate for return to normal conditions.

(3) Simulation by transient condition model (No. 2)

While method (2) above stresses transient response in a relatively short time, this method employs condition changes over a long period.

12) High level treatment water quality control (No. 2)

There are three types of high level treatment control according to timing by humans.

(1) Water quality input method

The quality of water in the aeration tank is set from the operator console and water quality measurements are made in the water quality testing laboratory.

(2) Water quality check method

In this method, the water quality trends and estimated values of the TOC, DO, etc. are displayed on the CRT and the operator performs checking by "OK" or "NG" operations.

(3) Simulation method

In this method, there is display of (2) and the control results forecast from these values and the operator makes corrections, etc. by evaluating these results.

13) High level treatment program control

In this system, the water quality is not measured and the treatment amount is controlled according to a daily pattern of sewage inflow during fair weather. The inflow amount Q_i is applied within certain limits and is classified according to the inflow pattern of life drainage.

14) Chlorine injection control

There are the following five aims for chlorine injection:

(1) Disinfection
(2) Odor removal
(3) BOD removal
(4) Prevention of sludge balking
(5) Prevention of corrosion

The use of residual chlorine in the evaluation of the injection results presents a problem in measurement and generally, the injection rate is calculated from the water quality, temperature, etc.

15) Sand transport machine operation

There are two types of sand transport machine control as follows:

(1) Estimation of settled amount

The estimation is made from the changes in the inflow amount and data concerning inflow amount increase rates and the accumulation patterns directly after changes are necessary.

Operation timing is by constant accumulation.

(2) Distribution estimation for settling basins

This estimation is made by making operating patterns of the running type bucket elevator sand transport machine.

3. Sewage Treatment Simulation and Water Quality Control

Computer simulation techniques are widely used to improve sewage treatment processes and develop control methods.

High level treatment dynamic simulation gives sewage inflow amounts and water quality by various types of time function forms. In various types of high level treatment, time changes of the required items are compiled by an X-Y plotter.

In the input function type, there are square waves, sine waves, curves, etc. and superimposition on a primary type is also possible.

This simulation program can be used with batch processing in total control systems of sewage treatment plants.

Estimations of changes in sewage inflow and quality can be made by a computer and by a simulator, it is possible to determine beforehand time changes of the treated water quality and the scale of excess sludge generation.

Time changes in the return sludge flow and required air flow are also determined and it is possible to set program control. In addition to the dynamic simulation program, a static simulation program which considered relations between the various condition variables has also been developed so that the operating values can be determined by display of the results on a CRT and trends can also be found.

IV. COMPUTER CONTROL OF WATER AND SEWAGE WORKS ELECTRICAL POWER EQUIPMENT

The electrical power equipment in water and sewage works is gradually increasing in capacity. Therefore, control for the efficient utilization of the equipment capacity is being automated and connections are often made with computers. The following sections describe an example of an automatic control system using a minicomputer.

1. Transformer Operation

1) Economic transformer operation

The number of units for optimum efficiency (little loss) in respect to the power demands is operated. When there is parallel transformer operation, the number of transformers used is controlled by the load current. When there are transformers with different ratings, combinations of transformers are selected so that loss is at a minimum.

2) Transformer overload operation

Transformer overload operation can be performed for peak loads.

(1) Overload ratio permitted by the ambient temperature drop

$$f_1=0.8\,(30-t_a)\,\% \qquad \text{..............(7)}$$

where t_a : ambient temperature (°C)

(2) Overload ratio permitted by temperature rise tests

$$f_2=1.0\,(t_0-5-t_T)\,\% \qquad \text{..............(8)}$$

where t_0 : temperature rise limit (°C)

(3) Short-time (0~4 hours) permissible overload ratio

The overload ratios are the f_3 values shown in *Table 4*.

(4) Overload ratio by load rate drop

$$f_4=0.5\times(90-L_f)\,\% \qquad \text{..............(9)}$$

where L_f : daily average load rate

(5) Overload ratio when conditions are superimposed

$$f=f_1+f_2+f_3+f_4 \qquad \text{..............(10)}$$

However, $f\leqq 25$ (continuous) $f\leqq 50$ (short-time)

Equations (7) to (10) are checked, the maximum point temperatures of the transformer are estimated by a computer and operation is safe.

(3) On-load tap changing control

The tap positions are detected, the taps are synchronized before starting parallel operation and the voltage is regulated so that the secondary voltage

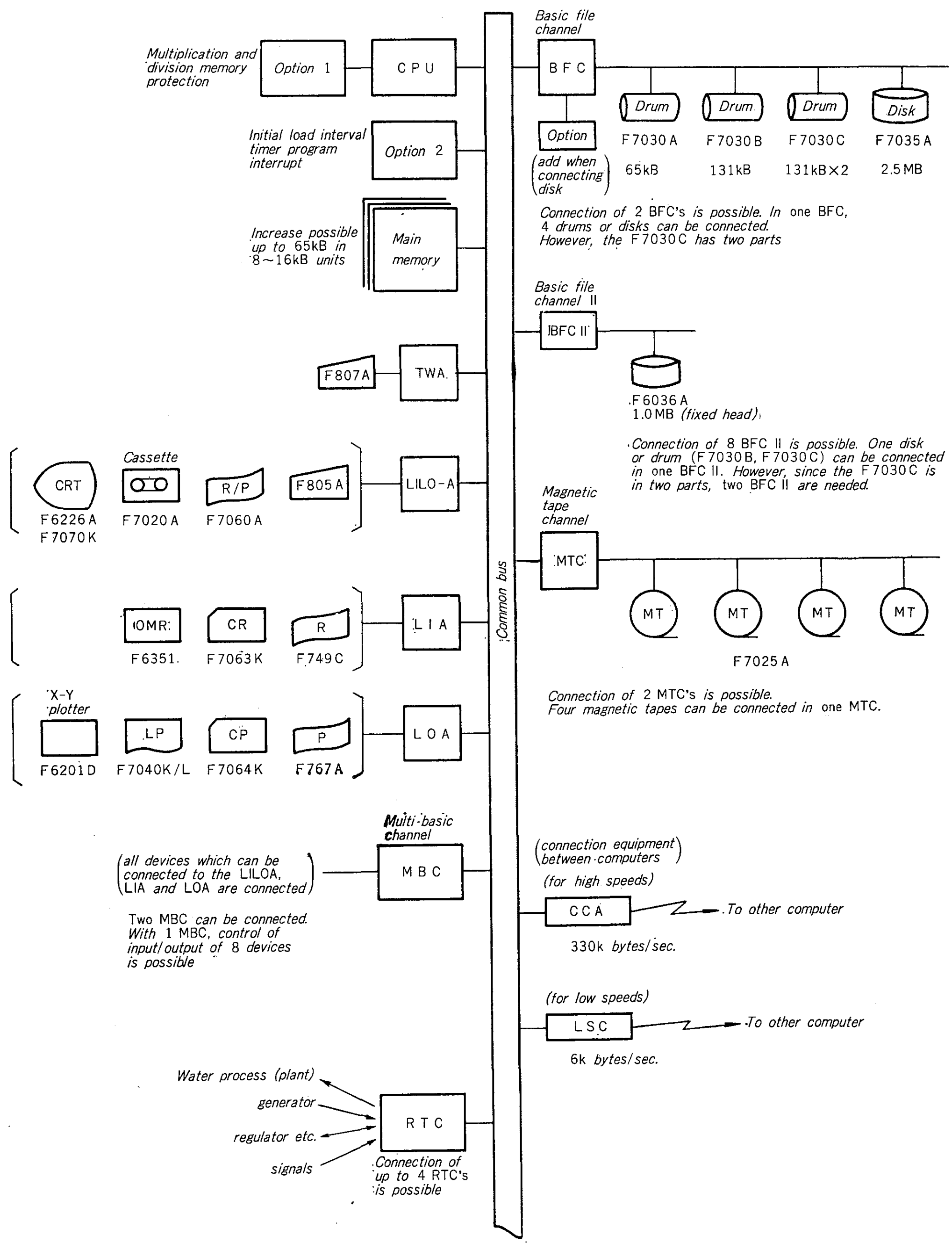


Fig. 13 Construction of FACOM U-200 system

Table 4 **Table of over load ratios (f_3)**

Over load time \ Load before over load	90	70	50
½	47	50	50
1	33	39	45
2	20	25	29
4	10	14	15

is within the specified range.

Currently, there are few on-load tap changers in water supply and sewage facilities but as transformer capacity increases, the cases of OLTC control will increase.

2. Automatic Load Limit Operation

When there is a fault in the transformers and the total load capacity can not be supplied or when operation is by the emergency generator during power failures, load limiting is required. This is performed as follows:

(a) equipment power limiting......speed control, etc.
(b) limiting number of devices in operation
(c) Total stoppage of equipment......this involtage part of the system or a portion of the equipment.

3. Automatic Power Factor Control

The capacitor for phase advancing is controlled in accordance with the amount of reactive power. To minimize operation frequency, the set value of the reactive power is changed according to the load power (or current).

4. Monitoring Recording

1) Power failure monitoring

Failure of commercial power are detected and operation is guided according to retransmission after the failure. In keeping with this, the emergency generator is automatically started.

2) Contract demand monitoring

There is monitoring so that the load capacity does not exceed the contracted power and alarms are given when required.

3) Safety records

Operation results records for the CB and other equipment are made at set intervals and accident recovery records are also kept concerning the accident and the repairs involved. These records are printed out on the typewriter.

V. FUJI COMPUTER CONTROL SYSTEMS

1. Hardware

The central processing computer used by Fuji Electric is the FACOM U-200.

The FACOM U-200 computer control system features easy increases and expansions of memory equipment and input/output equipment by a common bus. It is a highly reliable system with many optional functions and it is easy to perform control

Table 5 **Specifications of FACOM U-200**

Item		Specifications
1. Memory equipment		
• Elements		Magnetic core/dynamic MOS IC
• Word length	(Bit)	16 B+2 B (PC)
• Address units		word (16 bit)/byte (8 bit)
• Cycle time	(μs)	Core 0.65/IC 0.75
• Maximum memory capacity	(kB)	65 (including H/W fixed area)
• Increase units	(kB)	8/16
2. Processing control		
• Elements		TTL/MSI
• Processing system		Parallel binary, two complement displays, fixed decimal point
• No. of instructions (basic)		83
• Address system	(type)	6
• Interrupt levels		2 internal 4 external
• Data type		
binary fixed decimal point logic processing	(Bit)	8/16/32 1/8/16
• Processing speed Addition/subtraction	(μs)	1.58 (R-R)/3.15 (R-M)
Multiplication	(μs)	7.53~13.10 (R-M)
Division	(μs)	14.70 (R-M)
• Bus transmission speed	(MB/S)	2
• Universal registers	(piece)	8
3. Various functions		
• Multiplication and division instructions		OP. 1
• Double length shift instructions		OP. 1
		OP. 1
• Control functions Program interrupt		OP. 2
Interval timer		OP. 2
• Initial program load		OP. 2
• Power supply fault interrupt restarting		St.
• Floating decimal point processing		SR.
4. Basic software		
COMOS		○
DIMOS		○

or technical calculations with it. The system construction is as shown in *Fig. 13* and the central processing unit (CPU) specifications are given in *Table 5*.

For the computer control system, there are the RTC (real time controller) as process input/output equipment, the TELEPERM IS system as measuring equipment and as transmission equipment, the telemeter telecontrol equipment (CDT type, NTC type and F series) and the data highway equipment.

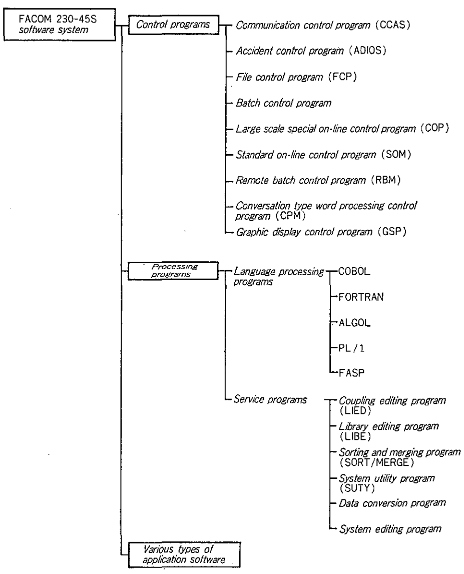


Fig. 14 Construction of FACOM 230-45S software system

2. Software

1) Basic software

The basic software centering around the monitor consists of the basic programs for computer system operation and it serves as an operating system.

The FACOM 230-45S and FACOM U-200 systems are shown in *Figs. 14* and *15* respectively as examples of basic software construction.

In the FACOM U-200 software system, the data processing software for control computers is standardized as the POPS (Process Oriented Programming System).

2) Data transmission software

Transmission software is employed to transmit data between the center and facilities and the transmission text, transmission control process, etc. are decided.

(1) Transmission text

Transmission text have emergency text, important text and general test etc., data are divided each text by its contents. *Fig. 16* shows the construction of transmission text.

The transmission code is the ISO7 unit code. Error detections use the horizontal/vertical parity system.

(2) Transmission control process

In the total control system, the 2,400 BPS or 1,200 BPS rates as used as transmission speeds because of the amount of data, required transmission time, etc. and the contension system is employed

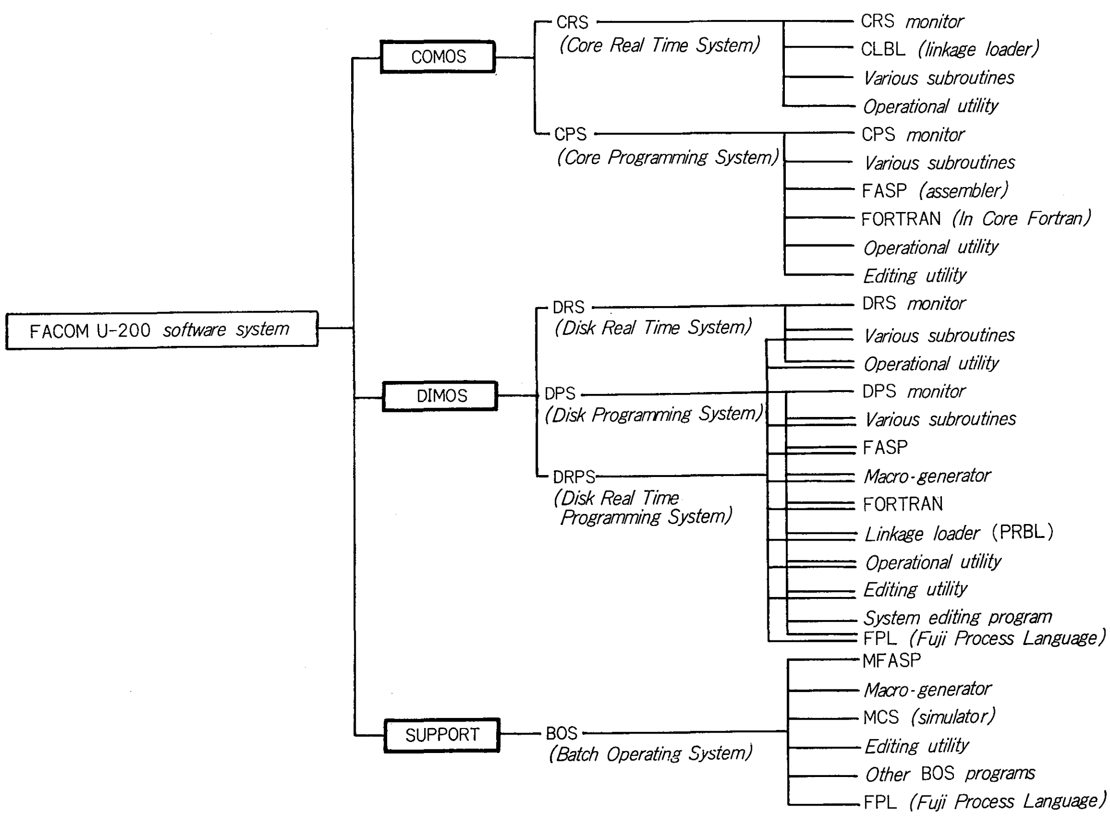
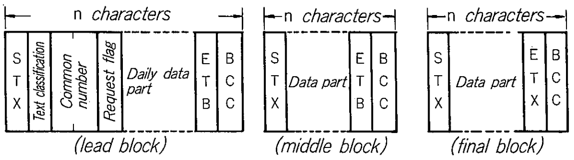
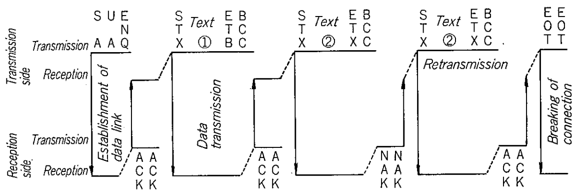


Fig. 15 Construction of FACOM U-200 software system



STX: Start of Text, text related
ETB: End of Transmission block
ETX: End of Text
BCC: Block Check Character (level parity)

Fig. 16 Construction of transmission text



ENQ: Enquiry (obtains reply of connected party)
ACK: Acknowledge (positive acknowledge)
NAK: Negative Acknowledge
EOT: End of Transmission

Fig. 17 Timechart of transmission control procedure

as the connection control system because of the centralized collection control system. *Fig. 17* shows the transmission process of the tuning synchronization and contension systems.

VI. CONCLUSION

This article has described the use of computer control in water supply and sewage processes. Fuji Electric has been delivering computers for water works processes for 15 years but in the future, such system will continue to be developed. The importance of application software in these systems is gradually increasing.

Efforts in research and development are continuing to determine characteristics, improve reliability, facilitate maintenance control and expand the system software.

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