Pressure Control Efficiency and Statistical Classification of Electrically Motor Valves in the Supervisory Water Distribution Network of Fukuoka City

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ABSTRACT: Fukuoka City is poor in water resources with no large rivers within the city district. For this reason it has taken various measures towards the creation of a "water-saving city", a city in which valuable water will not be wasted. One such measure has been the installation of the water distribution regulation system, one of the leading systems of its type in Japan. With this system, round-the-clock centralized monitoring of data from pressure gauges and flow meters attached to distribution pipes is carried out, while on the basis of this data, pressure and flow within the entire city district is regulated by the remote operation of motor valves. By operating this system, it has been possible not only to supply water evenly to consumers, but also it has been possible to reduce excess pressure and conserve water as water pressure can be regulated appropriately. Therefore in this study, the present efficiency of pressure regulation in terms of water distribution control is highlighted. A case study of block number 12 in the Fukuoka City water supply network is presented showing the different classification of electrically motor valves from a statistical point of view. Finally a presentation of the new term "pressure control efficiency" is introduced for this Block, which could be generalized for the entire water distribution network of the city.

1 INTRODUCTION

Fukuoka City is located in the northern part of Kyushu, Western Japan, at $33^0 35^\backslash$ north and $130^0 24^\backslash$ east. The city area is 338 km^2 and the population is 1.33 million as of October 1999. Fukuoka Metropolitan Area consists of Fukuoka City and 20 surrounding municipalities. The area has mild weather and climate, and no severe earthquake or flood has ever been recorded. The annual average temperature is 15-16^{0}C and the annual precipitation is approximately 1,630 mm with little snow. Because of seasonal winds, there is both an early summer rain season (June to July) and a typhoon season (September to October) (Kawamura 2001).

The sources of water supply in Fukuoka Metropolitan Area are surface water (87%), river-bed water (3%), and groundwater (10%). However, these percentages for Fukuoka City are 95%, 4%, and 1%, which indicate that groundwater as a water supply source is extremely small, whereas the ratios are 66%, 1%, and 33% for the surrounding municipalities indicating fairly high ratio of groundwater. One reason for the small use of groundwater in Fukuoka City is that the alluvial aquifer here is too thin so that salt-water intrusion may occur when too much groundwater is pumped up. Another reason is recent groundwater pollution problems caused by chlorinated hydrocarbons and also pesticides and herbicides. Furthermore, there are no major rivers in the area of Fukuoka Metropolitan Area, only several small rivers, so that the river water utilization rate is considerably high, e.g., in Fukuoka the rate is 58% in a normal year and 67% in a designed drought year (Zongue 1998).

The city is withdrawing water from five small rivers that flow through the city and that are managed by the prefectural government. These rivers do not have sufficient and stable discharge due to small catchment areas. The city is also receiving water (purchasing water) from the Chikugo River located outside the Metropolitan Area limits. It is the biggest river in Kyushu managed by the government. There are five water purification plants and all of them are treating water by rapid-filtration (Kawamura 1995).

Since the time Fukuoka City started the water supply service in 1923, expansion projects have been carried out 18 times in order to cope with the rapid increase of water demand due to the concentration of population in urban areas, development of industries, increase of living standard, etc. The big number of expansion projects shows the efforts that the city has taken in order to efficiently utilize the scarce water resources (Onizuka 2000).

As one of the most important projects, Fukuoka City has installed the water distribution regulation system. Therefore, in this paper the present situation of Water Supply Control and leakage prevention within the Fukuoka City water distribution network are illustrated. Secondly, characteristics of telemeters in a certain Block of the Fukuoka City water supply network with a statistically classification of the electrically controlled valves are presented. Finally a presentation of the new term "pressure control efficiency" is introduced for this Block, which could be generalized for the entire water distribution network of the city.

2 WATER SUPPLY CONTROL AND LEAKAGE PREVENTION

Water pressure control by this system begins in 1981 after completing the Water Control Center. This system includes 120 water pressure gauges, 68 flow meters and 149 electric control valves all at important points along the water distribution pipes (April, 2000). An engineer by visual observation can operate electric valves using remote control in order to secure the necessary water pressure through the pipe system. By utilizing this system, it has become possible to reduce excessive high water pressure and to secure a proper and constant water pressure in order to provide better service and reduce water leakage from the pipes. Figure 1 shows a schematic diagram of the system signal pathways.

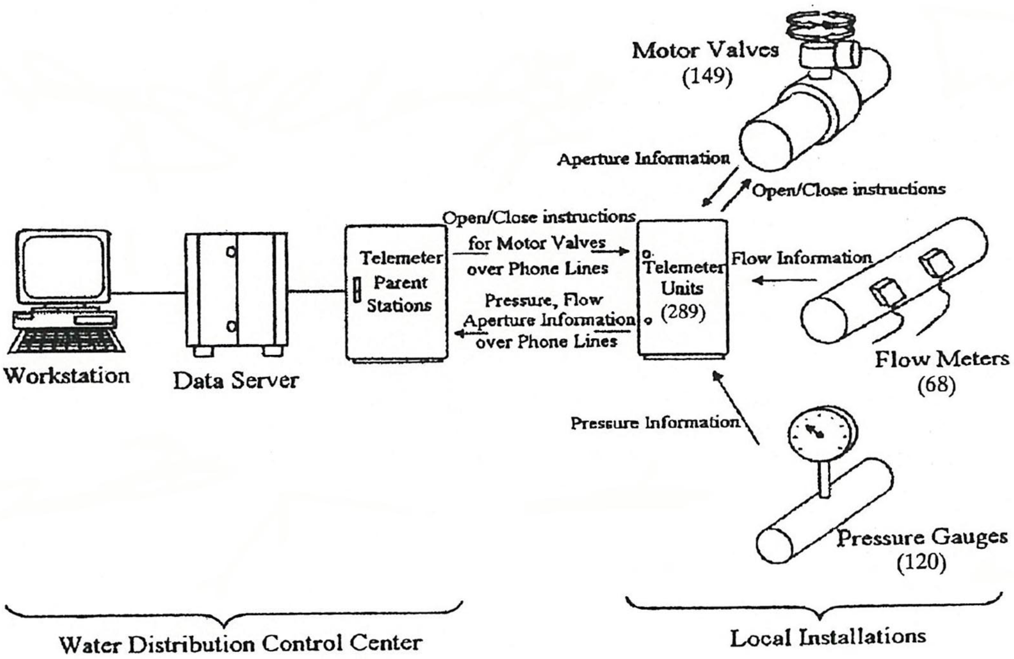

Figure 1. Schematic diagram of system signal pathways applied in Fukuoka city

The water pressure can be controlled as seen in Fig. 2, which compare between three different cases for pre control system, normal 24-hour operation and supply restriction in force during 1994 drought. With regulation carried out at pressures approximately 2.0 kg/cm^2 lower than before the introduction of the system, it is calculated that the system is responsible for water saving of about 4,000 to 5,000 m^3/day, while incidents of natural leakage from distribution pipes have fallen by around 30%, a very significant result. (Fukuoka City Waterworks Bureau 2001).

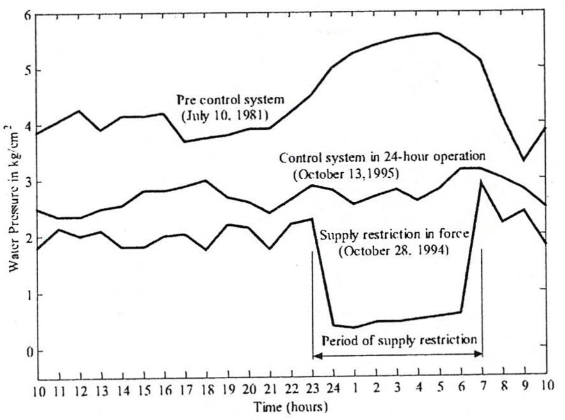

Figure 2. Water pressure regulation time series graphs

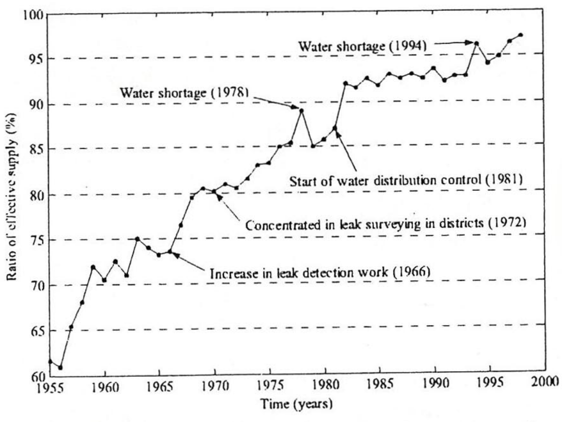

Figure 3. Changes of effective rate of water supply

Figure 3 shows the change in water transport efficiency in Fukuoka City (Fukuoka City Waterworks Bureau 2001). Ever since the first leakage prevention project was established in 1956, investigations have been under way. At the beginning of the project, the effective rate of water supply was as low as 61% as shown in Fig. 3. In 1998, however, the rate reached 97.1%, which is considered to be very high in Japan.

The rapid change in efficiency after 1966 was mainly due to an increase in leakage detection work and a program for the systematic replacement of distribution pipes. The change after 1972 was a result from concentrated inspections at places where many leakage incidents occurred and from applying the sound detection method. Furthermore, a Water Leakage Prevention Section was established in 1977 to strengthen the water leakage prevention system. At the same time, water leakage inspection of service pipes, which represent most of the water leakage cases, was carried out. The setup of a Water Control Center in 1981 also contributed to increase the efficiency (Shinoda 1998).

At present, In order to further improve the efficiency, the following three measures are taken as the foundation of its approach to counteract water leakage: (i) Using leak prevention surveys (leak detection method, water leakage measuring method and the acoustic leakage sound detection method) for early discovery of leaks followed by rapid repair, (ii) The old distribution pipes and those with a history of leakage are being actively replaced to maintain distribution pipelines and (iii) Managing water leakage through pressure regulation. Through these measures the ratio of effective supply rose to 97.1% in 1998, the highest figure for a major Japanese city (Fukuoka City Waterworks Bureau 2001).

3 A CASE STUDY OF BLOCK 12

In order to present the characteristics of different telemeters in Fukuoka City water distribution network, Block 12 of the city network is selected for this purpose due to its location in the center of the city. It is important to notice that the water supply network of Fukuoka city is divided into 21 blocks and the area served by each block takes into consideration separate water distribution areas, differences in land elevation, location of rivers and railroads, as well as local differences in water usage (Miyazaki 1999).

Our case study (Block 12) is surrounded from the north by Hakata bay, from the east by Hii River, from the west by Naka River and Block 9 and from the south by an elevated area (Block 50) and also by Block 13. A skeletonized figure of Block 12 containing 45 nodes and 49 pipes is shown in Fig. 4. In this block, there are 20 motor valves, 7 flow meters, and 11 pressure gauges. It is noticed from the figure that flow meters are connected to the main inlets and outlets and a valve is connected adjacent to each flow meter in order to control the flow entering or leaving the block (e.g., M1, V1; M4, V18; ...). The remaining motor valves are connected to the main junctions of this network (e.g., V2; V3; V5; ...) to make water distribution more efficient.

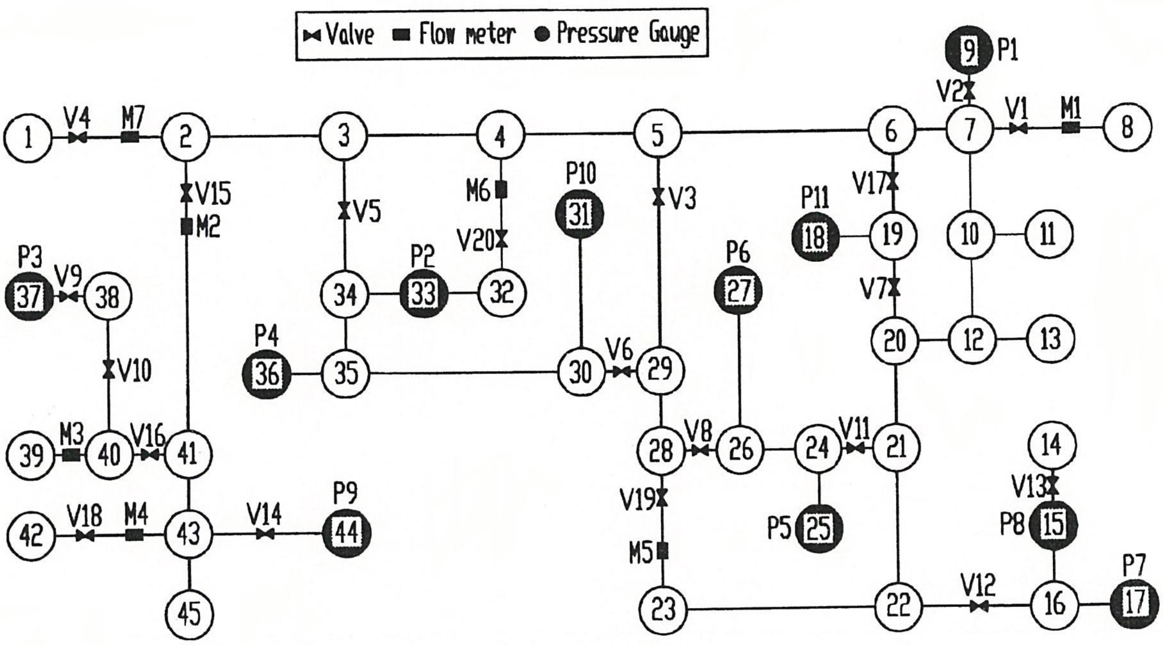

Figure 4. Block 12 of Fukuoka City water supply network

Motor valves are operated by remote control while pressure gauges and flow meters fitted to distribution pipes are monitored. The values of flow rate passing each flow meter, the opening percentage of each motor valve and the pressure intensity at each pressure gauge are recorded every minute. The analyzed data of this study are based on hourly data for all flow meters, pressure gauges, and motor valves since 1st April 1998 to 31st march 2001. This makes the total number of data for each telemeter 26304 (total number of hours during this period). The percentage of missing data for this period is 6.2%.

4 CHARACTERISTICS OF TELEMETERS

By analyzing the data of the studied three years, it is noticed that water feed the block through flow meters M1, M2, M3, M4 and M7. It is noticed also that M5 and M6 are internal flow meters. The direction of flow through all pipes can be changed for preventing the occurrence of red water and also to increase the efficiency of water supply in the case of pipe breakage caused by accident or fire (Shinoda 1999).

Figure 5-A shows a box-whisker plot for the statistical distribution of hourly discharge entering the block (positive sign) or leaving the block (negative sign) through all seven flow meters of this block. From this figure we can conclude that the median value of flow passing through the flow meters M4 and M7 equals zero. These two flow meters are used only in case of high water demand and also to facilitate the flow of excess water from this block to the other adjacent blocks (Awad 2002).

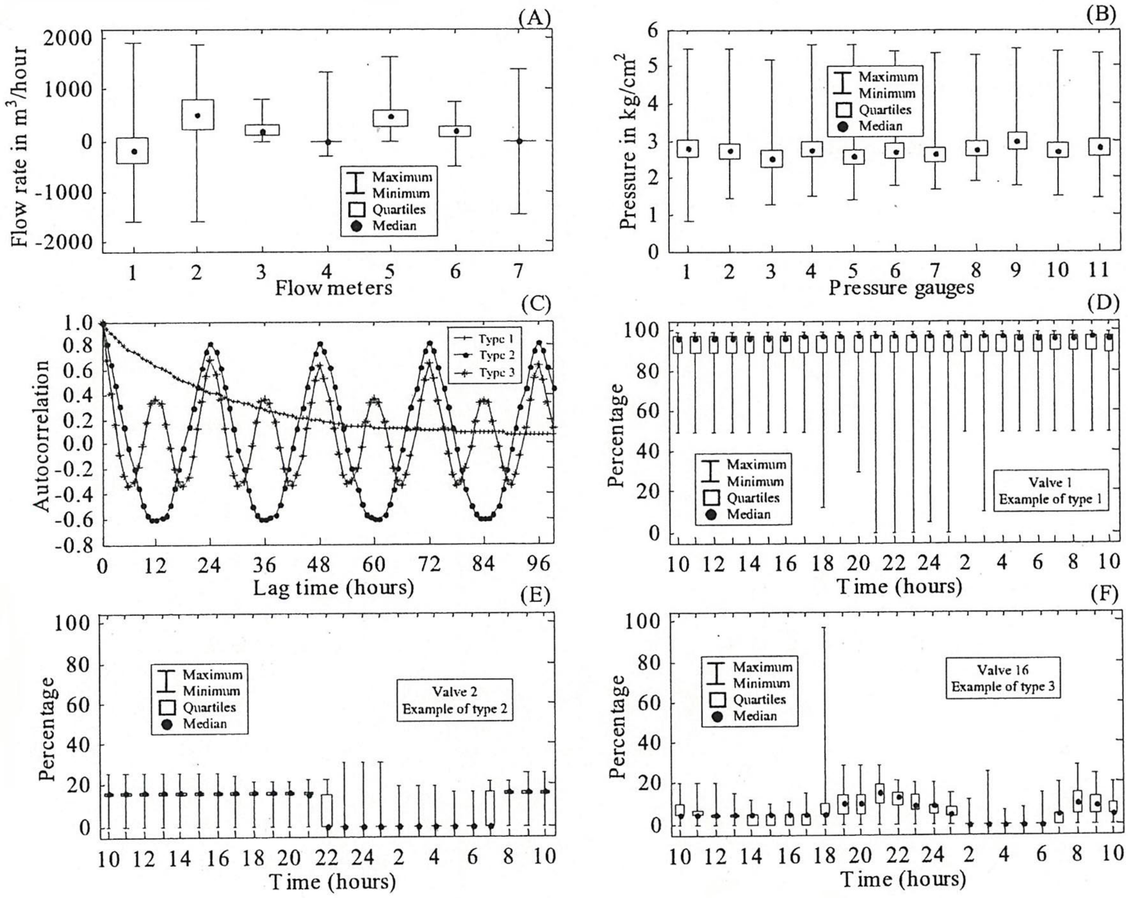

Figure 5. Characteristics of telemeters

In order to test the efficiency of water distribution control for pressure regulation in Block 12, Figure 5-B outlines the pressure monitored in all the 11 pressure gauges of this block. The box-whisker plot shows the median, upper and lower quartiles and also the maximum and lower pressure recorded for each pressure gauge. From this chart it is seen that the median value of pressure at all nodes varied from 2.50 kg/cm^2 to 3.00 kg/cm^2

and the majority of events represented by the upper and lower quartiles are within the target range (from 2.40 to 3.20 kg/cm^2). The next section will present additional analysis for detecting the events that has fallen outside the target range.

To guarantee a good service and valve schedule operation in the network, this paper presents a statistical classification of the valves connected to the network. Figure 5-C shows the collection of correlation coefficient computed for various lags which named autocorrelation function (ACF) for the typical three types of valves in this network. Figures 5-D, 5-E and 5-F shows a box-whisker plot of the statistical distribution of hourly degree of valve opening for the classified three types of valves in block 12. The box-whisker plot shows the median, upper and lower quartiles and also the maximum and minimum valve opening recorded for each type of the motor valves. V1, V2 and V16 are selected as representative of type 1, type 2 and type 3 respectively. The Following are the main characteristics of the three types of valves.

- *Type 1:* Six valves of this network fall in this type and they are Valves 1, 4, 14, 15, 18 and 19. All these valves are connected to the main pipes of the network and have approximately constant percentage of opening during the different hours of the day (see Fig. 5-D).
- *Type 2:* Valves 2, 3, 13 and 17 are classified in this type. This type of valves is completely closed during night time (from 10.00 p.m. to 6.00 a.m.) and they have approximately constant percentage of opening during the rest hours of the day. This type is connected to the internal pipes of the block to reduce pipe-leakage through the network, and also to decrease the pressure during the night time when the water demand is at minimum (see Fig. 5-E).
- *Type 3:* The remaining 10 valves are considered of this type. This type of valves is used to maintain the pressure value between 2.4 kg/cm2 and 3.2 kg/cm2. Therefore those valves are slightly opened around the rush-hours (8.00 a.m. and 9.00 p.m.) and they are completely closed during the late night hours (see Fig. 5-F).

5 PRESSURE CONTROL EFFICIENCY

In Block 12, the 20 electrically motor valves are operated in order to maintain the pressure at the 11 pressure gauges between upper target value (3.2 kg/cm^2) and lower target value (2.4 kg/cm^2). The pressure control efficiency could be defined as the percentage of events that falls inside this range. Figure 6-A shows the pressure control efficiencies for the different pressure gauges of Block 12, in this figure the percentage of events that fall outside the target range are also plotted.

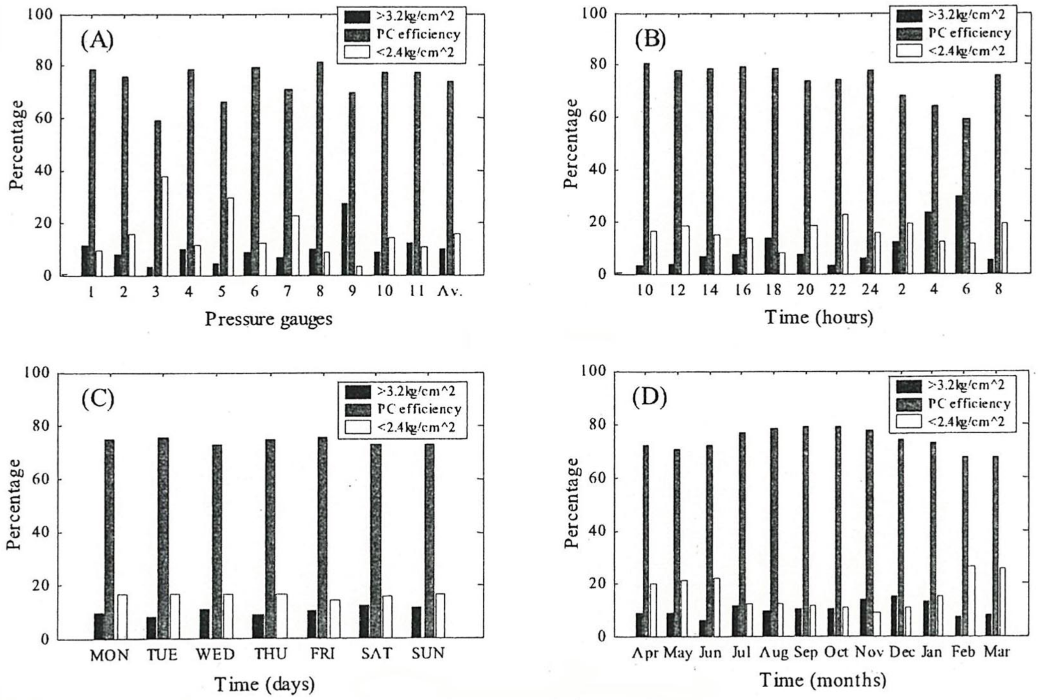

Figure 6. Pressure control efficiencies

Figure 6-A could be used to detect the nodes of the network that are well regulated (e.g. P8 at node 15), nodes with high pressure (e.g. P9 at node 44) and also nodes with relatively low pressure (e.g. P3 at node 37).

For testing the efficiency of pressure regulation with different time series, Figures 6-B, 6-C and 6-D show the percentage of previous mentioned events computed for all pressure gauges of Block 12. These figures show an increase of pressure values during the night hours (from 2.00 a.m. to 8.00 a.m.), a decrease of pressure during some months (from February to June) and an increase of pressure control efficiencies from July to November. The reason of the good results obtained from analyzing the previous time series graphs is the advanced "Demand Estimation Support" and "Schedule Control" applied in Fukuoka City water distribution network which is based on weather conditions and other factor for that particular time and could be correlated on the basis of the actual data received for that particular time. The reason that some of the events are fallen relatively outside the target pressure range is that Block 12 is responsible to feed an adjacent Block (Block 9) through the main pipe connecting node 7 and node 8 (See Fig. 4).

6 CONCLUSIONS

For constructing a good valve operation support based on the planned valve operation for flow and pressure regulation, and the operation knowledge database which is constructed on the basis of past experience, this paper present a statistical classification of the different types of valves connected to a water supply network.

With the assistance of Water Supply Control System and comparing the current situation with the situation of the pre-control system and the situation during 1994 drought, a large amount of water has been saved. A decrease of 30% of leakage from distribution pipes was achieved. An early discovery of distribution pipe abnormalities and rapid response by remote control, gathering and analyzing information to make water distribution more efficient and also an excellent regulation of pressure value through the distribution network were also accomplished.

With the ever-increasing complexity of the city-wide distribution pipe network, motor valve operation to regulate pressure and flow came to depend more and more on the experience and skills operators. For this reason, an improvement of valve operations support functions should be done based on valve operation planning for flow and pressure regulation, and the operation knowledge database which is constructed on the basis of past experience. This aims to prevent the events of pressure regulation falls outside the target pressure range and also to reduce the effort of investigator operators.

Based on the autocorrelation function showed in Fig. 5-C for the different three types of valves, an on-line prediction and efficiently control of valves opening could be carried out.

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