Instrumentation and Control

AWWA MANUAL M2

Third Edition

This AWWA content is the product of thousands of hours of work by your fellow water professionals. Revenue from the sales of this AWWA material supports its ongoing development. Unauthorized distribution, either electronic or photocopied, is illegal and hinders AWWA’s mission to support the water community.

American Water Works Association
# Contents

List of Figures, v

List of Tables, xi

Foreword, xiii

Acknowledgments, xv

Chapter 1 Introduction ............................................. 1
   The Water Utility System, 1
   How to Use This Manual, 3
   Reference, 4

Chapter 2 Hydraulics and Electricity ................................. 5
   Hydraulics, 5
   Electricity, 18
   References, 39

Chapter 3 Motor Controls ........................................... 41
   Introduction, 41
   Motors, 41
   Variable Speed Motor Control, 49
   Variable Speed Motor Control Systems, 50
   Motor Control Logic, 52

Chapter 4 Flowmeters ............................................... 67
   Meter Categories, 67
   Meter Coefficient of Discharge, 68
   Venturi Flowmeters, 69
   Modified Venturis, 74
   Orifice Plate Flowmeters, 74
   Magnetic Flowmeters, 76
   Turbine and Propeller Flowmeters, 80
   Sonic Flowmeters, 84
   Vortex Flowmeters, 86
   Averaging Pitot Flowmeters, 89
   Variable Area Flowmeters, 92
   Open Channel Flow, 94
   General Installation Precautions, 98
   Signal Output and Transport, 99
   References, 100

Chapter 5 Pressure, Level, Temperature, and Other Process Measurements ............................................. 101
   Pressure, Level, and Temperature, 102
   Electric Power and Equipment Status, 110
   Process Analyzers, 112
   General Considerations, 119
   References, 119

Copyright © American Water Works Association
Chapter 6 Secondary Instrumentation .......................... 121
   Introduction, 121
   Signal Standardization, 121
   Signal Power and Transmission, 122
   Transmitters, 124
   Controllers, 124
   Recording and Indicating Hardware, 126
   Function Modules, 128
   Converters, 129

Chapter 7 Telemetry .............................................. 131
   Analog Telemetry, 133
   Tone Multiplexing, 137
   Amplitude Modulation Tone, 137
   Frequency Shift Keying Tone, 138
   Communication Media and Channels, 138
   Reference, 142

Chapter 8 Final Control Elements ............................ 143
   Valves, 144
   Valve Summary, 153
   Pumping Systems, 154
   Miscellaneous Final Control Elements, 157

Chapter 9 Basics of Automatic Process Control ............ 161
   Feedforward Control, 162
   Feedback Control, 163
   Feedforward vs. Feedback Control, 164
   Manual vs. Automatic Control, 165
   Automatic Feedforward Control Methods, 166
   Automatic Feedback Control Methods, 168
   References, 178

Chapter 10 Digital Control and Communication Systems .... 179
   Digital Control Systems, 180
   Communication Systems, 188
   Applications and Site Planning, 194
   Technology Trends, 196
   References, 197

Chapter 11 Instrument Diagrams ................................ 199

Glossary, 207

Index, 215

List of AWWA Manuals, 225
Introduction

Just as water utility system varies in definition, so does automation and instrumentation. However, to provide a framework for this manual the following definitions will be used (AwwaRF/JWWA 1994):

**Automation:** the replacement or elimination of intermediate components of a system or steps in a process, especially those involving human intervention or decision making, by technologically more advanced ones.

**Instrumentation:** both the technology and installation of equipment to monitor and control operations and carry out information processing associated with observation or adjustments of operations.

In the broadest sense, an instrument is defined as a device that performs a specific job. In a water utility, an instrument is usually a measuring or control device. In an automatic system, the controlling factor, such as flow or pressure, has to be reliably sensed or measured. Automation and instrumentation are closely associated because one depends on the other.

THE WATER UTILITY SYSTEM

To provide a consistent approach, the following paragraphs apply to water treatment and distribution systems, their important elements, the operator’s responsibilities, and automation and instrumentation’s role.

A water distribution system delivers potable water, at a suitable pressure, in the amount required at customer service connections, through a piping network. The distribution system can consist of elements such as main pumping stations, booster pumping stations, storage reservoirs, standpipes, elevated tanks, water mains, valve stations, and wells. The operator has the duty to maintain the elements of the system and to see that they perform correctly and reliably.

An operator’s main responsibilities are supervision and control. Supervision means examining system performance information and deciding if it is acceptable. If, in the operator’s opinion, performance is unacceptable, then the operator must
change an element or make an adjustment to the system to bring performance back to an acceptable condition. This is called manual control. When instruments are provided to make the necessary change or correction without the intervention of the operator, the system is called automatic control. However, regardless of the extent to which automatic control is used, the operator still may need to intervene manually during abnormal or emergency situations.

Because treatment plants, distribution system pumping stations, storage reservoirs, and other facilities may be at various, separate locations, the information needed to supervise and control the system must be gathered at some centralized point near the operator. Provision must also be made at this central location for remote control of any of the facilities that the operator may be required to regulate or change.

The operator will usually be working through some intermediate or intervening instrument to cause the systems to perform. Some of the instruments will be entirely mechanical, such as levers, chains, and cables; some will be hydraulic systems, using water or oil pressure for power sources and control; some will be pneumatic systems, using compressed air for power, control, and instrumentation; and some will be electrical systems for power, control, and instrumentation. A swing check valve will close automatically, for example, when not forced open by the flow of water through it. An indicating pointer can be positioned by a system of cable and pulleys to provide position indication. Oil or water pressure can be used to hold a valve closed, whereupon the loss of pressure will cause it to open automatically. Similarly, compressed-air pneumatic systems can be arranged to cause devices to operate automatically; pneumatic instrumentation and control systems are used extensively. Electricity is used more than any other source of power for control and instrumentation.

Generally, an electrical system, together with various mechanical, hydraulic, and pneumatic subsystems, allows an operator to supervise and control the water system. These electrical systems may include any or all of the following:

- Power system, using local, remote, or automatic control
- Telemetering, monitoring, and alarm system
- Communication system, data acquisition, and data processing

Operations are performed automatically for several reasons:

- the operator does not have to do them
- the operator cannot do them
- they can be done faster and better automatically
- they can be more efficient

As with automation, instrumentation is an extension of the operator. Instruments see, feel, measure, and record information for the operator. Instruments can perform a variety of operations, including:

- measuring
- remembering
- calculating
- receiving
- monitoring
- signaling
- switching
- recording
- comparing
- regulating
- transmitting
- indicating
• integrating  • summating  • programming
• timing  • anticipating  • analyzing
• converting  • detecting  • alarming

Each individual instrument is a single device with a specific task. Collectively, instrument systems can seem extremely complex; but the operator who understands each device and its unique function will be able to use each instrument as an aid to efficient supervision and control. An operator should be acquainted with all the automatic controls and instruments in use in the utility. This will give the operator the confidence needed to use the equipment effectively. With a broad knowledge of instrumentation and its applications, the operator becomes the driving force to seek operational improvement through the technology of instrumentation.

HOW TO USE THIS MANUAL

This manual introduces the major topics of automation and instrumentation. While not an exhaustive source of specific details, the manual can be used to identify water utility system automation and instrumentation elements. At a pumping station, for example, an operator will be able to examine an item of equipment and understand what it does, how it works, and identify the functions of its associated devices. Having identified a device, the operator may refer to the operations manual for further information. By using the plans of the station, equipment instruction manuals, equipment nameplate data, and other general information, the operator should be able to learn the names of the various devices and become acquainted with the intended purpose of an overall assembly of the equipment. This assembly can, for example, include a pump, motor, motor starter, and pump discharge valve, together with instrumentation and protective devices working together to perform a function as a complete unit.

This procedure can be used to learn more about local and remote controls, metering, and instrumentation. This manual can be used to understand their functions, as well as their relationships to the connected equipment.

This operator’s manual may cover considerably more material than would apply to many small facilities; yet the manual may not mention every device found in a particular system. In these cases, the operator is encouraged to seek other references, some of which can be found in this manual.

The chapter arrangement of this manual is intended to group related topics. The second and third chapters review the hydraulic and electrical principles used in automation and instrumentation, as well as the basics of electric motor controls. The fourth and fifth chapters discuss instruments that measure process variables such as flow, pressure, level, and temperature. These types of instruments are called primary instrumentation. The sixth and seventh chapters present secondary instrumentation, those instruments that respond to and display information from primary instrumentation. The eighth chapter looks at the final control elements, such as pumps and valves. The last three chapters introduce the basics of automatic and digital control elements.

The topics of each chapter are introduced in the following paragraphs.

Chapter 2 Hydraulics and Electricity briefly reviews hydraulics and electrical power as the subjects relate to automation and instrumentation. Water utility operators are usually more familiar with hydraulics than electricity, and knowledge of both is necessary to get the most out of this manual.
Chapter 3  Motor Controls introduces the principles of the controls that stop and start motors, as well as the control of variable speed motors. The chapter also discusses motor control logic and presents motor control diagrams.

Chapter 4  Flowmeters discusses the most common flowmeters in service in water supply systems. These include the Venturi meter (Venturi), modified Venturis, orifice plate, magnetic, turbine and propeller, sonic, vortex, averaging Pitot, and rotameter. Also included are open channel flowmeters—weirs and flumes. Topics covered are basic theory, installation, maintenance, advantages, and disadvantages.

Chapter 5  Pressure, Level, Temperature, and Other Process Measurements introduces the primary sensors associated with three process variables encountered in water utility systems: pressure, level, and temperature. This chapter will touch on, in general terms, analytical instrumentation that is finding wide use in water systems, particularly in water treatment plants. An overview is also included of many of the less common sensors in use today.

Chapter 6  Secondary Instrumentation explains the pneumatic systems (those using air pressure) and electronic systems that control secondary instrumentation. Topics include the air supply system, pneumatic controllers, recording and indicating hardware, computing devices, converters, and applications.

Chapter 7  Telemetry is remote metering, taking a measurement at one location then transmitting it to another location. Specific topics include transmitting devices, output devices, controllers and function modules, communications, and various types of telemetry.

Chapter 8  Final Control Elements provides an overview for those applications that can produce a change in the process of treating and distributing water: valves and pumps. In general, this chapter describes the various types of final control elements and how they operate within an automated system.

Chapter 9  Basics of Automatic Process Control discusses how the elements presented in the previous chapters work together in a process that occurs without continuous operator input. The chapter provides basic information on process control and the most common techniques used to automate process control in water utilities.

Chapter 10  Digital Control and Communication Systems shows how computer and digital technology enable operators of process control systems to quickly recognize status changes and respond immediately. This chapter introduces the concepts, hardware, and software of digital control.

Chapter 11  Instrument Diagrams presents the standard instrument diagrams or process and instrument diagrams frequently used in the water utility systems.

REFERENCE