

# CONTENTS

Preface	v
About the English-Language Edition	vii
List of Contributors	ix

## Chapter 1 INDUSTRY AND INSTRUMENTATION

1.1 The Word "Instrumentation"	1
1.2 The Development of Instrumentation	2
1.3 Trend toward Total FA	4
1.4 Classification and Use of Instruments	6
References	9

## Chapter 2 PROCESS CONTROL

2.1 Fundamentals of Feedback Control	11
2.1.1 Configuration of a control system	11
2.1.2 Characteristics of a control system	13
2.1.3 Feedback control and stability	19
2.2 Process Characteristics	23
2.2.1 Process degrees of freedom and controlled and manipulated variables	23
2.2.2 Process characteristics	25
2.2.3 Process models	26
2.3 Control Formats for Various Types of Processes	32
2.3.1 Single loop control systems	32
2.3.2 Compound loop control system	39
2.4 Optimal Adjustment of Control Systems	45
2.5 Sequential Control	50
2.5.1 Meaning of "sequential control"	51
2.5.2 Types of sequential control	51
2.5.3 Sequential control description	52
2.5.4 Devices for sequential control	57
Practice Questions	58
Answers to Questions	59
References	59

*Contents*

*xi*

## Chapter 3 DETECTION AND CONVERSION OF INDUSTRIAL VARIABLES

3.1 Measurement of Industrial Variables.....	62
3.1.1 Methods of measurement.....	62
3.1.2 Accuracy of measurement .....	66
3.2 Measurement of Temperature.....	71
3.2.1 Thermoelectric thermometers .....	72
3.2.2 Resistance thermometers.....	84
3.2.3 Protective tube.....	91
3.2.4 Thermistor thermometers.....	92
3.3 Measurement of Flow.....	98
3.3.1 Differential pressure flowmeters .....	99
3.3.2 Float-type area flowmeters.....	105
3.3.3 Volumetric flowmeters.....	110
3.3.4 Turbine flowmeters.....	113
3.3.5 Magnetic flowmeters .....	117
3.3.6 Vortex flowmeters.....	125
3.3.7 Ultrasonic flowmeters.....	130
3.4 Measurement of Pressure.....	135
3.4.1 Pressure transmitters.....	136
3.4.2 Types of pressure detectors .....	138
3.5 Measurement of Liquid Level.....	141
3.5.1 Float liquid-level meters.....	141
3.5.2 Pressure differential liquid-level meters .....	141
3.5.3 Displacer liquid-level detectors .....	144
3.5.4 Purge-type liquid-level meters.....	145
3.5.5 Ultrasonic liquid-level meters.....	146
3.5.6 Capacitance liquid-level meters.....	147
3.6 Measurement of Displacement and Angle.....	148
3.6.1 Resistance potentiometer methods .....	148
3.6.2 Electromagnetic induction methods.....	148
3.6.3 Magnetic balance method.....	152
3.6.4 Magnetic strain method.....	153
3.7 Measurement of Rotation.....	153
3.7.1 Measurement using tachometer generators .....	153
3.7.2 Pulse output sensors.....	155
3.7.3 Digital counting tachometers.....	156
3.8 Measurement of Composition .....	158
3.8.1 Gas chromatography .....	158
3.8.2 Infrared analyzers .....	163
3.8.3 Oxygen analyzers.....	166
3.8.4 pH meters and ORP meters .....	169

3.8.5	Moisture/humidity meters .....	172
3.8.6	Turbidity meters.....	174
3.8.7	Conductivity meters .....	176
3.8.8	Other composition measuring devices .....	179
3.9	B/M Systems.....	188
3.9.1	Basis weight sensor (B sensor).....	189
3.9.2	Moisture sensors (M sensors).....	191
3.9.3	Calipers (paper thickness gauges).....	192
3.9.4	Moisture sensor for thick paper.....	193
3.9.5	Color sensors.....	194
3.9.6	Ash sensors.....	195
3.10	Signal Converters .....	195
3.10.1	The purpose of signal converters.....	195
3.10.2	Thermocouple signal converters.....	197
3.10.3	Resistance signal converters .....	199
3.10.4	Two-wire signal transmission .....	200
3.10.5	Pulse signal converters .....	201
3.10.6	Computer input equipment.....	202
	Practice Questions.....	205
	Answers to Questions .....	205
	References.....	205

## Chapter 4 RECORDERS AND CONTROLLERS

4.1	Recorders.....	209
4.1.1	Types of recorders .....	209
4.1.2	Recorder functions.....	210
4.1.3	Pen recorders .....	212
4.1.4	Multipoint recorders.....	218
4.2	Controllers.....	222
4.2.1	Pneumatic and electronic controllers.....	222
4.2.2	Analog electronic controllers.....	223
4.2.3	Digital controllers .....	226
4.2.4	Programmable controllers .....	231
4.2.5	Batch controllers and blending controllers .....	235
4.3	Computing Stations and Set Stations.....	241
4.3.1	Alarm set stations .....	241
4.3.2	Programmable computing units.....	242
4.3.3	Manual set stations and manual operating stations .....	243
	References.....	245

## Chapter 5 SYSTEM CONTROL EQUIPMENT

5.1	Overview of System Control Equipment .....	248
5.1.1	Development.....	248

5.1.2 Configuration of a total FA system .....	252
5.2 Distributed Control System.....	256
5.2.1 Concept of the distributed control system.....	256
5.2.2 Configuration of the distributed control system and its functions .....	259
5.2.3 Feedback control .....	267
5.2.4 Sequential control .....	271
5.2.5 Man-machine interface .....	276
5.2.6 Communication with other systems.....	284
5.2.7 Engineering.....	285
5.3 Production Line Control System.....	291
5.3.1 Summary of production line control systems.....	291
5.3.2 Types of production line control systems.....	292
5.3.3 FA computer systems .....	295
5.3.4 FA computer system hardware.....	298
5.3.5 FA computer software .....	303
5.4 Computer System Equipment for Production Management ...	306
5.4.1 Computer components and configuration .....	306
5.4.2 Software for production management computer systems..	316
5.5 Data Communication and Equipment.....	325
5.5.1 Data communication and standards .....	325
5.5.2 Methods of data communications.....	327
5.5.3 The IEEE-488 instrument bus.....	329
5.5.4 The RS-232 C interface and modems .....	331
5.5.5 Local area networks .....	334
5.5.6 Optical communications.....	335
5.6 Basic Components of Digital Control.....	336
5.6.1 Microprocessors.....	336
5.6.2 Memory elements and storage equipment.....	343
5.6.3 Display elements and devices.....	346
5.6.4 Analog/digital conversion .....	351
5.6.5 Optical communication elements.....	353
References.....	354

## Chapter 6 FINAL CONTROL ELEMENTS

6.1 Types of Control Valves.....	355
6.1.1 Pneumatic control valves .....	355
6.1.2 Electrical control valves .....	355
6.1.3 Hydraulic control valves.....	356
6.1.4 Self-powered control valves.....	356
6.2 Choice of Control Valves .....	356
6.2.1 Various conditions affecting choice.....	356
6.2.2 Sizing .....	360

6.2.3	Flow characteristics	361
6.2.4	Rangeability	363
6.2.5	Materials	364
6.3	Control Valve Bodies	367
6.3.1	Characteristics of various types of valves	367
6.3.2	Rating	373
6.3.3	Connection to piping	374
6.4	Control Valve Actuators	374
6.4.1	Conditions under which an actuator should be installed	374
6.4.2	Power sources	374
6.4.3	Types of actuators and their characteristics	376
6.5	Positioners and Accessories	384
6.5.1	Positioner functions	384
6.5.2	Pneumatic pressure positioners	384
6.5.3	Current-to-pneumatic positioners	384
6.5.4	Current-to-current positioners	386
6.5.5	Accessories	386
6.6	Self-powered Valves	388
6.6.1	Pressure-regulating valves	388
6.6.2	Temperature control valves	389
6.6.3	Flow control valves	389
6.6.4	Float valves	389
	Practice Questions	390
	Answers to Questions	390
	References	390

## Chapter 7 SYSTEM ENGINEERING

7.1	System Engineering Basics	392
7.1.1	Plant construction overview	392
7.1.2	System design considerations	395
7.2	Instrumentation System Design	399
7.2.1	Job planning	399
7.2.2	System specifications	403
7.2.3	Device and function specifications	407
7.2.4	Instrumentation work specifications	430
7.2.5	Related work	434
7.2.6	Instrumentation drive system design	436
7.2.7	Other system functions (safety, failsafe and redundancy measures)	444
7.3	Control Room and Man-Machine Interface	453
7.3.1	Human engineering and control panel design	453
7.3.2	Control room engineering	457
7.4	Instrumentation Work and Startup	460

7.4.1 Overview.....	460
7.4.2 Instrumentation work planning .....	460
7.4.3 Instrumentation work design .....	463
7.4.4 Startup execution.....	467
7.4.5 Startup operations.....	469
7.5 Quality Assurance .....	470
7.5.1 Engineering quality.....	470
7.5.2 Design review (DR).....	471
References.....	482

## Chapter 8 ADVANCED CONTROL

8.1 Control Theory Considerations Control .....	483
8.2 Feedforward Control .....	486
8.2.1 Feedforward control in a heat exchanger.....	486
8.2.2 Combining feedforward control and feedback control.....	488
8.2.3 Determination of feedforward elements.....	489
8.2.4 Feedforward control application examples .....	490
8.3 Control of Dead-Time Processes .....	492
8.3.1 Dead-time processes.....	492
8.3.2 Smith controllers .....	494
8.3.3 Sampling PI controller .....	500
8.4 Non-interacting Control .....	502
8.4.1 Interaction between process variables.....	502
8.4.2 Influence exerted by mutual interaction.....	504
8.4.3 Expressing the degree of interaction .....	504
8.4.4 Controlled variable and manipulated variable combination .....	508
8.4.5 Non-interacting control.....	509
8.4.6 An example of non-interacting control .....	511
8.5 Self-tuning Controller.....	511
8.5.1 Overview.....	511
8.5.2 Gain-scheduling control.....	514
8.5.3 Self-tuning controller (STC).....	515
8.5.4 STC based on the expert method .....	517
8.5.5 STC application considerations .....	521
8.6 Optimal Control.....	521
8.6.1 The meaning of "state" .....	521
8.6.2 Integral optimal regulator .....	522
8.7 Kalman Filter.....	524
8.7.1 Kalman filter formula.....	524
8.7.2 Application to the parameter estimation problem .....	525
8.8 Other Forms of Advanced Control.....	527
References.....	527

Chapter 9 CONTROL OF PROCESS UNITS (Application I)	
9.1 Overview .....	529
9.2 Control of Fluid Transport Processes.....	530
9.2.1 Pump control.....	530
9.2.2 Compressor control.....	533
9.3 Control of Heat Transfer Processes.....	540
9.3.1 Control of heat exchangers.....	540
9.3.2 Heating furnace control.....	546
9.4 Control of Distillation Processes.....	550
9.4.1 Binary-component distillation column control .....	550
9.4.2 Multi-component distillation column control.....	566
9.5 Control of Reaction Processes .....	573
9.5.1 Control of a stirred-tank polymerization reactor .....	573
9.5.2 Control of a gas-phase solid-catalytic reactor .....	580
9.6 Other Process Control.....	590
9.6.1 Control of refrigeration equipment .....	590
9.6.2 Evaporator control .....	592
9.6.3 Drying process control .....	595
Practice Questions.....	600
Answers to Questions .....	601
References.....	602

Chapter 10 INSTRUMENTATION TO MANUFACTURING INDUSTRIES  
(Application II)

10.1 Instrumentation Application in the Petroleum Industry.....	604
10.1.1 The petroleum industry and instrumentation.....	604
10.1.2 Topping unit instrumentation.....	606
10.1.3 Off-site instrumentation .....	614
10.2 Instrumentation Applications in the Iron- and Steel-Industry .....	621
10.2.1 Overview of instrumentation in the iron-and steelmaking process.....	621
10.2.2 Blast furnace instrumentation.....	624
10.2.3 Continuous casting equipment instrumentation.....	635
10.2.4 Instrumentation for an electrolytic galvanizing line.....	642
10.3 Instrumentation Applications in the Power Industry .....	648
10.3.1 Overview .....	648
10.3.2 Thermal power plants .....	648
10.3.3 Boiler control .....	649
10.3.4 Turbine control.....	663
10.3.5 Power plant system control .....	667
10.3.6 Nuclear power plant overview.....	669

10.3.7 Pressurized water reactor control system .....	010
10.4 Instrumentation Applications in the Food Processing	
Industry .....	687
10.4.1 Overview .....	687
10.4.2 Whiskey distillery instrumentation .....	689
10.4.3 Sugar refinery instrumentation .....	693
10.5 Instrumentation Applications in the Paper Manufacturing	
Industry .....	706
10.5.1 Overview of an integrated paper mill .....	706
10.5.2 Pulp plant instrumentation .....	709
10.5.3 Instrumentation applied to the papermaking process.....	719
10.6 Waterworks Instrumentation Applications .....	726
10.6.1 Overview of waterworks facilities.....	726
10.6.2 Water treatment-related detectors .....	727
10.6.3 Filtration equipment instrumentation .....	731
10.6.4 Chemical injection equipment instrumentation .....	732
10.6.5 Instrumentation for water-supply and distribution facilities.....	737
10.6.6 An integrated control system for large-scale, wide-area waterworks facilities.....	738
10.6.7 Water distribution information management system.....	739
10.6.8 Wastewater system overview .....	745
10.6.9 Overview of activated-sludge processes .....	745
10.6.10 Wastewater treatment instrumentation .....	747
10.6.11 Sludge treatment instrumentation .....	749
10.7 Instrumentation Application in the Automobile Industry .....	751
10.7.1 Overview of automobile industry instrumentation.....	751
10.7.2 Production management at a painting factory .....	752
10.7.3 Storage control .....	755
10.8 Product Control in Batch Processing .....	759
10.8.1 Batch process recipe management.....	760
10.8.2 Batch process control .....	763
10.8.3 Recipe management and operation methods.....	769
References.....	773

## APPENDIXES

App.1 Reference Thermoelectromotive Force Tables.....	778
App.2 Reference Resistance Value of Pt 100 .....	782
App.3 Tables of Laplace Transform.....	784

Index.....	785
------------	-----