DOCUMENT RESUME

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IDENTIFIERS	*Millwrights; Power Plant Operators; *Steam

ABSTRACT

This packet of four learning modules on steam is one of six such packets developed for apprenticeship training for millwrights. Introductory materials are a complete listing of all available modules and a supplementary reference list. Each module contains some or all of these components: goal, performance indicators, study guide (a check list of steps the student should complete), a vocabulary list, an introduction, information sheets, assignment sheet, job sheet, self-assessment, self-assessment answers, post-assessment, instructor post-assessment answers, and a list of supplementary references. Supplementary reference material may be provided. The four training modules cover steam formation and evaporation, types of steam, steam transport, and steam purification. (YLB)

ED254728

APPRENTICESHIP

MILLWRIGHT

RELATED TRAINING MODULES

14.1 - 14.4 STEAM

CE041004

STATEMENT OF ASSURANCE

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APPRENTICESHIP

MILLWRIGHT
RELATED TRAINING MODULES

SAFETY

1.1 General Safety
1.2 Hand Tool Safety
1.3 Power Tool Safety
1.4 Fire Safety
1.5 Hygiene Safety
1.6 Safety and Electricity
1.7 Fire Types and Prevention
1.8 Machine Safeguarding (includes OSHA Handbook)

ELECTRICITY/ELECTRONICS

2.1 Basics of Energy
2.2 Atomic Theory
2.3 Electrical Conduction
2.4 Basics of Direct Current
2.5 Introduction to Circuits
2.6 Reading Scales
2.7 Using a V.O.M.
2.8 OHM'S Law
2.9 Power and Watt's Law
2.10 Kirchoff's Current Law
2.11 Kirchoff's Voltage Law
2.12 Series Resistive Circuits
2.13 Parallel Resistive Circuits
2.14 Series - Parallel Resistive Circuits
2.15 Switches and Relays
2.16 Basics of Alternating Currents
2.17 Magnetism

COMPUTERS

3.1 Digital Language
3.2 Digital Logic
3.3 Computer Overview
3.4 Computer Software

TOOLS

4.1 Boring and Drilling Tools
4.2 Cutting Tools, Files and Abrasives
4.3 Holding and Fastening Tools
4.4 Fastening Devices
4.5 Basic Science - Simple Mechanics
4.6 Fasteners

DRAFTING

5.1 Types of Drawing and Views
5.2 Sketching
5.3 Blueprint Reading/Working Drawings
5.4 Working Drawings for Machines and Welding
5.5 Machine and Welding Symbols
5.6 Blueprint Reading, Drafting: Basic Print Reading
5.7 Blueprint Reading, Drafting: Basic Print Reading
5.8 Blueprint Reading, Drafting: Basic Print Reading
5.9 Blueprint Reading, Drafting: Basic Print Reading
5.10 Blueprint Reading, Drafting: Basic Print Reading
5.11 Blueprint Reading, Drafting: Basic Print Reading
5.12 Blueprint Reading, Drafting: Basic Print Reading
5.13 Blueprint Reading, Drafting: Basic Print Reading
5.14 Drafting, Machine Features
5.15 Drafting, Measurement
5.16 Drafting, Visualization

HUMAN RELATIONS

6.1 Communications Skills
6.2 Feedback
6.3 Individual Strengths
6.4 Interpersonal Conflicts
6.5 Group Problem Solving
6.6 Goal-setting and Decision-making
6.7 Worksite Visits
6.8 Resumes
6.9 Interviews
6.10 Expectation
6.11 Wider Influences and Responsibilities
6.12 Personal Finance

BOILERS

7.1 Boilers - Fire Tube Types
7.2 Boilers - Watertube Types
7.3 Boilers - Construction
7.4 Boilers - Fittings
7.5 Boilers - Operation
7.6 Boilers - Cleaning
7.7 Boilers - Heat Recovery Systems
7.8 Boilers - Instruments and Controls
7.9 Boilers - Piping and Steam Traps

TURBINES

8.1 Steam Turbines - Types
8.2 Steam Turbines - Components
8.3 Steam Turbines - Auxillaries
8.4 Steam Turbines - Operation and Maintenance
8.5 Gas Turbines

16.5 Compound Numbers
16.6 Percent
16.7 Ratio and Proportion
16.8 Perimeters, Areas and Volumes
16.9 Circumference and Wide Area of Circles
16.10 Area of Plane, Figures and Volumes of Solid Figures
16.11 Metrics

HYDRAULICS

17.1 Hydraulics - Lever
17.2 Hydraulics - Transmission of Force
17.3 Hydraulics - Symbols
17.4 Hydraulics - Basic Systems
17.5 Hydraulics - Pumps
17.6 Hydraulics - Pressure Relief Valve
17.7 Hydraulics - Reservoirs
17.8 Hydraulics - Directional Control Valve
17.9 Hydraulics - Cylinders
17.10 Hydraulics - Forces, Area, Pressure
17.11 Hydraulics - Conductors and Connectors
17.12 Hydraulics - Troubleshooting
17.13 Hydraulics - Maintenance

METALLURGY

18.1 Included are ILS packets:
W 3010
W 3011-1
W 3011-2
MS 9001 (1-3-4-8-9-6-7-5-2-9)
MS 9200, 9201

POWER DRIVES

19.1
101. A-B-C-D-E
102. C-D-E
103. B-C-D-E
104. A-C-E-F-G-H-I-J
107. A
108. A

WELDING

20.1
602. A-B-C-D-G-I-L-M
603. A-B-F-G-I
W. 3011-1 refer to Mettallurgy 18.1
WE. MA-18

MILLWRIGHT
SUPPLEMENTARY REFERENCE DIRECTORY

Note: All reference packets are numbered on the upper right-hand corner of the respective cover page.

Supplementary Packet #	Description	Related Training Module	
1.8	Concepts & Techniques of Machine Safeguarding, U.S.D.L., O.S.H.A.	1.8	Machine Safeguarding
12.1	Correspondence Course, Lecture 1, Sec. 2, Steam Generators, Types of Boilers I, S.A.I.T., Calgary, Alberta, Canada	7.1	Boilers, Fire Tube Type
12.2	Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Types of Boikers II, S.A.I.T., Calgary, Alberta, Canada	7.2	Boilers, Water Tube Type
12.3	Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Boiler Construction & Erection, S.A.I.T., Calgary, Alberta, Canada	7.3	Boilers, Construction
12.4	Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fittings II, S.A.I.T., Calgary, Alberta, Canada	7.4	Boilers, Fittings
12.4	Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fitting I, S.A.I.T., Calgary, Alberta, Canada	7.4	Boilers, Fittings
12.5	Correspondence Course, Lecture 10, Sec. 2, Steam Generation, Boiler Operation, Maintenance, Inspection, S.A.I.T., Calgary, Alberta, Canada	7.5	Boilers, Operation
12.7	Correspondence Course, Lecture 3, Sec. 2, Steam Generation, Boiler Details, S.A.I.T., Calgary, Alberta, Canada	7.7	Boilers Heat Recovery Systems
		PUMPS	
13.1 13.2 13.4 13.6 13.7	Correspondence Course, Lecture 9, Sec. 2, Steam Generator, Power Plant Pumps, S.A.I.T., Calgary, Alberta, Canada	9.1 9.2 9.4 9.6 9.7	Types & Classifications Applications Calculating Heat & Flow Monitoring & Troubleshooting Maintenance
13.3 13.5	Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Pumps, S.A.I.T., Calgary, Alberta, Canada	9.3 9.5	Construction Operation

Supplementary Packet #	Description	Related Training Module
14.3 12.8	Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Steam Generator Controls, S.A.I.T., Calgary, Alberta, Canada	14.3 Steam Transport 7.8 Boilers, Instruments & Controls
14.4	Correspondence Course, Lecture 11, Sec. 2, Steam Generators, Piping II, S.A.I.T., Calgary, Alberta, Canada	14.4 Steam Purification
15.1	Correspondence Course, Lecture 1, Sec. 4, Prime Movers, & Auxiliaries, Steam Turbines, S.A.I.T., Calgary, Alberta, Canada	8.1 Steam Turbines, Types
15.2	Correspondence Course, Lecture 4, Sec. 3, Prime Movers, Steam Turbines I, S.A.I.T., Calgary, Alberta, Canada	8.2 Steam Turbines, Components
15.3	Correspondence Course, Lecture 2, Sec. 4, Prime Movers & Auxiliaries, Steam Turbine Auxiliaries, S.A.I.T., Calgary, Alberta, Canada	8.3 Steam Turbines, Auxiliaries
15.4	Correspondence Course, Lecture 6, Sec. 3, Prime Movers, Steam Turbine Operation & Maintenance, S.A.I.T., Calgary, Alberta, Canada	8.4 Steam Turbines, Operation & Maintenance
15.5	Correspondence Course, Lecture 8, Sec. 3, Prime Movers, Gas Turbines, S.A.I.T., Calgary, Alberta, Canada	8.5 Gas Turbines
16.2	Boilers Fired with Wood & Bark Residues, D.D. Junge, F.R.L., O.S.U., 1975	10.2 Combustion Types of Fuel
16.2	Correspondence Course, Lecture 5, Sec. 2, Steam Generators, Fuel Combustion, S.A.I.T., Calgary, Alberta, Canada	10.2 Combustion Types of Fuel
16.3	Correspondence Course, Lecture 5, Sec. 2, Plant Services, Fuel & Combustion, S.A.I.T., Calgary, Alberta, Canada	10.3 Combustion Air & Fuel Gases
17.1	Correspondence Course, Lecture 12, Sec. 3, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada	12.1 Feedwater, Types & Operation
17.2	Correspondence Course, Lecture 12, Sec. 2, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada	12.2 Feedwater, Water Treatments

Supplementary Packet #	Description	Related Training Module
17.3	Correspondence Course, Lecture 7, Sec. 2, Steam Generators, Boiler Feedwater Treatment, S.A.I.T., Calgary, Alberta, Canada	12.3 Feedwater, Testing
18.1	Correspondence Course, Lecture 2, Sec. 5, Electricity, Direct Current Machines, S.A.I.T., Calgary, Alberta, Canada	11.1 Generators, Types & Construction
18.1 18.2	Correspondence Course, Lecture 4, Sec. 5, Electricity, Alternating Current Generators, S.A.I.T., Calgary, Alberta, Canada	11.1 Generators, Types & Construction 18.2 Generators, Operation
19.1	Correspondence Course, Lecture 5, Sec. 4, Prime Movers & Auxiliaries, Air Compressor I, S.A.I.T., Calgary, Alberta, Canada	13.1 Air Compressors, Types
19.1	Correspondence Course, Lecture 6, Sec. 4, Prime Movers & Auxiliaries, Air Compressors II, S.A.I.T., Calgary, Alberta, Canada	13.1 Air Compressors, Types 13.2 Air Compressors, Operation & Maintenance
20.1	Basic Electronics, Power Transformers, EL-BE-51	15.4 Transformers
21.1	Correspondence Course, Lecture 6, Sec. 5, Electricity, Switchgear & Circuit, Protective Equipment, S.A.I.T., Calgary, Alberta, Canada	15.3 Circuit Protection
22.1	Correspondence Course, Lecture 10, Sec. 3, Prime Movers, Power Plant Erection & Installation, S.A.I.T., Calgary, Alberta, Canada	15.1 Installation Foundations

RECOMMENDATIONS FOR USING TRAINING MODULES

The following pages list modules and their corresponding numbers for this particular apprenticeship trade. As related training classroom hours vary for different reasons throughout the state, we recommend that the individual apprenticeship committees divide the total packets to fit their individual class schedules.

There are over 130 modules available. Apprentices can complete the whole set by the end of their indentured apprenticeships. Some apprentices may already have knowledge and skills that are covered in particular modules. In those cases, perhaps credit could be granted for those subjects, allowing apprentcies to advance to the remaining modules.

We suggest the the apprenticeship instructors assign the modules in numerical order to make this learning tool most effective.

SUPPLEMENTARY INFORMATION

ON CASSETTE TAPES

Tape 1: Fire Tube Boilers - Water Tube Boilers and Boiler Manholes and Safety Precautions

Tape 2: Boiler Fittings, Valves, Injectors, Pumps and Steam Traps

Tape 3: Combustion, Boiler Care and Heat Transfer and Feed Water Types

Tape 4: Boiler Safety and Steam Turbines

NOTE: The above cassette tapes are intended as additional reference material for the respective modules, as indicated, and not designated as a required assignment.

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Modules 18.1, 19.1, and 20.1 have been omitted because they contain dated materials.

INSTRUCTIONAL LEARNING SYSTEMS

14.1

STEAM — FORMATION AND EVAPORATION

Goal:

The apprentice will be able to describe steam formation and evaporation.

Performance Indicators:

1. Describe temperatures for steam formation.
2. Describe types of heat.
3. Describe formation of steam.
4. Describe evaporation.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete the self-assessment.
* Complete the post-assessment.

Vocabulary

* Celsius scale
* Condensation
* Evaporation
* Fahrenheit scale
* Latent heat
* Latent heat of fusion
* Latent heat of evaporation
* Saturation temperature
* Sensible heat
* Temperature of evaporation
* Temperature of vaporization
* Vapor

Introduction

Steam formation requires water to be changed from a liquid to a vapor state. This requires that water be heated to the boiling point. Two types of heat are used in converting water to steam. One is a sensible heat that raises the temperature to boiling and a latent heat that will change the state of water without further rise in temperature.

The apprentice should have a theoretical understanding of the steam formation process.

Information

Temperatures

Heat is used to convert solids into liquids and liquids into gases. Steam is regarded as a vapor instead of a gas because it does not follow all of the rules of gaseous behavior. The process of converting water to steam requires 100°. The Fahrenheit scale which is common to American thought has a freezing point of 32° and a boiling point of 212°. Regardless of the measuring scale, water must reach boiling point before steam is produced.

The boiling point will vary at different elevations above sea level. Also, the boiling point will vary with the pressures that are placed upon the liquid. The 100° C is based on atmospheric pressure. Liquids under pressure will boil at a range of temperatures which are controlled by the pressure. Water will boil at high altitudes much quicker than at sea level.

Types of Heat

Sensible heat is heat that can be sensed and measured with a thermometer. Latent heat is a hidden heat that may cause a state of change in another substance without changing the temperature of the substance. If ice is being changed into its liquid state, the melting temperature is 0°C. As the ice continues its melting, the temperature will remain at 0°C until it is water. When latent heat is used to convert a solid to a liquid, it is called the latent heat of fusion.

If latent heat is applied to water at 100°C, the water will change to a vapor state. The water will continue to boil at 100°C. The heat that converts liquids to a vapor form is called the latent heat of evaporation.

Formation of Steam

Water is heated to the boiling point with sensible heat. After boiling point, the latent heat changes the water into steam. Steam is formed at the boiling point temperature. That temperature may be more or less than a 100°C, depending on the pressure in relation to atmospheric pressure. That boiling point is called the temperature of vaporization or temperature of evaporation or saturation temperature. That is the temperature at which steam formation takes place.

Evaporation

If we set a pan of water in the sun, it will slowly disappear through evaporation. If we add heat to the pan, the water will evaporate much quicker.

Information

In the process of evaporation, the water simply turns into vapor form and floats away. In steam production, the process of evaporation is controlled by steam generation equipment. Condensation is the opposite of evaporation. As the vapor cools, it is converted back to a liquid state.

Assignment

* Complete the job sheet.
* Complete the self-assessment and check answers.
* Complete the post-assessment and ask the instructor to check answers.

Job Sheet

CHECK BOILING TEMPERATURE

* Obtain a Celsius scale thermometer that records beyond 100°C.
* Place a teapot of water on the burner and place thermometer in water so that it can be read. (Note temperature of water.)
* Light burner and bring water to boiling point. (Note temperature.)
* Allow water to continue boiling for 10 minutes. (Note temperature.)
* Which temperature readings show sensible heat?
* Which temperature readings show latent heat?
* What is the boiling point of water?

Self Assessment

MATCH THE FOLLOWING TERMS AND PHRASES.

_____ 1.	Celsius scale	A.	Changes liquid to gas
_____ 2.	Fahrenheit scale	B.	Changes solid to liquid.
_____ 3.	Latent heat	C.	Boiling point 100°.
_____ 4.	Latent heat of fusion	D.	Changing of liquid to vapor.
_____ 5.	Sensible heat	E.	Boiling point 212°.
_____ 6.	Latent heat of evaporation	F.	Freezing point on Celsius.
_____ 7.	Temperature of evaporation	G.	Hidden heat that changes forms of substances with changing in temperature.
_____ 8.	Condensation	H.	The boiling point after adjustment for pressure.
_____ 9.	Evaporation	I.	The opposite of evaporation.
_____ 10.	0°	J.	Heat that can be sensed or measured.

• Self Assessment Answers

C 1.

E 2.

G 3.

B 4.

J 5.

A 6.

H 7.

I 8.

D 9.

F 10.

Post Assessment

1. The ______________ scale has a freezing point of 32° and a boiling point of 212°.

2. The ______________ scale has a freezing point of 0 and a boiling point of 100°.

3. The exact point at which water boils is determined by the ______________ on the water.

4. Steam is regarded as a ______________ because it does not behave by the rules of most gases.

5. A heat that can be sensed and measured is called ______________ heat.

6. A hidden heat that changes water to steam without increasing the temperature is called ______________ heat.

7. A heat that converts a solid into a liquid is called the latent heat of ______________.

8. The exact boiling point where steam is formed is called the temperature of ______________.

9. ______________ is the opposite of evaporation.

10. The vaporization of a liquid is called ______________.

Instructor Post Assessment Answers

1. Fahrenheit
2. Celsius
3. Pressure
4. Vapor
5. Sensible
6. Latent
7. Fusion
8. Vaporization or evaporation or saturation
9. Condensation
10. Evaporation

Supplementary References

* Select own reading material for this package.

14.2

STEAM — TYPES

Goal:

The apprentice will be able to describe types of steam.

1

Performance Indicators:

1. Describe saturated steam.
2. Describe dry steam.
3. Describe wet steam.
4. Describe superheated steam.
5. Describe steam tables.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Dry saturated steam
* Saturated steam
* Steam tables
* Thermodynamic properties
* Wet steam

Introduction

Although all steam is formed at the temperature of evaporation, it will differ in its thermodynamic properties. These differences can affect the efficiency of plant operation unless they are understood.

Some steam has heavy concentrations of suspended water particles which can create problems for turbine blades. Most plants use superheaters to raise the temperature of the steam beyond the temperature of evaporation. An operator must understand the basic types of steam in order to deal with its applications in power production.

Information

Water turns to steam when heated to a 100°C at atmospheric pressure. This boiling point temperature is the saturation temperature. The saturation temperature will vary according to the pressure on the water.

Saturated Steam

Saturated steam is steam at the temperature of saturation or evaporation. It is steam that has just undergone conversion from the liquid to a vapor state.

Wet Steam

Saturated steam with particles of water suspended within the steam is called wet steam.

Dry Saturated Steam

Saturated steam without suspended water particles is called dry saturated steam.

Superheated Steam

Steam cools and starts reverting to water. This creates a wet steam that is undesirable. To avoid wet steam, saturated steam is heated beyond the temperature of saturation. Steam with temperatures higher than saturation levels is called superheated steam. Superheated steam is used in turbines so that erosion of blades by wet steam can be avoided.

Steam Tables

The properties of steam will vary with the pressure. Steam tables have been developed to show the thermodynamic properties of steam at various pressures. The thermodynamic properties include volume, latent and sensible heat values, relationships of heat and pressure and internal energy values of steam. Steam tables are available for saturated and superheated steam. The operator must know how to read the steam tables and interpret the information for practical applications. The following steam table shows the saturation temperatures under pressures ranging from 1/4 pound to 3206 pounds absolute.

Information

	PRESS. ABS.	TEMP. °F	PRESS. ABS.	TEMP. °F	PRESS. ABS.	TEMP. °F	PRESS. ABS.	TEMP. °F	PRESS. ABS.	TEMP. °F	PRESS. ABS.	TEMP. °F
	0.25	59.30	50	281.01	240	397.37	430	451.73	750	510.86	1900	628.56
	0.50	79.58	60	292.71	250	400.95	440	454.02	775	514.59	2000	635.82
	0.75	92.29	70	302.92	260	404.42	450	456.28	800	518.23	2100	642.77
	1.0	101.74	80	312.03	270	407.78	460	458.50	825	521.79	2200	649.46
	1.5	115.69	90	320.27	280	411.05	470	460.68	850	525.26	2300	655.91
	2.0	126.08	100	327.81	290	414.23	480	462.82	875	528.66	2400	662.12
	2.5	134.44	110	334.77	300	417.33	490	464.93	900	531.98	2500	668.13
	3.0	141.48	120	341.25	310	420.35	500	467.01	925	535.24	2600	673.94
	4.0	152.97	130	347.32	320	423.29	520	471.07	950	538.42	2700	679.55
	5.0	162.24	140	353.02	330	426.16	540	473.01	975	541.55	2800	684.99
	7.0	176.85	150	358.42	340	428.97	560	478.85	1000	544.61	2900	690.26
	9.0	188.28	160	363.53	350	431.72	580	482.58	1100	556.31	3000	695.36
	11.0	197.75	170	368.41	360	434.40	600	486.21	1200	567.22	3100	700.31
	13.0	205.88	180	373.06	370	437.03	620	489.75	1300	577.46	3200	705.11
"0" GAGE PRESS	14.6	212.00	190	377.51	380	439.60	640	493.21	1400	587.10	3206	705.40
	15	213.03	200	381.79	390	442.12	660	496.58	1500	596.23	3300	705.40
	20	227.96	210	385.90	400	444.59	680	499.88	1600	604.90	3500	705.40
	30	250.33	220	389.86	410	447.01	700	503.10	1700	613.15	4000	705.40
	40	267.25	230	393.68	420	449.39	720	506.25	1800	621.03	5000	705.40

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Assignment

* Complete job sheet.
* Complete the self-assessment and check answers.
* Complete the post-assessment and ask the instructor to check your answers.

Job Sheet

Using a saturated steam table, find the saturation temperatures at the following pressures.

1. 14.6 pounds
2. 40 pounds
3. 420 pounds
4. 1600 pounds
5. 3206 pounds

What is atmospheric pressure at sea level?

What is absolute pressure?

Self Assessment

Match the following terms and phrases.

____	1. Saturated steam	A. Steam with temperatures higher than temperature of evaporation.
____	2. Dry steam	B. Steam with suspended water particles.
____	3. Superheated steam	C. Steam without suspended water particles.
____	4. Wet steam	D. Shows thermodynamic properties of steam.
____	5. Steam tables	E. Steam at temperature of evaporation.

Self Assessment Answers

E 1.

C 2.

A 3.

B 4.

D 5.

Post Assessment

1. Where can an operator find the thermodynamic values of steam at various levels of pressure?

2. Why is superheated steam used for turbine operation?

3. What is saturated steam called when it has water particles suspended within the steam?

4. What is steam called when at the temperature of evaporation?

5. What is the temperature of evaporation at atmospheric pressure?

Instructor
Post Assessment Answers

1. Steam tables

2. Prevent erosion of turbine blades by wet steam.

3. Wet steam

4. Saturated steam

5. $100^{\circ}C$

Supplementary References

* Saturated Steam Tables provided by instructor or from reference library.

INSTRUCTIONAL LEARNING SYSTEMS

14.3

STEAM — TRANSPORT

Goal:

The apprentice will be able to describe steam transport.

Performance Indicators:

1. Describe condensate removal.
2. Describe piping, pipe insulation and valve control.
3. Describe separators and traps.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Drip or drain line
* Insulation
* K value
* Steam separator
* Steam trap
* Thermal conductivity
* Water hammer

Introduction

This package briefly describes the movement of steam through piping and provisions for removing condensate from the steam line. Other packages have dealt with the specifics of piping, steam purification and valves. Although these items are important to the transport of steam, they will not be repeated in detail in this package.

Information

The transport of steam through piping must be carefully controlled. Water must be continually drained from the steam. The presence of water in the steam will create the condition known as water hammer. Water hammer can cause an explosion in the lines and equipment damage. Air and carbon dioxide must also be removed from the lines. Drainage must be provided for all types of steam including superheated steam. Any cooling of the steam produces condensate which can damage turbines and other equipment. Drains and drip lines must be installed at all points where condensate is likely to collect.

Drip or Drain Lines

Drip or drain lines should be installed at natural drainage points such as:

* At the ends of mains
* Ahead of risers
* Ahead of expansion joints and bends
* Ahead of valves and regulators

A drip leg should be provided at each drainage point. The drip leg should be the same diameter as the pipe. The drip leg allows gravity drainage of water from the steam flow.

Water Hammer

Water hammer is a condition in the line that results in shock waves that resemble hammer blows. It usually occurs in steam lines as a result of condensate in the line. The water or condensate tends to trap pockets of steam. The cooler water condenses the steam which creates a pressure pocket. Equalization of this pressure pocket causes shock waves in the pipe.

Most water hammer can be avoided by installing drains, drip pockets and traps to remove the condensate from the steam lines. Steam valves should be opened slowly, with drain valves open, allowing the line to warm up. Hot steam in a cold line can create condensate and water hammer.

Pipe Insulation

Power plant pipe is covered with insulation to prevent heat loss and condensation. The insulation is also a safety feature to protect employees from getting burns. The material should be of high insulation value and able to withstand corrosion. Insulation materials are selected on the basis of their thermal conductivity K value. The K value indicates the amount of heat that will

Information

be transmitted through a material. Since insulation is the exact opposite of conductivity, the lower the K value of a material, the better is its insulating quality. Some common insulating materials and their K values are:

* Plastic foams	.09 - .28 K
* Glass fiber	.29 - .35 K
* Magnesia	.35 - .42 K
* Calcium silicate	.37 - .60 K
* Asbestos	.37 - .72 K
* Reflective metal	.53 - .66 K
* Diatomaceous silica	.70 - .80 K

Valves

Several types of valves are used in the transport of steam. Valves are selected according to their specific functions in the movement of steam. Valves have been discussed in detail in other packages on boiler piping and boiler fittings.

Pipe

There are many types and sizes of pipe in a power plant. Pipe is selected to withstand specific conditions of pressure, temperature and resistance to corrosion. Pipe construction is discussed in a package on boiler piping and will not be repeated here. The selection of the proper diameter pipe and pipe material is important to safe and efficient operation of a steam plant.

Steam Separators and Steam Traps

Steam separators remove condensate from steam. They are commonly called steam purifiers. The separators are designed with baffles or centrifugal devices that separate the water from the steam to prevent water hammer and erosion caused by wet steam.

A steam trap is a device which removes water from steam separators and steam lines without the loss of steam. Several types of traps are used for this purpose.

A more detailed treatment of steam purifiers and steam traps is included in the next package of this series — Steam Purification.

Assignment

* Read page 1, 20-34 in supplementary reference.
* Complete the self-assessment and check your answers.
* Complete the post-assessment and have the instructor check your answers.

Self Assessment

1. List 3 places where drip or drain lines should be installed?

2. What causes water hammer in steam lines?

3. How can water hammer be prevented?

4. On insulation materials, what does the K value mean?

5. Which of the following insulation material have the best insulation quality?

   * Asbestos .5 K
   * Glass fiber .3 K

Self Assessment Answers

1. At end of mains, ahead of risers, ahead of expansion joints and bends, ahead of valves and regulators.

2. Condensate

3. Removing condensate from steam lines and warming up lines before steam flow.

4. Thermal conductivity

5. Glass fiber. The lower value is best.

Post Assessment

Match the following terms and phrases:

_____	1. Water hammer	A. Thermal conductivity
_____	2. Drip leg	B. Device for removal of water from separators
_____	3. K value	C. Steam purifier
_____	4. Steam trap	D. Should be installed at each drainage point
_____	5. Steam separator	E. Caused by condensate in steam line

Instructor Post Assessment Answers

E 1.

D 2.

A 3.

B 4.

C 5.

Supplementary References

* Correspondence Course. Lecture 11, Section 2, Second Class. Steam Generators. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Courses
Power Engineering

SECTION 2

STEAM GENERATION

First Class
Lecture 14

STEAM GENERATOR CONTROLS

In order to ensure safe, economical, and reliable operation of the steam generator, instruments and controls are necessary. The boiler outlet conditions such as steam flow, pressure, and temperature must be measured and the quantities of fuel, air, and water must be adjusted to maintain the desired values of the outlet steam conditions. This measuring and adjusting must be done continuously during the time the boiler is in operation. The subject of the instrumentation and control necessary to perform the measurement and adjustment is of necessity quite complex and extensive and its coverage in this course must be limited to not much more than basic concepts.

METHODS OF MEASUREMENT

In measuring the values of the variables involved in the power plant operation, many different types of instruments may be used, not only to indicate the measured value, but also to record the value, usually continuously, on a chart. The instruments are also often used to send signals to control certain flows.

The measuring instruments may be located directly at the point where the measurement is being taken or they may be located remote from the measurement point, for example, in a central control room.

Some of the more commonly used designs of measuring instruments are described in the following sections.

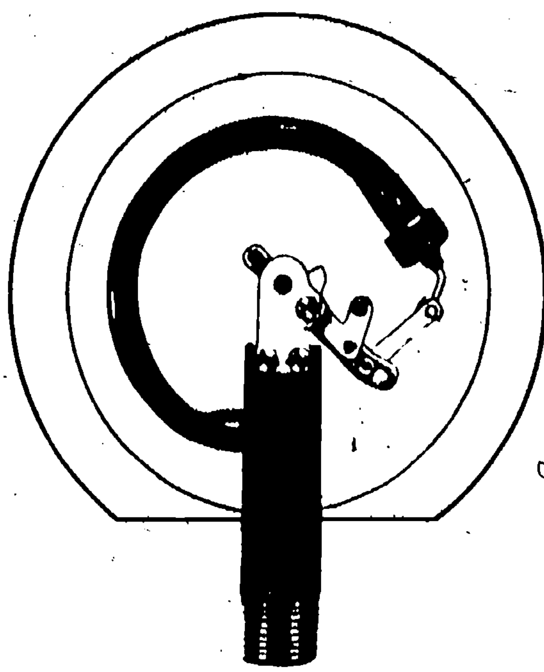
1. PRESSURE MEASUREMENT

Pressure is one of the most commonly measured variables in power plant operation. These pressure measurements include steam pressure, feedwater pressure, furnace pressure, condenser pressure, lubricating oil pressure and many others.

The Bourdon tube, the bellows, and the diaphragm are three devices commonly used to measure pressure. Another device which is sometimes used is the liquid or mercury filled U-tube used for low pressure work.

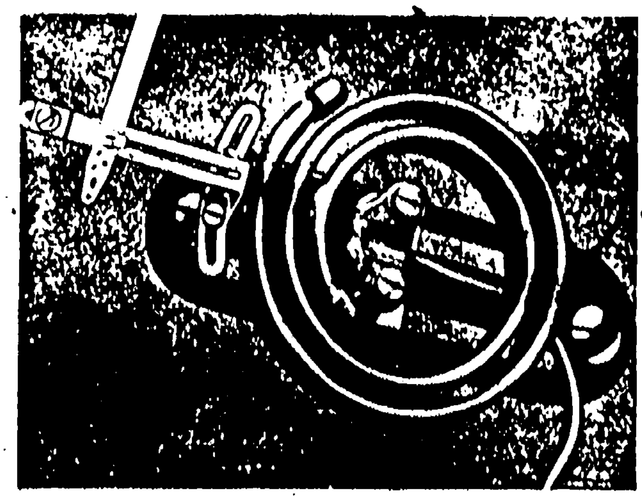
The Bourdon tube may be in the form of a C, a spiral, or a helix. In each case a hollow flattened or oval shaped tube is used, sealed at one end. The open end is fixed and is connected to the source of pressure while the sealed end is free to move. Pressure tends to straighten the tube and the movement of the free end is a measure of the pressure.

The Bourdon tube types are illustrated in Figs. 1 to 3 inclusive.



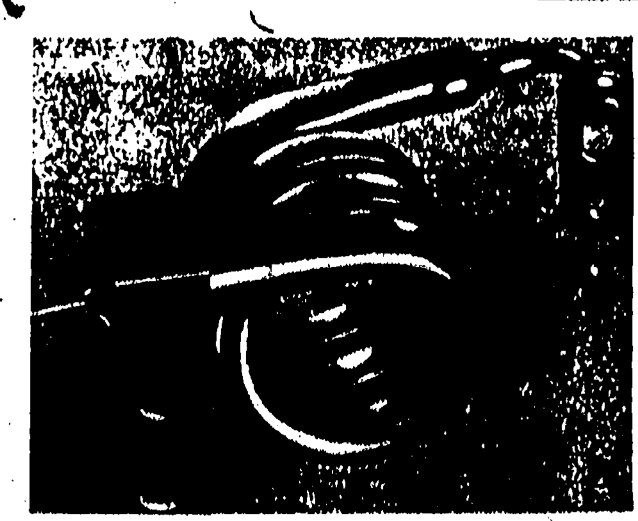
C Bourdon Tube

Fig. 1



Spiral Bourdon Tube

Fig. 2



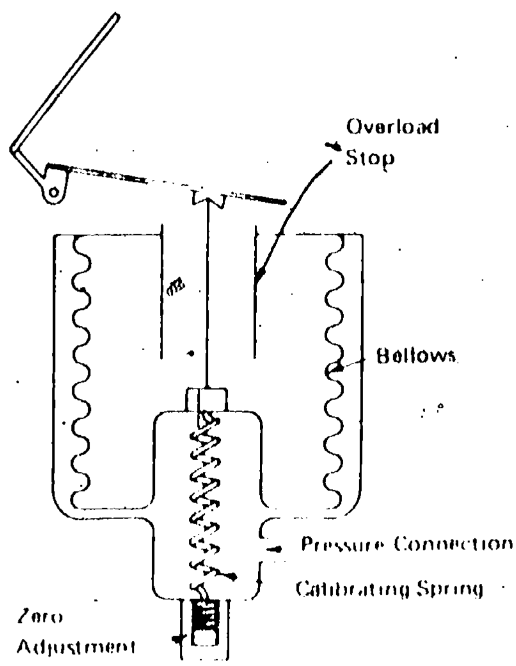
Helix Bourdon Tube

Fig. 3

The bellows consists of a chamber which is corrugated in such a way that it will expand or contract in the direction of its length rather than in the direction of its side walls.

The pressure to be measured may be applied to the inside of the bellows, in which case it will expand or elongate. Conversely the pressure may be applied to the outside of the bellows causing it to contract or shorten. The bellows may also be used to measure the difference between two pressures by applying one pressure to the inside of the bellows and applying the other pressure to the outside of the bellows.

Fig. 4 is a sketch of a bellows type pressure gage in which the pressure to be measured is between the bellows and the case.



Bellows Pressure Gage

Fig. 4

The diaphragm type of pressure gage is used primarily to measure low pressures such as draft in a boiler furnace and is normally calibrated in inches of water. It consists essentially of a non-metallic diaphragm, sometimes called a limp diaphragm, which, when pressure is applied to it, will distort and either stretch, compress, or deflect a spring.

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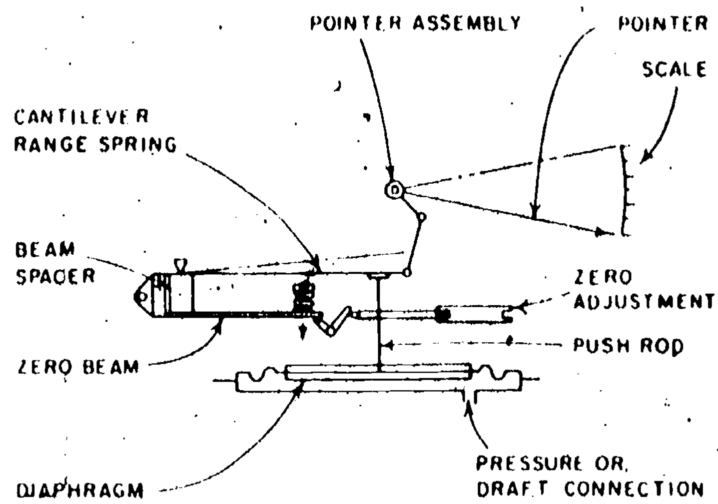
The principle of operation of this type is shown schematically in Fig. 5.



Diaphragm Pressure Gage

Fig. 5

For low pressures and drafts (suction), liquid or mercury U-tubes or variations thereof are sometimes used. Depending on the pressure (or suction) either mercury or a colored oil is used. One end of the U-tube is connected to the source of pressure or suction, the other to atmosphere. The difference in the levels of the two legs represents the pressure of the suction head in linear units of the medium being used. If pressure is measured, the connected leg is depressed; if suction, the leg to atmosphere is depressed. Inclined draft gages are of this variety.

Connecting one side of the U-tube to one point of pressure or suction in a system and the other side to a different point in the same system gives a drop or differential pressure between the two points. The instrument thus becomes a differential pressure gage and is used for various readings, such as draft loss across an air heater.

2. TEMPERATURE MEASUREMENT

Most power plant operations involve the transfer of heat and resulting temperature changes. Therefore, temperature is another of the most commonly measured variables in the plant. Examples include steam temperature, feedwater temperature, flue gas temperature, oil temperature, cooling water temperature and many others.

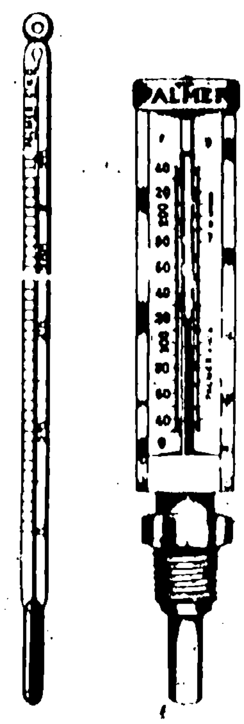
Temperature measuring instruments used in power plants include glass-stem thermometers, remote-indicating bulb thermometers, bimetallic thermometers, and thermoelectric pyrometers.

Glass-stem Thermometers

The principle of operation of this type involves the expansion and contraction of a column of mercury or alcohol due to temperature changes. The thermometer consists of a thick-walled glass tube with a small bore and formed into a bulb at one end. The bulb contains the mercury or alcohol which expands or contracts with temperature changes and so rises or falls in the small bore tube. The reference scale numbers are either etched on the outside of the glass tube or secured adjacent to it.

The mercury filled type is more stable at high temperatures than the alcohol filled type and is used for temperatures up to about 300°C and in some cases up to about 500°C. The alcohol type is better suited for low temperatures due to its very low freezing point.

Fig. 6 shows two types of glass-stem thermometers.

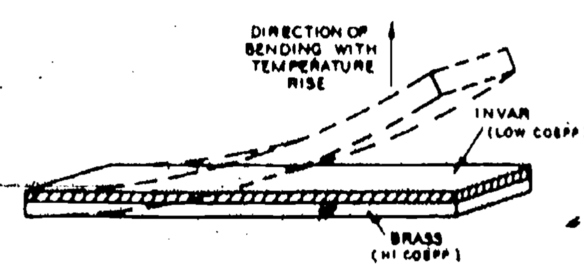


Glass-stem Thermometers

Fig. 6

Bimetallic Thermometers

The operation of this type depends upon the fact that dissimilar metals when heated will expand at different rates. The thermometer is made up of two thin strips of different metals welded together face to face. When heated, the strips expand at different rates causing the assembly to bend as shown in Fig. 7.



Bimetal Strip

Fig. 7

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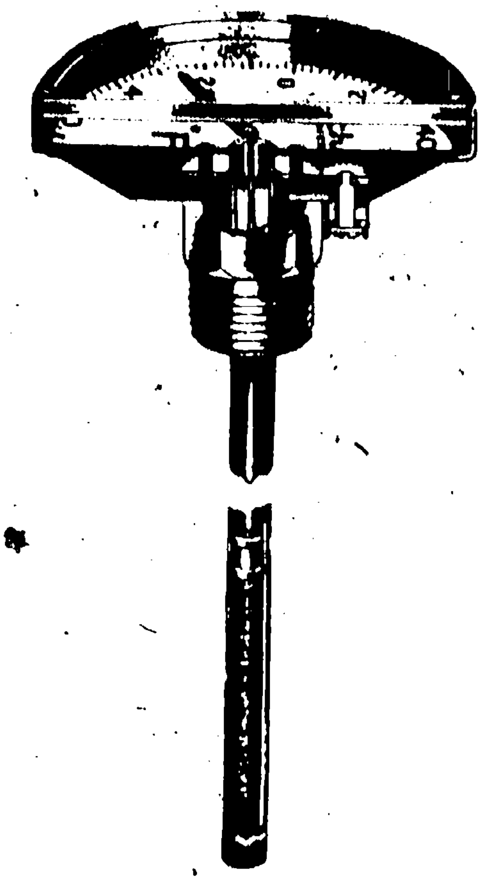
This bending movement is used to move a pointer thus indicating a temperature change.

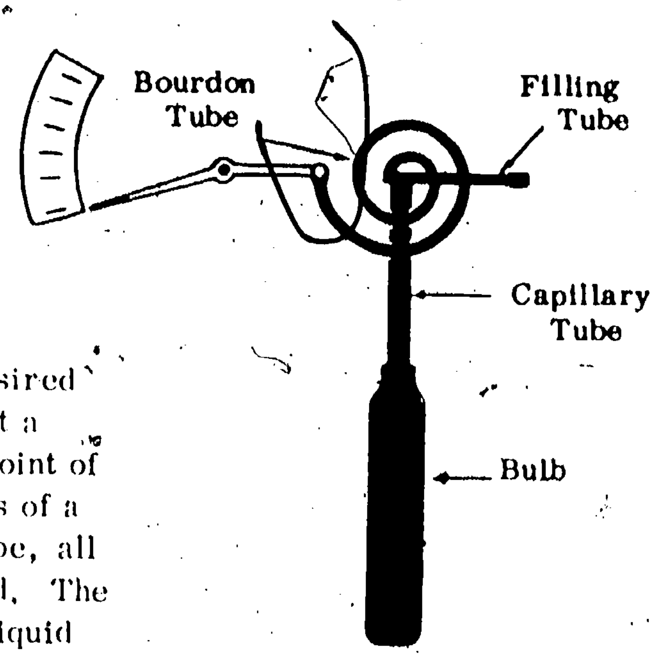
Brass and invar, which is an iron nickel alloy, are often used as the metals as they have a wide difference in expansion coefficients, brass expanding about twenty times more than does invar.



In order to obtain greater rotation of the pointer, the bimetallic strip is usually wound in the form of a helix as shown in Fig. 8.

Helical Bimetallic Strip Thermometer

Fig. 8



Remote Bulb Thermometer

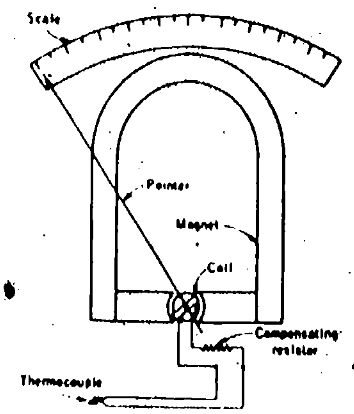
Fig. 9

Remote-indicating Bulb Thermometers

This type is used where it is desired to indicate or record the temperature at a location some distance away from the point of measurement. The instrument consists of a bulb, a capillary tube and a Bourdon tube, all of which are filled with a gas or a liquid. The expansion or contraction of the gas or liquid due to temperature changes causes movement of the Bourdon tube which is linked to the indicating pointer or recording pen.

Fig. 9 illustrates the principle involved. The bulb, the Bourdon tube and the capillary tube are filled with liquid through the filling tube which is then sealed. Movement of the Bourdon tube due to expansion or contraction of the liquid will cause the pointer to move. Although the capillary tube shown in the illustration is quite short, it may in actual practice be 15 or even 30 m in length. (PE1-2-11-6).

Thermoelectric Pyrometers



Thermoelectric Pyrometer

Fig. 10

The thermoelectric pyrometer, shown in Fig. 10, makes use of a thermocouple which produces an electrical voltage which varies with temperature changes.

A thermocouple consists of two wires, each made up of a different metal. The two wires are joined together at one end and, if this junction is heated, a voltage is developed at the free ends of the wires. The high temperature joint is called the hot junction and the free ends are called the cold junction.

The voltage produced varies with the temperature difference between the junctions and this voltage is measured by connecting the free ends or cold junction of the thermocouple to a millivoltmeter which is calibrated to read in degrees of temperature. A bimetal strip is used to provide compensation for changes in cold junction temperature.

Various combinations of metals are used to make up the dissimilar wires, depending upon the temperatures being measured. For instance, for temperatures up to 400°C, one thermocouple wire would be copper and the other constantan, which is an alloy of copper and nickel. For temperatures up to 850°C, the wires are iron and constantan, for temperatures to 1100°C the wires are chrome and alumel, and for temperatures to 1400°C the wires are platinum and platinum-rhodium.

3. FLOW MEASUREMENT

In regard to the flow of a fluid in a pipe or other conductor, it can be shown that, if there is an increase in the fluid's velocity, then there will be a corresponding decrease in its pressure. This is in accordance to Bernoulli's theorem which states that the sum of the potential energy, the pressure energy, and the velocity energy is a constant for fluid flow in a conductor.

This principle can be used to measure flow in a pipe by placing a constriction in the pipe. The constriction causes a velocity increase and a corresponding pressure drop. This pressure drop will vary as the velocity varies and the velocity will vary if the flow varies. High flows give high pressure drops across the constriction and vice versa and the flow is proportional to the square root of the pressure drop produced by the flow.

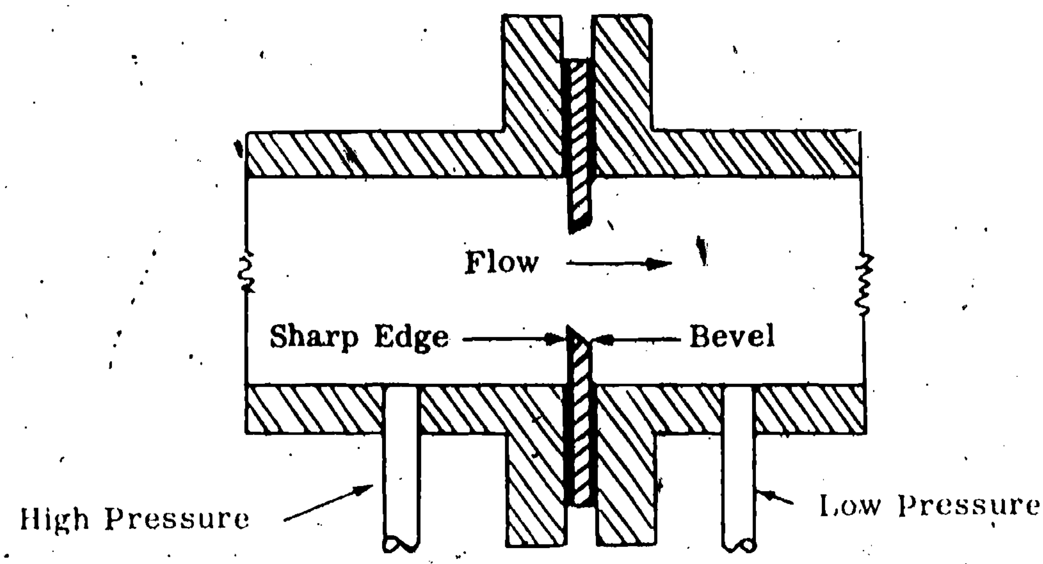
For steam flow measurement, it is customary to use a thin plate orifice or nozzle as the constrictive device. For liquid flow measurement, it is customary to use either a nozzle or a venturi tube, although orifice plates are sometimes used. For gas flow measurement in a pipe, orifice plates are probably used more than other devices. For measurement of air or flue gas through a boiler, drops across various sections such as the air heater or economizer can be used. In some cases this is not feasible and venturi sections may be built into the air ducts.

In order to measure the differential across the constriction or primary element it is necessary to use pressure taps. The location of these pressure taps in relation to the primary element is extremely important. The manufacturer of the flow meter equipment will give exact instructions as to the installation of the primary element and the exact measurement to be used from the primary element to the taps. The method of installing these taps is also important if good results are to be obtained.

The tap holes should be drilled radially to the pipe and at the exact location specified by the instrument manufacturer. For gas applications, taps should be located on the top of the pipe; for liquid or steam, at the side of the pipe. Under no conditions should they be located at the bottom of the pipe due to the possibility of dirt, mill scale, or other deposits. After drilling remove all burrs and round all edges inside the pipe. When installing the tap, do not allow it to project into the pipe as this will interfere with the flow pattern and cause errors in regard to the pressure differential being determined.

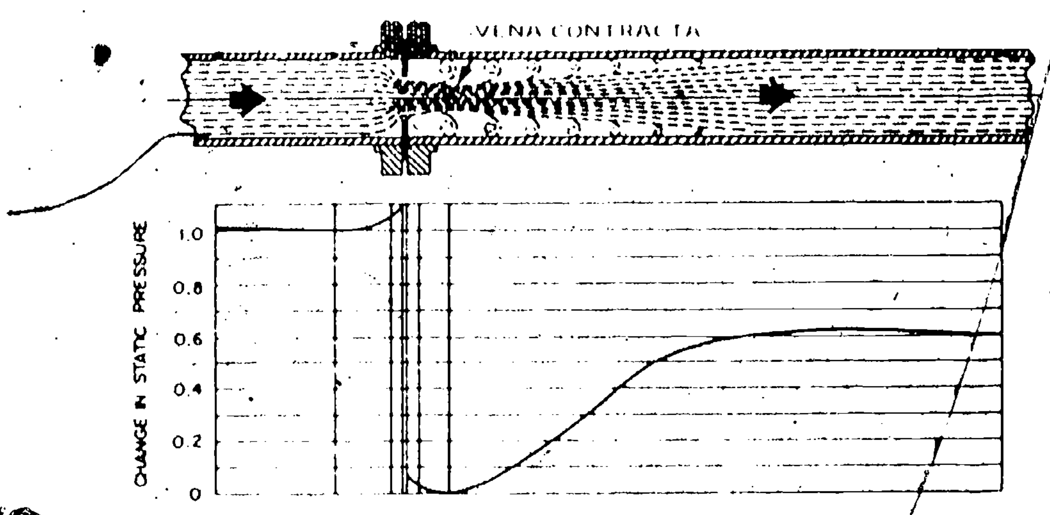
Fig. 11 shows the arrangement of an orifice plate with pressure taps while Fig. 12 illustrates the pressure variations produced by flow through an orifice plate.

Note that, in reference to Fig. 12, the lowest pressure occurs at the point where the fluid has the smallest cross-sectional area and this point is called the <u>vena contracta</u>. It is located a short distance downstream from the orifice plate and from this point the pressure begins to increase again.



Orifice Plate with Pressure Taps

Fig. 11



Pressure Variations through Orifice Plate

Fig. 12

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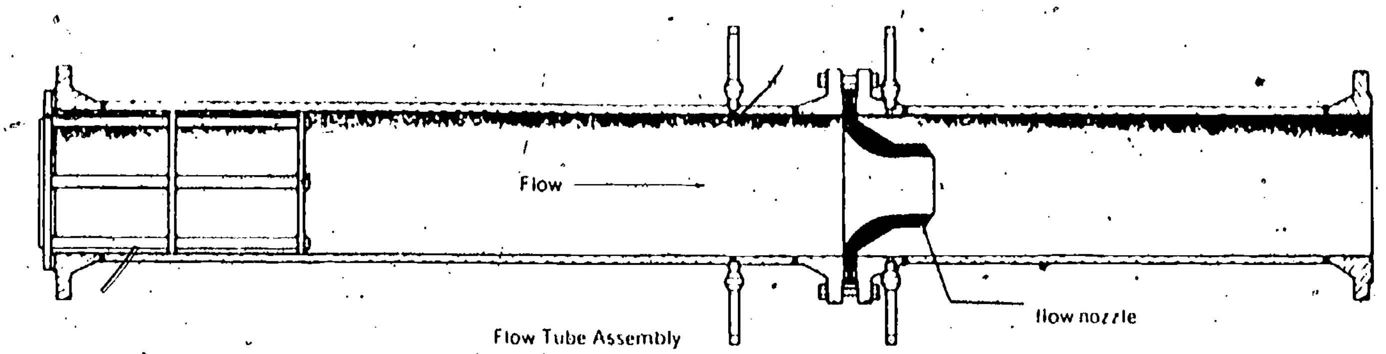
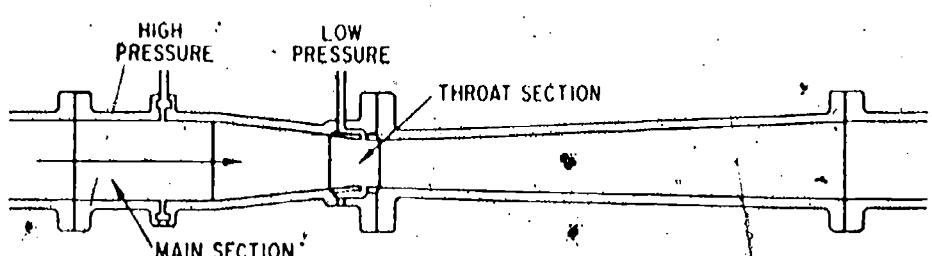
Two other types of flow measuring constrictions, the flow nozzle and the venturi tube are shown in Figs. 13 and 14 respectively.



Flow Nozzle

Fig. 13



Venturi Tube

Fig. 14

The flow nozzle is much more expensive than the orifice plate and is more difficult to install. However, it requires less of a straight pipe run before and after it than does the orifice plate and in addition produces less permanent pressure drop.

The venturi tube also produces less permanent pressure drop than does the orifice plate and it has a smoother flow as well. Furthermore, it will handle 60% more flow with the same pipe size and the same pressure difference than will the orifice plate. However, the venturi is heavy and bulky and very expensive.

(PE1-2-11-10)

4. LEVEL MEASUREMENT

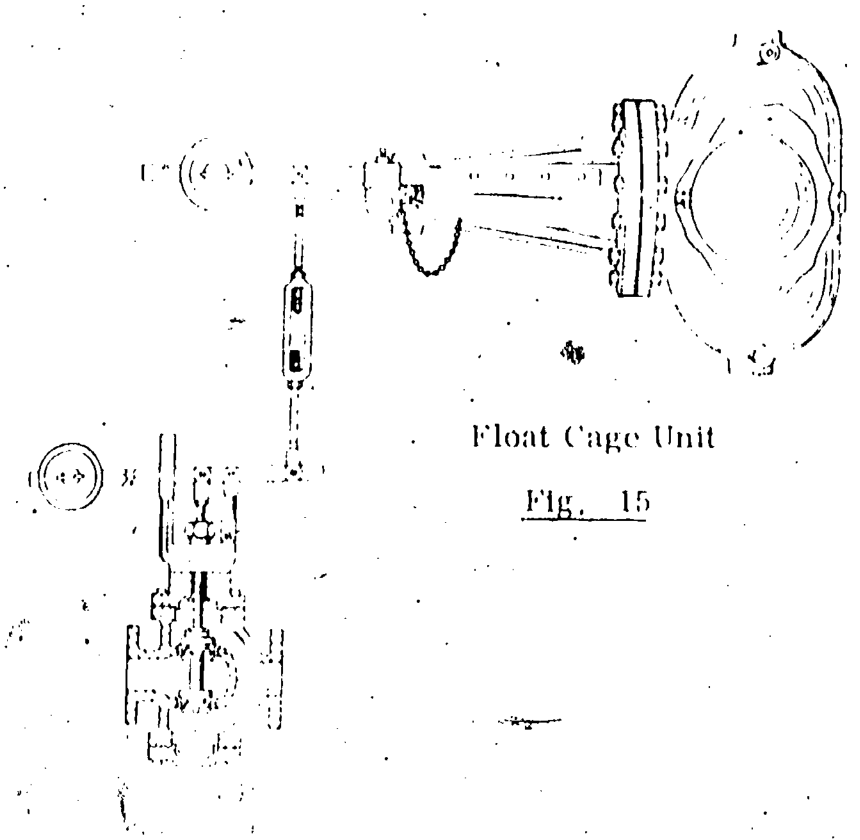
Level measurements required in power plant operation include boiler water level, condenser hot well level, fuel tank level, storage water tank level, etc.

A commonly used device which indicates visually the level in a tank or vessel is the gage glass. Another visual indicator is the float-weight device which uses a float attached to a weight by means of cables and pulleys. The float is positioned within the tank while the weight hangs outside adjacent to a scale which is marked with units of level. Still another method of indicating level is to blow air at a given point below the surface of the liquid and then measure the pressure of the air balanced by the head of liquid.

To provide indication of level that can be used to generate a signal for control systems, other methods are used such as the float cage or, more usually, some form of differential pressure gage such as a float manometer.

Float Cage Units

In this type, the float cage or float chamber is mounted on the outside of the pressure vessel and is connected at the bottom to the liquid space of the vessel and at the top to the vapor space of the vessel. As a result, the float within the cage will rise and fall with the liquid level in the vessel and this movement can be used to operate a valve or to vary a control signal.



Float Cage Unit

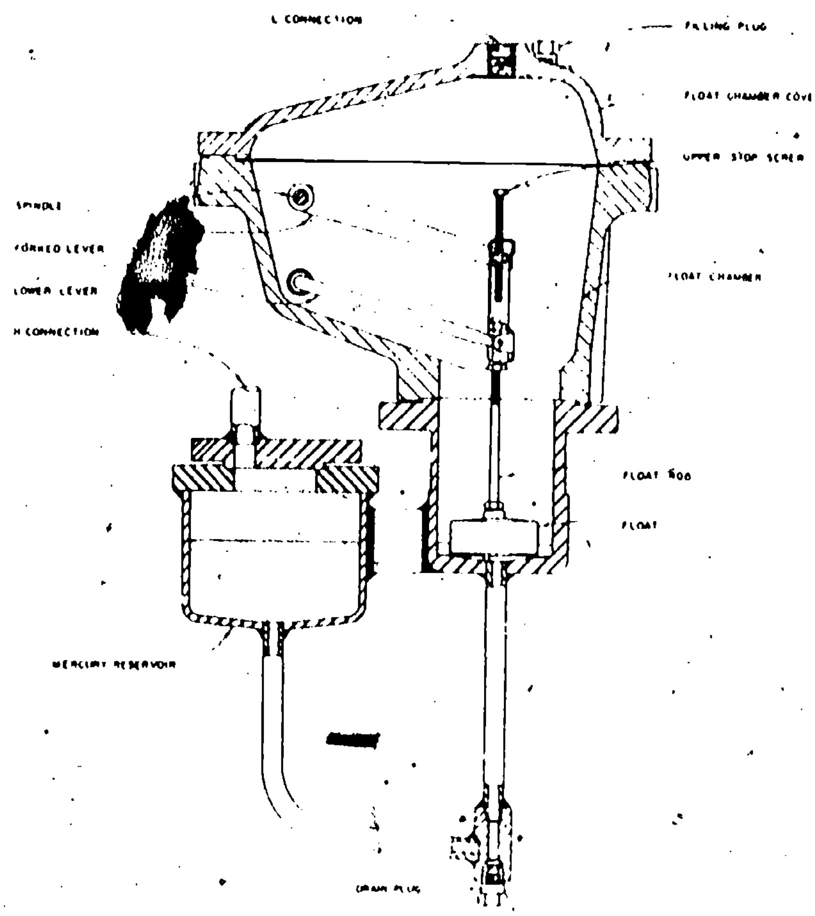
Fig. 15

Fig. 15 shows the arrangement of a float cage unit which operates a level valve.

Note that with this type, the float cage is under the same pressure that exists in the vessel, therefore, some type of a seal must be used at the point where the float arm extends from the float cage.

Differential Pressure Gage

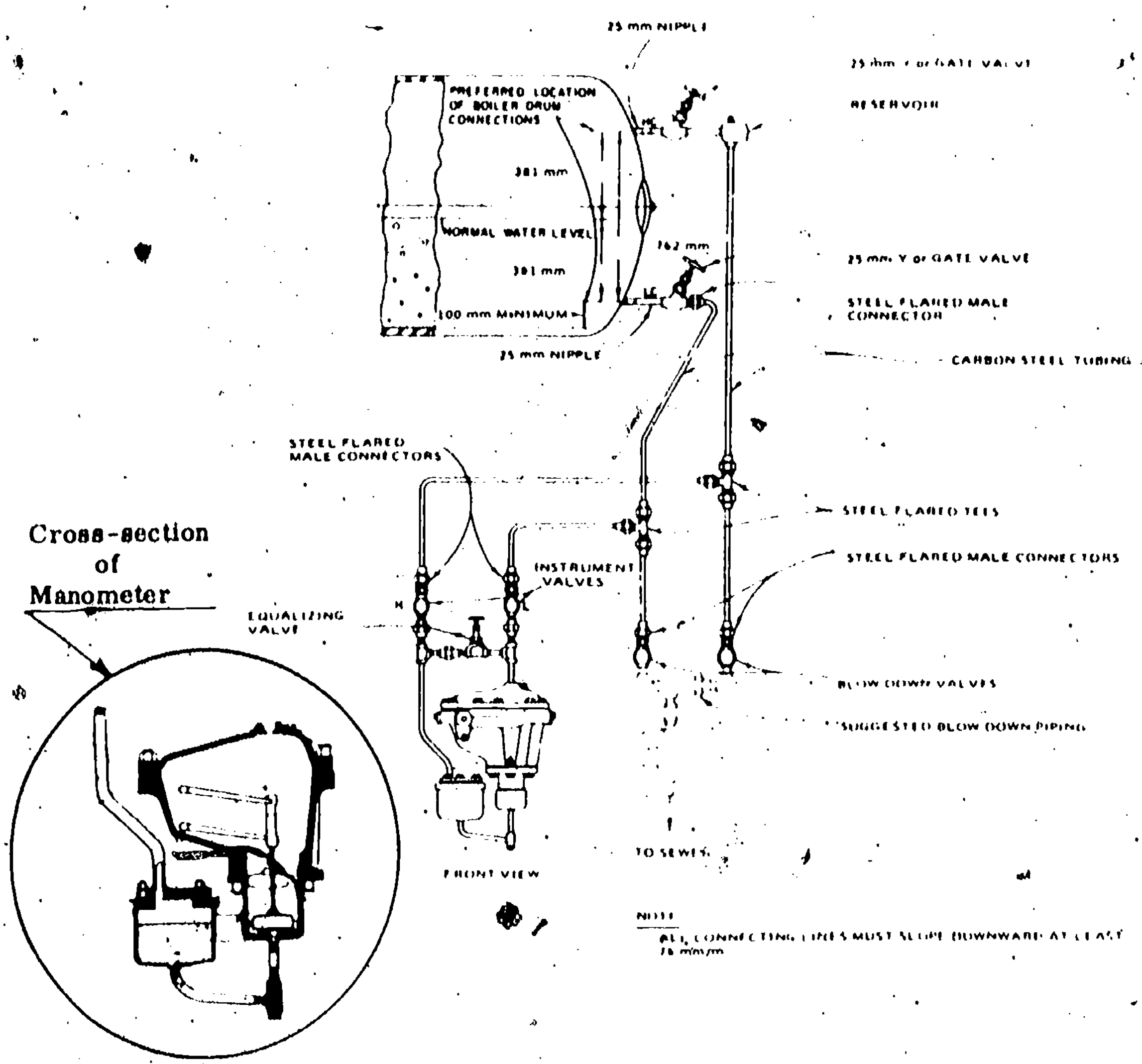
In this type, a mercury manometer, such as that shown in Fig. 16, is connected to the pressure vessel. The top connection from the vessel has a reservoir which maintains a constant head in the high pressure line of the manometer. The lower connection from the vessel has a varying head due to the rise and fall of the level in the vessel and this varying head is applied to the low pressure side of the manometer. This varying head will cause a rise and fall in the mercury level in the manometer and thus cause movement of the float. This movement is then used to vary a control signal.



Float Type Manometer

Fig. 16

Fig. 17 shows the arrangement applied to a steam boiler.



Float Manometer Arrangement

Fig. 17

In addition to the above methods, steam boilers frequently use thermo-hydraulic and thermo-expansion devices to provide level control signals and these latter devices will be discussed under the heading of feedwater control.

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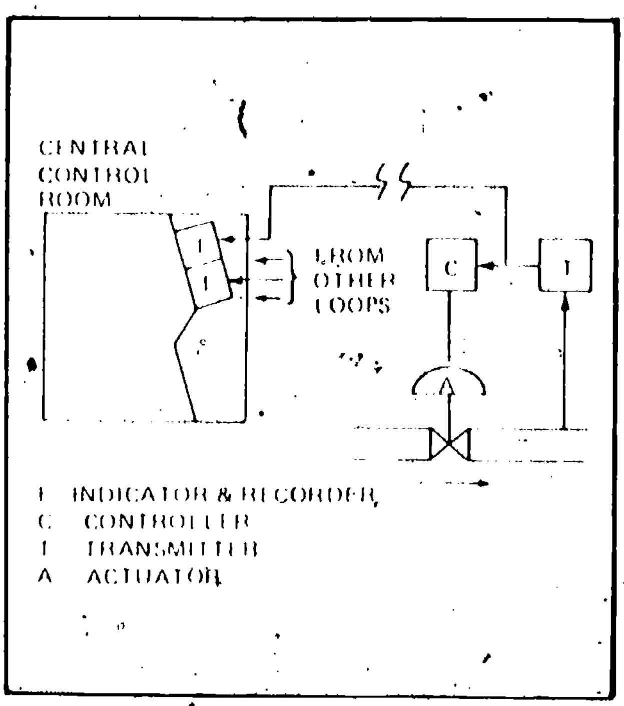
CONTROLLERS, TRANSMITTERS, ACTUATORS

The basic components of a control system can generally be considered as the controller, the transmitter and the actuator.

The controller is equipped with a sensing device which recognizes changes in the controlled variable such as steam pressure, steam flow, temperature, etc. The controller responds to these changes by sending out varying pneumatic or electric-electronic output signals. These varying output signals are then responded to by actuators or positioners which cause movement of valves, dampers, etc.

In many cases, a transmitter is used to sense the changes in steam pressure, etc., rather than the controller. This transmitter then converts these changes into varying signals, either pneumatic or electric-electronic and transmits these signals to the controller which is usually located some distance away. In this case the controller would not be equipped with a sensing device as the sensing is being done by the transmitter. The transmitter signal is also used to operate indicating and recording instruments, normally located in a central control room, which then show changes in the value of the steam pressure or other controlled variable.

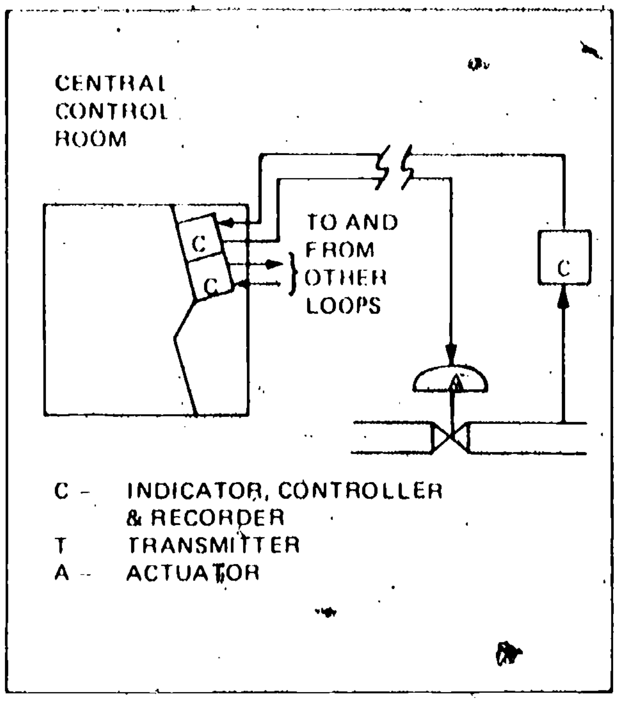


Simple Control Arrangement

Fig. 18

Fig. 18 shows a simple pressure control system where changes in the pressure within the pipe is sensed by a transmitter. The transmitter signal is sent to a controller and also to an indicator and recorder located in the control room. The controller, which is located adjacent to the control valve, causes the actuator to operate the valve in accordance to the pressure changes within the pipe.

A system which is used more often than that in Fig. 18 is shown in Fig. 19.



Central Control Arrangement

Fig. 19

In the system in Fig. 19 the controller, indicator and recorder are all located in a central control room where they receive the transmitter signals. The controller in turn sends a signal to the actuator to operate the valve in accordance to pressure changes in the pipe.

With this method, the operator is able to make adjustments to the controller without leaving the control room. Another advantage is that the controller is located in a clean environment where ambient temperatures and vibration are not extreme.

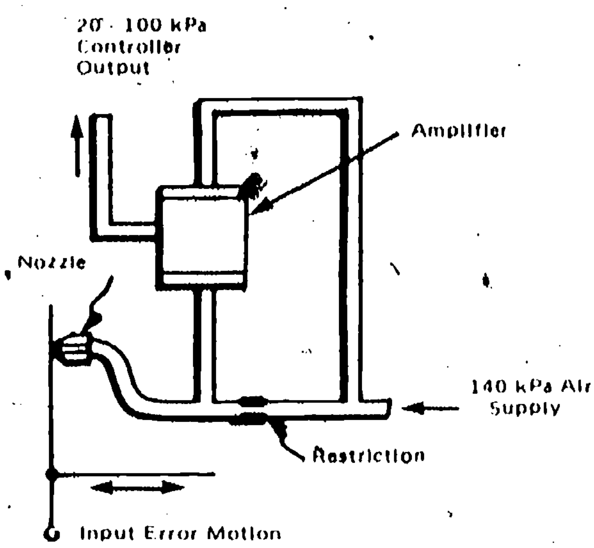
As mentioned previously, the control signals or impulses may be pneumatic or they may be electrical or electronic. The advantage of one system over the other depends upon the application requirement. The pneumatic signal is much slower than the electrical-electronic signal and for long distances the transmission speed may be very important.

The first cost of a pneumatic system, however, is much less than an electronic system. The power output from a pneumatic controller is sufficient to directly drive an actuator while the output from an electronic controller is a control signal only and therefore the actuator must have a separate power source which may be pneumatic, electrical or electric hydraulic.

1. CONTROLLERS

On-Off Controller

A simple sketch of the most basic of controllers appears in Fig. 20.



On-Off Controller

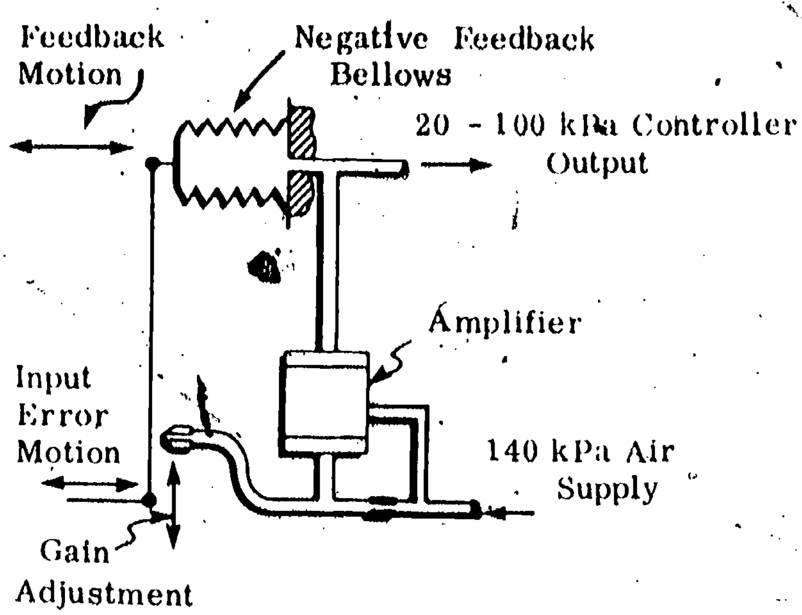
Fig. 20

The unit shown in Fig. 20 is a pneumatic type and is known as an on-off controller. The sensing device which is not shown in the sketch, provides the input error motion which, depending upon whether the value of the measured variable is above or below the set point, will cause the flapper to be either held against the nozzle or away from it. If the flapper is held against the nozzle then the output from the controller will be at a maximum. Conversely, if the flapper is held away from the nozzle, then the output from the controller will be at a minimum.

Proportional Controller

The on-off controller sketched in Fig. 20 only recognized whether the measured variable was above or below the set point and therefore it controlled by means of an on-off cycle. To eliminate this cycling a proportional controller, such as that sketched in Fig. 21, can be used.

The proportional controller not only recognizes whether the measured variable is above or below the set point, but it also takes into account the amount that the measured variable is above or below the set point.



Proportional Controller

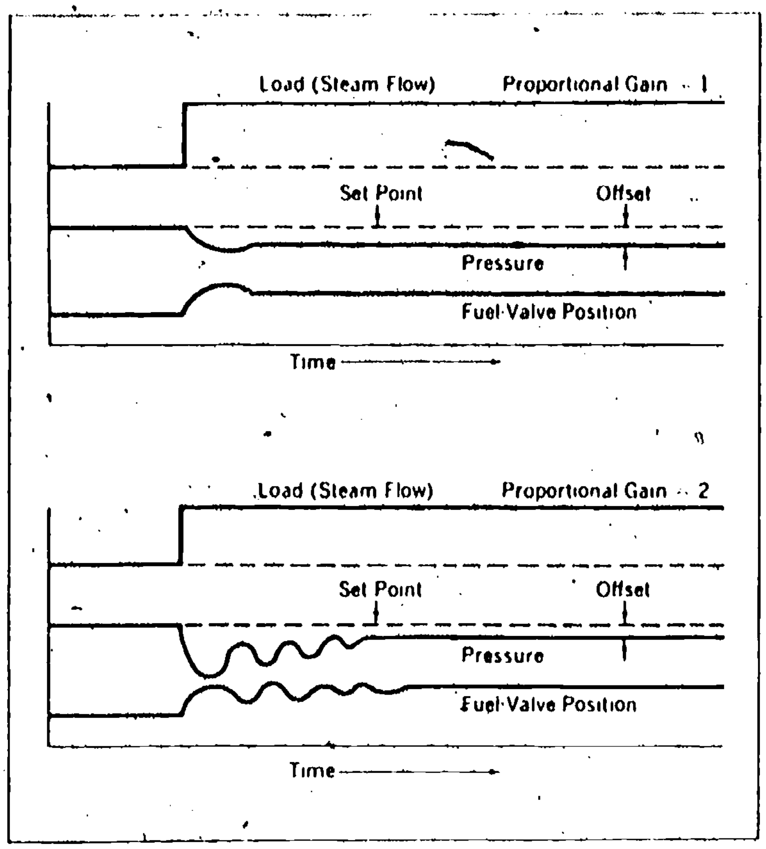
Fig. 21

Referring to Fig. 21, the controller sensing device, not shown in the sketch, produces the input error motion in either direction according to whether the measured variable is above or below the set point. For example, if the measured variable is pressure then the sensing device could be a Bourdon tube and on an increase in pressure the Bourdon tube will move the flapper toward the nozzle. This will cause an increase in controller output pressure. At the same time this increased output will act within the negative feedback bellows which will expand and re-position the flapper in a direction opposite to the original motion. The resulting effect of this is that for every value of the measured variable there is one and only one clearance between flapper and nozzle and only one controller output pressure.

The term "proportional gain" or "gain" is used to denote the ratio of the change in controller output to the change in the measured variable. To illustrate, if the measured or controlled variable changes in the amount of 100% of its range and this causes a 100% change in the controller output, then the gain is $\frac{100}{100}$ or 1. If a 50% change in the controlled variable causes a 100% change in controller output then the gain is $\frac{100}{50}$ 2.

A limitation of a proportional controller is that it cannot entirely eliminate error and return the variable to the set point. There will always be a difference between the new corrected value of the variable and the set point and this difference is known as "offset".

This offset and the effect of gain upon the offset is shown in Fig. 22.



Controller Offset

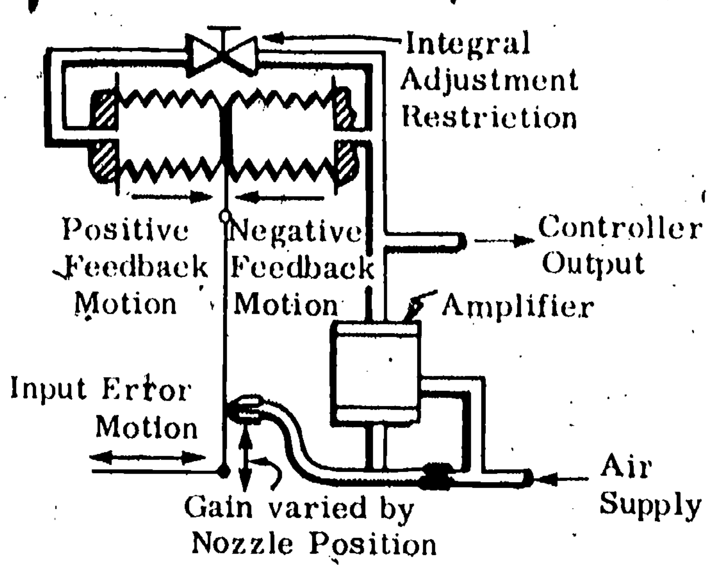
Fig. 22

It can be seen by comparing the two graphs in Fig. 22 that increasing the gain of the controller will reduce the offset but will not eliminate it. If the gain is increased too much in an effort to further reduce the offset then oscillation or hunting of the system will occur.

Proportional Plus Integral (Reset) Controller

The offset of the system can be eliminated by the addition of the integral or reset device to the proportional controller. This integral device causes the proportional action of the controller to repeat itself until the controlled variable returns to its set point. In other words the integral or reset device keeps increasing the controller output until the variable is at the set point once again.

A proportional plus reset controller is shown schematically in Fig. 23.



Proportional Plus Integral (Reset)

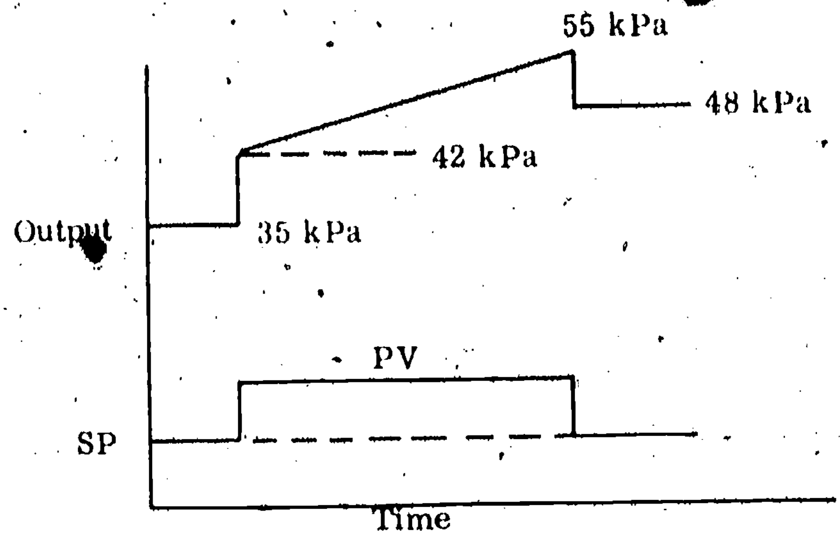
Fig. 23

The controller in Fig. 23 is in effect a proportional controller to which has been added an adjustable restriction and a positive feedback bellows. The positive feedback bellows provides the reset action while the negative feedback bellows provides the proportional action.

The operation of the controller is as follows: When the variable is at the set point the pressure in both bellows is the same, say 35 kPa. If the variable increases above the set point the controller sensor, not shown, will move the flapper toward the nozzle. The controller output will increase to say 42 kPa and this pressure will also exist in the negative bellows and will for a short time exceed that in the positive bellows. However, due to the air passing through the restriction, the pressure in the positive or reset bellows will also increase and the flapper will be moved toward the nozzle again causing a further increase in controller output to say 55 kPa. This further increase will return the variable to the set point and the flapper will move away from the nozzle once again which will reduce the controller output to say 48 kPa and the variable will be maintained at the set point.

The above operation is shown graphically in Fig. 24 where SP is the set point and PV is the process variable, say steam pressure.

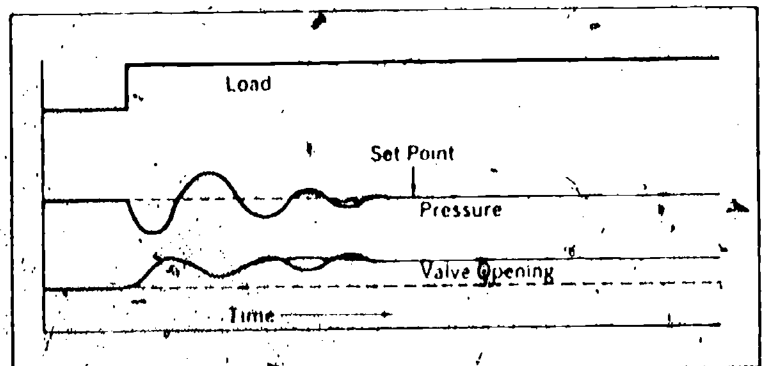
(PE1-2-11-19)



Proportional Plus Reset Action

Fig. 24

The same situation is shown in Fig. 25 in reference to boiler load, boiler pressure and fuel valve opening.



Proportional Plus Reset Boiler Control

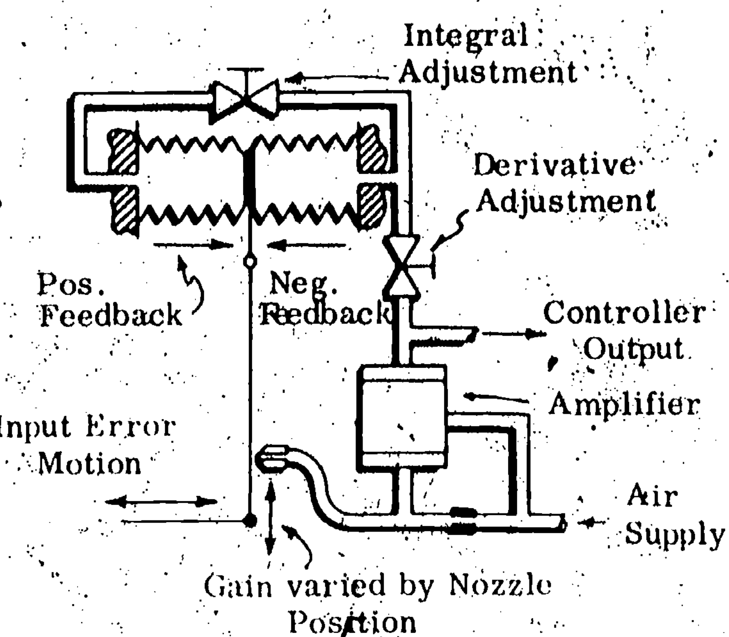
Fig. 25

Proportional Plus Reset Plus Derivative Controller

In many cases the variable will increase or decrease from the set point very rapidly and at an increasing rate. For instance if all load is suddenly lost from a boiler then the variable steam pressure will increase above the set point rapidly and at an increasing rate. When this happens the fuel valve controller output must be increased even further than that achieved by the proportional and reset action. This further increase is provided for by derivative (rate) action.

Derivative or rate action is a mode of control that provides an output from the controller that is proportional to the rate of change of the deviation from the set point.

To add derivative action to a proportional plus reset controller it is necessary only to add a restriction in the air line to the feedback bellows as shown in Fig. 26.

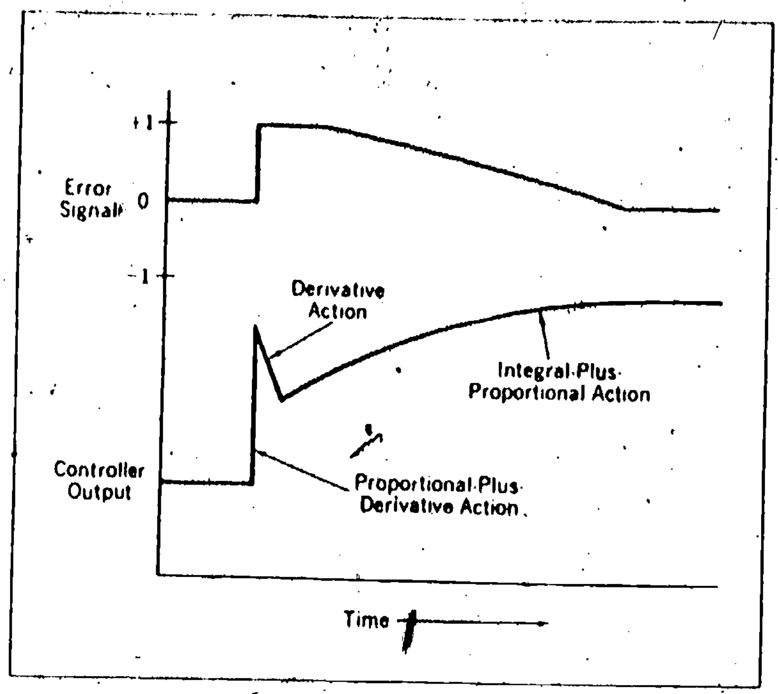


Proportional Plus Reset Plus Derivative Controller

Fig. 26

Referring to Fig. 26 when the variable deviates from the set point the flapper is moved by the controller sensor, not shown, toward the nozzle. The derivative or rate restriction causes a time delay in the action of the negative feedback bellows which allows for an immediate and large increase in controller output. Then as the output pressure seeps through the rate restriction, the negative feedback bellows repositions the flapper giving proportional action. Reset action by the positive feedback bellows is further delayed by the reset or integral restriction.

The final result of a proportional plus reset plus rate controller is a quicker return to the set point because the controller output causes the final control element, such as a fuel valve, to move further in the required direction than if only proportional plus reset action was used and this is illustrated by the graph in Fig. 27.



Proportional Plus Reset Plus Rate Action

Fig. 27

2. TRANSMITTERS

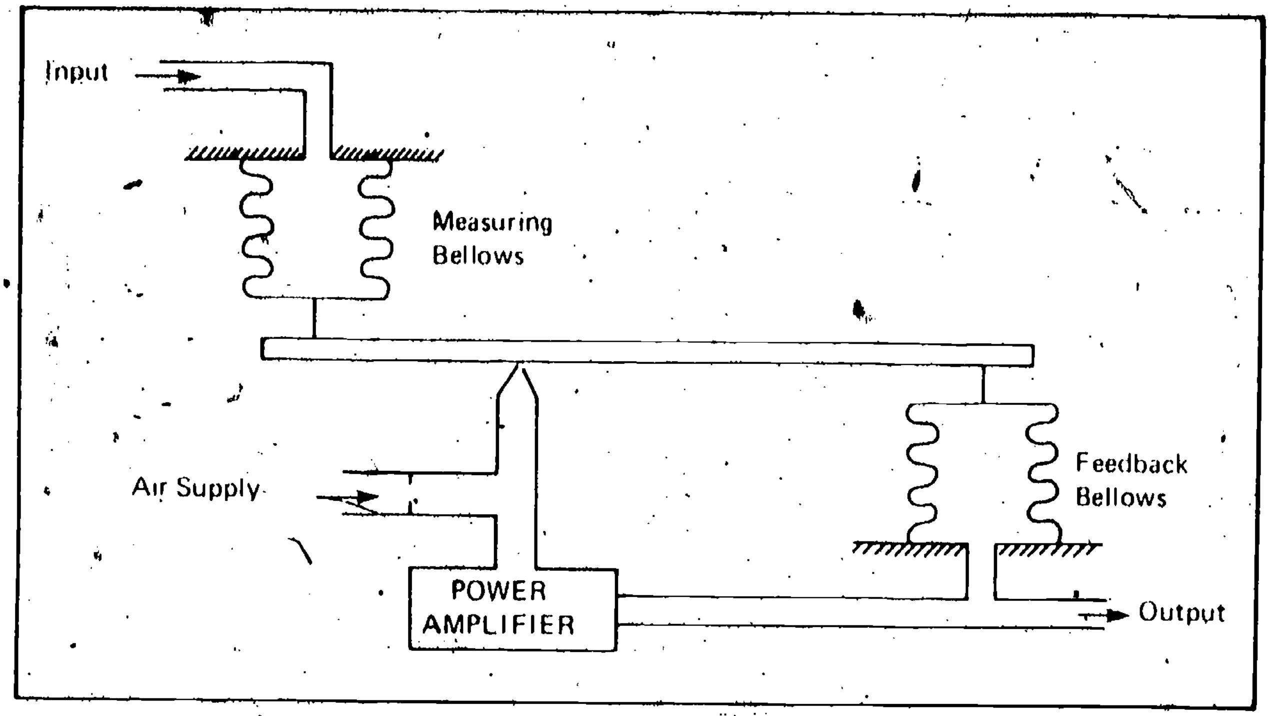
The transmitter is a device which measures the controlled variable and converts this measurement into a standard transmission signal such as 20 to 100 kPa pneumatic or 4 to 20 milliamps electrical. This signal is then sent to a controller as well as to recording and indicating instruments.

Pressure Transmitters

The sensor, or measuring element, of most pressure transmitters is some type of bellows, Bourdon tube or diaphragm and the basic mechanism of a pneumatic pressure transmitter is the flapper - nozzle assembly.

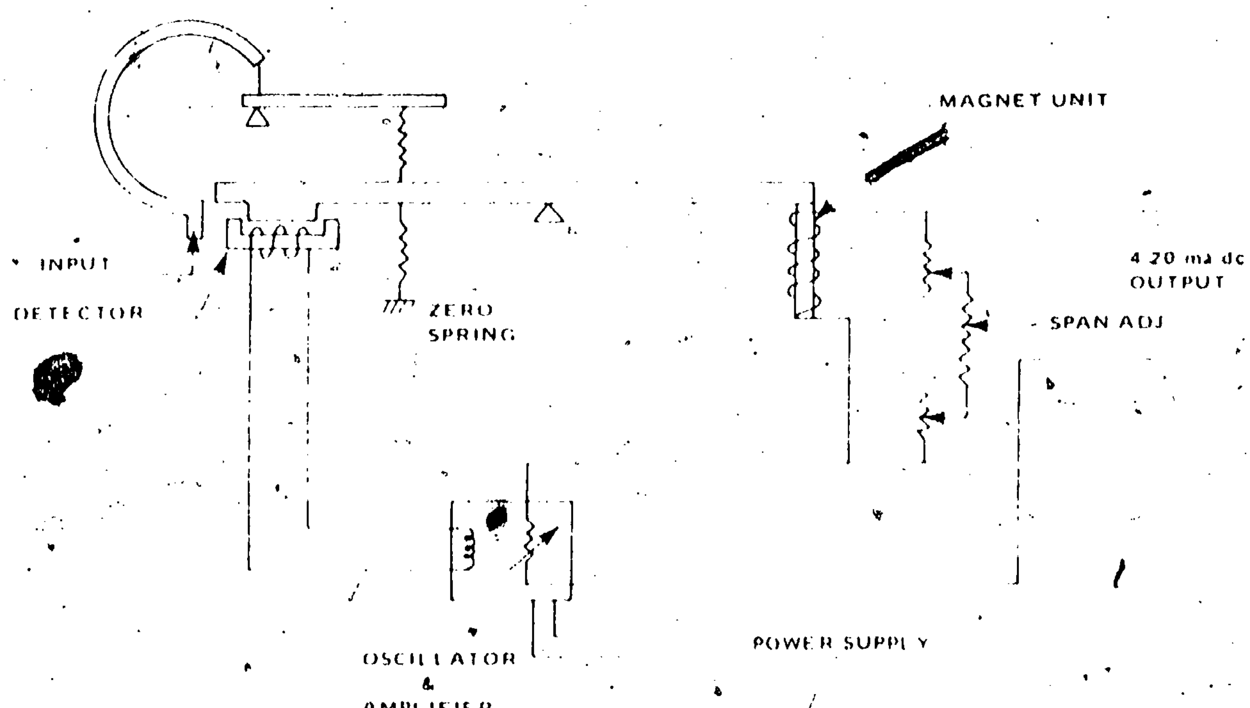
A pneumatic pressure transmitter is shown schematically in Fig. 28.

In the transmitter in Fig. 28 when changes in the measured pressure occur the measuring bellows will move the flapper in relation to the nozzle. This will change the output pressure or signal from the transmitter. The feedback bellows, which is acted upon by the output pressure, repositions the flapper and in this way the output is kept in proportion to the measured variable.



Pneumatic Pressure Transmitter

Fig. 28



Electronic Pressure Transmitter

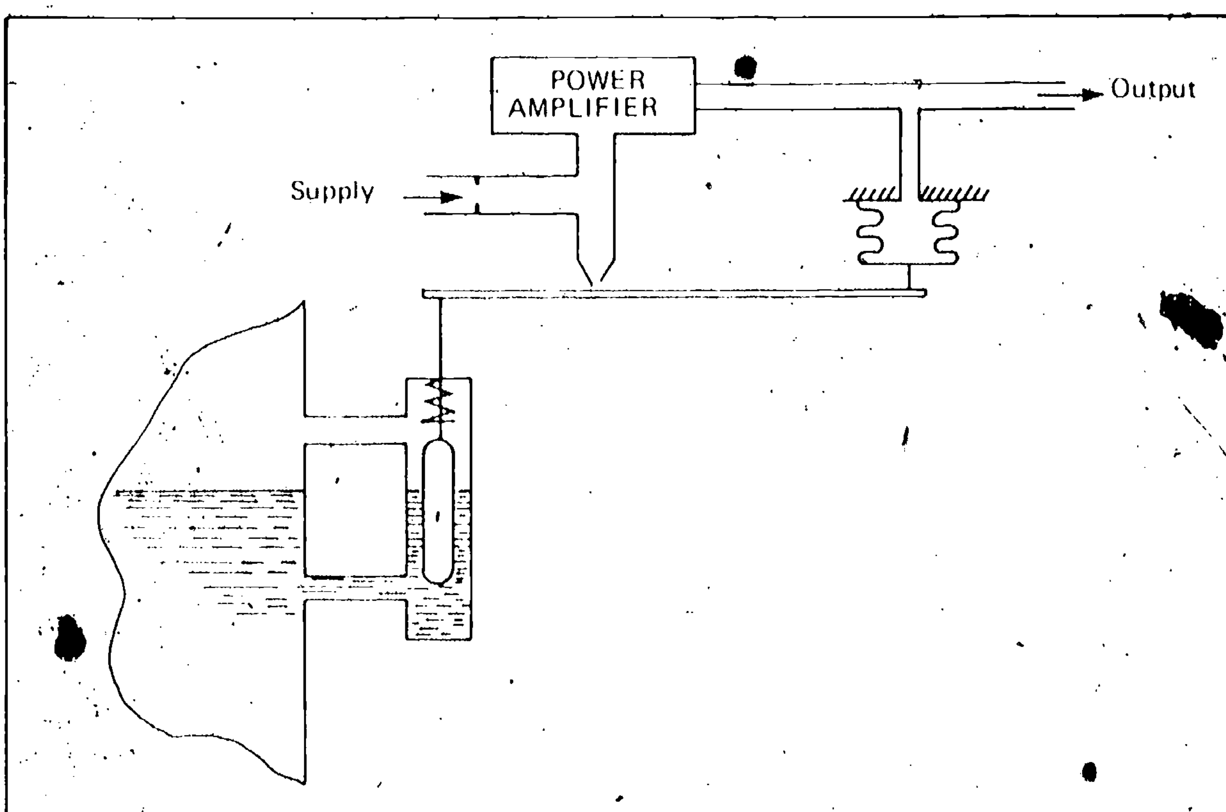
Fig. 29

(PE1-2-11-23)

The electronic pressure transmitter in Fig. 29 consists of a movable beam, detector, oscillator, magnet unit and Bourdon tube sensor. If the pressure being measured is at a minimum then the gap between the beam and the detector coil will also be at a minimum. As a result the inductive reactance in the detector coil will be at a maximum and therefore the output from the oscillator will be at a minimum value (4 ma). When the measured pressure increases, the Bourdon tube will move the beam away from the detector coil thus reducing the inductive reactance and increasing the transmitter output. This output current passes through the magnet unit which exerts an upward force upon the beam that opposes the force of the Bourdon tube. This magnet unit can be compared to the feedback bellows in the pneumatic transmitter in Fig. 28.

The zero spring and span adjustment are used for calibrating purposes. When the value of the controlled variable is at minimum the zero spring adjustment is used to adjust the detector gap so that the transmitter output is also at minimum. As the controlled variable varies over a desired range, the transmitter output varies from minimum to maximum due to the span adjustment.

Level Transmitter



Pneumatic Level Transmitter

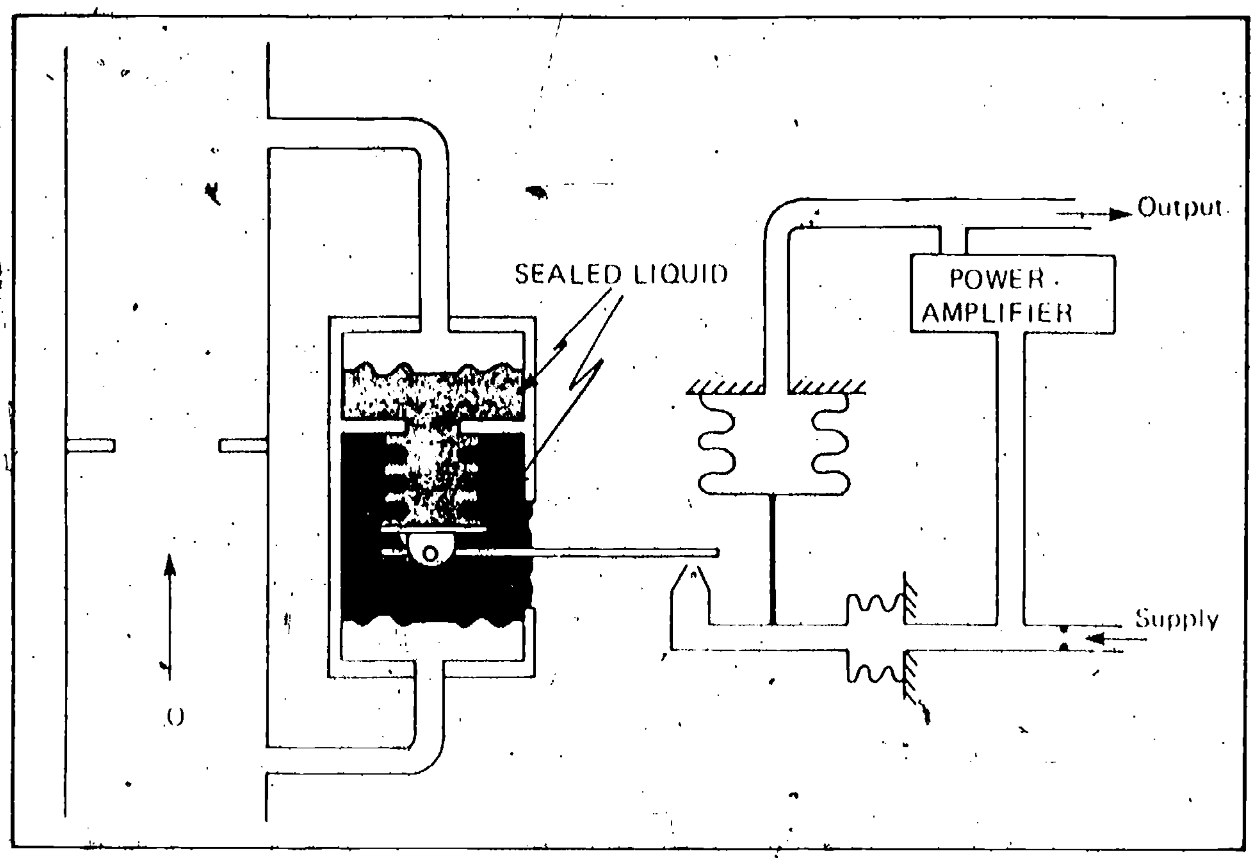
Fig. 30

(PEI 2-11-2)

Fig. 30 shows a schematic sketch of a pneumatic level transmitter which uses a float to move the flapper as the level varies. This changes the transmitter output and the feedback bellows repositions the flapper to keep the output proportional.

Flow Transmitter

The pneumatic flow transmitter shown in Fig. 31 uses an orifice plate to produce a pressure drop which varies with flow and a bellows type sensor to measure the pressure drop.

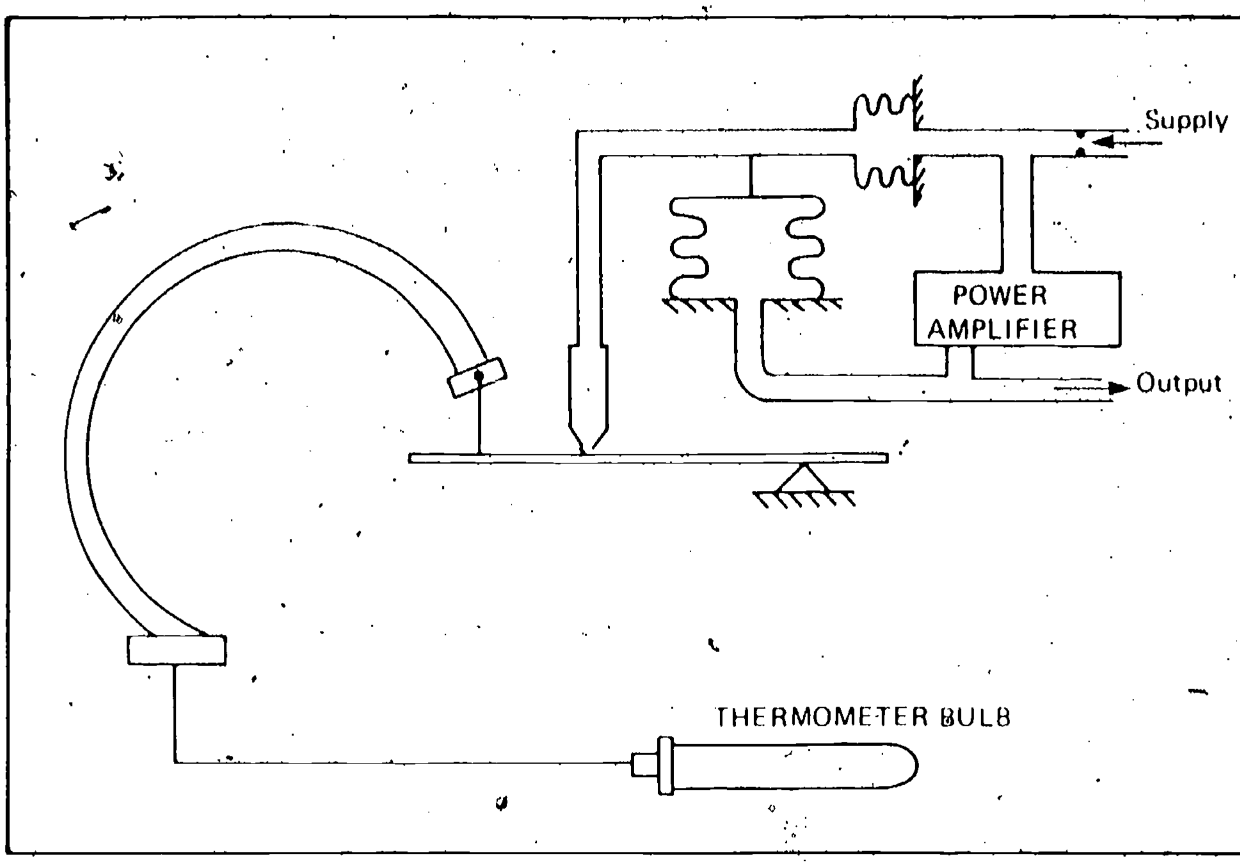


Pneumatic Flow Transmitter

Fig. 31

The bellows moves the flapper in relation to the nozzle thus varying the transmitter output. The feedback bellows maintains the proportional action.

Temperature Transmitter



Pneumatic Temperature Transmitter

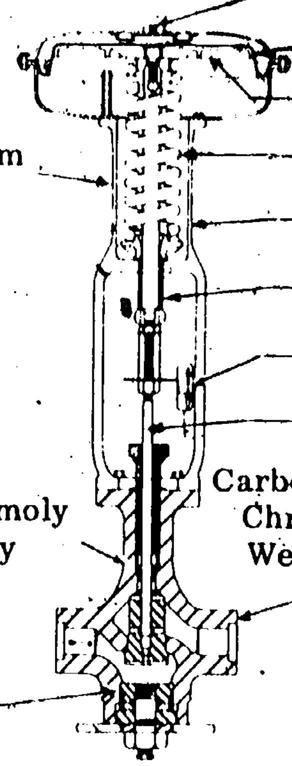
Fig. 32

Fig. 32 is a schematic diagram of a pneumatic temperature transmitter. The thermometer bulb causes a varying pressure within the Bourdon tube as the temperature changes. The Bourdon tube moves the flapper in relation to the nozzle and the output is maintained in proportion by the feedback bellows.

3. ACTUATORS

Actuators are the devices which receive the output signals from the controllers and convert these control signals to mechanical motion in order to operate valves, dampers, etc.

Actuators may be classified according to the type of signal they receive-pneumatic or electric. They may also be classified according to the method used to convert to mechanical motion and this method of conversion may be either pneumatic or some form of electric system. A further classification of actuators has to do with the type of mechanical motion which they produce, rotary or linear.



Diaphragm Actuator

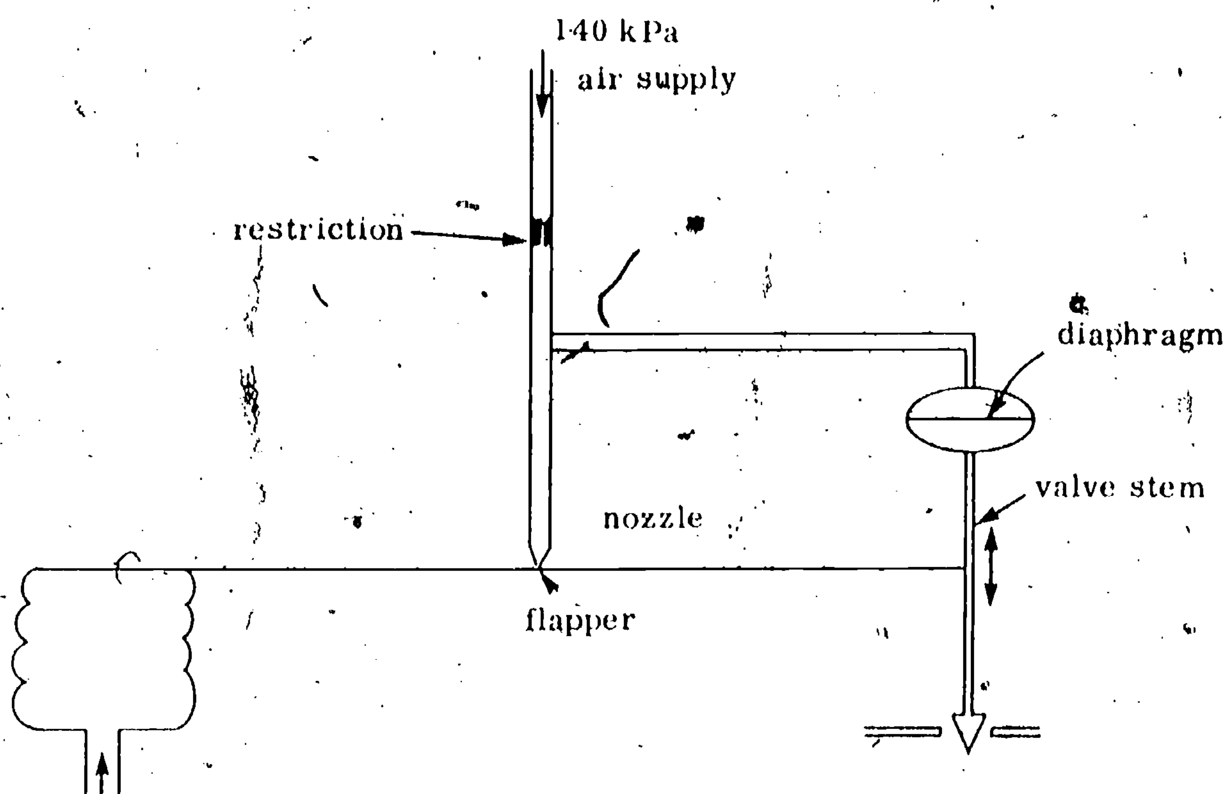
Fig. 33

Fig. 33 shows a pneumatically operated diaphragm actuator which produces a linear motion to operate a valve. In operation, this actuator receives an air pressure signal from a controller through the air pressure connection above the diaphragm. Usually the air signal ranges in value from 20 to 100 kPa depending upon this value, the actuator diaphragm will move the valve a certain amount. In moving downward, the diaphragm works against a spring which returns the diaphragm when the signal pressure reduces. The adjusting screw allows for setting of the spring compression and it is usually adjusted so that the valve stem just starts to move when the signal pressure is at the minimum of 20 kPa.

Normally the position of the valve depends upon the control signal. However, due to valve stem friction or process variations, the position of the valve may tend to deviate from that desired. If this is the case, a positioner is usually used in conjunction with the actuator.

Basically the positioner is an amplifier taking the control signal at low pressures and using a higher pressure air supply to move the actuator according to variations in the control signal.

A schematic arrangement of a positioner appears in Fig. 34.

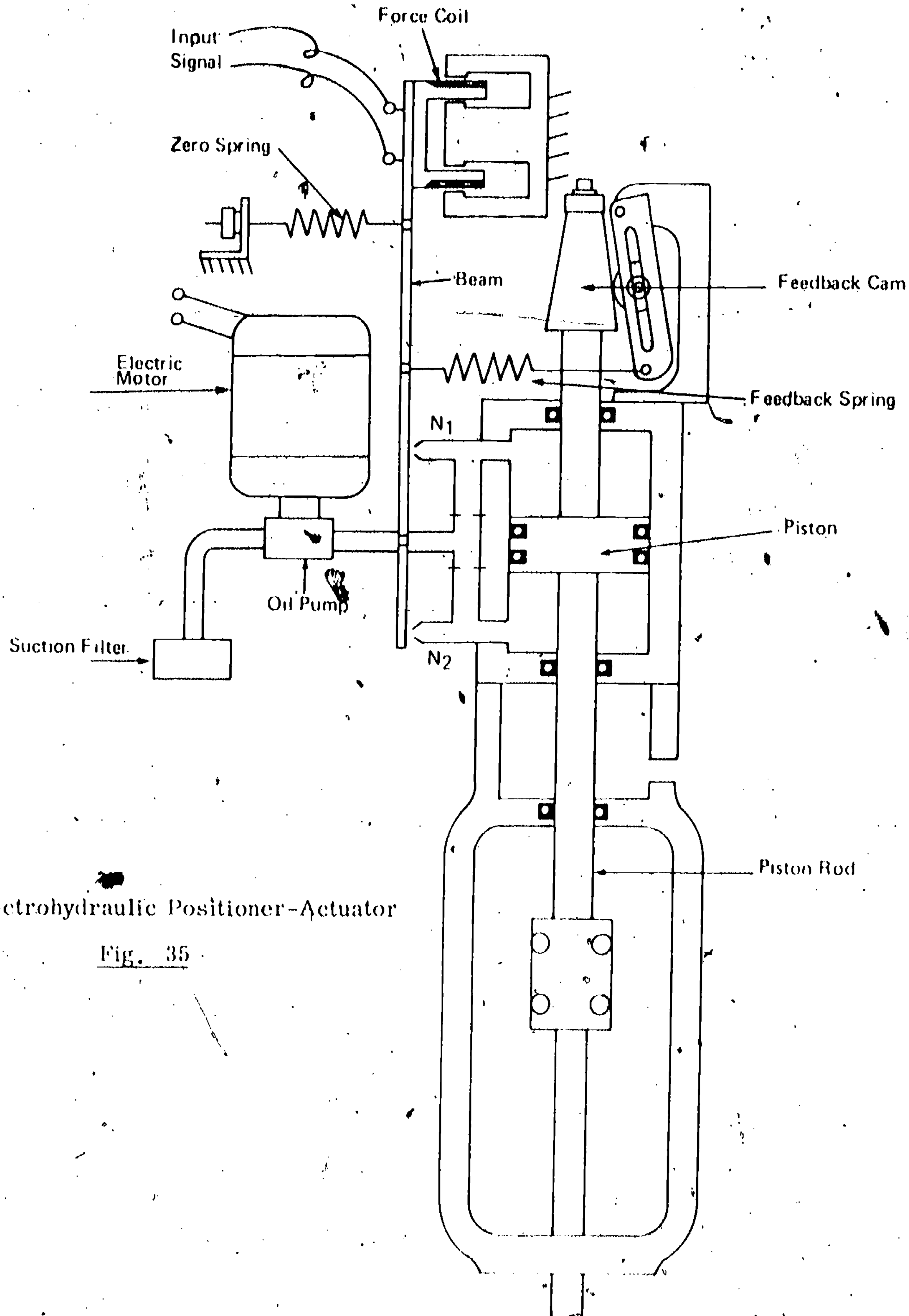


Positioner Arrangement

Fig. 34

With this arrangement the control signal is applied to a bellows which positions a flapper in relation to a nozzle. An increase in control signal pressure will move the flapper closer to the nozzle causing the nozzle pressure to increase and downward movement of the valve stem results. As the valve stem moves downward the flapper is moved away from the nozzle giving proportional action and stabilizing the valve movement. If valve stem movement is prevented due to friction or other cause, the nozzle pressure will continue to increase until the resisting force is overcome.

A schematic diagram of an electrohydraulic positioner-actuator appears in Fig. 35. In this type the control signal is electric and the mechanical movement is linear and is produced by hydraulic action on a piston.



Electrohydraulic Positioner-Actuator

Fig. 35

(PE1-2-11-29)

Referring to Fig. 35, the electric motor runs continuously driving the oil pump which produces a high pressure flow of oil through the nozzles N_1 and N_2. The control signal is applied to a force coil and on an increase of signal the coil will move within the core surrounding it. This moves the beam and restricts nozzle N_1 causing a build up of pressure above the piston. As the piston moves down, the feedback cam allows the beam to be repositioned. If the signal decreases, nozzle N_2 will be restricted and the piston will move upwardly. The movement of the piston rod can be used to position a valve, damper etc.

FEEDWATER CONTROL SYSTEMS

Most shop-assembled boilers in the lower capacity range and the lower operating pressure range are equipped with self-contained feedwater systems of the thermo-hydraulic or thermo-expansion types. For higher capacity boilers and those operating at higher pressures, a pneumatic or electrically operated feedwater control system is used. These may be single, two, or three element types.

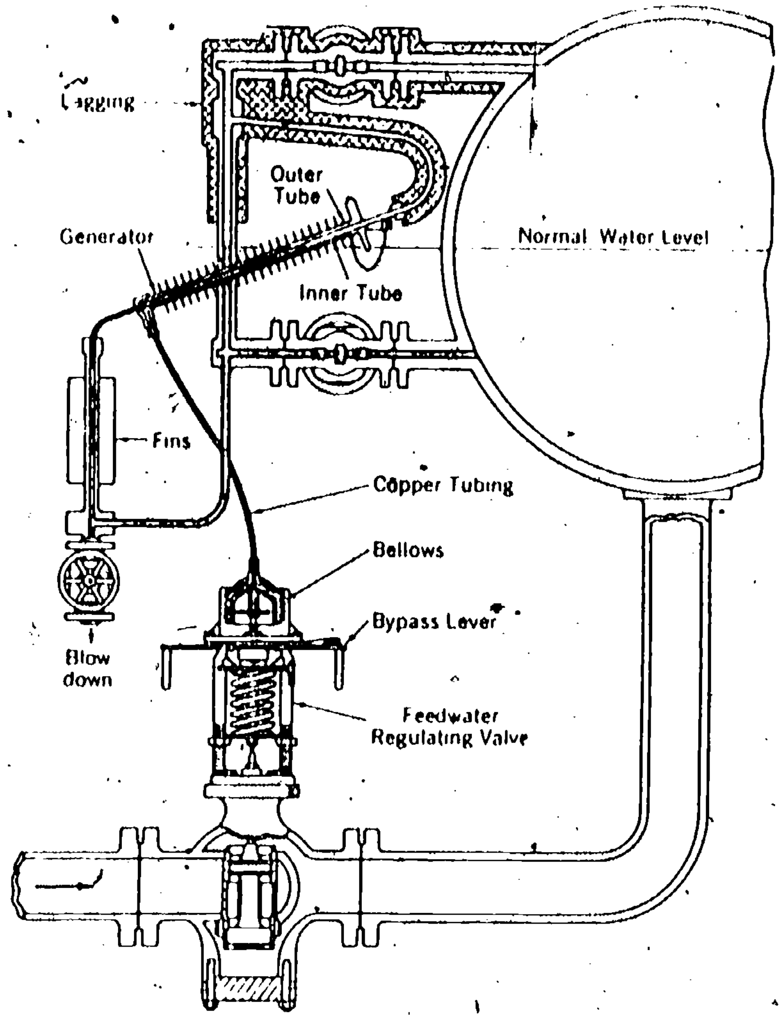
Thermo-hydraulic Regulator

This system consists essentially of a feedwater regulating valve which is actuated by a generator. The generator consists of two tubes, one within the other. The ends of the inner tube are connected to the steam and water spaces of the boiler thus the level of water in the inner tube will be the same as the boiler drum level. The outer tube is connected at the bottom to a bellows on the feedwater regulating valve.

To put the regulator into operation the outer tube and the bellows are filled with water and sealed off. In operation the heat from the steam in the upper portion of the inner tube causes the surrounding water in the outer tube to flash to steam, forcing water down into the bellows until the water levels in the inner and outer tubes are equal. This will cause the bellows to expand and open the feedwater valve in direct proportion to the water level in the generator.

If the water level in the boiler and therefore in the inner tube rises, some of the steam in the outer tube will condense which will decrease the pressure in the bellows. As a result the feedwater valve will close in proportion.

Fig. 36 shows the arrangement of the thermo-hydraulic regulator.



Thermo-hydraulic Control

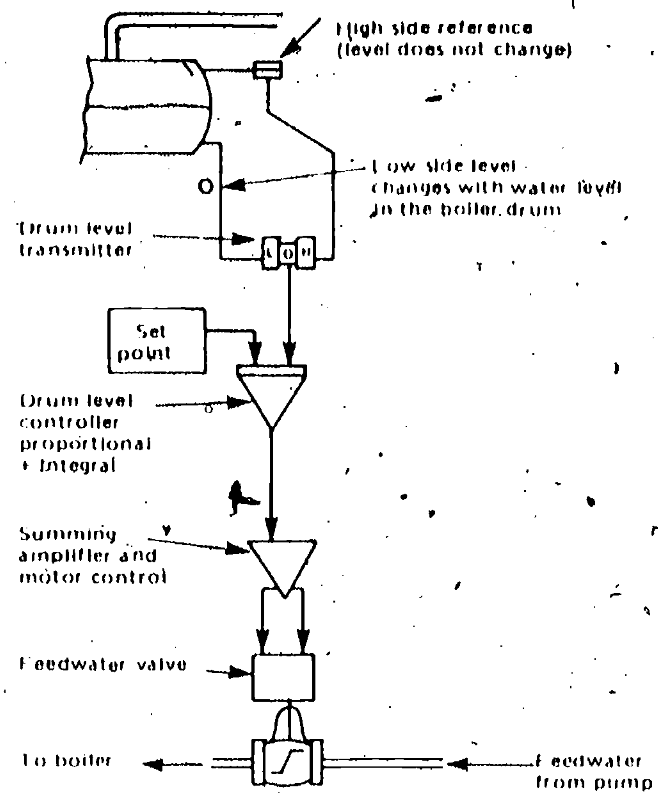
Fig. 36

Thermo-expansion Regulator

This regulator consists essentially of a tube mounted on a rigid beam. The tube is connected to the steam and water spaces of the boiler, the water level in the tube thus varying with the water level in the boiler.

Upon a drop of water level in the boiler, the water will also drop in the tube thus exposing more of its length to high temperature steam. This causes the tube to lengthen due to expansion and this movement is transmitted by a linkage to a feedwater regulating valve causing it to open. When the water level increases, the tube will contract due to the effect of the comparatively cool water. This movement will tend to close the regulating valve.

Single Element Feedwater Control



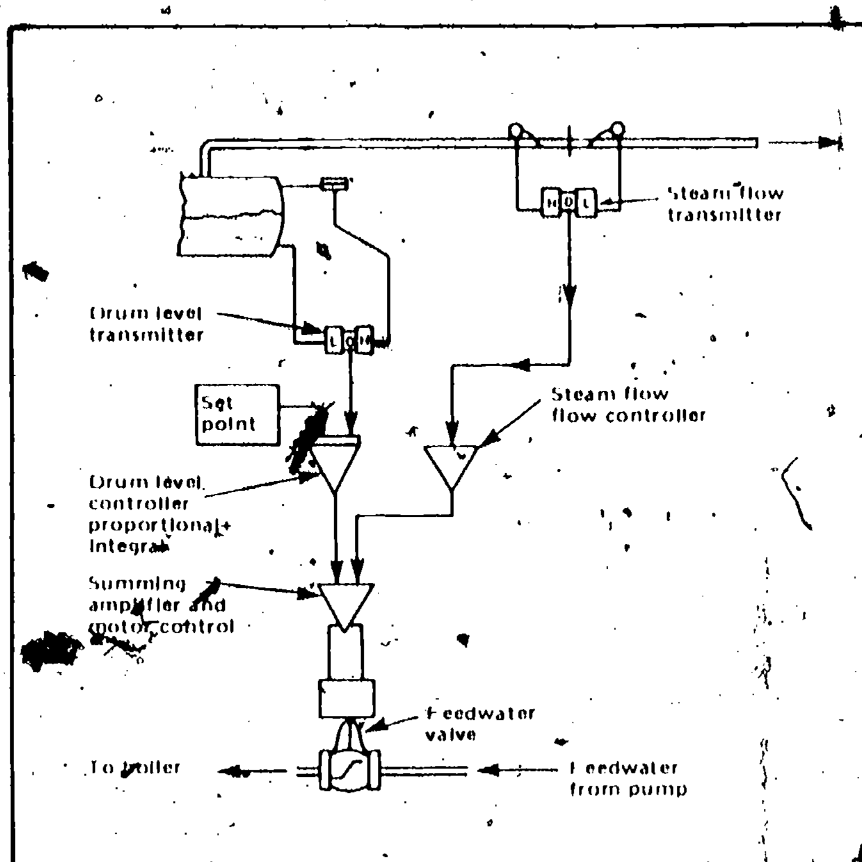
Single Element Control

Fig. 37

Referring to the single element control in Fig. 37, the drum level transmitter sends a signal to the controller which applies proportional-plus-integral action according to the difference between the drum level signal and the set point and thus the position of the feedwater valve is changed.

This type of control will maintain a constant drum level for slow load changes but during more rapid changes it will not compensate for swell or shrinkage. Load increases create swell which causes the single element control to see an increased drum water level. This results in the control reducing feedwater flow when, instead, an increased flow is required because of the increased steam flow from the boiler. Conversely, load decreases cause shrinkage so the control will see a low drum level and will admit large amounts of water into the boiler which are not required due to decreased steam flow.

Two Element Feedwater Control



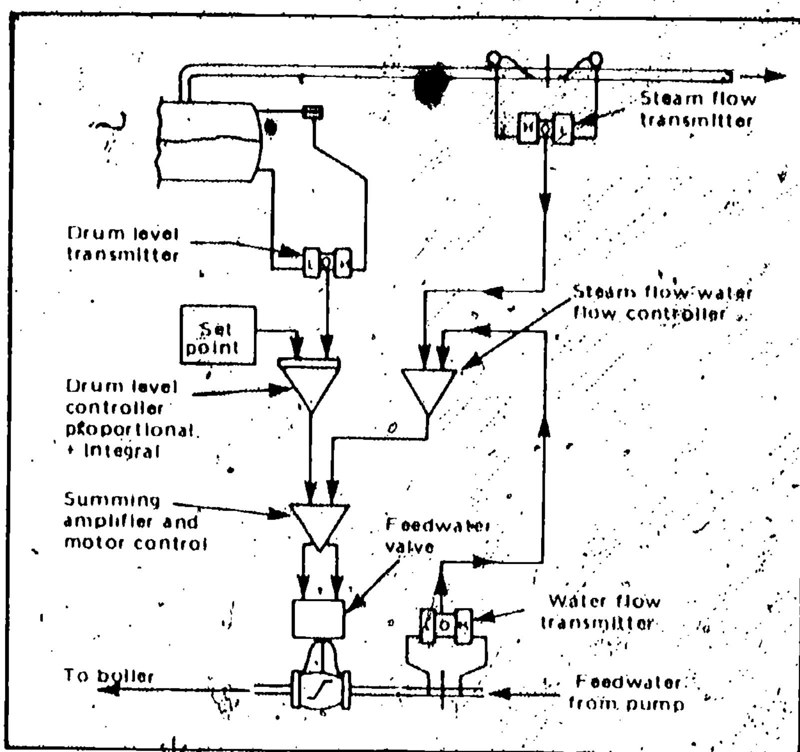
Two Element Control

Fig. 38

The two element control in Fig. 38 measures and responds to two variables, steam flow and drum level. The steam flow measurement maintains feedwater flow proportional to steam flow and the drum level measurement corrects for any imbalance between water input and steam output. In this way, the control can make the necessary adjustments to cope with the swell and shrinkage characteristics of the boiler.

Three-Element Feedwater Control

The three element control in Fig. 39 incorporates steam flow measurement, feedwater flow measurement, and drum level measurement. The steam flow measurement provides a set point for the steam flow-water flow controller. Feedback is provided by the feedwater flow measurement and feedwater flow is matched to steam flow. Drum level measurement keeps the level in the drum from varying due to flow meter errors, blowdown, etc.



Three Element Control

Fig. 39

COMBUSTION CONTROL SYSTEMS

The combustion process in the boiler furnace must be regulated in accordance to the demand for steam from the boiler. If the steam demand increases, then so must the combustion increase in order to maintain the required steam pressure. Similarly, if the steam demand drops, then the combustion of fuel must be reduced accordingly.

Combustion is regulated by controlling fuel flow and air flow into the furnace and the flow of combustion products out of the furnace. In addition to making sure that sufficient fuel and air are admitted, the control must maintain the proper ratio of air to fuel in order to achieve safe and efficient combustion.

Combustion control systems can be categorized as on-off, positioning, and metering.

On-Off Control

On-off control systems, also called two-position systems, are found only on firetube and small watertube boilers. The main control element is a bellows operated switch which is activated by the boiler steam pressure. When the pressure drops to a preset "cut-in" value the pressure switch starts up the draft fans and the burner. When the boiler pressure reaches a preset "cut-out" value then the pressure switch shuts down the boiler again.

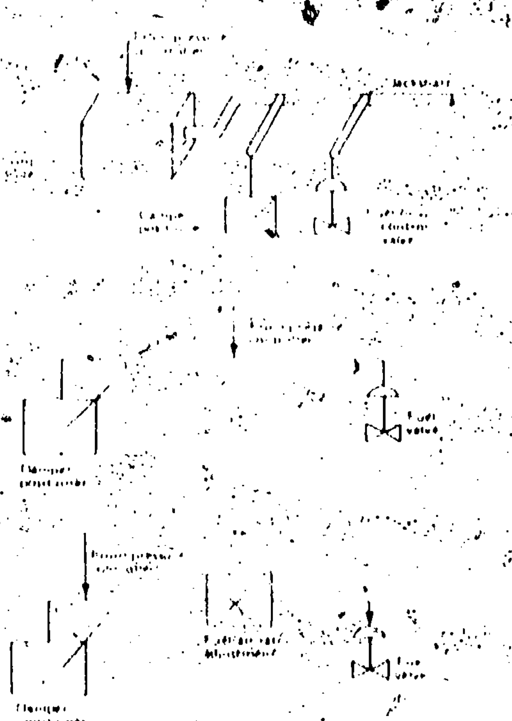
The main disadvantage of this system is that the boiler operation is inefficient plus the fact that boiler pressure varies appreciably between the "cut-in" and the "cut-out" point.

Positioning Control

In this system, as in the on-off control, steam pressure is the measured variable. The master controller responds to changes in steam pressure by positioning draft dampers and fuel valve by means of actuators in order to maintain the firing rate in accordance to boiler load.

The most simple arrangement of positioning control is to have the master controller operating a jackshaft. The jackshaft is linked to the damper and the fuel valve and operates these in parallel.

Another simple arrangement is to have the master controller send a signal in parallel to the damper actuator and to the fuel valve actuator. This arrangement can be improved by including a manual air/fuel ratio adjustment.



Parallel Positioning Arrangement

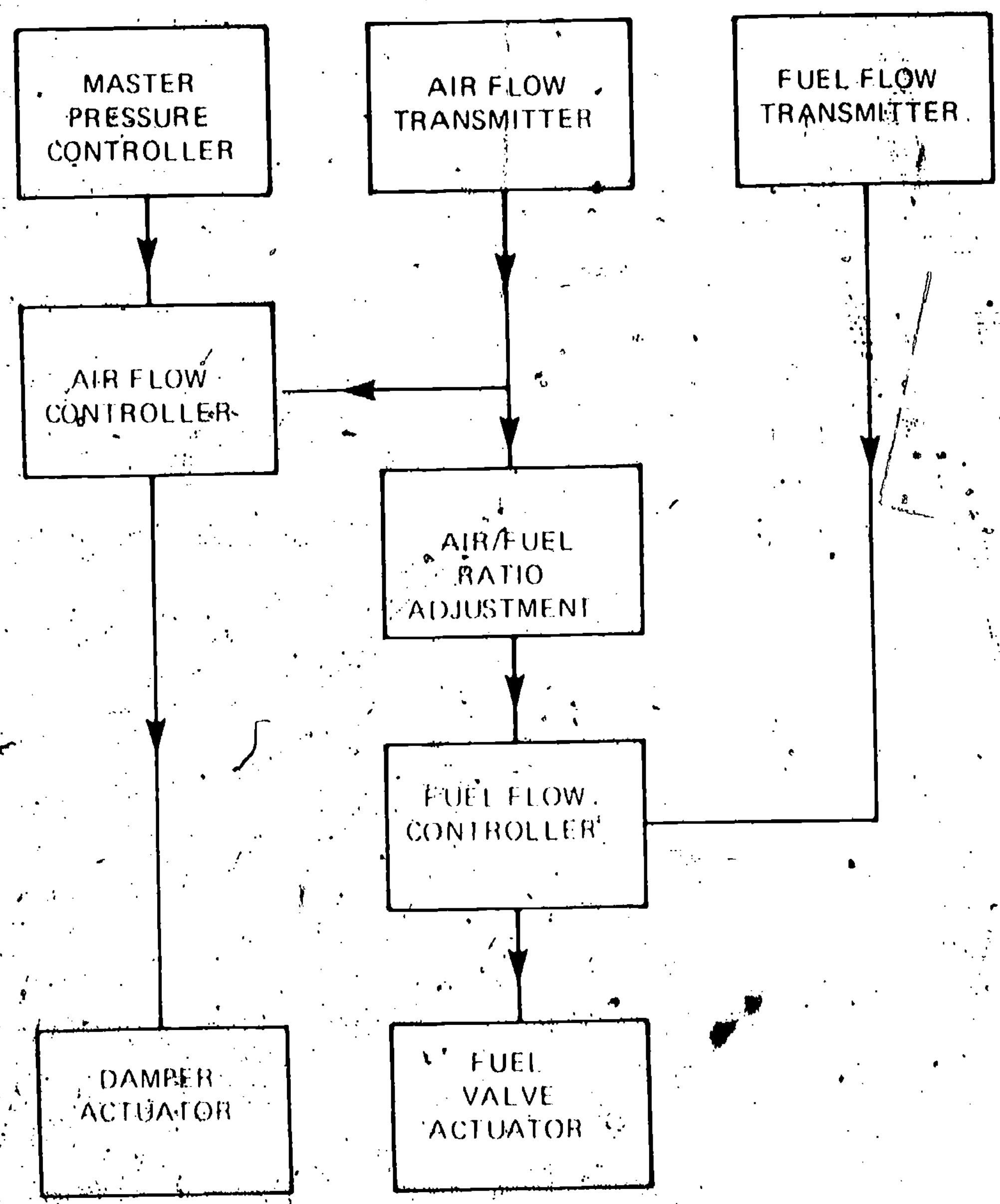
Fig. 40

Fig. 40 shows the three positioning control arrangements described above.

Metering Control

In the metering control system the master controller sends signals to the fuel valve and draft dampers as was done in the positioning system. However, with metering control these controller signals are modulated in accordance to actual fuel and air flows which are measured or metered. In this way an optimum fuel/air ratio can be maintained over the entire operating range.

The metering control system may be arranged in series or parallel. A block diagram of a series arrangement is shown in Fig. 41.



Metering Control Series Arrangement

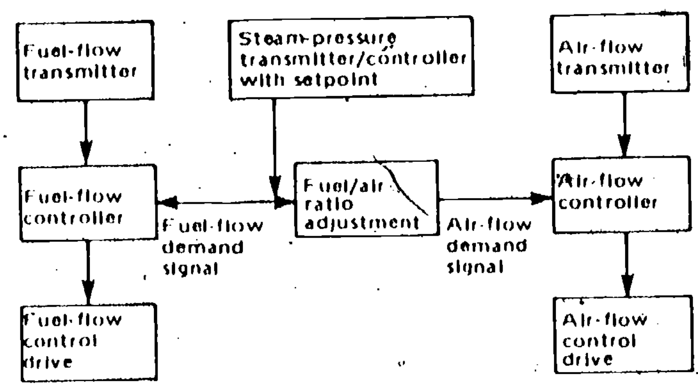
Fig. 41

(PE1-2-11-36)

Referring to Fig. 41, on a change in boiler pressure the master controller signal will change causing the air flow controller to adjust damper position by means of the damper actuator. The air flow transmitter will sense the change in air flow and a feedback signal will be sent back to the air flow controller. The same signal will be sent through the air/fuel ratio adjustment to the fuel flow controller which will reposition the fuel valve by means of the fuel valve actuator. The fuel flow transmitter senses the change in fuel flow and a feedback signal is sent to the fuel flow controller. The amount that the fuel flow changes with a change in air flow depends upon the air/fuel ratio adjustment.

The parallel system of metering control is more commonly used than is the series system because it offers greater response to load changes since air and fuel flow corrections are made simultaneously.

A block diagram of a simple parallel system appears in Fig. 42.



Metering Control Parallel Arrangement

Fig. 42

Referring to Fig. 42, if the steam pressure decreases from the set point of the steam pressure transmitter/controller then this controller will transmit a demand signal to the air flow controller which compares the new air flow requirement with the metered feedback signal from the air flow transmitter. The resulting corrective output signal is sent to the air flow control drive which opens dampers or increases fan speed until the actual air flow matches the demand signal. At the same time the signal from the steam pressure transmitter/controller is also being received by the fuel flow controller which compares the new fuel flow requirement with the metered feedback signal from the fuel flow transmitter. The resulting corrective output signal is sent to the fuel flow control drive which adjusts the fuel valve until the actual fuel flow matches the demand signal.

Combustion Control Arrangements

It is necessary that the amount of combustion air be proportioned to the amount of fuel being burned and this proportioning can be done manually or automatically. The amount of air supplied must be over and above that required for theoretical perfect combustion in order to assure that sufficient oxygen contacts all the fuel. This air is referred to as excess air and it must be kept to a minimum otherwise boiler efficiency will decrease. Conversely if insufficient excess air is supplied then incomplete combustion will result giving lower boiler efficiency as well as the formation of combustible products that can present an explosion hazard in the boiler furnace and passes.

In order to determine the amount of air required for varying boiler loads, three basic guides are used for control systems. These are steam flow-air flow, fuel flow-air flow, and gas analysis.

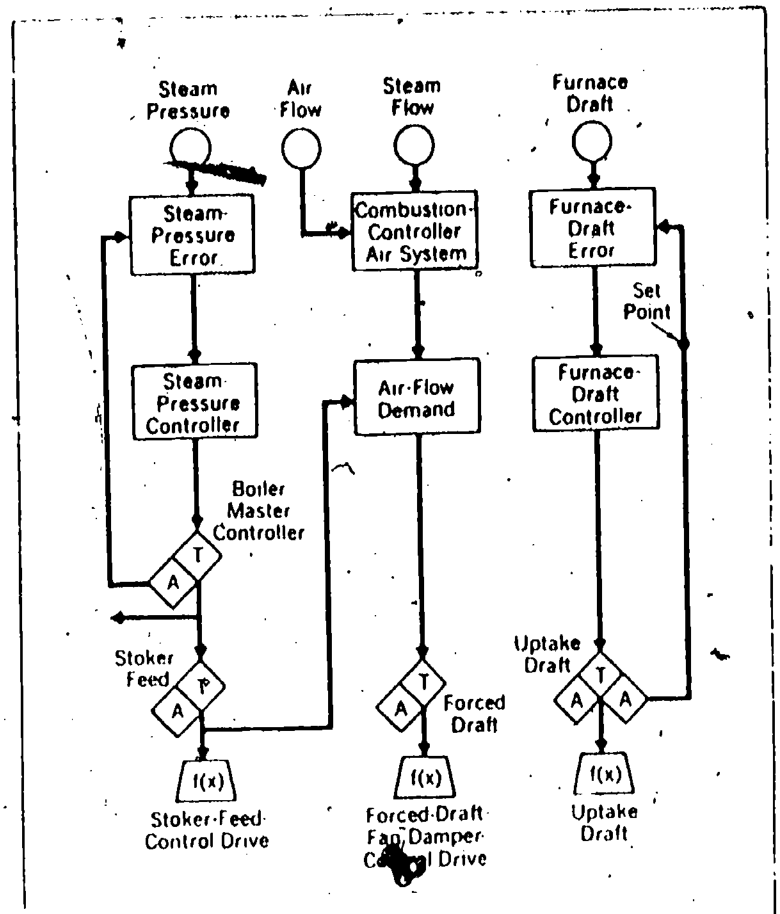
1. Steam Flow - Air Flow

As mentioned in the previous section, the proportion of air to fuel (air/fuel ratio) is extremely important as far as boiler efficiency and safety are concerned. The most direct way to determine whether the air and the fuel are in the correct amounts would be to measure the fuel flow and the air flow and to adjust them when necessary in order to maintain the correct ratio. However, with certain types of fuel, such as coal, it is difficult to measure fuel flow. In these cases, the steam flow is measured and is used as an indication of fuel consumption or heat absorption. The air flow is also measured and is maintained in a certain ratio with the steam flow. In this way a ratio is indirectly maintained between the air flow and the fuel flow.

A block diagram of a steam flow - air flow combustion control system is shown in Fig. 43.

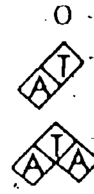
Control symbols used in Fig. 43 are defined in Table 1.

Referring to Fig. 43, upon a change in boiler pressure, the steam pressure transmitter will simultaneously signal a change in both fuel flow and air flow through the steam pressure controller and boiler master controller. The correct air/fuel ratio is maintained by the combustion controller which receives signals from the steam flow transmitter and the air flow transmitter.



Steam Flow - Air Flow Control
(Babcock and Wilcox)

Fig. 43



O	Transmitter
◇T/A	Hand-automatic selector station (analog control)
A T A	Hand-automatic selector station (analog control) with bias
f (X)	Power device (valves, drives, etc.)

Control Symbols

Table 1

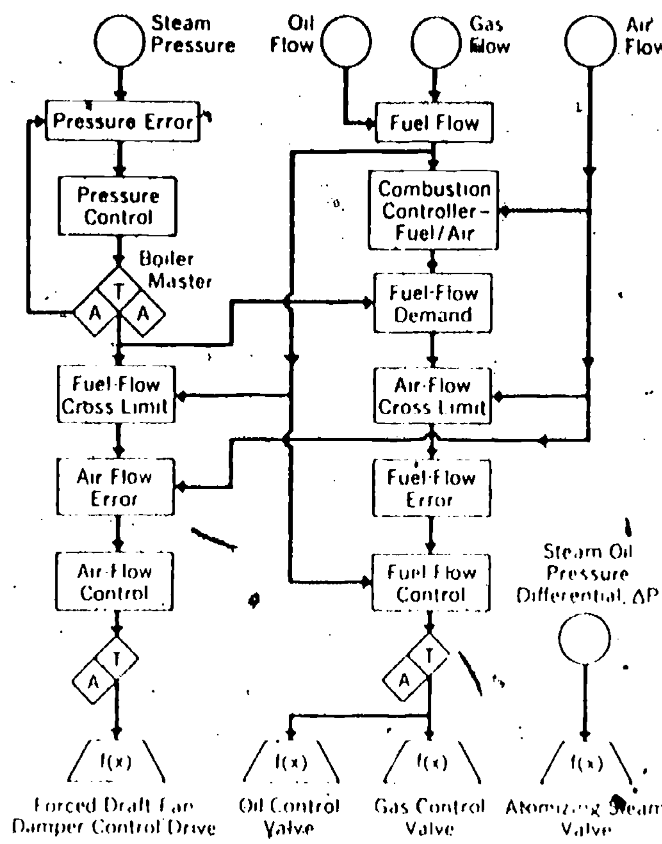
A change in the air flow to the furnace will cause a change in furnace draft and the furnace draft controller will change the uptake draft to maintain the correct furnace draft.

(PE1-2-11-39)

2. Fuel Flow - Air Flow

The fuel flow - air flow system can be used where it is practicable to measure the fuel flow to the furnace as well as the air flow. These measurements can then be used to maintain the correct air/fuel ratio.

Fig. 44 is a block diagram of a fuel flow-air flow control system for a dual fuel boiler which can burn oil or gas separately or together.



Fuel Flow - Air Flow Control
(Babcock and Wilcox)

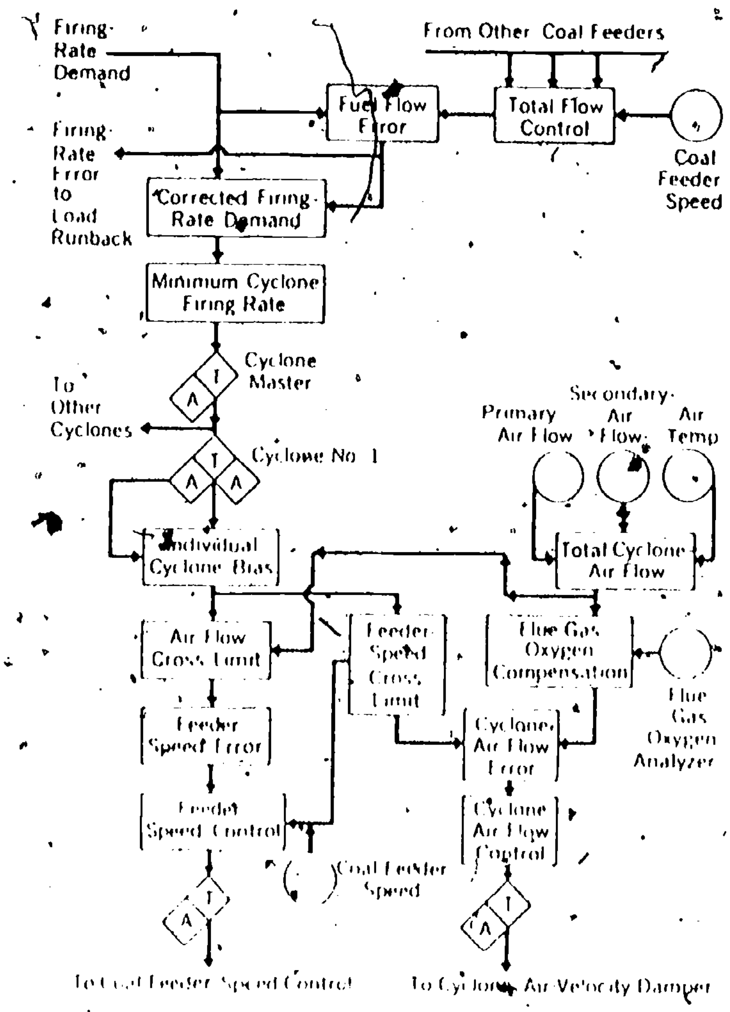
Fig. 44

In the system in Fig. 44, the fuel and air flows are controlled according to changes in boiler steam pressure. The steam pressure transmitter signals through the boiler master to both the forced draft fan control and to the fuel control valves. The fuel flow is then readjusted to maintain correct air/fuel ratio by the fuel/air controller.

3. Gas Analysis

Gas analyzers can be used to maintain correct air-fuel ratios. Flue gas samples are continuously analyzed and indications are made of the amounts of oxygen and combustibles present in the flue gas. The percentage of oxygen in the flue gas relates to the air/fuel ratio and a signal from the analyzer can be used for control purposes in adjusting the air flow to the furnace.

A block diagram illustrating a system of combustion control using a gas analyzer appears in Fig. 45.



Combustion Control with Gas Analyzer
(Babcock and Wilcox)

Fig. 45

(PE1-2-11-41)

The system in Fig. 45 is for a cyclone furnace fired boiler. On a change in firing rate demand due to a change in boiler pressure, a signal change is sent to the coal feeder speed control and to the cyclone air damper. The air flow is readjusted to maintain the correct air/fuel ratio by a signal from the flue gas oxygen analyzer.

A new concept for a combustion control guide is megawatt generation-air flow. The megawatts generated represent a direct index of heat input to the unit and this system is more accurate than the steam flow-air flow system as the relationship of steam flow to heat input can be affected by changes to feedwater or steam temperature. This is because a variation of either temperature necessitates more or less transfer of heat to each pound of steam. The megawatt generation-air flow method is now being applied in new boiler instrumentation and control systems for steam electric generating plants.

STEAM TEMPERATURE CONTROL

In the case of steam generators which produce superheated steam, it is necessary to maintain the temperature of the superheated steam at a constant value. The following reasons make this particularly important when superheated steam is used to drive a turbine.

1. Turbines are designed to operate most efficiently under set conditions of temperature.
2. Steam temperature changes will cause differential expansion or contraction between the turbine rotor and the turbine casing.
3. Excessive rise in steam temperature will cause weakening of metals used in both the superheater and the turbine.
4. Excessive drop in steam temperature will result in condensation taking place in the turbine low pressure stages with subsequent blade erosion and loss of efficiency.

The main problem in steam temperature control is to maintain the same final steam temperature at both high and low loads. One or more of the following methods may be used to achieve this control.

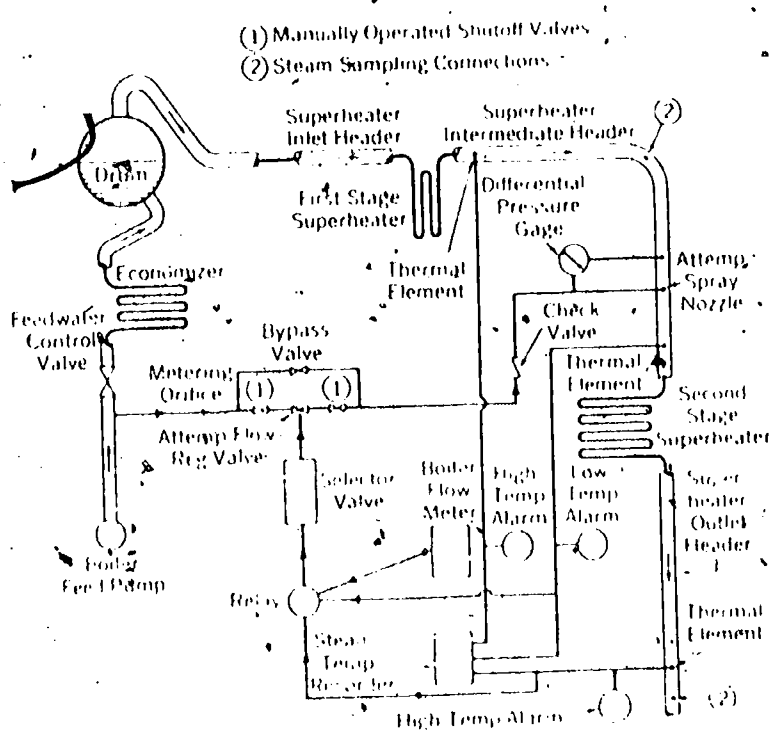
1. Desuperheating
2. Attemperation
3. Gas recirculation
4. Gas bypass
5. Twin furnace
6. Tilting burners

These methods were all described in Lecture 3, Section 2.

(PE1-2-11-42)

Because of the thermal inertia in large superheaters, the response of steam temperature to the controlling mechanism is quite slow. Therefore in order to anticipate any steam temperature changes, the combustion air flow or the steam flow is measured and a signal transmitted which governs the initial adjustment of the control. The final adjustment is by final steam temperature. This arrangement is known as a two element control, the two elements being air or steam flow and final steam temperature.

An improvement on the foregoing system is the three element control which can be used with spray attemperators. Fig. 46 illustrates the arrangement.



Three Element Temperature Control
(Babcock and Wilcox)

Fig. 46

In the system in Fig. 46, three signals are received by the attemperator regulating valve relay. One signal from the flow meter (steam or air), one signal from the thermal element located after the attemperator spray nozzle and before the second stage superheater, and one signal from the thermal element located after the second stage superheater (final steam temperature). The initial response to temperature changes is provided by the signal from the flow meter and the signal from the thermal element located just after the attemperator spray nozzle. Final adjustment is according to final steam temperature as signalled by the thermal element located after the second stage superheater.

(PE1-2-41 43)

QUESTION SHEET

POWER ENGINEERING

First Class
Sect. 2, Lect. 11

1. (a) Sketch, describe, and compare the three principle primary flow elements used to create differential pressure in a line.

   (b) Explain the relationship between flow and differential pressure.

2. Sketch and describe briefly the arrangement of a float manometer used for boiler water level indication.

3. Describe the functions of the following control components:

   (a) the controller

   (b) the transmitter

   (c) the actuator

4. With the aid of simple sketches, define and explain:

   (a) On - off action

   (b) proportional action

   (c) integral action

   (d) derivative action

5. With the aid of sketches, describe the operation of the following:

   (a) pneumatic transmitter

   (b) electronic transmitter

6. Explain the purpose of a positioner used in conjunction with an actuator.

7. Describe briefly the basic arrangement of each of the following feedwater control systems:

   (a) single element

   (b) two element

   (c) three element

(Continued)

(PE 2-2-11-Q)

8. Describe generally the following combustion control systems:

   (a) On - Off

   (b) positioning

   (c) metering

9. Explain the principle of operation of each of the following combustion control arrangements:

   (a) steam flow-air flow

   (b) fuel flow-air flow

10. Discuss steam temperature control with reference to methods, problems, and necessity.

(PEJ-2-11-Q-2)

INSTRUCTIONAL LEARNING SYSTEMS

14.4

STEAM — PURIFICATION

Goal:

The apprentice will be able to describe the process of steam purification.

Performance Indicators:

1. Describe steam separation.
2. Describe steam scrubbers.
3. Describe superheaters.
4. Describe steam traps.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Baffle type separator
* Balanced pressure trap
* Ball float trap
* Centrifugal type separator
* Controlled disc trap
* Inverted bucket trap
* Liquid expansion trap
* Mechanical traps
* Metallic expansion trap
* Scrubber elements
* Sediment separator
* Steam scrubber
* Steam separator
* Superheater
* Thermodynamic traps
* Thermostatic traps
* Tilting disc impulse trap

Introduction

The purity of steam that enters the turbine will determine its efficiency of operation and its machine life. Steam purification refers to the removal of condensate from steam.

Several pieces of specialized equipment contribute to the purification process. Essentially, steam separators, scrubbers and superheaters remove the moisture from steam. Steam traps collect and dispose of the condensate without a loss of steam. Although steam separators are commonly referred to as purifiers, scrubbers, superheaters and traps are vital to completion of the purification process.

Information

<u>Steam purification</u> refers to the removal of condensate from the steam along with air and carbon dioxide. As steam flows through a pipe it tends to cool and condense. This produces condensate (water) which can cause a rupture of the piping due to water hammer or cause erosion damage to the turbine blades. The major piece of equipment for steam purification is the <u>steam separator</u>.

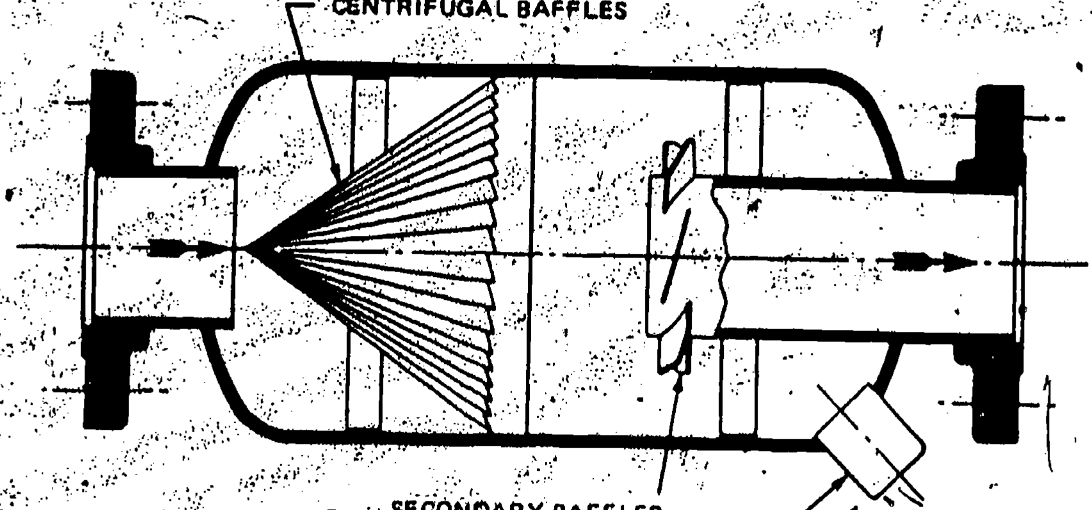
Steam Separators

There are two basic types of steam separators:

1. <u>Baffle type</u>
2. <u>Centrifugal type</u>

The baffle type steam separator is usually located in the main steam drum and is part of the drum internals. It has corrugated baffles and walls which collect moisture and reverses the steam flow. The reversal of steam flow slings the water particles out of the steam.

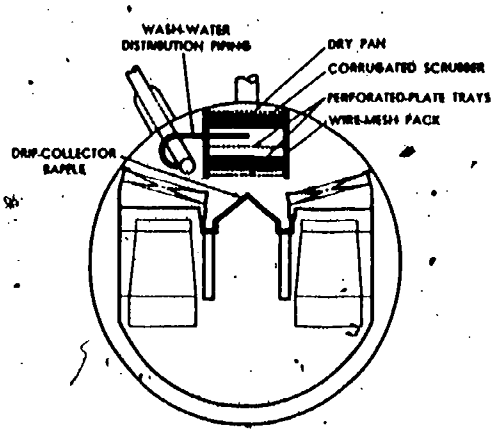
The centrifugal type separator uses centrifugal baffles to swirl the steam which tosses the water particles to the side walls. The separated water drains out. The purified steam passes through the baffles to the outlet.



Information

Steam Scrubbers

A second stage of purification is performed by steam scrubbers. A scrubber consists of corrugated steel plates or scrubber elements. The scrubber elements are closely arranged and overlap slightly. The steam is forced to change directions as it passes over the corrugated sections of the scrubber. Moisture and solids that escaped through the separator are thrown out of the steam flow. The water drains out and the steam moves upward to the outlet.



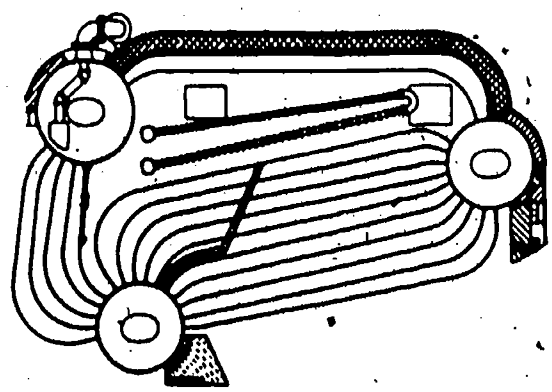
Steam Washer

Superheater

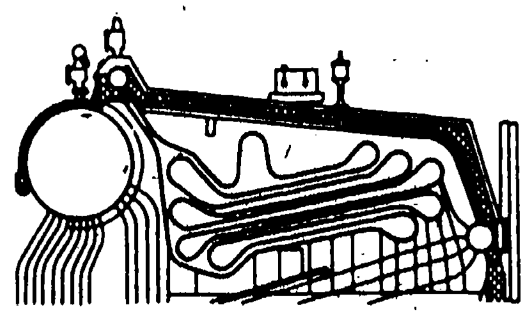
After the saturated steam leaves the drum it is piped to a specialized heating surface that is called a superheater. The superheater wrings all remaining moisture from the steam by heating the steam well beyond the temperature of saturation. This is the third stage of the purification process. A superheater consists of several parallel tube circuits that run between headers.

Superheaters are classified according to the way in which they receive heat — radiant, convection or a combination. They can be classified according to the location of the headers -- overdeck, interdeck, interbank and intertube. Some superheater arrangements are shown below and on the next page.

Information



Drainable overdeck superheater employing a system of fins for extending surface



This combined radiant and convection superheater, arranged in overdeck position, has extra large radii at the bends

Steam TRAPS

Steam traps are an important part of the steam purification process. The water removed in separation must be drained off without allowing steam to escape at the same time. Several types of traps have been devised to remove the water from separators and lines. These are classified according to the principles of operation.

1. Mechanical Traps

   a. Ball float type
   b. Inverted bucket type

2. Thermostatic Traps

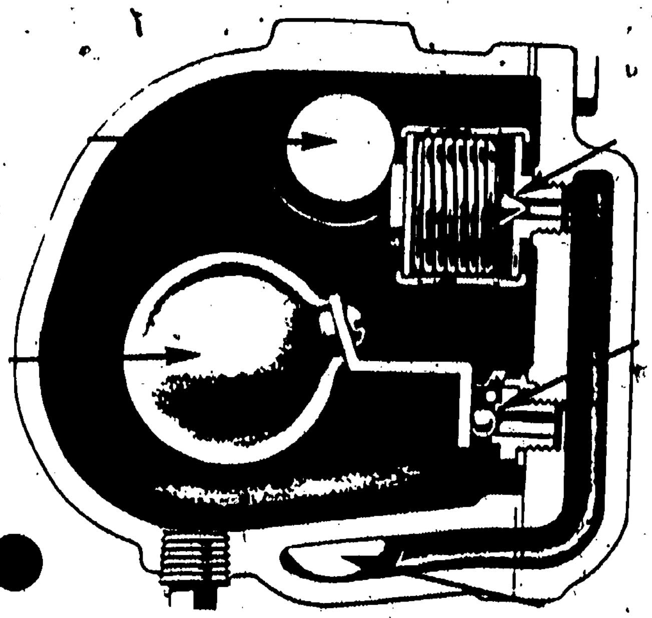
   a. Balanced pressure type
   b. Liquid expansion type
   c. Metallic expansion type

3. Thermodynamic Traps

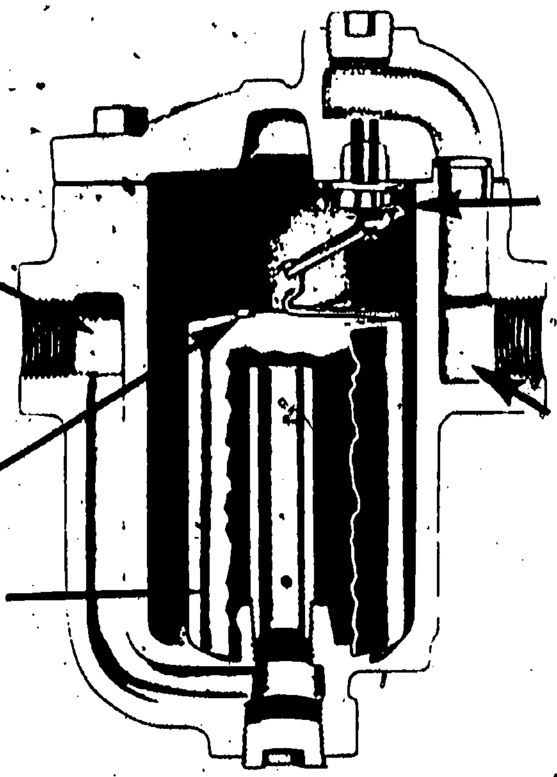
   a. Tilting disc impulse type
   b. Controlled disc trap

The mechanical traps operate by a float mechanism which responds to the difference in densities of steam and water. Both the ball float and inverted bucket traps operate on mechanical principles.

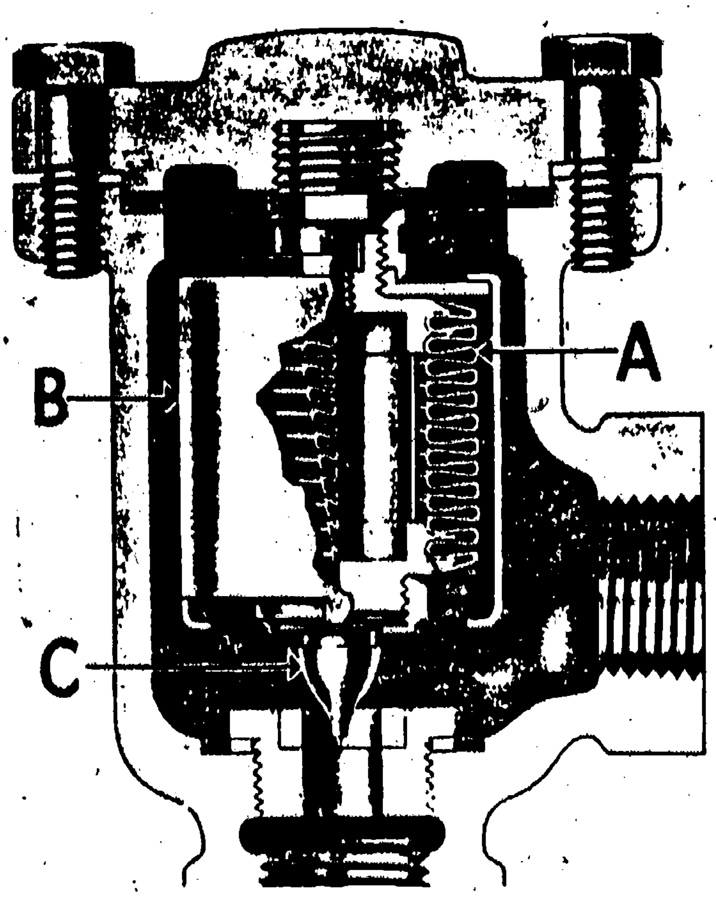
Information



Ball Float Trap

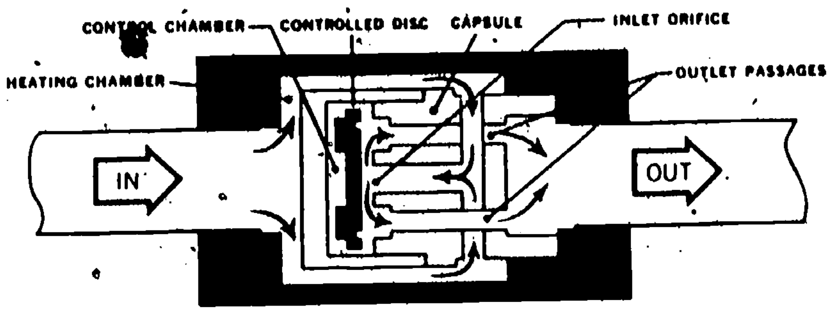


The thermostatic trap operates on the difference in temperature between water and steam. The hot condensate enters the trap and heats an alcohol mixture that is encased in the trap. The heating of the alcohol causes increased pressure and the discharge valve closes. As the condensate cools, the pressure will be reduced to open the valve. A balanced pressure trap is shown.



Information

Thermodynamic traps respond to the heat of the steam and condensate. A controlled disc trap diagram is featured below.

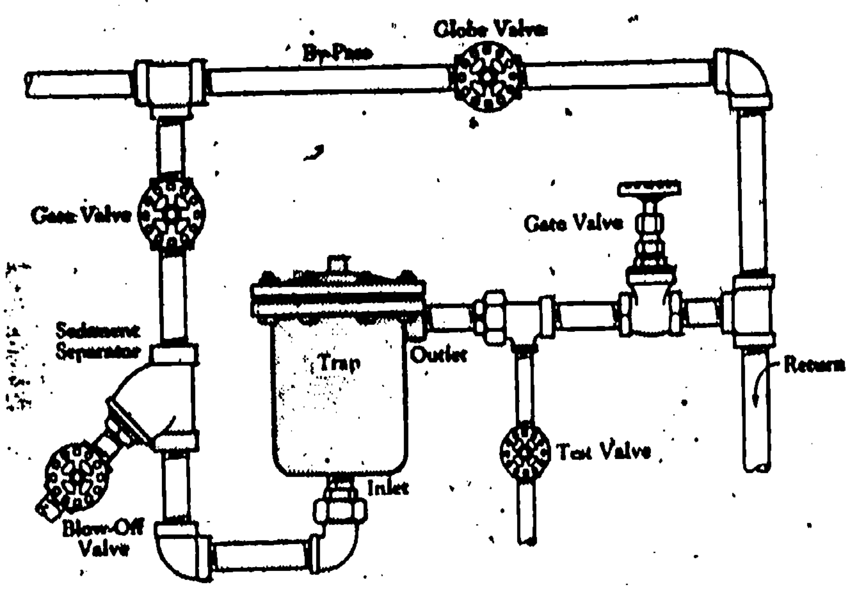


Sediment Separator

Some provision must be made for keeping scale deposits from fouling up the steam traps. The traps should be fitted with strainers to screen out debris.

Trap Piping

The installation of traps should allow for clean out and repair. A typical arrangement for trap piping is shown in the following diagram.



Assignment

* Read pages 1 - 15 in supplementary reference.
* Complete self-assessment and check answers.
* Complete post-assessment and have instructor check answers.

Self Assessment

Match the following terms and phrases.

____ 1. Steam purification	A.	A type of superheater
____ 2. Baffle type	B.	Second stage of purification
____ 3. Balanced pressure	C.	First stage of purification
____ 4. Inverted bucket	D.	Removal of condensate from steam.
____ 5. Tilting disc impulse	E.	Third stage of purification
____ 6. Convection type	F.	A thermodynamic trap
____ 7. Steam scrubber	G.	A type of steam separator
____ 8. Steam separator	H.	A mechanical trap
____ 9. Superheater	I.	Corrugated steel plates
____ 10. Scrubber element	J.	A thermostatic trap

Self Assessment Answers

D 1.

G 2.

J 3.

H 4.

F 5.

A 6.

B 7.

C 8.

E 9.

I 10.

Post Assessment

1. List two major types of steam separators.

2. Where are steam separators usually located in the steam plant?

3. What is steam purification?

4. What equipment is used in the second stage of steam purification?

5. What are the corrugated steel plates of a scrubber called?

6. What is the name of the specialized heating surface that takes over the third stage purification of steam?

7. List three types of thermostatic traps.

8. List two types of mechanical traps.

9. List two types of thermodynamic traps.

10. List three types of superheaters based on the way they receive heat.

Instructor Post Assessment Answers

1. Baffle, centrifugal
2. Steam drum
3. Removal of condensate
4. Steam scrubbers
5. Scrubber elements
6. Superheater
7. Balanced pressure, liquid expansion, metallic expansion
8. Ball float, inverted bucket
9. Tilting disc impulse, controlled disc
10. Radiant, convection and combination

Supplementary References

* Correspondence Course. Lecture 11, Section 2, Second Class. Steam Generators. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

14.4

SECTION 2

STEAM GENERATORS

Second Class
Lecture 11

PIPING II

CONDENSATE HANDLING

It is necessary that all steam lines be constantly and adequately drained of condensation. If this is not done then the condensate will be carried along with the team and may produce water hammer and, as a result, rupture of pipes and fittings. In addition to the danger of water hammer, the condensate may be carried along with the steam to engines and turbines with resulting damage to this equipment.

Drainage is necessary even in the case of pipelines carrying superheated steam, as condensation forms during the warming up period. Also, after the line has been warmed up and put into service, there is a possibility that water may be carried over from the boiler by the steam.

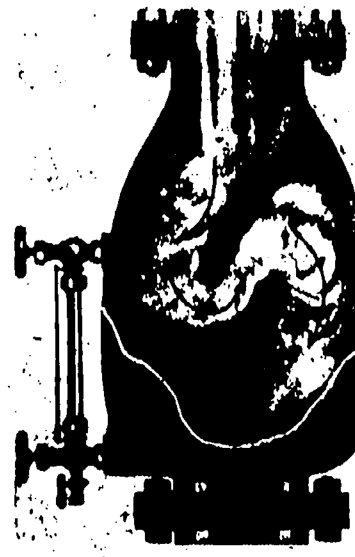
The drainage system must also remove air and carbon dioxide from the pipelines, otherwise pitting and corrosion will occur.

Drip or drain lines should be installed at all points where condensate may collect such as: ahead of risers, at ends of mains, ahead of expansion joints and bends, and ahead of valves and regulators. If the pipeline does not contain natural drainage points such as those listed above, then drains should be provided at intervals of 150 metres. At each point of drainage a drip leg should be provided and these drip legs should be the same diameter as the pipe up to 102 mm size, and at least 102 mm diameter for piping larger than 102 mm size. The purpose of the drip leg is to allow the condensate to escape by gravity from the fast moving steam.

Steam Separators

Steam separators, also known as steam purifiers, are designed to separate condensate from the steam. They not only remove moisture droplets and other suspended impurities, but will also remove pockets of water which are moving along with the steam.

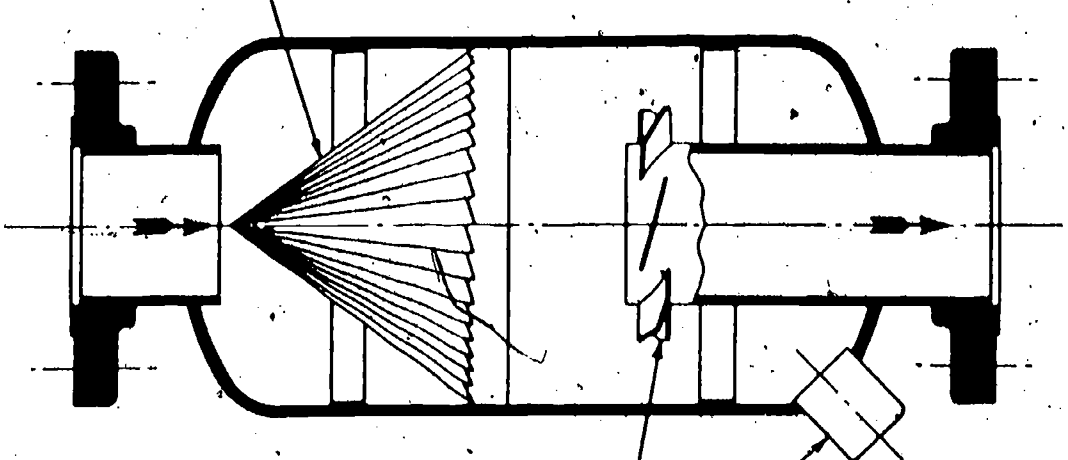
The separator either causes the steam to suddenly change its direction of flow or else it imparts a whirling motion to the steam. Both of these actions cause the moisture and other particles to be thrown out of the steam stream.



Baffle Type Steam Separator

Fig. 1

The separator in Fig. 1 features a corrugated baffle and corrugated walls. These corrugations serve to collect the moisture and, in addition, the baffle causes a complete reversal of the steam flow which causes the moisture particles to be thrown out.



Centrifugal Type Steam Separators

Fig. 2

PE2-2-II-2

The separator in Fig. 2 makes use of centrifugal baffles to give the steam a whirling motion. The moisture particles are thrown out to the inside wall of the separator and then pass to the drain. The purified steam then passes through secondary baffles to the separator outlet. The secondary baffles are used to reduce the whirling motion of the leaving steam.

The condensate collected by the steam separators is drained off from them by means of a trap. Gage glasses are sometimes provided on the separator as in Fig. 1 in order to ascertain if the trap is working satisfactorily. A better way of checking on the operation of the trap is to use a test valve at the trap outlet.

Steam Traps

A steam trap is a device which is used to discharge the water of condensation from steam lines, separators, and other equipment without permitting steam to escape. The method by which the trap performs this function varies with the particular design of trap. However, no matter what principle of operation is involved, all traps should provide the following:

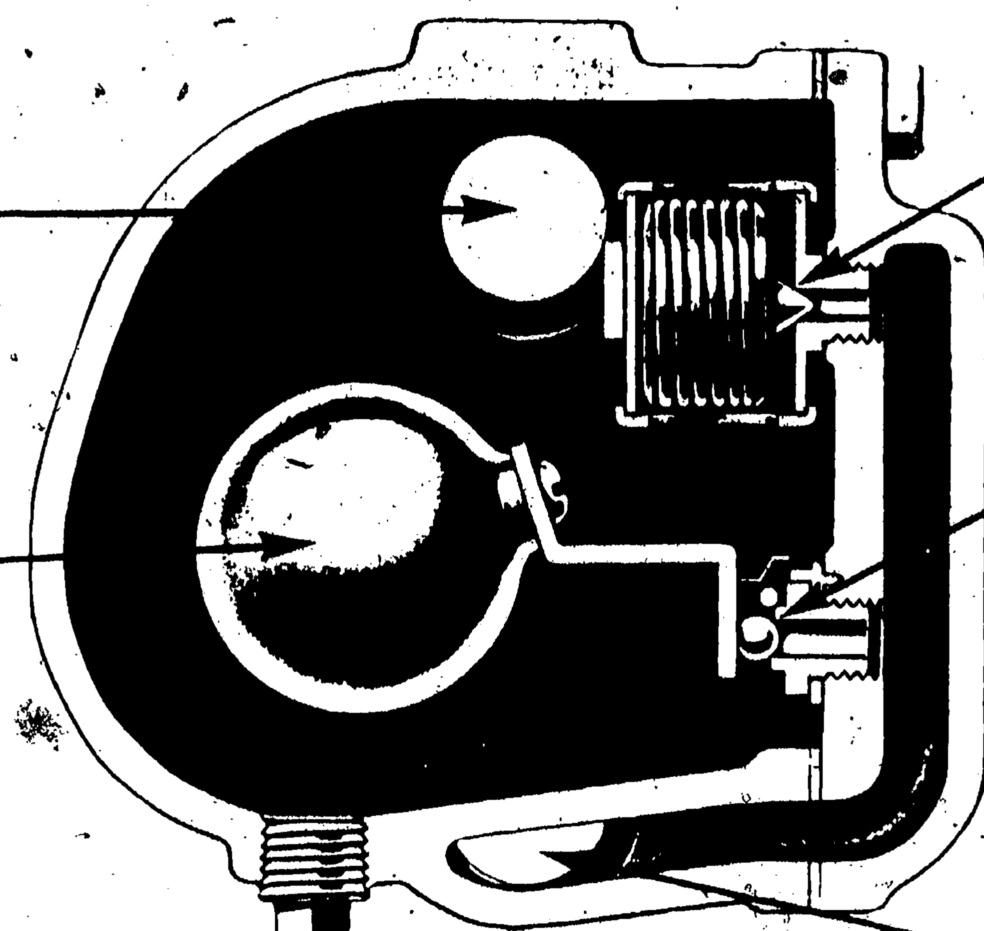
1. Long life and dependable service.
2. Resistance of trap parts to corrosion.
3. Efficient venting of air and carbon dioxide.
4. Ability to operate against the back pressure which will be present in the return line.
5. Ability to operate satisfactorily in the presence of scale or sediment.

Classes of Traps

There are a great many different designs of traps but they can be divided into three general classes according to their principle of operation. These classes are: mechanical, thermostatic and thermodynamic.

1. Mechanical Traps

This type depends upon the difference in density between steam and condensate to open or close the trap discharge valve. This done by means of a ball type float or a bucket type float.



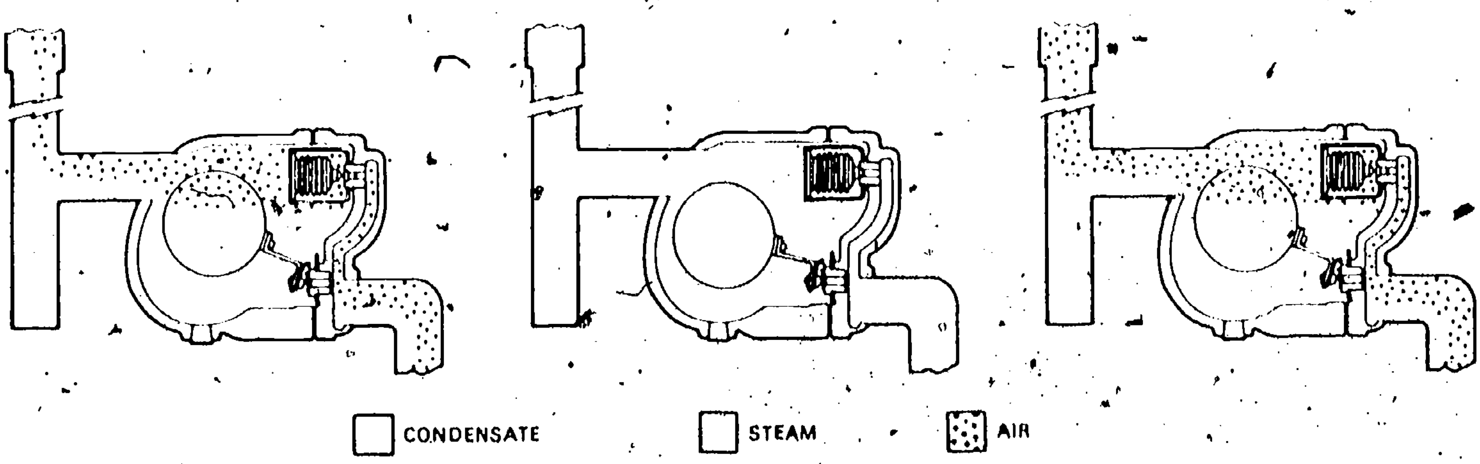
Redue

Ball Float Trap

Fig. 3

Fig. 3 shows a sectional view of a ball float trap. As condensate flows into the trap, the stainless steel float will rise and eventually open the discharge valve allowing a flow of condensate to the discharge outlet. Air and other gases such as CO_2 will escape to the discharge through the thermostatic vent. When steam reaches the trap, it will surround the thermostatic vent bellows causing the bellows to expand and close the vent thus preventing the discharge of steam. In addition, when the condensate level in the trap drops to a certain point, the float-operated valve will close and prevent the escape of steam.

Fig. 4 illustrates the operation of a similar type of float trap.



1. On start up, the main float-actuated valve is normally closed. Air is pushed through the open thermostatic air vent by system pressure. When condensate reaches the trap (above), the float opens the main valve to permit flow. Remaining air continues to discharge through the open vent.

2. When steam reaches the trap, the thermostatic air vent closes in response to the higher temperature. Condensate continues to flow through the main valve which is positioned by the float to discharge condensate at the same rate as the rate at which condensate is flowing to the trap.

3. Air from the system will now begin to accumulate in the top of the trap. When the temperature of the air drops a few degrees below saturated steam temperature at the existing pressure, the balanced pressure thermostatic air vent opens and discharges the air.

Float Trap Operation
(Armstrong Machine Works)

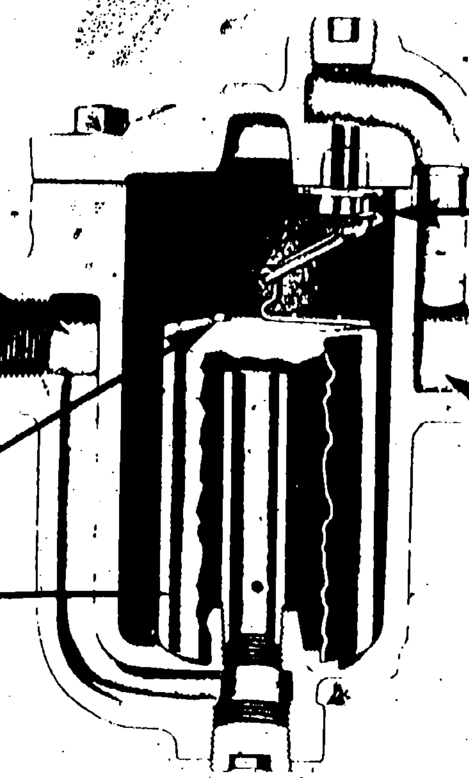
Fig. 4

The float trap will work equally well whether the condensate load is light or heavy and its operation is not affected by changes in steam pressure. It does not become air-locked upon start-up when there is a large amount of air present because it will discharge this air immediately and automatically.

The ball float trap, however, does have the disadvantage of being liable to damage from water hammer, and the thermostatic air vent is not suitable for use with superheated steam. In addition, this type of trap is not suited for outdoor use as it will freeze up.

Another commonly used mechanical trap is the inverted bucket trap shown in Fig. 5.

Referring to Fig. 5, initially the bucket hangs down holding the discharge valve open. Condensate enters the trap and flows under the bottom edge of the bucket to fill the trap body. Then the condensate will flow out through the open discharge valve to the outlet. Any steam which enters the trap will collect at the top of the inverted bucket giving it buoyancy and causing it to rise thus closing the discharge valve. Air and CO_2 gas will also collect at the top of the inverted bucket and will pass through the vent at the top of the bucket to the upper part of the trap body.



Inverted Bucket Trap
(Armstrong Machine Works)

Fig. 5

Some steam will also pass through this vent but will condense in the cooler environment near the top of the trap. As more condensate enters the trap and as the steam within the inverted bucket condenses, the bucket will sink and again open the discharge valve. The accumulated air and CO_2 will discharge first and then the condensate will discharge until more steam enters the bucket to once again close the discharge valve.

Another design of the inverted bucket trap features a large vent at the top of the bucket and this vent is controlled by a bi-metallic strip. In this case, air and CO_2 will escape freely through the vent, but when steam enters the bucket the bi-metallic strip will close the vent and the steam will remain within the bucket until it condenses.

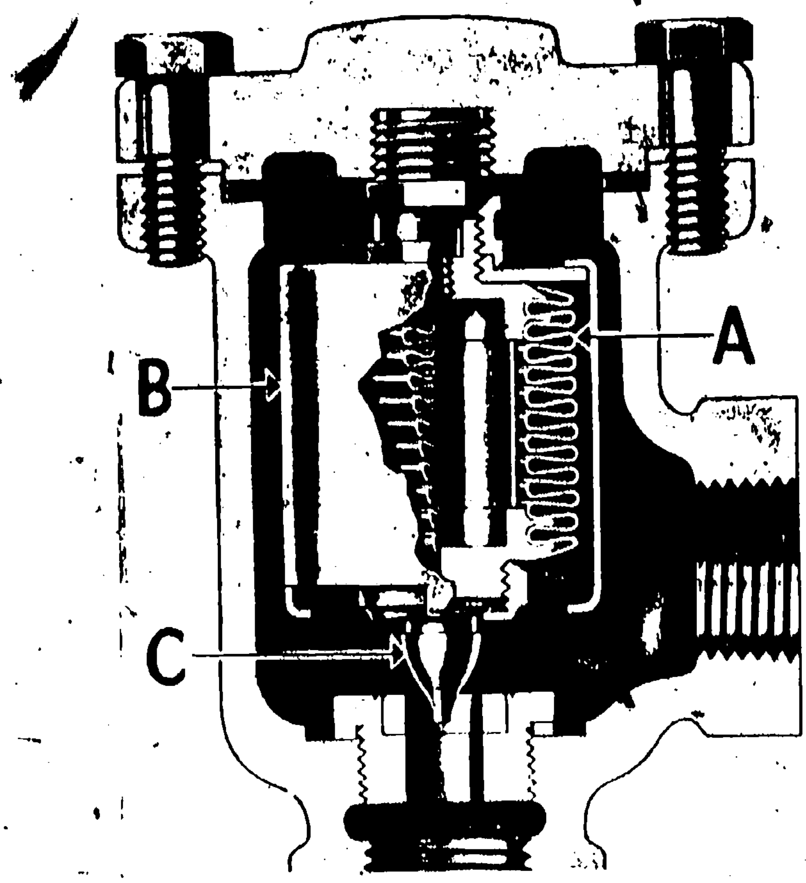
The inverted bucket trap is simple in construction and easy to dismantle for inspection and cleaning. It can be used for draining superheated steam lines and is better able to withstand water hammer than is the ball float trap.

This type of trap, however, will not discharge air rapidly and may be subject to air binding. Also, like the ball float trap, it is liable to freeze if exposed to low ambient temperatures.

2. Thermostatic Traps

The operation of the thermostatic trap depends upon the difference in temperature between the steam and the condensate. Three general designs are used: the balanced pressure type, the liquid expansion type, and the metallic expansion type.

Fig. 6 shows the main elements of the balanced pressure thermostatic trap.



Balanced Pressure Trap

Fig. 6

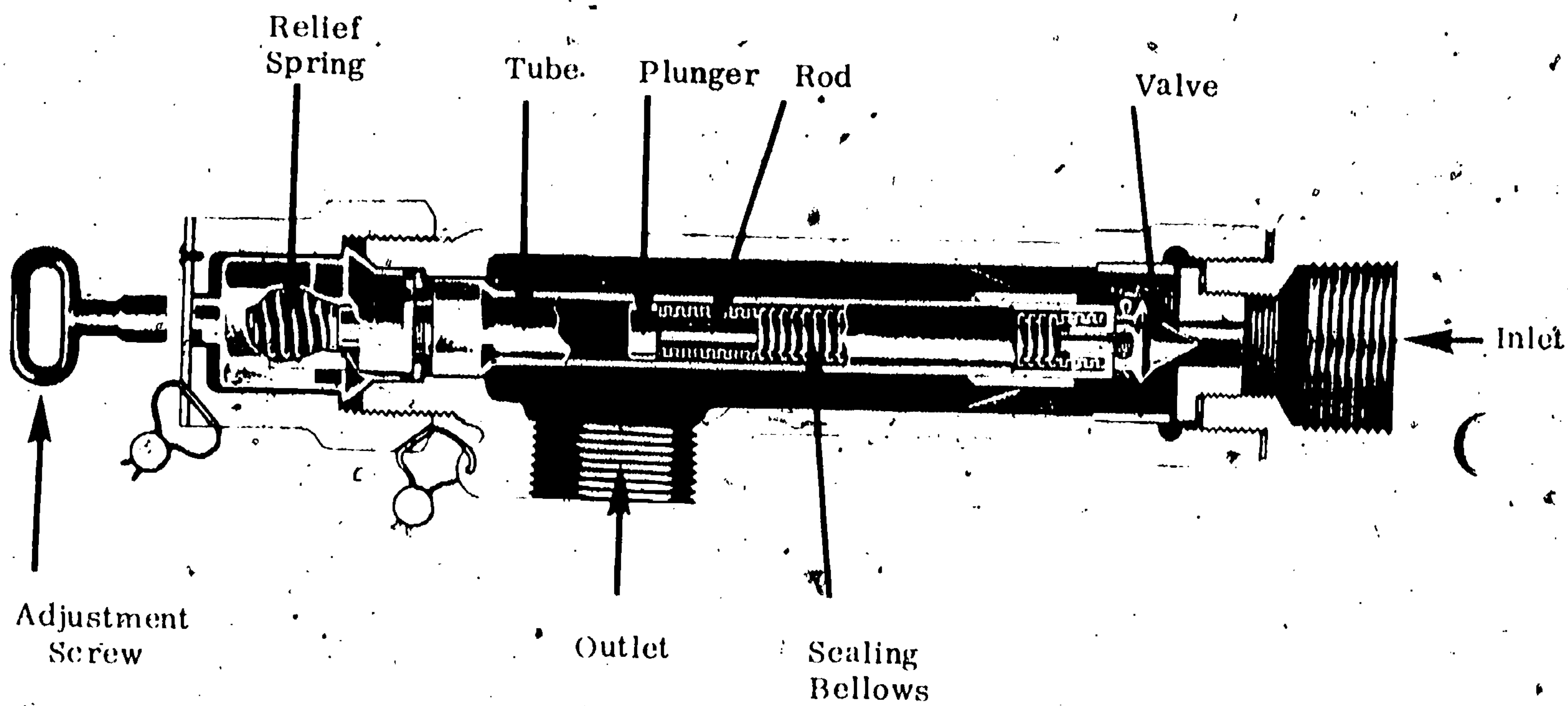
Referring to Fig. 6, A is a sealed corrugated element which is filled with an alcohol mixture, B is a metal shield surrounding the element and C is the trap discharge valve.

On start-up, the trap is in the open position as shown in Fig. 6. The air in the system is quickly discharged through the wide open valve. Then cool condensate will flow into the trap and will be discharged. However, as the condensate entering the trap becomes hotter, the alcohol within the element will begin to boil and produce pressure which will cause the element to expand and close the discharge valve. The hot condensate surrounding the element will then cool allowing the alcohol mixture within the element to cool and its vapor to condense. The element now contracts opening the valve and the cycle is repeated.

This type of trap is small and compact but it nevertheless can handle a large amount of condensate. The large amount of air present at start-up is also discharged rapidly. Another advantage of this type is that it is self-draining and therefore will not freeze up.

A disadvantage of this trap is that the corrugated element is liable to damage from water hammer or from corrosion. Also, it cannot be used with superheated steam as high temperature will create excessive pressure within the element.

The liquid expansion trap shown in Fig. 7 uses a thermostatic element or tube, which is filled with a special oil, to control the opening or closing of the trap discharge valve.



Liquid Expansion Trap

Fig. 7

Referring to Fig. 7, the operation of the trap is as follows: upon the start-up of the system, the trap discharge valve is wide open allowing a flow of air and cool condensate from the system. When hotter condensate or steam enters the trap, the liquid within the tube will expand and push the plunger along, thus closing the valve by means of the plunger rod. When the condensate cools, the liquid within the tube will contract and the plunger will move back thus opening the valve and allowing the cool condensate to escape.

The sealing bellows acts as a packless gland to prevent leakage of liquid from the tube. The relief spring prevents damage from water hammer or over-expansion of the element due to sudden high superheat temperatures. The adjustment screw allows the trap to be adjusted to discharge the condensate at the desired temperature.

The liquid expansion trap has the advantages of being adjustable and not subject to freezing. Also, it can be used with superheated steam and can withstand water hammer to some extent. It is, however, liable to corrosion of the tube if the condensate contains corrosive substances.

The metallic expansion trap uses the expansion of either a long rod or a bi-metallic strip to operate the trap discharge valve.

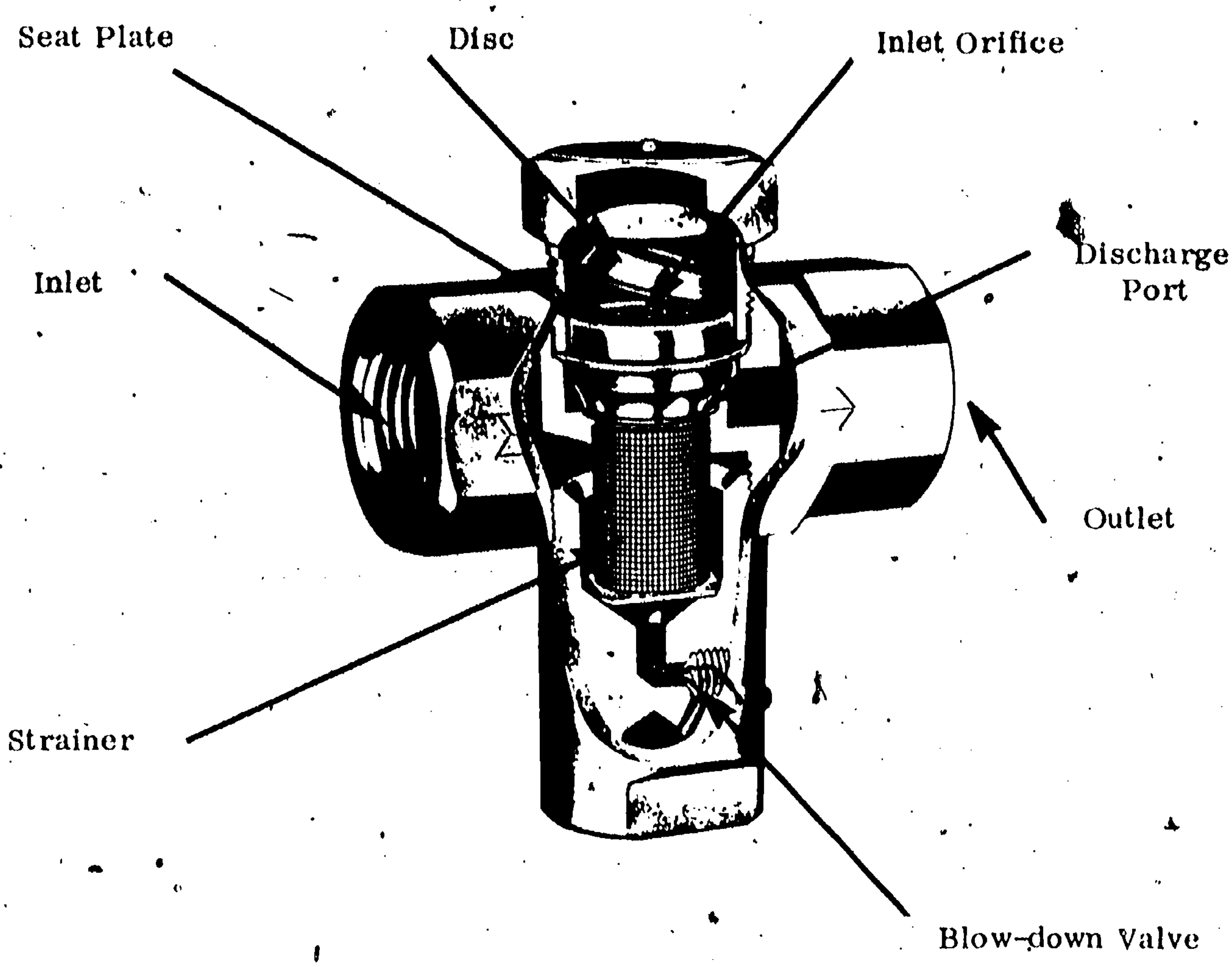
These types are only used for special applications as they have certain disadvantages. In the case of the rod type, in order to get enough movement of the valve the rod has to be quite long (about one metre in length). With the bi-metallic type the movement is also slight and the valve tends to not close tightly.

3. Thermodynamic Traps

The thermodynamic trap utilizes the heat energy in steam or in hot condensate to control its opening and closing.

A commonly used type of thermodynamic trap, called a tilting disc impulse trap, is illustrated in Fig. 8.

Referring to Fig. 8, when cool condensate or air enter the trap they flow upward through the inlet orifice and tilt the disc upward to pass through holes in the seat plate and through the discharge ports to the trap outlet. If steam enters the trap it flows at high velocity under the disc causing a reduction in pressure at this point and causing a pressure build up in the chamber above the disc. This forces the disc down thus closing the trap. If hot condensate enters the trap it will flash into steam as it leaves the inlet orifice. This flash steam will also flow at high velocity under the disc causing a reduction in pressure and flash steam above the disc will again force the trap closed. The trap will remain closed until the steam above the disc condenses.



Impulse Trap (Tilting Disc Type)
(Yarnall-Waring Co.)

Fig. 8

This trap features an integral strainer to prevent particles from entering the operating portion of the trap. Another feature is an Allan wrench-operated blow-down valve for the purpose of blowing out any sediment which may collect at the strainer.

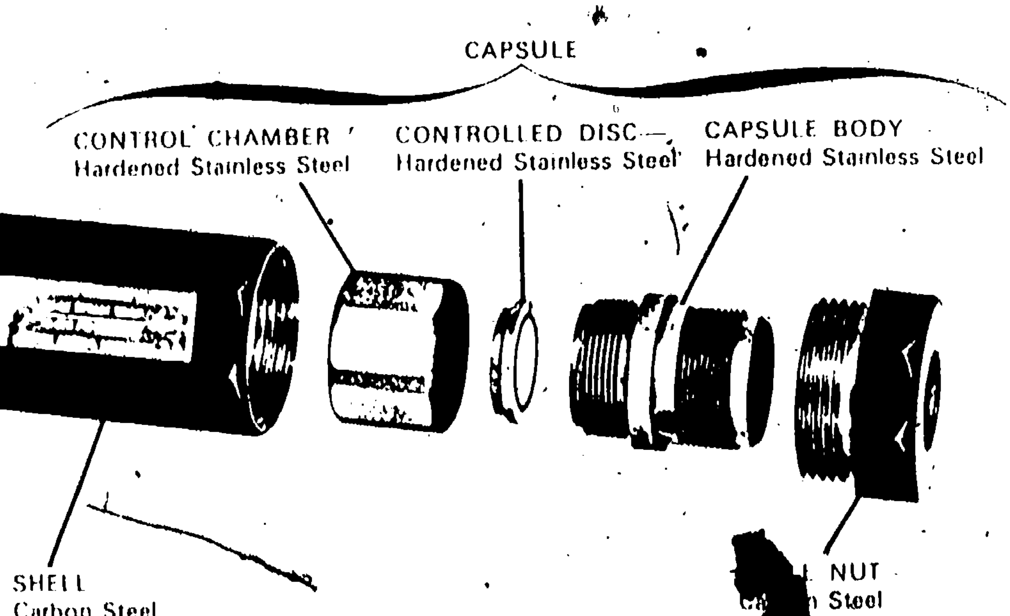
All stainless steel construction of the trap body and parts reduces the possibility of corrosion.

Controlled Disc Trap
(Armstrong Machine Works)

Fig. 9

The principle of operation of another type of thermodynamic disc trap is illustrated by the sketch in Fig. 9. This type is known as a controlled disc trap.

Referring to Fig. 9, condensate and air entering the trap pass through the heating chamber, around the control chamber and through the inlet orifice. This flow lifts the disc off the inlet orifice and the condensate and air pass to the outlet passages. When steam enters the disc its increased velocity of flow across the face of the disc reduces the pressure in this area and the pressure in the control chamber above the disc forces the disc against the orifice thus shutting off the trap. The steam in the control chamber gradually bleeds off around the disc and the trap will open once again. It will then discharge any condensate present and close once again in the presence of steam.



Controlled Disc Trap Construction
(Armstrong Machine Works)

Fig. 10

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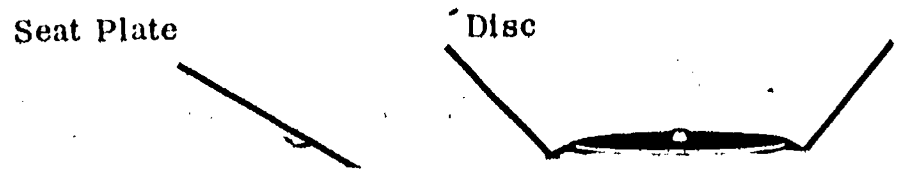


Pressure Differential

The pressure differential of a trap is the difference in pressure between the pressure at the trap inlet and the pressure at the trap outlet. For example, if the trap is draining a main steam header operating at a pressure of 690 kPa gage and if the trap is discharging against atmospheric pressure, then the pressure differential is 690 kPa. If, however, the same trap is discharging against a back pressure of 70 kPa then the pressure differential is 620 kPa.

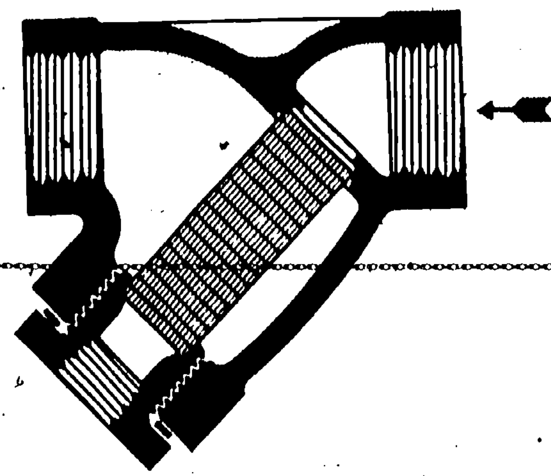
The smaller the pressure differential between the trap inlet and outlet the smaller is the trap capacity. The greater the pressure differential the greater will be the trap capacity.

Trap capacity also depends upon the size of the discharge orifice of the trap and the temperature of the condensate. The larger the discharge orifice the greater will be the trap capacity and vice versa. The higher the temperature of the condensate the smaller the capacity of the trap because the high temperature condensate will generate flash steam which will tend to partially choke the discharge orifice.

Strainers

In order to prevent dirt, scale, chips, etc. from getting into the working parts of traps, a strainer, also called a sediment separator, should be installed close to and ahead of every trap. The strainer will effectively trap all foreign particles and will, in addition, provide a pocket for their accumulation from which they can be blown out.

The strainer normally is made up of a steel body with a woven wire or perforated steel screen. Stainless steel or monel is frequently used for the screen material in order to reduce corrosion.



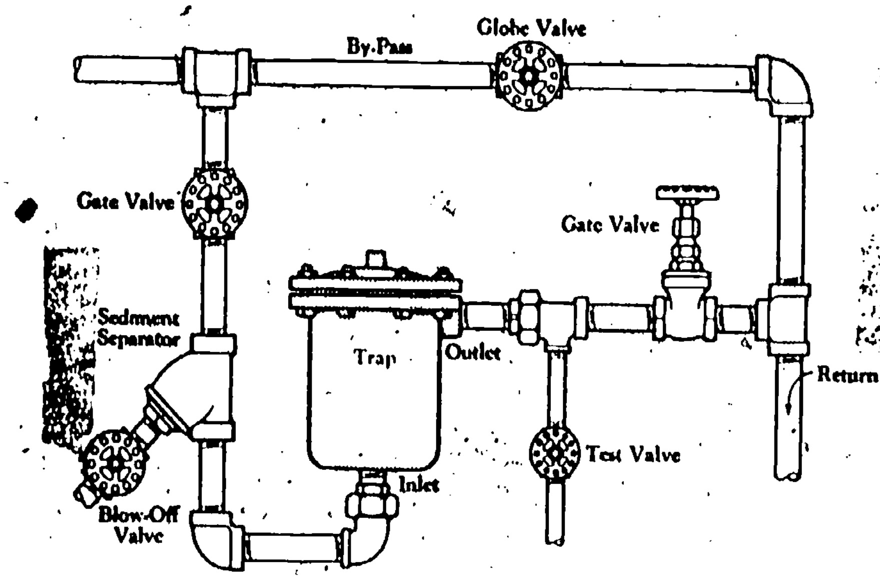
Screwed Strainer

Fig. 11

Fig. 11 shows a strainer featuring threaded connections and a woven wire screen. The connection at the bottom of the screen may be fitted with a plug or, preferably, a blow-off valve.

Trap Piping

A typical piping arrangement for an inverted bucket type trap appears in Fig. 12. The trap is fitted with isolation valves and a bypass valve so that it can be repaired or inspected. In addition, a strainer with blow-off valve is installed ahead of the trap and a test valve is fitted at the trap outlet. The test valve is used to determine whether or not the trap is working properly.



Trap Piping Arrangement

Fig. 12

Trap Installation and Maintenance

A trap must be installed in the proper manner in order for it to operate efficiently. Some of the more important considerations regarding trap installation are listed as follows:

1. Make sure that the trap has the proper capacity and pressure rating for the job. (Trap sizing calculations will be covered in the next section).

2. Before hooking up the trap, blow the lines through at full steam pressure. Then clean any strainer screens installed.

3. The trap should be installed in an accessible location close to and below the drip point. Check directional markings on the trap to make sure it is not installed backwards.

4. Unions and shut-off valves should be installed on either side of the trap and in addition a strainer, test valve, and a by-pass valve are recommended. (See Fig. 12). Do not use piping smaller than the size of the trap connections.

5. Inlet lines to the trap should be pitched toward the trap.

6. If a group of traps drain into a common return line then a check valve should be installed between each trap and the return line.

7. Use self-draining traps on installations subject to freezing temperatures.

8. Use a separate trap on each piece of apparatus as short circuiting will occur if more than one unit is drained by a single trap.

In order to determine whether or not a trap is working properly, it must be tested. The most positive method of testing is to observe the discharge from the trap by means of a test valve. (See Fig. 12).

By observing the discharge it can be seen whether the trap closes off tightly, blows live steam, discharges continuously or does not discharge at all.

Other methods of testing are: determining the temperature before and after the trap by the use of thermometers or pyrometers, determining the pressure before and after the trap by means of pressure gages, determining the operation of the trap by means of a listening device such as a stethoscope.

In addition to regular testing, traps should be dismantled for inspection at least once a year. During this inspection the following things should be done:

1. The trap body and operating parts should be examined for corrosion, erosion, mechanical wear, etc.

2. All internal parts should be cleaned and worn valves, seats, levers etc., should be replaced as should cracked buckets, floats or bellows.

3. All gasket seating surfaces should be thoroughly cleaned and new gaskets used on reassembly.

In addition to the inspection of the traps, all strainers should be cleaned and inspected regularly and a record log or card should be kept for each trap showing dates and details of inspection, repair and replacement.

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Trap Sizing

In order to determine the size of trap necessary for a particular application, it is necessary to calculate the amount of condensate to be handled by the trap per hour.

In the case of a trap used to drain a steam main, the greatest rate of steam condensation will occur during the warming up period when the pipeline is being brought up to the operating temperature. After this temperature has been reached the only condensation will be that produced by normal radiation losses from the pipe.

If the warm-up is done automatically, that is, without manual supervision, then the trap must be sized to handle the large amount of condensate produced during this warm-up period.

If, however, as is usually the case, the warm-up is manually supervised, with the initial heavy condensate load being removed, not through the trap, but by means of "free blow" drain valves, then the trap need only be sized to handle the condensate produced by radiation losses occurring after the warm-up period when the "free blow" drains are shut.

1. Automatic Warm-up

The warming-up load is calculated by means of the following formula.

$$C = \frac{0.494\, M\, (t_2 - t_1)}{L}$$

WHERE:

C	amount of condensate in kg.
0.494	specific heat of steel pipe.
M	total mass of pipe in kg.
t_2	final temperature of pipe $^{\circ}$C.
t_1	initial temperature of pipe $^{\circ}$C.
L	latent heat of steam at final temperature kJ/kg.

The warming-up load C is then divided by the number of minutes required for the warm-up and then multiplied by 60 to give the load in kg/h.

EXAMPLE 1:

Find the warm-up load in kg/hr in warming-up 30 m of 203.2 mm Schedule 40 steel pipe to a working pressure of 1350 kPa in a warm-up time of 10 minutes. Initial temperature of pipe is 10°C.

Example 1

SOLUTION:

$$C' = \frac{0.494\ W\ (t_2 - t_1}{L}$$

where

W = 1266 kg (Table 2 Lecture 10 Section 2)

t_2 = 193°C (Steam Tables) approx.

t_1 = $10^{o}C$ (Given)

L = 1967 kJ/kg approx. (Steam Tables)

$$\therefore C = \frac{0.494 \times 1266\ (193 - 10)}{1967} = 58.18\ \text{kg}$$

In order to accomplish this warm-up in 10 minutes, the condensate rate /hr would be: -

$$58.18 \times \frac{60}{10} \quad \underline{\underline{349\ \text{kg/h}}} \quad \text{(Ans.)}$$

When choosing a trap for a particular service it is usual to increase the calculated condensate load in order to provide a safety factor. This is to ensure that the trap will have ample capacity in the event of a change in operating conditions such as a drop in pressure in the line. In Example 1, the safety factor is not necessary if the capacity of the trap chosen is such that it can discharge 349 kg/h at a warm-up pressure of just above 0 kPa. Then, as the pressure rises in the pipeline, the trap capacity will automatically increase. Also, the 349 kg/h is the warm-up load and it is much greater than the load the trap will have to handle after the system is warmed up.

2. Manual Supervised Warm-up

In this case, as mentioned previously, the trap has only to handle the condensate produced by radiation loss during the normal operation as the large amount of condensate produced during the warm-up is discharged manually by means of free blow drains.

The amount of condensate produced by radiation can be determined from Table 1 which lists amounts for various pipe sizes.

CONDENSATION IN INSULATED PIPES carrying saturated steam in quiet air at 21°C. Insulation assumed to be 75% efficient.

Pressure kPa (guage)			103.4	206.9	413.7	862	1241	1724
Pipe Size ins	mm	m^2 per lineal m	Kilograms of Condensate/h /metre of pipe					
1	25.4	0.105	0.075	0.09	0.104	0.15	0.18	0.21
1¼	31.75	0.132	0.09	0.104	0.134	0.18	0.21	0.25
1½	38.1	0.151	0.104	0.12	0.15	0.21	0.24	0.28
2	50.8	0.19	0.12	0.15	0.19	0.25	0.3	0.34
2½	63.5	0.23	0.15	0.18	0.22	0.3	0.36	0.42
3	76.2	0.28	0.18	0.21	0.27	0.36	0.42	0.49
3½	88.9	0.32	0.19	0.24	0.3	0.4	0.48	0.57
4	101.6	0.36	0.22	0.27	0.33	0.45	0.54	0.64
5	127.0	0.44	0.27	0.33	0.4	0.55	0.66	0.76
6	152.4	0.53	0.3	0.37	0.48	0.66	0.76	0.88
8	203.2	0.69	0.4	0.48	0.61	0.82	0.98	1.13
10	250.4	0.86	0.48	0.58	0.76	1.01	1.19	1.4
12	304.8	1.02	0.57	0.69	0.86	1.19	1.37	1.66
14	355.6	1.12	0.63	0.76	0.97	1.3	1.54	1.8
16	406.4	1.28	0.7	0.85	1.1	1.48	1.39	2.06
18	457.2	1.44	0.79	0.95	1.27	1.66	1.95	2.28
20	508.0	1.6	0.86	1.06	1.36	1.83	2.16	2.53
24	609.6	1.9	1.18	1.25	2.83	2.16	2.55	3.03

Table 1

Table 1 can be used to find the condensate load due to radiation for the pipeline in Example 1, which is 203 mm diameter size and operates at 1344 kPa (abs) or 1241 kPa (guage).

The table shows that the kilograms of condensate per hour for 203 mm pipe at 1241 kPa is 0.98 kg for each lineal metre. As the pipe is 30 m long then the condensate load is:

0.98 x 30   29.4 kg/h at 1241 kPa

If the trap is installed between the boiler and the end of the steam main then a safety factor of 2 should be allowed and the selected trap capacity would be:

29.4 x 2   58.8 kg/h at 1241 kPa.

If the trap is installed at the end of the main then a safety factor of 3 should be allowed and the selected trap capacity would be:

29.4 x 3   88.2 kg/h at 1241 kPa

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The condensate load for normal radiation losses can be calculated by the following formula if a table such as Table 1 is not available.

$$C = \frac{A\ U\ (t_1 - t_2)\ E}{L}$$

where

C	=	Condensate in kg/h
A	=	External area of pipe in m^2
U	=	Heat loss from uninsulated pipe $kJ/m^2/^oC$ temp. difference/h
t_1	=	Steam temperature ^oC
t_2	=	Air temperature ^oC
L	=	Latent heat of steam at operating pressure
E	=	1 - efficiency of insulation

Example 2

Find the condensate load due to radiation in 30 m of 203.2 mm steel pipe operating at 1344 kPa (abs) and covered with 75% efficient insulation.

Given that U = 63.34 $kJ/m^2/^oC$ and the ambient temperature is 21^oC.

SOLUTION:

$$C = \frac{A\ U\ (t_1 - 1_2)\ E}{L}$$

where

A	=	$0.69 \times 30\ m^2$ (Table 1)
U	=	63.34 (Given)
t_1	=	193^oC approx. (Steam Tables)
t_2	=	21^oC (Given)
E	=	1 - 0.75 = 0.25 (Given)
L	=	1967 kJ/kg (Steam Tables)

$$\therefore C = \frac{0.69 \times 30 \times 63.34\ (193 - 21)\ 0.25}{1967}$$

$$= \underline{\underline{28.66}}\ \text{kg/h} \quad \text{(Ans.)}$$

This amount must be increased by the appropriate safety factor of 2 or 3 depending upon the trap location as explained previously.

Water Hammer

The term "water hammer" is used to describe a series of hammer blow-like shocks produced by a sudden change of velocity of water or other liquid flowing within a pipeline. These shocks may have sufficient magnitude to rupture the pipe or pipe fittings or to damage connected equipment.

The sudden change of velocity necessary to produce water hammer may be caused by the rapid closing or opening of a valve, the sudden stoppage in flow due to a pump trip-out, or by the rapid condensation of a pocket of steam within the pipe.

In the case of a valve being quickly closed in a pipeline through which water is flowing, the first effect is the sudden decrease in the velocity of the water and a correspondingly sudden increase in pressure at the valve. This causes a pressure wave to travel back upstream to the inlet end of the pipe where it reverses and surges back and forth through the pipe, getting weaker with each successive reversal. This pressure wave due to water hammer is in addition to the normal water pressure within the pipe and depends upon the magnitude and rate of change in velocity as well as the elasticity of the pipe and of the water. Complete stoppage of flow is not necessary to produce water hammer as any sudden change in velocity will bring it about to a greater or less degree depending upon the above conditions.

Where too rapid closing of a valve is the cause of the water hammer, the remedy, of course, is to ensure that the valve closes slowly. The period of effective closing of a gate valve takes place in the last 20% of the valve travel and this portion should be undertaken as slowly as possible. If the valve is equipped with a bypass, as large valves often are, then the bypass should be closed last. When opening a gate valve the first 20% of the valve travel is the most critical portion and this should be opened as slowly as possible after first opening the bypass if the valve is so equipped. As a general rule, all valves should be opened and closed slowly and cautiously.

Where water hammer is due to the sudden stopping of a motor-driven pump due to a power failure, the following occurs. Upon the power interruption the pressure at the pump discharge drops and the water in the discharge line stops and then reverses direction. Subsequent rapid closing of the check valve at the pump will cause severe shock when the energy of the reverse flow is violently expended against the check valve disc.

Devices which can be used to reduce the shock in a pump discharge line are air chambers, relief valves, or check valves having a built-in dashpot to prevent rapid closing of the disc.

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A pump trip-out may also cause water hammer in the pump suction line in cases where the water flows to the pump through a long line by gravity or under pressure from another pump and air chambers or relief valves may be used here as well.

In the case of a steam line, water hammer may occur if condensate is present in the line. As the steam passes through the line above the surface of the condensate it may raise up behind it a mass of the condensate (water) and thus an isolated pocket of steam is formed. Being in contact with the cooler water the steam will suddenly condense and a low pressure will be formed in the pocket. Water rushing into this low pressure pocket will cause severe shock to the pipe and piping fittings.

Abnormal amounts of condensate will be produced within a steam pipe in the case where the pipe is contained within an underground tunnel or conduit which becomes flooded due to a broken water main or other causes. The flood water coming in contact with the steam pipe will cause excessive condensation. When this condensation cools below steam temperature it will cause water hammer.

It has been found that this type of water hammer will occur in a steam line that is horizontal or pitched upward from the source of steam and it will be most violent when the steam pipe is dead-ended by a blank or a closed valve. It has also been found that, if the condensate can be removed as fast as it forms, then the water hammer will not occur. This points out the need for amply sized traps.

In order to reduce the damage, should water hammer occur, rupture diaphragms may be installed. Also, the use of cast iron valves and fittings should be avoided.

To avoid water hammer in steam lines they must be properly pitched and drainage points installed between valves and at pockets in the line where water could accumulate. The drainage points should be equipped with drip pockets, free-blow drain valves, and traps. In addition, gate valves in the line must not be installed with their stems below the horizontal because the valve bonnets would act as pockets.

When warming up a steam line all drain valves must be opened wide before steam is admitted and the steam admission valve should be only cracked open or only its bypass opened if so equipped. The valve should be slowly and carefully opened fully after the line has been warmed up. The drain valves are left open until all of the warm-up condensate has been discharged. The trap will then be able to handle the condensate that forms under normal operating conditions.

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PIPING INSULATION

Piping is covered with insulation for the following reasons: to reduce heat loss and condensation, to prevent uncomfortably high ambient temperatures within the power plant, to prevent injury to personnel from contact with hot surfaces, and to prevent sweating of cool pipe surfaces.

A material suitable for use as an insulation should have the following characteristics.

1. High insulating value,
2. Long life,
3. Vermin proof,
4. Non corrosive,
5. Ability to retain its shape and insulating value when wet,
6. Ease of application and installation.

An insulating material may be defined as one which transmits heat poorly and it has been found that substances having a large number of microscopic air pockets dispersed throughout the material make the most efficient insulators. This is because the extremely small air spaces restrict the formation of convection currents and the air itself is a poor conductor of heat.

The <u>thermal conductivity</u> k of a material is a measure of the amount of heat that will be transmitted through this material. Therefore the lower the value of k for a material, the better will be its insulating ability. Most insulations have k values between 0.3 and 0.8 $W/m^2/^oC/m$. The k value for any one material will vary according to the temperatures to which it is exposed. For example, a material having a k value of 0.3 at 150°C may have a k value of 0.6 at 538°C.

Pipe Insulation Materials

1. Diatomaceous Silica

This material is bonded with clay and asbestos. Because of fairly high cost it is generally used for the high temperature layer under less costly types of insulation. Its k value varies from 0.7 to 0.8.

2. Asbestos

Asbestos insulation is processed from asbestos fibre and combined with diatomaceous silica and heat resisting binders. Its k value varies from 0.37 to 0.72.

3. Calcium Silicate

This insulation is a compound of lime and silica with some asbestos fibre added for strength. It has k values from 0.37 to 0.60.

4. Glass Fibre

This is a comparatively low cost and lightweight insulation having k values from 0.29 to 0.35.

5. Magnesia (85%)

This material is composed of magnesium carbonate reinforced with asbestos fibre and has a k value of from 0.35 to 0.42.

6. Plastic Foams

These are plastics that have been processed into a foam during manufacture and then formed into pipe covering sections. They have k values from 0.09 to 0.28 and have largely taken the place of cork and felt insulation which was formerly used for low temperature service. They are available for temperatures as low as -170°C and as high as 120°C.

7. Reflective Metal Insulation

This is a fairly new type of insulation constructed of metal reflective sheets of stainless steel, spaced and baffled to form isolated air chambers around the piping. The highly polished reflective sheets reflect the heat and prevent loss due to radiation but yet absorb little heat by conduction. The k factor varies from 0.53 to 0.66.

Applications

The following indicates the the general application of various piping insulations for different temperature ranges.

Above 1040°C - refractory fibres are generally used or in some cases reflective metal insulation.

650°C - 1040°C - double layer construction is used with the inner layer diatomaceous silica and the outer layer calcium silicate.

150°C - 650°C - calcium silicate is generally used with double layer construction for pipe temperatures over 316°C.

0 - 260°C - glass fibre is most commonly used as it is generally the most economical and has good resistance to normal abuse.

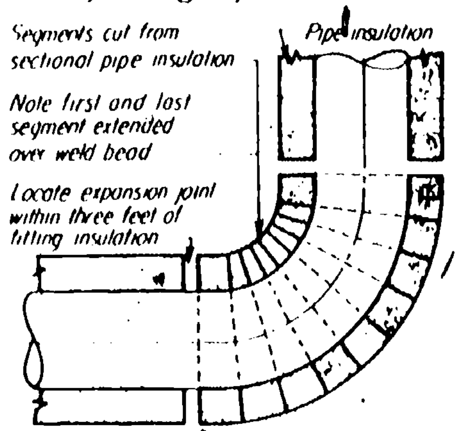
The effectiveness of a particular insulation is expressed as an efficiency E where:

$$E = \frac{\text{Heat loss from bare pipe minus heat loss from insulated pipe}}{\text{heat loss from bare pipe}}$$

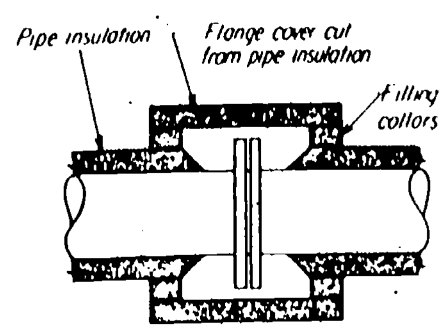
The heat losses are expressed in kJ/h/lineal metre.

Piping insulation is usually fabricated in half-cylindrical sections for fitting over the pipe. The sections are held together by metal wire or bands and then a surface finish is applied, usually of a canvas type.

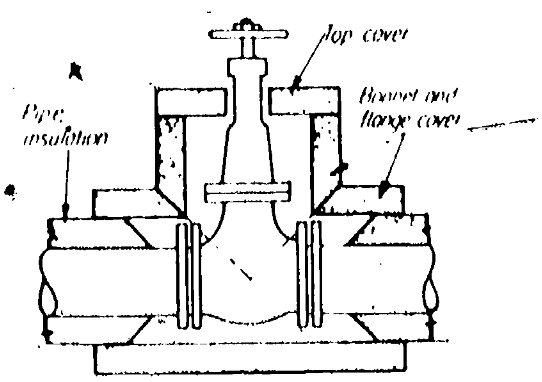
Special shapes and arrangements of insulation are used for fittings such as elbows, flanges, and valves such as shown in Fig. 13.



Elbow



Flange



Valve

Insulation of Fittings
Fig. 13

VALVES

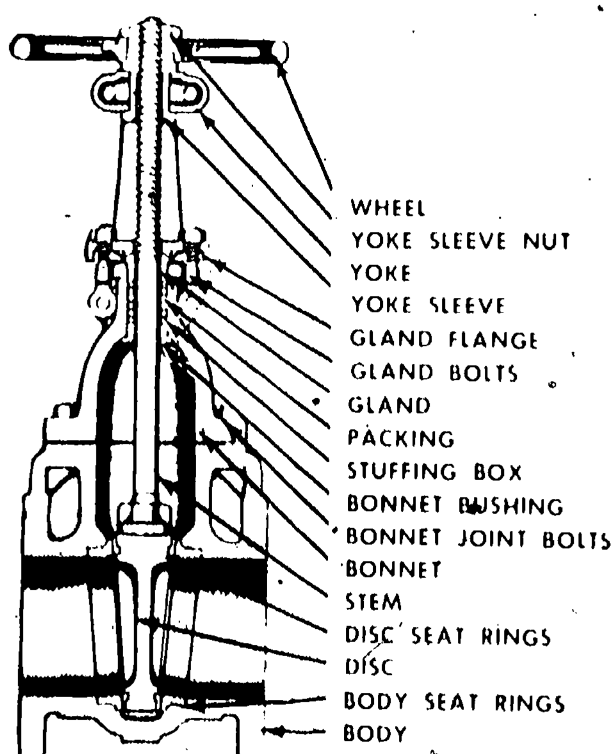
Various types of valves are required in any piping system in order to control and regulate the fluid flow within the system. The valves represent a considerable percentage of the overall cost of the system and therefore must be selected with care and with consideration of the following details; working pressure and temperature, type of fluid (corrosive or erosive), flow volume, valve operating cycle, and cost of installation and maintenance.

Valve Design

There are a number of basic designs of valves and these include the gate valve, the globe valve, the angle valve, the check valve, the ball valve, and the butterfly valve.

1. The Gate Valve

The gate valve as illustrated in Fig. 14 consists of a gate-like disc, actuated by a screwed stem and handwheel, which moves up and down at right angles to the path of flow. In the closed position the disc seats against two faces to shut off flow.



Gate Valve

Fig. 14

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Gate valves are not suitable for throttling service or where frequent opening and closing is required. They are suitable for conditions requiring full flow or no flow, such as stop valves or isolating valves and they have the advantage that, when fully opened, the flow resistance is low with a minimum of pressure drop as the flow moves in a straight line.

Several different designs of gates or discs may be employed. The solid wedge disc is the most common and it is the type shown in Fig. 14. It consists of a solid wedge-shaped disc which seats against matching tapered seat faces.

The double wedge disc gate valve has the two disc faces arranged so that they can move independently of one another against tapered seat faces.

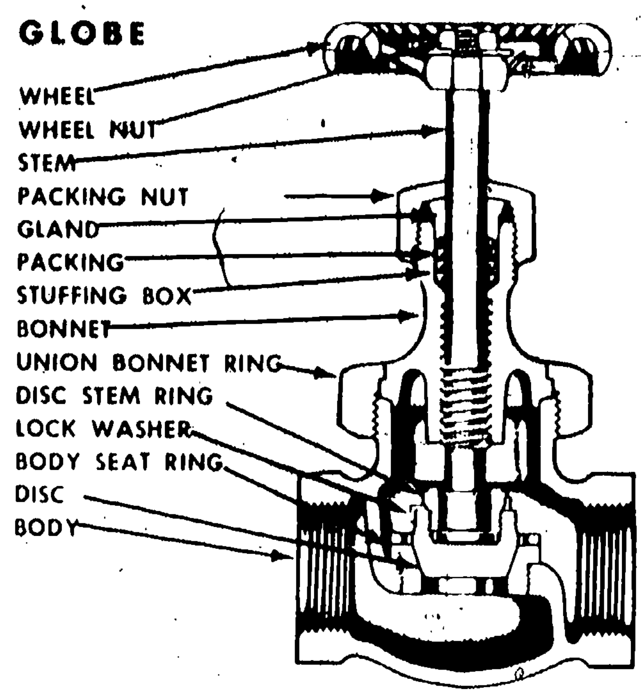
The parallel slide gate valve has a disc with parallel faces which slides down between parallel set faces.

2. The Globe Valve

The globe valve, shown in Fig. 15, is constructed in such a way as to cause the flow of the fluid passing through to change direction twice. The disc and the seat are parallel to the main flow path and the disc is moved toward or away from the seat by means of a threaded stem.

Due to its construction, the globe valve is ideal for throttling or regulating flow with a minimum of wire-drawing and seat erosion. Another advantage of the globe valve compared to the gate valve is that it is cheaper to manufacture. On the other hand, the globe valve offers much more resistance to flow than does the gate valve and also it presents a pocket within its body which may collect condensate or sediment. It is seldom used in sizes larger than 300 mm due to difficulty in opening and closing against fluid pressure.

As with the gate valve, the globe valve may employ different disc designs.



Globe Valve

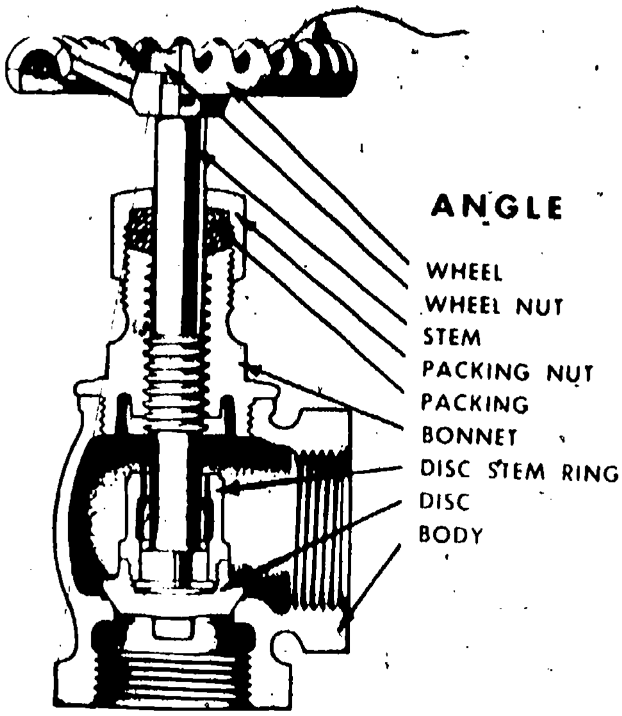
Fig. 15

The plug type disc is a long tapered metal disc which is most suitable for severe service such as throttling, blow-off, soot blowers, etc. The valve shown in Fig. 15 features a plug type disc.

The composition disc is a flat disc fabricated from various materials such as synthetics and asbestos which are suitable for a variety of services such as air, steam, water, oil, etc., where the throttling is not severe and pressures are not high.

A third type of disc is known as the conventional disc. It is a metal disc having a short taper which fits against a narrow seat. This type is not suited for severe throttling service as the narrow seat and short tapered disc are subject to erosion and wire drawing.

3. The Angle Valve



Angle Valve

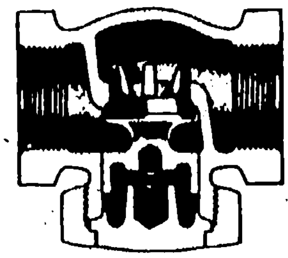
Fig. 16

The angle valve, Fig. 16, uses the same seating principle as the globe valve and has the same operating characteristics. It is used when making a 90 degree turn in a line as it gives less restriction to flow than using a globe valve with a 90 degree elbow to provide the turn. Another advantage of using the angle valve is the reduction in the number of joints and fittings required when a separate elbow is not used.

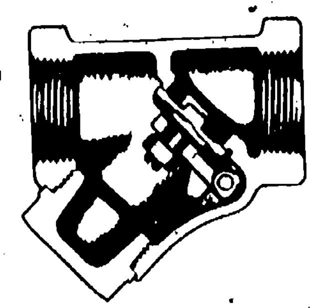
4. The Check Valve

The check valve is a valve which prevents reversal of flow in piping. The flow of the fluid keeps the check valve open while gravity and reversal of flow will cause the valve to close.

The two basic types of check valve which are illustrated in Fig. 17 are the swing check and the lift check.



Swing Check



Lift Check

Fig. 17

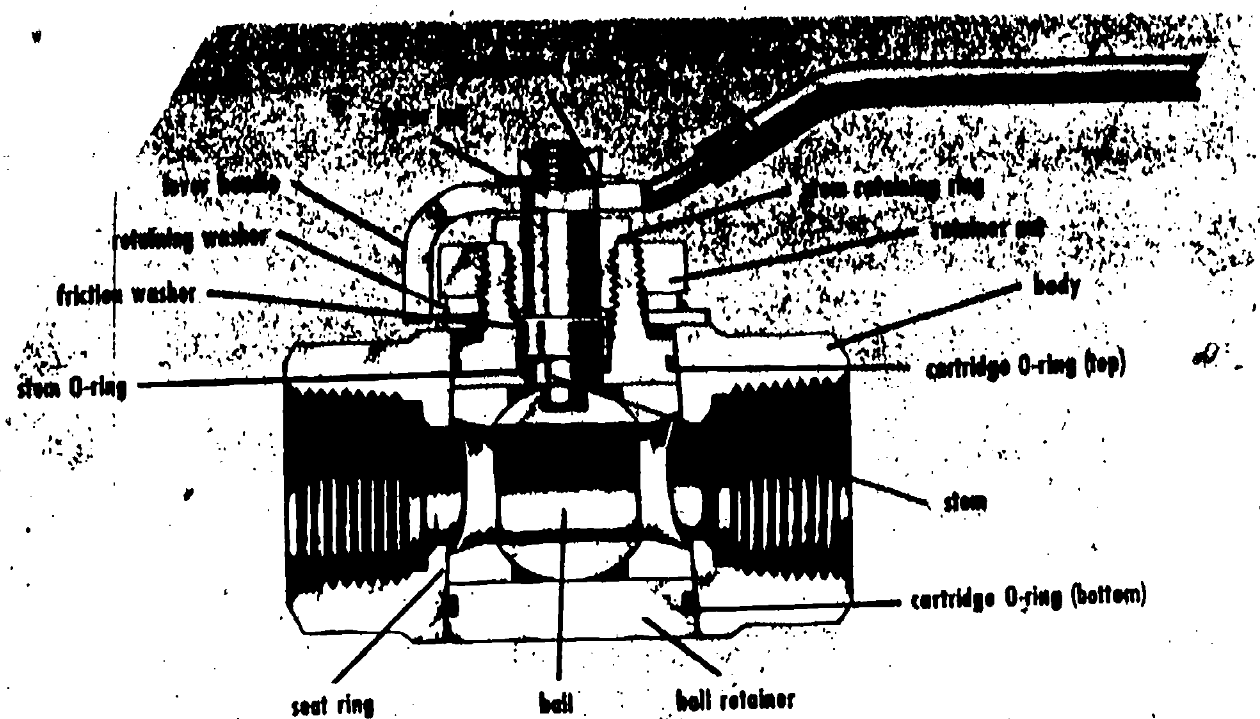
The swing check valve features a straight line flow and therefore offers little resistance to flow. The disc which is hinged at the top swings freely in an arc from the fully closed to the fully open positions.

The flow through the lift check valve undergoes two changes of direction as it passes through a horizontal section upon which the disc seats. The disc moves vertically upward to allow the flow to take place and moves downward to close if the flow should reverse. A dashpot is used to cushion the action of the disc.

5. The Ball Valve

The ball valve, Fig. 18, features a spherical shaped plug with a bored passage through it. The valve can be opened by means of a lever so that the bored passage in the plug or ball lines up with the seat openings. A 90 degree movement of the lever moves the ball into the shut position with the bored passage at right angles to the seat openings.

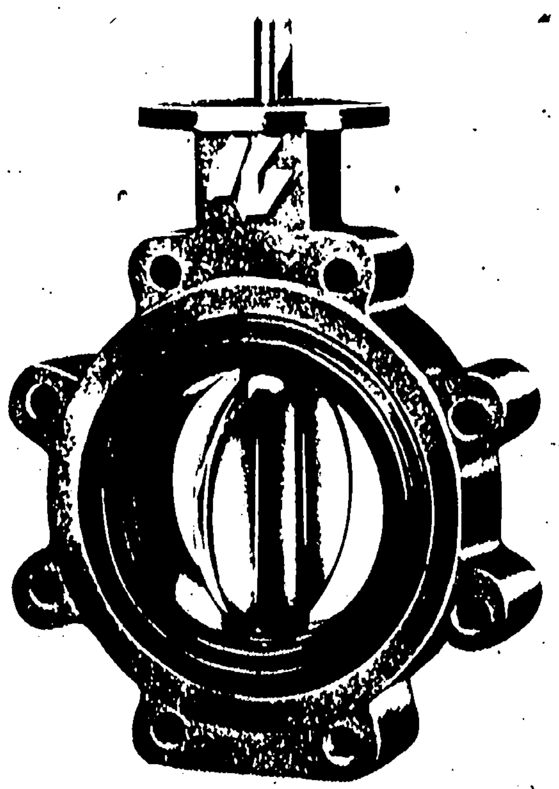
Ball valves have the following advantages: quick open-shut action, little tendency to stick, minimum restriction to flow, easy maintenance, and the lever serves as an open-shut indicator.



Ball Valve

Fig. 18

6. The Butterfly Valve



Butterfly Valve
Fig. 19

The butterfly valve features a flat disc that can be rotated 90 degrees from the wide open to the fully closed position. The valve shown in Fig. 19 would normally be fitted with a handwheel and an electric motor, either of which can be used to turn the disc.

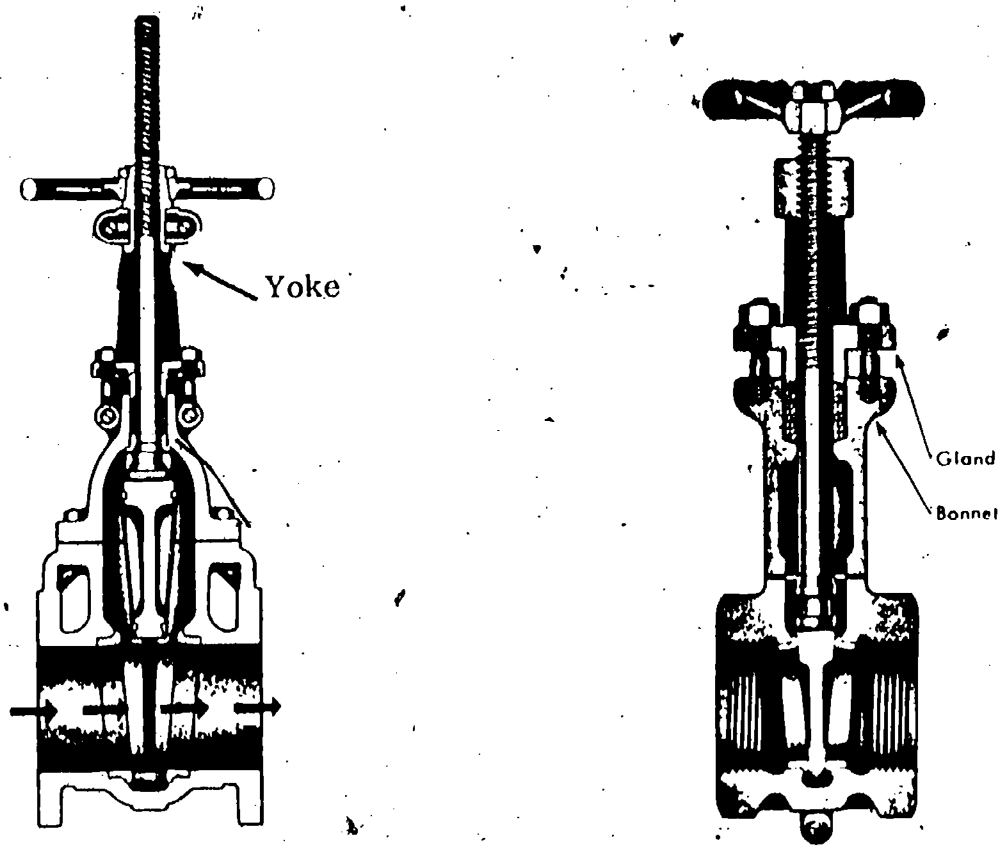
The butterfly valve is commonly used in thermal power stations, hydroelectric power stations, the oil and gas industry, and in water works and sewage plants. They have the following advantages: ease of operation, relatively light weight, little restriction to flow, and absence of sliding parts. They are not normally used for pressures above 860 kPa.

Valve Stem (Spindle) Design

The valve stems for globe, gate and angle valves may conform to any one of several designs.

1. Rising Stem, Outside Screw

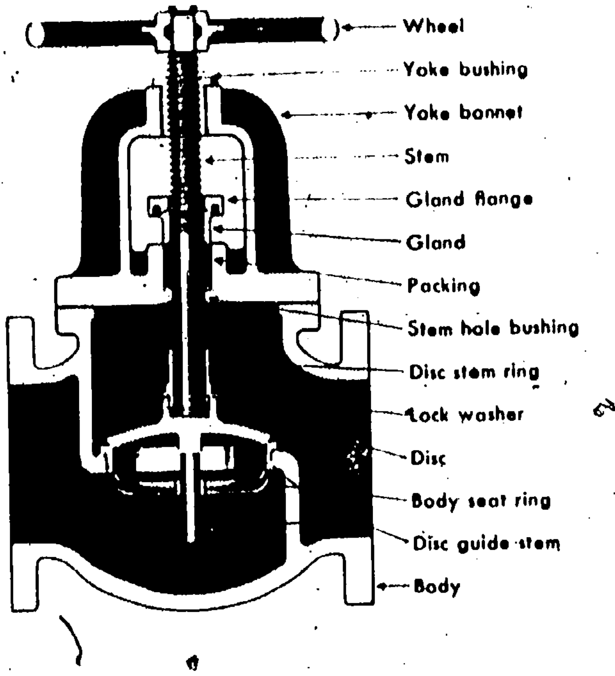
In this design the valve stem rises when the valve is opened and lowers when the valve is shut. In addition, the screwed part of the stem is outside the valve body. With this design the position of the valve stem will indicate whether the valve is open or shut and the screwed part of the stem is not subjected to corrosion or erosion from the fluid within the valve and also, lubrication of the stem screws is possible.



(a) (b)
Rising Stem, Outside Screw Gate Valves

Fig. 20

Fig. 20 shows two rising stem outside screw gate valves. With the valve in (a) the stem rises but the handwheel does not. With the valve in (b) the handwheel rises with the stem. The valves in Fig. 20 are also referred to as outside screw and yoke valves as the threaded part of the stem engages with a threaded sleeve held within a yoke piece.



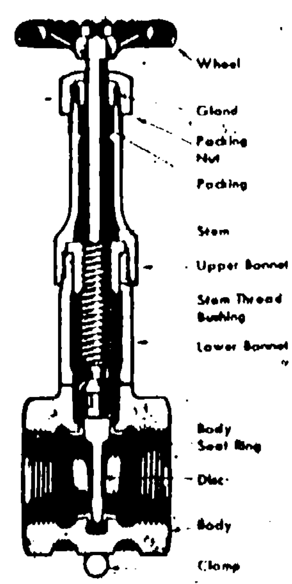
Rising Stem, Outside Screw Globe Valve

Fig. 21

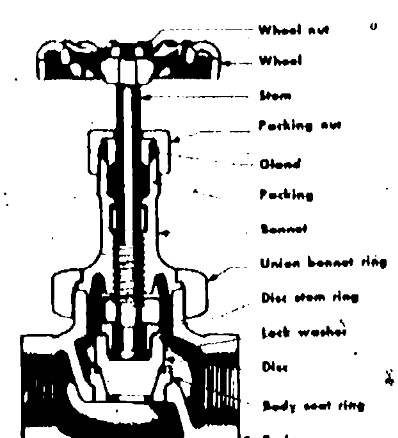
Globe valves and angle valves are of the rising stem type and may or may not employ the outside screw design. Fig. 21 shows a rising stem, outside screw and yoke globe valve.

2. Rising Stem, Inside Screw

With this design the stem rises as the valve is opened but the threaded part of the stem is inside the valve body. Fig. 22 illustrates the design for both gate and globe valves.



Gate Valve



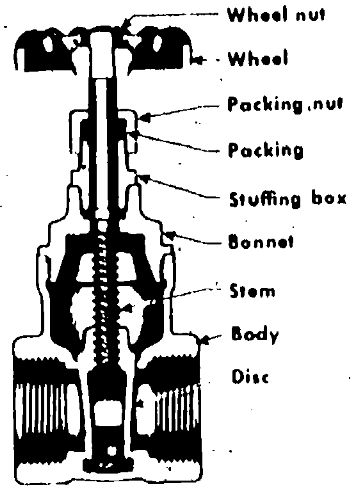
Globe Valve

Rising Stem, Inside Screw Valves

Fig. 22

3. <u>Non-rising Stem, Inside Screw</u>

In the case where a gate valve is to be used and head room is limited, then the non-rising stem, inside screw design is used. With this type, as the stem is turned, the gate climbs up the threaded part of the stem which is inside the valve body as shown in Fig. 23.



Non-rising Stem, Inside Screw Gate Valve

Fig. 23

Fig. 24

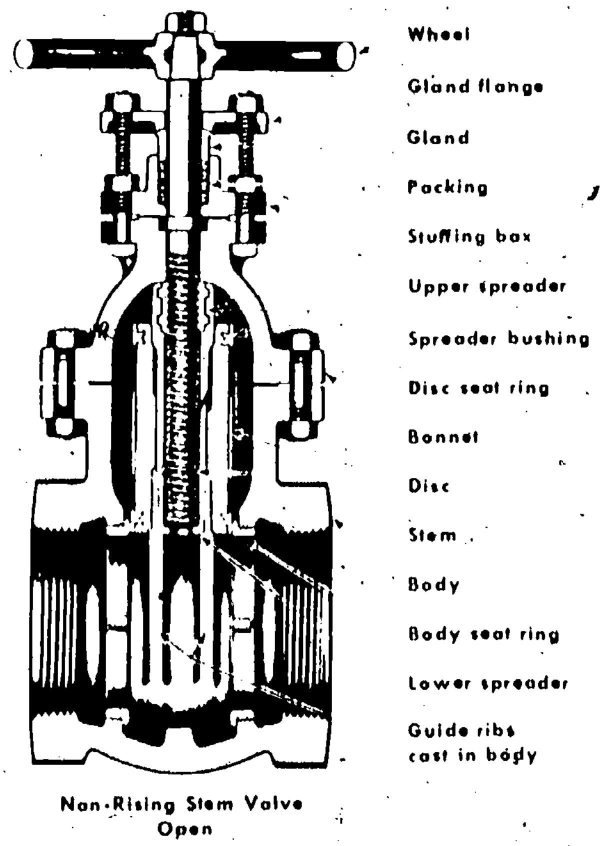


Fig. 24 shows the details of a non-rising stem, inside screw valve in the open position.

PE2-2-11-33

In order to simplify plans, sketches, blueprints etc., symbols are used for the various types of pipe fittings and valves. Fig. 25 illustrates the symbols used by the American Society of Mechanical Engineers.

SYMBOLS FOR PIPE FITTINGS AND VALVES

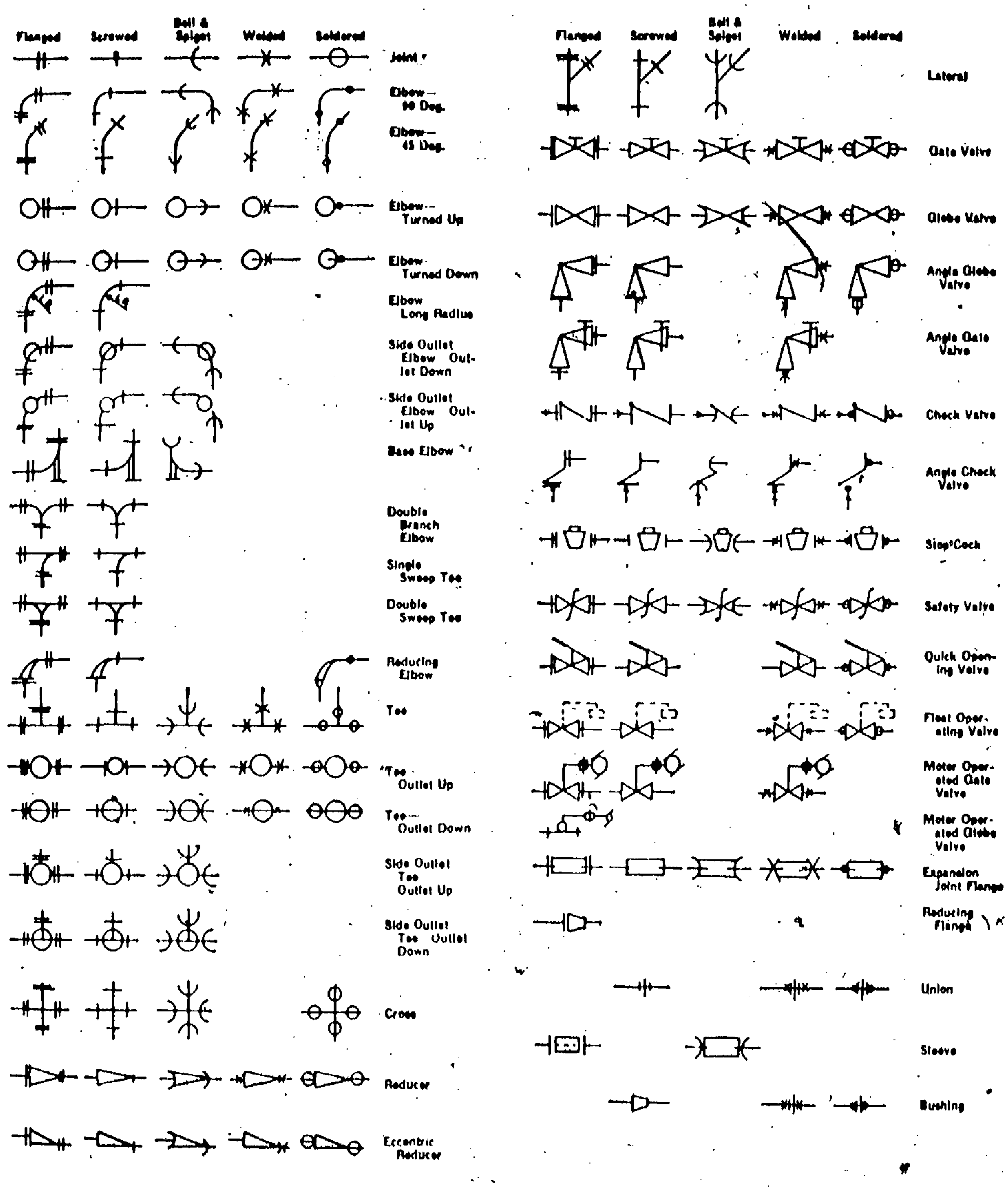


Fig. 25

QUESTION SHEET

POWER ENGINEERING

Second Class
Sect. 2, Lect. 11

1. Sketch and describe the operation of:
   (a) a mechanical trap.
   (b) a thermostatic trap.
   (c) a thermodynamic trap.

2. (a) Sketch a piping arrangement for a steam trap.
   (b) Discuss the points to be considered regarding trap installation.

3. Describe three conditions which will affect trap capacity.

4. Discuss "water hammer" in regard to its causes, effects and remedies.

5. Discuss trap testing, inspection and maintenance.

6. (a) Describe, with the aid of simple sketches, the construction and operation of a gate valve and a globe valve.
   (b) Discuss the advantages and disadvantages of each type.

7. Describe an application for each of the following types of valves:
   (a) angle valve
   (b) check valve
   (c) butterfly valve

8. Describe the various types of valve stem designs and give the advantages and disadvantages of each.

9. Sketch and describe a steam separator and explain its purposes.

10. (a) 150 metres of 250 mm diameter schedule 80 steel pipe at an ambient temperature of 21°C is brought to a working steam pressure of 1750 kPa in 30 minutes. Find the warm-up load in kg/h of condensate.
    (b) If the piping insulation is 75% efficient, what is the condensate load during normal operation?

PE2-2-11-Q