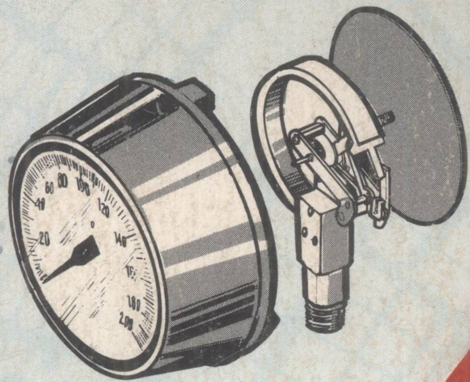
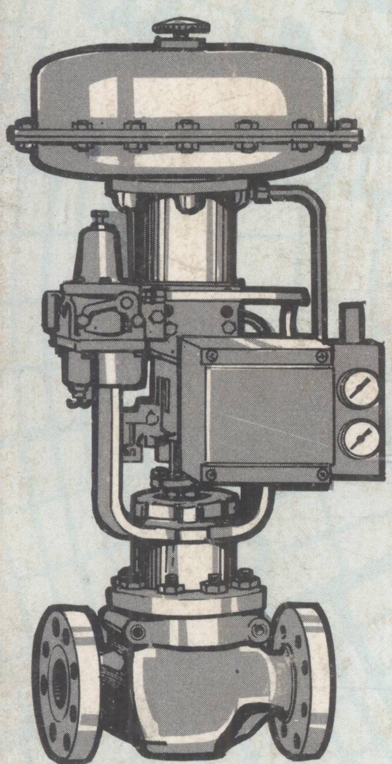
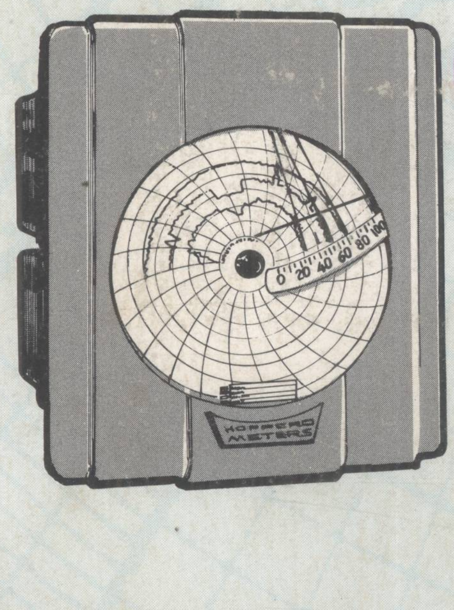


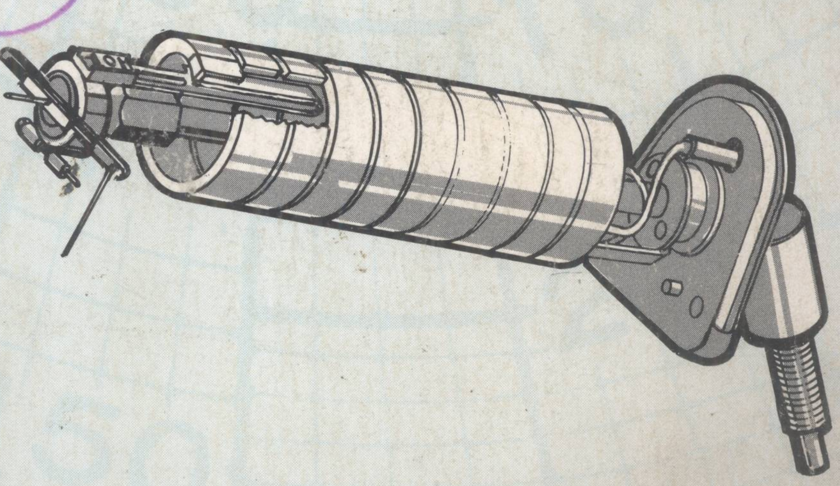


Instrumentation Training Course

Volume 1

PNEUMATIC INSTRUMENTS





Instrumentation Training Course

Volume 1

Pneumatic Instruments

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Preface

This work has evolved over the last 20 years. Initially, it was a collection of lecture notes developed and used in a variety of training situations. The need then, and now, was for a systematic and orderly structure that would reduce the maze of instrumentation to a coordinated and integrated entity. The method that evolved was to start with a series of basic components that are common to all pneumatic and mechanical instruments, then combine these into subassemblies that are then arranged into the fundamental instrument types. These fundamental instruments are idealized, and each represents a basic instrument type. Given such a structure, the learner can relate each instrument being studied to the fundamental instrument. New instruments, as they appear on the market, then can readily be fitted into the basic structure.

Accordingly, a very careful attempt has been made to reduce each instrument being studied to a chain of functional components, and to show how that instrument relates to fundamental instruments it exemplifies. Once the basic components and elementary instruments are understood, it becomes a relatively easy way to fit each new instrument studied into the basic structure. This approach has proven to be much more fruitful than a direct comparison of instruments.

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CHAPTER 1

Industrial Instrumentation

INTRODUCTION

The advancement of science and technology has brought about a number of very important changes in the basic structure of industry. Most products are, for example, manufactured through some type of automatic processing equipment. This equipment is often complex and demands a variety of skilled personnel to keep it in operation. Technicians are called upon to analyze problems, install equipment, evaluate operation, and repair faulty equipment. A wide range of experience is needed in different areas in order to cope with these situations.

At one time, most industrial equipment could be placed into operation with a few simple tools and some common sense. Today, however, a large part of our equipment contains numerous control devices that perform precise operations automatically. Technical personnel must, therefore, be concerned with evaluation procedures, calibration techniques, instrumentation, and troubleshooting methods in order to keep things in a good state of repair. Equipment breakdown often causes a production line to cease operation if the equipment is inoperative for any period of time. Preventative maintenance and operational efficiency have, therefore, become more important with the increased dependency upon automation.

Equipment operation and evaluation relies heavily upon measurement techniques and instrument analysis. Technical personnel are constantly called upon to evaluate equipment performance by measuring specific conditions of operation. The area of instrumentation has, therefore, become a very vital part of industry today.

Instrumentation is a rather broad area of industry that deals with the measurement, evaluation, and control of process variables such as temperature, pressure, flow rate, fluid level, force, light intensity, and humidity. These variables are usually involved in a manufacturing operation of some type that eventually leads to a finished industrial product. Automatic production operations are largely responsible for a major part of all instrumentation applications.

The primary areas of concern in instrumentation are pneumatics, electronics, mechanics, and hydraulics. Each of these areas is unique, but they are all very similar in many respects. The systems concept is commonly used to show this relationship.

THE SYSTEMS CONCEPT

The systems concept is not particularly new to the study of industrial equipment or machinery. This approach simply represents a diagrammed method of showing the intricate parts of a complex piece of equipment in some logical order. Through this approach, a "big picture" of the basic system is first presented. This idea is then used to show an interrelationship between various system parts. Fig. 1-1 shows the primary parts of a system in block-diagram form.

The role played by each block represents the second step of the systems concept. This role, or, more specifically, the function of each block, is much more meaningful when viewed in its composite form. The composite diagram of the system is then used as a general reference for the next step, which is component analysis of each block.

Component analysis represents the most sophisticated area of study. This is often described as the "nuts and bolts" part of the presentation. The intricate workings of discrete components are primarily included in this approach to the subject. A basic classification of similar component operations is also imperative at this point. As a general rule, one should now begin to see how the intricate pieces of a complex industrial system begin to fall in place. The systems approach will serve as the general format in this presentation of pneumatic instruments.

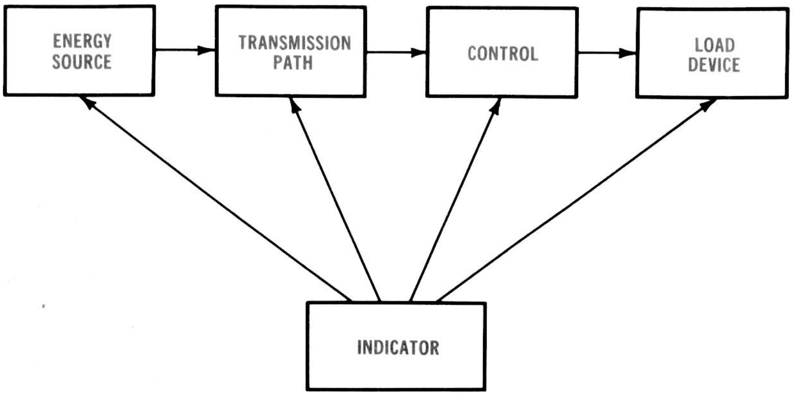


Fig. 1-1. Block diagram showing the primary parts of a system.

SYSTEM PARTS

The essential parts of an operating system include an energy source, a transmission path, control, a load device, and an optional indicator. Each part of the system has a specific role to play in the overall operation of the system. This role becomes extremely important when a detailed analysis of the system is to take place. Large numbers of discrete components are sometimes needed to achieve a specific block function. Regardless of the complexity of the system, each block must still achieve its function in order for the system to be operational. Being familiar with these functions and being able to locate them within a complete system are very important steps in understanding the operation of the entire system.

The *energy source* of a system has the primary responsibility of changing energy from one form into another form that is more useful. Primary forms of energy include such things as heat, light, sound, chemical, nuclear, and mechanical energy. In its primary form, energy is not always useful to an operating system. It is, therefore, changed into something more useful by the energy source.

The *transmission path* of a system is rather simplified when compared with other system parts. Its sole responsibility is the transfer of energy. It simply provides a path for energy to flow from the source to the load device. In some systems, this function is achieved by pipes or flexible tubes that simply connect the energy source to the load. In complex systems, there may be a number of alternate conduction paths between different components.

The *control* section of a system is generally considered to be the most complex part of the entire system. In its simplest form, control is used to turn a system on or off. The term *full control* or *two-state control* is used to describe this operation. Control of this type may occur anywhere between the energy source and the load device. In addition to this, a system may necessitate some type of partial control. This type of control usually causes a gradual change to occur somewhere in an operating system. Changes in time, pressure, and flow rate are typical of this type of control.

The *load* of a system refers to a specific part, or number of parts, that are designed to achieve work. The term *work,* in this case, refers to an operation that occurs when energy changes form. Typically, heat, sound, and mechanical motion take place when work occurs. The load of a system generally consumes a large portion of the energy produced by the source. The load is generally the most recognizable part of a system because of its obvious work function.

The *indicator* of a system is designed to display typical operating conditions at numerous points throughout a system. In some applications, an indicator is optional, while in others it is an essential part. In the latter case, specific system operations are usually dependent upon indicator readings. The term *operational indicator* usually applies to this type of application. Test indicators are also used to measure specific values in maintenance and troubleshooting operations. Meters, gauges, and chart recorders are frequently used to perform this type of operation. To some extent, an indicator may add to the total load of an operating system.

FLUID POWER SYSTEMS

The term *fluid power* is commonly used in industry today to describe those systems that employ liquid or gas as a means of controlling power. In ordinary usage, the terms *fluid* and *liquid* are commonly used interchangeably. Scientifically, however, the term *fluid* applies to both liquids and gases. In practice, the word *hydraulic* is commonly used to describe liquid applications of fluid power, while the term *pneumatic* applies to gaseous applications. The operating principles behind these two distinct systems are very similar in many respects.

Hydraulic Systems

In industry, hydraulic systems use liquid as a medium to transfer force between the source and the load device. This type of system is commonly found in equipment used in fabrication operations and material-handling processes. Hydraulic systems are simple to operate, are very reliable, and can be easily adapted to many applications. Fig. 1-2 shows a double-acting hydraulic system used to control a punch-press ram.

The primary energy source of the hydraulic system is an electric-motor-driven pump and reservoir. Rotary mechanical energy of the motor is changed directly into fluid energy through this device. The pump, in this case, sets hydraulic fluid into motion throughout the system. Fluid entering the pump inlet port is set into motion and forced to leave the outlet port. Each revolution of the pump rotor blade causes a fixed amount of fluid to be forced into the system. Fluid entering the system at this point encounters some resistance to its flow. The resistance to fluid flow ultimately causes the development of hydraulic pressure.

The transmission path of Fig. 1-2 may include solid metal tubes between some components, with flexible tubing or hoses connected to others. As hydraulic fluid is forced to pass through the transmission lines, it encounters a form of resistance to its flow which ultimately builds up system pressure. Typically, both high and low pressure are available in the system. Initial flow from the pump is higher than the pressure appearing in the return line.

A typical hydraulic system has both full and partial control of system fluid. The hand shutoff valve of Fig. 1-2 permits full control of system fluid. Pressure can likewise be altered by changing the speed of the motor-driven pump. In addition to this, the four-way valve is used to restrict flow, alter the flow path of high- or low-pressure fluid, and completely stop fluid flow. The pressure-relief valve is an additional control element that provides automatic release of system pressure. As a general rule, there may be many forms of control that apply to a single hydraulic system.

The double-acting cylinder of the hydraulic system serves as the load. Functionally, this part is used to change the flow of hydraulic fluid into linear motion. The composite load of the entire system includes transmission-line resistance, cylinder resistance, and the outside work load.

The indicator of the hydraulic system is an optional item. In this application, the indicator is used to show system pressure under normal load conditions. Indicators of this type are often placed near the load to show the representative work force at a specific location.

Pneumatic Systems

Pneumatic systems are commonly used in applications where air serves as a medium through which force is transferred between the source and the load device. This type of system is commonly used to lift and clamp products during machine operations, in process-control applications, and to power hand tools. Pneumatic systems represent a unique form of fluid power that has an open-ended return line. Systems of this type derive air from the atmosphere, compress it to increase pressure, store it in a receiving tank, distribute it to do work, and ultimately return it to the atmosphere. A simple low-pressure pneumatic system is shown in Fig. 1-3.

The composite energy source of the pneumatic system consists of an electric-motor-driven compressor and a storage tank to hold air. Through the action of the compressor, outside air is forced into the receiving tank under pressure, where it is stored and eventually used to pass through the system.

After air has been compressed and placed in the receiving tank under pressure, it must then be conditioned before it can be used. The conditioning process is first responsible for the removal of foreign matter such as dirt and moisture. This

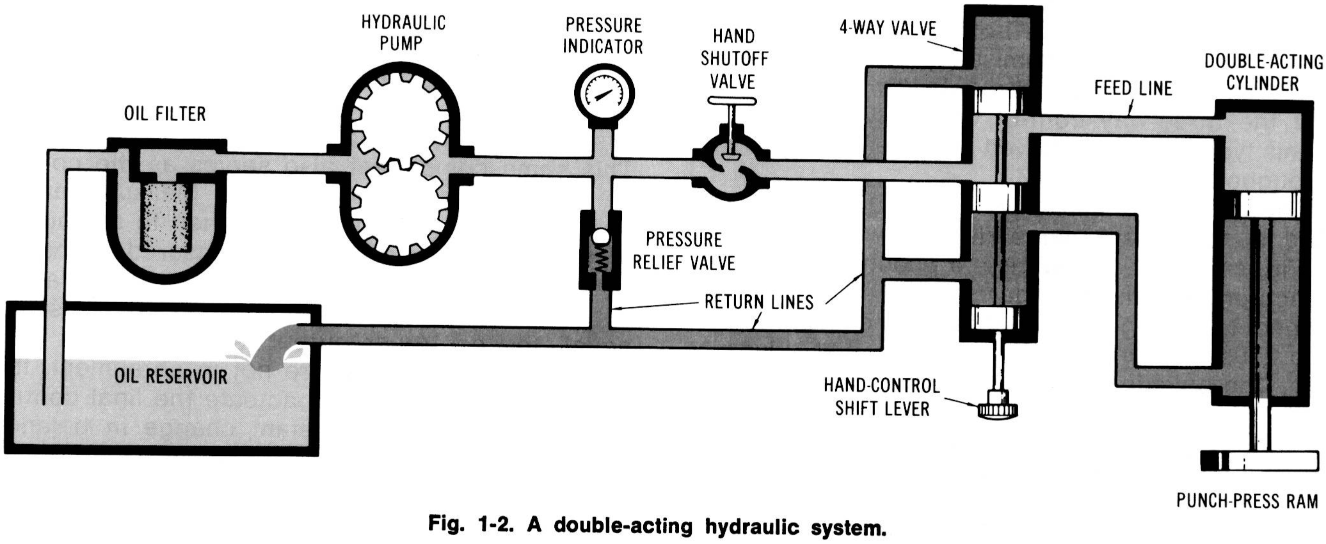


Fig. 1-2. A double-acting hydraulic system.

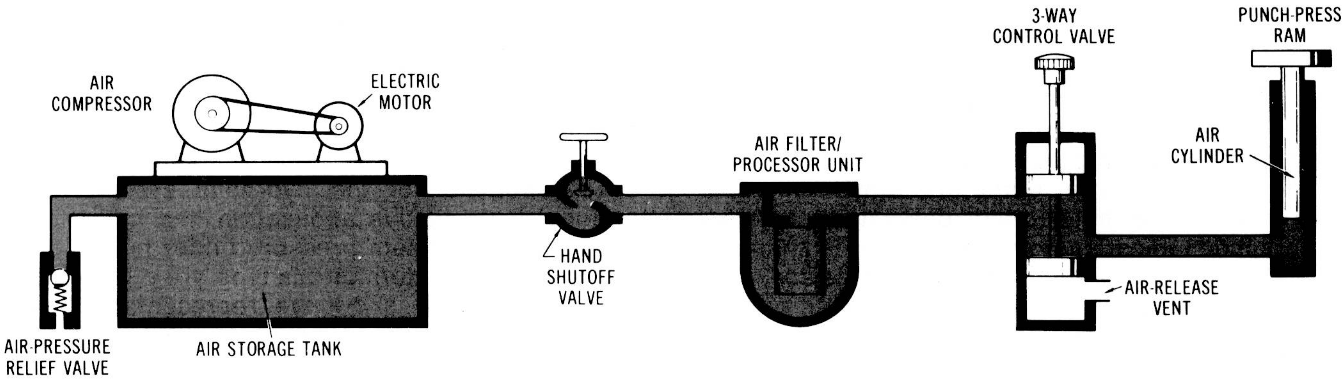


Fig. 1-3. A simple low-pressure pneumatic system.

operation is primarily achieved by an air filter unit with a condensation trap. In addition to this, a fine mist of oil is added to the air as it passes through the conditioner. This operation provides continuous lubrication for parts in the remainder of the system. Conditioning may also include some method of regulating pressure. A typical pneumatic conditioning unit often achieves cleaning, lubrication, and pressure regulation in a single component.

The transmission path of a pneumatic system is composed of such things as pipes, tubing, and flexible hoses. This part of the system is primarily responsible for the distribution of air to each of the system components. A single transmission line is used to distribute air from the receiving tank to individual components. A unique feature of the pneumatic transmission path is its method of return. Air is simply dumped into the atmosphere instead of being returned to the receiving tank. Distribution of this type, therefore, only necessitates a single path for air to flow through the system.

The pneumatic system in Fig. 1-3 has both full and partial control of air. The hand shutoff valve and pressure-relief valve both provide full control of air through the transmission path. Air flow is also changed partially through the air regulator and the three-way control valve. System control of this type may be achieved at numerous locations throughout the system.

The primary function of the pneumatic system load is to achieve some desired work function. In Fig. 1-3, the load device is a pneumatic cylinder punch-press ram. This part of the system is designed to change the mechanical energy of air into a usable form of linear motion that drives a ram. The outside work being achieved by the ram also has some direct influence upon the total performance of the entire system. All of this represents the composite load, which includes such things as transmission-line resistance and control resistance. Other pneumatic loads may be used to actuate a valve that controls another process or produces rotary motion.

The indicator of a pneumatic system is frequently an optional item. Its primary application is in the monitoring of system pressure. Other applications include pressure monitoring after regulation. Indicators may also be used to perform test procedures which aid in troubleshooting faulty components.

PNEUMATIC INSTRUMENTS

Pneumatic instruments respond to air pressure as a medium that initiates some form of control in the operation of a system. Instruments of this type are used to measure and evaluate a condition of operation, and to actuate a control element that alters a manufacturing process. The primary elements of this type of system are an expansion of the basic systems concept. This includes such things as measuring instruments, controllers, and the final control element. In a strict sense, pneumatic instruments are used to initiate control that is ultimately used to alter the operation of a second system. Fig. 1-4 shows a block diagram of this system application.

The pneumatic part of the system has an energy source, transmission path, controller, and load device. The final control element of the process system serves as the load device of the air system. This same component also serves as the control element of the process system. Measurement is achieved by an instrument attached to the output of the process system. The measured output is compared at the summing point with a manual setpoint adjustment. When these two values are equal, the controller output is in a null or zero state. When the values are not in agreement, the controller is energized to actuate the final control element. Through a constant change in balance and unbalance, the output of the process system is altered to agree with the setpoint control position. Automatic control of a process variable is com-

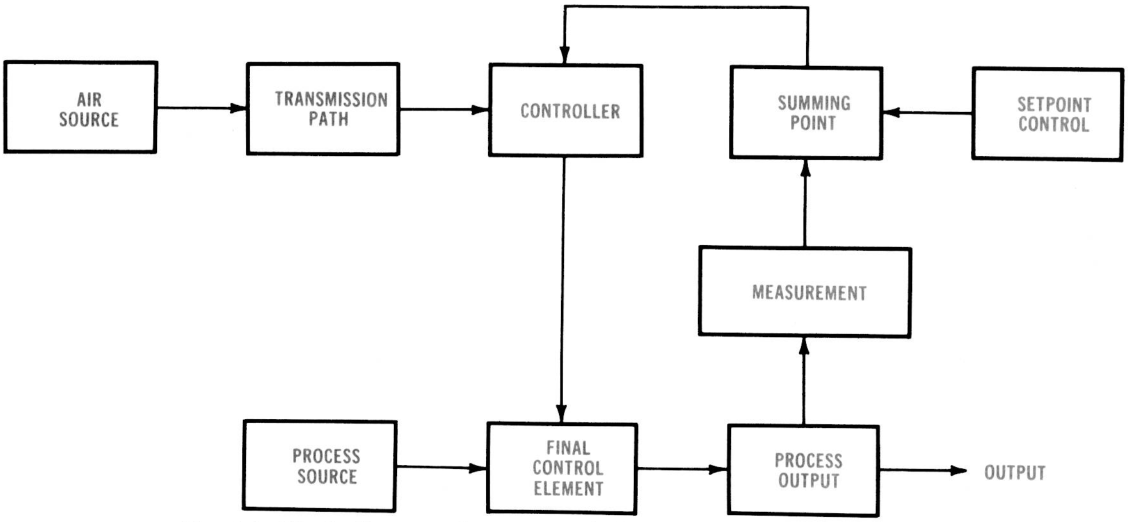


Fig. 1-4. Block diagram of a pneumatic instrument control system.

monly achieved through the use of pneumatic instruments today.

SUMMARY

Most of the products manufactured by industry today are produced through some type of automatic processing equipment. Equipment of this type relies heavily upon measurement techniques and instrument analysis.

Instrumentation is a broad area of industry that deals with the measurement, evaluation, and control of process variables such as temperature, pressure, flow rate, fluid level, force, light intensity, and humidity.

The primary areas of concern in instrumentation are pneumatics, electronics, mechanics, and hydraulics. The systems concept is used to show an interrelationship between these areas.

The systems concept is a diagrammed method of showing the parts of a piece of equipment in a logical order. A block diagram of primary system functions is represented in a "big picture" of the system. Typically, this includes an energy source, transmission path, control, a load device, and an optional indicator.

The energy source is responsible for changing energy from one form into another form that is more useful for system operation.

The transmission path of a system is responsible for transferring energy from the source to other system parts.

Control of a system may be either full or partial. Full control turns the system on or off, while partial control involves a variable condition.

The load of a system performs the work function. Energy from the source generally changes form when it produces work.

Indicators are designed to display operating conditions or to test system values in troubleshooting operations.

The energy source of a hydraulic system is a pump that circulates fluid through the system components. The path is through metal pipes or flexible hoses. Control is either full or partial through valves and regulators. A cylinder serves as the load of the hydraulic system, while indicators are gauges and meters.

Pneumatic systems are unique when compared with hydraulic systems. Air, for example, is dumped into the atmosphere instead of being returned. Compressors are used to develop air pressure, which is stored in a receiving tank until it is needed.

Pneumatic instruments respond to air pressure as a medium of control. These instruments are used to measure and evaluate conditions of operations. In many applications, air is often used to control another process variable. In a strict sense, two interconnected systems are used to achieve this type of control.

CHAPTER 2

Lever Mechanisms and Adjustments

LEVER BASICS

Almost every instrument—transmitter, indicator, recorder, or controller—used in pneumatic instrumentation today employs a lever of some type in its operation. A lever is basically a simple machine that makes something work easier. For example, a lever can be used to multiply the force applied, increase the speed of movement, or cause a change in the direction at which something is moved. Essentially, the application of levers that we are concerned with in this study of instruments must deal with an effort force applied to an object that overcomes a form of resistance. A typical resistance is the weight of a component that must be moved a certain distance.

We often think of a lever as being a straight bar of material that is pivoted at one point. In fact, levers have many shapes, sizes, and classes. They range from straight or bent forms to the wheel, which is classified as a number of levers acting at a common pivot point.

A lever is basically a piece of material that is free to turn about a fulcrum or pivot point. When a force is applied to this piece of material, it produces a motion. In doing this, the resulting motion may be used to move a weight acting at some other point along the piece of material. The resulting output of the lever is primarily based on its general operating classification. In this regard, levers are considered to be either first, second, or third class.

First-Class Levers

An effort/resistance force diagram for a first-class lever is shown in Fig. 2-1. Note that when the effort force is great enough to overcome the resistance force, it causes the resulting force to move upward from the fulcrum. A child's seesaw and a measuring balance are common examples of the first-class lever.

A very important concept of parallel forces can be applied to the measuring-balance lever. If the effort force at one end of the lever equals the resistance force at the other end at the same time, balance occurs. Concurrent forces, in this case, act together and produce a single resulting force that will push down. If the effort force is greater than the resistance force, the balance will move in a clockwise direction. A counterclockwise turning action will occur when the resistance force exceeds the effort force.

The turning effect of the resulting force of a lever is called the *moment* of the force. The moment of a force is equal to the force multiplied by the distance of the force from the fulcrum about which it turns. Moment-balance transmitters and moment-balance positioners utilize this principle in their operation.

In general, the fulcrum of a first-class lever lies somewhere between the effort force and the resistance force. The mechanical advantage of this type of lever is quite variable. It may be equal as in a condition of balance, greater than one, or less

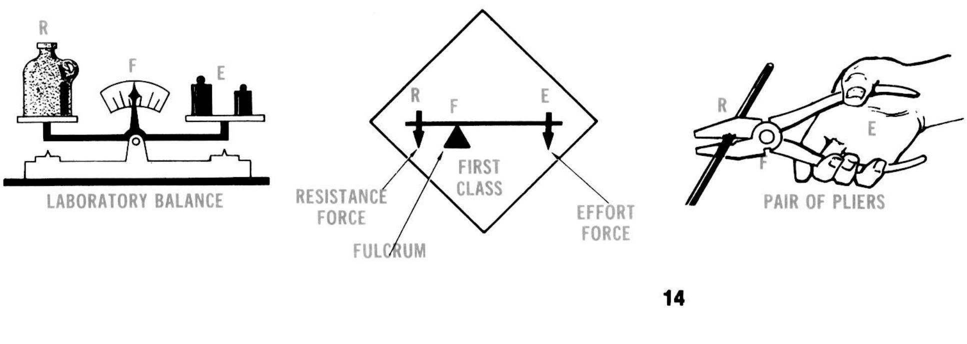


Fig. 2-1. First-class levers.

than one depending on the representative force value or fulcrum position.

Second-Class Levers

In a second-class lever, the resistance force lies somewhere between the fulcrum and the effort force. A wheelbarrow and a nutcracker are typical examples of a second-class lever. Fig. 2-2 shows an effort/resistance force diagram for a second-class lever. Since the resistance force is always smaller than the effort force, a lever of this type has a mechanical advantage that is always greater than one.

Third-Class Levers

A third-class lever has the effort force acting between the resistance force and the fulcrum. The effort force is always smaller than the resistance force in this type of lever. As a result, the mechanical advantage, of necessity, is always less than one. Fig. 2-3 shows an effort/resistance force diagram for a third-class lever. Note particularly the position and direction of the force applied to the fulcrum.

Third-class levers are primarily designed to enable us to multiply distance at the expense of force. Common examples of the third-class lever are ice tongs, tweezers, and the human forearm.

Instrument Applications of Levers

Levers are used to achieve a number of unique operations in instruments today. These operations are primarily dependent upon the classification of the lever and the resulting force of its action. Primary considerations of lever applications are:

1. Converting a force acting through a distance into a different force acting through some other distance.
2. Increasing a movement at the expense of a force or a force at the expense of a movement.
3. Creating one moment that is equal to another moment.
4. Reversing the direction of a motion.

LINK AND LEVER MECHANISMS

Industrial instruments used for recording are all similar in principle. Except for some electronic instruments, almost all recorders employ elementary arrangements of links and levers. In this chapter, link/lever mechanisms will be discussed and their limitations will be examined. A typical pneumatic recording instrument that employs a link/lever mechanism is shown in Fig. 2-4.

Components

The mechanism of a typical instrument consists of:

1. An "input" lever (Fig. 2-5).
2. An "output" lever (Fig. 2-6).
3. A "link" connecting a lever to an input, or connecting two levers.

We shall define a lever as a member that rotates about a point, or pivot. Levers may have either two sides or one side. An example of a two-sided lever is the child's seesaw. The handle on a rotary wall-mounted can opener is an example of a one-sided lever.

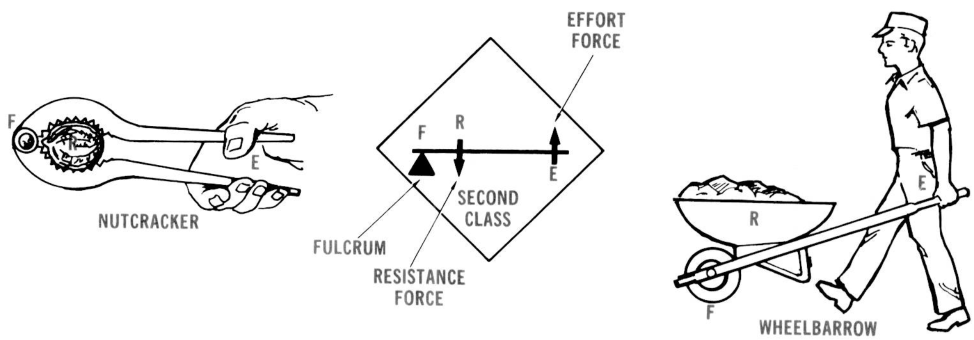


Fig. 2-2. Second-class levers.

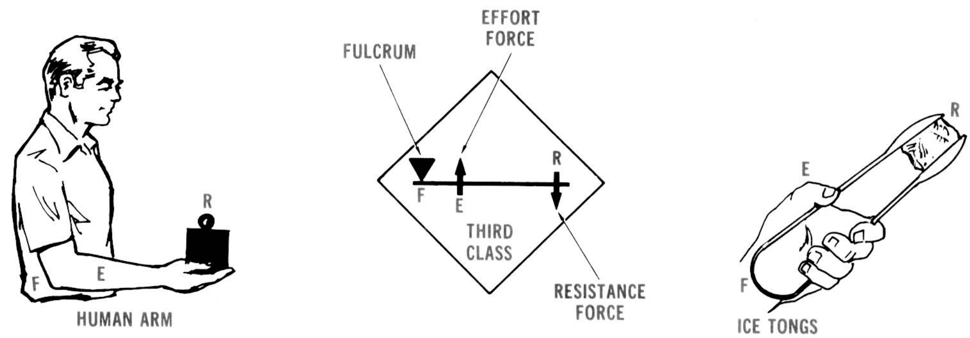
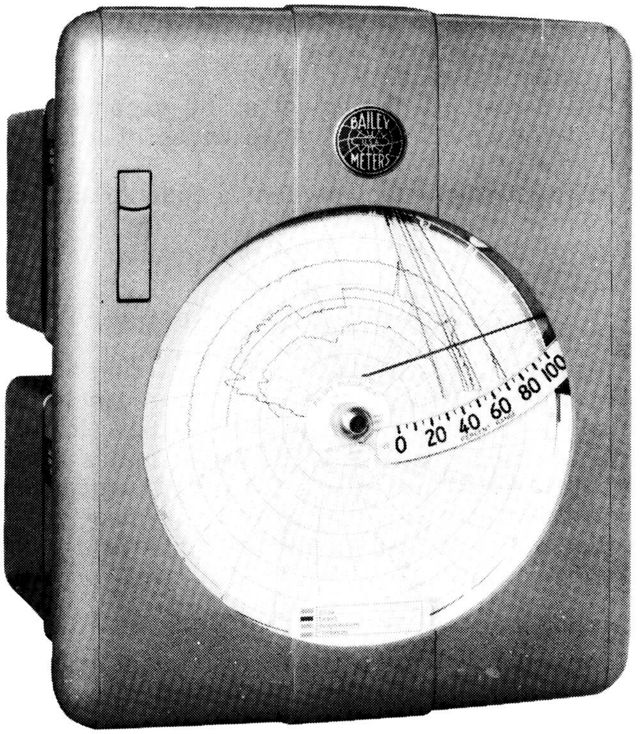


Fig. 2-3. Third-class levers.



Courtesy Bailey Controls Co.

Fig. 2-4. A typical pneumatic recording instrument.

NOTE: In certain respects, the one-sided lever is more nearly a wheel and axle mechanism. In our work, however, the one-sided lever shall, in all cases, travel less than 180°—usually about 15° or 20°—which makes the mechanism more nearly a lever than a wheel.

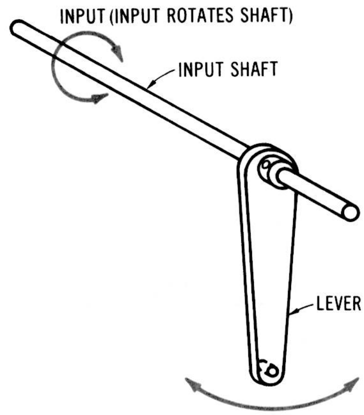
Arrangements

The input lever may be one- or two-sided. In a one-sided lever, the input to the mechanism comes through the shaft about which the lever rotates. That is, the input causes the shaft to rotate, and the lever that is attached to the shaft rotates with it. The "link" is attached to this lever (see Fig. 2-5A).

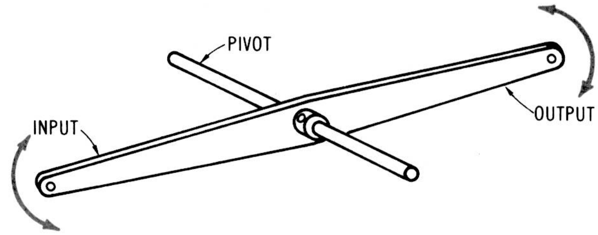
If the input lever is two-sided, the input comes to one side of the lever. This causes the lever to rotate about its pivot, moving the second side of the lever to which the link is attached (see Figs. 2-5B and C).

The link attached to the input lever is connected to the output lever. The motion of the input lever is passed by the link to the output lever, causing the output lever to rotate. This lever is solidly attached to a shaft that rotates with the lever. Attached to this shaft is the pen (or indicator). Also attached to this shaft are the levers that feed the integrators, controllers, contacts, etc. (see Fig. 2-6).

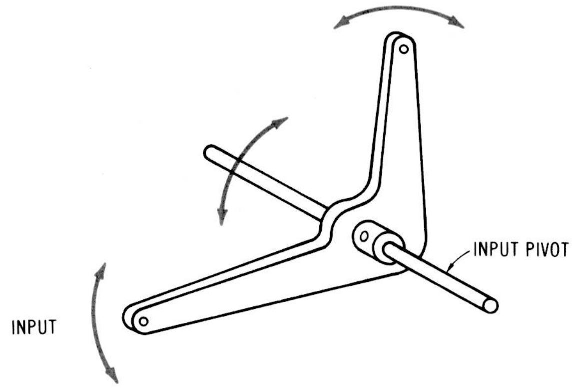
Links are almost always straight; thus, the levers connected by the link must be in the same plane. That is, they must be the same distance from the back (or the front) of the instrument case. If they are not in the same plane, levers will be "offset."



(A) One-sided.



(B) Two-sided; 180°.



(C) Two-sided; 90°.

Fig. 2-5. Input levers.

Principle of Operation

The input to the mechanism causes the input lever (or shaft) to rotate. This rotation is transferred to the output lever by the link. The rotation of the output lever causes the output shaft to rotate, which, in turn, causes the pen to move. Other levers that drive the controller, integrator, alarm contacts, etc., depending on the particular instrument, may also be attached to the output shaft.

The movement of the input lever in the actual instrument is usually small compared to the movement of the output lever. In order to get the input lever to drive the output lever through its proper