MECHANICAL EQUIPMENT

TABLE OF CONTENTS

1. OBJECTIVES

This course covers the following areas pertaining to mechanical equipment:

- Vibrations
- Valves
- Steam Traps
- Flow sheets

At the completion of training the participant will be able to:

- explain terms as they relate to vibration; amplitude, natural frequency, forcing frequency, damping, resonance, critical speed
- explain the major factors that affect the natural frequencies of an object;
- identify how excessive vibration can lead to equipment damage;
- explain why operation at or near critical speed should be avoided;
- explain how mass unbalance and misalignment cause vibrations and why they can change during operation;
- define the terms hog, sag and eccentricity as they apply to rotating shafts;
- identify why the selection for a valve in a system is important;
- state the effect of a loss of control signal or actuating fluid supply on a valve position
- explain why impurities in hydraulic fluid and instrument air must be minimized
- state two visual methods of determining a manual valve position;
- identify two operational checks that can be done to check manual valve position;
- explain the precautions taken while operating a manual valve;
- explain how a solenoid valve can be used for On/Off control of a pneumatically operated valve;
- explain the operation of a typical electric motor valve;
- explain manual operation of a typical motorized valve and the associated precautions;
- identify the purpose of a check valve;
- describe the principle operation of a check valve;
- state the purpose of a safety and relief valves;
- explain the terms as they relate to safety and relief valves; lifting pressure, capacity, popping action, blow down, chatter, and simmering;
- identify when it is permissible to gag a safety valve;
- explain the operation of a steam trap;
- identify three functions of a steam trap;
- state the three checks that confirm the correct operation of steam traps;
- identify components on a flow sheet.

Notes:

2. VIBRATIONS

2.0 INTRODUCTION

Vibrations are found almost everywhere in power plants. Rotating machinery vibrates due to unbalances, misalignments and imperfect bearings; piping and heat exchangers vibrate due to flow pulsations, structures vibrate because vibrations are transmitted onto them from various equipment that they house, and even power lines vibrate due to wind gusts. These are just some typical examples and not a complete list.

Vibration, in general, reduces equipment life and, in extreme cases, can result in equipment damage or even catastrophic failures. On the other hand, existence of vibration can also be used to diagnose equipment problems and provide early warning before any expensive damage occurs. Vibration control and monitoring are essential for safe and economic plant operation.

There is a broad use of vibration monitoring in the operation and maintenance of nuclear power plants. Some large and expensive pieces of equipment, such as turbine-generators, main heat transport pumps and boiler feed pumps, are monitored on a continuous basis. Other equipment has vibration readings taken and assessed periodically to evaluate the condition of the equipment and prevent costly damage. This forms a part of a predictive maintenance program.

In this section the basic characteristics and causes of vibration, the consequences of excessive vibration, and the methods of its prevention will be covered. This knowledge will enable you to understand some preventive operating and maintenance practices.

2.1 BASIC CONCEPTS

Let's start with an object supported rigidly at one end and moving in one plane as shown in Figure 1. We could view it as, for example, an approximation of an I-beam embedded in a wall, a cantilevered centrifugal pump impeller, or a fuelling machine snout.

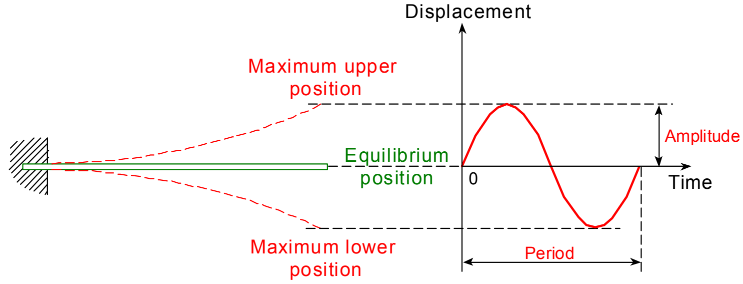


Figure 1

Notes:

Imagine that the object is deflected to one of the maximum positions and then let go. The object will move through the equilibrium position to the opposite maximum position, back through the equilibrium position to the original maximum position[1] and so on. This repetitive motion about the equilibrium position is called vibration.

It's the part that occurs between two consecutive passes through the equilibrium position in the same direction is called one cycle. Figure 1 shows how the displacement of a fixed point on the object changes during one cycle.

Amplitude and Frequency

Referring to Figure 1, we can define some basic characteristics of vibration.

Amplitude

Amplitude (A) is the maximum displacement from the equilibrium position, or the maximum velocity or acceleration, depending on the vibration transducer used. For simplicity, we will focus on displacement, in which case the customary unit for vibration amplitude is a micron ($1\mu m$)[2]. This is a small fraction of a meter: $1\ \mu m = 10^{-6}$ m.

Frequency

Frequency (f) is the number of vibration cycles per unit of time. The unit of frequency is a hertz (Hz), which is one cycle per second. Since the rotational speed of rotating machinery is expressed in revolutions per minute (RPM), it is common to express the frequency of its vibration in cycles per minute (CPM). Because one minute has 60 seconds, the relationship between hertz and CPM is: 1 Hz = 60 CPM.

Forced and Natural Frequencies

Forced frequency of vibrations is the frequency that results from application of a pulsating force. An object subjected to a repeated excitation force vibrates at the same frequency as the applied force. This type of vibration is referred to as forced vibration.

Natural frequency is a frequency at which the object would vibrate after the initiating force is removed and the object is left on its own. This type of vibration is referred to as free or natural vibration. In practice, due to friction and energy transmission to surrounding objects, the amplitude of free vibration decreases until the object comes to rest[3].

A classic example is a plucked guitar string, and an example from a plant would be a vibrating pipe after a water hammer blow.

[1] For simplicity, friction is ignored.
[2] μ is a Greek symbol pronounced *mu*.
[3] This effect is discussed in the section on vibration damping on page 7.

Notes:

What causes natural vibration to continue after the initial disturbance has been removed? It is a combination of the object's inertia and stiffness. The latter produces a restoring force and/or torque when the object is not in its equilibrium position. The term restoring reflects the fact that the force/torque is always directed towards the equilibrium position and attempts to restore the equilibrium state. In most cases, this force/torque is the result of stresses produced in the object when it is removed from the equilibrium position. For example, a restoring torque is produced in a deflected pipe or a twisted shaft.

To review what happens during one cycle, refer to Figure 2 in which the spring represents the object's stiffness, while the suspended mass its inertia.

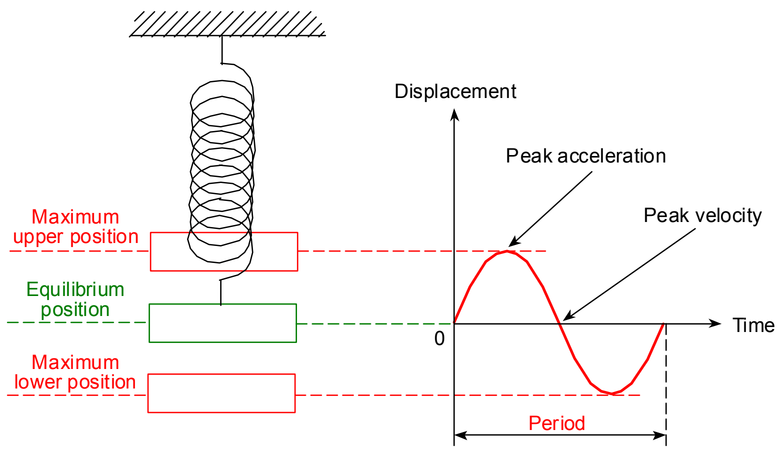


Figure 2

After the object is deflected and released, the restoring force will accelerate the object according to the Newton's Law of Acceleration. The restoring force will then diminish and become zero at the equilibrium position.

However, due to its inertia, the object cannot stop infinitely quickly. Instead, it will move to the opposite side of the equilibrium position where the opposite restoring force will decelerate the object. At the maximum displacement, the object's velocity is zero, but the restoring force is still there and will accelerate the object again toward the equilibrium position. The object will continue to move from one side to the other.

If the object were friction-free and perfectly isolated such that no energy could leave or enter, the object would vibrate forever with constant amplitude. In reality, vibration will sooner or later cease because of friction and energy transmission to the surroundings.

The natural frequency of a free vibration is the same every time this vibration occurs, regardless of amplitude (unless the object gets deformed plastically). For example, when the initial amplitude is doubled, so is the restoring force/torque. The object accelerates/ decelerates twice as fast, and therefore it needs exactly the same time to complete one cycle.

It turns out that every real object has infinitely many frequencies, each corresponding to a different type and mode of vibration. These are described below.

Notes:

2.2 TYPES OF VIBRATION

There are three types of vibrations in terms of the direction of motion and deformations experienced by the vibrating object:

- Lateral (Figures 1 and 2);
- Axial, and
- Torsional (Figure 3)

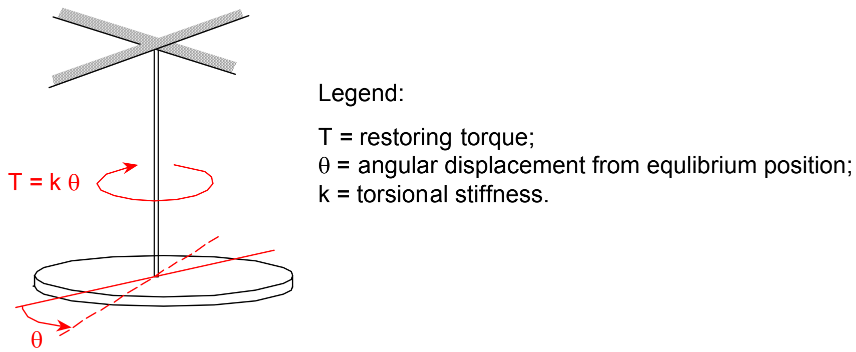


Figure 3

Lateral

Lateral vibration is the most common. It occurs when the object deflects/bends laterally to its longitudinal axis. When the object is supported loosely, it can vibrate laterally without bending (Figure 4 and b). Examples of equipment subjected to lateral vibration are rotating machinery shafts, pipes and heat exchanger tubes.

Axial

Axial vibration occurs when the object is subjected to pulsating axial forces. This can happen, for example, in rotating machinery shafts, pipes, and fuel bundle strings in the reactor fuel channels.

Torsional

Torsional vibration occurs when the object goes through a pulsating angular motion around an axis of reference—usually its own longitudinal axis. Typical examples are rotating machinery shafts and turbine or compressor blades.

Notes:

Very seldom, if ever, does an object experience only one type of vibration. The reason is a vibrating object is typically subjected to many pulsating forces acting simultaneously.

Some of them excite lateral vibrations, others axial or torsional. Furthermore, each of the vibrations can have different modes. Figure 4 shows some of them for a constant diameter shaft vibrating laterally: Modes (a) and (b) show a rigid shaft in loose or soft bearings, while modes (c) and (d) concern a flexible shaft in tight and stiff bearings.

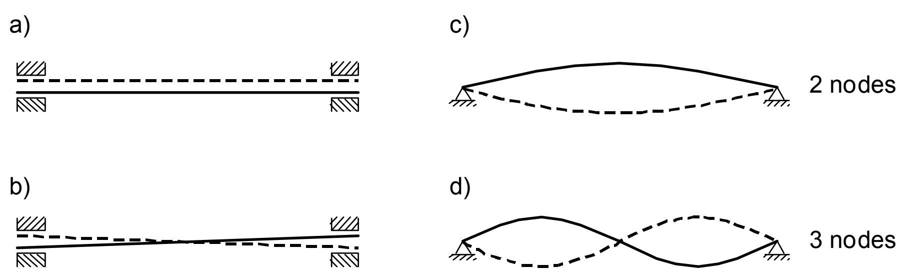


Figure 4

Mode (c) has only two nodes (points where displacement is zero) in the bearings, while mode (d) has three nodes: two in the bearings and one in the middle.

Other modes with 4, 5, and more nodes also exist. In fact, each object has infinitely many modes for each type of vibration. Fortunately, the higher modes have their natural frequencies so high above the range of forced frequencies that they do not occur.

The concept of natural frequencies is important for prevention of excessive vibration. For the reason explained later, we should avoid situations where a forced frequency equals a natural frequency. We must therefore know the factors affecting the values of natural frequencies. This will help understand how some operating conditions can change these frequencies.

2.3 FACTORS AFFECTING NATURAL FREQUENCIES

The major factors affecting the natural frequencies of an object are the object's inertia and rigidity.

Inertia

The larger the object's inertia is, the smaller the acceleration that a given restoring forces or torque imparts. Therefore, the object will vibrate slower. Since more time will be needed to complete one cycle, fewer cycles will occur in a unit of time, i.e., the object's natural frequencies will be lower.

Notes:

The inertia of a vibrating object depends on its mass and, in most cases, its distribution within the object. The mass and its distribution are determined by the object's size, shape and the density of its material(s).

The distribution of mass does not count only in these modes of vibration in which all points of the object have the same acceleration (Figure 4a). Otherwise, the mass distribution matters. For example, for the vibration mode shown in Figure 4 b), inertia would increase if more of the object's mass were concentrated at its ends.

Rigidity

Rigidity affects natural frequencies as follows. The stiffer the object, the larger the restoring force (torque); thus, for a given inertia, the restoring force/torque will produce larger accelerations. The object will vibrate faster and natural frequencies will, therefore, increase.

Like inertia, the rigidity of a vibrating object depends on its shape, size and material(s). It also depends on the type and mode of vibration. In most cases, the object exhibits a different stiffness when it is subjected to axial compression, lateral bending or twisting. If you compare the vibration modes shown in Figures 4 c) and 4 d), you will notice that it is more difficult to bend the object in the manner shown in part d). You can infer that stiffness increases with the number of nodes, and that is why the corresponding natural frequency is higher.

In rare cases, the rigidity of an object is affected by its internal pressure (pressure hoses are a good example) or tension (as in a guitar string or a turbine blade subjected to a large centrifugal force).

The natural frequencies of an object may[4] also depend on one more factor: the rigidity of its support. The softer the support is, the lower the natural frequencies are because soft supports reduce the restoring force (torque). This happens because the vibrating object deforms less since its support deforms.

For example, the natural frequencies of a shaft supported on two plain bearings mounted on a foundation are affected by the rigidity of the bearing structure (including the oil film in the bearing) and the rigidity of the foundation.

[4] The effect of support's rigidity is negligible when the object is much softer. This rigidity would have to be reduced drastically before it could lower the object's natural frequencies enough to be of concern.

Notes:

Operating conditions and maintenance practices can affect the natural frequencies of equipment. For instance:

- A failed pipe hanger will lower natural frequencies of the pipe because it will reduce its stiffness;
- Cracking or sagging of the concrete foundation supporting a bearing can change the natural frequencies of the shaft in this bearing;
- Corrosion, or cavitations, can eat away significant amounts of metal;
- Replaced parts may differ from the originals.

2.4 DAMPING

Vibration damping is dissipation of the mechanical energy of a vibrating object.

In free vibrations, damping reduces the amplitude of vibration to zero. This is usually a gradual process. When damping is large enough, free vibration will cease even before the first cycle is completed. In an extreme case, an object, after being displaced, will not even return to its original equilibrium position.

In forced vibrations, damping removes mechanical energy from the vibrating object, while the exciting forces add it. Amplitude stabilizes at a value at which the energy added equals the energy removed; therefore, the larger the damping, the smaller the amplitude.

The main sources of damping are:

- Internal friction in the material of the vibrating object;
- Friction between sliding surfaces of the vibrating object and some other object; and
- Friction between the object's surface and the surrounding fluid (fluid damping).

Although fluids, in general, provide some damping, sometimes they cause vibration. This will be described in the next section.

2.5 RESONANCE

Resonance occurs when a forced frequency is equal to one of the natural frequencies. Resonance is potentially dangerous because it can produce excessive vibration. The reason why amplitude increases is explained

Notes:

below, starting with a simple example from our youth.

When you tried to get a swing going, you had to push at the right time with the right frequency and, if you did, it was easy to get a good swing, i.e., good amplitude.

If you did not use the right frequency, amplitude would decrease and it would appear that the swing was resisting the force much more. That right frequency was the frequency at which the swing was moving on its own when you were not pushing it. Using the vibration terminology, we can say that it was easy to increase amplitude when the swing was in resonance.

When an object is in resonance, the vibration amplitude increases because the resistance of the object to vibration is lowest. At frequencies away from any natural frequency, the object resists vibration through its inertia, stiffness and damping.

At natural frequencies, only damping resists vibration, whereas inertia and stiffness sustain vibration in the manner described in the section on forced and natural vibration. In the vicinity of a natural frequency, the resistance of the object's inertia and stiffness to vibration weakens, causing the amplitude to rise (Figure 5).

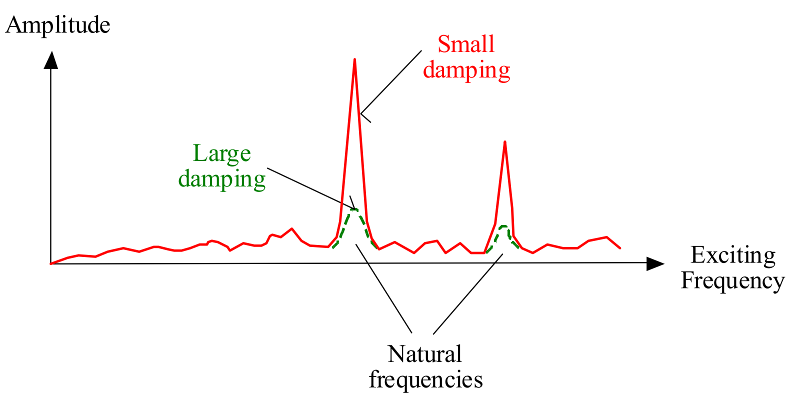


Figure 5

Since only damping resists vibration at a natural frequency, it follows that a resonance can raise vibration amplitude dramatically when damping is low.

In plants, resonance sometimes occurs in equipment such as rotating machinery, piping or heat exchanger tubes.

2.6 CRITICAL SPEED

The concept of critical speed applies to rotating machinery only, and it focuses on the major part—the rotor. Critical speed is the speed of a rotating machine at which one of the natural frequencies of the rotor-bearing-foundation system equals the forced frequency that

Notes:

corresponds to the rotational speed.

The term rotor-bearing-foundation system reflects the fact that the rotor's natural frequencies are affected by the stiffness of its support.

The reason why rotational speed is stated in the definition above is that many problems in rotating machinery produce a forced vibration at the 1∗RPM frequency. For example, shaft unbalance generates a force rotating at the shaft speed. Thus, a resonance occurs when the rotational frequency is equal or close to one of the natural frequencies of the rotor-bearing-foundation system, i.e., when the machine is running at a critical speed. The resonance will increase vibration, particularly if damping is small. From Figure 5, you can see that vibration will increase not only at the single value of a critical speed but also at a speed range around it.

A typical rotating machine (e.g., a pump-motor set) has two, and sometimes more, rotors coupled together, each of them supported in its own bearings. Each rotor has infinitely many natural frequencies, and thus, the corresponding critical speeds. Fortunately, only the lowest one or two (rarely three) of them might be within the operating speed range of the machine; the others would be above. In some cases, all critical speeds are above the normal operating speed.

The manufacturer usually specifies the relevant critical speed ranges, although for small machines this information may not be available.

However, some operating conditions can change the critical speeds. This usually happens through a change in the rigidity of the rotor support. The support consists of the bearings and their housings, the foundation and last, but not least the oil film in the bearings if they are plain type. The support rigidity can change for a number of reasons. For example:

- an oil temperature change would affect the oil film thickness, hence its stiffness[5];
- bolts holding the bearing could become loose; or
- a crack could develop in the bearing housing or the foundation.

An abnormally large change in the shaft support stiffness can, thus, shift a critical speed close to normal operating speed, causing vibration to increase.

Operation at or near critical speed should be avoided because vibration will increase and may become unacceptable. This condition means that normal operating speed must be sufficiently far[6] from the nearest critical speeds.

[5] Details are explained in Module 5.

Notes:

Unfortunately, in poorly designed or improperly installed machines, this margin is narrow, making them susceptible to small changes in their critical speeds.

In some machines, like turbine generators and high-speed pumps and compressors, the normal operating speed is above the lowest critical speed(s). These machines pass through the critical speed(s) during run-up and rundown.

This is perfectly safe as long as there are no excessive exciting forces (e.g., due to excessive shaft unbalance or bearing misalignment) and sufficient damping[7] exists.

Run-up and rundown of pumps, compressors and fans is usually so fast that passing through a critical speed range takes less than a second. Therefore, operations staff has no influence on the process.

At the other extreme are steam turbine generators whose run-up and rundown are much longer[8]. This gives operations staff time to ensure that no excessive exciting forces are present and sufficient damping exists when the machine is about to enter a critical speed range. The critical speed range is then passed as fast as other concerns (e.g., thermal stresses) allow, and speed is never held there. When the machine must be tripped on very high vibration, the trip is followed by breaking of condenser vacuum. Because the density of the condenser atmosphere rises many times, so does the retarding torque the atmosphere exerts on the rotor. Thus, the time spent inside the critical speed ranges is greatly reduced.

2.7 DAMAGE CAUSED BY EXCESSIVE VIBRATIONS

Excessive vibration should be avoided and quickly eliminated when detected, because it accelerates equipment wear, causes damage and can lead to a failure, sometimes even a catastrophic accident.

Vibration effects causing wear and damage are:

- Fatigue;
- Rubbing or fretting;
- Impact; and
- Loosening of parts.

---

[6] Minimum ± 20%.
[7] In rotating machinery, damping is usually provided by the oil film in the bearings, by the cast iron casing and by the concrete foundation.
[8] Run-up may take up to 1 hour, while rundown up to 2 hours.

Notes:

Fatigue

Fatigue affects components such as bearings, couplings, blades and vanes in rotating machinery, tubes in heat exchangers, and piping and tubing. According to EPRI (Electric Power Research Institute), socket welds in small diameter (≤ 2”) tubing are the most common components suffering fatigue failure.

Rubbing and Fretting

Rubbing sometimes occurs in rotating machinery and affects components such as seals, plain bearings, pump wear rings, turbine and compressor blades, and pump and fan vanes. Electrical insulation of cables and wires can also experience this type of damage, leading to ground and phase-to-phase faults.

Fretting usually occurs in heat exchangers when vibrating tubes rub against support plates.

Impact

Impact can take place in rotating machinery or piping systems when the amplitude is high. Components such as seals, pumps or fan vanes, and turbine or compressor blades, can impact on adjacent stationary parts and cause damage to both. Vibrating piping can impact on adjacent equipment. In heat exchangers, vibrating tubes can impact on one another mid-span between their support plates.

Loosening of components

Loosening of components such as bolts, nuts, or shims can result in subsequent damage to a loosened part. An example would be a loose belt cover or a gauge. Loose electrical contacts can cause a loss of power.

Normally, the wear caused by vibrations develops slowly. Operator field surveillance and preventive maintenance routines can identify the problem before a failure happens. However, some extreme cases have occurred in power plants and resulted in almost instantaneous catastrophic damage.

For instance, if a long blade in a low-pressure turbine broke off, vibrations would increase to such a high level that the bearings, seals and couplings would fail immediately, followed by severe rubbing inside the machine. The generator hydrogen seals would also likely fail, resulting in an almost certain hydrogen and oil fire.

All this potential for damage requires us to be vigilant and have high quality inspection and monitoring routines in place.

2.8 MASS UNBALANCE AND COUPLING MISALIGNMENT

Most of the vibration problems in plants occur in rotating equipment. To a lesser degree, we have to deal with piping vibration and vibration in heat exchangers. These are usually flow-induced vibrations.

In this section, we shall concentrate on two major mechanical causes of vibration in rotating machinery; mass unbalance and coupling (shaft) misalignment.

Notes:

Mass Unbalance

Mass unbalance is the most common cause of vibration problems. It occurs when the rotor mass centerline does not line up with the axis of rotation. The term mass centerline refers to the line that joints the centers of mass of imaginary thin slices into which the rotor may be divided. Figure 6 illustrates a simplified case of a rotor with mass unbalance. In reality, the mass centerline looks like a snake wrapped closely around the axis of rotation.

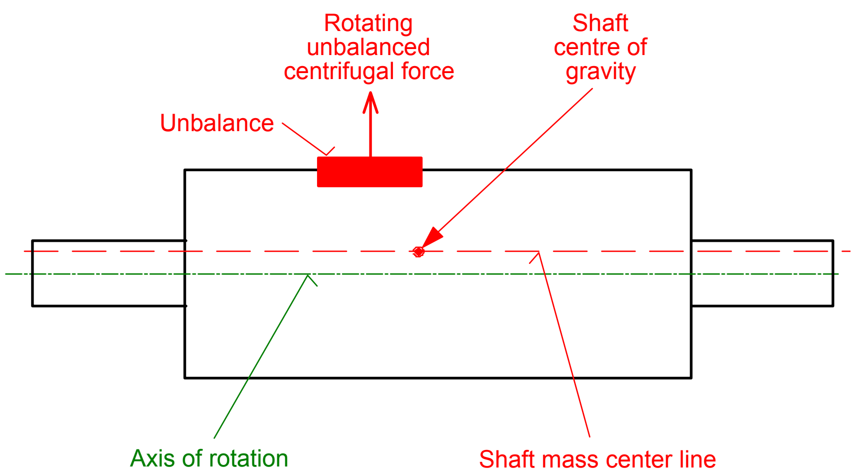


Figure 6

The rotating unbalanced centrifugal force produced by a given mass unbalance increases rapidly with rotational speed[9]. This makes high-speed machines, such as screw compressors, gas turbines or some pumps, extremely sensitive to even a small increase in mass unbalance.

Mass unbalance of new or repaired rotors is caused by limited accuracy of machining and assembling their parts.

The unbalance is minimized by balancing the rotor, which is achieved by placing some corrective weights on the light side of the rotor, or removing some material from the heavy side. If balancing is done properly, the residual unbalance is so small that it causes no vibration problem.

We will focus on those operating conditions that can increase rotor unbalance. Some of them change unbalance temporarily and others permanently (until maintenance is performed). Examples of permanent changes are:

[9] The force is proportional to the square of speed.

Notes:

- Loss of a rotor part—in the most extreme cases, the resultant unbalance can be catastrophic, but sometimes the lost part is so small that only a small increase in vibration results.

- Corrosion deposits or wear, e.g., due to erosion, abrasion, scoring, etc. In most cases, changes in mass unbalance are small and they develop slowly.

The most typical cause of a temporary change in mass unbalance is transient thermal bowing of the rotor. This happens when one side of the shaft is warmer than the opposite side.

Examples of operating conditions that can cause it are:

- Fast load changes—cooling or heating of the rotor can be so fast that slight differences in the deposits on the shaft surface can interfere with heat transfer and produce a slightly uneven temperature in the rotor. Slow cooling or heating does not cause this problem because there is enough time for heat conduction inside the rotor to equalize temperature.

- Rubbing—the frictional heat produced at the site of rubbing makes one side of the shaft hotter.

- Hogging—described on page 19.

- Partial plugging of some cooling passages (e.g., by carbon dust) in electric motors and generators.

- Asymmetrical currents in individual rotor windings in electric motors and generators—the windings carrying larger currents get hotter than their counterparts. This situation can be caused by a number of problems such as a cracked rotor winding.

Some of the above conditions are more likely to occur during rotating machinery startup or load changes. This is one of the reasons why these are often accompanied by increased vibration.

Periodic inspections and proper startup techniques can minimize these effects.

Misalignment

Another fairly common mechanical cause of vibration is coupling (shaft) misalignment. Figure 7 shows the two basic types of coupling misalignment: parallel and angular. Parts I and III show the initial positions of both shafts, while parts II and IV after half a turn, under a simplifying assumption that the left shaft and its bearings are infinitely stiff.

In practice, both shafts and its bearings are somewhat flexible. Hence,

Notes:

reaction forces exerted by the right shaft on the left shaft cause it to vibrate, too. To minimize these forces, and thus vibration, we quite often use flexible couplings. This term is misleading because these couplings can absorb only a very small misalignment. Any misalignment beyond the manufacturer's specifications will likely cause excessive vibration.

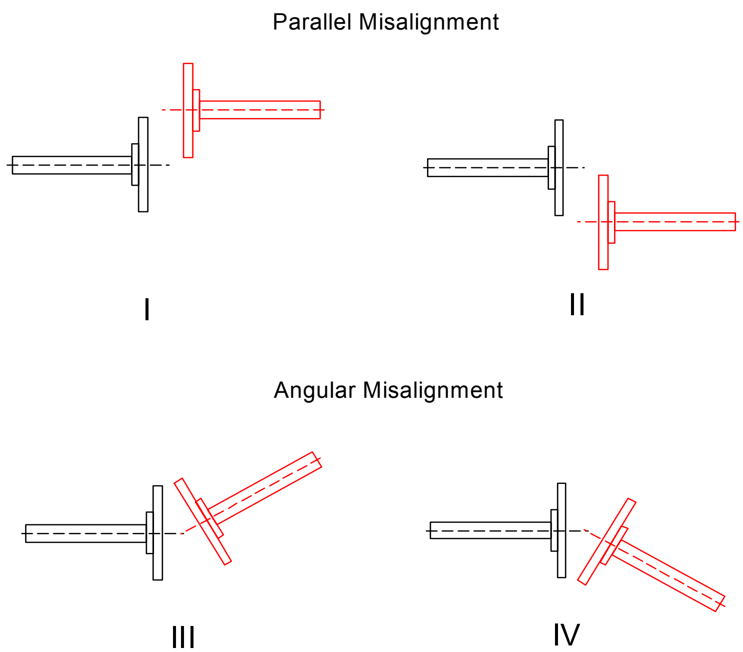


Figure 7

Like mass unbalance, shaft misalignment can also change during operation. There are a number of operating conditions that may cause misalignment and vibration:

- Machine casing with bearing pedestals can become deformed due to uneven thermal expansion or mechanical stresses caused, for example, by the piping connected to the casing;
- Concrete machine foundation can thermally expand, or settle or crack due to aging;
- A bearing can become loose in its housing, the housing can crack or its connection to the casing or foundation can become loose;
- Bearings can suffer an excessive local wear called wiping.

The first condition is the most frequent and it usually occurs during operational transients such as equipment startups and shutdowns, or load changes. Along with transient thermal bowing, it is a reason why these operational transients produce increased vibration.

2.9 HOG AND SAG

Notes:

Mass unbalance and coupling misalignment can be affected by shaft deformations referred to as hog and sag. They are most pronounced in long shafts like in steam turbine generators.

Hog is an upward bending of the rotor and happens when the top of the shaft is hotter then the bottom. This temperature differential is produced by thermal stratification of the fluid around the rotor. That is, the colder and therefore heavier fluid collects at the bottom, while the warmer and hence lighter fluid is pushed to the top. This process takes place when the rotor is left stationary and the machine is cooling down or is being warmed up. For example, rotor hogging will occur in a hot water pump after its trip or when sealing steam is applied to turbine glands if the rotor is left stationary.

Hogging is a fast process. It may take only several minutes to bow the shaft enough to close some radial clearances in the machine. An attempt to turn the rotor in this condition could damage the machine's internals (e.g., turbine blades) and bearings through rubbing.

Incidentally, hogging also affects the machine's casing. The rotor is our primary concern, however. Firstly, because it's bowing introduces a mass unbalance, which does not affect the casing; and secondly, because rotor hogging is faster and larger than casing hogging. The reason for this is that the rotor changes its temperature faster than the casing, which is heavier and therefore needs more heat transfer to change its temperature.

Sag is a downward bending of the rotor under its own weight. Some, very small, sag is present during normal operation because the rotor is not infinitely rigid. But when the rotor is stationary, sag increases because the same part of the rotor is subjected to a constant stress for an extended period; the top half is in compression, while the bottom half is in tension. A similar process, which we all have seen, affects a loaded bookcase shelf.

Unlike hogging, sagging is a slow process and it takes days rather than minutes to develop to a troublesome level.

Another term that is closely associated with hogging and sagging is shaft eccentricity.

Eccentricity is a measure of the rotor deflection from the perfectly straight line. Figure 8 shows how rotor eccentricity is measured. The measurement is unavailable when the rotor is stationary.

Notes:

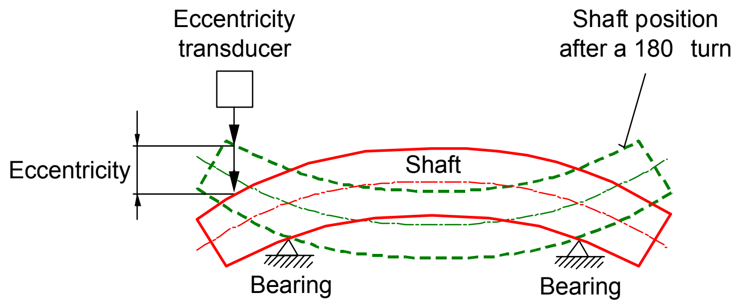


Figure 8

In plants, eccentricity is monitored only on high-pressure turbine rotors. This allows us to avoid turbine run-up when the rotor is bowed.

Eccentricity of these rotors can be caused by sagging or hogging. However, rubbing or excessively fast heating or cooling of the rotor can also produce it.

Regardless of its cause, shaft bowing has adverse consequences, and they depend on rotor speed. At high speeds, shaft bowing will result in high vibration because the rotating unbalanced centrifugal force will be excessive. At low speeds, however, that force will be too small to produce high vibration even when shaft bowing is sufficient to cause mild rubbing. If we monitored bearing vibrations only, we may be unaware of rotor bowing, but it could wear/damage seals. Monitoring rotor eccentricity, however, would warn us about the danger.

We have implemented certain operational procedures to prevent excessive rotor sag/hog. For example:

- The turbine-generator rotor is slowly rotated by the turning gear to roll out sag/hog before run-up, and to prevent excessive hogging after rundown.

- Standby hot water pumps are not left stationary, but are slowly rotated by a small back flow from the discharge of a running pump. Otherwise, the rotor would bow and the pump may not be available for service when needed.

REVIEW QUESTIONS

VIBRATION

Notes:

1. Define each of the following terms as it relates to mechanical vibration.
   a. Amplitude
   b. Natural Frequency
   c. Forcing Frequency
   d. Damping
   e. Resonance
   f. Critical speed

2. Explain two (2) major factors that affect the natural frequencies of an object

3. State and explain four mechanisms that can cause failure from excessive vibrations.

4. Explain why operation of a rotating machine near a critical speed should be avoided.

5. Explain how mass unbalance can cause vibration.

6. Explain how misalignment can cause vibration.

7. State and explain two (2) mechanisms that can cause permanent mass unbalance during operation of a rotating machine.

8. State and explain five (5) mechanisms that can cause temporary mass unbalance during operation of a rotating machine.

9. State and explain four (4) mechanisms that can cause misalignment during operation of a rotating machine.

10. Define the following terms as they apply to rotating shafts?
    a. hog
    b. sag
    c. eccentricity

3. VALVES

Notes:

3.0 INTRODUCTION

Valves are the most common components in nuclear power plants. There are several thousand of them in each unit of the plant. They come in many different designs and are used for a multitude of services. From an operating viewpoint, it is practical to classify them according to the function they perform in the systems. A valve can usually provide one of the following services:

- regulating,
- isolating,
- back flow prevention, or
- pressure relief.

Valves can be manually operated or can be equipped with an actuator. Actuators can be powered by a number of mediums:

- pneumatic,
- electrical, or
- hydraulic.

In a previous course you looked at valves classified by their closing element: ball, gate, diaphragm, globe, etc. In this section we will look at valves from the point of view of their service or purpose in the system. .

3.1 REGULATING VALVE SERVICE

Valves performing a regulating function are normally referred to as control valves. The equipment code designation for control valves is CV. A control valve is often the final device in a control loop. A control valve can be open or closed or at any position in between as determined by the control scheme. Control valves are typically fitted with a valve positioner. A valve positioner is a device that that compares the control signal (representative of the desired valve position) and compares it to the actual valve position and then sets the valve to the desired position by manipulating the driving force on the valve. The majority of control valves in a CANDU station use a pneumatic operator to drive them. A few use hydraulics.

One of the important design parameters of control valve is the valve characteristic. If it is to properly control a system action the valve must have the proper characteristic. The discussion will revolve around globe valves. It is very common to use globe valves as control valves however; they are by no means the only type used for this service.

Notes:

Vee-ball valves, needle valves and butterfly valves are also used extensively and even they do not comprise a complete list.

3.2 VALVE CHARACTERISTICS

From the operating viewpoint, it is important to know how much fluid will pass through a valve when it is at a certain position and what pressure drop will the valve cause.

Both parameters: flow and pressure drop are a function of so called valve trim. Valve trim, in general, is all removable parts of the valve in contact with the process fluid. Practically, it is the seat and the closing element i.e., plug, gate, disc, ball, etc. Figure 9 shows a typical globe valve.

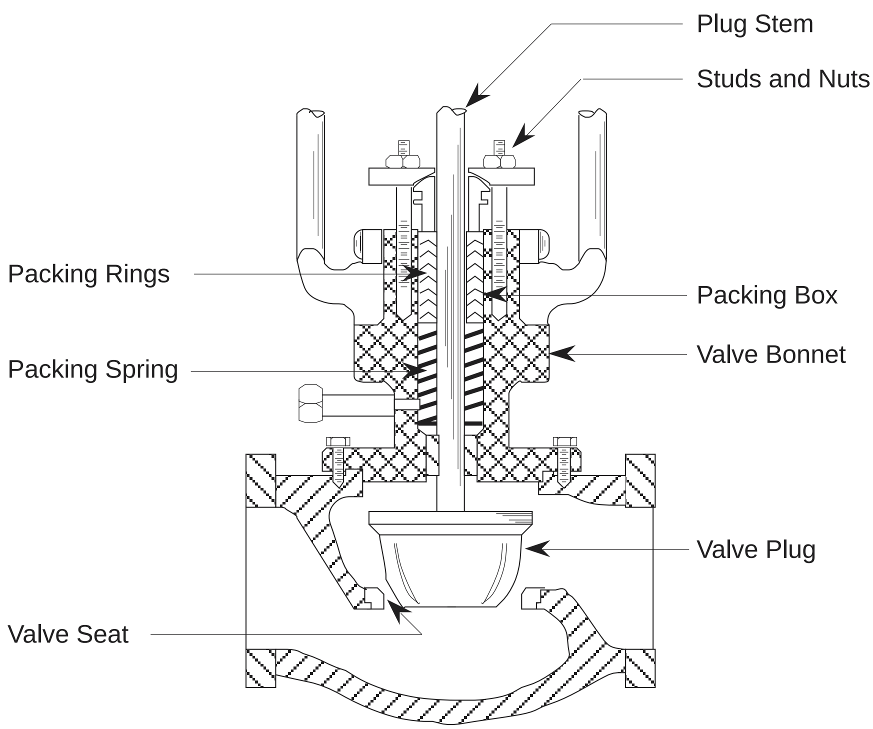


Figure 9

Relationship between the travel of the valve closing element (valve position) and the corresponding flow through the valve is called valve characteristic.

Notes:

Measuring the flow through a valve at different stem positions and plotting the data graphically obtain the flow characteristic. The flow through the valve is pressure dependent. However, the valve manufacturer doesn't know the pressure differential across the valve after it is installed in a system. That is why valves are tested by the manufacturers and flow characteristic produced at a constant pressure differential[10]. This characteristic provided by the manufacturer is called inherent flow characteristic.

The relationship between the travel and flow will depend on the shape of the valve trim. The most typical inherent flow characteristics are in Figure 10.

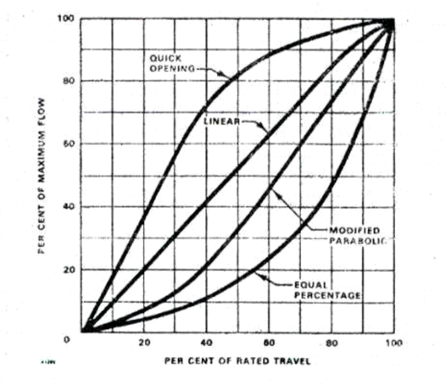


Figure 10

Valve characteristics are associated with another term: valve gain or sensitivity. It is defined as the ratio of the change in flow to the change in travel when there is a constant differential pressure across it. In reality the gain is the slope of the valve characteristic.

Quick Opening Characteristic

The quick opening characteristics produces the maximum change in flow at low valve travels with a nearly linear relationship. Further increases of valve travel yield sharply reduced changes in flow so when a valve is close to the fully open position, the change in flow approaches zero. This type is used mainly for on-off service. The majority of gate valves have this characteristic. An example of a quick opening globe valve plug is in Figure 11

[10] For historical reasons, the pressure drop is typically 1 psi (pound per square inch), i.e., not S.I.

Notes:

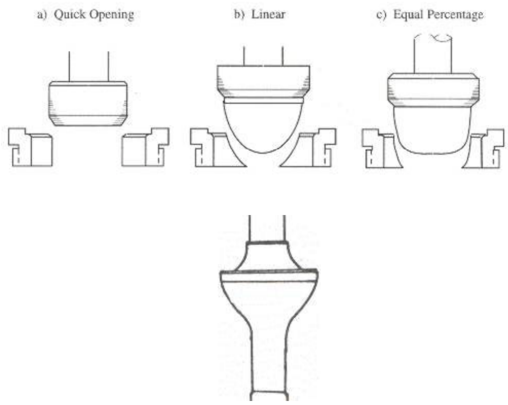


Figure 11

Linear Flow Characteristic

The linear flow characteristic produces flow directly proportional to the valve travel. The valve gain will be constant at all flows. The linear characteristic valves are commonly used where the pressure differential across a valve can be kept approximately constant because this makes the flow-rate proportional to the valve travel. An example of application is feed valves in the HT system (the pressures at the HT pressurizing pump discharge and in the HT system are fairly constant). An example of a linear globe valve plug is in Figure 11b).

Equal Percentage Characteristic

The equal percentage characteristic (also known as parabolic) produces equal percentage changes in the existing flow for equal increments of valve travel. When the valve plug, disc or ball is nearly closed and the flow rate is low, the change in flow will be small. At large flows/openings, the change will be large. An equal percentage valve will exhibit a low gain at low flows and a large gain at large flows.

Valves with an equal percentage flow characteristic are generally used on applications where a large part of the pressure drop is normally absorbed by the system itself and a relatively small part is available at the valve. These valves are also used where highly varying pressure drop conditions are expected. An example of a globe valve plug producing equal percentage characteristics is in Figure 11c).

Modified Parabolic Characteristic

The last characteristic we want to discuss is the modified parabolic characteristic. It falls between the equal percentage and linear characteristics. This characteristic also produces an increasing gain with increasing valve opening. Modified parabolic valves are sometimes substituted for equal percentage valves.

Notes:

Many butterfly, ball and plug valves and even some gate valves, produce this type of characteristic. Figure 11d) shows an example of a globe valve plug producing a modified parabolic characteristic.

The flow through a valve at a given position is proportional to the square root of the pressure differential across the valve (for example, to double the flow, the pressure differential must increase four times). This relationship holds true for all valve characteristics (because we are talking about a constant valve position).

As the final point, let us explain the effect of valve position on the inlet and outlet pressures and flow rate in piping systems:

- Valve opening increases the flow through the valve and lowers the pressure on the upstream side of the valve (because system friction losses increase with flow);
- If the valve discharges to atmosphere, the discharge pressure stays constant;
- If the valve discharges into a piping system, the discharge pressure tends to rise, again because of the system friction losses;
- The mass flow rate of steam or gas flowing through a given valve at a given position and subjected to a given pressure differential increases with the valve inlet pressure because fluid density rises with pressure;
- When fully open, a gate valve will have a smaller pressure drop and a larger flow than a globe valve of the same size.

In addition to poor control the incorrect selection of a valve can lead to turbulent flow and cavitation. Turbulent flow will increase system pressure losses and can increase erosion in the system. Cavitation can severely damage valves and pipe work.

3.3 VALVE FAILURE MODES

As mentioned previously most of the control valves in a CANDU station are pneumatically driven and most of the actuators are of a diaphragm type. Valves driven by a diaphragm actuator can be made to fail open or closed on the loss of air supply.

Effect of Loss of Control Signal or Actuating Fluid on Valve Position

When either the control signal or the supply of actuating fluid is lost we want the valve to fail-safe. It means the valve will automatically put itself into the position (open or close) that results in a safe state of the system.

Notes:

A valve can fail:

1. Opened,
2. Closed, or
3. Locked in the last position.

The fail-safe position is either determined by the design of the valve body and actuator or can come from the positioner[11] that will put valve into the desired fail-safe position. Depending on the application, the system/plant designer decides on the fail-safe mode and selects the appropriate valve and actuator.

In general terms, when the actuating fluid supply is lost, a valve equipped with a spring will return to a fail-safe position. Energy stored in the spring will do it. Most of diaphragm actuators operating control valves will have a spring that in case of a failure will return valve into the desired position. Figure 12 shows the two possible arrangements.

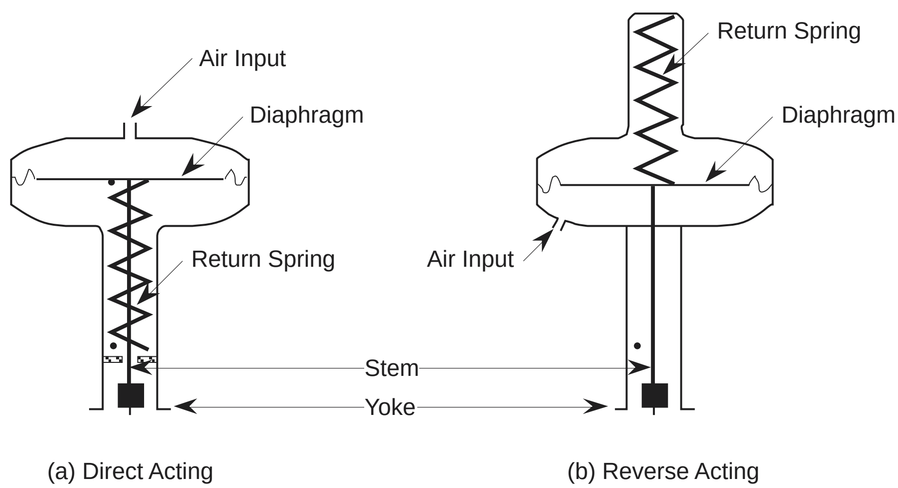


Figure 12

In the left drawing, the actuating air will deflect the diaphragm downward. If the supply of actuating air is lost, the spring will return the valve stem and plug upward to the fail-safe position. In the right drawing, actuating air will deflect the diaphragm upwards. After a loss of actuating air, the spring will move the stem and plug upwards into its fail-safe position.

The fail-safe position will also depend on the type of the globe valve body. Figure 13 shows the two possible types.

[11] A valve positioner is a device that accurately positions a control valve in accordance with the control signal. With a positioner, the signal goes to the positioner instead of directly to the valve actuator.

It should be noted that a reverse acting valve is a relatively rare device. The majority of valves are of the direct design.

Notes:

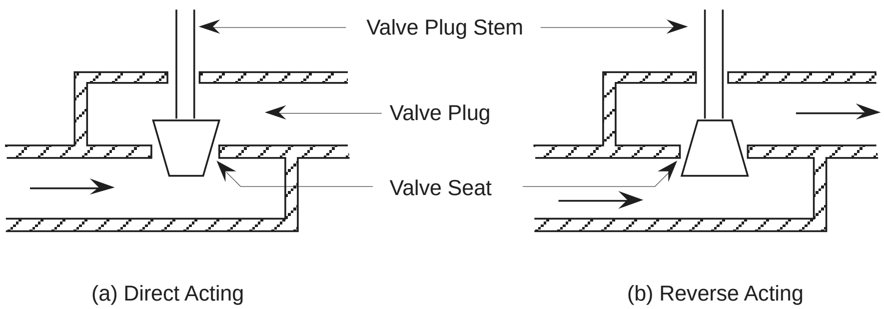


Figure 13

Possible combinations of valve actuator and body types, and the corresponding valve actions and failure modes, are summarized in a table below.

Actuator	Valve Body	Valve Action	Failure Mode
Direct	Direct	Air to Close	Fail Open
Reverse	Reverse	Air to Close	Fail Open
Direct	Reverse	Air to Open	Fail Closed
Reverse	Direct	Air to Open	Fail Closed

Table 1

In addition to diaphragm type actuators there are also piston actuators. This type of actuator uses the actuating power (pneumatic or hydraulic) to drive the valve both directions. Some of them have a spring in the cylinder that would perform the same function as in case of diaphragm actuators. In case of actuating fluid supply loss; the spring would put the valve in the fail-safe position. However, some piston actuators are not equipped with the spring. Figure 14 shows an example.

Notes:

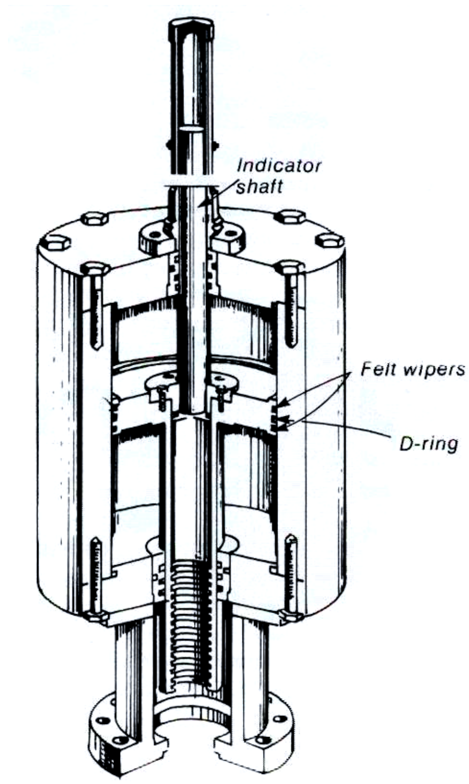


Figure 14

Loss of actuation fluid supply to the shown actuator will result in the fail-in-the-last-position action. The problem often is that fluid can subsequently slowly bleed past cylinder rings and seals, changing the valve setting.

In critical applications, there often is a stand-by reservoir with stored pressurized fluid that will allow operation of the valve(s) for a limited number of strokes.

If the control signal is lost, the valve will also assume its fail-safe position appropriate for the system. The actions of the actuator (venting/draining) will be identical as those for the loss of actuation fluid.

3.4 ACTUATOR FLUIDS

Piston and diaphragm type actuators typically use air as the driving force. There are however a few applications when where oil is used. These applications are usually when either large force are required to move the valves or when the time-delay by using air, a compressible fluid, will cause excessive operating delays.

Impurities in hydraulic fluid or instrument air

Control and isolating valve reliability is an important requirement in plant operations. One factor that contributes to reliable valve operation is cleanliness of hydraulic fluids and instrument air.

Impurities that can cause malfunction or even failure of pneumatic and hydraulic actuators are:

- Water,
- Particulates, and
- Oil.

Notes:

Water gets into hydraulic fluids and instrument air usually by condensation from humid ambient air. Water accelerates corrosion in instrument air systems, water can cause malfunction of small control elements in positioners, and freeze if part of the system is exposed to the outside atmosphere. If in large quantities, it can cause water hammer.

In hydraulic systems, water causes hydrolysis of the fluid—a process that produces organic acids, resins, waxes and sludge in general. The acids promote corrosion and accelerate fluid breakdown. In fire resistant fluids (FRFs), acids also promote electro-kinetic erosion[12]. Corrosion products can close tight clearances (several μm) and disable/ slow down the valve or cause its erratic operation.

Water in air problems are minimized by keeping the dew point[13] of the instrument air supply low. In hydraulic fluid systems, we periodically drain some oil from the bottom of the storage tank and low points of the system. If the fluid is FRF that is heavier than water, then we use Fuller's earth[14] cartridges and vacuum treatment[15].

Particulates can plug and/or erode small control and trip elements in hydraulic systems, and fine orifices and pistons in control systems. The defense is filtration of hydraulic fluids and air filtration at the suction to instrument air compressors.

Oil in instrument air systems can plug small internal passages and orifices in control systems and cause their malfunction. Most of the oil is removed in intercoolers, after coolers, separators, dryers and receivers.

[12] Electro-kinetic erosion is a complex process based on electro-chemical reaction between the metal and stationary and moving layers of the fluid. Its explanation is beyond the scope of the course.

[13] Dew point is a temperature at which water vapour in the air starts condensing out or sublimating directly to ice. A typical dew point requirement for dried instrument air is -40^{o} C.

[14] Fuller's earth is a hydrated compound of mainly silica and alumina. It absorbs many chemicals including water.

[15] Vacuum treatment consists of heating the fluid and subjecting it to high vacuum. Most of the water evaporates and a vacuum pump gets rid of vapour.

3.5 ISOLATING VALVE SERVICE

Notes:

Valves installed in a system with the primary purpose of isolating valves are generally either fully open or fully closed. They may be manually operated or operated by an actuator.

Manually operated valves are usually given the designation V and ones operated by an actuator MV. Pneumatic, hydraulic or electric motor driven actuators are common.

3.6 MANUAL VALVES

Verification of manual valve position

Determination/verification of a manual valve position is an integral part of pre-operational valve checks. Some manual valves are equipped or inherently designed with the position indication. For example, a position of a handle on a ball or butterfly valve clearly indicates the position of the valve. A globe valve with a rising stem may be equipped with position indication as well. However, if the closing/throttling part of a valve is disengaged from the spindle/stem, the indication may give wrong information.

It is a good operational practice to perform the following additional valve position checks:

- observe situational information, i.e., temperature gauges, level gauges, pressure gauges to help determine the valve is in the anticipated position.
- check direction of flow. Use of the sense of hearing and touching can also provide additional information on the valve position.

Precautions in operation of manual valves

While operating a manual valve certain precautions must be taken

The following is a list of personal safety precautions:

- Apart from the standard safety gear, wear gloves to prevent hand injuries and stroke valve in small increments.
- Consider body mechanics with respect to valves in awkward location/position.

Equipment related precautions are:

Notes:

- correctly identifying the valve to be operated.
- check valve condition which involves:
    - checking for leaks; and
    - checking for damage; and
    - watch for unusual operating characteristics, i.e., higher than usual resistance to handle operation, higher than expected temperature, noise, or vibration.

Use good operating practices which include:

- open the valve in small increments to prevent water/steam hammer, unless specified otherwise; and
- check/verify that the desired set-point has been met by checking system parameters controlled by the valve.

3.7 PNEUMATIC MV'S

Pneumatic operators power many on-off valves. They look almost identical to control valves, except on-off valves are rarely equipped with a positioner. The position of an on-off pneumatic actuator is determined the electrical logic circuits. The logic circuits control solenoid valves that either apply air pressure or vent the actuator.

Use of solenoid valves

A solenoid valve (Figure 15) consists of an electrical coil, that produces an electromagnetic force, and a plunger connected to a plug. The valve is opened or closed by an electric signal admitted to the coil and is returned to its original position by a spring or by the weight of the plunger, plug and stem when the signal is removed or lost.

Solenoid actuated valves are typically small[16] valves that are used for on/off flow control. We find them in our plant in low flow, low pressure and low temperature systems. The most common application of solenoid valves in our plants is in the instrument air system. They admit compressed air to actuators of pneumatically operated valves.

[16] Usually smaller than 25mm, i.e.1 inch.

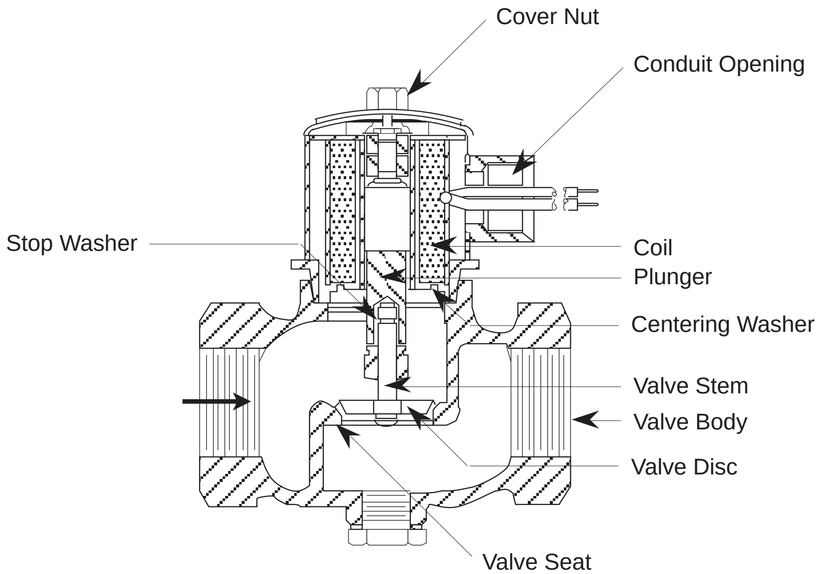


Figure 15

Notes:

Figure 16 shows a diagram with a solenoid valve used for ON/OFF control of a pneumatically operated valve. The pneumatically (air) operated valve (AOV) is an air-to-open valve.

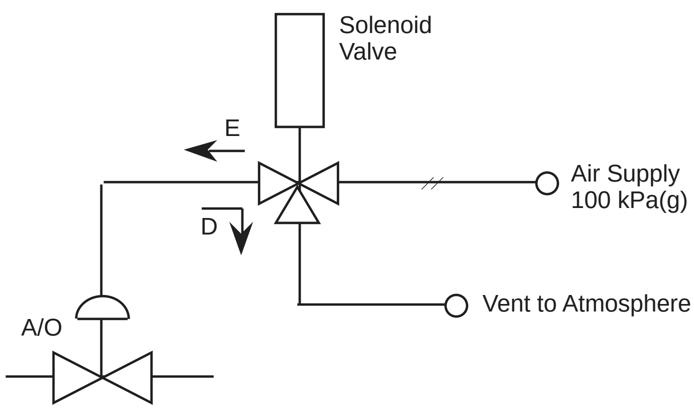


Figure 16

If the AOV were an air-to-close valve, the solenoid valve would be energized to admit pressurized instrument air to close the valve. When the solenoid valve is de-energized the air would be cut off, and simultaneously the pressure trapped between the two valves is vented to atmosphere. The AOV would open by the action of a spring in its actuator.

3.8 ELECTRICAL MOTOR DRIVEN MV'S

Notes:

Principle of Operation of Electric Motor Actuator

Electric motor actuators develop high torques but they actuate valves slowly. Therefore, they are used for on/off service or where changes in valve setting are not very frequent. An example of common use in our plants is gate valves in various systems. Figure 17 gives an example of an electric motor actuator with the main parts labeled. We will use it to explain the principle of operation.

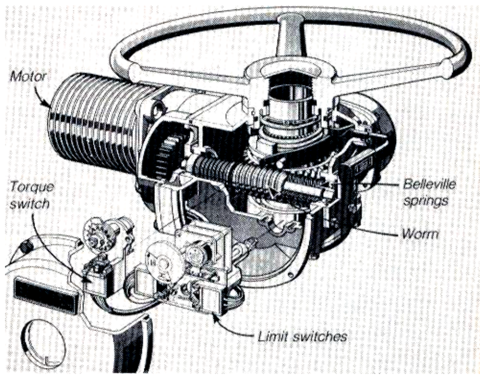


Figure 17

The electric motor drives a worm and engaged worm wheel. The worm wheel drives the valve stem. The actuator can be put into manual mode (in which the motor drive is disengaged) and be operated by the hand-wheel.

Electric motor actuators have a number of controls/settings to achieve desired operation of the valve and prevent damage to some valve parts–seats and stem in particular. They are:

- Torque cutout,
- Open and close limit cutouts,
- Position indication, and
- Speed setting.

Notes:

Torque Cutout

The torque cutout is designed to limit torque applied to the worm gear and transmitted onto the valve stem and seats. The worm gear stops turning when the valve is in one of the extreme positions (fully closed or open) or, less likely, stuck in between. When this happens, the worm has a tendency to move axially like the screw in a stationary nut. The worm gear acts like a nut and the worm like the screw. Under normal operating conditions, this tendency is limited by the spring or Belleville washers[17]/springs at the end of the worm. These springs impose a predetermined thrust load.

Before the worm can move along its axis, it must overcome the force of the springs.

When load exceeds the torque setting, the springs are compressed even more. The resultant axial movement of the worm trips the torque switch lever.

Limit Switch Cutout

Open and close limit switches/cutouts switch off the motor just before the valve stem reaches fully open or closed positions. Inertia of the electric motor rotor, gear assembly and the valve stem will cause the valve stem to move a bit after the power to the motor has been cut off.

The position indication gauge shows the position the actuator is in.

Speed Setting

The Speed setting enables us to vary operating time within certain given limits. It is sometime important to have a valve opened or closed within predetermined time. It can be dictated by prevention of water hammer, pump overheating or other operational limits. The use of this feature is not common.

3.9 MANUAL OPERATION OF A MOTORIZED VALVE

A majority of motorized valves (MOV) in plants can also be operated manually using a hand wheel that is an integral part of the valve. The hand wheel is engaged by operating a clutch lever provided with the valve. The lever prevents the electric motor from operating the valve while the operator uses the hand wheel to move the valve.

The actuator will stay in the manual mode until power is restored to the motor.

[17] Unlike normal flat washers, Belleville washers are shaped into a cone. Then two of them are put together with broad bases of the cone touching. A number of these pairs are stacked up on the shaft. When this stack is subjected to an axial force, they deflect towards the flat position and act like a spring.

Notes:

If power operation is attempted during manual operation, an automatic mechanical disengagement mechanism allows the motor to take over and drive the actuator. The manual clutch is disengaged and the hand wheel does not rotate while the valve is driven by the motor. This safety feature is designed into all motorized actuators to prevent accidental injury to an operator operating the valve manually.

If the clutch lever has to be continuously held in order to keep the hand wheel engaged during manual operation, the possibility exists that both the hand wheel and the motor gear train could be disengaged at the same time. This would indicate that the clutch assembly needs adjustment.

Some motorized valve actuators have free motion (slack) built into the drive train to allow accidentally jammed valves to be freed. The actuator is placed on manual and using a slack in the gear, the valve is jarred free.

It is a poor operating practice to use a wrench or similar devices to tighten the hand wheel on a motor driven actuator.

3.10 VALVE BACKSEATING

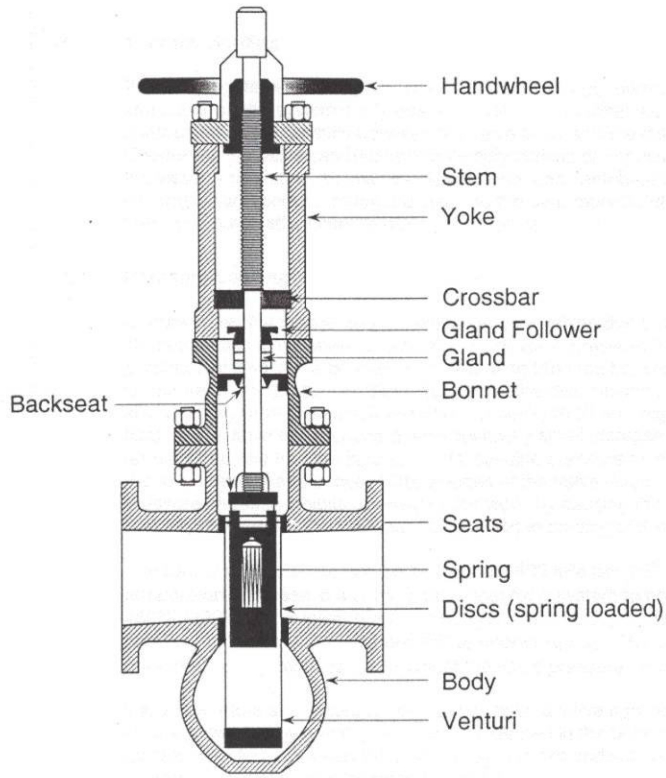
Normal practice is to open a valve fully, then back off about ¼ turn from the fully open position. This is done to facilitate the next operation of the valve and prevent seizing. However, some valves are designed with internal backseats.

The function of the backseat is to prevent leakage along the stem and to unload packing that may otherwise start leaking under the full system pressure. Figure 18 shows a typical gate valve with the backseat.

Another advantage of a valve with the backseat is that, if necessary, the valve packing can be replaced under power, i.e., without depressurizing the system. The valve is placed in a fully back seated position, and it is determined that a bone fide backseat has been established. Then, the gland follower can be removed and the packing replaced by maintenance staff. However, a special approval process has to be followed and the Approved Work Protection Procedure used.

Caution should be exercised when operating a cold back seated valve in a normally hot system. Damage can occur to the valve as it expands and warms up to the system temperature if fully opened to the back seated position while still cold. The backseat may become stuck against the body of the valve, making it difficult to close the valve. It may even become necessary to isolate the valve and allow it to cool down in order to close it.

Notes:



Manually Operated Isolating Valve

Figure 18

3.11 PURPOSE OF INTERGATE VALVE

The purpose of the intergate valve is to provide pressure relief of the bonnet cavity in some isolating gate valves. Figure 18 shows the bonnet and the bonnet cavity between the disc and the backseat.

Failure to use an integrate valve correctly may result in rupture of the valve body; especially in the presence of a heat source. Heat would result in a hydraulic pressure build-up that may rise beyond the valve body strength. Pressure in the bonnet cavity may also cause an inability of the actuator to operate the valve.

Intergate valves are left open during normal operation. An intergate valve that was closed for isolation should be opened before we open the isolating gate valve. This will relieve any excess bonnet pressure and will make opening of the isolating valve easier and reduce the chance of damaging the gate valve.

3.12 BACK FLOW PREVENTION SERVICE

Valves designed for the prevention of backflow are referred to as check valves. The device code designation for check valves is NV.

Notes:

3.13 PURPOSE AND PRINCIPLE OF OPERATION OF CHECK VALVES

The purpose of check valves is to insure that fluid flows in only one direction. There are two basic types of check valves:

- Swing, and
- Lift.

Examples are in Figure 19

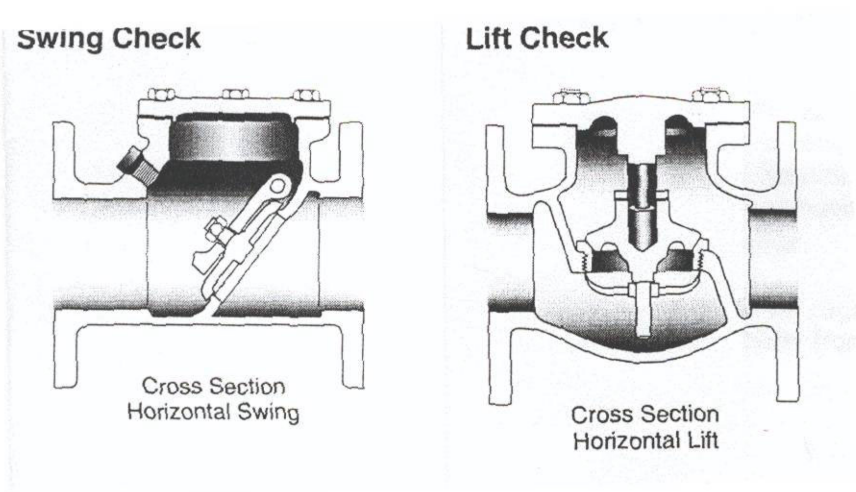


Figure 19

When the flow is coming from the right in the swing check valve and from below in the lift check valve, it will open the valve and pass through. However, if the flow is in the opposite direction, it will slam the valves closed.

There are a number of reasons why we want the flow come in one direction only. Two examples are:

- To prevent back flow from the operating system into a shut down pump in two- pumps-in-parallel operation
- To prevent back flow of extraction steam to the turbine, this could contribute to its overspeed upon a rapid disconnection of the generator from the grid.

3.14 RELIEF VALVES, SAFETY VALVES AND SAFETY-RELIEF VALVES

Notes:

Although relief, safety and safety-relief valves are considered to be synonymous by the operating staff, standards, codes and our governing documents make a distinction among them. Here are simple definitions of these valves:

Relief Valve

Relief valve is a pressure relief device having a gradual lift generally proportional to the increase in pressure over opening pressure. It is primarily used for liquid service.

Safety Valve

Safety valve is a pressure relief device characterized by rapid opening or pop action. It is primarily used for steam, air and gas service.

Safety Relief Valve

Safety-relief valve is a pressure relief device characterized by rapid opening or pop action, (when used for compressible fluids) or by opening in proportion to the increase in pressure over the opening pressure (when used for liquids).

All three defined pressure relief valves are designed to prevent internal fluid pressure from rising above a predetermined maximum pressure in a vessel or a system exposed to emergency or abnormal conditions. In simple terms, all three valves provide overpressure protection in our plants.

The following terms apply to safety relief devices.

Lifting or opening pressure

Lifting pressure or opening pressure is the value of increasing inlet static pressure of a pressure relieving valve at which there is a measurable lift, or at which the discharge becomes continuous as determined by seeing, feeling, or hearing.

Capacity

Capacity is the mass or volume rate of the fluid discharged by a pressure relief valve when its inlet pressure equals the flow rating pressure. The latter pressure is above the lifting pressure because every pressure relief valve needs some pressure rise to open enough to reach its rated capacity.

Popping

Popping action is a rapid movement of the valve disc in the opening direction. The speed of movement is higher as compared with the initial and final parts of the valve travel.

Notes:

Popping action is important in safety valves because it facilitates a discharge of a large volume of the compressible fluid, which is necessary to lower pressure. With incompressible fluids, system pressure drops quickly when a relief valve opens. Popping action only happens with compressible fluids because they expand rapidly when pressure drops along their flow path through the valve. This expansion produces an additional force on the valve disc that drives it open

Blowdown

Blow down is the difference between the popping pressure (the pressure at which the popping action starts) and reseating pressure expressed either as a percentage of the popping pressure or in pressure units.

Chatter

Chatter is an abnormal rapid reciprocating motion of the movable parts of a pressure-relieving valve in which the disc contacts the seat. The impact on the seat is usually very strong, and therefore can rapidly damage the valve.

Flutter

Flutter is the same reciprocating motion, but the disc does not contact the seat. For example, these adverse effects can be caused by:

- Insufficient gas or vapour flow to the valve,
- Insufficient blow down, or
- Excessive back pressure from undersized discharge piping.

Simmering

Simmering is the audible or visible escape of fluid between the seat and disc at an inlet static pressure below the popping pressure and at no measurable capacity. It applies to safety or safety relief valves on compressible-fluid service. A slight, short-lasting simmering can be tolerated. It is used as a sign of upcoming opening. However, larger amount indicates seat damage and a need for a repair. Prolonged simmering can lead to erosion of the valve seat/disc by the leaking fluid.

Safety-Relief Valve Gagging

A gag is a mechanical device that is applied manually onto a pressure-relieving valve to prevent it from opening.

This can be done before hydrostatic testing of the vessel protected by the valve, or when the valve has failed and is no longer fit for service. Figure 20 gives an example of a safety relief valve gag.

Notes:

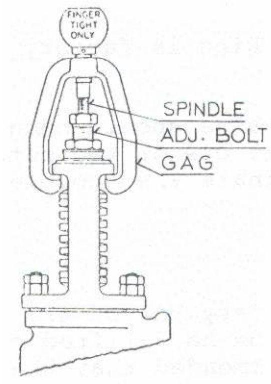


Figure 20

Gagging obviously is a serious act because the pressure-relieving valve is taken out of service and the system has lost its protection. There are strict rules and an approval process for the application of gags.

Gags shall be applied in accordance with PRV (pressure relief valve) manufacturer's instructions where they exist or code requirements.

The application of gags to restrict RV operation shall require the acceptance of the TSSA (Technical Standards and Safety Authority) with the following exceptions:

- Gagging ASME Section III (Rules for Construction of Nuclear Facility components RVs require prior approval from the CNSC (Canadian Nuclear Safety Commission- in addition to acceptance of the TSSA (Technical Standards & Safety Authority).
- Gagging of RVs for hydrostatic pressure testing. Since pressure testing is not considered to be either operation or use of a system or the plant, an RV can be gagged in this situation without the permission of the TSSA Inspector.

Notes:

REVIEW QUESTIONS

VALVES

1. Explain how an electrically operated motorized valve can be operated manually.
2. Explain the proper way to free a stuck valve when operating electric operator manually.
3. State two visual methods of determining the position of a valve.
4. State two operational checks that can be done to determine the position of a valve.
5. What is the purpose of a check valve?
6. Briefly describe how a check valve operates.
7. Give three reasons why the selection of the correct control valve in a system is important.
8. What is the purpose of safety and relief valves in a system?
9. Describe the difference between a safety valve and a relief valve.
10. Define each of the following terms as they apply to safety and relief valves
    a. Lifting pressure
    b. Capacity
    c. Popping action
    d. Blown down
    e. Chatter
    f. Simmering
11. Give two (2) circumstances where it is permissible to gag a safety or relief valve.
12. Would a two or a three way solenoid valve be used to control a pneumatically actuated MV? Explain the reasons for your choice.
13. For the following combinations of actuator and valve body designs, state the failure mode of the valve on loss of air supply.
    a. Direct actuator and direct valves
    b. Reverse actuator and a direct valve
14. Briefly describe the mechanism of an electric motor valve actuator and describe the operation of two sets of switches that might be used to stop the motor.
15. State three impurities that must be minimized in hydraulic or pneumatic supplies to valve actuators. Briefly explain the consequences of not maintaining the fluids free of these impurities.

Notes:

4. STEAM TRAPS

4.0 INTRODUCTION

A steam trap is a device that lets out water or condensate from a system, but holds back steam. We want to get rid of condensate for a few reasons, mainly because it can lead to water hammer, and because we also want to get rid of non-condensable gases such as air or carbon dioxide that might have entered the system or came out of water. So a steam trap must perform three functions:

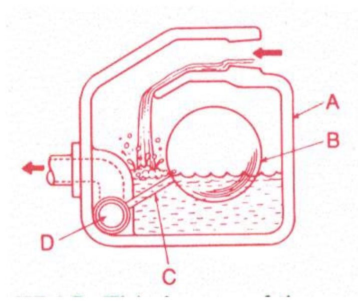
- it must let out condensate but hold back the steam to save it for useful work;
- it must eliminate air and gas quickly, particularly on startup after the system has been shut down for a period; and
- it must accomplish removal of condensate, air, and gases by responding promptly to changing conditions in the line.

In other words, a steam trap must open up quickly when condensate or air approaches it, but close up quickly when steam approaches it. The steam trap will accomplish this by differentiating between water and steam e.g., by sensing the different densities or temperature.

Industrially used steam traps can be divided into three classes:

- **Mechanical –** these traps operate on change of phase of the fluid, i.e., they open to water and close to steam (Figure 21);
- **Thermostatic –** they are actuated by temperature, i.e., they open to cooler condensate but close to hot steam (Figure 22)
- **Thermodynamic –** they operate by using difference in thermodynamic energy of steam and condensate (Figure 23)

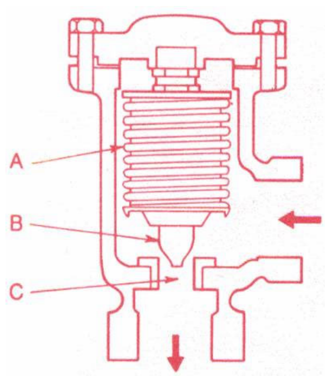
Notes:



Mechanical Steam Trap

Figure 21

Figure 21 is an example of a mechanical float trap. Housing (A) contains a float (B) with a lever (C). The other end of the lever is attached to a discharge valve (D). When condensate starts filling the housing, the float rises, gradually opening the discharge valve. Increasing condensate flow raises the float more, maintaining the proper condensate level in the trap housing. There are other types of mechanical traps but all work on the same principle, i.e., they respond to a difference in density between steam and water/condensate.

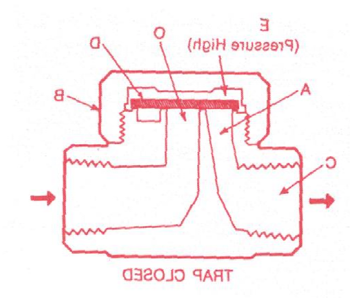


Thermostatic Steam Trap

Figure 22

Figure 22 is an example of a thermostatic steam trap. A corrugated bellows (A) is mounted in a housing. At the bottom of the bellows is a valve (B), which closes the orifice (C) when the bellows expands. Cooler condensate will contract the bellows, which in turn opens the valve, and the condensate is drained. Again, other types of thermostatic trap are available but all work on the principle of temperature difference between steam and condensate.

Notes:



Thermodynamic Steam Trap

Figure 23

Finally, figure 23 example of a thermodynamic steam trap. This disc type trap consists of a flat disc (D) positioned over a centre inlet orifice (O) and an angular discharge (A) leading to a discharge port (C). All are enclosed within a bonnet (B). When operation starts, pressure in the inlet orifice (O) pushes the disc (D) up, opening the discharge (A). Now, a very hot condensate and steam come to the trap the high velocity of flow outward past the rim of the disc (D) up into the chamber (E) tends to reduce the pressure on the underside of the disc causing some of the condensate to flash into steam. At the same time, the flashing condensate flowing outward at high velocity strikes the sidewall of the chamber (E) causing a buildup of pressure in the chamber snapping the disc shut. The disc remains in the closed position until the pressure on the bonnet falls due to the condensing of the steam in the bonnet and the cycle is repeated. The common principle of various designs of thermodynamic steam traps is the use of heat energy in hot condensate and steam, i.e., flashing and condensation.

A proper operation of steam traps is assessed by using three simple methods:

- Visual observation,
- Sound, and
- Temperature measurements.

Visual observation of condensate discharging from the trap is the easiest and most reliable method to check the trap performance. We have to be aware of difference between flash and live steam. A mixture of flash steam and condensate will be discharged several times a minute as the trap cycles. The presence of flash steam is normal and does not imply a trap failure. However, if live steam is discharged at high velocity, the trap has probably failed. If we cannot see the trap discharge, we have to use one of the other methods.

Sound method is based on careful listening to trap operation. We can use some precision method like an ultrasonic testing device or some less precise instruments like an industrial stethoscope down to a piece of ¾" pipe or a screwdriver. What we would hear depends on a type of trap. With a thermodynamic trap we would hear opening and snap closing of the disc several times per minute. If rapid chattering is heard, the trap has failed. We would hear cycling sound of a correctly working mechanical trap and a continuous whistling sound of a failed trap. Finally, with a thermostatic trap, we would again hear cycling of a well functioning trap and no sound if the trap fails closed.

Notes:

Temperature measurement method measures temperatures upstream and downstream of the trap. With a properly working trap the temperature difference between upstream and downstream would be significant. If the temperatures are equal or close, the trap is probably malfunctioning. Modern hand held infrared and laser temperature measurement devices are used today to determine is steam traps are operating correctly.

A word of caution: none of the above methods is a cure-all method for all trap troubleshooting. Usually a combination is used to check the indication provided by one method.

Notes:

REVIEW QUESTIONS

STEAM TRAPS

1. State three functions of a steam trap.
2. State three operation checks that can be done to verify steam trap operation.
3. With reference to the drawings in the text briefly explain how a steam trap performs its function.

5. FLOW SHEETS

Notes:

5.0 INTRODUCTION

Flow sheets are a major piece of operational documentation. They show the flow paths of the many systems in the plant and the line up of the flow paths during normal plant operation. Each device in the plant is shown somewhere on a flow sheet. Flow sheets are used to show the correct operation of the system, alternatively flow paths and isolation points for work protection.

As with everything else in the plant, system numbers organize flow sheets. As a general statement, equipment is shown on a flow sheet with the same or a similar system number. Of course in a plant the size of a nuclear generating station it is hard to say many things that are absolutely true. There are many exceptions. Here are some general statements about flow sheets. They are true more often than they are false.

- Since most devices on a flow sheet have the same system number only the equipment device code is shown on the flow sheet except for the few devices with a different system number. The common system number is shown in a note some where on the flow sheet
- The notes on a flow sheet are usually useless to you. However, once in awhile a vital piece of information is included in the notes. Always read the notes.
- Flow sheets are drawn to show the operation of the system. In many cases they are also arranged to give some physical representation of the equipment layout in the plant. However, when the two conflict the operation is shown.
- The thicker the line on the flow sheet the larger the pipe of the higher the voltage.
- Flow sheets show the normal line up of equipment at full power.
- Sometimes to show interconnections between systems equipment is shown on more than one flow sheet. In this case on the flow sheet that best shows the equipment it is drawn in solid lines. On flow sheets where it is added to show the interrelation ship between systems it is shown in broken lines
- Flow sheets are shown exactly as the station is built
- Connectors are used to show connections to other flow sheets
- Alarm messages are shown at the instrument that causes the alarm
- Instrumentation loops are shown as a circle located in the system at the point where the primary element (the part of the loop that senses the process) is located.
- Letters inside the circle show the purposes of the loop.

FLOW SHEET EXERCISE

Notes:

Flow sheets for this exercise are from Bruce NGS B.

1. On flow sheet 43000-0001 through 43000-0002 trace the path of feed-water from CD1, to 43210-P1, LCV3, LP Heater Bank B, BFP3, HP Heater HX5A and finally to 33110-BO3.
2. Using the legend sheet find and sketch the symbol for the following devices.
   a. A.C. motor
   b. Disconnect switch fused
   c. Normally open globe valve
   d. Normally closed butterfly valve
3. On flow sheet 33000-0001 rev. 12 at grid D8 there is an instrument loop 63737-PT2 (G).
   a. What is the significance of the (G)?
   b. What are the instrument functions served by the loop?
   c. What parameter is being measured?
4. On 53100-0001-02 there are five alarms associated with 53230-T11. What are they?
5. On 43000 the deaerator is shown at the top of the page and the boiler feed pumps at the bottom. Why is this done?
6. The boiler feed pump suction valves are locked open. Which operating manual section details this?
7. Hydrazine addition takes place between the deaerator and the deaerator storage tank. Which flow sheet shows the hydrazine addition equipment?