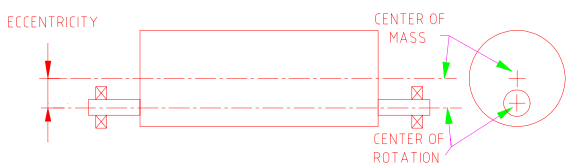
1.9 Vibration

Vibration in equipment is the result of unbalanced forces. The transference of unbalanced forces through equipment into neighbouring structures causing them to shake is vibration. The motion of a body is limited by what connects it to a machine and the walls in which it moves. Every time there is a change of direction unbalanced forces produce a shock. This shock travels throughout the machine and is transmitted to all connected items. Out-of-balance is corrected by adding or removing material so that when the equipment is operating the unbalance is controlled to an acceptable level.

The rate of vibration is called the frequency. It is measured in cycles per second and has the units Hertz. A four-pole electric motor rotates at about 1500 RPM. This is 25 cycles per second or 25 Hertz. Vibration caused by an external applied force is known as a forced vibration because the mass oscillates at the frequency of the external force. An example is the shake produced by the moving pistons and crankshaft in a car engine.

The four methods of vibration control are listed below.

Reduce or eliminate the exciting force by balance or removal.
Use sufficient damping to limit amplitude.
Isolate the vibration source from the surrounds by using spring mounts of appropriate stiffness.
Introduce a counterbalancing force opposite in phase to the exciting force.



Most importantly every moving mass must be balanced about its center of rotation. Every rotating mass must be balanced to an acceptable standard. Out–of-balance rotors cause vibration because the center of mass of the rotor is eccentric (not running true) to its center of rotation. The spinning, off-center mass is continually being flung outward. The machine’s bearings hold the mass in place and react against the developed forces. Vibration results as first the mass is on one side of the bearings and then it is on the other. Balancing aims to distribute the mass evenly about the running center. The drawing above shows eccentricity between the center of mass and the center of rotation.

Materials such as rubber dampen shaking. The rubber flexes and absorbs the movement within itself. Rubber makes a good vibration damper. Because rubber cannot compress much to accommodate movement, rubber dampers are normally used for low amplitude, high frequency vibration where noise transference is a problem. Shock absorbers are used for large amplitude, low frequency situations where springs alone would produce bouncing. An example is in car suspensions.

A vibrating mass can also be isolated from its surroundings by springs. The springs deflect under the shaking body. Installing isolation springs make the spring’s natural frequency the governing frequency for forced vibration transfer. How far a spring will compress under load depends on its stiffness. Altering the spring stiffness controls the amount of vibration transferred to the attachment. Too stiff will transmit vibration, while insufficient stiffness will cause bounce. The correct spring stiffness can be found using charts available from specialist vibration control companies.

An out-of-phase mass is a method not often used to control vibration. It is possible to use a weight with an opposite vibration pattern to negate the out-of-balance forces. This method has been used in motor car engines where a shaft with an eccentric mass is spun in the opposite direction to the crankshaft.

Causes of out-of-balance

The table below lists some common causes for unbalance.

a)	Bent or bowed between support bearings
b)	Overhung weight bends shaft under gravity
c)	Unevenly distributed solid or liquid inside rotor
d)	Loose parts on the rotor
e)	Eccentrically manufactured diameters on the rotor
f)	Misalignment of the drive train to the rotor axis
g)	Loose drive couplings flop about
h)	Loose tolerances between assembled parts on rotor
i)	Shoulders on rotor are made out-of-square to axis
j)	Voids or cavities within the rotor
k)	Misalignment of bearings force shaft to bow

The frictional losses along the pipe cause a pressure loss. If the gas is now at a lower pressure it must be at a correspondingly lesser density. (It is less squashed together than it was at the start.) This means the density of a flowing gas varies along the length of the pipe. The effect is greater at higher velocities.

For a mass of gas to enter a pipe an equal mass must leave the pipe. We know the density is continually thinning as the pressure drops along the pipe. One kilogram of less dense gas requires more space (volume) than the same weight of a more compressed gas. To get one kilogram of expanding gas, which is taking up more volume, out from the end of the pipe it must go faster than when it entered the pipe. Gas flowing through a pipe expands as the pressure falls and speeds up the further it travels along the pipe.

Expanding gas cools. This principle is used in refrigerators and air conditioners. A gas flowing in a pipe is expanding as the density falls. This is why compressed air lines are cool to touch and why water droplets collect in pneumatic valve actuators. The temperature has fallen low enough to condense the water vapour.

WHERE PRESSURE LOSSES COME FROM IN PIPES

Liquid moving in a pipe has to push its way along pipe walls, around bends, through valves, past projections and enclosed items. Throughout its progress friction robs energy. Three factors affect pressure loss in pipes.

Surface Friction

Along walls the liquid has to overcome friction. Wall friction depends on surface roughness. The higher the projections into the liquid the more the friction. At low velocities a laminar sub layer of slow flowing liquid covers the roughness. But at high velocities the sub layer thins as eddies in the turbulent center flow extend to the projections.

Direction Changes

Liquid that is forced to change direction loses energy. When a liquid goes around a 90^o bend its momentum has to be redirected. From going at velocity in one direction it now has to go at the same velocity in a completely different direction. To do this it converts pressure into the energy it needs to change direction. A pressure loss results. The more sudden the change in direction the greater the energy it needs and the higher the corresponding pressure losses.

Liquid viscosity

A liquid that easily slides requires less energy to move than one that does not want to flow. Honey is thousands of times more viscous than water. Pushing honey through pipes, around corners and past valves requires far more energy than for water. If the honey was warmed it would then flow easier and the pressure loss would be less.

MINIMISE FRICTION IN PIPELINE CONSTRUCTION

During design, procurement and installation of a pipeline follow the recommendations in Table 1.

DESIGN	Select smooth bore pipes.	100 meters of 100 mm (4”) plastic pipe containing water moving at 1 m/s (3.25 ft/s) will lose 900 mm (35”) of pressure. The same flow in a 100 mm steel seamless pipe will lose 1000 mm (39”) pressure.
	Minimise flow disruptions.	Use long radius elbows; use pipe reducers; minimise the number of flanges; use full bore straight through valves; use pipe size branch tees and reduce down on the branch (a must on suction lines); use instrumentation which does not project into the flow.
	Keep flow velocities low.	Select pipe sizes that are practicable while keeping flow velocities reasonable.
CONSTRUCTION	Cut gasket holes to the bore diameter.	Make the gasket bore hole to the pipe bore diameter. Do not let the gasket project into the liquid flow path, as it will cause unnecessary friction and turbulence.
	Clean off weld splatter.	Weld splatter sits on the pipe surface and disrupts the liquid flow pattern. The splatter can come lose and damage down stream instruments and equipment.
	Keep butt weld peaks low.	Like gaskets cut with the diameter less than the pipe bore, welds with high peaks project into the liquid flow. Try keep welds below the height of the sub-layer thickness.
	Make multiple segment mitered bends.	‘Lobster back’ 90^o bends are used when large diameter long radius bends are not available. Make them out of equal sized 15^o segments instead of the usual 22.5^o segments

TABLE 1 Practices that minimise pressure loss in pipes.

In a steam jacketed tank the inside wall is made as thin as possible to reduce the thermal resistance. The outside wall of the jacket is insulated to prevent heat loss to the cold surroundings. If it were not insulated the outer wall of the steam jacket would radiate heat into the cold surroundings. An uninsulated, jacketed tank would waste a lot of steam to heat the contents. Much heat would be lost as radiation from the tank's outer wall and as convection of the air touching the outside wall. Insulation saves a great deal of otherwise wasted energy.

Heat Loss Maximisation

In situations where maximum transfer of heat is required it becomes necessary to find ways to:

- make the fluid contact the hot surfaces as much as possible by using turbulence,
- keep the temperature difference between the surface and the fluid as great as possible,
- keep the thermal resistance of materials separating cold fluids from hot fluids the as low as possible,
- get the heat transfer coefficient of the fluids up,
- remove any surface scaling,
- use materials of high thermal conductivity (i.e. low thermal resistance).

For example, boiling a pot of water over an open fire in the forest takes longer than boiling the same pot over a fireplace hearth in a house and both take longer that boiling the same amount of water in an electric kettle.

Out in the open air, the pot gets only a small amount of the fire's heat. Most is radiated in all directions. Some radiation hits the pot and some convective heat from the hot rising air touch the pot. In the hearth the pot gets radiation off the hot surrounding bricks and the fire and also convection heat from the hot rising air. In the kettle the water gets heat from direct contact with the heating elements. All the heat in the kettle's heating elements is injected into the water and little is lost to the surroundings.

When trying to heat-up a substance it is necessary to insure that the maximum heat possible is put into it and not lost to the surroundings.

almost a certainty over the years. If you must connect plastic to metal use a flanged joint of suitable pressure rating. Even with a flexible sealant between the two materials it is likely that over years of service many connections will leak.

Plastic threaded fittings

Plastic threads are usable only in low-pressure service where they will remain at a constant temperature. If you are looking for 50 years of trouble free life from above ground reticulated gas plastic piping be sure all plastic connections are welded or flanged, not threaded.

Mixing pipe fittings and compatibility

Using pipe fittings made of different metals can lead to galvanic corrosion of one of the parts. One item will eventually fail and leak. Check the galvanic series for both parts and only use different metals if they are very close in the series.

It is also necessary to check the chemical compatibility of mixed threaded fittings to insure they will handle the chemicals and conditions in contact with them. Mixing brass fittings with stainless steel or steel fittings will lead to danger and failure in the wring chemical environment.

Different coefficients of expansion between threaded parts can produce high stress in one or the other at high temperature and a gap between the two at low temperature.

Don't mix thread standards. BSP and NPT are totally different threads and must never be forced together. They have different flank angles and except for the 1/2" and 3/4" sizes, they have a different pitch. They are not compatible. If you have a job with mixed threads make sure that you go and get the right fittings or the right adapter fittings. Good practices always save a lot of problems in the future.

Pressure test piping

Always pressure test threaded pipe work to 1.25 times its working pressure before putting it into service. While the piping is under pressure, go around to all the threaded joints and 'soapy water' test them for leaks. Spray on a mixture of water and liquid detergent and look for bubbles forming as the air leaks out. If bubbles appear remake the joint.

Once installed repeat the 'soapy water' test every 36 months as a regular preventative maintenance routine on all threaded gas and air pipelines.

2.10 Process control valves

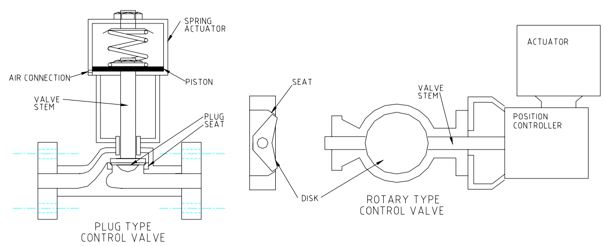
Control valves regulate the flow of a liquid or gas by opening or closing internal passages. They form part of a control loop used to control a process. The control valves responds to instructions from the controller and adjusts the internal openings accordingly..

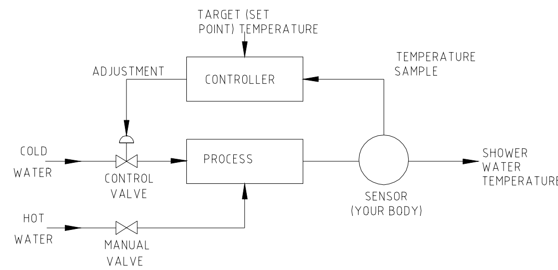
Purpose of control valves

A control valve varies the rate of flow passing through itself. The valve stem moves, altering the size of the passage and this increases decreases or holds steady the flow. The control valve opening is altered whenever the process parameter being controlled does not equal the value it is meant to be (the set point).

Operation of a control valve

A control valve consists of three key components - the valve, the actuator and the controller. The valve can be one of two basic types. A plug and seat design, in which a plug is closed against a seat or a quarter turn valve in which a disc, ball or cone is turned against a seat. The drawings below show the two types of control valve.





The actuator is used to move the valve stem. They are usually air (pneumatically) or electrically driven. The controller calculates the size of the change to the valve internal passage to bring the flow to the desired rate.

The rate of flow through the valve depends on the pressure difference between the inlet and outlet. To slow the flow the valve is closed which causes more back-pressure and a greater difference between the inlet and outlet pressures. To increase the flow the valve is opened which reduces the back-pressure and the pressure difference across the valve.

The portion of the valve that regulates the flow is known as the valve trim. It consists of a fixed-in-place seat and the movable plug, disc, ball or cone. The trim can be selected to create a variety of passage shapes that control the flow.

Control valve tuning

The controller tuning dictates the way the valve responds to the changing process parameter. Tuning of a control valve sets the speed and intensity of the valve response when the need for a correction is detected.

The controller contains internal logic that produces an output to the actuator to move the stem a predetermined amount. This logic looks at:

a) the size of the discrepancy between the set point and the current value of the controlled parameter (Proportional)
b) the length of time the discrepancy has been present (Integral)
c) the speed at which the discrepancy has been changing (Derivative)

and determines how fast and how far to move the stem.

Once the position of the trim is altered the controller waits for the next sample signal from the sensing element to check the difference remaining to the set point. The valve stem is moved and the flow altered until the difference between the set point and the actual value of the controlled parameter is within tolerance. An example of tuning a control valve can be likened to a person under a shower adjusting the taps to get the water temperature right. The sketch below shows the logic involved in controlling the water temperature.

If the hot water is first put on, the control valve becomes the cold water tap. Your body senses the temperature of the water. If the water is too hot you open the cold water tap. You wait a while (the time lag) to sense the effect of increasing the cold water flow. The cold water is adjusted until the temperature from the combined flows is just right. Once the temperature is right the valves are left alone and the temperature is stable. If a change occurs, such as someone doing the laundry with cold water, a drop in cold water flow to the shower occurs and the water temperature gets hotter. You again sense the changing temperature and make the necessary adjustments. In response the cold water tap is opened further or the hot water tap is closed.

This whole process involved sensing the temperature and moving valve positions until the parameter under control (temperature) stabilised. A control valve works the same way.

Problems with control valves

- Control valves may not properly regulate the parameter they are controlling. If the process cannot be controlled product quality issues arise.

2.15 Gear box drives

A gearbox is used to control the operating speed of industrial equipment. Proper selection, care and maintenance of gearboxes is critical. Failure of the gearbox causes the equipment and associated plant to stop. Keywords: service duty, drive, breather, lubricant, oil analysis.

Gear box selection

Load type	- Steady, consistent - Intermittent, on-off, fluctuating - Impact, hammering, surging
Environment	- Temperature of location - Cooling and heat dissipation - Dustiness - Humidity, dampness
Forces	- How are the forces created? - Where are the forces located? - Where are the forces transmitted?
Robustness	- Is the mounting sturdy? - Will the shaft handle the torque? - Is the casing solid and rigid? - Is there sufficient excess service duty to handle unexpected loads?
Drive	- Direct coupled, chain, belt driven - Minimum bearing loads required - Orientation of gearbox in relation to forces generated
Gear type	- Loads and forces applied to gears - Heat generated by the meshing - Lubrication type
Maintenance	- Parts availability - Standardisation across the site - Skill level of maintainers - Presence of procedures
Operations	- Production demands - Operator care - Overload potential

A gearbox is selected for the duty it must perform. It converts a high input speed to a lower output speed and so permits one driver element, such as an electric motor, to do numerous duties. Each selection must take consideration of the following points.

For example, in the selection of a gearbox to be direct coupled to an agitator for a stirred tank, consideration must be given to the distance the output shaft bearings are apart. Bearings positioned further apart cope better with the bending forces generated by the paddles located at the end of the agitator shaft.

The load type will affect the selection of the gear type. Steady, continuous loads can be accommodated by spur gears but impact loads can break spur gear teeth. A more robust gear to use in impact load situations would be a helical gear. This gear shape offers more tooth cross-sectional area and because of the helix dissipates impact forces axially and tangentially.

Another style of gearing often seen on slow moving, high load applications is the worm and worm wheel. Planetary gearboxes are available where space is limited for standard design gearboxes.

Gearbox care

A well-selected gearbox will have a long service life. Long term maintenance will involve checking oil levels and for critical or expensive gearboxes checking oil quality. Oil quality ought to be tested at least every year for stationary plant and every sic months for mobile plant. More often if the loading or service duty is arduous. A simple site test for gearbox oil is to take a sample and look at the color, note the smell, look and feel for presence of grit and feel the slipperiness compared to fresh oil. If you are concerned then send a sample to a lubrication test lab.

An oil analysis includes tests for the oil's lubricity, changes in the oil's condition, condition of additives, solids particle counts for larger than 2, 5 and 15 micron particles, moisture pick-up, dust/dirt contamination and the metals in the oil.

The choice of lubricant is critical. The oil must retain its properties at the operating temperature. The gearbox manufacturer is best able to advise the oil to use. Where the manufacturer cannot be contacted, one of the major oil companies can offer practical suggestions on the oil to use. Mixing of different oils in the same gearbox is poor practice. Unless you can tell the oil supplier with certainty what oil is already in the gearbox so a match can be specified, do not cross mix oils. Mineral and synthetic oils are not compatible. It is better to drain the old oil out, flush the gearbox through with the new oil, put in the new oil to the required level and run the gearbox for two to three hours and finally dump, flush and refill the gearbox again.

Breathers are fitted to prevent shaft seals blowing out as the internal pressure rises when the gearbox is warming up to operating temperature. A breather allows moisture in the air and dirt from the surroundings to enter the gearbox. Locate and protect the breather to reduce the risk of contamination. Check with the gearbox manufacturer to see if a

3.4 5 Whys

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It's important when resolving a problem that you address the problem and not a symptom of the problem. Determining the real problem is called finding the root cause. There are special techniques for determining the root cause of a problem. We'll review one technique known as "The 5 Whys."

What Is It?
The five whys is a form of root cause analysis. You start with a statement of the situation and ask yourself why it is happening. Then you look at your answer and ask "Why" again and again until you have done so five times. By refusing to be satisfied with just one explanation, you increase the possibility of identifying the root cause of the situation.

How does it work?
After describing the situation. You ask yourself why that situation is occurring and enter your response in the appropriate space in the tool. You then look at your first answer and ask yourself why that situation is occurring. You do this again and again until you have asked why five times or until you can no longer answer the why question.

When would I use it?
Very often, the real cause of a problem or situation is not obvious. The obvious explanation often reveals yet another problem. The five whys is very helpful in such situations.

By repeatedly asking the question "Why" (five is a good rule of thumb), you can peel away the layers of symptoms which can lead to the root cause of a problem. Very often the ostensible reason for a problem will lead you to another question. Although this technique is called "5 Whys," you may find that you will need to ask the question fewer or more times than five before you find the issue related to a problem.

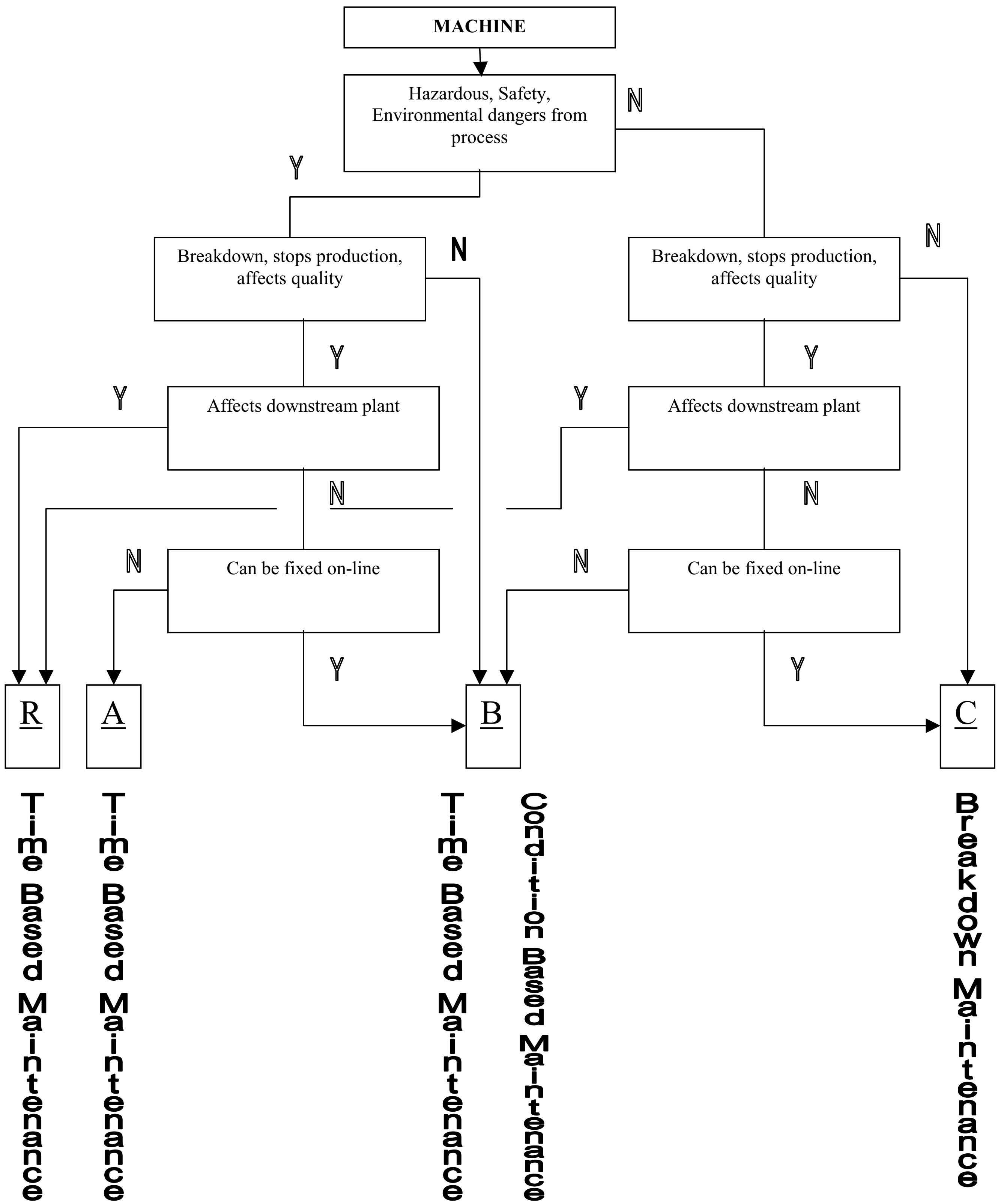
Benefits Of The 5 Whys
Help identify the root cause of a problem. Determine the relationship between different root causes of a problem. One of the simplest tools; easy to complete without statistical analysis.

When Is 5 Whys Most Useful?
When problems involve human factors or interactions. In day-to-day business life; can be used within or without a Six Sigma project.

How To Complete The 5 Whys
1. Write down the specific problem. Writing the issue helps you formalize the problem and describe it completely. It also helps a team focus on the same problem.
2. Ask Why the problem happens and write the answer down below the problem.
3. If the answer you just provided doesn't identify the root cause of the problem that you wrote down in step 1, ask Why again and write that answer down.
4. Loop back to step 3 until the team is in agreement that the problem's root cause is identified. Again, this may take fewer or more times than five Whys.

Problem Statement: You are on your way home from work and your car stops in the middle of the road.
1. Why did your car stop?
- Because it ran out of gas.
2. Why did it run out of gas?
- Because I didn't buy any gas on my way to work.
3. Why didn't you buy any gas this morning?
- Because I didn't have any money.
4. Why didn't you have any money?
- Because I lost it all last night in a poker game.
5. Why did you lose your money in last night's poker game?
- Because I'm not very good at "bluffing" when I don't have a good hand.

As you can see, in both examples the final Why leads the team to a statement (root cause) that the team can take action upon. It is much quicker to come up with a system that keeps the sales director updated on recent sales or teach a person to "bluff" a hand than it is to try to directly solve the stated problems above without further investigation.



MACHINE
Hazardous, Safety, Environmental dangers from process
Y
N
Breakdown, stops production, affects quality
N
Breakdown, stops production, affects quality
N
Y
Y
Y
Affects downstream plant
Y
Affects downstream plant
N
N
N
Can be fixed on-line
N
Can be fixed on-line
Y
Y
R
A
B
C
Time Based Maintenance
Time Based Maintenance
Time Based Maintenance
Condition Based Maintenance
Breakdown Maintenance

5.4 Flanges leaking

As well as using the checklist, read the notes in the sections on Chemical and Material Compatibility, Bolting and Gaskets in Flanged Connections and Threaded Connections.

Observation	Possible Cause	Remedy
Leaking flange	Gasket material incompatible.	▪ Check gasket material selection.
	Gasket is too thick.	▪ Use thinnest gasket possible.
	Bolts are loose.	▪ Use high tensile bolts and nuts. ▪ Tension bolt to 75% of yield stress in proper sequence. ▪ Use same bolt size and specification throughout. ▪ If nuts bind on bolt threads get a new bolt and nut to the right specification.
	Pipe work was over-pressured.	▪ Install pressure relief to a safe place.
	Corrosion attack.	▪ Protect bolts from chemical and environmental corrosion.
	Flanges are out of square.	▪ Cut off flanges and replace them square to pipe and each other. ▪ Remove any pipe misalignment by removing and installing the pipe again.
	Flange faces are dirty, distorted.	▪ Clean off all old gaskets so face is like new. ▪ File burrs of flange faces so faces are flat. ▪ Replace or re-machine faces that are deeply scored or corroded.