07
Thermodynamics

Objectives

When you completed study of this chapter you should be able to:

- Understand the laws associated with thermodynamics;
- Explain the concepts of thermodynamic systems;
- Be familiar with the practical applications of thermodynamic principles.

7.1 Law's of Thermodynamics

7.1.1 First law Thermodynamics

The First Law of Thermodynamics in general deals with the law of conservation of energy and may be stated as:

"Although energy assumes many forms, the total quantity of energy is constant and when energy disappears in one form, it appears simultaneously in other forms".

7.1.2 The Second Law of Thermodynamics

The various interpretations of the second law are given below:

"Available energy of the isolated system decreases in all real processes and is converted in ideal processes."

"The entropy of the isolated system increases in all real processes and is conserved in ideal processes."

"Available energy is the maximum portion of energy that could be transformed into useful work by processes which reduce the system to a state in equilibrium with the earth and its atmosphere."

7.1.3 Third Law of Thermodynamics

The third law can be stated as follows:

"Absolute entropy is zero for all perfect crystalline substances at absolute zero temperature."

"The entropy of a pure substance in complete thermodynamic equilibrium becomes zero at the absolute zero temperature."

"It is impossible by any procedure, no matter how idealized to reduce any assembly to the absolute zero in a finite number of operations".

The third law may be used to evaluate the entropies of pure substances according to fundamental definition of entropy

7.2 Thermodynamic System

The thermodynamic analysis of any transformation necessitates the specification of a restricted region of space or a finite portion of matter. This specific portion on which attention is focused is termed as System and everything outside the system which has a direct bearing on its behaviour is known as Surroundings. The system is separated from its surroundings through a closed surface known as Boundary. The interactions between system and surrounding occur through the boundaries.

7.2.1 Types of Systems

The classification of system is done on the basis of

- **Flow of mass and energy across the boundary**

  There are two types under this class
  - *Open System*: A system is known to be 'Open System' if both mass and energy flow across the boundary between system and surrounding
  - *Closed System*: The system will be referred to as 'Closed System' if mass does flow across the boundary but only energy flows across the boundary between system and surroundings

- **Composition**

  There are two types under this class
  - *Homogeneous System*: If the composition is uniform throughout the system, it is 'Homogenous System'.
  - *Heterogeneous System*: A system with a difference in composition throughout is referred to as Heterogeneous System.

    An 'Isolated System' is one which has no interactions with its surroundings.

7.2.2 Thermodynamic Equilibrium

When there is no unbalanced force in the interior of a system and none between a system and its surroundings, the system is said to be in a state of Mechanical equilibrium.

When a system in mechanical equilibrium does not tend to undergo a spontaneous change of internal structure, it is said to be in a state of Chemical equilibrium.

When a system in mechanical and chemical equilibrium does not tend to undergo a spontaneous change in the coordinates of a system when it is separated from its surroundings by a diathermic wall, it is said to be in a state of Thermal equilibrium.

A system satisfying conditions for all three types of equilibrium is said to be in a state of Thermodynamic equilibrium. In this state there will be no tendency for any change in the state of system or surroundings.

7.2.3 Process

A process is said to occur when transformation, either physical or chemical in nature, takes place within the system causing a change in the state of the system, thereby resulting in a change in properties of the system. A system, while traversing from a fixed initial state to a fixed final state, passes through a series of intermediate states know as 'path of process'.

- **Quasi-static and Non-Quasi-static processes**

  During a quasi-static process, the system departs from equilibrium infinitesimally at every instant. If the departure from equilibrium is not infinitesimal, then process is non-quasi-static.

- **Reversible and Irreversible**

  A reversible process brings about such changes in system and surroundings that both system and surroundings can be restored to their original condition by reversing the direction of the interactions. A process not fulfilling this condition is irreversible. The salient characteristics of a reversible process are:
  - It is a frictionless process
  - It is never more than differentially removed from equilibrium
  - Driving forces are differential in magnitude
  - Process can be reversed without leaving any change in the system or surroundings
  - It produces maximum work and requires minimum expenditure of work. All real processes are irreversible

- **Cyclical process**

  A system is said to undergo a cyclic process if during the course of change it is restored to its original state

  - Isochoric - Process during which volume remains constant
  - Isobaric - Process during which pressure remains constant
  - Isothermal - Process during which temperature remains constant
  - Adiabatic - Process during which there is no transfer of heat from system to surrounding and vice versa
  - Isentropic - Process during which entropy remains constant.
  - Throttling - Process during which enthalpy change is zero

7.2.4 Evaluation of Thermodynamic Properties

The most common means for the evaluation of thermodynamic properties are:

- **Tables of thermodynamic properties**
  In this category the steam table is most pertinent. The steam table tabulates enthalpy, entropy, sp. volume and internal energy over a wide range of pressure and corresponding saturation temperatures.

  Two types of tables are available:

  - For properties of saturated liquid and vapor phase in equilibrium. The saturated liquid at 32°F is assigned values equal to zero for enthalpy and entropy. The range varies from 32°F to critical point at 705.34°F
  - For properties of super heated steam ie steam at a temperature higher than the saturation temperature. This is actually gas region

- **Thermodynamic Diagram**
  The widely used thermodynamic diagrams are:
  - T-s or Temperature entropy diagram
  - P-H or pressure enthalpy diagram
  - H-S or Enthalpy-Entropy OR Mollier diagram

7.3 Applications of Thermodynamics Principles

7.3.1 Nozzle

A device, in which kinetic energy and internal energy of a fluid are interchanged as a result of changing cross-sectional area available for flow, is termed a nozzle.

A convergent nozzle is one in which with an incompressible fluid the nozzle area continues to decrease and velocity increases as the pressure decreases. On the other hand, for compressible fluids, the area first decreases and then increases so that the nozzle has a converging section followed by a divergent section. Such a nozzle is called a convergent divergent nozzle.

A common example is the converging nozzle designed to produce a high velocity stream. However, converging and diverging sections are used separately or combined for many industrial applications as in turbine ,jet engines ,ejectors and diffusers.

7.3.2 Compressor

A machine, used to provide gas at high pressure by the application of work from the external agency on the gas, is known as a compressor.

The compressor is used for the following purposes

- Transporting fluids
- Providing high pressure for carrying out reactions and separation processes
- For pneumatic instruments
- For transferring mechanical energy to a fluid for agitation, solid particle transportation, etc.

Compressing devices

The different types of compressing devices are

- Centrifugal fans
- Rotary or positive displacement compressors and blowers
- Centrifugal compressors or turbo-compressors
- Reciprocating compressors
- Jet compressors

Single and double acting compressors

In the single acting compressor the air is admitted to one side of piston only while in case of double acting air is admitted to each side of piston alternatively so one side of piston performs suction stroke and the air on the other side is compressed.

Multi-stage compression

In a single-stage compressor, the whole range of compression is accomplished in one cylinder, ie in one step or stage. Contrary to this, if the whole range of compression (from initial to final pressure) is accomplished in a unit in which there are two or more cylinders in series, each compressing over only a part of total pressure range, then the compressing system is termed as multi-stage compression.

The advantages of multi-stage compression are

- Reduction of driving power required for given pressure ratio
- Improved volumetric efficiency for a given pressure ratio
- Permits high delivery pressure with reasonable volumetric efficiency
- Size and strength of cylinders can be adjusted to suit volume and pressure of air
- Multi-cylinders give better mechanical balance and improved cooling during compression

7.3.3 Ejector-System

The operating principle of an ejector is basically to convert pressure energy of the motive steam into velocity. This occurs by adiabatic expansion from motive steam pressure to suction-load operating pressure. This adiabatic expansion occurs across a con-verging and diverging nozzle. This results in supersonic velocity off the motive nozzle, typically in the range of mach 3 to 4. In reality ,the motive steam expands to a pressure lower than the suction load pressure. This creates a low-pressure zone for pulling the suction load into the ejector. High-velocity motive steam entrains and mixes with the suction gas load. The resulting mixture's velocity is still supersonic. Next, the mixture enters a venturi where the high velocity recon-verts o pressure. In the converging region, velocity is converted o pressure as cross-sectional flow area is reduced. At the throat section, a normal shock wave is established. Here, a significant in pressure and loss of velocity across the shock wave occurs. Flow across the shock wave goes from supersonic ahead of the shock wave, to sonic at the shock wave and subsonic after the shock wave. In the diverging section, velocity is further reduced and converted into pressure. Motive pressure, temperature and quality are critical variables for proper ejector operating performance. The amount of motive steam used is a function of required ejector performance. The nozzle throat is an orifice and its diameter is designed to pass the specified quantity of motive steam, required to effect sufficient compression across the ejector. Calculation of a required motive nozzle throat diameter is based on the necessary amount of motive steam, its pressure and specific volume.

Motive steam quality is important because moisture droplets affect the amount of steam passing through the nozzle. High-velocity liquid droplets also prematurely erode ejector internals, reducing performance. Operating a vacuum unit requires an ejector system to perform over a wide range of conditions. Loads vary from light to above design. The ejector system must be stable over all anticipated operating conditions.. Also, an accurate understanding of ejector system back pressure for all operating modes is necessary for stable operation. An ejector does not create its discharge pressure, it is simply supplied with enough motive steam to entrain and compress its suction load to a required discharge pressure. If the ejector back pressure is higher than the discharge pressure it can achieve, then the ejector "breaks" operation and the entire ejector system may be unstable.

7.4 Heat Conversion & Power Cycles

7.4.1 Parts of an Engine

Cylinder

The basic part of the engine is the cylinder. The piston moves up and down inside the cylinder. The engine described here has one cylinder. This setup is typical of most lawn mowers, but most cars have more than one cylinder (four, six and eight cylinders are common). In a multi-cylinder engine the cylinders usually are arranged in one of three ways: **inline**, **V** or **flat** (also known as horizontally opposed or boxer), as shown in the following figures.

Different configurations have different smoothness, manufacturing-cost and shape characteristics that make them more suitable in some vehicles.

Spark plug

The spark plug provides the spark that ignites the air/fuel mixture so that combustion can occur. The spark must happen at just the right moment for things to work properly.

Valves

The intake and exhaust valves open at the proper time to let in air and fuel and to let out exhaust.

Piston

A piston is a cylindrical piece of metal that moves up and down inside the cylinder.

Piston rings

Piston rings provide a sliding seal between the outer edge of the piston and the inner edge of the cylinder. The rings serve two purposes:

They prevent the fuel/air mixture and exhaust in the combustion chamber from leaking into the sump during compression and combustion.

They keep oil in the sump from leaking into the combustion area, where it would be burned and lost.

Combustion chamber

The combustion chamber is the area where compression and combustion take place. As the piston moves up and down, you can see that the size of the combustion chamber changes. It has some maximum volume as well as a minimum volume. The difference between the maximum and minimum is called the displacement and is measured in liters or CCs (Cubic Centimeters, where 1,000 cubic centimeters equals a liter). So if you have a 4-cylinder engine and each cylinder displaces half a liter, then the entire engine is a "2.0 liter engine." If each cylinder displaces half a liter and there are six cylinders arranged in a V configuration, it is a "3.0 liter V-6." Generally, the displacement indicates something about how much power an engine has. A cylinder that displaces half a liter can hold twice as much fuel/air mixture as a cylinder that displaces a quarter of a liter, and therefore the output expected is about twice as much power from the larger cylinder (if everything else is equal). So a 2.0 liter engine is roughly half as powerful as a 4.0 liter engine.

Connecting rod

The connecting rod connects the piston to the crankshaft. It can rotate at both ends so that its angle can change as the piston moves and the crankshaft rotates.

Crank shaft

The crank shaft turns the piston's up and down motion into circular motion just like a crank on a jack-in-the-box does.

Sump

The sump surrounds the crankshaft. It contains some amount of oil, which collects in the bottom of the sump (the oil pan).

Valve train

The valve train comprises of the valves and a mechanism that opens and closes them. The opening and closing system is called a camshaft. The camshaft has lobes on it that move the valves up and down.

Most modern engines have what are called overhead cams. This means that the camshaft is located above the valves, The cams on the shaft activate the valves directly or through a very short linkage. Older engines used a camshaft located in the sump near the crankshaft. Rods linked the cam below to valve lifters above the valves. This approach has more moving parts and also causes more lag between the cam's activation of the valve and the valve's subsequent motion. A timing belt or timing chain links the crankshaft to the camshaft so that the valves are in sync with the pistons. The camshaft is geared to turn at one-half the rate of the crankshaft. Many high-performance engines have four valves per cylinder (two for intake, two for exhaust), and this arrangement requires two camshafts per bank of cylinders, hence the phrase "dual overhead cams."

Ignition system

The ignition system produces a high-voltage electrical charge and transmits it to the spark plugs via **ignition wires**. The charge first flows to a **distributor**, which you can easily find under the hood of most cars. The distributor has one wire going in the center and four, six, or eight wires (depending on the number of cylinders) coming out of it. These **ignition wires** send the charge to each spark plug. The engine is timed so that only one cylinder receives a spark from the distributor at a time. This approach provides maximum smoothness.

Cooling system

The cooling system utilized in most cars consists of the radiator and water pump. Water circulates through passages around the cylinders and then travels through the radiator to cool it off. Air-cooling makes the engine lighter but hotter, generally decreasing engine life and overall performance.

Air intake system

Most cars are normally aspirated, which indicates that air flows through an air filter and directly into the cylinders. High-performance engines are either turbocharged or supercharged, which means that air coming into the engine is first pressurized (so that more air/fuel mixture can be squeezed into each cylinder) to increase performance. The amount of pressurization is called boost. A turbocharger uses a small turbine attached to the exhaust pipe to spin a compressing turbine in the incoming air stream. A supercharger is attached directly to the engine to spin the compressor.

Starting system

The starting system basically consists of an electric starter motor and a **starter solenoid**. When you turn the ignition key, the starter motor spins the engine a few revolutions so that the combustion process can start. It takes a powerful motor to spin a cold engine. The starter motor must overcome:

- All of the internal friction caused by the piston rings
- The compression pressure of any cylinder(s) that happens to be in the compression stroke
- The energy needed to open and close valves with the camshaft
- All of the "other" things directly attached to the engine, like the water pump, oil pump, alternator, etc.

This is because considerable energy is needed and because a car uses a 12-volt electrical system, hundreds of amps of electricity must flow into the starter motor. The starter solenoid is essentially a large electronic switch that can handle that much current. When the ignition key is turned on , it activates the solenoid to power the motor.

Lubrication system

The lubrication system makes sure that every moving part in the engine gets oil so that it can move easily. The two main parts needing oil are the pistons (so they can slide easily in their cylinders) and any bearings that allow things like the crankshaft and camshafts to rotate freely. In most cars, oil is sucked out of the oil pan by the oil pump, run through the oil filter to remove any grit, and then squirted under high pressure onto bearings and the cylinder walls. The oil then trickles down into the sump, where it is collected again and the cycle repeats.

Fuel system

The fuel system pumps gas from the gas tank and mixes it with air so that the proper air/fuel mixture can flow into the cylinders. Fuel is delivered in three common ways: carburetion, port fuel injection and direct fuel injection.

In carburetion, a device called a carburetor mixes gas into air as the air flows into the engine.

In a fuel-injected engine, the right amount of fuel is injected individually into each cylinder either right above the intake valve (port fuel injection) or directly into the cylinder (direct fuel injection).

Exhaust system

The exhaust system includes the exhaust pipe and the muffler. Without a muffler, it is common to hear sound of thousands of small explosions coming out the tailpipe. A muffler dampens the sound. The exhaust system also includes a catalytic converter.

Emission control system

The emission control system in modern cars consists of a **catalytic converter**, a collection of sensors and actuators, and a computer to monitor and adjust everything. For example, the catalytic converter uses a catalyst and oxygen to burn off any unused fuel and certain other chemicals in the exhaust. An oxygen sensor in the exhaust stream makes sure there is enough oxygen available for the catalyst to work and adjusts things if necessary.

Electrical system

The electrical system consists of a battery and an alternator. The alternator is connected to the engine by a belt and generates electricity to recharge the battery. The battery makes 12-volt power available to everything in the car needing electricity (the ignition system, radio, headlights, windshield wipers, power windows and seats, computers, etc.) through the vehicle's wiring.

7.4.2 Internal Combustion Engines

Internal Combustion (IC) engines have absolutely revolutionized transportation, power generation and have perhaps altered the way the society operates forever. Typical IC engines are classified as Spark and Compression ignition engines.

The simplest model for IC engines is the air-standard model, which assumes that:

- The system is closed.
- Air is the working fluid and is modeled as an ideal gas throughout the cycle.
- Compression and expansion processes are isentropic.
- A reversible heat transfer process characterizes the combustion of fuel and air.
- Heat rejection takes place reversibly and at constant volume.

Spark Ignition Engines (Otto Cycle)

The spark-ignition engines are the most common type used in cars. Larger engines operate using a four-stroke cycle, while smaller engines operate on a two-stroke cycle. In a simple four-stroke cycle, a combustible mixture of air and fuel is drawn into a cylinder during the intake stroke, and the temperature and pressure of the mixture is raised during the compression stroke. At near the maximum compression, a spark initiates combustion of the mixture, raising its temperature and forcing expansion. The expanding gases do work on the piston during the power stroke and then the burnt gases are purged during the exhaust stroke. Typically 3000 or more such cycles are repeated in a minute.

The Otto cycle is an air-standard model of the actual cycle. In addition to the air-standard assumptions listed above, the combustion process is configured as a reversible constant volume heat addition process. The four steps of the air-standard Otto cycle are detailed below:

(1-2) Isentropic compression ***(Compression Stroke)***

(2-3) Constant-volume, reversible heat addition ***(Ignition)***

(3-4) Isentropic expansion ***(Power Stroke)***

(4-1) Reversible, constant-volume heat rejection ***(Exhaust)***

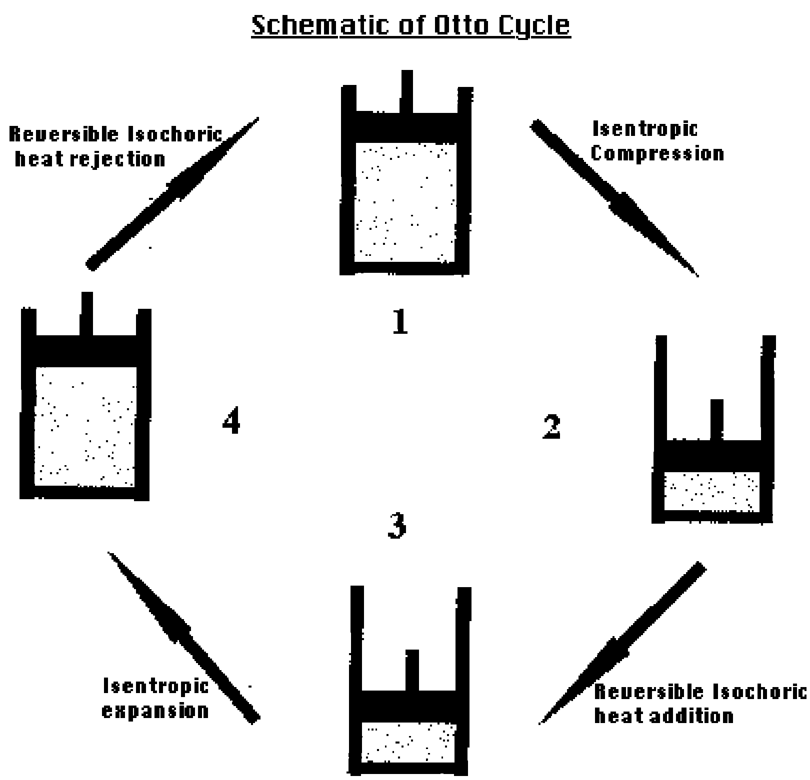

Figure 7.1
Otto Schematic Cycle

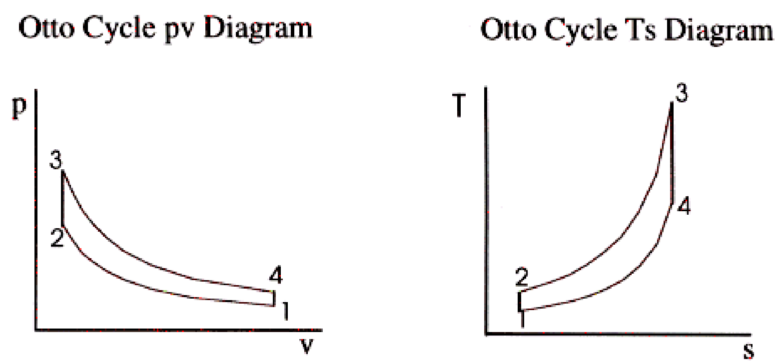

Figure 7.2
Otto Cycle Diagram

Compression Ignition Engine (Diesel Cycle)

Compression Ignition engines are specifically used in marine applications, power generation and heavier transportation vehicles. Here, in a typical four-stroke cycle, air is drawn into the cylinder in the intake stroke and then compressed during the Compression Stroke. At near maximum compression, finely atomized diesel fuel is sprayed into the hot air, initiating auto-ignition of the mixture. During the subsequent power stroke, the expanding hot mixture does work on the piston, then the burnt gases are purged during the exhaust stroke

The Diesel Cycle is an air-standard model of the actual cycle described above. The Diesel Cycle differs from the Otto Cycle only in the modeling of the combustion process: In a Diesel Cycle, it is assumed to occur as a reversible constant pressure heat addition process, while in an Otto Cycle, the volume is assumed constant. The four steps of the air-standard Diesel Cycle are outlined below:

(1-2) Isentropic Compression (Compression Stroke)

(2-3) Reversible, constant pressure heat addition (Ignition)

(3-4) Isentropic expansion to initial volume (Power Stroke)

(4-1) Reversible constant-volume heat rejection (Exhaust)

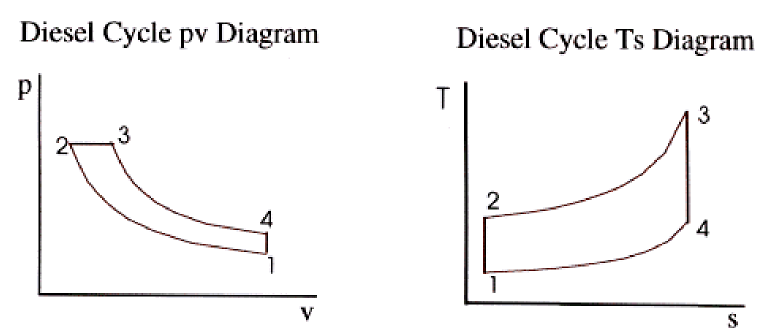

Figure 7.3
Diesel Cycle Diagram

7.4.2 Steam Turbine

The steam turbine obtains its motive power from the change of momentum of a jet of steam flowing over a curved vane. The steam jet, in moving over the curved surface of the blade, exerts a pressure on the blade owing to its centrifugal force. This centrifugal pressure is exerted normal to the blade surface and acts along the whole length of the blade; the result of this centrifugal pressure plus the effect of change of velocity is the motive force on the blade. This motive power enables the turbine to drive the electric generator.

A steam turbine consists of a pair of blade rings consisting of a fixed ring of blades and moving ring. Both the moving and fixed blades are designed so that the jet shall not strike the blade but will merely glide over it in parallel direction. The fixed blades are fixed to the turbine casing and face the moving blades in opposite direction. The object of fixed blade is to receive steam jet discharging from the moving blade ring and to divert it to the next ring of moving blade by changing its direction. This diversion may continue over several rings of moving and fixed blades until the whole of K.E. of the steam is expanded.

Impulse Turbine and Reaction Turbine

- In the impulse turbine, the steam expands in the nozzle. In the reaction turbine, the steam expands as it flows over the blades so blades act also as nozzles
- In an impulse turbine, there is a pressure drop across the fixed blade ring converting the energy of steam into K.E. There is no pressure drop across the moving blade ring; the work done on the rotor being equal to the loss of K.E. provided there are no losses. In a reaction turbine, there is a continuous pressure drop across both fixed and moving blades and there is an additional reaction force on the moving blade due to their nozzle action

Compounding

Compounding is a method of reducing the rotor speed by utilizing several blade rings. In compounding, a multiple system of rotors in series keyed on a common shaft, is used and the steam pressure or jet velocity is absorbed in stages, as it flows over the rotor blades. The chief methods of reducing rotor speed are

- Compounding for Velocity
- Compounding for Pressure
- Pressure Velocity Compounding
- Reaction Turbine

Bleeding

Bleeding is the name given to process of draining steam from turbine at certain points during its expansion and using this steam for heating the feed water supplied to boiler. The process of bleeding increases the thermal efficiency.

Steam Turbine Trouble Shooting Guide

The cost-effectiveness of a turbine plant depends to a large extent on its operating reliability. Turbine availability is one criterion for operating reliability. Turbine availability is effected mostly by damage to main turbine components, the rotor and the casing. Slight primary damage or operational irregularities affecting these items can cause consequential damage, which then requires expensive and time-consuming major repairs. The goal of operational monitoring is to prevent, or at least reduce the scope of damage and faults. Operating conditions which can result in immediate or repeated damage must, once they have been recognized, be prevented by appropriate corrective action. Safety and protective equipment is used to monitor operating parameters which are subject to great rates of change in the event of faults. This equipment automatically performs the appropriate actions when set limits are reached.

Monitoring Tasks of Operating Personnel

An inspection tour of the entire turbine plant shall be made at least once per shift. Basic measures for preventing damage include cleanliness, immediate elimination of leaks in the steam, water and must be eliminated immediately, shall be entered in the machine logbook.

It is not admissible to operate at levels not noted in the Commissioning Data Record, even when these levels lie within the safety margin between commissioning and damage limits. This rule still applies even if the turbine was operated at these limits during testing of the turbine by the manufacturer's authorized representative. This involves carefully calculated risks and abnormal operating conditions and is the manufacture's responsibility.

Aids for Use in Operational Monitoring

The following aids can be used by the operating personnel to assist them in their monitoring tasks

- Indicating instruments
- Recording instruments
- Audible and/or visual indicators

The instrument reading must be compared with the normal levels specified in the Commissioning Data Record. The set points for annunciating equipment, are also given in this record.

The charts and traces produced by recording instruments are of assistance in reconstructing operating events. For this reason, it is essential for all measuring instruments to run synchronously. Testing and maintenance of measuring instruments must be performed regularly.

Monitoring Prior to Start-up

The systems and their associated measuring instruments shall be checked to ensure that the start-up preconditions are fulfilled prior to each start-up. The results of these checks and the type and time of operating action taken must be recorded.

Monitoring During Start-up

A heightened degree of monitoring is required during start-up. Start-up records shall be kept up to the point wherethe machine is connected to the grid. The following parameters and switching conditions as indicated on the operational measuring instruments provided, must be included in the start-up record.

Start-up conditions

Relative casing and rotor expansion, absolute and differential values for casing wall temperatures, bearing oil and control fluid pressures, oil temperatures downstream of the oil cooler and in the bearings, steam pressures and temperatures, switching conditions of the steam and drain systems.

Run-up procedure and no-load operation

Speed hold points, run-up times, babbitt metal temperatures, shaft and bearing vibration, noise behavior, oil temperatures downstream of the oil cooler and in the bearing, speed, casing and rotor positive expansion, casing wall temperatures, control system response, steam parameters.

Monitoring during Operation

The requisite data and switching actions for monitoring the turbo machine shall be recorded in a shift report. The levels noted in the report and recorded by the recording instruments shall be critically compared to specified limits and any deviations or corrective measures implemented, shall be recorded in the shift report. Gradual changes in operating parameters pose the greatest threat, as they are frequently not recognized immediately, in contrast to sudden changes. The actual values obtained of bearing temperatures and control stage operations during start-ups (after major repairs) must be monitored on the turbine to match the technical status of the equipment, mass flow, expansion behavior, temperature response of bearings, shaft and bearing vibration, casing wall temperatures, stage pressures. Long-term monitoring shall be performed for:

- Leak tightness of the steam and oil system
- Proper functioning of the seal-steam system
- Proper functioning of the drain system.

Preparing the Turbine for Operation

The turbine as received is ready for alignment. Place the turbine on its foundation or setting with shims installed under each support to assist alignment.

- These shims can be removed as required, if it is necessary to lower the turbine at a later stage
- The turbine should then be levelled and "rough aligned" with the driven machine. The rise of the turbine and of the driven machine must be taken into consideration at this stage
- Final coupling alignment should be made after the turbine has been brought to normal operating temperature
- Be sure that the turbine has bearing on each of its supports

- Clean up the outside of the turbine
- Lift the two halves of the turbine casing
- Inspect the inside casing and clean up
- Be sure that the labyrinths are in the right position
- Take care that it is lifted squarely so that the wheels, shaft packings, etc are not damaged. After the interior to the casing is cleaned, make up the casing joint and replace the top half of the casing
- Exercise the same caution as with lifting
- Disassemble the thrust bearing and clean all parts taking care when handling the parts so that they are not damaged and can be returned to their original positions
- Remove and clean the steam end and exhaust end bearing, making sure that all oil passages are opened
- Use lint free cloths to dry part
- Clean out the bearing cases
- Leave the upper half until after the flushing operation. Replace the bearing case caps

Operating Instruction

Starting The Turbine (initial start-up or after prolonged shutdown)

- Consult driven machine Instruction Book with regard to its start-up
- Check the oil level in the main oil tank and the condition of oil
- Check general external conditions
- Make sure that electrical system and controls are operative
- Make sure the cooling water is in normal operation
- Start-up lube oil and control oil systems and check the pressures
- Check that the actuator is fed with air
- Check that oil circuit solenoid valve is reset in run position
- Reset T & T valve in closed position
- Put idle/rated switch in the idle position
- Check for any annunciator window and reset if necessary
- Open all drains on steam inlet line, on turbine and on extraction line
- Operate the exhaust condensate collection system
- Open all valve drains on inlet line including the T & T valve drains
- Reduce drains opening if too much steam flows. Don't close completely.
- Stay 10 to 15 minutes at the idle speed (warm-up speed) under governor control
- Listen for unusual noises which might indicate rubbing or other internal problems. If any such noises are encountered, shut down the turbine. Find the cause and remedy it
- Close all drains when they begin to blow steam and no condensate.
- Turn idle/rated switch to the rated position and speed ramps on governor mini speed reference
- When the actual speed equals the speed reference, set to synchronous speed
- After the actual speed equals the speed reference, proceed to generator synchronization

- After coupling, increase the speed reference a little to produce power
- After bubo, the generator is now available for normal operation
- Operate in even speed (power) or in pressure (cascade) control by using the governor

Normal Shut Down

- Disable cascade control
- Decrease the turbine speed set to decrease the power down to about 5 to 10%
- Open generator breaker or go to step 4
- Push STOP on the governor and confirm
- Close steam inlet stop valve
- Wait for complete stop of the shaft rotation
- Close exhaust stop valve
- Open all drain lines on turbine and leave them open
- Keep the lube oil console and the turning gear running in automatic control for 10 hours minimum (until the turbine has cooled down completely)

7.4.4 Jet Engines

Jet engine propelled aircrafts are propelled by the reaction thrust of the exiting gas stream. The gas stream acquires energy to propel the aircraft forward in a basic jet engine as follows. Air enters the inlet section of the aircraft, where it is compressed to a high pressure by a compressor. The high pressure air then enters a combustion chamber where fuel is added to air and the mixture is burned. The chemical energy of the fuel is converted to thermal energy of the air stream. This high pressure, high temperature stream enters a turbine, which powers the compressor. A centrally mounted shaft connecting the turbine and compressor transmit the turbine power. At the end of the turbine, a nozzle converts the internal energy of the air stream into kinetic energy. The thrust created by the exiting,high-speed gas stream propels the aircraft.

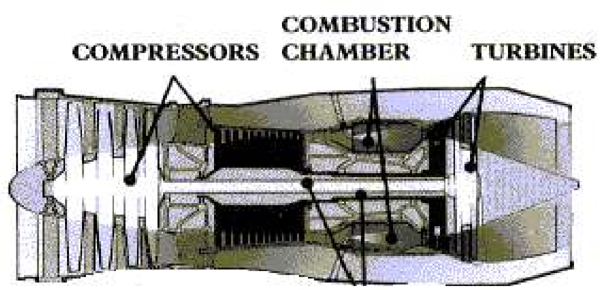

Figure 7.4
Schematic Representation of a Jet Engine

7.4.5 Rocket Engines

One of the most amazing efforts man has ever undertaken is the exploration of space. A big part of the amazement is the complexity. Space exploration is complicated because there are so many problems to solve and obstacles to overcome. The grey areas to be confronted are:

- The vacuum of space
- Heat management problems
- The difficulty of re-entry
- Orbital mechanics
- Micrometeorites and space debris
- Cosmic and solar radiation
- The logistics of having restroom facilities in a weightless environment

But the major problem of all is harnessing enough energy simply to get a spaceship off the ground. That is where **rocket engines** come in.

The Basics

Rocket engines are fundamentally different. Rocket engines are **reaction** engines. The basic principle driving a rocket engine is the famous Newtonian principle that "to every action there is an equal and opposite reaction." A rocket engine is throwing mass in one direction and benefiting from the reaction that occurs in the other direction as a result.

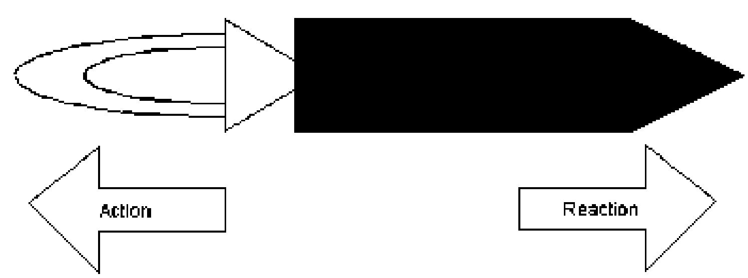

Figure 7.5
Reaction Process

This concept of "throwing mass and benefiting from the reaction" can be hard to grasp at first, because that does not seem to be what is happening. Rocket engines seem to be about flames and noise and pressure, not "throwing things."

A rocket engine is generally throwing mass in the form of a **high-pressure gas**. The engine throws the mass of gas out in one direction in order to get a reaction in the opposite direction. The mass comes from the weight of the fuel that the rocket engine burns. The burning process accelerates the mass of fuel so that it comes out of the rocket nozzle at high speed. The fact that the fuel turns from a solid or liquid into a gas when it burns does not change its mass. If you burn a pound of rocket fuel, a pound of exhaust comes out the nozzle in the form of a high-temperature, high-velocity gas. The form changes, but the mass does not. The burning process accelerates the mass.

How Rocket Engines Work

Thrust

The "strength" of a rocket engine is called its thrust. Thrust is measured in "pounds of thrust" in the U.S. and in Newtons under the metric system (4.45 Newtons of thrust equals 1 pound of thrust). A pound of thrust is the amount of thrust it would take to keep a 1-pound object stationary against the force of gravity on Earth. So on Earth, the acceleration of gravity is 32 feet per second per second (21 mph per second)

One of the peculiar rockets have is that the objects that the engine wants to throw actually weigh something, and the rocket has to carry that weight around. A the Space Shuttle launch comprises of three parts:

- The Orbiter
- The big external tank
- The two solid rocket boosters (SRBs)

Solid-Fuel Rockets

Solid-fuel rocket engines were the first engines created by man. They were invented hundreds of years ago in China and have been used widely since then. The idea behind a simple solid-fuel rocket is straightforward.. Here's a typical cross section:

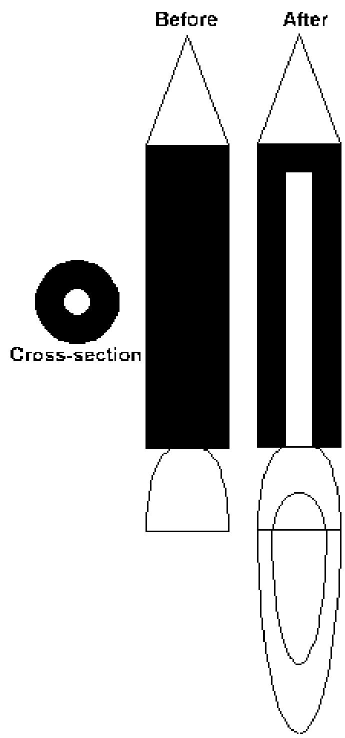

Figure 7.6
A Solid-fuel Rocket Immediately Before and After Ignition

On the left is the rocket before ignition. The solid fuel is shown in green. It is cylindrical, with a tube drilled down the middle. When the fuel is lighted , it burns along the wall of the tube. As it burns, it burns outward toward the casing until all the fuel has burned. In a small model rocket engine or in a tiny bottle rocket the burn might last a second or less. In a Space Shuttle SRB containing over a million pounds of fuel, the burn lasts about two minutes.

The propellant mixture in each SRB motor consists of an ammonium perchlorate (oxidizer, 69.6 percent by weight), aluminum (fuel, 16 percent), iron oxide (a catalyst, 0.4 percent), a polymer (a binder that holds the mixture together, 12.04 percent), and an epoxy curing agent (1.96 percent). The propellant is an 11-point star-shaped perforation in the forward motor segment and a double- truncated-cone perforation in each of the aft segments and aft closure. This configuration provides high thrust at ignition and then reduces the thrust by approximately a third 50 seconds after lift-off to prevent overstressing the vehicle during maximum dynamic pressure.

An "11-point star-shaped perforation" might look like this:

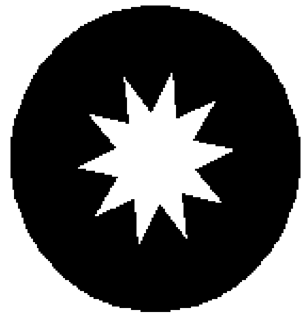

Figure 7.7
Channel Configuration

The idea is to increase the surface area of the channel, thereby increasing the burn area and therefore the thrust. As the fuel burns the shape evens out into a circle. In the case of the SRBs, it gives the engine high initial thrust and lower thrust in the middle of the flight.

Solid-fuel rocket engines have three important advantages:

- Simplicity
- Low cost
- Safety

They also have two disadvantages:

- Thrust cannot be controlled.
- Once ignited, the engine cannot be stopped or restarted.

The disadvantages mean that solid-fuel rockets are useful for short-lifetime tasks (like missiles), or for booster systems. When you need to be able to control the engine, you must use a liquid propellant system.

Liquid-Propellant Rockets

In 1926, Robert Goddard tested the first liquid-propellant rocket engine. His engine used gasoline and liquid oxygen. He also worked on and solved a number of fundamental problems in rocket engine design, including pumping mechanisms, cooling strategies and steering arrangements. These problems are what make liquid-propellant rockets so complicated.

In most liquid-propellant rocket engines, a fuel and an oxidizer (for example, gasoline and liquid oxygen) are pumped into a combustion chamber. There they burn to create a high-pressure and high-velocity stream of hot gases. These gases flow through a nozzle that accelerates them further (5,000 to 10,000 mph exit velocities being typical), and then they leave the engine. The following highly simplified diagram shows you the basic components.

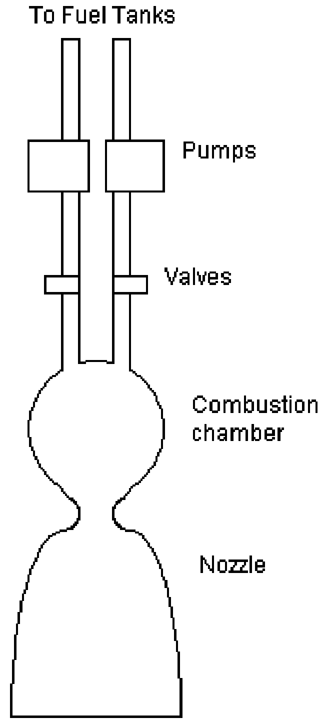

Figure 7.8
Channel Configuration

This diagram does not show the actual complexities of a typical engine (see some of the links at the bottom of the page for good images and descriptions of real engines). For example, it is normal for either the fuel of the oxidizer to be a cold liquefied gas like liquid hydrogen or liquid oxygen. One of the big problems in a liquid propellant rocket engine is cooling the combustion chamber and nozzle, so the cryogenic liquids are first circulated around the super-heated parts to cool them. The pumps have to generate extremely high pressures in order to overcome the pressure that the burning fuel creates in the combustion chamber. The main engines in the Space Shuttle actually use two pumping stages and burn fuel to drive the second stage pumps.

- All kinds of fuel combinations get used in liquid propellant rocket engines. For example:
- Liquid hydrogen and liquid oxygen - used in the Space Shuttle main engines
- Gasoline and liquid oxygen - used in Goddard's early rockets
- Kerosene and liquid oxygen - used on the first stage of the large Saturn V boosters in the Apollo program
- Alcohol and liquid oxygen - used in the German V2 rockets
- Nitrogen tetroxide / monomethyl hydrazine - used in the Cassini engines

7.5 Refrigeration & Liquefication

Refrigeration is the withdrawal of heat from a substance or space so that temperature lower than that of the natural surroundings is achieved.

Refrigeration may be produced by

- Thermoelectric means
- Vapor compression systems
- Expansion of compressed gases
- Throttling or unrestrained expansion of gases.

7.5.1 Refrigeration cycle

Since the temperature below the surroundings is not only to be reached but maintained, it necessitates the absorption of heat continuously at low level. This is possible only in a flow process.

Heat is absorbed by means of evaporation of fluid (known as refrigerant). The evaporation fluid for a continuous operation must be brought to its original state so that it can again absorb heat at low level. The complete series of steps through which the fluid passes, constitutes the refrigeration cycle. The basic four steps of a refrigeration cycle are

- Absorption of heat at low temperature.
- Compression.
- Rejection of heat at higher temperature.
- Expansion.

7.5.2 Types of Refrigeration Cycle

Various refrigeration cycles are

- Carnot cycle
- Air refrigeration cycle
- Vapour compression cycle
  - With expansion engine
  - Conventional

Vapor compression systems are employed in most refrigeration systems. Here, cooling is accomplished by evaporation of a liquid refrigerant under reduced pressure and temperature. The fluid enters the compressors at state 1 where the temperature is elevated by mechanical compression (state 2). The vapor condenses at this pressure, and the resultant heat is dissipated to the surrounding. The high pressure liquid (state 3) then passes through an expansion valve through which the fluid pressure is lowered. The low-pressure fluid enters the evaporator at state 4 where it evaporates by absorbing heat from the refrigerated space, and reenters the compressor. The whole cycle is repeated.

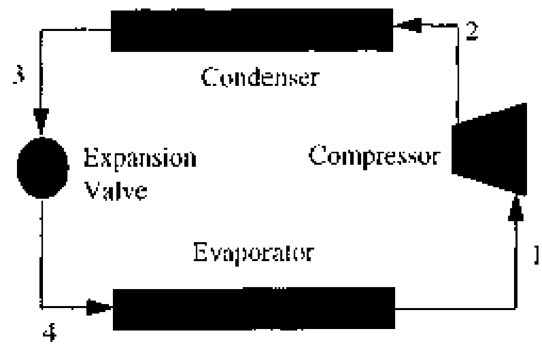

Figure 7.9
Vapour Compression Cycle

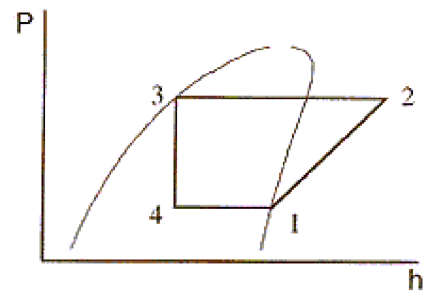

Figure 7.10
Phase diagram for Vapour Compression Refrigeration Cycle

7.5.3 Ideal Refrigerant

The refrigerant chosen for a particular refrigeration operation should be such that it has

- Low vapor pressure in the condenser, giving low design and maintenance cost
- Vapor pressure in evaporator a bit higher than atmospheric pressure, thus preventing air leakage into the system as
  - Air adversely affects the heat transfer
  - Moisture present in the air tends to freeze
  - Increases the amount of work to be supplied to compressor for a definite amount of refrigeration
- Large latent heat of vaporization and low heat capacity giving low mass flow rates
- Constant entropy of saturated vapor
- Low Cost
- Non-explosive nature

- Non-corrosive properties preventing choking
- Non-poisonous properties providing safety for personnel
- Immiscible with lubricating oil

7.5.4 Heat Pump

It is a device used for the heating of buildings and houses during winter and cooling them during summer. In winter, it absorbs heat from the surroundings and rejects heat into the building, while in summer it absorbs heat from building and rejects to surroundings.

To accomplish heating during winter a refrigerant is evaporated in a coil placed underground or in the outside air. The vapor is compressed to such a pressure that it may be condensed with air or water at temperatures above room temperature. The heat transferred to air during condensation is used for heating the house. During summer, to cool the house, the flow of refrigerant is reversed.