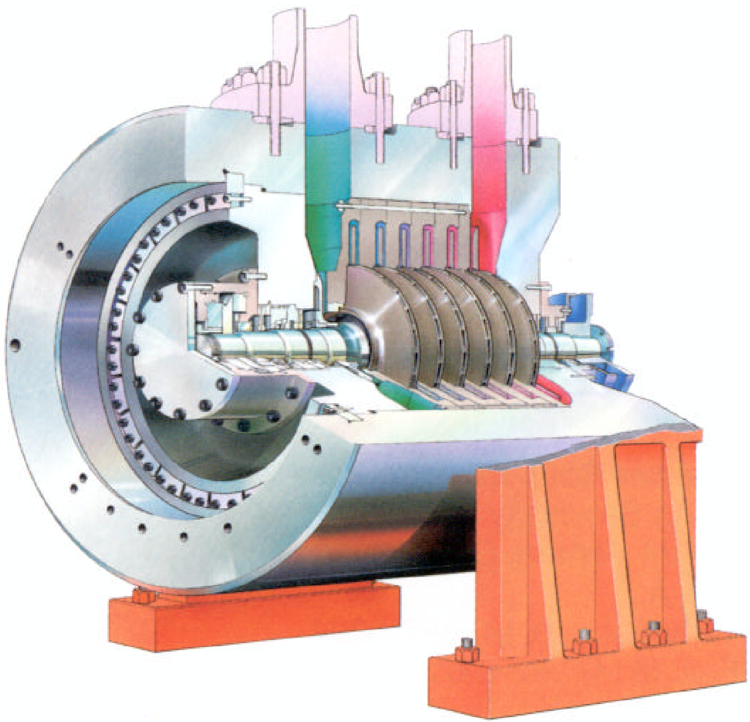
IMPORTANT NOTICE

This information is intended for training purposes only and will not be updated or revised as standard issue. Refer to the OEM manual for verification of all procedures prior to conducting any operation or maintenance of the unit.

Module 1

CENTRIFUGAL COMPRESSOR TRAINING NOTES



CENTRIFUGAL COMPRESSOR BASICS

INTRODUCTION

A centrifugal compressor is a machine in which gas is compressed by an impeller or impellers rotating at high speed during operation. The impeller imparts velocity and pressure to the gas, which flows in a radial direction in the impeller (from the center outward).

Rolls-Royce Energy Systems, Inc. (referred to as R-R), manufactures multi-stage barrel compressors and pipeline compressors. The multi-stage barrel compressor is normally used for low flow and “high” head conditions while the pipeline compressor is normally used in high flow and low “head” conditions.

APPLICATIONS

	BARRELS	PIPELINERS
GAS LIFT	X	
GAS REINJECTION	X	
GAS DEPLETION	X	X
GAS GATHERING/BOOSTING	X	
GAS PROCESSING/REPRESSURIZATION	X	
GAS STORAGE	X	X
GAS TRANSMISSION		X

The **design philosophy** for choosing a barrel compressor is:

1. Maximum component standardization
2. Optimum aerodynamic performance predictability
3. Minimum lead time
4. Cost control
5. Maximum rotor and support system rigidity
6. Maximum reliability
7. Optimum maintainability

The **design philosophy** for choosing a pipeline compressor is:

1. Complete custom aerodynamic design
2. Maximum efficiency
3. Maximum performance adaptability
4. Maximum performance flexibility
5. Maximum flexibility of configuration
6. Designed for direct gas turbine drive
7. Optimum maintainability

ROLLS-ROYCE CENTRIFUGAL COMPRESSOR NOMENCLATURE

BARREL COMPRESSORS

Product nomenclature is based upon product application.
For **Barrel Compressors** the nomenclature used is:
First character **R** refers to Rotating Compressor.
Second character **A** through **F** refers to Relative Frame Size & Nominal Impeller Diameter.

CLASS	NOMINAL IMPELLER DIAMETER
A	11-1/4 inches
B	16-1/2 inches
C	20-1/2 inches
D	26-1/2 inches
E	34 inches
F	42-1/2 inches

If the casing is capable of containing more than the required number of compression stages the number of stages the compressor casing can contain is followed by the symbol /, or a dash (-), and, the number of installed compression stages (i.e., 8-7, 6/4, 4/2,etc.).

If only one stage is required, then the third character will be omitted and it is understood as meaning a one-stage compressor.

The forth character is **B** or **S** denoting the type of casing split.

B denotes a barrel type casing with a vertical split (Fig. 1). **S** denotes a horizontally split casing (**Fig.2**).

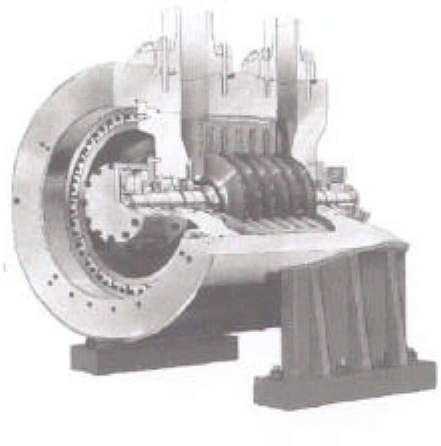
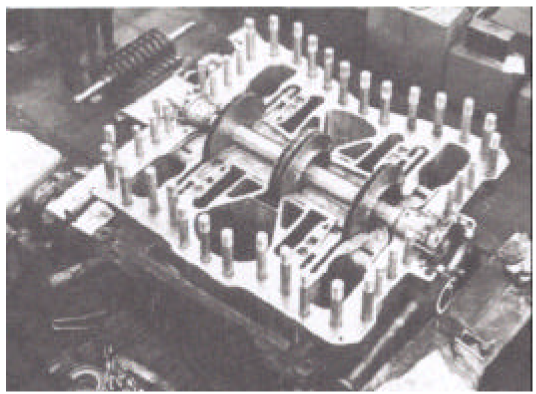


Figure 1

Figure 2



PIPELINE COMPRESSORS

For **Pipeline Compressors** the nomenclature can be identified as follow:

The first character is **R** for Rotating Compressor.
The second character is **A** through **F** used for Relative Frame Size & Nominal Impeller Diameter.
The third character is a numeral **2** or higher and denotes the number of stages used for compression of the gas.

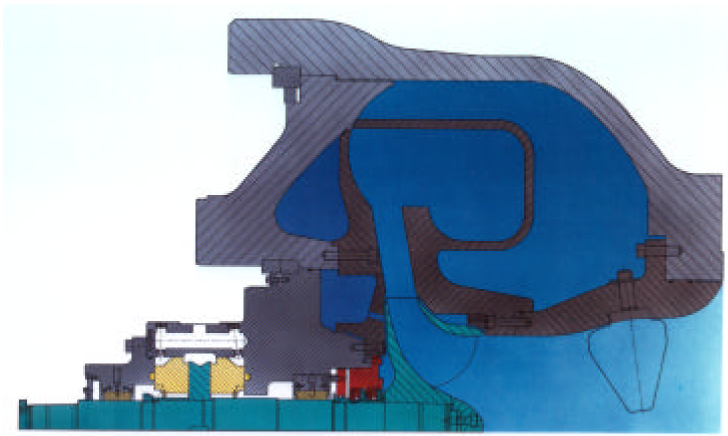
CLASS	NOMINAL IMPELLER DIAMETER
A	11-1/4 inches
B	16-1/2 inches
C	20-1/2 inches
D	26-1/2 inches
E	34 inches
F	42-1/2 inches

If the casing is capable of containing more than the required number of stages designed for compression, then the number of stages the compressor casing can contain is be followed by the symbol /, or a dash (-), and, the number of installed compression stages (i.e., 2/1, 4/3, etc.).

If only one stage is required, the third character will be omitted and it is understood as meaning a one-stage compressor.

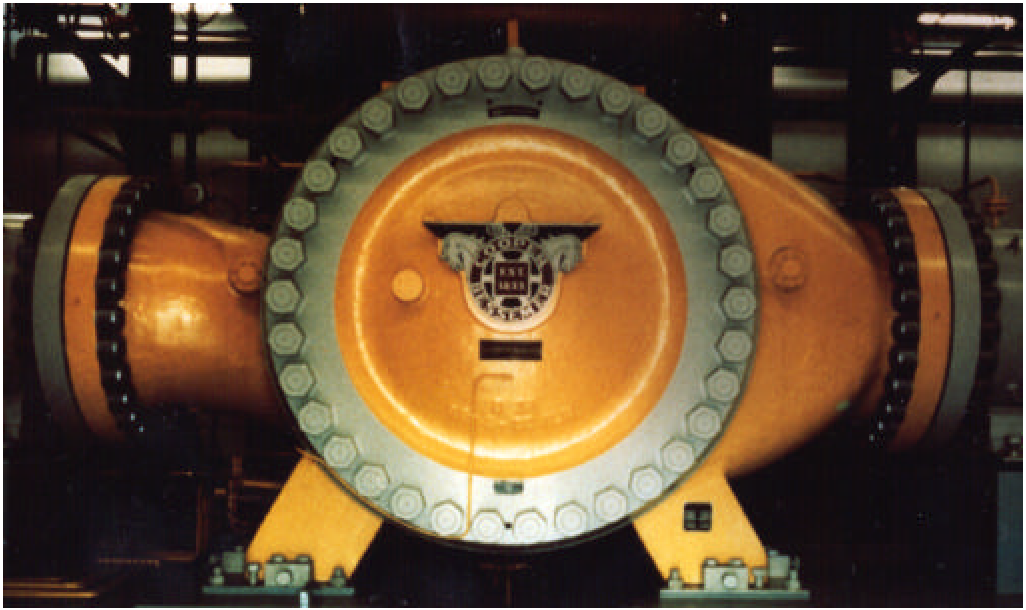
The fourth character is **A**, **B** or **BB** denoting the type of casing and rotor support.

A denotes axial gas inlet with an overhung rotor. (Shown below)



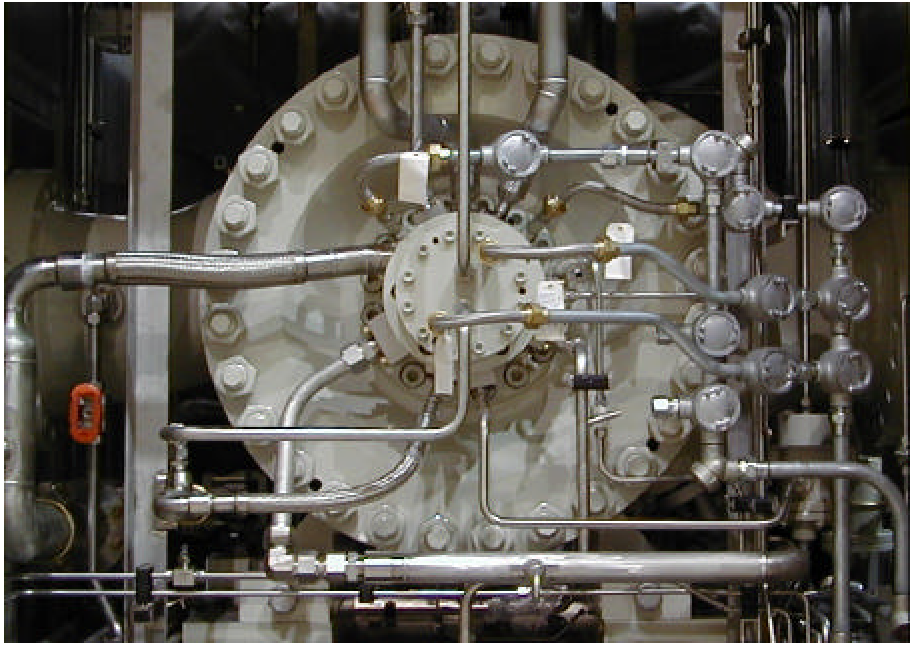
Example – RFA

B denotes a side inlet casing with overhung rotor. (Shown below)



Example – RFB

BB denotes a side inlet casing with beam-style rotor. (Shown below)



Example – RBB

The fifth character used is a two-digit (2) number denoting the nominal flange diameter in inches.

AERODYNAMIC PERFORMANCE can be defined as the operational efficiency of the machine parts, which convert or add to energy of the gas in the gas path. There are two industry-accepted methods used for describing aerodynamic performance. These are, the **adiabatic method** and the **polytropic method**.

The **ADIABATIC METHOD OF CALCULATION** is an isentropic or constant entropy process, which is the industries accepted method for pipeline compressors. The adiabatic process by definition means that no heat transfer takes place in the system; therefore, there is no change in entropy. As an exact theory this is only valid for extremely small pressure ratios, or, is an acceptable approximation for small pressure ratios since there is a small amount of heat loss through the casing. **Entrophy** is a thermodynamic measure of the amount of energy that is unavailable for useful work in a system undergoing change.

POLYTROPIC METHOD OF CALCULATION is the industry-accepted method for compressors with high compression ratios and multiple stages. The polytropic process by definition means there are heat losses thereby requiring additional energy to perform the same amount of work on the gas. This heating effect comes from gas friction, turbulence, conduction or radiation. The extent of these losses is dependent on the gas exponent and the polytropic efficiency.

The designer of the compressor accounts for the aerodynamic design elements and speed required to meet the customer specifications for compression of gas(s).

MAJOR COMPONENTS

Major Operating Components of a Centrifugal Compressor fall into two groups.
A **Rotating Assembly** and a **Stationary Assembly**.

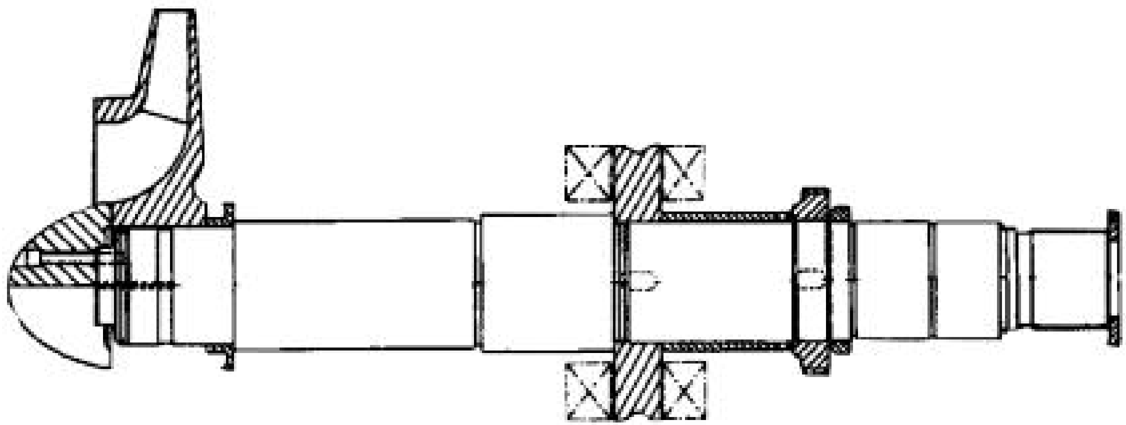
ROTATING ASSEMBLY

The **Rotor** is normally coupled to the driver by means of a flexible type coupling. The rotor receives mechanical energy through this coupling, which it imparts to the impeller(s) firmly mounted on the shaft. The rotor can be of overhung or beam-style design. The overhung rotor design has the impeller outboard of the bearing support system and the beam-style design has the impeller(s) located between the journal bearings.

The overhung rotor design has the following characteristics:

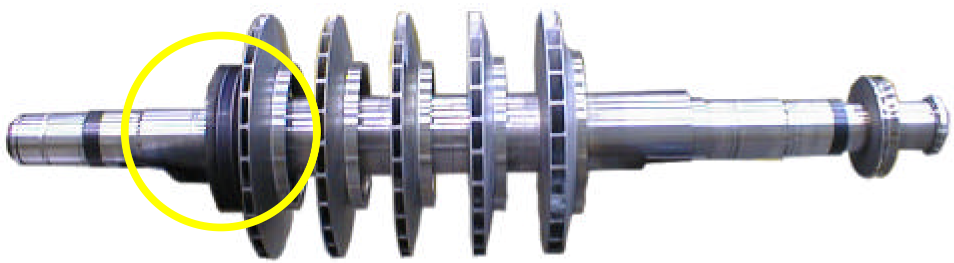
1. Most efficient aerodynamic configuration (designed without a thrust balance piston).
2. Low speed operation (stiff-shaft design).
3. Best access for performing maintenance actions.
4. Limited to single-stage configurations.
5. Higher parasitic losses (large thrust bearing used to absorb high static thrusts at Startup).

Typical Overhung Rotor

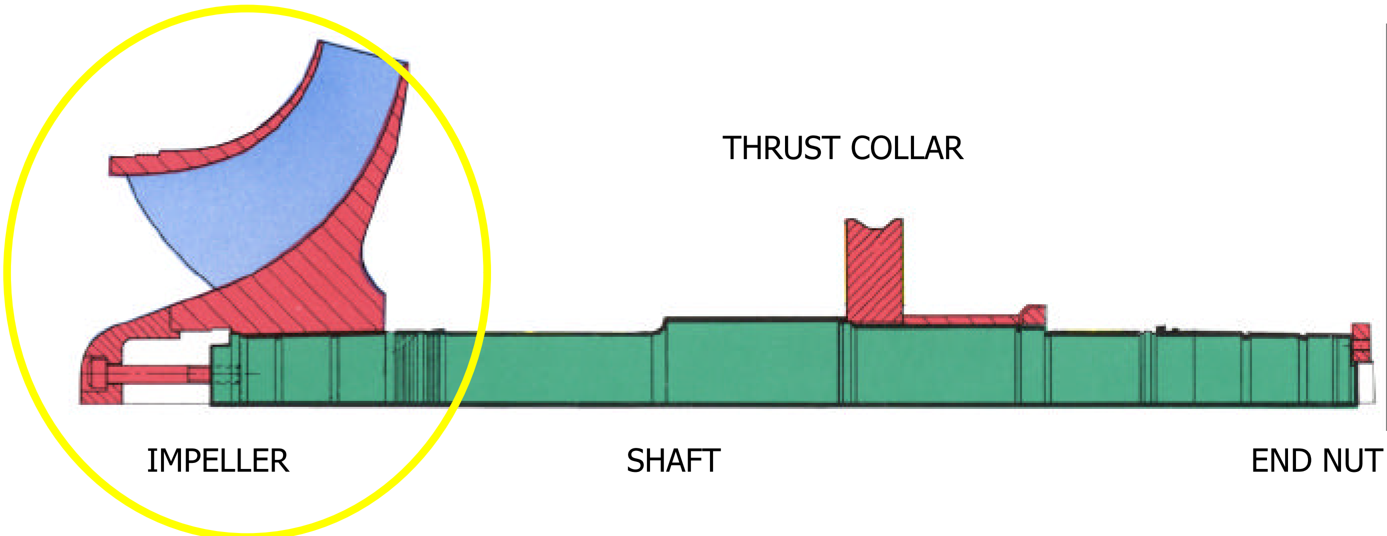


The beam-style rotor design has the following characteristics:

1. Maximum head flexibility with re-staging capability.
2. Minimum starting torque requirement.
3. Low parasitic losses (utilizing a smaller thrust bearing).
4. Required for two or more stage configurations.
5. Somewhat less efficient due to thrust balance and seal balance (if employed) losses.
6. Flexible shaft design (minimum operating speed limitation imposed due to need to operate above the first lateral bending mode).



Example Beam – Style Rotor



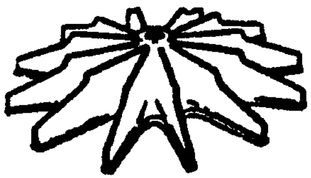
Impeller – The **rotating element**, which imparts momentum to the gas during operation. The impeller does all work on the gas. Its primary purpose is to impact on the gas while spinning very fast, thus, greatly increasing the velocity of the gas. The pressure rise in the impeller is approximately 2/3 of the total pressure increase of the compressor.

There are three (3) types of impellers normally used in the centrifugal compressor. These are:

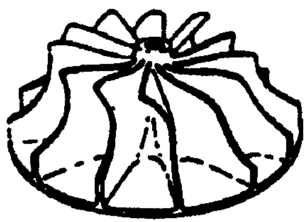
OPEN – Built with the blades in a radial direction no enclosing covers on either the front or backsides (normally found in superchargers).

SEMI-CLOSED – Built with the blades in a radial direction with an enclosing cover on the backside which extends to the periphery of the blade (normally found in air compressors).

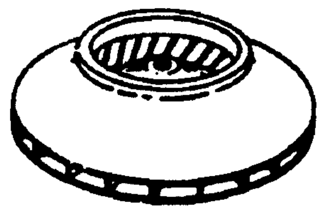
CLOSED – Built with backward or forward leaning blades and has enclosing covers on both the front and backside (normally found in multi-stage centrifugal compressors). R-R uses closed impellers.



Open



Semi–closed



Closed

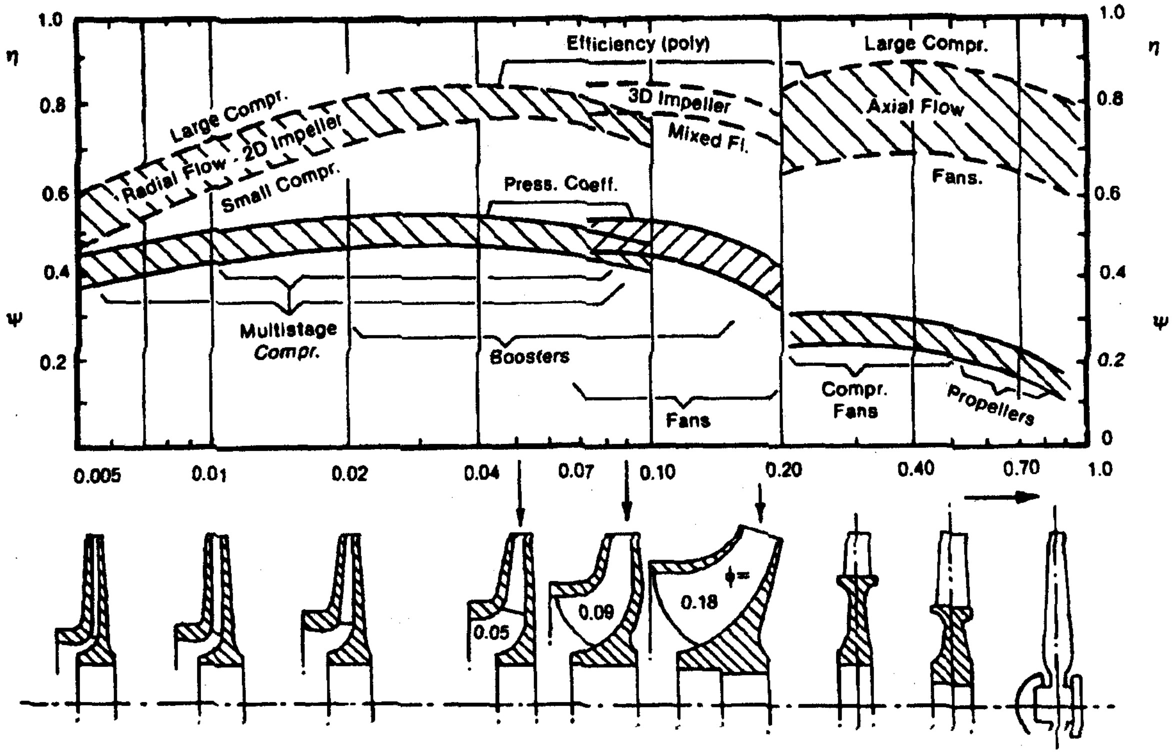
The objective in selecting a given type and construction of an impeller is to obtain the best performance with mechanical, manufacturing, and cost limitations considered.

The single inlet closed type impeller is good for moderate and large flows. Using backward leaning blades produces a hydraulic characteristic with a wide stable range most suitable for the majority of applications.

The two dimensional impeller is of two-piece construction with the cover being welded to the blades. The two dimensional blade configurations are generated through carefully controlled metal removal from thick hub-forgings thus eliminating the need for the delicate and time consuming process of welding the blades to the hub.

To extend the peak aerodynamic efficiency levels found in well designed, two dimensionally bladed impellers to flow coefficients well above (0.10), R-R uses impeller designs with inducer sections (compound-curved, twisted or three dimensionally curved blades) for coefficients of (0.08) or greater.

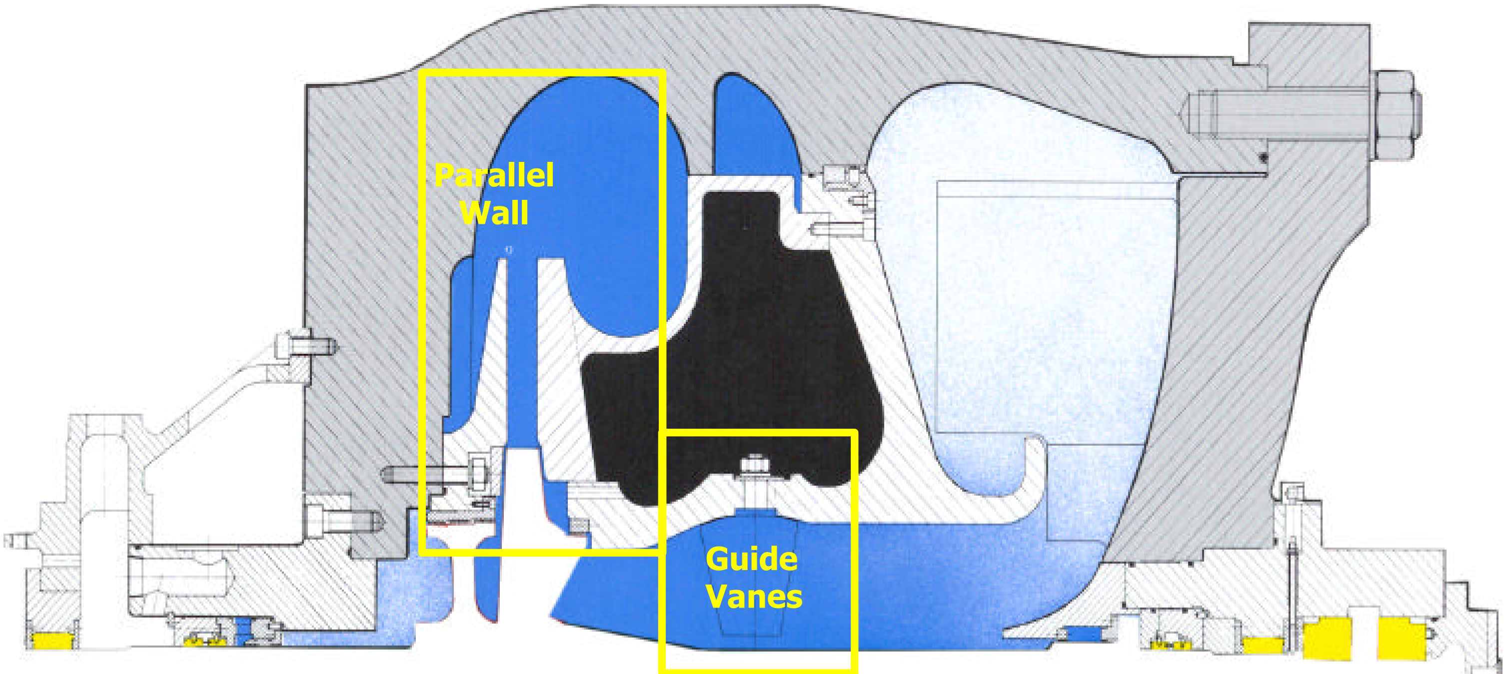
The design of an aerodynamic assembly largely revolves around the required impeller configuration. The configuration changes in impeller design as a result of increasing flow for a given head and speed (or flow coefficient) can be seen in the following illustration.



All Rolls-Royce impellers used in centrifugal compressors contain backward leaning blades to provide the widest possible operating characteristics.

The **THRUST COLLAR** is mounted on the rotor and works in conjunction with the thrust bearing. The thrust collar transmits the axial thrust (movement) from the rotor to the thrust bearing. The bearing housing encased within the compressor casing encloses the thrust bearing. The loads that are absorbed through the housing to the casing are then transferred to the compressor feet, which are attached to sole plates, which are grouted to the base.

The **THRUST BALANCE PISTON**, also called the balance drum, is located after the last impeller on the discharge end of the beam style rotor. The thrust balance piston is sized to compensate for the total impeller thrust developed during operation. For high-pressure compressors with large overall pressure differential an over-compensated balance drum may be used to place a thrust to the inboard counter-thrust shoes of the thrust bearings. This arrangement greatly reduces the danger of thrust bearing failure from overload. Should the thrust increase, the counter-thrust shoes are first unloaded before loading the outboard, or, normally loaded active shoes during operation.



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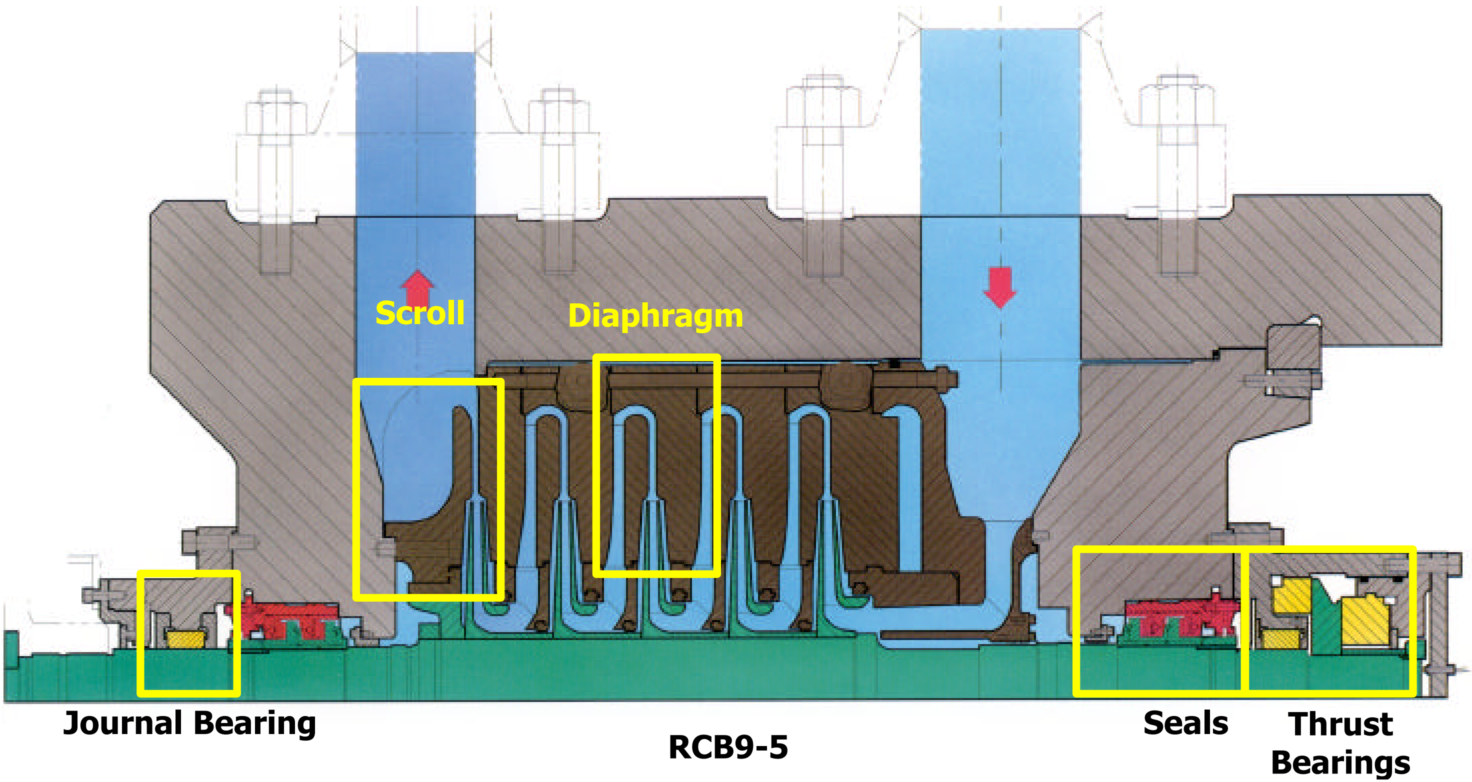
PIPELINE COMPRESSOR



STRAIGHT – THROUGH BARREL COMPRESSOR

STATIONARY ASSEMBLIES

Refer to illustrations on the previous two pages:

The **DIAPHRAGM** is a stationary element used wall between individual stages of a multi-stage compressor. The diaphragm accurately controls the direction and flow of gas through the compressor, converting kinetic energy to pressure energy between stages.

The interior of each diaphragm has a vaned return passage, which directs the gas into the inlet guide vanes of the succeeding stage. The diffuser and return passage are designed to gradually and efficiently convert the velocity of the gas to the succeeding stage. Approximately one-third of the stage pressure rise occurs in the diffuser by converting gas velocity to pressure through diverging walls.

The DIFFUSER is a stationary passageway following an impeller in which velocity energy imparted to the gas by the impeller is converted into static pressure. There are three basic types of diffusers.

1. Parallel Wall
2. Volute
3. Combination of Parallel Wall and Volute

The **Volute** and combination **Parallel Wall/Volute** is described under the **Collector** since they are end diffusers.

The **Parallel Wall** diffuser is formed by the backside of the diaphragm preceding the stage and the front side of a diaphragm immediately following the stage in a multi-stage compressor. The outside diameter of the diffuser is usually between (1.8 – 2.0) times the impeller diameter for best efficiency.

There are two (2) types of parallel wall diffusers, the open **vaneless** or **vaned**. In a vaneless diffuser, the gas continues to travel at the same angle as it leaves the impeller, where as in a vaned diffuser, the direction and value of velocities from the impeller are controlled by means of vanes.

The vaned diffuser directs the gas outward in a shorter path than vaneless diffuser and is generally more efficient than vaneless diffusers. A vaned diffuser has a more narrow range of stability than a vaneless diffuser. As flow varies from design flow, the angle of the gas impinging upon the vane moves further from its design and begins to produce turbulent flow. This turbulence reduces efficiency at off design flows and reduces effective stable operating range. The Rolls-Royce designed low solidity vaned diffuser provides excellent stable range and is basically used with low flow coefficient impellers and when continuous operation is expected to be at one flow.

The **Collector** gathers the gas stream from the diffuser over a 360-periphery angle and decelerates the gas further before discharging it into an end diffuser or discharge nozzle. Collectors are either of **plenum** (equal peripherally constant cross section) or **volute** (equal peripherally increasing cross section) configurations. Due to their clear efficiency advantage, volutes are greatly preferred in booster design. For best results, volutes should be sized individually for every new flow condition. This requirement is largely met at Rolls Royce by casting only part of the volute into the casing and coring the remaining volute portion into a removable insert, a provision that permits wide adaptability.

The **Volute** is analogous to a logarithmic spiral. The volute (sometimes called the scroll) is usually a part of the casing and used on a single stage compressor, such as pipeline units of the last stage of a multi-stage compressor. In a volute casing, gas from the impeller is collected at a constant velocity in a volute channel and all diffusion is accomplished in the discharge nozzle. A compressor with a volute casing is more efficient then an open parallel wall diffuser and has a greater stability range.

The combination of the parallel wall vaned diffuser and volute casing results in a highly efficient compressor, which is matched for the gas conditions.

The **Guide Vanes** are stationary elements, which may be fixed or adjustable to provide a desired flow direction of the gas inlet of an impeller. Adjustable guide vanes are used when the compressor is driven at a constant speed to shift the compressor performance in a predictable manner. Adjustable guide vanes are particularly effective on moderate to high flow single stage configurations. Increasing pre-rotation (inlet vane angle change into rotation) will shift the entire compressor characteristic including surge limits to lower flows and simultaneously tends to flatten the characteristic. Counter rotation has the opposite effects.

The **Casing & Cover** are the stationary components, which contain the pressure and enclose the rotor and associated internal components. The casing and cover also include the inlet and discharge connections. Three basic categories are as follows:

1. Horizontally split compressor (used for low to moderate pressures).
2. Vertically split barrel compressor (moderate to high pressures).
3. Vertically split pipeline compressor (gas transmission – high flow/low head conditions).

SUPPORTING SYSTEMS

The **Bearing Support** system consists of (2) **Journal** and (1) **Thrust** Bearing.
There are currently (2) types of bearings available. They are the conventional lubricated bearings and the non-lubricated magnetic bearings. The conventional lubricated bearings are used on all Rolls- Royce centrifugal compressors and the non-lubricated magnetic bearings are currently only used on beam-style pipeline compressors at customers request.

The **Journal Bearings** perform (3) major functions:

1. They support loads both steady state and dynamic.
2. They provide stiffness and dampening.
3. They control shaft position.

Bearings – The conventional lubricated journal bearings are multi-shoe semi-self-aligning, tilting pad bearing. The self-adjusting action of these bearings result in high dampening properties in the individual bearings pads, thus, enabling the bearings to overcome instability and lessen vibration of the compressor shaft. The tilting pad also assures complete freedom from oil film whirl **oil whip**, which is a phenomenon that tends to be present with high rotating speeds in a lightly loaded bearing when running at close to twice a critical speed. This oil whip is characterized by high amplitude shaft vibration at a frequency slightly less then one-half the rotative speed.

Thrust Bearings – is used to prevent axial motion of the rotating shaft and thus holds the axial position of the rotor assembly accurately within the compressor. There is an axial thrust produced toward the eye of the impeller due to the unbalanced pressure differential across the impeller. This thrust load and the size of the thrust balance drum is considered when sizing the thrust bearing. The physical location of the thrust bearing is on the suction side of the compressor outboard of the journal bearing for beam-style rotors and between the journal bearings on overhung rotors.

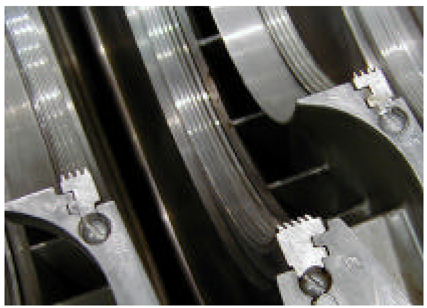
Various types of **Seals** are used to control product leakage within the compressor. There are four basic types of seals that are used. These are as follows:

1. **"O" ring seals:**

   O-ring type seals are used when a static seal is required. The O-ring can be of rubber or synthetic material and forms a seal between (2) stationary components (case and cover for example) thus preventing leakage.

2. **Labyrinth Seals:**

   Labyrinth type seals, in the simplest form, are a device to limit the loss of gas without contact between the shaft and compressor casing stationary component. The labyrinth can be sectionalized to provide one or more annuli, which are either buffered or educated, or, both, to eliminate the loss of process gas or to channel its flow in a controlled manner.



3. Oil Film Seals:

The oil film seal is used to prevent leakage of the compressed gas to atmosphere. Since the leakage of natural gas in even very small quantities is unacceptable, a very thin, high-pressure oil film is used under a free-floating cylindrical ring to accomplish the sealing. A bushing type seal is normally used for this purpose, however, a face seal in conjunction with the bushing seal can be found in extreme high suction pressure (above 240 BAR / 3,248 psia) applications.

Dry Seals:

The dry gas face seal is a face type seal, which uses dry, clean gas instead of seal oil therefore eliminating the seal oil system. In this type of seal, a small amount of gas flows across the face of the seal for cooling and is then vented to a safe atmosphere when the seal is operating. When the compressor is not rotating, the soft carbon stationary ring is pushed against the face of the rotating seal element by springs to form a leak proof seal.

OPERATIONAL CHARACTERISTICS

The operating characteristics centrifugal compressor is dependent upon the aerodynamic assembly design and the gas conditions in which it will be operating. The operating points for the aerodynamic assembly will change as the customer's conditions change. When this change adversely affects the operating efficiency of the unit, a redesign of the aerodynamic assembly should be considered.

The operating conditions for a centrifugal compressor can be expressed in graphic form by utilization of a (plot or map). A plot or map will reflect the operating points for a compressor for a given head and flow at some rpm. An assumption may be made that if an rpm of a compressor is maintained constant and head increases (pressure), then flow must decrease. This is known as the characteristic curve of the compressor.

Stonewall or **Choke** is the maximum stable flow and maximum head condition for the centrifugal compressor.

Surge is the minimum stable flow and maximum head condition for the centrifugal compressor.

SURGE CONDITION

1. As the flow through a centrifugal compressor is progressively reduced the discharge pressure increases.

2. With this mass flow reduction, a recirculation pattern develops in the impeller.

3. At some minimum flow, the recirculation flow pattern collapses. The impeller can no longer develop the discharge pressure required to maintain flow through the compressor.

4. Since the pressure developed is less than that in the downstream system flow reversal occurs. The delivered flow from the compressor then immediately drops to zero.

5. When the flow drops to zero, the pressure of the downstream system has dropped.

6. Compressor flow will once again develop head and move toward maximum head. If the position or status of the discharge valve or restriction has not been altered, the flow and discharge pressure will change along the compressor characteristic curve until the surge point is again reached.

   In short, if the downstream system cannot accept, or, utilize the compressed gas delivered by the compressor, or, if the required flow from the compressor for a given speed is not maintained, the compressor could, and, probably will, surge if not properly protected.

This is the end of the Centrifugal Compressor Training Notes (module one) presentation.