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Research Article

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Introduction to Compressors and Increasing wear Resistance of Centrifugal Compressor Shaft Bushing Bushings by Replacing Composition of Bushing Material

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Abstract

This article is a research article focused on studying the wearing of bushing connections within shafts, particularly in flash gas compressors. The article aims to identify various factors contributing to malfunctions that hinder the smooth operation of these compressors. The methodology involves a comprehensive study of the bushing connections and proposes new compositions of materials for compressor bushings. These new materials would replace bronze, potentially by incorporating nonferrous elements into bronze alloys. This alteration aims to enhance the wear resistance of the bushings against friction, ultimately improving the efficiency and longevity of the compressor's operation. This research could have significant implications for the field, potentially leading to advancements in compressor technology and improved performance in various industrial applications

Keywords: Compressor, Friction Force, Shaft, Bushing, Friction, Temperature, and Wear Resistance

1. Introduction

Compressors are classified into two groups according to the method of compression. Positive Displacement (or Volumetric) compressors all operate by trapping a quantity of gas within a fixed volume then reducing that volume to produce an increase in pressure. There are several types of positive displacement machine. The reciprocating type is designed to use the linear motion of a piston within a cylinder while rotary types use a rotating device such as a vane, screw, or lobe for compression. In theory reciprocating compressors are like positive displacement piston pumps. Gas is usually compressed in stages with cooling of the gas between stages. The two-stage compressor shown above has double acting pistons. The piston compresses and sucks on each movement of the piston. A two-stage compressor with a compression ratio of 3:1 on each stage will compress air at atmospheric pressure to 8 barg or 9 bara. A three-stage compressor with 3:1 on each stage will compress air to 26 barg or 27bara. By using higher compression ratios and multiple stages very high pressures can be reached.

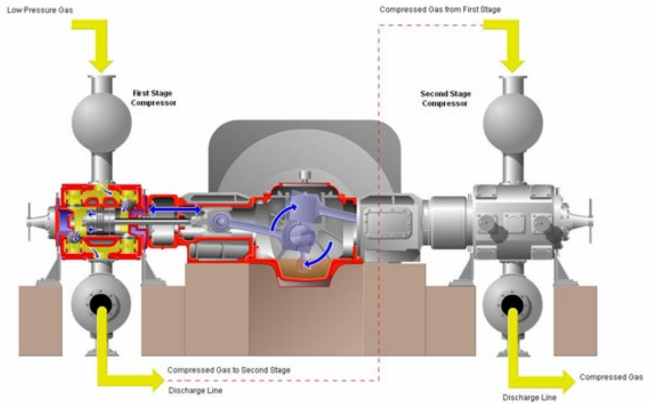


Figure 1: Reciprocating Compressor

Capacity control in reciprocating compressors is done by using "unloaders". Unloaders are simply mechanical devices that hold the inlet valves in the open position. Gas drawn into the cylinder is simply expelled back out through the inlet without being compressed (figure 1). Rotary screw compressors are positive displacement compressors. These compressors consist of two rotors within a casing shaped like a figure '8' where the rotors compress the air internally. There are no valves - the meshing and un-meshing of the rotors at the inlet port and outlet port creates a "space" that is squeezed and moved along from the inlet to the outlet. The driven rotor directly drives the idling rotor - there is no need for external driving gears.

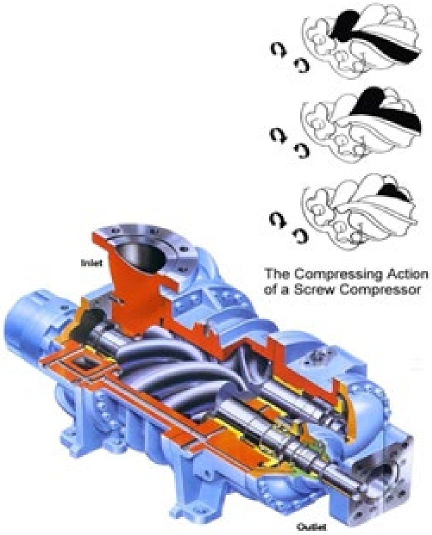


Figure 2: Screw Compressor

Capacity control is usually done by internal recycle of gas. Oil is injected into the intake side of the compressor. The oil seals the internal clearances between the rotors and the casing and absorbs the heat of compression. The oil is separated from the compressed air in the discharge receiver cooled and then re-circulated to the suction. There is no need for an oil pump - the high pressure at the receiver provides the force to push the oil back to the suction (figure 2). Screw compressors are extremely reliable. They can run for years before needing an overhaul. Most plant air/instrument air compressor packages use screw compressors.

2. Dynamic Compressors

Dynamic machines make use of rapidly rotating impellers to accelerate the gas to high speed. By changing the direction and decelerating the gas much of its kinetic energy is converted to pressure energy (figure 3). Centrifugal compressors use the same operating principle as centrifugal pumps. They can be single stage or multiple stages. A casing can have multiple rotors, but the casing can be one stage in a multi-stage process. The word "stage" usually refers to the stage in a process.

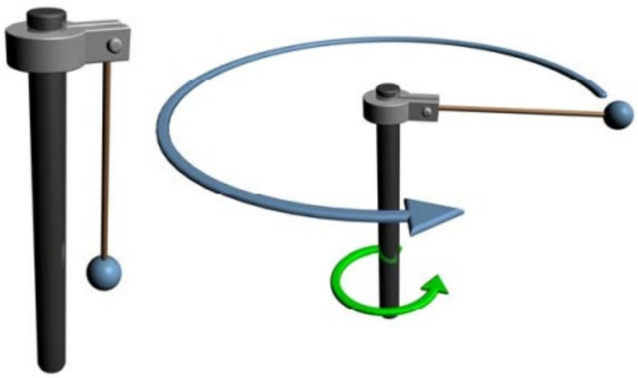


Figure 3: Spinning Force

The part of the centrifugal compressor that moves the gas is the impeller. The gas enters through the eye of the impeller and the rotating impeller accelerates the gas towards the outer rim. When the gas reaches the tip of the impeller blades it is at its maximum velocity and possesses the maximum amount of energy. As the gas leaves the impeller it is pushed into passageways called diffusers. The flow area in the diffuser is larger than that in the impeller so the velocity of the gas begins to decrease. This causes the gas pressure to increase. The diffuser converts the kinetic energy of the gas to increased pressure.

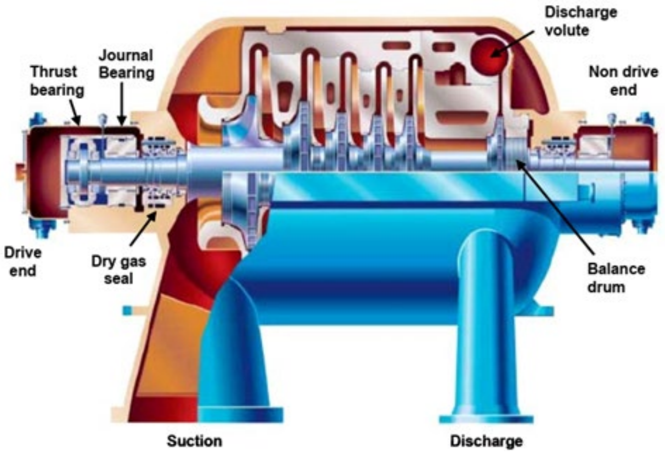


Figure 4: Centrifugal Compressor

This compressor can be one stage in a **process.** The pressure difference between discharge and suction produces an axial thrust on the shaft in the direction of the suction. This force can be in the order of 10 tones in mainline compressors. The balance drum is used to oppose the axial thrust. The outboard side of the balance drum is connected to the suction by a balance line. The difference in pressure on the two sides of the drum will oppose most of the axial thrust acting on the shaft (figure 4). The internal compressor stages (and the rim of the balance drum) have simple labyrinth seals. The dry gas seals at the drive and non-drive end are described in the next pages. Because of the balance line both dry gas seals are only subjected to suction pressure. Dry gas seals in compressors are similar in operation to mechanical seals on pumps. Instead of using a flushing liquid [as in pumps] dry gas seals use dry gas.

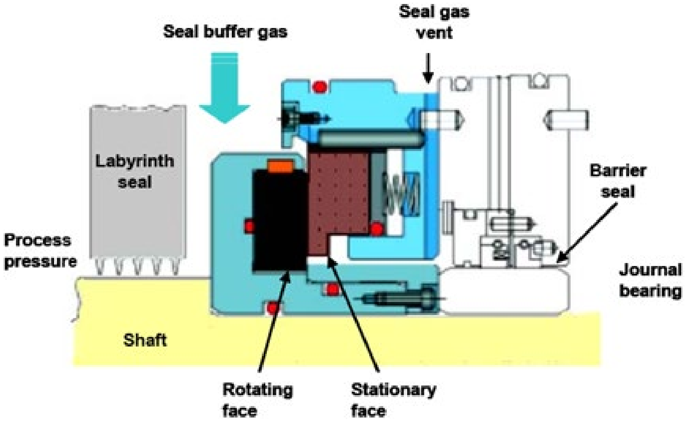


Figure 5: Dry Gas Seal Shaft Friction -Contact Area

The seal gas pressure is controlled slightly above the process pressure. A small amount of seal gas will leak through the labyrinth into the process. The rotating face of the seal has spiral grooves that drive the seal gas toward the shaft. This gas creates an aerodynamic wedge that separates the seal faces by microns. Seal gas must be perfectly clean and dry. The gas will exit through the seal gas vent. The function of the barrier seal is to keep lubricating oil out of the seal. The seal has micron size clearances. Any oil or particulate contamination will ruin the seal (figure 5). The purpose of the Flash gas compressors are used in oil processing facilities to compress gases that is “flashed” from a separation of hydrocarbon liquid when the liquid flows from a higher pressure to a lower pressure separator. Flash gas compressors typically handle low flow rates and produce high compression ratios.

3. Research Methods

A flash gas compressor is a type of compressor used in refrigeration systems and natural gas processing facilities. It's designed to handle gases that undergo phase changes, particularly from liquid to gas (or "flashing") due to changes in pressure or temperature. The wearing of centrifugal compressor shaft journal bushings made of bronze due to high temperature and friction is a common issue encountered in industrial applications. Centrifugal compressors commonly operate under conditions of elevated temperature owing to the compression of gases. Such thermal conditions may accelerate the degradation of bushing surfaces, particularly if the lubricating properties of the oil deteriorate in response to heat exposure. The interaction between the shaft and the journal bushing, especially under conditions of substantial loads and high rotational speeds, can result in abrasive wear and surface deterioration.

This frictional activity contributes significantly to the generation of heat, thereby exacerbating the wear phenomenon. To resist such working environment special bronze alloys used at compressor thrust and journal bushings. The prevalent usage of bronze in journal bushings is attributable to its commendable mechanical attributes and resistance to corrosion. However, when subjected to high temperatures and substantial loads, bronze bushings may experience accelerated wear and potential deformation. Above operation conditions of centrifugal compressors lead to wearing by friction, that result in vibration issue at compressors. Vibration transmitters detect high vibration and shutdown compressor, which lead to additional flaring of natural gas and environmental pollution. To prevent these happening changes should be done at compressor bushing and sleeve material by adding additional nickel and molybdenum alloys to increase it wear resistance and produce more durable material bushings.

The determination of axial force in a centrifugal compressor is an important aspect of its operation and maintenance. Axial force refers to the force acting along the axis of rotation of the compressor (figure 6). It typically arises due to various factors such as impeller design, operating conditions, and mechanical interactions within the compressor. The axial force in a centrifugal compressor can have significant implications for its performance, reliability, and longevity. Excessive axial force can lead to issues such as increased wear and tear on components, vibration, and reduced efficiency. Therefore, it is essential to accurately determine and manage axial forces in centrifugal compressors. To determine axial force in a centrifugal compressor, engineers typically conduct analyses based on factors such as impeller geometry, fluid dynamics, and operating conditions. Experimental methods, numerical simulations, and analytical calculations may be employed to assess axial forces under different scenarios.

Once the axial force is determined, appropriate measures can be taken to address any issues or optimize the compressor's performance. This may involve adjusting operating parameters, modifying impeller design, or implementing maintenance strategies to mitigate excessive axial forces and ensure reliable operation of the centrifugal compressor. In a centrifugal compressor, erosion can occur due to various factors such as the presence of abrasive particles in the gas being compressed, high gas velocities, or inefficient flow patterns within the compressor. Erosion typically affects components such as impeller blades, diffusers, and casings, leading to material loss and degradation of performance over time. When erosion is detected at the distance of the determined axial force, it suggests that the erosion is likely occurring in areas where the axial force is exerted on the components. This could indicate that the erosion is being exacerbated by the mechanical forces acting on the components due to the axial force.

The detection of erosion at the location of the axial force highlights the importance of considering mechanical factors, such as axial force, in understanding and addressing erosion issues in centrifugal compressors. It also suggests that addressing the underlying causes of the axial force, such as imbalances in the compressor or inefficient flow patterns, may help mitigate erosion and prolong the life of the compressor components. To address erosion in this scenario, strategies such as redesigning components to improve erosion resistance, optimizing flow patterns to reduce abrasive wear, and implementing erosion-resistant coatings or materials may be considered. Additionally, regular inspection and maintenance to monitor erosion progression and take preventive measures can help minimize the impact of erosion on compressor performance and reliability. The provided statement outlines a specific action taken to increase the friction resistance of a part, specifically the bushing in a centrifugal compressor.

There was likely an observed problem with friction in the bushing of the centrifugal compressor, which could lead to issues such as wear, heat generation, or reduced efficiency. A contact strip was chosen as a solution to address the friction issue. Contact strips are often used to modify surface properties and improve friction characteristics in mechanical systems. The selected contact strip was impregnated with a composition containing nickel powder. Nickel powder is known for its ability to enhance surface hardness and wear resistance when applied to materials. After impregnation with the nickel powder composition, the contact strip was reinforced using laser technology. Laser reinforcement involves using a laser to heat and bond materials, often resulting in improved mechanical properties and durability. By impregnating the contact strip with nickel powder and reinforcing it with laser technology, the goal was to enhance the friction resistance of the bushing in the centrifugal compressor.

This process likely aimed to reduce wear and improve the overall performance and longevity of the compressor system. Overall, this approach demonstrates a proactive method to address friction-related issues in mechanical systems, utilizing advanced materials and manufacturing techniques to optimize performance and reliability. The research conducted based on the reinforcement of the centrifugal compressor bushing material yielded significant improvements in resistance to abrasion. Specifically, the resistance to abrasion increased by up to 2.5 times compared to the material's original state or previous performance. This outcome suggests that the impregnation with nickel powder composition and reinforcement with laser technology effectively enhanced the durability and wear resistance of the bushing material (figure 7). The nickel powder likely contributed to increased hardness and wear resistance, while the laser reinforcement further improved the bonding and mechanical properties of the material.

Achieving 2.5 times increase in resistance to abrasion indicates a substantial improvement in the performance and longevity of the centrifugal compressor bushing. It implies that the implemented solution successfully addressed the underlying friction-related issues and mitigated the effects of wear and tear, ultimately leading to a more reliable and efficient operation of the compressor system. This research outcome underscores the importance of utilizing advanced materials and manufacturing techniques to enhance the performance and durability of critical components in industrial machinery such as centrifugal compressors. It also highlights the effectiveness of proactive measures in mitigating wear-related problems and optimizing the reliability of mechanical systems.

The prevalent usage of bronze in journal bushings is attributable to its commendable mechanical attributes and resistance to corrosion. However, when subjected to high temperatures and substantial loads, bronze bushings may experience accelerated wear and potential deformation. Alternative materials exhibiting superior resistance to heat and wear, such as babbitt alloys or ceramic coatings, warrant consideration. Augmenting the lubrication system to ensure adequate oil flow and cooling to the bushing surfaces is imperative, as it serves to mitigate frictional forces and thermal effects. Application of surface treatments or coatings to the bushing surfaces represents a viable strategy for enhancing wear resistance. Techniques such as thermal spraying can facilitate the deposition of robust coatings such as chromium carbide or tungsten carbide.

Design optimization of the bushing housing and shaft geometry can help minimize stress concentrations and optimize load distribution, thereby mitigating wear on the bushing surfaces. Calculating stress and force on a centrifugal compressor shaft and bushing connection point involves several factors, including the operating conditions, geometry of the components, material properties, and applied loads. Stress analysis conducted at CAESAR II simulation software and force applied to compressor shaft bushing connection regarding to API 617 standards and shaft seal John Crane Dry gas seal first critical lateral speed 1034 RPM and last critical speed 13801 rpm given to compressor after replacing composition of shaft bushing sleeve connection. Modern bronze is typically 88 % copper and about 12 % tin. After this simulation it was identified that replacing bronze material composition and adding nickel alloy by 1 % increases temperature resistance of material and increases torsional critical strength (table1).

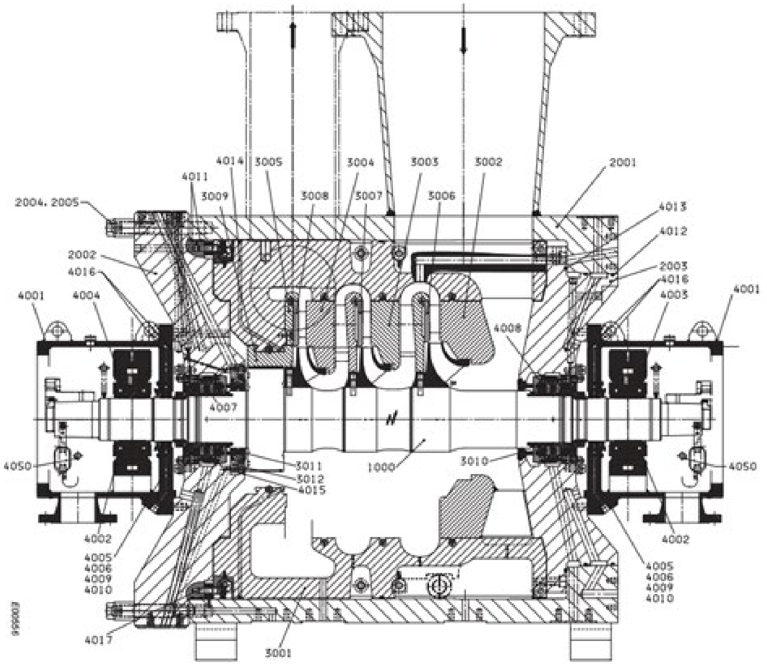
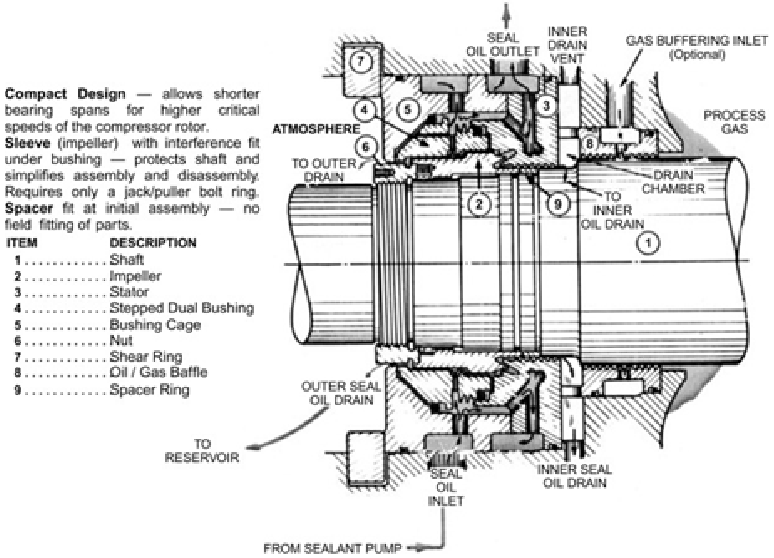


Figure 6: Flash Gas Compressor Drawing

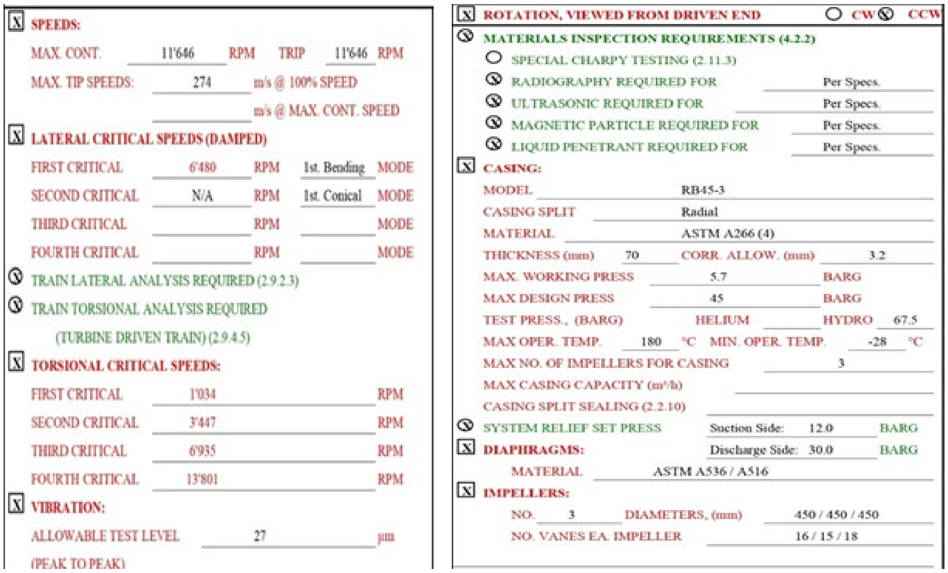

Compact Design — allows shorter bearing spans for higher critical speeds of the compressor rotor. **Sleeve** (impeller) with interference fit under bushing — protects shaft and simplifies assembly and disassembly. Requires only a jack/puller bolt ring. **Spacer** fit at initial assembly — no field fitting of parts.

ITEM	DESCRIPTION
1	Shaft
2	Impeller
3	Stator
4	Stepped Dual Bushing
5	Bushing Cage
6	Nut
7	Shear Ring
8	Oil / Gas Baffle
9	Spacer Ring

Figure 7: Shaft end Overview of Bushing, Sleeve

Centrifugal compressor data sheet (API617-6th)	Values	Units
SPEEDS Max Cont.	11646	RPM
Lateral Critical speed (Damped)		
Torshinal critical speed 1st critical 2nd critical 3rd critical 4th critical	1034 3447 6935 13801	RPM
Vibratin	27	µm
Casing thicknes	70	mm
Corrosion allowance	3.2	mm

Table 1: Compressor Simulation Data Sheet Value From CAESAR


☒ SPEEDS:
MAX. CONT. 11'646 RPM TRIP 11'646 RPM
MAX. TIP SPEEDS: 274 m/s @ 100% SPEED
m/s @ MAX. CONT. SPEED
☒ LATERAL CRITICAL SPEEDS (DAMPED)
FIRST CRITICAL 6'480 RPM 1st. Bending MODE
SECOND CRITICAL N/A RPM 1st. Conical MODE
THIRD CRITICAL RPM MODE
FOURTH CRITICAL RPM MODE
⊘ TRAIN LATERAL ANALYSIS REQUIRED (2.9.2.3)
⊘ TRAIN TORSIONAL ANALYSIS REQUIRED
(TURBINE DRIVEN TRAIN) (2.9.4.5)
☒ TORSIONAL CRITICAL SPEEDS:
FIRST CRITICAL 1'034 RPM
SECOND CRITICAL 3'447 RPM
THIRD CRITICAL 6'935 RPM
FOURTH CRITICAL 13'801 RPM
☒ VIBRATION:
ALLOWABLE TEST LEVEL 27 µm
(PEAK TO PEAK)

☒ ROTATION, VIEWED FROM DRIVEN END ○ CW ⊘ CCW
⊘ MATERIALS INSPECTION REQUIREMENTS (4.2.2)
○ SPECIAL CHARPY TESTING (2.11.3)
⊘ RADIOGRAPHY REQUIRED FOR Per Specs.
⊘ ULTRASONIC REQUIRED FOR Per Specs.
⊘ MAGNETIC PARTICLE REQUIRED FOR Per Specs.
⊘ LIQUID PENETRANT REQUIRED FOR Per Specs.
☒ CASING:
MODEL RB45-3
CASING SPLIT Radial
MATERIAL ASTM A266 (4)
THICKNESS (mm) 70 CORR. ALLOW. (mm) 3.2
MAX. WORKING PRESS 5.7 BARG
MAX DESIGN PRESS 45 BARG
TEST PRESS., (BARG) HELIUM HYDRO 67.5
MAX OPER. TEMP. 180 °C MIN. OPER. TEMP. -28 °C
MAX NO. OF IMPELLERS FOR CASING 3
MAX CASING CAPACITY (m³/h)
CASING SPLIT SEALING (2.2.10)
⊘ SYSTEM RELIEF SET PRESS Suction Side: 12.0 BARG
☒ DIAPHRAGMS: Discharge Side: 30.0 BARG
MATERIAL ASTM A536 / A516
☒ IMPELLERS:
NO. 3 DIAMETERS, (mm) 450 / 450 / 450
NO. VANES EA. IMPELLER 16 / 15 / 18

Result

1. Axial force has been determined.
2. The process of erosion was detected at the distance of the determined axial force.
3. To increase the friction resistance of that part, the selected contact strip is impregnated with nickel powder composition and reinforced with laser.
4. As a result of research conducted based on reinforcement, resistance to abrasion increased up to 2.5 times.

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