PRESENTATION APPRAISAL & UPDRAFT STUDY OF DIESEL ENGINE MECHANICAL BOLT AIR COMPRESSOR

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Abstract

In almost every industrial sector there is a requirement of compressed air. This compression of air is achieved by using air compressors. In general, there are three types of air compressors on the basis of function- Centrifugal, Reciprocating and Screw Compressors. This paper represents the performance evaluation and thermal analysis of a diesel engine driven screw air compressor carried out in two main analysis namely- Air Flow analysis and Heat Flow analysis. Also, in this paper an attempt has been made to study its impact on the performance of the compressor after modification of geometry and altering the selection of fan. A simulation has been carried out using flow simulation software for the above mentioned analysis.

Keywords: Screw Compressor; Diesel Engine; Air Flow; Surface Heat Load; Heat Flux; Flow Domain.

Parameter	Symbol	SI Unit
Diameter	d	mm
Density	ρ	kg/m^3
Free Air Delivery	FAD	cfm
Pressure	P	kg/cm^2
Volume Flow Rate	Q	m^3/sec
Angular Velocity	N	rpm
Temperature	T	°C

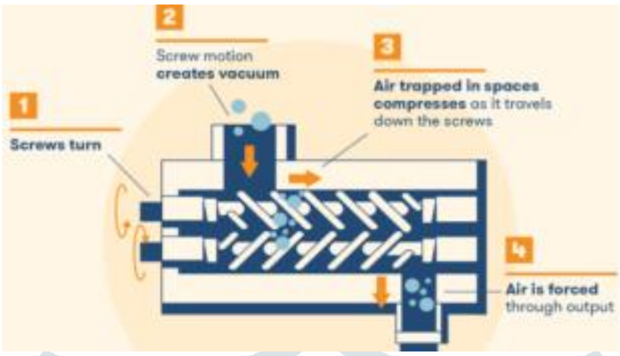
Introduction

The positive displacement rotary screw compressor uses oil injection. When air or gas is trapped in a compression chamber, its volume is mechanically reduced, which results in a proportional increase in pressure before discharge. Each rotor, which is commonly referred to as a twin screw compressor, is made up of a group of helical lobes attached to a shaft. The male lobe rolls down the female flute like a continuous piston, encasing air and continuously constricting space. The leading strip of the male lobe reaches the female groove's shape with rotation and traps the air in the previously established pocket [2], [5], [7].

Oil injected rotary screw compressor

When the male rotor lobe approaches the groove's end, the air that has been trapped is released from the airend. Oil-free or oil-injected twinscrew compressors are also options. Four essential tasks are carried out by oil:

1. Cooling 2. Lubrication 3. Sealing 4. Noise dissipation [6]



Layout of a rotary screw compressor

Construction and mining, general engineering, and other sectors employ KPCL Diesel Engine Driven Portable Compressors. These devices have a wide range of capacities (4.38 to 21.23 m3/min) and pressures (7 to 12.5 kg/cm2). Engines designed to give the best fuel efficiency and lowest emissions in their class power screw compressors. These engines are included in the compressors, which offer consumers long-lasting performance at a cheap cost of ownership [3]

Canopied Kirloskar Diesel Screw Compressor

Literature Review

A literature survey has been done in order to understand the working and schematics of a rotary screw compressor and also of diesel powered screw compressors. Further literature survey has been done in order to understand the analytical calculation methodology for estimating air flow, heat flow and heat load estimation.
Junfeng Wang [1], In this paper, a full 3D transient Computational Fluid Dynamics (CFD) model of a twin screw compressor with oil injection is described in detail. Volume of Fluid (VOF) two phase flow model is used for gas and liquid phases. The rotor meshes are generated by SCORGTM grid generator and read into the CFD solver at each time step. The compression pocket is tracked using a customized post-processing technique and the pressure-volume diagram within it is also obtained and analyzed.

The simulation runs efficiently and results are obtained in about 12 hours on 24 CPU cores. Simulations demonstrate that the approaches used in this paper are robust and fast, and can be readily applied to industrial compressor systems for rapid design iterations and improvements.

Camelia POPA [2], A suitable procedure for optimization of the screw compressor shape, size, dimension and operating parameters is described here, which results in the most appropriate design for a given compressor application and fluid. Some optimization issues of the rotor profile and compressor parts are discussed, using 5/6 screw compressor rotors to present the results. It is shown that the optimum rotor profile, compressor speed, oil flow rate and temperature may significantly differ when compressing different gases or vapors or if working at the oil-free or oil flooded mode of operation. To determine the most effective compressor design for any particular duty, a comprehensive multivariable optimization of screw compressor geometry and operating circumstances was carried out. This was accomplished using a computer program the authors created to simulate compressor processes. This program provides a general description of the lobe segments in terms of a number of important parameters, can generate different lobe shapes, and simultaneously calculates compressor thermodynamics.

Xiangjing Liang [3], Under unloading conditions, the twin screw air compressor's operation was examined. Based on the principles of ideal gas and conventional thermodynamic relations, a mathematical model representing the operation of an oil-injected twin screw compressor under unload conditions was developed, taking into account the impacts of oil injection, gas-oil heat transfer, internal leakage, etc. By comparing the outcomes of the simulation model and testing, the experiment was conducted to validate the model. The simulation and test findings also demonstrated that, when the discharge pressure was decreased, volumetric efficiency rose with an increase in rotating speed. As discharge pressure and rotating speed grew, so did the shaft power. This model offers a reference for the highly efficient and energy-efficient functioning of screw compressors and can be used to estimate performance under unload scenarios

System Description & Design

The term "Compressor Package" refers to the combination of all the components along with the bare compressor itself that ultimately forms the final finished product. The components that generally comprises of a Diesel Engine driven Compressor Package are:

a) Bare Compressor (also called as Airend) b) Diesel Engine c) Air Oil Separator Tank d) Radiator type oil cooler e) Fuel Tank f) Battery g) Safety and Discharge Valves h) Pressure and Temperature switches

Apart from the above components there are two main components namely- the baseframe, this forms the base of the entire package on which all the components are mounted, and the canopy, which forms as an outer covering for the package.

Oil injected screw air compressor package layout

There are two main flow circuits in a compressor package; Air flow circuit and Oil flow circuit.

Air flow Circuit

While in operation, all the canopy doors remain closed. The intake air is taken as atmospheric air which flows from below the baseframe into the intake filter. Upon filtration, the intake valve facilitates the flow of air into the airend. Air trapped in between the rotor spaces get compressed along with the lube oil already present inside the compressor. After compression, the high pressure and high temperature mixture of air and oil flows into the AirOil Separation Tank, where the separator element present inside the tank separates the Oil from the Air. Subsequently, the oil free high pressure air is then passed on to the discharge valves after going through the minimum pressure valve. Discharge ball valves channelize the air for application [2], [8].

Oil Flow Circuit

Consequently, the temperature and pressure of the lube oil increases. This compressed high temperature and high pressure oil then mixes with air in the same state and the mixture flows out of the airend and into the Air Oil Separator Tank. The separation process is carried out by the separator element. The oil droplets being heavier and denser hit the element and fall down to the base of the tank. After the separation process is complete the oil being of high temperature and cannot be reused for lubrication, is channeled through to the oil cooler. A radiator type oil cooler is used. Upon cooling, the oil is recirculated back into the airend and the cycle continues. An Oil Stop Valve (OSV) is used to regulate the flow of oil from the separation tank to the oil cooler [4].

Methodology

To find out the flow velocity of air inside the package during operation we need the operating parameters of the fan and subsequently calculate the velocity at the flow domain of the fan. The operating parameters of the fan are as follows:

Blade diameter = 939.8 mm (38 inches)
No. of blades = 4
Shroud Type: Nozzle
Rotational Speed: 2024 rpm
Air Density: 1.09 Kg/m^3
Air Flow Rate: 12.51m^3/sec

The analysis has been carried out by CFD simulation where the Mass flow rate of air, velocity of air within the package and the fan flow domain velocity has been considered as boundary conditions. A 3D flow domain was created at first which consisted of two surface domains- the air domain and the fan domain. Upon creation of flow domain the meshing of the domains was carried out.

Changes were made to the shape after the initial simulations were done in order to enhance the package's air flow and maximise the fan, so that the power requirement of the fan can be reduced. Another set of simulation has been run with the modified geometry to find the impact of the modifications on the air flow.

The setup or the pre-processing of the meshed components for the second set of simulations consisted of the following inputs:

1. There are 4 different air inlet passages into the package with one chief outlet. 2. The outlet is at the end of the package (Radiator Oil Cooler) where the flow of air is channeled out along with the exhaust air of the engine. 3. Atmospheric air at 25°C and 1 atm pressure is assumed as inlet air.. 4. K-Epsilon Turbulence Model is used. 5. For Fan, the domain motion is rotational and the angular speed is 2420 rpm. 6. The Mixing Model for the fan interference regions with air inlet and outlet is taken to be Frozen Rotor. 7. Air mass flow rate inside the package during operation is12.51 m3 /sec. 8. Air mass flow rate at the outlet is 14.0112 m^3/sec. [3]

The simulation consisted of 1000 iterations and the results were observed. Post-processing of the acquired result has been carried out to visually represent the data in an understandable way. The following schematic will give an overview of the methodology followed:

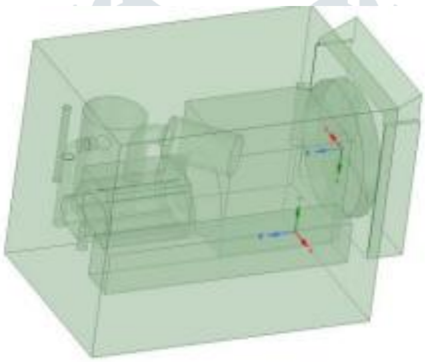
CFD Simulations

As stated previously, a specific path of operations were followed for carrying out the CFD simulations for the compressor package as specified. This gave the understanding of the flow and the behavior of air over the surfaces which can actively affect the process of surface cooling. The initial procedure followed was as per the procedure followed in [1].

Flow Domain Creation

The 3D geometry of the package was simplified and processed so as to obtain only the area of where the air flow will be prevalent. All the standard fasteners, bolts, nuts, rivets and screws were removed and a geometric clean-up was carried out. Holes and pipes were also removed and only the components that are majorly affected by overheating and require surface cooling are kept.

All the components inside the package i.e., the engine, compressor, separator tank, fuel tank and intake filter are kept in the air domain whereas, a separate domain was created for the fan where the air interference with the fan and fan blade is only considered as a separate domain.



Meshing

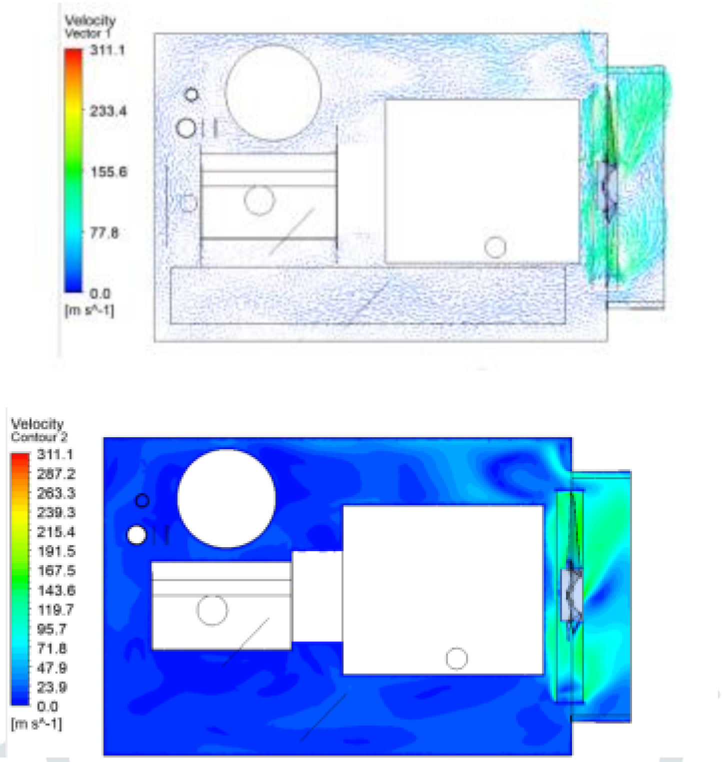
A very fine mesh has been generated in this simulation in order to obtain a more accurate result.

Setup and pre-processing

Pre-processing is the first step of CFD simulation. Here, all the necessary boundary conditions, inlet and outlet conditions and analysis model selection are carried out. The data input in the solver directly affects the output of the simulation. For the first set of simulations, we have considered only one inlet of air (through the base frame) and one primary outlet (behind the fan).

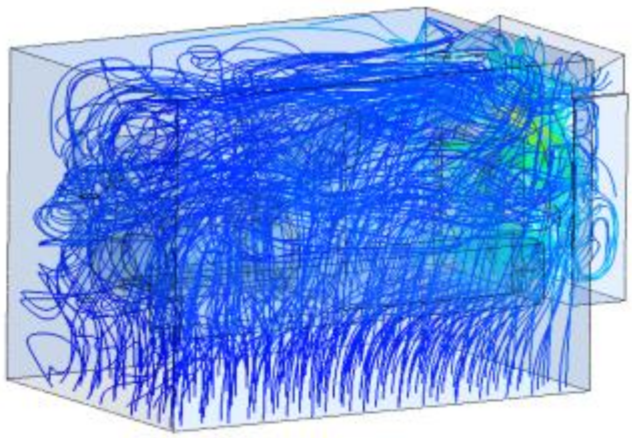
The Turbulence model chosen here is K-Epsilon Model and the mixing model is Frozen Rotor, since we need to calculate the velocity of the air flow and the domain of the fan has to remain stationary, even if the blades are rotating at an angular speed of 2420 rpm. The mass flow rate of air at the outlet is calculated to be 14.0112 m3/sec and the inlet condition of air is atmospheric air at 25°C and 1 atm pressure.

Results



Velocity of airflow in the package (Center Plane)

As seen in the above simulation, the maximum velocity of air inside the package is 311 m/sec, which is excessively high. As a result, the fan is required to draw more power from its motor which eventually makes the fan even bigger and the cost also increases. Also, the air flow is much turbulent and needs to be streamlined. Hence, an alternate solution is provided in order reduce the fan power and rapid air flow within the package. This solution will reduce the power consumption of the fan as well as streamline the flow of air for much better surface cooling effect for each of the components.

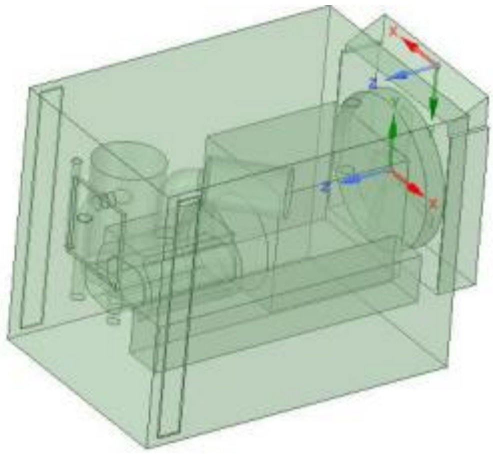


Velocity Streamline

Modification in geometry

1. Two slits of dimension (230 x 150) mm are created on either side of the airend on the canopy by removing the material. 2. A square cutout of dimension 460 mm is provided at the front of the canopy above the airend. 3. Atmospheric Air is allowed to enter through the above mentioned openings as inlet air needed for compression function.

Now, after implementing the above modifications, the following is the new flow domain that is obtained for new set of simulations needed:



Flow domain for modified geometry

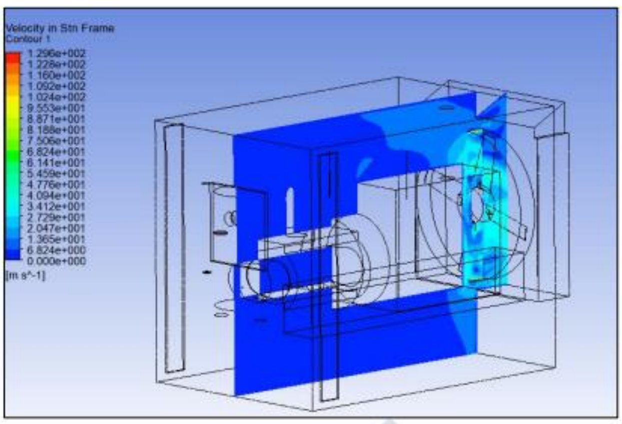
Sizing	
Size Function	Curvature
Max Face Size	2.e-002 m
Mesh Defeaturing	Yes
Defeature Size	Default (1.e-004 m)
Growth Rate	Default (1.20)
Min Size	1.e-003 m
Max Tet Size	5.e-002 m
Curvature Nor...	Default (18.0 °)
Bounding Box Di...	3.24410 m
Average Surface ...	0.22960 m²
Minimum Edge L...	6.4e-004 m

Statistics	
Nodes	997039
Elements	5347446

Mesh Quality

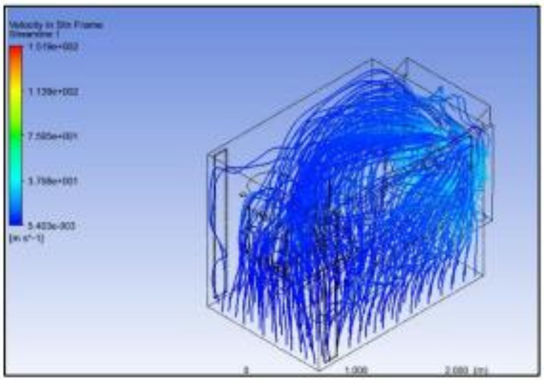
For setup and pre-processing, the following conditions have been taken as input for simulation of the modified geometry:

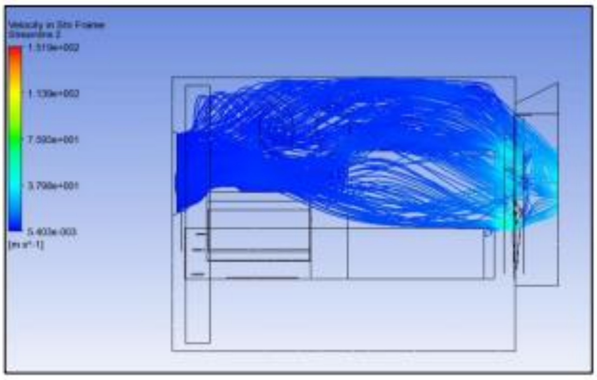
1. There are 4 different air inlet passages into the package with one chief outlet. 2. The outlet is at the end of the package (Radiator Oil Cooler) where the flow of air is channeled out along with the exhaust air of the engine. 3. Atmospheric air at 25℃ and 1 atm pressure is assumed as inlet air.. 4. K-Epsilon Turbulence Model is used. 5. For Fan, the domain motion is rotational and the angular speed is 2420 rpm. 6. The Mixing Model for the fan interference regions with air inlet and outlet is taken to be Frozen Rotor. 7. Mass flow rate of air inside the package during operation is12.51 m^3/sec. 8. Mass flow rate of air at the outlet is 14.0112 m^3/sec. [3]



Velocity of air flow in the package (Center Plane)

As seen in the above images, the maximum velocity has been reduced from 311 m/sec to about 130 m/sec. This is due to the influx of more amount of air through the various inlets with the modified geometry. Also, the following images show the velocity streamline inside the compressor package.





Conclusion

The modified geometry gives a much improved streamline flow of air inside the package with the fan operating at the stated rpm. This will allow a better surface cooling for each and every component inside as the air flow is not erratic and it is properly channelized. For example, the engine gives the highest surface heat load inside the package. Hence, a cutout has provided in the frontal face of the canopy so that the air coming in from that inlet will directly flow over the engine and as a result will cool the surface down faster. Initial procedure was as per [1].

Moreover, the velocity of flow inside the package has been reduced. The maximum velocity of air inside the package has been reduced to 151 m/sec in stationary frame. Hence, there is a reduction of about 51% in the velocity. This will directly reduce the rpm required for the fan and consequently, the power consumption.

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