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Weight Reduction & Stress Analysis of Air-Conditioning Compressor Crankshaft

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Abstract: ***The hermetically sealed reciprocating compressor is a major component in any refrigeration and air-conditioning systems. The design depends on the cooling capacity of the system, size, location, type of ac system etc. The compressor mainly consists of two parts, which are called as short-kit and an electric motor used for driving the short-kit (short-kit and electric motor are both called as long kit). The short-kit mainly includes a crank case, piston, connecting rod and crankshaft. Present work mainly deals with the redesigning of a short-kit component i.e., Crankshaft by reducing its weight. Crankshaft is a major part in the system which affect through various working stresses and the only dynamic part which has greater possibility to reduce the weight. The weight of any component can be reduced in two ways; either by suggesting an alternate material or by redesign. In this project an attempt was made to reduce the weight of the crankshaft by considering their design. As a start of design the shaft is designed according to the specifications of the compressor without considering any other factors. The designed shaft is analyzed and the results obtained are reviewed. The most important factors that are concentrated are stress distribution and deflections. The designed shaft is optimized for its topology. The reviewed design is analyzed and the better design for the minimum weight is considered, According to optimized design parameters the shaft is re built. The future scope of project deals with the alternative materials which equalizes the present material properties.***

Keywords: Compressor, Crankshaft, refrigeration, conditioning

1. Introduction

1.1 Refrigeration& Air Conditioning:

1.1.1 Refrigeration

Refrigeration is the process of removing heat from an enclosed space, or from a substance. Vapour compression cycle is process used in refrigerator and Air conditioning system

Vapour-compression cycle

The vapour-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Figure 1 provides a schematic diagram of the components of a typical vapour-compression refrigeration system.

The thermodynamics of the cycle can be analyzed on a diagram as shown in Figure 2. In this cycle, a circulating refrigerant such as Freon enters the compressor as a vapour. From point 1 to point 2, the vapour is compressed at constant entropy and exits the compressor superheated. From point 2 to point 3 and on to point 4, the superheated vapour travels through the condenser which first cools and removes the superheat and then condenses the vapour into a liquid by removing additional heat at constant pressure and temperature. Between points 4 and 5, the liquid refrigerant goes through the expansion valve (also called a throttle valve) where its pressure abruptly decreases, causing flash evaporation and auto-refrigeration of, typically, less than half of the liquid.

1.1.2 Air Conditioning

Basic components of air conditioning system:

- Compressor
- Condenser
- Expansion valve
- Evaporator

The basic operation of the air-conditioning cycle is as follows:

1. The compressor compresses **cool Freon gas**, causing it to become **hot, high-pressure Freon gas** (red in the diagram above).
2. This hot gas runs through a set of coils so it can dissipate its heat, and it condenses into a **liquid**.
3. The Freon liquid runs through an expansion valve, and in the process it evaporates to become **cold, low-pressure Freon gas** (light blue in the diagram above).
4. This cold gas runs through a set of coils that allow the gas to absorb heat and cool down the air inside the building.

2. Compressors

The majority of refrigerators use compressors (one or more), which are their key elements. Compressors, in general, can be of volumetric type (a fixed volume of fluid is taking at low pressure and delivered at high pressure), or of dynamic type (the fluid is accelerated/decelerated and dynamic pressure recovered), the latter being more appropriate for large flow-rates, and the former for large pressure jumps. Different types of compressors are used according to refrigeration capacity (size). In a hermetically sealed reciprocating compressor, all components (electrical windings, stator, rotor, crank-shaft, compressor chamber, and exhaust duct) are exposed to both lubricant oil and low-pressure cold gas from the vaporiser, within a single steel shell.

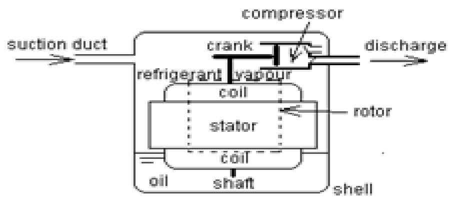

Figure 1: Sketch of a hermetically sealed reciprocating compressor.

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2.1Hermetically Sealed Compressor

In the hermetically sealed compressor, the electric motor and compressor are both in the same airtight (hermetic) housing and share the same shaft. Figure 6-18 shows a hermetically sealed unit. Note that after assembly, the two halves of the case are welded together to form an airtight cover. Figure 6-19 shows an accessible type of hermetically sealed unit. The compressor, in this case, is a double-piston reciprocating type. Other compressors may be of the centrifugal or rotary types.

Cooling and lubrication are provided by the circulating oil and the movement of the refrigerant vapor throughout the case.
The advantages of the hermetically sealed unit (elimination of pulleys, belts and other coupling methods, elimination of a source of refrigerant leaks) are offset somewhat by the inaccessibility for repair and generally lower capacity.

Principle parts of hermetically sealed compressors
1. Crankshaft
2. Connecting rod
3. Piston
4. Crankcase

2.1.1 Components of compressor:
- Short kit (Mechanical Accessories)
- Long kit (Electrical Accessories)

2.1.2Specifications
- Design Reciprocating
- No. of cylinders 2
- Speed 3500 rpm
- Weight including oil 27.7 kgs
- Suction pressure 5.34 kg/cm^2 or 76Psi
- Discharge pressure 21.09 kg/cm^2 or 300Psi
- Power input 2075 watts
- Application Room Air conditioner
- Frequency 60 Hz

2.1.3Application
Evaporating temp range -3.9 to+12.8deg cent:
+25 to + 55deg F
Refrigerant R-22
Refrigerant control Capillary
Compressor cooling 12.0 C MM: 425 CFM (min)
General applications Room Air Conditioner
Cooling capacity –Rated 5140 Kcal/:20400 Btu/hr
Energy efficient ratio 2.48Kcal/W hr: 9.8 Btu/W hr
Current 9.7 amps
LRA 60 Amps
Evaporating temp 7.2 deg C 45 deg F
Condensing temp 55 deg C 131 deg F
Liquid sub cooling temp 46 deg C 115 deg F
Return gas temp 35 deg C 95 deg F
Ambient temp 35 deg F 95 deg F

2.2 Compressor Parts

1. Crank case
2. Piston
3. Connecting rod
4. Piston pin
5. Roll pin
6. Spinner
7. Crank shaft
8. Outboard bearing
9. Thrust bearing plate
10. Thrust plate
11. Flat head m/c screws
12. Hex. Head washer face cap screws
13. Valve plate
14. Rivets
15. Discharge valve leaf
16. Discharge valve retainer
17. Intake valve pin
18. Intake valve leaf
19. Valve plate gasket
20. Cylinder head gasket
21. Cylinder head
22. IPR valve
23. Discharge muffler
24. Suction muffler
25. Cylinder head clamp
26. Flange 12 point cylinder head bolt screws
27. Stator stack
28. Stator wound
29. Torx external bolt heads
30. Rotor
31. Lower housing
32. Compressor mounting brackets
33. Discharge connector tube
34. Shock loop
35. Spring mounting brackets
36. Compressor suspension-springs
37. Upper housing
38. Process tube
39. Suction tube
40. Hanger bracket
41. Hermetic terminal
42. Terminal guard

2.3 Short-kit Importance

Short-kit is the main part in the compressor where the main assembly of crankshaft, connecting rod and piston are mounted within a crankcase. This was connected to an electric motor at the long end of the crankshaft. The primary function of the short-kit is to compress the refrigerant to high pressure and temperature gas and is delivered through its outlet port. Main parts of the short-kit are as follows:
1. Crankcase
2. Crankshaft
3. Connecting rod
4. Piston
5. Piston pin
6. Out board bearing
7. Thrust plate
8. Roll pin

2.3.1CRANKSHAFT
Definition:
A crankshaft is used to convert the reciprocating motion of the piston into rotary motion or vice versa.

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Materials & Manufacture

The crankshafts are subjected to shock and fatigue loads. Thus the material of the crankshaft should be though and fatigue resistant. The crankshafts are generally made of carbon steel, special steel or special
cast-iron. The crankshafts are made by drop forging or casting process. But the former method is more common.

2.3.2Bearing pressures and stresses in crankshaft:
The bearing pressures are very important in the design of crankshafts the maximum permissible bearing pressure depends upon the maximum gas pressure, journal velocity, amount and method of lubrication and change of direction of bearing pressure. The following two types of stresses are induced in the crankshaft.
1. Bending stress
2. Shear stress due to torsional moment on the shaft.

The failures of the crankshaft are caused by progressive fracture due to repeated bending or reversed torsional stresses. Thus the crankshaft is under fatigue loading and, therefore, its designs should be based upon endurance limit. Since the failure of a crankshaft is likely to cause serious problems, the factor of safety is always maintained from 3 to 4 based on the endurance limit.

3. Definition of Problem

This project deals with the Weight reduction of crankshaft which is used in air conditioning compressors. The crankshaft which is optimized and analyzed is being used in many R&A/C compressors. The problem is to reduce its weight. As the project deals with the design optimization of the crankshaft, the previous work is reviewed and the results are taken as a reference for present project work. The main problem is that the crankshaft should be optimized for its minimum weight and it should be also taken care that stress should not exceed allowable stresses given for the material.

3.1 Description about the problem

The present crankshaft that is being used in the A.C. compressor weighs about 0.938 kg. Total weight of the compressor assembly is 27.7 kg. In this design I have done static analysis of the crankshaft, free-free modal analysis.

4. Objectives and Goals

In design optimization we have to state the design variables. The figure shows the design of the crankshaft that to be optimized. The present shaft that is being used in compressor weighs about 938 grams. Now the objective here the desired objective that is to be minimized its weight without sacrificing its function and performance.

The main functioning unit of a hermetically sealed compressor (explained in next chapter) is a **shot-kit** which consists of all mechanical components viz... Crankcase, piston, connecting rod, crankshaft, out board bearing, thrust plate etc. The short-kit is a reciprocating system where the crank shaft in it is driven by an electric motor. The power obtained from the electric motor is utilized in compressing the Freon refrigerants.

The main part which connects the electric motor and the compressing unit is the crankshaft of the short-kit. The present focus of work is of reducing the weight of the crankshaft in the compressor. Crankshaft is one of the major components of the short-kit and has wider possibilities for design optimization. The crankshaft is to be re-designed for the present working stresses and to make the compressor perform better.

5. Methodology

The project mainly is of two stages where in stage one, the study of the present existing model is done by determining the various properties, loads, material considerations, applications etc. The stage two of the project is dedicated to actual work, where the possible modification of model is done.

In this gives the information about the methods that are used for obtaining the optimized solution. With previous dimensional parameters the shaft is modeled in **UNIGRAPHICS**software. The modified shaft is also modeled. The models can be meshed for further analysis using a meshing package **HYPERMESH** or free/mapped mesh in **ANSYS**. Meshing of the component plays an important role in ansys, as it is basis for the analyzing the component in any software package which supports finite element techniques. The meshed component is imported into **ANSYS** software, which is being used broadly for analysis.

5.1 Design Literature

Mechanical engineering design involves the knowledge of strength of materials, properties of materials, metallurgy, production techniques, theory of machines, applied mechanics etc...The fundamental principles of these subjects have to be applied in evolving a design.

The various steps involved in the process of design could generally be summarized as follows.
- A close study of the conditions to be fulfilled; the aim of the design
- Preparation of simple schematic diagrams
- Conceiving the shape of the unit/machine to be designed
- Preliminary strength calculations
- Consideration of factors like selection of material and manufacturing method to produce most economical design.
- Mechanical design.
- Preparation of detailed manufacturing drawing of individual components and assembly drawings.

Design work may be classified into three kinds viz...
1. Adaptive design,
2. Development design,
3. New design.

5.1.1Design terms
Ultimate strength is an attribute directly related to a material, rather than just specific specimen of the material

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Factor of safety (**FoS**), is the percentage of capability over the requirements that a structure has.

- Sdesign = Syield / SF
- Sdesign = Sproof / SF

An appropriate safety factor is chosen by using several considerations. Prime considerations are the accuracy of load and wear estimates, the consequences of failure, and the cost of over engineering the component to achieve that factor of safety. For example, components whose failure could result in substantial financial loss, serious injury or death usually use a safety factor of four or higher (often ten). Non-critical components generally have a safety factor of two. An interesting exception is in the field of aerospace engineering, where safety factors are kept low (about 1.15–1.25) because the costs associated with structural weight are so high. This low safety factor is why aerospace parts and materials are subject to more stringent quality control.

- A factor of safety of 1 implies no "over engineering" at all. Hence some engineers prefer to use a related term, Margin of Safety (MoS) to describe the design parameters. The relation between MoS and FoS is MoS = FoS − 1. Margin of Safety is often described in percentage, i.e., a 50% Margin of Safety is equivalent to a factor of safety of 1.5.
- Margin of Safety is also sometimes used to as design constraint. It is defined MS=Factor of safety - 1
- For example to achieve a factor of safety of 4, the allowable stress in an AISI 1018 steel component can be worked out as R = UTS / FS = 440/4 = 110 MPa, or R = 110×106 N/m².

Definitions of **Factor of Safety**

- The ratio of the ultimate breaking strength of the material to the force exerted against it. If a rope will break under a load of 6000 lbs., and it is carrying a load of 2000 lbs., its factor of safety is 6000 divided by 2000 which equals Factor of safety (FoS), also known as Safety Factor, is a multiplier applied to the calculated maximum load (force, torque, bending moment or a combination) to which a component or assembly will be subjected.

Cyclic stress in engineering refers is an internal distribution of forces (a stress) that changes over time in a repetitive fashion.

Cyclic stress and material failure:-When cyclic stresses are applied to a material, even though the stresses do not cause plastic deformation, the material may fail due to fatigue. Fatigue failure is typically modeled by decomposing cyclic stresses into mean and alternating components. Mean stress is the time average of the principal stress.

Alternating stress is the difference between the mean and the maximum or the mean and the minimum value the principal stress takes on. Engineers try to design mechanisms whose parts are subjected to a single type (bending, axial, or torsional) of cyclic stress because this more closely matches experiments used to characterize fatigue failure in different materials.

5.1.2 Stress analysis is an engineering discipline that determines the stress in materials and structures subjected to static or dynamic forces or loads (see statics and dynamics) (alternately, in linear elastic systems, strain can be used in place of stress).
The aim of the analysis is usually to determine whether the element or collection of elements, usually referred to as a structure, can safely withstand the specified forces. This is achieved when the determined stress from the applied force(s) is less than the *ultimate tensile strength*, *ultimate compressive strength* or fatigue strength the material is known to be able to withstand, though ordinarily a safety factor is applied in design.

A key part of analysis involves determining the type of loads acting on a structure, including tension, compression, shear, torsion, bending, or combinations of such loads.

Sometimes the term stress analysis is applied to mathematical or computational methods applied to structures that do not yet exist, such as a proposed aerodynamic structure, or to large structures such as a building, a machine, a reactor vessel or a piping system.

A stress analysis can also be made by actually applying the force(s) to an existing element or structure and then determining the resulting stress using sensors, but in this case the process would more properly be known as testing (destructive or non-destructive). In this case special equipment, such as a wind tunnel, or various hydraulic mechanisms, or simply weights are used to apply the static or dynamic loading. Mechanical failures are two types:

- yielding-in which case permanent deformation has taken place.
- Fracture-i.e.separation failure.

In case of ductile materials, failure taken place by yielding. In many ductile materials the yield point is same both in tensile as well as compression loading. Where as in the case of brittle materials, failure takes place by fracture.
Under the following conditions a ductile material may have similar failure as for brittle materials.

- Cyclic loading at normal temperature (fatigue).
- Long time static loading at elevated temperature(creep).
- Impact or very rapidly applied loading(especially at low temperatures).
- Work hardening by a sufficient amount of yielding.
- Severe quenching in heat treatment.

5.1.3 Theories of Failures

Theories of failures have been devised to present the basis for the design of the machine parts subjected to combined stresses. These are based upon static and fatigue strength of the materials. The different types of failures are :

1. Maximum normal stress theory
2. Maximum shear stress theory(tresca)
3. Maximum strain theory
4. Maximum destortion energy theory(vonmises)

Tresca is the father of the field of plasticity, irrecoverable deformations, which he explored in an extensive series of brilliant experiments begun in 1864. He is the discoverer of the Tresca (or maximal shearstress) criterion of

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materialfailure. The criterion specifies that a material would flow plastically if

$$\sigma_{tresca} = \sigma_1 - \sigma_3 > \sigma_{max}$$

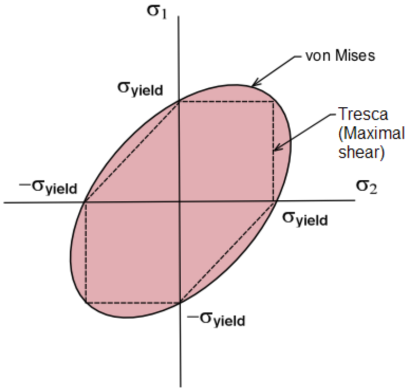

Figure 14: Comparison of Tresca and Von Mises Criteria

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Tresca's criterion is one of two main failure criteria used today. The second important criterion is due to Von Mises. Von Mises stress, σ_v, or simply Mises stress, is a scalar function of the components of the stresstensor that gives an appreciation of the overall 'magnitude' of the tensor. This allows the onset and amount of plastic deformation under triaxial loading to be predicted from the results of a simple uniaxial tensile test. It is most applicable to ductile materials. The fundamental criterion for failure using the von Mises theory is 0.577.

$$\tau_0 = \frac{\sqrt{2}\sigma_0}{3}$$

whereτ_0 is the allowable shear.

Plastic yield initiates when the Mises stress reaches the initial yield stress in uniaxial tension and, for hardening materials, will continue provided the Mises stress is equal to the current yield stress and tending to increase. Mises stress can then be used to predict failure by ductile tearing. It is not appropriate for failure by crack propagation or fatigue, which depend on the maximum principal stress.

In 3-D, the Mises stress can be expressed as:

$$\sigma_v = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}}$$

where$\sigma_1,\sigma_2,\sigma_3$ are the principal stresses. In 1-D, this reduces to the uniaxial stress.

or, in terms of a local coordinate system:

$$\sigma_v = \frac{1}{\sqrt{2}}\sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)}$$

Von Mises yield criterion

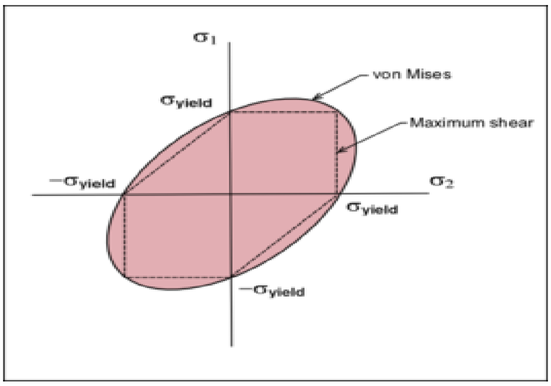

Figure 15: Von Mises stress in two dimensions.

This criterion for the onset of yield in ductile materials was first formulated by Maxwell in 1865 but is generally attributed to von Mises in 1913. Originally suggested by Maxwell purely on the grounds of mathematical simplicity, the corresponding yield functionΦ is the simplest function that meets certain physical requirements for yielding, taking the form = $J_2 - k^2$ whereJ_2 is the second deviatoric invariant of the stress tensor and k is the yield stress in shear. The use of von Mises yield criterion is therefore sometimes called $\boldsymbol{J_2}$ **flow theory**.

Von Mises yield criterion can be interpreted physically in terms of the maximum distortion strain energy, octahedral shear stress theory, or Maxwell-Huber-Hencky-von Mises theory. This states that yielding in 3-D occurs when the distortion strain energy reaches that required for yielding in uniaxial loading. Mathematically, this is expressed as:

$$\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right] \leq \sigma_y^2$$

In the case of plane stress, $\sigma_3 = 0$, von Mises criterion reduces to:

$$\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 \leq \sigma_y^2$$

In the 2-D stress space shown in the figure above, this equation represents the interior of an ellipse. Stress states σ_1,σ_2 not touching the boundary of the ellipse produce only elastic deformation. Yielding initiates when the stress state pushes against the boundary. This ellipse is the projection, onto a plane, of the yield surface in 3-D stress space, which takes the form of a cylinder equiaxial to the three stress axes.

Also shown on the figure is Tresca's maximum shear stress criterion (dashed line). This is more conservative than von Mises' criterion since it lies inside the von Mises ellipse.

In addition to bounding the principal stresses to prevent ductile failure, von Mises' criterion sometimes gives a reasonable estimation of fatigue life, especially with complex loading (mode II & III loading).

6. Introduction to ANSYS

ANSYS is software for finite element analysis and design. We can use this software to calculate the properties and operating conditions. ANSYS is a general-purpose program, which can be used for any type of analysis. In fact the program can be used in all disciplines of engineering structural, mechanical, electrical, electromagnetic, thermal, fluid and magnetism. The easiest way to communicate with the ANSYS program is by using the ANSYS menu system called Graphical User Interface (GUI). The GUI consists of windows, menus, dialog boxes and other components that allow you to enter input data and execute ANSYS functions simply picking buttons with the mouse (or) typing in responses to prompts. All users both engineers and advanced should use the GUI for interactive ANSYS work.

ANSYS has evolved into multi-purpose design and analysis software recognized around the world for its multitude of capabilities. The interactive made of operation that it provides greatly simplifies the model generation and geometry, materials and boundary conditions before

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analysis. ANSYS provides solutions to various structural analysis problems.

The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, non-linear, transient dynamic analysis. ANSYS software provides a set of comprehensive tools for creating, editing, viewing finite element models and subsequent analysis results.

The ANSYS program has many finite element analysis capabilities ranging from a simple, linear, static analysis to complex, non-linear, transient dynamic analysis. The ANSYS analysis documentation set describes specific procedures for performing analysis for different engineering disciplines

A typical ANSYS analysis has three distinct steps

- Build the model
- Apply loads and obtain solution
- Review the results

6.1 Solid92 Element

3-D 10-Node Tetrahedral Structural Solid

SOLID92 Element SOLID92 has a quadratic displacement behavior and is well suited to model irregular meshes. The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element also has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

SOLID92 Geometry

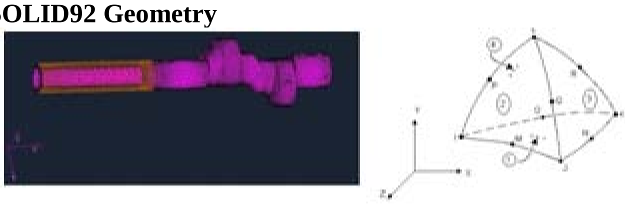

Figure 4: .solid-92 element

7. Modeling and Analysis

7.1 Unigraphics Modeling and Finite Element Analysis

Fig17: forge crankshaft
Fig18: machined crankshaft

Figure 5: .Tetra hadral meshing of a crankshaft and Solid 92-element was taken

Fig20. FE MODEL of modified Crankshaft

7.2 Boundary Conditions

Loading Conditions

A distributed Total load of 4616.4 N was applied from connecting rod to crank shaft.(taken from R&D dept.)

The Load Obtained Using Following Conditions:
SUCTION PRESSURE = 95 PSIG
DISCHARGE PRESSURE = 550 PSIG
SUCTION TEMPERATURE = 35 Deg C

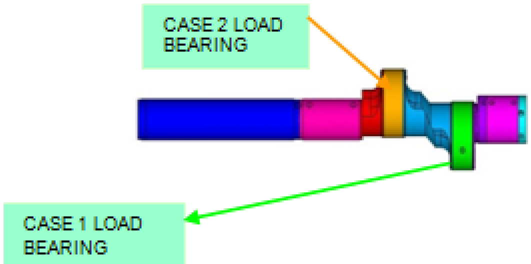

Figure 6: Loads acting on existing crankshaft

7.3 Load Calculations

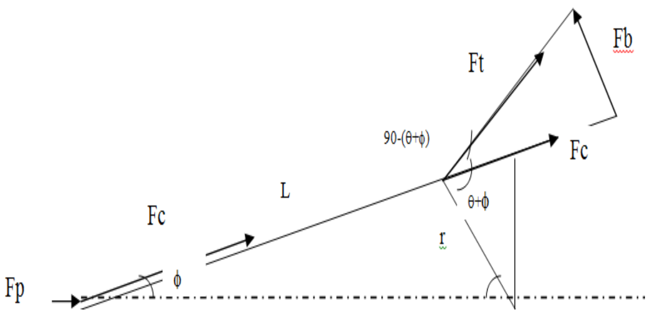

Figure 7: Free body diagram of loads on existing shaft

Where,
θ = Crank Angle
Fp = Force acting on Piston
Ft = Crank-pin effort (perpendicular to crank)
Fc = Force acting along Connecting rod
Fb = Thrust force on Crank shaft (along the crank)
L = Length of Connecting rod between the centers
r = radius of crank pin circle

By resolving we get,

$Fc = Fp / \cos\phi$

$Fb = Fc * \cos(\theta+\phi)$

$Ft = Fc * \sin(\theta+\phi)$

The maximum torque applied to crank shaft, T is

$$T = Ft * r$$

7.4 Constraints on Shaft

Center node constrained in the Y & Z direction along with rot X. The crankshaft was constrained at both bearing surfaces by MPC to a center node. The center node is located in the center of the shaft and in the middle of the bearing width. This center node was constrained to ground. One bearing was fixed in the YZ & rot X direction and the other bearing in the YZ direction. This center node was fixed in the X direction for the last bearing asShown

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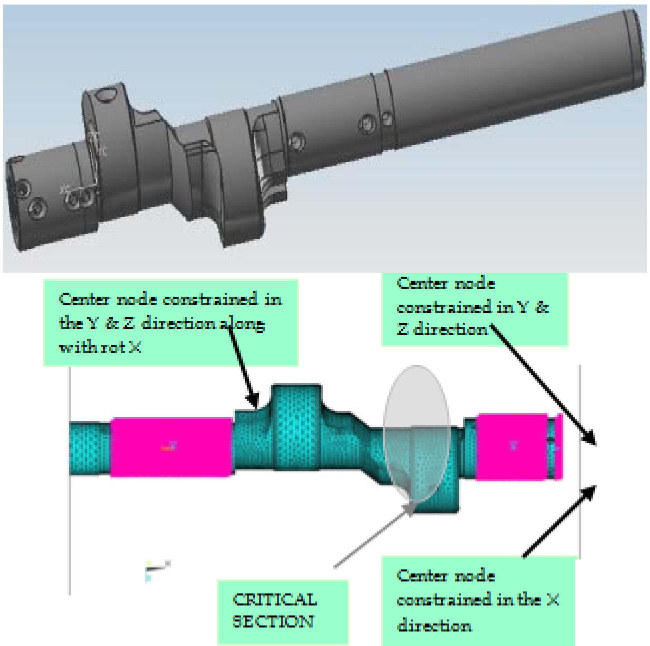


Figure 23: Constrains on an existing FE model of crankshaft

7.5 Mesh Generation

A fine tetrahedral element was generated according to the quality specification. These quality specifications are gathered from the hyper mesh. All the quality criteria's were maintained with in the default values in the hyper mesh. Quality criteria are mentioned as follows.

1. Quality criteria & Internal angles
2. Warpage & Chordal deviation
3. Aspect-ratio & Jacobean
4. Skew angle & Length
5. Tetcollapse.

Warpage angle
If one node of the plane element deviates from the plane then the angle between node and the plane is called warpage angle.
Twisting of either 2D or 3D element is also called warpage angle.
This angle should not be more than 5 degrees.

Aspect-ratio
It is defined as the ratio of maximum length of the element to the minimum length of the element.
It should not be more than 5

Skew angle
It is defined as the angle between two altitudes of the vertices in a triangle element
Should not more than 60 degrees

Chordal deviation
It defined as the deviation of the finite element model from actual geometric model.
Should not be more than 0.1

Internal angles
Perfect square element is an ideal element
Minimum angle should not be less than 45 deg
Maximum angle should not be greater than 135 deg

Length
Length is defined as the distance between tow nodes in the element
Minimum length should not be less than 65% of the element size

Jacobian.
It is a matrix; it is defined as the partial derivatives of natural coordinates w.r.t the global coordinates.

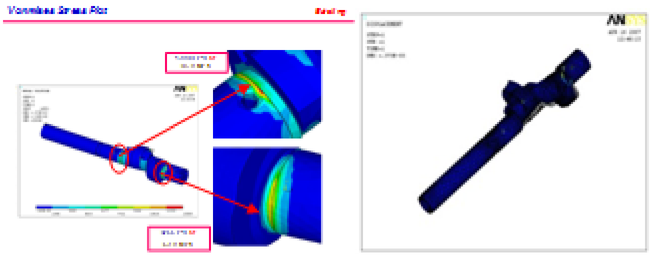
Perfect square element has a jacobian value 1
Tetcollapse
It is a quality criterion which is used for tetrahedron elements.

Value of the tetcollapse should not be less than 0.5.

8. Results and Discussions

8.1 Structural Static Analysis

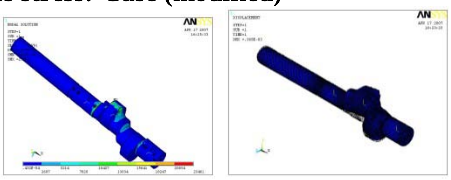
8.1.1 Results of existing shaft:(Case)



Displacement- Case (existing)

8.1.2 Results of modified shaft:

Vonmises stress:-Case (modified)



Displacement:-Case (modified)

8.2 Modal (Free-Free) Analysis (Existing):

frequency table for existing design.

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	79.178	1	1	1
2	80.743	1	2	2
3	164.61	1	3	3
4	327.51	1	4	4
5	401.51	1	5	5
6	404.77	1	6	6
7	449.30	1	7	7
8	471.23	1	8	8
9	659.83	1	9	9
10	769.23	1	10	10

Sub step frequency deformed shape.

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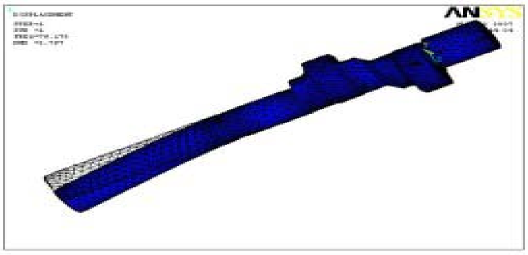
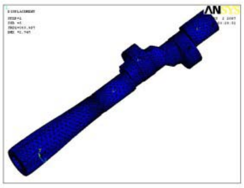


8.3 Modified-Design

Frequency table for modified design.

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	72.611	1	1	1
2	73.795	1	2	2
3	301.32	1	3	3
4	378.37	1	4	4
5	385.07	1	5	5
6	400.54	1	6	6
7	402.30	1	7	7
8	419.37	1	8	8
9	563.51	1	9	9
10	691.14	1	10	10

sub step frequency deformed shape.



9. Results Comparisons

Table 5: Details of FEA model

S.No	Type of Design	Material	Nodes	Elements	Element Type	Element Size
1	Existing	AISI 1118	48077	28998	SOLID92	0.3inch
2	Modified	AISI1118	40045	22770	SOLID92	0.3inch

Table 6: Material properties of aAW5520EXN Compressor Crankshaft

S. No	*property*	*value*
1	Young's modulus	$7870Kg/m^3$
2	Poison's ratio	0.29
3	Mass(existing)	0.938Kg
4	Mass(modified)	0.863Kg

Table7: Static analysis results

S.No	*Type of Design*	*Stresses Case(Mpa)*		*Mass (Kg)*	*FOS*	
		Min	Max	Min		
1	Existing	63.8	95.8	59.28	0.938	3.28
2	Modified	107.8	161.75	118.54	0.863	1.947

Allowable yield tensile strength: **315Mpa**

Table 8: Modal analysis (free-free) results:(range: 0-10000Hz)

Motor frequency: 60 Hz Pump frequency: 58.5 Hz

S.No	Mode freq	Existing(Hz)	Modified(Hz)	Rated freq(Hz)
1	1^{st} mode	79.178	72.611	58.5
2	2^{nd} mode	80.743	73.795	117
3	3^{rd} mode	164.61	301.32	175.5
4	4^{th} mode	327.51	378.37	234
5	5^{th} mode	401.51	385.07	292.5
6	6^{th} mode	404.77	400.54	351
7	7^{th} mode	449.30	402.30	409.5
8	8^{th} mode	471.23	419.37	468
9	9^{th} mode	659.83	563.51	526.5
10	10^{th} mode	769.23	691.14	585

10. Conclusion

The following conclusions were drawn from the above investigation:

- Study is made on the compressor of Air conditioning system.
- One of the components, Crankshaft is chosen for the analysis by reducing its weight. So that, cost of the compressor may be brought down.
- Weight of crankshaft is reduced by making hallow shaft using UG NX3.
- The solid shaft and hallow shaft is analyzed in ANSYS 10.

The results obtained are reviewed and drawn the following conclusions….

1. In case of New Compressor Crankshaft the maximum stress is not in critical section (design stress is 161.7 mpa which is far less than maximum stress of Compressor Crankshaft i.e. 315 mpa). So the crankshaft is under safe permissible limits.
2. The factor of safety of existing crankshaft is 3.28 but the factor of safety of a modified crankshaft is 1.947.Even though decrease in FOS, the modified crankshaft is under designed conditions.(FOS of any component must be greater than 1.5 times of design stress)
3. The existing Compressor Crankshaft weight is 0.938Kg. Whereas the weight of the modified crankshaft is 0.863Kg. So, 75grams of weight is reduced from existing crankshaft.(i.e.7.5% of weight reduction from the existing crankshaft)
4. The vibrations of modified crankshaft are lower than the existing crankshaft. The data is shown in table8.These vibration frequencies are compared with rated frequencies. They are far away from the rated frequencies. So, the resonance may not occur in the crankshaft and the component is under permissible noise limits, under safe condition.
5. In mass production due to weight reduction the cost of the Compressor is may also reduce.

11. Suggestions

- Change of title from Weight Optimization of crankshaft of AC compressor
  To Weight Reduction and stress analysis of AC compressor's crankshaft
- Incorporated the theories of failures and vonmises criteria

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These suggestions are incorporated in the thesis report

12. A Review Published In Journal

Steel to Gain Market Share in Engine Crankshaft Applications

Material's ability to reduce weight and improve performance encourages growth. **DETROIT, MI, October 9, 2000 -** The use of bar steel in crankshafts will increase by as much as 50 percent, from 40 to 60 percent of the market share, by mid-2002 because of the material's capability to improve engine performance and reduce weight, at economical costs, according to a recent study by American Iron and Steel Institute (AISI) Bar and Rod Market Development Group (BRMDG). This growth would be at the expense of cast iron, which currently possesses 60 percent of the crankshaft market.

The BRMDG initiated the study, "Steel's Technical and Economic Progress in the Production of Lighter and Smaller Engine Components," in 1998 in response to the automotive industry's quest to increase fuel economy, reduce costs and weight, and improve customer satisfaction. The report provides an in-depth look at how crankshafts produced from bar steel forgings contribute to achieving these goals.

Additionally, the report explains that this potential increase in steel market share is due to innovative steel forming and processing technologies that have advanced the state of the art during the past decade.

12.1 Improved Performance

An engine crankshaft attaches to connecting rods, which fastens to pistons, and transfers engine power to the transmission. Forged steel crankshafts offer a host of benefits compared to cast iron units including greater durability, improved Noise Vibration Harshness (NVH) characteristics and higher load-bearing capacity for torque at lower engine speeds (RPMs), resulting in fuel efficiency improvements.

Automakers currently using forged steel crankshafts include: Ford Motor Co., DaimlerChrysler, Honda, British Leyland, Saab, Volkswagen, Mitsubishi and Volvo.

12.2 Lightweight

As automakers strive to reduce weight in vehicles, the powertrain continues as a key focus in helping achieve that goal. Using forged steel-in place of cast iron-reduces the mass of the crankshaft by eight percent according to Krupp Gerlach, an automotive component manufacturer that recently completed a study demonstrating the benefits of forged steel compared to cast iron crankshafts in an actual series production engine. The crankshaft's total length is also reduced by nine percent as a result of steel's unique mechanical properties, particularly the ratio of yield point to tensile strength.

The new generation of steels, including vanadium micro alloys and Air-Cooled Forging Steels (ACFSs), features improved strength and fatigue properties, enhanced machinability and greater consistency due to specific, controlled testing processes (sensitive to defects) performed during each production phase. These improvements enable forgers to produce crankshafts that are near-net shape, reducing production cycle and try-out times and, in turn, cost as there is less need for machining and rework.

12.3 Benefits vs. Costs

Modern engineered steels, coupled with innovative processing and forming technologies, have significantly decreased the manufacturing costs associated with producing forged steel crankshafts.

- Light weight
- High performance
- Greater torsional stiffness
- Improved NVH characteristics
- Greater durability
- Net or near-net shape
- Less machining
- Less or no rework
- Lower rejection rates
- Greater consistency and product repeatability
- Inspection simplicity
- Fewer warranty claims
- Improved customer satisfaction

"As the steel industry continues to make technological advancements, forged steel crankshafts will improve in quality, performance and cost making them even more viable for engine applications," said Jürgen Kneller, author of the study.

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