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IMPROVING THE PERFORMANCE OF THE CAR AIR CONDITIONING SYSTEM BY MODIFYING GEOMETRY OF INLET PAD USING CAE SIMULATION

Atul Prataprao Kale
Dr. Tushar Y. Badgujar (HOD ME)
Prof. Poonam S. Talmale

Abstract

The air conditioning condenser is the heart of every vehicle air conditioning system. My research is to extend the life of automotive air conditioning capacitors. Currently, the low KM value of the fault affects the co mfort of customers using the air conditioner and causes brand dissatisfaction. When I checked, I saw a wide ran ge of high failure rates. This high breakdown mileage indicates fatigue failure of the product. This type of failur e in the rupture of the A/C condenser input PAD is an interesting topic for my research and study. To do this, we use the best tools for analysis, data layering and evidence base, as well as CAE simulation and QC Story metho dologies. The main challenge is to simulate the failure of the test table and car level, which is difficult for my kn owledge and skills. We can simulate defects with various connections and try to determine the stress/weakness l evels in the current design through CAE simulations. For this, we tested the samples before and after and analyz ed the results. Before implementation, a comparative study of the existing model and the new design was carried out on the test bench. The results showed that the failure rate was reduced and the service life of the air conditio ner increased.

[Keywords – CAE, Inlet PAD, QC Story, Rig level etc.]

1. INTRODUCTION

The main function of the air conditioning condense r is to cool the vapor pressure of the refrigerant and complete the phase change to the liquid state. Refri gerants have temperatures. In the actual operation o f the vehicle, the air conditioner will have many loa ds. My aim is to examine air conditioner condenser malfunctions and to overcome their malfunctions. One of the problems encountered is the vibration of the engine side, which is transmitted from the exha ust hose to other parts of the air conditioner. Field d ata collection during operation shows cracks formin g in the inlet pad in the brazed region of the cooling system condenser. cause the air conditioner to malf unction. Refrigerant leakage from microtubes has a lso been observed in some faults. Generally speakin g, engine vibration is not the only cause of physical failure. These items are subjected to a variety of lo ads that vary over time and operation.

2. LITERATURE REVIEW

As per Arturo Alejandro Torres Arevalo &Changhao Han, they have considered Dynamic load which is coming from engine to condenser due to vehicle operation. In their research paper value of dynamic load is not defined. As per Abdul Kareem Wahab he has considered 100Mpa load for validating the condenser failure. In various research papers Heat load is considered for calculating the efficiency of A/C system.

Various researchers have analysed failures by using CAE simulations, Pareto analysis and why why analysis.Based on the study of researcher's paper here we are adopting a QC story methodology of problem solving technique for analysis of our problem.

Various researchers have used CAE tool for simulation of model by providing the various load inputs. CAE tool have saved actual expenses for making the practical model.The benefits of CAE include reduced product development cost and time, with improved product quality and durability. Design decisions can be made based on their impact on performance. Designs can be evaluated and refined using computer simulations rather than physical prototype testing, saving money and time

AbdulkareemAbdulwahab , Sami Mysen [1] In the air conditioning machine, condenser is considered to be the important component. Here I have noticed researcher have focused more on evaluating the performance of condenser, but he has not considered types of failures that can occur in condenser during the actual usage in real world. Also, he has calculated the heat rejection by condenser thru the calculated manner instead of calorimeter test bench.

Z. Zhou et al [2] this paper proposes a novel augmented data driven self-attention based deep learning model for the chiller fault diagnosis. In this study he has presented the theoretical as well as practical results but there is a gap between the theoretical and practical study. Literature study of Y. Zhao et al. [3] where his study on A statistical fault detection and diagnosis method for centrifugal chillers based on exponentially weighted moving average control charts and support vector regression, in that This paper presents a new fault detection and diagnosis (FDD) method for centrifugal chillers of building air-conditioning systems. Fault analysis is done thru the theoretical theory but actual filed analysis is missing in this research paper.

The objective of the current study is to address the failure of condenser inlet PAD & Introduce the New modified design to reduce the vibration passing through the hose.This is planned with New PAD design and by implementing the new flexible hose material. Intend of this change is to improve the life of the SUV air conditioning system. Further, the modified inlet pad design and recommended new hose were tested on a vibration test bench. The results of the tests validated thru CAE simulation. The dimensions of the fins, shape and tubing arrangements are also analysed. The principle of a condenser is to expel the heat out of the refrigeration system by the condensation of vapor. Generally, there is no phase change occurring in the external fluids. In the condenser operated with forced convection mode, the circulated air over the specific surface is maintained with the help of a blower for effective heat transfer. The heat rejection from the condenser is theoretically calculated from the standard value of the compression cycles, without the considering the addition of heat supplied by the compressor inefficiency. The fluid flow of the refrigerant is assisted by the external gravity and hence the inlet tube is aligned at the top whereas the outlet tube is aligned at the bottom. The concept of pipe rising is excluded from the design and extensive care is taken for the adjustment of pipe levels during installation process. Horizontal or vertical air flow is commonly preferred. In the attempt of comparison with various tubes of different diameters, it is considered to focus on smaller tubes with varying diameters to match with the internal surface area of a larger segment.

Study from Z. Zhou et al [2] this paper proposes a novel augmented data driven self-attention based deep learning model for the chiller fault diagnosis. Firstly, to solve the data imbalance problem, a stable synthetic minority oversampling technique (SSMOTE) is presented to generate the artificial fault data, which are then mixed with the raw fault data to achieve data augmentation. Further, to enhance the diagnosis accuracy, the self-attention mechanism based temporal convolutional network (STCN) is developed to classify normal and fault datasets. The developed STCN is realized by stacking the modified blocks which can dynamically pay attention to different data information through combining the self-attention mechanism and the traditional residual block together. What is more, in the STCN, the skip connection structure is added to the self-attention mechanism to solve the gradient disappearance problem. Finally, detailed experiments and comparisons are performed. Experimental results show that, compared with other data augmentation methods, the SSMOTE can complete a large scale expansion of the minority faultdatasets, and its augmented data have better effect on handling the data imbalance problem. Moreover, the skip self-attention mechanism based deep learning model can achieve better diagnosis accuracy. Literature study of Y. Zhao et al. [3] where his study on A statistical fault detection and diagnosis method for centrifugal chillers based on exponentially weighted moving average control charts and support vector regression, in that This paper presents a new fault detection and diagnosis (FDD) method for centrifugal chillers of building air-conditioning systems. Firstly, the Support Vector Regression (SVR) is adopted to develop the reference PI models. A new PI, namely the heat transfer efficiency of the sub-cooling section (ε sc), is proposed to improve the FDD performance. Secondly, the Exponentially Weighted Moving Average (EWMA) control charts are introduced to detect faults in a statistical way to improve the ratios of correctly detected points. L. Yang et al. [4] in his literature study on “The impact of evaporator fouling and filtration on the performance of packaged air conditioners” Int.J.Refrig.(2007) The goal of the study presented in this paper was to evaluate the impact of different filter types on the performance of three typical packaged air conditioners under both clean and fouled conditions. In a companion paper, combinations of six different levels of filtration and four different coils were tested under clean and fouled conditions. From the tests, it was found that fouling has a relatively small impact on air-side effective heat transfer coefficient but can have a large impact on coil pressure drop. Data from the experimental study were used in developing simulation models for the three packaged air conditioners. Simulations show that the equipment cooling capacity is reduced with fouling primarily because of a decrease in air flow due to the increased pressure drop. In Review of J. Winkler et al. [5] on “Impact of installation faults in air conditioners and heat pumps in single-family homes on U.S. energy usage” Appl. Energy (2020) Field studies have demonstrated that installation-related faults are commonplace. However, the national impact of installation-related faults cannot be accurately estimated by only simulating a limited number of homes at several fault levels because of the variety of home characteristics and climates involved. In our analysis, we use an improved residential building stock simulation tool to predict the annual energy increase and additional utility costs resulting from two common installation faults: indoor airflow rate and refrigerant charge level. As per S.A. Tassou et al.[6] “Fault diagnosis and refrigerant leak detection in vapour compression refrigeration systems” Int.J.Refrig.(2005) This paper reports on the development of a fault diagnosis and refrigerant leak detection system based on artificial intelligence and real-time performance monitoring. The system has been used successfully to distinguish between faulty and fault free operation, steady-state and transient operation, leakage and over charge conditions. Work currently underway is aimed at testing additional fault conditions and establishing further rules to distinguish between these patterns. In literature study of C. Sun et al[7]“A hybrid piecewise FDD strategy for refrigeration charge fault of airborne vapor-compression cycle system” Int. J. Refrig. (2022) This study presents an experimental rig of a multi-evaporator refrigeration system, in which the pressure difference between two evaporators can be maintained by using both the pressure regulating valve (PRV) and electronic expansion valve (EEV)-based ejector. The proposed EEV-based ejector that is used to partially recover the throttling losses of the PRV consists of an EEV and the main body of an ejector. The established experimental system can work in both PRV-based mode and ejector-based mode by switching the valves. Via experimental means, the performances of both modes were evaluated by varying the cooling loads. Moreover, the effects of the spindle-blocking area percentage of the EEV-based ejector and the condensing temperature on the system performance were identified. Literature review of H.Shahnazari *et al.*[8] “Modeling and fault diagnosis design for HVAC systems using recurrent neural networks” Comput. Chem. Eng.(2019)Modern heating, ventilation and air conditioning (HVAC) systems rely on automation to ensure occupant comfort and meet the energy regulations set by governments. However, as the level of automation increases, it becomes increasingly important to diagnose and repair failures in control components such as actuators and sensors, to minimize discomfort or wasteful energy expenditure. These considerations have motivated interest in fault diagnosis and fault tolerant control (FTC) frameworks and their applications to HVAC systems.

Literature review by M. Farzad et al.[10] System performance characteristics of an air conditioner over a range of charging conditions Int J Refrig (1991) said that A separate indoor unit houses the evaporator, expansion device and evaporator blower. As the refrigerant charge of these systems is adjusted during field installation, the potential exists for not setting the charge exactly to the manufacturer's specifications. The objective of the work reported here was to quantify the influence of the refrigerant charge on the steady-state and cyclic operation of a residential split-system air conditioner. D. Butler,[11] Refrigerant leakage and leak detection. Proceedings of institute of refrigeration seminar, refrigerants... & CFCs in the UK refrigeration and air conditioning industries. Usage and scope for substitution (1992) Refrigerant Containment is the prevention or minimisation of a refrigerant fluid leaking to the atmosphere. Is Zero Leakage Possible? A leak is defined as: 'A leak is a hole or porosity in an enclosure capable of passing a fluid from the higher-pressure side to the lower pressure side.' A leak may be the tail-end of a weld fracture, a speck of dirt on a gasket or a microgroove between fittings. All sealed systems leak. The leak could be at 1kg/s or 1g/million years. K.E. Hummel et al.[12] Survey of the use and emissions of chlorofluorocarbons from large chillers ASHRAE Trans (1992) says thathe impacts of air conditioning and refrigeration systems on stratospheric ozone are primarily linked to release of ozone-depleting refrigerants. Their contributions to global warming stem both from release of refrigerants and from emission of greenhouse gases (GHGs) for associated energy use. Because the energy-related component has a significantly higher warming impact, phaseout of hydrofluorocarbon (HFC) refrigerants with less efficient options will increase net GHG emissions. The same conclusion applies for perfluorocarbon (PFCs), though they are less commonly used as refrigerants. Integrated assessment of ozone depletion, global warming, and atmospheric lifetime provides essential indications in the absence of ideal refrigerants, namely those free of these problems as well as safety, stability, compatibility, cost, and similar burdens. This study examines the trend in refrigerant losses from chiller use. It documents both substantial progress in release reductions and the technical innovations to achieve them. It contrasts the impacts of current refrigerants with alternatives and with the chlorofluorocarbons (CFCs) they replaced. The study examines the sensitivity of efficiency to charge loss. It also summarizes thermodynamic and environmental comparisons of options to show that phaseout decisions based on chemical composition alone, without regard to attributes of individual substances, can result in greater environmental harm than benefit

3. PROBLEM DEFINITION

Air conditioning condensers play an important role in automot ive HVAC systems. An air conditioner condenser is a heating system that cools the refrigerant and helps convert the vapor st ate to liquid state. In the4W 1H this problem is described as fo llows.**What** - A/C Condenser leakage from Micro Tubes & Inlet PAD to side header joinery area.

When - During vehicle usage by end user/customer.

Where - From various dealers across India.

Which - This failure is reported on SUV car.

How Big - Monthly Average incidences for this failure are around 10-15

4. PROBLEM STATEMENT

A/C Condenser which is used on SUV car is made from the Aluminium alloy A3003 grade & it is lighter in weight and having a higher material strength. This paper deals with the failure analysis thereafter best selection of new design of a A/C Condenser inlet PAD.

5. OBJECTIVE

The main objective of this project is to analyse all failure modes thoroughly which were reported as a field failure & take the appropriate action to address the allfailure modes of A/C Condensers. Further alternate solutions are validated with the help of bench level vibration test and performed CAE simulation prior to implementation.

6. METHODOLOGY

Approach from problem definition to solution implementation and monitoring the results adopted. After selection of problem for resolution QC story approach was adopted. Before starting analysis, it is important to understand current process, its failure rate etc. In analysis phase Fault Tree Analysis (FTA) was made to understand different probable causes and then these were validated to find out exact root cause

To find out solution of the problem and validate the solution following methodology was adopted.

Experimental study of selected processes was planned as per following tests.

1) Field return parts analysis.

2) Condenser Mfg. Process walk thru.

3)Bench level failure mode simulation for A/CCondenser.

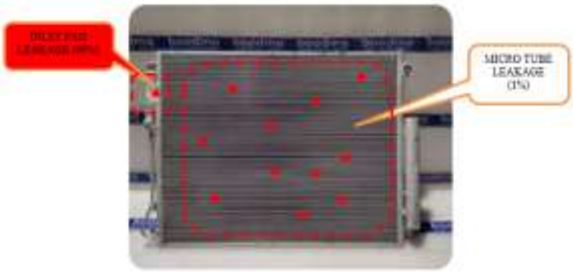
4) Vehicle level vibration measurement.

5) Endurance test of selected solution.

1. Field Return parts analysis

1.1 Trend chart: Field failure Trend chart shows the month-on-month field failure incidences of A/C Condensers were reported from Customer.

1.2 Concentration Diagram:

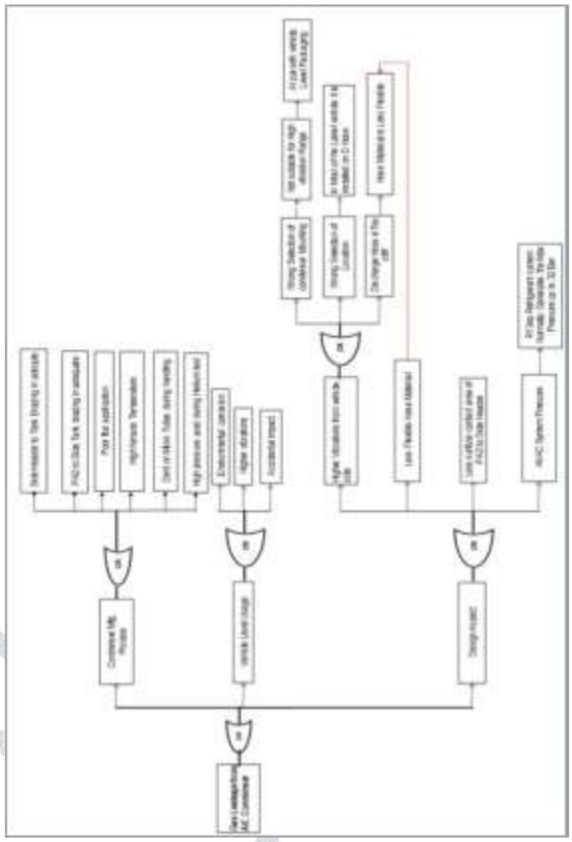


1.3 Kilometre wise failures

1.4.Process Flow & Process Walk Thru

1.5 Fault Tree Analysis

Fault tree analysis (FTA) is a type of failure analysis in which an undesired state of a system is examined. The functional failure probability of that function is determined by the integrity of the constituent components as well as the logic of the systems' architecture.



1.6 Identification of source of variation

Sr. No	Standard Source of Variation	Hypothesis Validation	Remark
1	Side Header to Tank Brazing in adequte	Field return part cut section taken & measured brazability No such issue observed	Invalid
2	PAD to Side Tank brazing in adequate	Field return part cut section taken & measured brazability No such issue observed	Invalid
3	Poor flux application	Surprise Process walk thru done at M/s-Pranav Vikas mfg. line No such issue observed during visit.	Invalid
4	High furnace Temperature	Measured furnace actual temperature v/s set temperature, found to be OK	Invalid
5	Dent on Micro Tubes during handling	New Parts visually inspected for dent damage related observation, No such issue observed	Invalid
6	High pressure used during Helium test	Helium chamber is having a set pressure of 32 Bar , it is measured & observed to be 31.9 Bar. No issue in pressure	Invalid
7	Environmental corrosion	Failed condensers Micro tubes analyzed for the corroisn leakage, observed external content is forming a white rust on tubes & this is leading for Micro Tube leakage	Valid
8	Higher vibrations	Vibrations mesured on customer vehicle & observed at Higher side.	Valid
9	Accidental impact	There is No Accidential history on the condenser failed vehicles	Invalid
10	Higher Vibrations from vehicle side 1)Wrong Selection of condenser Mounting 2)Wrong Selection of Location 3)Discharge Hose isToo stiff	1) & 2) We have done the Industry Benchmark - Condenser mtg, are at par with the current design 3)Observed Higher Vibrations & Less flexibility during vehicle level measurement study. Found Discharge Hose is stiff/less flexible.	Valid
11	Less surface contact area of PAD to Side Header	During failed parts analysis it is observed PAD resting area on side header is having a less contact area. If this contact area is more then there will be a rigid support & failure will not happen	Valid
12	HVAC System Pressure	A/C Condenser failure is from the one location only	Invalid

1.7 Root Cause analysis of identified causes

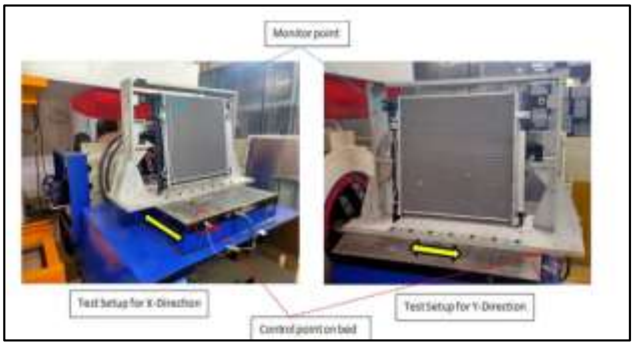
Sr No	Valid Probable Cause	WHY	WHY	WHY	WHY	WHY
1	Environmental corrosion	White corrosion on tubes	Condenser Tubes come in a contact with salty water	High Humidity & vehicle operation in sea shore	Beyond customers control	
2	Higher vibrations	Discharge Hose material is Too stiff	Less Flexible	Wrong selection of Hose Material		
3	Higher Vibrations from vehicle side 1) Wrong Selection of condenser Mounting 2) Wrong Selection of Location 3) Discharge Hose is Too stiff	Discharge Hose material is Too stiff	Less Flexible	Wrong selection of Hose Material		
4	Less surface contact area of PAD to Side Header	PAD Mounting is on Radius area	Less surface contact	Component level Design Selection		

1.8 Environmental Corrosion

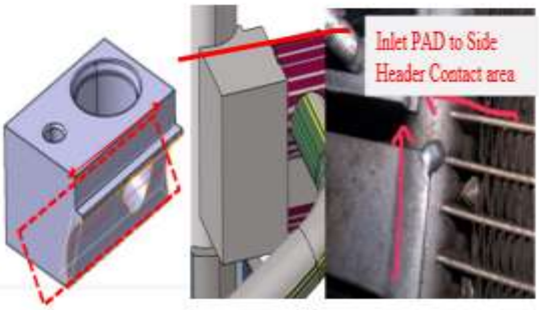
Sr No	Probable Cause	Testing and Observations	Conclusion
1	Environmental corrosion	Completed the Salt Spray Test of condenser Tubes it is observed meeting the 600 Hrs. against the specification of 300 Hrs.	Hypothesis invalid

1.9 Higher Vibrations

Sr No	Probable Cause	Testing and Observations	Conclusion
2 & 3	Higher Vibrations &Discharge Hose is too stiff	CAE Simulation done &observed stress atCondenser	Hypothesis Valid



2.0 Less Surface area of PAD with Side Header Tank



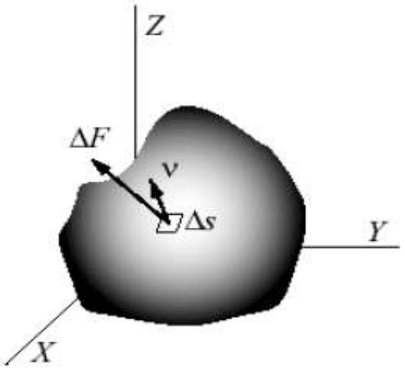
7. EXPERIMENTATION

Structural Analysis: Structural analysis is a computation deflection and internal forces or stresses within structures either, for design or for performance evaluation of existing structure. Structural analysis needs input data such as the applied forces or environmental effects, the structures geometry and support conditions and the materials properties. Output qualities may include support reactions, stresses, and displacements. In design, the calculated stresses are compared to the allowable stresses for the materials used while the calculated displacements are compared to various standards for serviceability.

Finite Element Analysis: Finite element analysis (FEA)or finite element method (FEM) is a numerical technique for solution of boundary-value problems.it was first developed for use in structure analysis. In its application, the object or system is represented by a equations of equilibrium in conjunction with applicable physical consideration such as compatibility and constitutive relations are applied to each element and a system of simultaneous equations is constructed. The system of equations is solved for unknown values using the techniques of linear algebra or nonlinear numerical schemes, as using the techniques of linear algebra or nonlinear numerical schemes as appropriate. While being an appropriate method the accuracy of the FEA methos can be improved by refining the mesh using more elements and nodes.

Concept of Stress: First , we look at the external traction T that represents the force per unit area acting at a given location on the bodys surface . traction T is a bound vector, which means T cannot slide along its line of action or translate to another location and keep the same meaning.

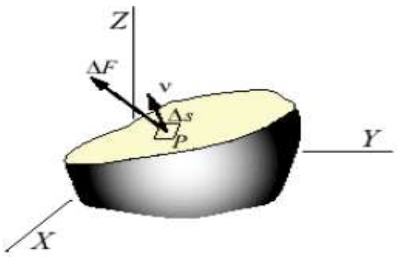
The stress field is the distribution of internal “Tranctions” that balance a given set of external transctions and body forces. in other words , a tranction vector cannot be fully described unless both the force and the surface where the force acts o have been specified. Given both ***dF***and***ds,***the traction T can be defined as



Representation of 3D Model

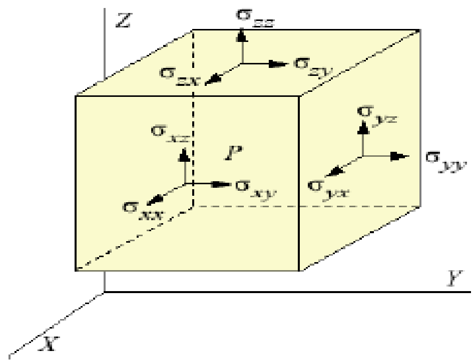
$$T = \lim_{\Delta s \to 0} \frac{\Delta F}{\Delta s} = \frac{dF}{ds}$$

the internal traction within a solid, or stress, can be defined in a similar manner. Suppose an arbitrary slice is made across the solid shown in the above figure, leading to the free body diagram shown below figure. Surface tractions would appear on the exposed surface, similar in form to the external tractions applied to the body’s exteriors surface. The stress at point ***P*** can be defined using the same equation as was used for T.



Free Body

Surface tractions or stresses acting on an interna datum plane are typically decomposed into three mutually orthogonal components. One component is normal to the surface and represents direct stress. the other two components are tangential to the surface and represents shear stresses. defining a set of internal datum planes aligned with a Cartesian coordinate system allows the stress state at an internal point ***P*** to be described relative to x, y, and z coordinates directions.



Stress Component on Free Body

For example , the srtress state at pont P can be represented by an infinitensimal cube with three stress components on each on each of its six sides (One direct and two shear components)

Since each point in the body is under static equiliburm (no net force in the absence of any body forces), only nine stress components from three planes are needed to describe the stress state at a pont P.Refering to below figure,these nine components can be organized in to the matrix

$$\begin{bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{bmatrix}$$

here shear stress across the diagonal is identical (i.e.Sxy = Szy, and Szx = Sxz) as a result of static equilibrium (no net moment). Thus, grouping of the nine stress components is known as the stress tensor (or stress matrix).

Stress Strain Relationship

Stress always being discussed with the existing of stain. The stress- strain relationship is very important in structure design because the stress and strain can be known during the design . the ignorance of stress strain relationship can lead to the failure of the design. The stress-strain relationship can be described from the equation

$$\varepsilon_x = + \frac{\sigma_x}{E} - \frac{\nu\sigma_y}{E} - \frac{\nu\sigma_z}{E}$$

$$\varepsilon_y = - \frac{\nu\sigma_x}{E} + \frac{\sigma_y}{E} - \frac{\nu\sigma_z}{E}$$

$$\varepsilon_z = + \frac{\nu\sigma_x}{E} - \frac{\nu\sigma_y}{E} - \frac{\sigma_z}{E}$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G} \qquad \gamma_{yz} = \frac{\tau_{yz}}{G} \qquad \gamma_{zx} = \frac{\tau_{zx}}{G}$$

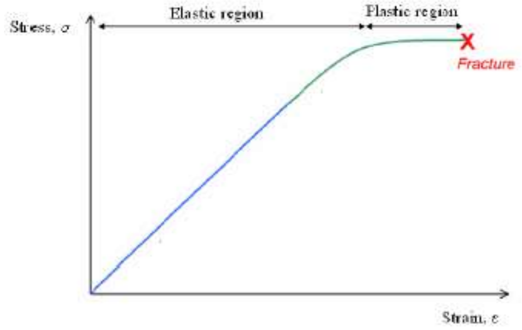
Poisons Ratio

When a deformable body is subjected to an axial tensile force not only it does elongate but it also contracts laterally. Compressive force acting on a body causes it to contract in the direction of the force and yet its sides expend laterally. Within the elastic range the ration of this strain is constant, since the deformation are proportional. This constant is referred to poison's ratio, v, and it has a numerical value that is unique for material that is both homogeneous and isotropic as the equation below,

$$\upsilon = - \frac{\varepsilon_{lat}}{\varepsilon_{long}}$$

Tensile Strength

Once past the elastic limit, the material will not relax to its initial shape after the force is removed (Hooke's Law and Modulus of Elasticity). The tensile strength where the material becomes plastic is called yield tensile strength. This is the point where additional deformation (strain) of the material is unrecovered, On the stress-strain curve below, this point is in between the elastic and the plastic region. The ultimate tensile strength of a material is the limit stress at which the material breaks, with sudden release of the stored elastic energy. This point is the fracture marked X on the curve shown in below Figure.



Stress – strain curve

Von Mises Equivalent Stress

Von Mises stress, is a scalar function of the components of the stress tensor that gives an appreciation of the overall "Magnitude" of the tensor. 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 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.

The principal stresses ($\sigma 1, \sigma 2, \sigma 3$) are calculated from the stress components by the cubic equations

$$\begin{bmatrix} \sigma_x - \sigma_0 & \sigma_{xy} & \sigma_{xz} \\ \sigma_{xy} & \sigma y - \sigma_0 & \sigma_{yz} \\ \sigma_{xz} & \sigma_{yz} & \sigma_z - \sigma_0 \end{bmatrix} = 0$$

The three-principal stress are labelled $\sigma 1, \sigma 2$ *and* $\sigma 3$. The principle stresses are ordered so that $\sigma 1$ is the most positive (tensile) and $\sigma 3$ is the most negative (Compressive)

The Von Mises or Equivalent stress σe is computed as:

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

The Von Mises criterion is a frequently used stress criterion to state the magnitude of multiaxial stresses acting on a element by a single parameter. In present CAE Simulation, Von Mises stress is used to evaluate the stress on the components.

8. EXPERIMENTATION PLAN

Following tests were planned to validate New PAD Design

1) CAE Simulation for Existing v/s New A/C Condenser PAD.

2) Vibration test of current A/C Condenser till failure.

3) Vibration test of New A/C Condenser-Test till get the double life than existing design.

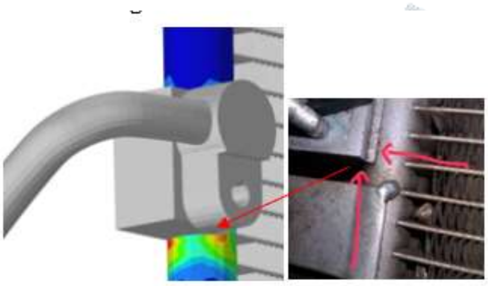
4) Brazing analysis for PAD to Side Header brazing area.

5) Stress measurement for HST V/s BS make flexible Discharge Hose.

To conduct various tests as decided in experimental plan it is necessary to finalize process parameters for different surface treatment.

CAE Simulation for Existing PAD

CAE simulation of existing condenser has given us an idea on red zones in current design. Red zones are matching with the current field failure, our failure location area is from the red zone only.



Existing Condenser Inlet PAD- CAE Simulation

CAE simulation for Proposed PAD

CAE

Vibration test of current A/C Condenser till failure.

Existing A/C Condenser is having the Designed life of 140 Hrs and current part is meeting the Design specifications. As per 5 parts vibration analysis existing part is meeting the average life of 157.2 Hours but looking at field failure rate this life is not sufficient to meet the vehicle level standard warranty target.

Existing Part						
Sr. No	Part Name	Acceleration Level	Design Specifications	Failure Location	Failure (Hours)	Average Life (Hours)
1	Existing_Condenser-Sample_1	7G	140 Hrs	Inlet PAD	156	157.2
2	Existing_Condenser-Sample_2	7G	140 Hrs	Inlet PAD	148	
3	Existing_Condenser-Sample_3	7G	140 Hrs	Inlet PAD	160	
4	Existing_Condenser-Sample_4	7G	140 Hrs	Inlet PAD	150	
5	Existing_Condenser-Sample_5	7G	140 Hrs	Inlet PAD	172	

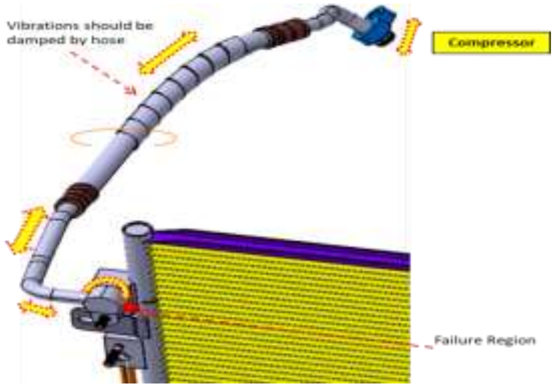
Table – Vibration Measurement

Vibration Test Inference: At bench level, Existing A/C Condenser has passed its design life of 140 Hrs. However tested samples have observed, lowest failure Hrs. Up to 148 Hrs. & whereas Maximum failure Hrs. are 172 Hrs. Average life of **157.2 Hrs.** is observed. All the A/C Condenser failed at Inlet PAD area, which is matching with Actual field failure.

Vibration test of New A/C Condenser-

(Test till, get the double life than The Existing design)

Stress measurements for HST make Discharge Hose

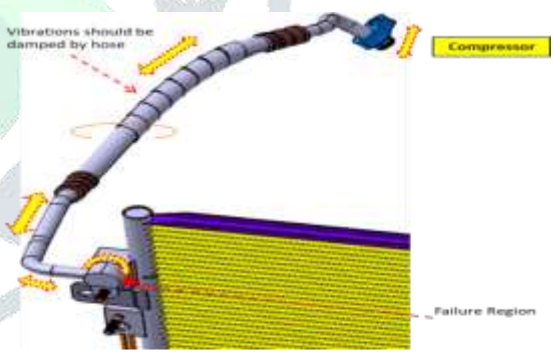


Stress Measurement @ A/C Condenser Level

Sr. No.	Option	Acceleration Level	Force value (N)	Stress (MPa)	Tensile Strength (MPa)
1	HST Hose	7	450	210	185

Vibration Test Inference: With Existing Condenser PAD & HST Make Discharge Hose, 210 MPa stress is observed at Condenser Inlet PAD area.

Stress measurement for BS make flexible Discharge Hose



Stress measurement for BS make flexible Discharge Hose

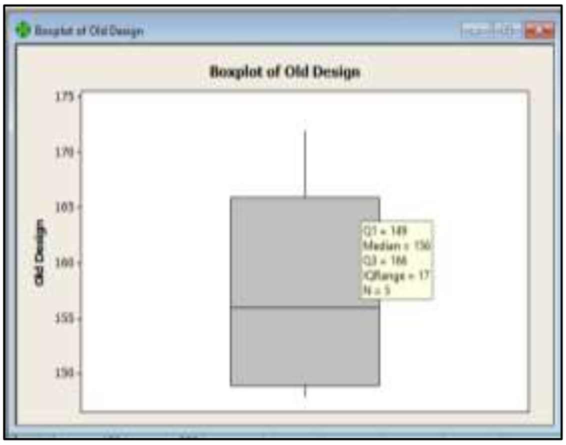
Sr. No.	Option	Acceleration Level	Force value (N)	Stress (MPa)	Tensile Strength (MPa)
1	BS Hose	7	450	158	185

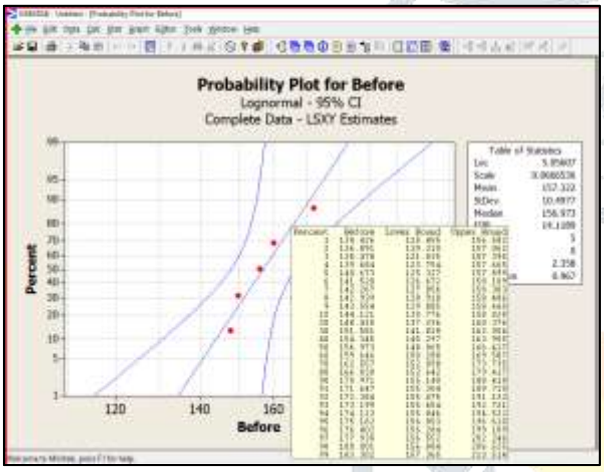
Vibration Test Inference: With Existing Condenser PAD & Proposed BS Make Discharge Hose, 158 MPa stress is observed at Condenser Inlet PAD area. When compared with existing design which is reduced by 52 MPa.

RESULT AND DISCUSSION

8.1 Experimental Observations

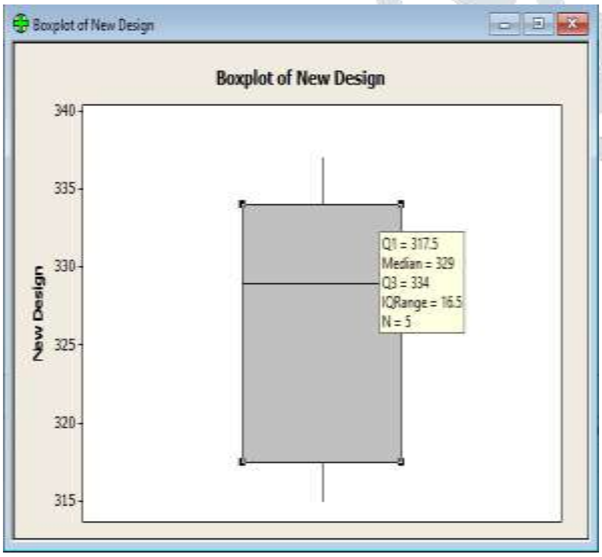
8.1.1 Vibration Test Results – Old Design

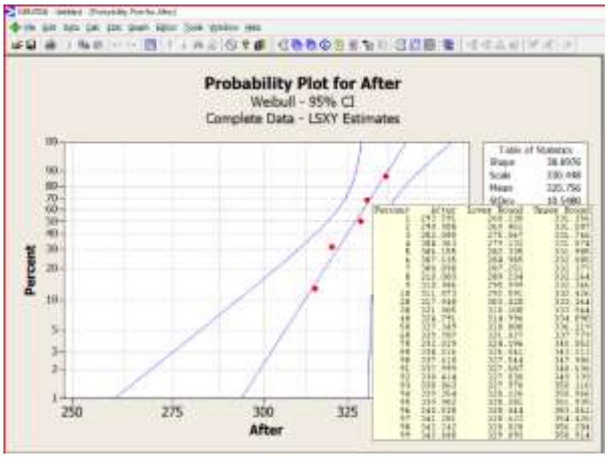




8.1.1 Fig. Box Plot & Probability Plot for Existing Design

8.1.2 Vibration Test Results – New Design





8.1.2 Fig. Box Plot & Probability Plot for New Design

Test Inference:

1. With New design Median is 329 Hours whereas with Old Design Median was 156 Hours.
2. With New design, PAD life is improvement by 173 Hours
3. B10 life of Existing Design is 144.1Hours & with New design improved up to 311.8 Hours.

9. IMPLEMENTATION

9.1 TWO PROPORTION TEST

To compare results of modified and earlier processes statistical test with help of Minitab software called as 2 proportion test was carried out. This test compares two proportions at 95% confidence to understand whether changes were statistically significant or non-significant First step is to write practical statement.

Practical Statement:

• Failures before solution implementation is more than failures after implementation of solution.

After practical statement we write statistical statement as follows.

• **Statistical Statement:**

• Ho: Failures proportion Before improvement = Failure proportion After Improvement

• Ha :Failure proportion Before improvement >Failure proportion After Improvement.

We used the following test for analysis.

• **Analysis:** 1-1, proportion --- 2 P test

Fig. 9.1 shows Results of 2P test statistical conclusion is as follows.

• **Statistical Conclusion:**

P Value = 0.

Reject Ho and accept Ha.

```
Difference = p (1) - p (2)
Estimate for difference:  0.00688721
95% lower bound for difference:  0.00498226
Test for difference = 0 (vs > 0):  Z = 5.55  P-Value = 0.000

* NOTE * The normal approximation may be inaccurate for small samples.

Fisher's exact test: P-Value = 0.000
```

Fig. 9.1: Minitab Results for 2p Test

As p value is zero null statement is not valid which concludes that there is significant difference in two proportion hence there is significant improvement in result after the implementation of New Design. The practical conclusion is as follows.

Practical Conclusion:

• Failure before improvement was more than Failures after improvement**.**

• Hence, we should go ahead with implementation of proposed solution of New PAD Design and Discharge Hose flexible hose material change from HST make to BS Make.

9.2 MONITORING OF RESULTS

To understand the effectiveness of results it was required to monitor the results carefully, for these results were monitored for field failures and results were plotted and field failure trend was monitored. Field failure trend chart is showing the improvement and field failures weredrastically reduced which proves solution implemented is giving good results in actual application.

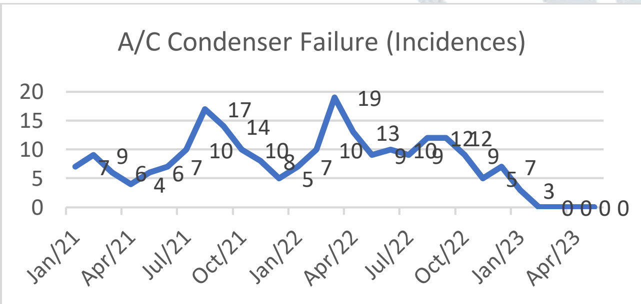


Fig. 9.2: Trend Chart for A/C Condenser Failure.

9.3 COST BENEFITS OF PROJECT

A/C Condenser New PAD implementation Project has given benefits in terms of elimination of field failures which resulted into reduction inwarranty cost and reduction in field complaints. The change in Design of A/C Condenser PAD also resulted in savings in terms of warranty cost; Table 9.3, shows the calculation of warranty cost worth INR 14.82 lacs net cost which is direct saving other than quality improvement and customer satisfaction.

A/C Condenser Warranty Cost Calculation		
Total Condenser Failed (Qty)	A	228
Condenser Part cost (INR)	B	4250
A/C Gas R&R + Labour R&R Cost (INR)	C	800
A/C Gas Charge @ 400 Gram	D	1200
Transportation & Courier cost (INR)	E	250
Per vehicle cost (INR)	F=(B+C+D+E)	6500
Total Warranty Cost (INR)	G=(A*F)	14,82000

Tab.9.3. Cost Benefit Calculation

9.4 MONITORING OF PROJECT

After the implementation of New PAD and BS make Discharge hose there is No field failure reported as on date. This new design was implemented in the month of Feb'23. Further we are monitoring field failures.

CONCLUSION & FUTURE SCOPE

10.1 CONCLUCION

In this study of Automobile, A/C Condenser failure detailed analysis were carried out. Existing failed parts analysed for its failure mode. Failure mode was simulated on test bench as well as stress was noticed with CAE simulation at failure location. In this project QC story methodology approach of problem solving was used to deeply investigate this problem. For this project advance quality tool of Fault Tree Analysis (FTA) is used. 1st time FTA was used by NASA. New design is tested and validated on bench level and thru the CAE simulation.

Based on this projects root cause analysis, testing & further validation of root cause following conclusions can be drawn.

1. Atbench level, Existing A/C Condenser has passed its design life of 140 Hrs. However tested samples have observed, lowest failure Hrs. Up to 148 Hrs. & whereas Maximum failure Hrs. are 172 Hrs. Average life of 157.2 Hrs. is observed. All the A/C Condenser failed at Inlet PAD area, which is matching with Actual field failure.
2. At bench level, New Proposed design A/C Condenser has passed its design life of 280 Hrs. However tested samples have observed, lowest failure Hrs. Up to 315 Hrs. & whereas Maximum failure Hrs. are 337 Hours. Average life

of**326.4Hours** is observed. With New A/C Condenser PAD Design, there is a life increase by **169.2 Hours** as compared with old A/C Condenser PAD Design.

3. With Existing Condenser PAD & HST Make Discharge Hose, 210 MPa stress is observed at Condenser Inlet PAD area.
4. With Existing Condenser PAD & Proposed BS Make Discharge Hose, 158 MPa stress is observed at Condenser Inlet PAD area. Stress at A/C Condenser PAD is reduced by 52 MPa.
5. Discharge Hose lesser Flexibility also can contribute for Fatigue failure.

10.2 FUTURE SCOPE

There is always a future scope for any type of research work. For this particular work on -Analysis of A/C Condenser failure has following future scopes.

1 The solutions which were ruled out due to vehicle level packaging issue of increasing the flexible hose length can be studied further to see actual effect on condenser inlet PAD for stress and fatigue.

2 Increase in weld spot at PAD to side header area can improve the holding strength this change also can be studied further for improving the condenser PAD life.

3 Other failures like Micro tube leakage, can be addressed by adding the paint layer on tube surface etc. can be studied further to eliminate failures and zero defects can be achieved.

4 From vehicle side engine mounting material can be optimized to reduce the vehicle level vibrations to avoid fatigue failures. This can be studied further.

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AUTHORS

Atul Prataprao Kale,

Student of Mechanical Engineering, Late G.N.Sapkal College of Engineering Nashik

Email: atulpkale@gmail.com

(M): 9922900870

Prof. Dr. Tushar Y. Badgujar,

Associate Professor,

Department of Mechanical Engineering, Late G.N.Sapkal College of Engineering Nashik

Email: tybadgujar@gmail.com

(M): 9423696542

Prof. PoonamS. Talmale,

Associate Professor,

Department of Mechanical Engineering, Late G.N.Sapkal College of Engineering Nashik

Email: poonam.talmale05@gmail.com

(M): 9970944210