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Fatigue and Static Structural Analysis of Car Wheel using Finite Element Method - A review

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Abstract:- *This review reports the state of the art in modeling chemical and physical processes of Wheels have vital importance for the safety of the vehicle and a special care is needed in order to ensure their durability. The development of the vehicle industry has strongly influenced the design, the material selection and the manufacturing processes of the wheels. The wheels loading manner is a complex one; further improvement and efficient wheel design will be possible only if their loading will be better understood.*

In this paper, the review about various papers which is based on analyzed with the finite element method and experimental works, using the different loading test. The static stresses are studied in order to find the zones with higher stress concentration and fatigue life prediction are studied in order to improve the life cycle of wheel and also to suggest the better design solution.

Keywords:- *Wheel rim; 3-dimensional model; Finite element analysis; Static structural and fatigue analysis; S-N curve*

I. INTRODUCTION

The wheel is a device that enables efficient movement of an object across a surface where there is a force pressing the object to the surface. Early wheels were simple wooden disks with a hole for the axle. Because of the structure of wood a horizontal slice of a trunk is not suitable, as it does not have the structural strength to support weight without collapsing; rounded pieces of longitudinal boards are required.

The spoke wheel was invented more recently, and allowed the construction of lighter and swifter vehicles. Alloy wheels are automobile wheels which are made from an alloy of aluminum or magnesium metals (or sometimes a mixture of both). Alloy wheels differ from normal steel wheels because of their lighter weight, which improves the steering and the speed of the car, however some alloy wheels are heavier than the equivalent size steel wheel. Alloy wheels are also better heat conductors than steel wheels, improving heat dissipation from the brakes, which reduces the chance of brake failure in more demanding driving conditions. Over the years, achieving success in mechanical design has been made possible only after years of experience coupled with rigorous field-testing. Recently the procedures have significantly improved with the emergence of innovative method on experimental and analytical analysis. Alloy wheels intended for normal use on passenger cars have to pass three tests before going into production: the dynamic cornering fatigue test, the dynamic radial fatigue test, and the impact test. Many alloy wheels manufacturing company had done numerous amount of testing of their product but their method on simulation test on alloy wheel information often kept limited.

Historically, successful designs was arrived after years of experience well aided worth extensive field -testing. Since the 1970's several innovative methods of testing and experimental stress measurements have been initiated. In more recent years, the procedures have significantly improved by the emergence of a variety of experimental and analytical methods for structural analysis. Durability analysis, that is: fatigue life prediction and reliability methods, for dealing with various inherent in engineering structures has been used for the study of automotive rims.

In its basic form a wheel is a transfer element between the tire and the vehicle. The main requirements of an automobile wheel are;

- It should be as light as possible so that unsprung weight is least.
- It should be strong enough to perform the above functions.
- It should be balanced statically as well as dynamically.
- It should be possible to remove or mount the wheel easily.
- It material should not deteriorate with weathering and age. In case, the material is suspected to corrosion, it must be given suitable protective treatment.

II. STATIC & FATIGUE ANALYSIS

The proposed work deals with estimating the fatigue life of alloy wheel by conducting the tests under radial fatigue load and comparison of the same with that of finite element analysis. Fatigue life prediction using the stress approach is mostly based on local stress, because it is not possible to determine nominal stress for the individual critical areas.

The necessary material data for fatigue life prediction with the stress concept is the well-known S–N curve. Therefore, S–N curves are required for each specimen which reflects the stress condition in the critical area of the component. In the fatigue life evaluation of alloy wheel design, the commonly accepted procedure for passenger car wheel manufacturing is to pass two durability tests, namely the radial fatigue test and cornering fatigue test.

Since alloy wheels are designed for variation in style and have more complex shapes than regular steel wheels, it is difficult to assess fatigue life by using analytical methods. In general, the newly designed wheel is tested in laboratory for its life through an accelerated fatigue test before the actual production starts. Based on these test results the wheel design is further modified for high strength and less weight, if required.

III. TYPES OF WHEEL (MATERIAL)

Steel and light alloy are the foremost materials used in a wheel rim however some composite materials together with glass-fibre are being used for special wheels.

A. Wire spoke Wheel

Wire spoke wheel is an essential where the exterior edge part of the wheel rim and the axle mounting part are linked by numerous wires called spokes. Today's automobiles with their high horse power have made this type of wheel manufacture obsolete. This type of wheel is still used on classic vehicles.

B. Steel Disc Wheel

This is a rim which practices the steel made rim and the wheel into one by joining (welding), and it is used mainly for passenger vehicles especially original equipment tires.

C. Light Alloy wheel

These wheels are based on the use of light metals, such as aluminium and magnesium has come to be popular in the market. This wheel rapidly become standard for original equipment vehicle in Europe in 1960's and for the replacement tire in United States in 1970's. The advantages of each light alloy wheel are explained as below.

- **Aluminium Alloy Wheel**
  Aluminium is a metal with features of excellent lightness, thermal conductivity, physical characteristics of casting, low heat, machine processing and reutilizing, etc. This metal main advantage is decreased weight, high precision and design choices of the wheel.

- **Magnesium alloy Wheel**
  Magnesium is about 30% lighter than aluminium and also admirable as for size stability and impact resistance. However its use is mainly restricted to racing, which needs the features of weightlessness and high strength. It is expansive when compared with aluminium

- **Titanium alloy wheel**
  Titanium is an admirable metal for corrosion resistance and strength about 2.5 times compared with aluminium, but it is inferior due to machine processing, designing and more cost. It is still in developed stage.

- **Composite material wheel**
  The composite material wheel is different from the light alloy wheel, and it is developed mainly for low weight. However this wheel has inadequate consistency against heat and for best strength.

IV. LITERATURE REVIEW OF PREVIOUS WORK

A Review on Modeling and Analysis of Car Wheel Rim using CATIA & ANSYS by **T. Siva Prasad et al.[1]** does stress analysis of car wheel rim by using CATIA & ANASYS. To determine best material for wheel so that by design and modifications the stresses can be reduces to improve the fatigue life of wheel rim. During this he considered two different materials namely aluminium and forged steel and their relative performances have been observed respectively. In addition to wheel rim is subjected to modal analysis, a part of dynamic analysis is carried out its performance is observed. In this paper they concluded that by observing the results of both static and dynamic analysis obtained forged steel is suggested as best material.

Sourav Das et al.[2] gives design of aluminum alloy wheel for automobile application which is carried out paying special reference to optimization of the mass of the wheel. The Finite Element analysis it shows that the optimized mass of the wheel rim could be reduced to 26Kg to 12.15kg as compared to the existing solid disc type Al alloy wheel. The FE analysis carried out which shows that the stress generated in the optimized component is well below the actual yield stress of the Al alloy. The Fatigue life estimation by finite element analysis, under radial fatigue load condition, is carried out to analyze the stress distribution and resulted displacement in the alloy wheels. S-N curve of the component depicts that the endurance limit is 90MPa which is well below the yield stress is 185MPa of the material and safe for the application. The FE analysis indicated that even after a fatigue cycle of 1×10^{20}, the damage on the wheel is found only 0.2%. And the damage region is found the flange portion of the rim.

Rajarethinam P et al. [3] presented paper on motorcycle wheel spokes. The radial, lateral, and tangential stiffness of motorcycle wheels spokes depends upon the rim's bending inertia, torsion inertia, the spoke sizes, and the spoke geometry. The spokes of rear bicycle wheel of different spoke patterns were instrumented with strain gauges in order to investigate the effect of the spoke pattern on the spoke strain and fatigue resistance properties of the wheels.

Analytical and numerical studies show that spoke strains due to radial loads and in service conditions are insensitive to the spoke pattern. Small variations in the spoke strains between the wheels in the road tests can be attributed to variations in the loads, but do not significantly affect the fatigue life of the wheels.

S. Ganesh et al.[4] gives analysis of alloy wheels which are made from an alloy of aluminum or magnesium metals or sometimes a mixture of both. At present four wheeler wheels are made of Aluminum Alloys. In this project a parametric model is designed for Alloy wheel used in four wheeler by collecting data from reverse engineering process from existing model. Design is evaluated by analyzing the model by changing the design of rim styles to be strong and balanced.

The wheel is analyzed for the calculated loading condition and the stress plot is obtained. In the case of bending test normal stress along Y-axis shows compression on the top rib and tension on the bottom rib and compression on the bottom rib. In the case of pressure loading, normal stress along X-axis shows compression on the top rim and on the inside portion of the rim there is a gradual transition from compression to tension. Normal stress along Y-axis shows bending stress coming on to ribs because when the rim is getting compressed, it forces the rib to move outwards. In the case of vertical loading normal stress along Y-axis shows tension on the outer rib and compression on the outer side of the rib. When a section plot is taken it will show a gradual transition from tension to compression.

Mechanical testing methods concerning the stress analysis for a vehicle wheel rim by **Alexandru Valentin et al.[5]** inform about life of wheels. The wheels loading manner is a complex one; further improvement and efficient wheel design will be possible only if their loading will be better understood. In that paper, the car rim is analyzed with the finite element method, using the 40^0 loading test. The static stresses are studied in order to find the zones with higher stress concentration and to suggest the better design solution. The results have been compared to those obtained using an experimental stand. The experimental results are numerically treated using the regression analysis method and the Wöhler fatigue curve is presented in Figure 1.

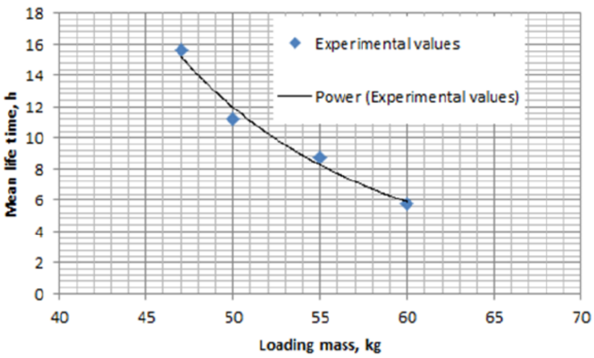

Figure 1. Wöhler fatigue curve

M. Saran Theja et al. [6] analyse the safe load of the alloy wheel, which will indicate the safe drive is possible. A typical alloy wheel configuration of Suzuki GS150R commercial vehicle is chosen for study. Finite element analysis has been carried out to determine the safe stresses and pay loads. The current design is 60% lighter than the original design.

In this work the overall dimensions are controlled by reducing number of spokes to the alloy wheel with same functioning stability and less weight. The stress and displacements in 4 spoke alloy wheel are lesser than six and five spokes alloy wheels.

Hongyu Wang et al. [7] gives the parametric three dimensional model of the rim section is built based on Solid Works, the finite element method is used to analyze stress and displacement distributions in a variable cross-section rim subject to the conjoint influence of radial load and inflation pressure. The optimization methods which combined multi-island genetic algorithm (MIGA) with sequential quadratic programming (NLPQL) is used for exploration. By adjusting control parameters of the rim shape quality is optimized. The results show that the optimization effect is good.

Numerical simulation of steel wheel dynamic cornering fatigue test by **Shu-Qin Pan et al. [8**] presented a computational methodology is proposed for fatigue life and failure prediction of automotive steel wheel by the simulations of dynamic cornering fatigue test. Following with a short review of theoretical models, numerical simulation models were described in conjunction with bilinear elasto-plastic finite element stress analysis under wheel rotating loading. The fatigue life and crack initiation locations are calculated using effective strain, Brown–Miller damage criterion, rainflow counting method and Palmgren–Miner cumulative damage rule.

They concluded that according to stress analysis of the key locations based on the critical plane theory, two principle stresses are not proportional and unstable principle planes are changing with loading direction. Principle planes variation changes a little, varying from -400 to 300, and the stress states of automotive steel wheel are in biaxial tensile and compression stresses during dynamic cornering fatigue test. and it is conservative and considerable to observe that fatigue test cycles and crack initiation locations are predicted using Brown–Miller damage criterion, which are close to the actual test results, and the minimum error is -4.4%.

Sanjay Chaudhary et al. [9] presented on Design and Analysis of Aluminum Alloy Wheel using PEEK Material. In the design of automobile, the industry is exploring polymeric material in order to obtain reduction of weight without significant decrease in vehicle quality and reliability. This is due to the fact that the reduction of weight of a vehicle directly impacts its fuel consumption. Thus in this project work the entire wheel design of two wheeler was chosen and analyzed by applying different load and redesign the wheel again to minimize the deformation and material will be changed from aluminum to PEEK(polyether ether ketone)The following materials were chosen:-

Aluminum Alloy
PEEK (Polyether ether ketone)
PEEK with 30% Glass fiber
PEEK-90 HMF 20
PEEK-90 HMF 40

The whole design is made by using NX 7.5. The whole design has been made as per original equipment manufacture (OEM'S) requirement. Analysis has been done by ANSYS 13.0 software to determine the various stresses, strain and fatigue life of the wheel. From the analysis it is clear that PEEK 90HMF20 (20% carbon fiber) is best material for the replace of Aluminium material.

Fatigue life prediction of a heavy vehicle steel wheel under radial loads by using finite element analysis by **N.S. Kuralay et al.[10]** gives analysis about The origin of fatigue failure that occurs on the air ventilation holes of a newly designed heavy commercial vehicle steel wheel in dynamic radial fatigue tests is studied. In these tests, all of the test samples failed in the same regions. The cause of this damage was studied via finite element analysis. In order to determine the reason of the fatigue failure, stress analysis was performed via the finite element method. In this way, stress concentrated regions, where fatigue failure is expected, were determined. Mechanical properties of the wheel material were determined by tensile tests and hardness measurements. The fatigue life of the damaged wheel was estimated using the stress–life (S–N) approach, utilizing the ultimate tensile strength of the processed wheel material and the Marin factors determined for the critical regions. To extend the life of the wheel disc and delay the onset of fatigue, design enhancement solutions were applied.

Liangmo Wang et al.[11] explain how To improve the quality of aluminum wheels, a new method for evaluating the fatigue life of aluminum wheels is proposed in this paper. The ABAQUS software was used to build the static load finite element model of aluminum wheels for simulating the rotary fatigue test. The equivalent stress amplitude was calculated based on the nominal stress method by considering the effects of mean load, size, fatigue notch, surface finish and scatter factors. The fatigue life of aluminum wheels was predicted by using the equivalent stress amplitude and aluminum alloy wheel S-N curve. The results from the aluminum wheel rotary fatigue bench test showed that the baseline wheel failed the test and its crack initiation was around the hub bolt hole area that agreed with the simulation. Using the method proposed in this paper, the wheel life cycle was improved to over 1.0×10^5 and satisfied the design requirement. The results indicated that the proposed method of integrating finite element analysis and nominal stress method was a good and efficient method to predict the fatigue life of aluminum wheels.

Sunil N. Yadav et al.[12] gives effect of camber angle on stress distribution and fatigue life of wheel rim of passenger car under radial load condition which arises due to off road field area and road unevenness. Finite element analysis (FEA) is carried out by simulating the test conditions to analyze stress distribution and fatigue life of the steel wheel rim of passenger car. Experimental analysis performed by radial fatigue testing machine for evaluation of fatigue life under influence of camber angle. For radial fatigue testing SAE J328 standard is use(16). This SAE recommended practice provides minimum performance requirements and uniform procedures for fatigue testing of wheels intended for normal highway use and temporary use on passenger cars. The finite element analysis as well as experimental analysis of passenger car wheel rim performed for radial load with the effect of camber angle on stress distribution and fatigue life.

Sunil N. Yadav et al.[13] gives effect of slip angle on stress distribution and fatigue life of wheel rim of passenger car under radial load condition which arises due to off road field area and road unevenness. Finite element analysis is carried out by simulating the test conditions to analyze stress distribution and fatigue life of the steel wheel rim of passenger car. The finite element analysis as well as experimental analysis of passenger car wheel rim performed for radial load with the effect of slip angle on stress distribution and fatigue life.

N. Satyanarayana et. al.[14] gives a detailed "Fatigue Analysis of Aluminum Alloy Wheel under Radial Load". During the part of project a static and fatigue analysis of aluminum alloy wheel A356.2 was carried out using FEA package. The 3 dimensional model of the wheel was designed using CATIA. Then the 3-D model was imported into ANSYS using the IGES format. The finite element idealization of this modal was then produced using the 10 node tetrahedron solid element. The analysis was performed in a static condition. After completion of meshing we apply pressure 2.8653MPa at rim The total deformation of wheel maximum is 0.2833mm and minimum is 0.031478mm at hub portion.

The life of wheel maximum 1.7667×10^6 cycles and the minimum cycles of wheel is 1.6533×10^5 at a cross sectional area of wheel. The wheel safety maximum at a hub portion because the load is maximum acting at a rim. Minimum load is acting at a hub. The damage of wheel high at a cross sectional area of wheel spokes.

P. V. Ravi Kumar et al.[15] have studied paper describes impact test and topology optimization of alloy wheel with constrain of plastic strain. Since the fail value of plastic strain for standard Cast Aluminium Alloy Wheel is 4.0%, cracks will appear if the Plastic Strain value is greater than 4%. This analysis will predict the plastic strains induced during impact testing. Topology Optimization is carried out by increasing the thickness of the rim until the plastic strain value is below 4%. Impact analysis is carried out using LS-Dyna software to predict the plastic strains during impact test. Topology Optimization is carried out by changing the thickness of the rim of the Cast Aluminium Alloy Wheel until the value of the plastic strain is less than 4.0%. They concluded that thickness of cast aluminium alloy wheel should be 5.9mm which will be perform satisfactory.

V. CONCLUSION

Various researchers have carried out a number of simulation as well as experimental investigations. Although promising, the results of the above investigations have been somewhat mixed. Most of these studies investigated, Fatigue and static structural analysis of wheel rim. Most have concluded that improved wheel life and reduction of wheel weight by using different materials.

Based on the review work it is to be noted that Aluminum alloy wheel rim is subjected to more displacement and stresses compared to Forged steel. The weight of Aluminum alloy wheel rim is optimized from 26 Kg to 12.15 Kg using topology method.

The optimized design of Aluminum alloy wheel is withstand Radial, Lateral and Bending loads used are 8976N, 4044N and 4488N and maximum stress induced in the wheel are 94MPa, 64MPa and 35MPa which are less than yield stress of material suggested i.e., 185MPa.

Various analysis of wheel rim stress that the maximum stress area was located at Spoke-Rim contact. Stresses induced in 5 Spokes Alloy wheel are less as compared with Al-Alloy of the 6 Spokes. Material reduction can be done by reducing number of Spokes. The objective was to reduce the weight of the alloy wheel has been achieved.

The objective of this paper is reducing the weight of the wheel and also reducing on stress without exceeding allowable stress on the specified material.

REFERENCES

[1] T. Siva Prasad,T. Krishnaiah, J. Md. Iliyas, M.Jayapal Reddy, "A Review on Modeling and Analysis of Car Wheel Rim using CATIA & ANSYS", International Journal of Innovative Science and Modern Engineering (IJISME), ISSN: 2319-6386, Volume-2, Issue-6, May 2014

[2] Sourav Das, "Design and Weight Optimization of Aluminium Alloy Wheel", International Journal of Scientific and Research Publications, Volume 4, Issue 6, June 2014, ISSN 2250-3153

[3] Rajarethinam P., Periasamy K., "Modification of Design and Analysis of Motor Cycle Wheel Spokes", International Journal Of Modern Engineering Research (IJMER), PP. 123-127

[4] S.Ganesh, Dr.P.Periyasamy, "Design and Analysis of Spiral Wheel Rim for Four Wheeler", The International Journal Of Engineering And Science (IJES), Volume 3, Issue 4, PP. 29-37, 2014, ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

[5] Alexandru Valentin RADULESCU, Sorin CANANAU, Irina RADULESCU, "MECHANICAL TESTING METHODS CONCERNING THE STRESS ANALYSIS FOR A VEHICLE WHEEL RIM", Mechanical Testing and Diagnosis ISSN 2247 – 9635, 2012 (II), Volume 2, PP. 33-39

[6] M. Saran Theja, M. Vamsi Krishna, "Structural and Fatigue Analysis of Two Wheeler Lighter Weight Alloy Wheel", IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 8, Issue 2 (Jul. - Aug. 2013), PP.
35-45

[7] Hongyu Wang, "Geometric Parameters Optimal Design of Variable Cross-Section Rim", SAE-China and FISITA (eds.), PP. 1003-1008

[8] Zhan-Guang Zheng , Teng Sun, Xi-Yong Xu, Shu-Qin Pan, Shuai Yuan, "Numerical simulation of steel wheel dynamic cornering fatigue test", Engineering Failure Analysis 39 (2014), PP. 124–134

[9] Ravi Lidoriya, SanjayChaudhary and Anil Kumar Mohopatra, "Design and Analysis of Aluminum Alloy Wheel using PEEK Material", International Journal of Mechanical Engineering and Research. ISSN No. 2249-0019, Volume 3, Number 5 (2013), PP. 503-516

[10] N. S. Kuralay, M. M. Topac, S. Ercan, " Fatigue life prediction of a heavy vehicle steel wheel under radial loads by using finite element analysis", Engineering Failure Analysis, March 2012, Volume 20, PP. 67-79

[11] Liangmo Wang - Yufa Chen - Chenzhi Wang - Qingzheng Wang, "Fatigue Life Analysis of Aluminum Wheels by Simulation of Rotary Fatigue Test", Journal of Mechanical Engineering 57(2011)1, PP. 31-39

[12] Sunil N. Yadav, N. S. Hanamapure, "Analyze the Effect of Camber Angle on Fatigue Life of Wheel Rim of Passenger Car by Using Radial Fatigue Testing", International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 2, Issue 5, September 2013, PP. 231-239

[13] Sunil N. Yadav, Prof. N. S. Hanamapure, "Analyze the Effect of Slip Angle on Fatigue Life of Wheel Rim of Passenger Car by Using Radial Fatigue Testing", International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization) Vol. 2, Issue 9, September 2013, PP. 4309-4318

[14] N. Satyanarayana & Ch.Sambaiah, " Fatigue Analysis of Aluminum Alloy Wheel Under Radial Load", International Journal of Mechanical and Industrial Engineering (IJMIE), ISSN No. 2231 –6477, Vol-2, Issue-1, 2012, PP. 1-6

[15] Ch. P. V. Ravi Kumar, Prof. R. Satya Meher, "Topology Optimization of Aluminium Alloy Wheel", International Journal of Modern Engineering Research (IJMER), Vol. 3, Issue. 3, May.-June. 2013, ISSN: 2249-6645, PP. 1548-1553

[16] John Kinstler, “The science and methodology of SAE wheel fatigue test specifications” SAE technical publication - 01-1826,2005

