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Validating FEA results with experimental strain gauge values in fatigue testing

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***Abstract*—This thesis deals with the estimation of the fatigue life of a cast wheel by carrying out tests under fatigue loading in bends and comparing them with finite element analysis (FEA). Fatigue life prediction using the stress approach is mostly based on local stress, as it is not possible to determine the nominal stress for individual critical areas. Implementation of the validation method using strain gauge readings and FEA strain values is used to determine whether the FEA method used is correct or not.**

Keywords—Fatigue life, FEA, Validation, Strain gauge

I. INTRODUCTION

Based on these test results, if necessary, the wheel design is further modified for high strength and lower weight. Finite element analysis is performed by simulating test conditions to analyse the stress distribution and fatigue life, safety and damage of a cast wheel. The S–N curve approach for predicting the fatigue life of cast wheels using cyclic loading simulation was found to agree with experimental results. The method will be useful for manufacturers/designers to reliably predict the fatigue life of similar structural components subjected to radial fatigue loading. Using ANSYS, we determine the total deformation and stress occurring in the cast wheel. [5].

A multi-objective analysis concept is performed to optimize the weight of the rim. Also to determine if the torque is applied to the mounting holes or also to the hub. Work is carried out gradually. We tried to minimize the number of experiments and levels of experiments. All experiments were considered at the first test, after which a proper finite element analysis was performed. Then experimentation is done for the same test and compared. In this way, a filter is applied for extensive experimentation. We performed DCFT with FEA as well as Experimentation for safe combinations. Here we got the final optimization result. The experimental results were compared with the finite element results to validate the adopted methods. Experimental results and modification and identification of suitable methods for applying torque to the rim.

The Dynamic Cornering Fatigue Test is an SAE standard test that simulates wheel loads caused by cornering. A test system in which the test wheel is mounted on a rotary table, the torque arm is fixed to the outer mounting pad of the wheel with screws, and a constant force is applied to the tip of the torque arm by means of a load actuator and a bearing. imparts a constant rotational bending moment to the wheel. If a bike passes the dynamic cornering fatigue test, it has a good chance of passing all other required endurance tests.
The Cornering Fatigue Testing (CFT) machine allows the simulation of an endurance fatigue test on car/light truck/bus wheels subjecting them to cornering fatigue stress and holding the test conditions constant throughout the test duration. This is the type of stress a wheel experiences during turning.[13]

II. FINITE ELEMENT ANALYSIS OF FATIGUE TEST

In the FEA model, the loading and boundary conditions were set similarly to the bench test. The wheel was fixed around the edge of the rim flange and loaded with a constant force at the end of the shaft. The load shaft and wheel were bolted together. Since the wheel deformation was the main concern, the load shaft was defined in the FEA analysis as a rigid body using a tie rod connection to the wheel. The J area under the wheel rim was under full restraint. There were 2 load cases for the cycle simulation and wheel responses were calculated. The direction at 0° gave the positive x-axis direction from the original direction of the cyclic loading force in the simulation.

Rim analysis consists of numerically analysing the stress levels that rims experience during operating conditions. These stress levels will then serve as input parameters for the fatigue analysis of the rims to evaluate their respective fatigue lives. In addition, the bearing capacity of the bolt spacing for heavy load conditions will be evaluated. A finite element (FE) method is implemented for all rim analyses. The reliability of the FEA approach is based on their previous experience in fatigue analysis studies. The magnitude of the static load and pressure contributes to increased stress on the rim components. [2]

Based on this type of FEM analysis, one can decide which parts are critical and then strengthen in those zones. For the FEA of the rim, we considered the following case of a dynamic load or moment applied to the mounting holes and the disc. In experimenting with strain gauges, strain gauges were used to find out the stress developed at different positions. These strain gauge values were compared with the FEA results in both cases. The minimum error scheme will be considered to study the stresses developed in the rim and analyse future failures.

Outcome of FEA of DCFT - Result of Analysis using ANSYS

There are two high voltage zones in the central area of the disc. These stresses are responsible for fatigue fractures of the rim. Finite element analysis identified likely failure locations in the wheel bolt holes, vents, and weld. The stress distribution on the rims varies from one area to another. Based on this type of FEM analysis, one can decide which parts are critical and then strengthen in those zones. On the other hand, the stress distribution may not be as high on some other parts, so excess can be removed from these areas to avoid material extravagance. In addition, if residual stresses remain in critical areas of the rim, it should be considered that these parts will be more durable and therefore safer. For the FEA of the rim, we considered the following case of a dynamic load or moment applied to the mounting holes and the disc. In experimenting with strain gauges, strain gauges were used to find out the stress developed at different positions. These strain gauge values were compared with the FEA results in both cases. The minimum error scheme will be considered to study the stresses developed in the rim and analyze future failures.

III. CORNERING FATIGUE TEST

According to the steel wheel cornering fatigue test standard, some premature failure cracks are clearly seen on the surface of the wheel, and some new phenomena and rules have been found, such as the following:

1. The failure points of the steel wheel mainly appear around the cooling hole and the disc bolt hole, but the fatigue crack is not located on the rim and the disc-rim welding joint. This means that the secondary process of pulling back the disc will reduce the fatigue strength of the disc and increase the stress concentration factors due to the thinning of the thickness and the occurrence of residual tensile stress during the disc pulling process.
2. Fatigue cracks may not be related to defects in the quality of the raw material and surface, but to mechanical fatigue damage due to stress from the rotation cycle and residual tensile stress.
3. These failures are both modes of frictional fatigue and stress concentration, while multiple origin of cracks are detected on the disc surface.[9]

The function of the machine is to apply a rotating bending moment to the wheel; the resulting stresses on the bike are very similar to the stresses produced when turning a car or truck on the road. A rotary fatigue testing machine applies a force to the central disc of the wheel. Wheel faults on the machine will be in the center of the test wheel and/or in the area of the wheel mounting holes.
The machine can be controlled in manual or fully automatic mode (load, speed) using controls located on the front of the control panel. The following settings can adjust:

1. Bending moment or speed set point
2. Percent value of increase in deflection for shut down criteria
3. Maximum speed for shutdown criteria
4. Maximum bending moment for shutdown criteria
5. Information regarding the wheel under test
6. No. of load cycles

The following parameters are displayed on the front of the control panel:
1. Applied Load (force / moment)
2. Speed (moment RPM)
3. Deflection
4. Cycles (Total revolutions of wheel)

IV. VALIDATION FOR CORNERING FATIGUE TEST

For validation purposes, strain gauges are mounted on the rim at four different locations. These results are compared with FEA results. A physical test known as the cornering fatigue test is performed and discussed below. After the test is completed, the test sample is removed from the assembly. Cracks are then observed by visual inspection. If the cracks are not visually visible, then a dye penetration test is used to detect the crack.

Gauge Location	**Strain Gauge Values ($X10^{-4}$)**					**FEA Strain Values ($X10^{-4}$)**	**Diff**
	S1	S2	S3	S4	Avg.		%
1	3.021	2.961	3.112	2.981	3.094	2.69	13.96
2	0.141	0.138	0.137	0.139	0.139	0.13	6.69
3	8.864	8.992	9.121	9.420	9.099	8.60	5.64

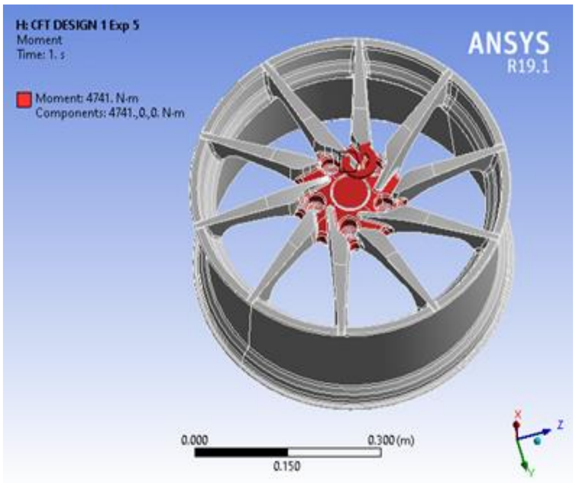

Fig. 1. Boundary conditions applied Sample

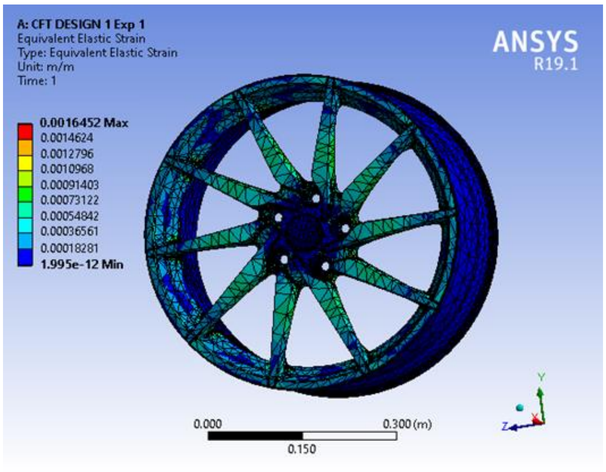

Fig. 2. Sample Strain Plot through FEA results

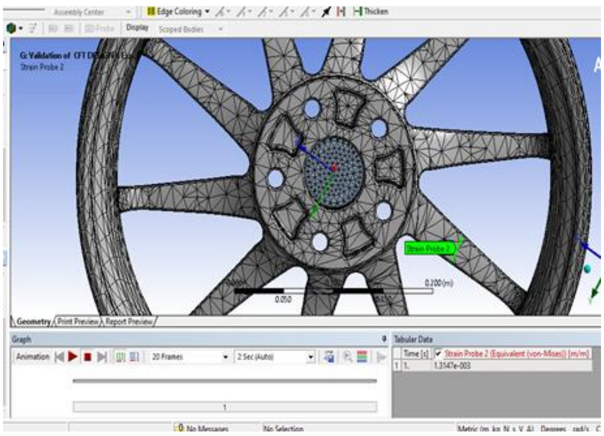

Fig. 3.Sample FEA STRAINGAUGE Plots

Bending Moment Calculation-

The bending moment is calculated as follows

$B.M = F_R d + F_L R$

$= F_R d + \mu F_R R$

Where F_R=Radial force acting on the wheel=1149 Kg

d=wheel offset=0.25

μ=Coefficient of friction between ground and tire=0.7
R=Maximum allowable Radius of statically loaded tire mounted on the wheel=0.24 m
B.M=4740.5 **=4741 Nm**

IV.COMPARISON OF FATIGUE TEST AND FEA RESULTS

TABLE 1.COMPARISON OF STRAIN VALUES

The cornering fatigue testing machine performs wheel testing under rotating conditions with a bending moment applied to the test wheel at an angle of 90 degrees. The stresses calculated in each element can be determined using FEA describing the stress distribution in the material. In order to evaluate the effect, we need to perform an analysis of wheel rim failures from the comparison.

Conclusion

Looking at the results, we can see that there is very little difference between the average strain values of the tested samples and the FEA results. We can successfully use this method for validation. Also, we can use the same method for multi-objective analysis as

Optimization, analysis of multiple material variations, design change, weight optimization, etc., where multiple experiments are involved.

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