A study on wheel force measurement using strain gauge equipped wheels

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Abstract: - In order to fully understand the dynamic behavior of a vehicle the forces and moments acting on the wheels need to be known with an acceptable level of accuracy. Since all the tire models used in the literature calculate the tire forces and moments based on parameters which are difficult to measure or estimate online, in this paper a different approach is undertaken. A wheel rim from a formula student car was fitted with strain gauges and a study was conducted with respect to the feasibility to estimate the static load applied to it. A a FE model was built with the aim to find a simple and feasible method to estimate the wheel strain when loaded under a static load and while turning. Furthermore, a FE analysis was carried out to validate the data obtained from testing. The results of this study highlight the challenges encountered and discuss possible solutions.

Key-Words: - automotive control systems, wheel force measurement

1 Introduction

In the world today, technology is developing at an increasing rate (Kanarachos 2014, 2015). The latest gadget of today will be tomorrow's antique and things for granted this is due to the rapid development in technology. One of those things include the wheel. wheels are used everywhere, as tyres, or in machinery (Ancient Origins 2014).

In automotive industry wheels play a major role. Wheel with axel allows to move the objects easily for one place to another, Improving the transport industry. The main function of the wheel is to move objects and reduce friction by the rotating motion.

By doing so the wheels take up a huge amount of external forces and loads due to gravity.

From Newton's third law, "Every action has an equal and opposite reaction". Assuming a vehicle is at rest, the weight of the vehicle is pushing down due to gravity and there is a reaction force from the ground pushing up.

Other forces on the wheel include force due to motion, where the vehicle is moving forward and there is a rolling resistance or friction acting against it. Once in motion and the vehicle brakes, there is braking force acting on the wheels which the brake grips the wheels in order to slow it down but due to the momentum the vehicle tends to move forward.

2 Problem Formulation

Dynamometric wheels measure the forces and moments in a wheels, this is done by attaching Strain gauges on the wheel hub. These strain gauges measure the tensile and compressive loads on the wheels. (Gutiérrez-López et al. 2015) (Hajiahmad 2015).

The applications of a dynamometric wheel are to accurately model the dynamic behavior of vehicles and tyres, in product development to improve durability and reliability, to manufacture safer and efficient products and for research and education.

2.1 Research methodology

The main objectives of this study are to design and evaluate a strain gauge equipped wheel using the following methods: Measurement of the wheel, Generation of CAD model.

3. Finite element analysis of the model.
4. Testing and validation of the models.
5. Estimation of wheel loads.

3 Problem Solution

Finite element analysis is mainly used in calculating numerical solutions for various problem and engineering and technology, these problems may include design of shaft, bridges, heating, building, fluid flow and so on. One of the main advantages of finite element analysis is to validate the safety and integrity of a alternative design using the computer, even before building the first prototype. The concept of finite element analysis is by dividing a larger body into smaller parts call elements, these elements hi connected by predefined points called nodes. The element behaviour is approximated from the nodal variable called the degrees the freedom. These elements are then assembled together with the considerations of loading and boundary conditions. This results in a number of equations and solution of these equations gives the approximate behaviour of the problem (R. Chandrupatla 2011).

3.1 Strain

Strain is a physical quantity that is related to the deformation of the material under load resulting in either tension or compression. It is a response of the system to an applied stress. When force is applied on a material it produces stress, which results in the deformation of the material. It is also defined as the amount of deformation in the direction of the applied force divided by the initial length of the material. (Nde-ed.org 2015)

It is expressed with the equation:

$$\varepsilon = \frac{\Delta L}{L} \qquad (1)$$

Where,

- L is the length,
- ΔL is the change in length.

Strain is a dimensionless quantity, it is positive under tension and negative under compression.

As the value of strain is very small, it is often expressed in microstrains (μ) 10e-6.

3.2 The strain Gauge:

Strain gauge is an instrument used to measure strain in an object undergoing load (acceleration, torque, vibration, pressure). It is usually referred to a thin wire grid or a foil folded in a pattern and bonded to a specimen. The elongation or compression in the specimen results in the stretching of the wires in the strain gauge causing the change in resistance. As the resistance of the gauge is known the change in resistance to the electrical signal determines the change in length and cross-sectional area (Roylance 2001).

The resistance is defined by the formula:

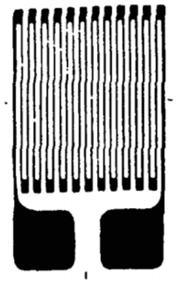

Figure 1: Wire resistance strain gauge (Roylance 2001)

$$R = \frac{\rho L}{A} \qquad (2)$$

where,

- R = Resistance of the wire,
- L = the length of the specimen,
- A= cross sectional area of the specimen,
- ρ= Material resistivity.

3.3 Testing

The process described above was the method used to apply the strain gauges on the wheel hub. In total of 4 strain gauges were attached to the wheel at a distance of 45 degrees from each other

To set up the experiment, a bolt and bracket assembly was made which were linked to a chain which would be steady enough to hold the

Figure 2: Test setup

weights, as the initial setup was made using ropes which failed when load was added onto it.

The hub was suspended using a engine hoist, where one of the chains was hung to the hook of the hoist and to bottom chain loop a metal hook was connected to add the weights.

One all the parameters are set on the strain indicator and the hook was added. All the channels are balanced using the balance button in the strain indicator. This is done to eliminate any false signals and the strain values are set to 'Zero'.

The weights were added to the hook on the bottom in increments of 10 kg (100N) up to 60 kg (600N).

The strain measurements were recorded after every load increment.

This process was repeated twice to ensure the results obtained was accurate and there were no errors

3.4 Load estimation

To determine the forces acting on the wheel, this method describes the relations how force and moment are related to strain (Jayashankar 2011).

The three wheel forces are F_x, F_y, F_z and the three moments:

$$M_y = -R_e \cdot F_x \text{ and } M_x = R_e \cdot F_y \text{ and } M_z = R_e \cdot F_z \quad (3)$$

where R_e = wheel radius

The formula derived has 6 parameters: 3 forces and 3 moments. All these parameters are the function for the wheel rim position in relation to the ground contact point α. The measurement s obtained from the channels would be in volts V.

$$\Delta V = \sum_{j=1}^{6} F_j \cdot SF_{ij}(a) \quad (4)$$

where,

$SF_{ij}(\alpha)$ is a function of angle α and

$$\Delta V_i = F_1\big(SF_{i1}(a) - R_e \cdot SF_{i5}(a)\big) +$$
$$F_2(SF_{i2}) - R_e \cdot SF_{i4(a)}) +$$
$$F_3(SF_{i3}) - R_e \cdot SF_{i6(a)}) \quad (5)$$

representing the equation in matrix form,

$$\{\Delta V\} = [SF]_a \cdot \{F\} \quad (6)$$

where,

$[SF]_a$ is 4X4 sensitivity matrix,

$\{\Delta V\}$ is the measurements vector,

$\{F\}$ is the force vector.

$$\{F\} = \begin{Bmatrix} F_z \\ M_z \\ F_z \\ F_x \end{Bmatrix} \qquad (7)$$

$$[SF]_a^{-1} \cdot \{\Delta V\} = \{F\} \qquad (8)$$

(Blasco et al. 2015)

3.5 Finite Element Analysis

FEA of the model was done on Hypermesh the figure shows the full mesh model with boundary conditions.

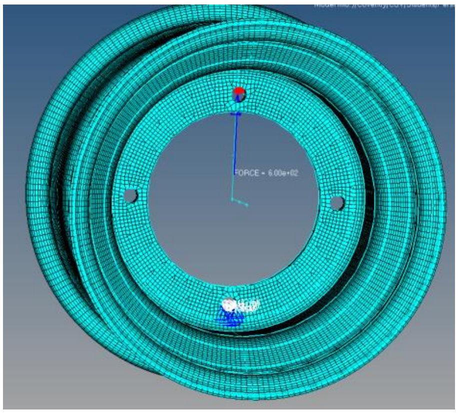

Figure 3: Finite Element Model

4 Results

Figure 4 depicts the strain results of the Finite Element model for different loads. The results plot the strain in ZZ axis. The location of the strain gauges is roughly taken from query command in Hyperview.

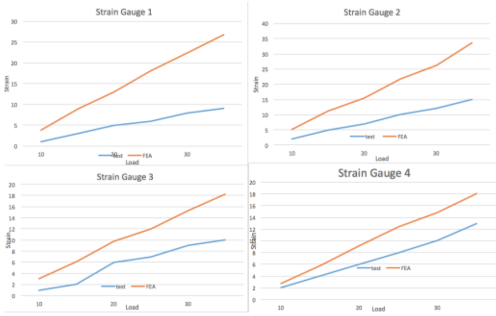

Figure 4: Comparison between FEA and test

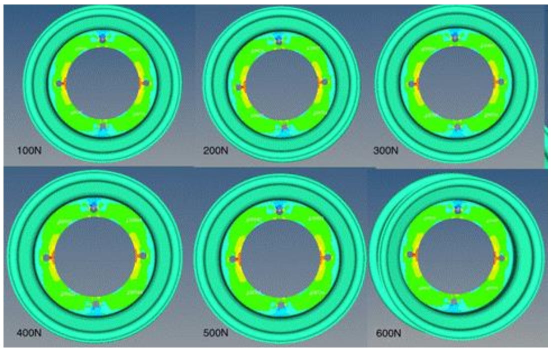

Figure **Error! No text of specified style in document.**: Finite Element Analysis results

5 Conclusions

The graphs show the comparison between FEA and test results of each strain gauge. From the graph we can see that that there a large deviation in results.

In this report, a detail description of the theory of FEA and strain gauge is explained. It also explains the procedure of strain gauge application on the wheels. The results from the strain gauges are validated with the FE results.

A results obtained has a large difference and the sources of error for the differences in results were noted. The solution for the issues were addressed.This method of obtaining the strain results can achievable with further research into the work.

References:

[1] Ancient Origins, (2014) *The Revolutionary Invention Of The Wheel* [online] available from <http://www.ancient-origins.net/ancient-technology/revolutionary-invention-wheel-001713> [14 August 2015]

[2] Blasco, J., Valero, F., Besa, A. and Rubio, F. (2015) *Design Of A Dynamometric Wheel Rim*.

[3] Chandrupatla, T. (2011) 4th edn. Hyderabad: Universities Press(India)

[4] Gutiérrez-López, M., García de Jalón, J. and Cubillo, A. (2015) 'A Novel Method For Producing Low Cost Dynamometric Wheels Based On Harmonic Elimination Techniques'. *Mechanical Systems and Signal Processing* 52-53, 577-599

[5] Jayashankar, A. (2011) Experimental & Modeling Study Of The Influence Of Support Stiffness On Load Sensing Bearings. Delft: Department of Precision and Microsystems Engineering

[6] Kanarachos, S., Kanarachos, A., Intelligent road adaptive suspension system design using an experts' based hybrid genetic algorithm (2015) Expert Systems with Applications, 42 (21), pp. 8232-8242.

[7] Kanarachos, S., Alirezaei, M., An adaptive finite element method for computing emergency manoeuvres of ground vehicles in complex driving scenarios (2015) International Journal of Vehicle Systems Modelling and Testing, 10 (3), pp. 239-262.

[8] Kanarachos, S., Alirezaei, M., Jansen, S., Maurice, J.-P., Control allocation for regenerative braking of electric vehicles with an electric motor at the front axle using the state-dependent Riccati equation control technique (2014) Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 228 (2), pp. 129-143.

[9] Kanarachos, S.A., A new method for computing optimal obstacle avoidance steering manoeuvres of vehicles (2009) International Journal of Vehicle Autonomous Systems, 7 (1-2), pp. 73-95.

[10] Kanarachos, S., Design of an intelligent feed forward controller system for vehicle obstacle avoidance using neural networks (2013) International Journal of Vehicle Systems Modelling and Testing, 8 (1), pp. 55-87.

[11] Roylance, D. (2001) *Experimental Strain Analysis* [online] 1st edn. Cambridge,: Department of Materials Science and Engineering. available from <http://ocw.mit.edu/courses/materials-science-and-engineering/3-11-mechanics-of-materials-fall-1999/modules/expt.pdf> [14 August 2015]