

## Design of Quarter Car Test Bench to Measure Forces on the Tire Contact Path

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**Abstrak** – Suspension system that located between vehicle body and wheels are designed to absorb shock from road surface. The dynamic behavior of the suspension and tire is depends on many factors. Some of the main factors are the vehicle load, speed, steering angle and the magnitude of the elasticity of the tire. The position of the tire-road contact is also always changed when the vehicle running make it difficult to observe the dynamic response of tires. To overcome this problem, in this paper, an in-door test-rig model is designed and evaluated experimentally. This study was conducted by five methods, namely; design, simulation, production, and experimentally test. The dynamic response evaluated includes geometric change of tires and the change of camber angle. The model build consist of framework components, the sprung mass as a representation of a quarter car body and un-sprung mass which are components of the suspension system, wheels and tires. The results show that the proposed design construction is not only saved to handle all forces and moments but also can fulfilled functions to simulate the dynamic response of  $\frac{1}{4}$  car model. Copyright © 2017 Department of Mechanical Engineering. All rights reserved.

**Keywords:** quarter car model, camber, geometry, steering, suspension.

### 1 Introduction

Suspension system that located between the vehicle body and the wheels are designed to absorb shock from road surface. The suspension consists essentially of spring, damper, and other components such as the swing arm, joints, rod stiffeners (anti-roll bar or stabilizer), and rubbers. Suspension functions are to: 1) Provide comfort and safety of passengers by means of the vehicle together with the wheels absorb vibrations, excitation and shock from the road surface. 2) Move the braking force and the driving force to the body by means of friction between the road with the wheels. 3) Supporting body on the axle and maintains geometric layout between the body and wheels.

Tire dynamics behavior is a research topic of interest nowadays in the field of automotive. In this field, research is conduct to develop a better understanding of automobile tires. This is accomplished by creating models of tire behavior. Basically, the tire can be modeled in two ways; analytical and empirical. It is very complicated to models the tire using an analytical

approach. It requires an advanced knowledge of the tire parameters, which are hard to measure or identify in practice. Conversely, in empirical models, tire behavior is described by a set of empirical data from the laboratory. The Magic Tire Formula introduced by Pacejka is an empirical model that incorporates the physical nature of the tire into the design. Due to this fact, this model has widely been used for tire forces analysis and simulation.

Several constructions of tire testers have been developed recently. These designs can be grouped into two main categories; testers that move the ground beneath an immobile tire and testers that move a tire over immobile ground. Both of these types are widely used in the research field and automobile industries. In the first category, the test set-ups are built to remain stationary in the research laboratory. These designs utilize a rolling drum or moving belt to simulate a tire moving over the road. The road disturbances are not included in this design. The second category of test set-ups is designed to record the data on a moving tire. This category can be used to test the tire in real driving conditions by performing the test in the moving vehicles.

These types of testers will produce more realistic data to what happens when the tire is actually being driven. The drawback of these types of testers is that the road where the test is performed may have uncertainties that will affect the test result. The uncertainties of drivers that maneuver the car will also reduce the measurement performance. Even the best skilled drivers will not be able to replicate the maneuvers that are controlled by a computer.

For these reasons, it is important to develop a quarter car suspension model with moving ground beneath immobile tire that also have function to simulate road disturbances. The key in the design of a quarter car model is to simulate the dynamic behavior of the suspension and tire in lab scale. The model was created using CATIA. However, the design theories of the quarter car model are not perfect. In this paper, in order to further strengthen the research on the precise design method of the quarter car, the design and analysis of the quarter car for automobile suspension had been completed.

## 2 Method Mechanical Structure of a Quarter Car Model

The structure design in this research is a physical construction that represents a quarter car model of front-right car. Construction consists of three main parts; frame, sprung mass and un-sprung mass. Frame is a rigid construction to support sprung mass. Sprung mass is a construction that representation of quarter car body. Un-sprung mass is suspension component. To drive a wheel, one internal combustion engine is use as an actuator. The rotor shaft on the combustion engine is then connected to drive shaft beneath the tire using by belt. This drive shaft had surface contact with tire that cause the tire is rotate when drive shaft rotates.

This research is design to build a unit of quarter car model. The design concept is based on a dynamic of sprung mass and un-sprung mass. Sprung mass construction is designed to have 1 degree of freedom that able to move translational in vertical direction to show the change of car body height. In other hand, un-sprung mass construction is designed to have 3 degree of freedom that can move translational in vertical direction, rotational in z-axis and rotational in x-axis. The move in vertical direction is to simulate the tire jump, the rotational in z-axis is to simulate the steering angle and rotational in x-axis is to simulate camber angle.

The aim of this research is reached by the following main steps:

- Make a drawing concept of the quarter car construction model. Theoretical study about construction functionality is done in this step to define appropriate joints for connection bar between

suspension component and frame of quarter car construction. Sketch drawing of this construction is shown in figure 1.

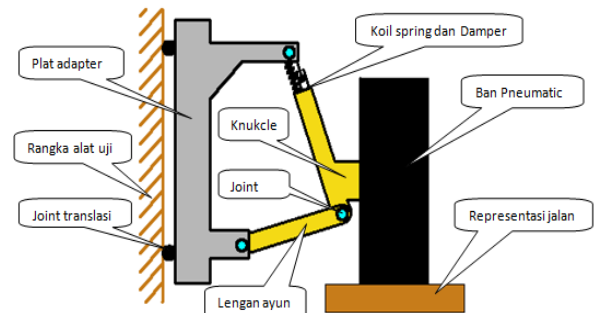


Figure 1. Sketch drawing of quarter car construction

- Calculate appropriate dimension of frame construction. Calculation is done to find minimum dimension for each bar of frame which is save for all force and moment.
- Make the assembly drawing and details drawing for all components of the construction. This assembly drawing gives more clear information about shape and dimension of the construction. The assembly drawing also uses to simulate the function of construction. Simulation is needed to make sure all dimension and materials chosen are saved for all forces and moments. Drawing details are used for production the construction. Figure 2 shown drawing assembly of the construction.

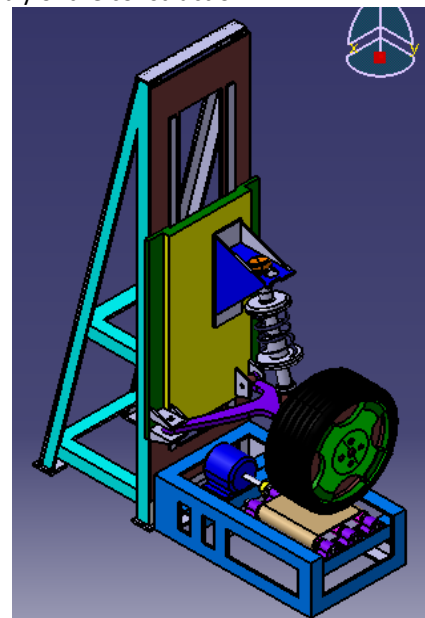


Figure 2. Drawing assembly of quarter car construction

To make sure construction frame are save for maximum load, force analyzing is also done using CATIA. This analyzing is done in complete frame construction by giving load input about 4110N pointed in the middle

driven shaft. The result of software analyzing is shown in figure 3.

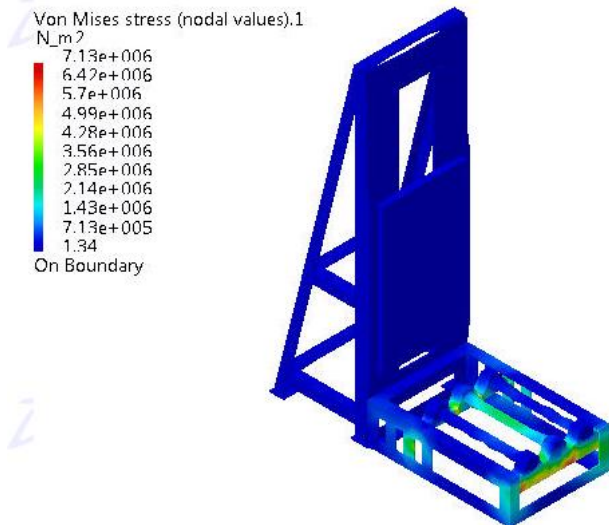


Figure 3. Result of Von Misses Stress using CATIA

Simulation result shows maximum stress is point on center bar that is  $7.13 \times 10^6$  N/m<sup>2</sup> that equal to 7.13N/mm<sup>2</sup>. This value is less than allowable shear stress which is 37N/mm<sup>2</sup>. By all the result, it can conclude that L-profile of ST-37 with dimension 50x50x5mm are save to use as material frame for quarter car model construction.

- Machining process for all components followed by assembly.
- Functionality test, the test is done which condition machine ON and OFF. The test is only to see output response of the wheel and tire while giving different input of steering angle. When machine is OFF, the wheel and tire was not move but when machine is ON, the wheel and tire moves. For condition machine is ON, both steering angle and speed inputs are varies. The dynamic responses of the tire are evaluated for all these conditions.
- Design a measurement strategy to measure force and moment.
- Measurement test and calibration.

### 3 Design Method

Tire contact forces are measured in bottom base construction, see figure 4. This measurement method is designed to fulfill the requirement in this study that no physical change of wheel hub construction and the measurement can be used for more than one type of the tire wheel. The bottom base construction is shown in figure 4.

Three force sensors Sz1, Sz2, and Sz3 are mounted in vertical direction to measure vertical forces. Two supports Sx1 and Sx2 are chosen in line with the contact path surface. These two sensors are used to measured longitudinal force. The other two sensors Sy1 and Sy2

are used to measure lateral forces and placed in position perpendicular to direction of wheel travel.

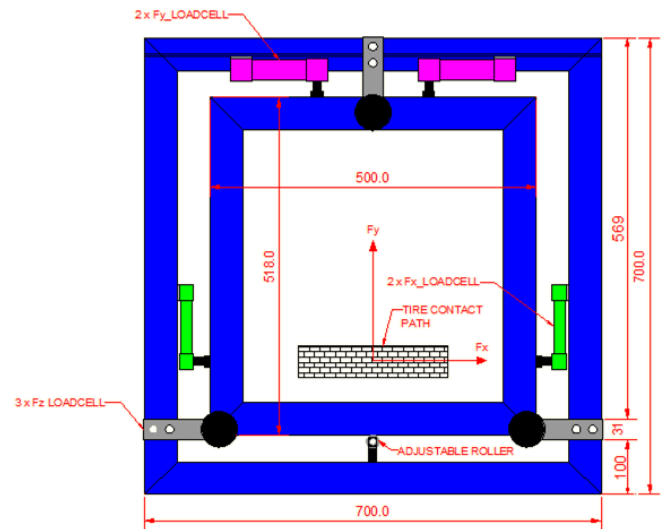


Figure 4. Load cell positions on the bottom base construction

## 4 Measurement Strategy

### 4.1 Load Capacity

Previous research that was done by Ian Hardianto Siahaan shown vertical force is the biggest force on the tire contact path. Lateral force and longitudinal force has magnitude less than 20% and less than 5% of vertical force respectively.

Vertical force is come from car weight and passenger weight. Family car with weight 1045 kg is chosen in this research and passenger weight is assumed to be 600 kg. Because of the construction is designed for a quarter car, such that total weight becomes 411 kg.

In this research, seven load cells are used to measure tire road contact forces. Three load cells are located in the bottom of base that used to measure vertical force. Rate capacity of this load cell is 250 kg each. To measure lateral force, two load cells with rate capacity 100kg are used. This load cells are located in tire wheel travel direction. The last two load cell are use to measure longitudinal force. These load cells are located perpendicular to the wheel travel direction. Rate capacities of load cells are 20kg.

The forces and moments equilibrium are examined from which the forces and moments can be defined. To do this, the forces configuration on the bottom base and on the wheel is firstly drawn as shown in figure 5. In these figures three views of the wheel connected to the measuring plate are depicted. Figure 5a shows the side view of the wheel and adapter plate. In figure 5b the front view is shown while in figure 5c the top view of the wheel and adapter plate is shown. With the known distances a, b and h the forces and moments in the wheel center can be computed.

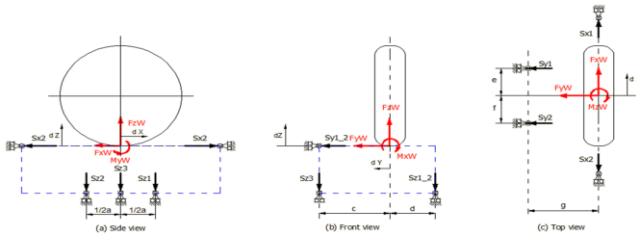


Figure 5. Measured forces on the adapter plate and force acting on the tire

Based on figure 5, magnitude of vertical force, lateral force and longitudinal force measured by the sensors are expressed in equations 1 to 3.

$$F_x = S_{x1} + S_{x2} \quad (1)$$

$$F_y = S_{y1} + S_{y2} \quad (2)$$

$$F_z = S_{z1} + S_{z2} + S_{z3} - Wtb \quad (3)$$

Three moments is then calculated using equation 4 to 6.

$$M_x = (S_{z1} + S_{z2}) \cdot d - S_{z3} \cdot c \quad (4)$$

$$M_y = S_{z1} \cdot 1/2 \cdot a - S_{z2} \cdot 1/2 \cdot a \quad (5)$$

$$M_z = -S_{y1} \cdot e + S_{y2} \cdot f \quad (6)$$

#### 4.2 Measurement hardware

Measurement hardware is needed for data logging as a result of measurement process that done by load cell. Hardware that used for measurement process consists of:

- Load cell
- Analog to digital converter
- Microprocessor
- LCD display
- Power supply
- Personal computer

Schematic diagram of measurement process is shown in figure 6.

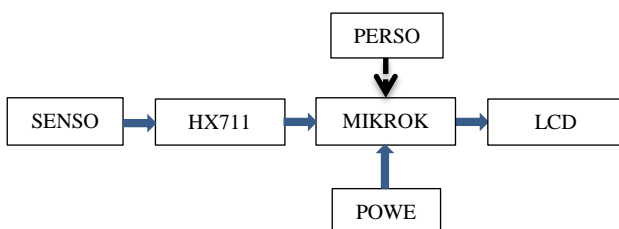


Figure 6. Schematic measurement process diagram

## 5 Conclusion

The design of a quarter car construction mainly refers to material and mechanical subjects. The key is to establish the relationship between the loading force come from total weight of car and the geometrical size of frame construction. In this paper, the frame construction is introduced in detail. Finally, to make sure all materials used are save to handle maximum force, forces distribution on frame are analyzed and simulated using CATIA. The results show that the simulation is consistent with the theoretical calculation; actual shear stress is less than allowable shear stress and accord with the technical requirements of the automobile suspension, which means that the design method is feasible.

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