JURNAL POLIMESIN
Unit Penelitian dan Pengabdian Kepada Masyarakat (P2M)
Politeknik Negeri Lhokseumawe
ISSN Print: 1693-5462, ISSN Online: 2549-1199
Website: http://e-jurnal.pnl.ac.id/index.php/polimesin

Design of indoor test-rig to measure dynamic forces and moments on tire contact path of family car

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Abstract

The vehicle's suspension system is designed to absorb shocks from road disturbance. The dynamic behavior of a tire suspension depends on many factors. Some main factors are vehicle load, speed, steering angle, road disturbances and the amount of tire elasticity. The dynamic behaviour of the tire is very difficult to observe when the vehicle is traveling on the road. To overcome this problem, in this paper, a test rig will be designed to be able to observe changes in tire dynamic properties experimentally for family car type. The design concept is based on the sprung and un-sprung mass dynamics. This research was conducted by five methods; study mechanism of measuring the tire dynamic behaviors, design of test equipment construction, simulations, and analysis of construction strength. The spring mass construction is designed to have 1 degree of freedom which is able to move the translation in a vertical direction to indicate changes in car body height. On the other hand, the un-sprung mass construction is designed to have 3 degrees of freedom that can move translation in the vertical direction, rotation in the z axis and rotation in the x axis. Movement in the vertical direction is to simulate a tire jump, rotation on the z axis is to simulate the steering angle and rotation on the x axis is to simulate the camber angle. The design result shows that the design construction not only saves to handle all forces and moments but can also fulfill functions to simulate the dynamic response of the car model. Simulation result shows maximum stress is point on C-D bar that is 7.13 N/mm^2. This value is less than allowable shear stress which is 37N/mm^2. By all simulation result, it can be concluded that all materials used are saved for this construction.

Keywords: Quarter car model, force, moment, dynamic forces, suspension.

1. Introduction

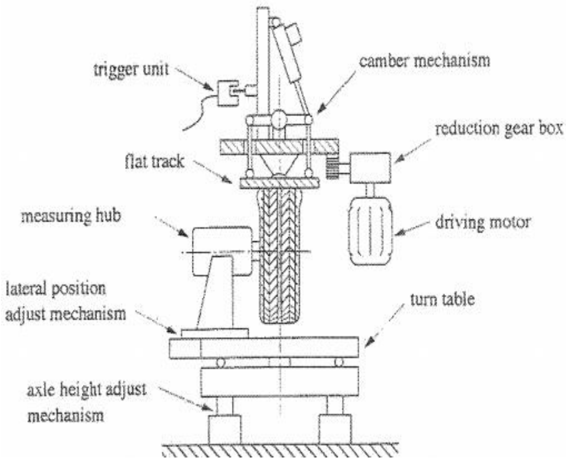
The suspension system located between the vehicle body and the wheels are designed to absorb shock from road surface. The suspension consists essentially of spring, damper, and other components such as the swing arm, joints, rod stiffeners (anti-roll bar or stabilizer), and rubbers. Suspension functions 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 in between road and tire. 3) Supporting body on the axle and maintains geometric layout between the body and wheels.

Interaction between tyre and terrain is the primary factor affecting the efficiency of the ride. The terrain on which the vehicle operates can range between dry or wet road to soil or clayey depending on the vehicle application whether it is off-road or on-road [1]. Tire dynamics behavior is a research topic of interest nowadays in the field of automotive. In this field, research is conducted to develop a better understanding of automobile tires. This is accomplished by creating models of tire behavior. Pneumatic tires play an important role in the overall performance of a vehicle. Tire performance is depends on the tire rolling resistance, cornering properties, tire traction, tire wear, tire temperature, tire noise, tire handling and characteristics, etc. There are various losses associated with the vehicle that affect its fuel economy as it is being operated. [2]. Besides this the contact patch features and the global deformation of tire are identified as the key factors for the tire force estimation [3]. Contact zone has a major effect on machine stiffness. For an accurate calculation, the contact stiffness should be known [4]. Basically, the tire can be modeled in two ways; analytical and empirical. It is very complicated to model 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 [5]. The Magic Tire Formula introduced by Pacekja [6] 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.

Tire forces are incredibly hard to measure, no sensors are available to measure tire force directly due to the dynamics behavior of the tire. The forces and moments measurements performed on the above tire tester constructions are not done directly on the tire contact path [7]. Several constructions of tire testers have been developed recently. These designs can be grouped into two main categories; the testers that move the ground beneath an immobile tire and testers that move a tire over immobile ground. Both 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. 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 the 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.

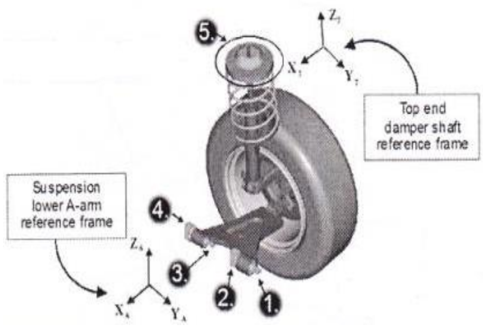
Examples of such early quarter car tire tester set-ups are shown in fig.1. Fig. 1a shows the Delft flat plank machine, now owned by the Eindhoven University of Technology [8]. On this tire tester a flat steel track that represents the road surface is upside down on top of the machine and it can move horizontally when the track rolls over the tire forces and moments are generated in the wheel center. The second tire tester model is an industrial designed tire tester and is shown in fig. 1b. This is an example of an industrial tire tester model as a product of Kistler Company [9]. The third model shown in fig. 1c shows a tire tester with a rolling drum to represent the road [10]. The vertical axle height can be adjusted to load the tire on the drum. Fig. 1d shows work done by H. Douville [11] that demonstrates the use of force transducers to measure forces at each suspension and lower arm connection.



(a)


(b)


(c)



(d)

Fig.1. Quarter car tire tester constructions

MacPherson strut suspension is one of common type of suspension. This kind of suspension was designed since the end of 1940 by earl Steele MacPherson, and first time used in 1949 by Ford Vedette. MacPherson suspension had new configuration at that time. Most of small and medium size of vehicle used this type of suspension [12]. MacPherson suspension consists of lower arm and telescopic strut bar. Main spring and damper is collinear to translation movement of strut bar.

2. Research Methods

Structural parts that used in this research are classified into raw materials and component. Raw materials include steel with L profile, steel plate, and shaft. These materials are used to build quarter car frame. The components are grouped into 3 categories:

- Suspension components; a complete set of car suspension with knuckle, disc brake and tire.
- Actuator components; internal combustion gasoline engine.
- Sensor components; tachometer and camera.

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 represents quarter car body. Un-sprung mass is suspension component. To drive a wheel, one internal combustion engine is used as an actuator. The rotor shaft of internal combustion engine is connected to tire drive shaft in the lower frame construction using a belt. This drive shaft had surface contact with tire that cause the tire is rotate when drive shaft rotates.

This research is designed to build a unit of quarter car model using CATIA V5 software. The design concept is based on a dynamic of sprung mass and un-sprung massTheSprung mass construction is designed to have 1-degree of freedom to move translational in vertical direction to show the change of car body height. In other hand, the un-sprung mass construction is designed to have 3-degrees of freedom, which can move translational about z-axis, and can rotate about the x and y-axes. The move in the 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 done in the following steps:

- The first step is to draw drawing a 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 fig.2.

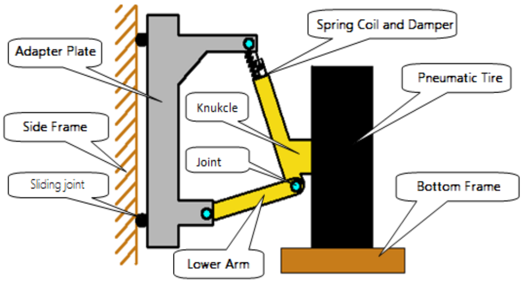


Fig.2. Sketch drawing of quarter car construction

- The second step is to calculate appropriate dimension of frame construction. Calculation is done to find minimum dimension for each bar of frame which is save for all.
- The third step is to make drawing assembly and drawing details 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 save for all forces and moments.

Test bench construction was drawn and analized using CATIA V5 software. Fig.3 shown drawing assembly of the construction. Based on the complete set of a MacPherson strut suspension, the frame is designed as a place to install suspension system. This test bench has two frames; bottom frame and side frame. Both of frame was designed rigidly and permanently connected to the floor. The adapter plate is attached in such a way to the side frame so that it can move translational in vertical direction to simulate the movement of the car body due to changes in the amount of load. Furthermore, this adapter plate is connected to the MacPherson suspension system completed with swing arm, knuckle, rim, tire and disk brake components. To be able to rotate the tire, the construction surface under the tire or bottom frame can move in a translational horizontal direction. A propulsion machine is used to move this road surface by rotating three driven shafts on it. The contact between tire and driven-shaft on the bottom cause the tire to rotate that simulate the movement of the car.

CATIA V5 part design tool is used to draw each part of the test bench. CATIA Analysis and simulation tool is then used to analyze stress distribution on the test bench frame due to load force. A structural analysis model was created using generative structural analysis applications. Generative structural analysis is an application that can precisely analyze the stress that occurs in the model with various kinds of loading conditions. The generative structural analysis application can be accessed from the start menu in the analysis and simulation application of CATIA V5.

To carry out structural static analysis with CATIA V5, material data is required. Material used for frame is L-profile ST-37 with dimension 50x50x5mm. ST-37 is material which is appropriate to use in steel structure. This material has good machinability and good properties for welding process because it has less than 0,20% carbon. This material properties are listed below:

- Yield strength: 240 Mpa = 2.4 x 108 N/m^2 = 2.4 x 102 N/mm^2
- Ultimate strength: 370 Mpa = 3700 kg/cm^2 = 37 kg/mm^2.
- Young modulus: 200 Gpa = 200000 Mpa = 2x1011 N/m^2 = 2x105 N/mm^2
- Poison ratio : 0.3
- Density: 7860 kg/m^3

3. Results and Discussion.

Mechanical structures of a quarter car are classified into two parts; bottom frame and side frame. The Bottom frame is designed to handle loads of a quarter of the car. This frame is also made to simulate tire rotation. while the side frame is designed to be able to simulate changes in car body height due to changes in car loads.

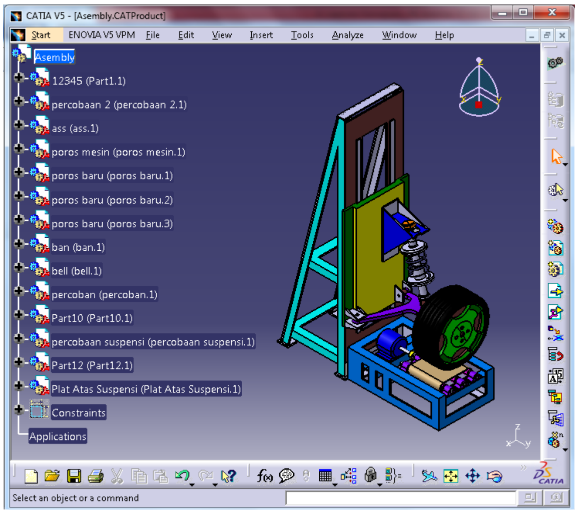


Fig.3. Drawing assembly of quarter car construction

3.1 Load Distribution

Distribution forces on the bottom frame are bigger than force distributed on the side frame. Force distributed on bottom frame is shown in fig.4.

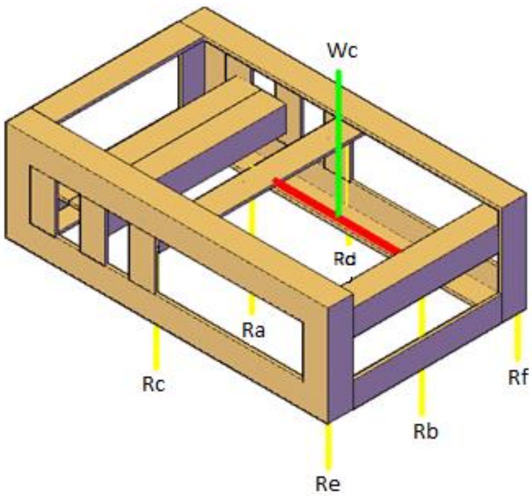


Fig.4. Forces distribution on bottom frame

Shaft A-B is load by force approximately 411 N. This force comes from sum a quarter car and passenger loads. A quarter car load is 261 N, and passenger load assumed to be 150 N. Baggage load is neglected in this study because this load has small effect to A-B shaft.

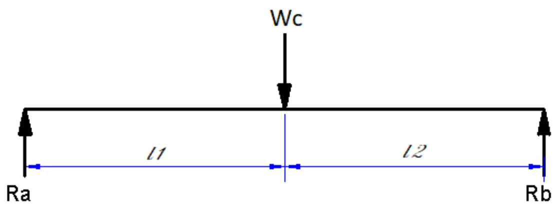


Fig.5. Free body diagram of A-B bar

The total load originating from the car will be distributed to points A and B of the A-B bar - ssuming that the car tires give the right force at the midpoint of the A-B bar. Then the magnitude of the reaction at points A and B is the same, that is equal to 205.5 N. The magnitude of this reaction force is calculated using the equation 1.

$$R_A = \frac{W_c \, x \, l_1}{l_2} \qquad (1)$$

Where:

R_A = Reaction force on point A

W_c = a quarter car load (205.5 N)

*l*1=*l*2=distance from applied force to point A and point B (0.25 m)

C-D and E-F bars are influenced by force with same magnitude. Free body diagram of C-D bar is shown in fig.6. The force that works on this bar is the reaction force on point A that is about 205.5kg. This force will be distributed along the C-D bar and will cause a reaction at points C and D of 102.75 N.

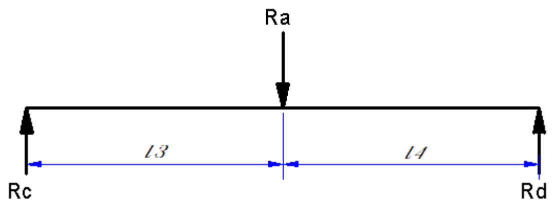


Fig.6. Free body diagram of C-D bar

Moments that occur along C-D bar are calculated based on fig.7. The result given maximum moment is 25687,5 N.mm that point in the middle of C-D bar as shown in fig.8.

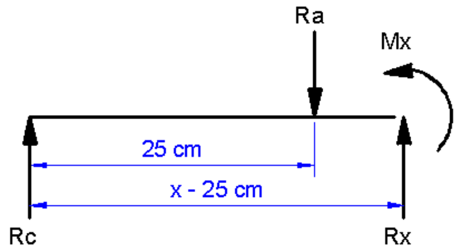


Fig.7. Free body diagram to calculate moment on C-D bar

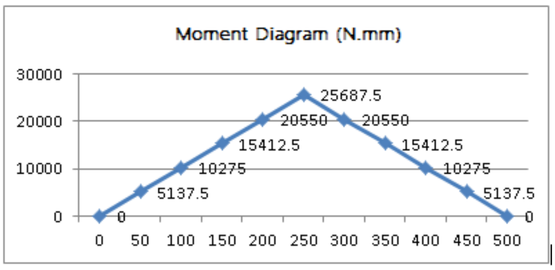


Fig.8. Moment diagram along C-D bar

3.2 Dimensional Calculation of Frame Material

Minimum dimension of material frame is calculated based on maximum moment that occur on the frame. Maximum load due to total weight of car with magnitude about 411 N is pointed in the middle of A-B bar. Reaction force to weight load is equal in point A and B that is about 205,5 N. Furthermore, reaction force on Ra and Rb feed through C-D and E-F bar respectively.

Ultimate strength of material ST-37 is 37 kg/mm^2. Using safety factor is 8 then stress become 46 N/mm^2. Allowable shear stress of this material is 0,8 times stress that is 37 N/mm^2. Actual shear stress on C-D bar is determined by formula $\tau = F/A$, whereas F is equal to Ra that is about 205,5 N and A is cross section of C-D bar that is about 475mm^2. This calculation lead to result of actual shear stress is 4,3 N/mm^2. Because of allowable shear stress, 37 N/mm^2, is bigger than actual shear stress, 4,3 N/mm^2, that mean L-profile of ST-37 with dimension 50x50x5mm is safe to use for frame construction.

3.3 Simulation Analysis of Construction

To make sure construction frame are safe for maximum load, force analyzing is also done using CATIA V5 software. This analyzing is done in complete frame construction by giving load input about 4110 N pointed in the middle-driven shaft. The boundary conditions and result of CATIA analyzing are shown in Figure 9 and 10.

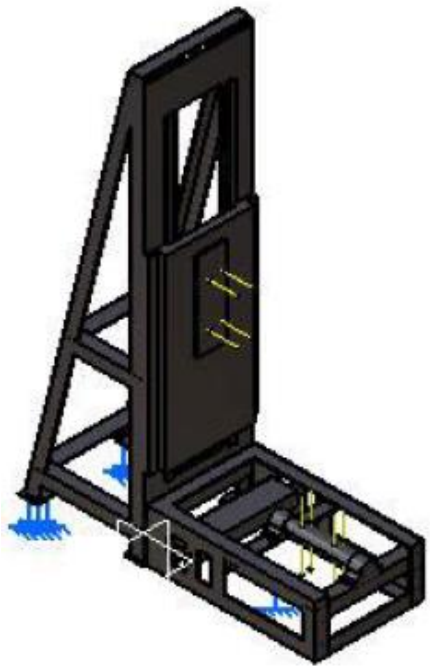


Fig.9. Boundary conditions of CATIA V5 analysis

Fig.10. Result of Von Misses Stress by CATIA V5

Simulation result showing maximum stress is point on C-D bar that is 7.13 N/mm^2. This value is less than allowable shear stress which is 37 N/mm^2. By all the result, it can conclude that L-profile of

ST-37 with dimension 50x50x5 mm are safe to use as frame material for quarter car model construction.

4. Conclusions.

The design of a quarter car construction mainly refers to material and mechanical subjects. The key is to establish the relationship between load force coming 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 safe to handle maximum force, forces distributions on frames are analyzed and simulated using CATIA V5. The result shows 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.

References.

[1] Zeinab El-Sayegh; Moustafa El-Gindy; Inge Johansson; Fredrik Öijer, "Truck tyre-terrain interaction modelling and testing: literature survey", *International Journal of Vehicle Systems Modelling and Testing*, vol. 12, no.3/4, pp.163 - 216, Feb 2018 .

[2] Virkar D S and Thombare D G, "Parametric Study and Experimental Evaluation of Vehicle Tire Performance," *International Journal of Mechanical Engineering and Robotics Research*, vol. 2, no. 2, pp. 221-231, April 2013.

[3] Hojong Lee and Saied Taheri, "Intelligent Tires? A Review of Tire Characterization Literature', IEEE Intelligent Transportation Systems Magazine, vol.9, pp 114 – 135, April 2017

[4] Mikhail N. Zakharov and Mikhail S. Kuts, "The Approach to Determine the Elastic Characteristic of the Contact of Rough Surfaces," *International Journal of Mechanical Engineering and Robotics Research*, vol. 9, no. 7, pp. 937-942, July 2020.

[5] Kim, J., "*Identification of Lateral Tire Force Dynamics Using an Extended Kalman Filter from Experimental Road Test Data*", Control Engineering Practice, 2009.

[6] H.B. Pacejka, "*Tire and Vehicle Dynamics*", Butterworth : Heineman, 2006.

[7] B. Bukhari, "Measurement Strategy To Estimate Forces And Moments On The Tire-Belt Contact Path For Hardware-In-Loop Test Setup", M.A. thesis, University of Applied Sciences, Netherlands, 2010.

[8] Vissers, J. P. M., and Blom, R. E. A. "Experiments on the flat plank tyre tester". (DCT rapporten; vol. 2003.092). Technische Universiteit Eindhoven, 2003

[9] Burkard, H and Wolfer, P., "*Measuring Wheel for Vehicle R&D"*, Kistler.

[10] Nikola Korunović*, Miroslav Trajanović,, Miloš Stojković, Dragan Mišić, and Jelena Milovanović, "Finite Element Analysis of a Tire Steady Rolling on the Drum and Comparison with Experiment", *Journal of Mechanical Engineering*, vol. 57, no. 12, pp. 888-897, 2011.

[11] Douville, H, Masson, P and A.Berry, "On-resonance transmissibility methodology for quantifying the structure-borne road noise of an automotive suspension assembly", *Elsevier*, september 2005.

[12] Mantaras, D.A, Laque, L, and Vera, C, "*Development and validation of a three-dimensional kinematic model for the MacPherson steering and suspension mechanisms*", Mechanism and Machine Theory, 39, 603-619, 2004