ARISTOTLE UNIVERSITY OF THESSALONIKI
SCHOOL OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
LABORATORY OF MACHINE DYNAMICS
HEAD PROFESSOR: NATSIAVAS SOTIRIOS
OCTOBER 2013
Brief presentation of master thesis

“Dynamic response of a vehicle and optimization of suspension arm”

• Duration 15 min
Dynamic response of a vehicle and optimization of suspension arm.

- Student: Vagelis Gryllakis
- Supervising Professor: Sotirios Natsiavas
- Supervising PhD: Nikolaos Potosakis
1. Preparation of car chassis for C.M.S.
2. C.M.S. in the car chassis with Radioss.
3. Results from C.M.S.
4. Preparation of suspension components for C.M.S.
5. C.M.S. in the suspension components with Radioss.
6. Results from C.M.S.
7. Creation of joints between the flexible chassis and the flexible suspension components in Motionview.
8. Modeling of tires, car rider and of the tossed out items.
9. Results from the selected scenarios “pot hole”, “bad road” and single line change.
10. Optimization of the front suspension arm.
Initial finite element car model.

- Complete finite element car model. It was designed for a crush analysis. (in block format, connections formed as spherical joints, big non-linear deformations and plastic materials etc.). Not suitable for mbd analysis.
B.I.W. isolation and rbe2 connections on the B.I.W.

- All the parts from the initial model that don’t play a key-role on multi-body dynamic analysis were tossed out. They are going to be modeled later.

- The B.I.W. (Body In White) is being isolated from the rest model. Then it is connected with RBE2. The appropriate properties and materials are assigned to the B.I.W. (Pshell and Mat1 in bulk data).
The tossed out items

• Among them there are the windows, the seats, the wheel, the bumpers and the whole engine system. They will be “re-modeled” later.
Boundary conditions on the B.I.W. for C.M.S.

- In order to do C.M.S.(Component Mode synthesis) we have to define the appropriate boundary conditions. In every point that the B.I.W. will be connected later with the suspension system, has to be properly designed an attachment(ASET).

- Here is a spherical attachment. It has the translational dofs fixed(1,2,3). In this point the suspension arm will be connected later in Motionview.
Results from C.M.S. analysis.

- After the C.M.S analysis we have all the modes that we need. Here we see the 1st elastic mode at circa 8.54 Hz.

- The 5th elastic mode at circa 14.06 Hz.
Results from C.M.S. analysis.

Video clip of 1st elastic mode.

Video clip of 5th elastic mode.
Suspension system.

1. Each component of the suspension system was isolated from the whole model and then processed for CMS.
2. As first job Pshell and mat1 were assigned in the suspension components.
3. Then boundary conditions were designed.
4. Finally they were ready for CMS and Motionview.
Examples of suspension components.

- The front suspension arm is ready to be attached with 3 spherical joints at the points where the rbe2 spiders are.

- The multiple linkage of the rear suspension has at both ends attachments for revolute joints.
Results from C.M.S. analysis at suspension parts.

- The 1\textsuperscript{st} and 5\textsuperscript{th} elastic modes of the front suspension arm.

- The 1\textsuperscript{st} and 11\textsuperscript{th} elastic modes of the rear multiple linkage.
Connection of the B.I.W. and the suspension system in Motionview.

1. Now the car chassis is a flexible body and ready with its attachments.
2. Also the suspension components are flexible bodies and ready with their attachments.
3. As next step is the creation of appropriate joints in the attachments points (fix joints, revolute joints, spherical joints, translational joints etc...)
4. This is taking place in Motionview.
B.I.W. connected with the suspension system. Modeled as flexible bodies.
Tires and Rider

1. The tires that were used were not the initial tires that the car had. Instead “Magic Formula 2002” tires were used, that were modeled from prof. Hans Pacejka. These tires are designed for mbd analysis (handling and maneuver).

2. The rider model that was used in the car is proposed by Cho Chung Liang and Chi Feng Chiang. (Modeling of a Seated Human Body Exposed to Vertical Vibrations in Various Automotive Postures.) It is a model with 14 dofs, 2-D in sagittal plane. Modeled by 5 rigid segments coupled by bushing elements (translational and rotational springs and dampers). Each segment has 3 DOFs, except viscera with only 2 DOFs. (head, torso, viscera, pelvis, thighs)
Rider’s model.

\[ \text{G}_i : \text{CG locations} \quad (i = 1\cdots5) \]
\[ \text{J}_i : \text{Joint locations} \quad (i = 1\cdots4) \]
\[ \text{C}_i : \text{Contact locations} \quad (i = 1\cdots3) \]
Modeling of tossed items.
The tossed items were modeled as concentrated masses equally distributed in the surface of the B.I.W. (CONMASS2 elements in Radioss)

- The con.masses distributed in the back area, on the floor of the B.I.W.
- The con.masses distributed in the front area, on the floor of the B.I.W.
Modeling of the Engine.

- The engine was modeled as a rigid body with its inertia matrix.
- The 4 initial engine mountings were changed and instead were used 3 for simplicity.
Model ready for various scenarios.

- Finally the car is assembled and ready to run its scenarios.
- The scenarios are acceleration on flat road, on road with pot hole, on road with half sine bump, on bad/good quality road and others.
Input Moment in various scenarios

- The input moment in all scenarios is the same. It is a smooth STEP function from Motionview. Input applied on front wheels.

At 2 sec we “hit the gas”.

At 3 sec we keep accelerating at constant moment.
Outputs from “pot hole” scenario.

Pot hole depth 25mm, length 1000mm.
Outputs from “bad quality road” scenario.

The bad quality road has measured data from real road profiles. The quality that is used is “H”, the worst, according to ISO 8608.

The “Road profile” of the “H” quality road.
Outputs from “bad quality road” scenario.

The vertical forces on the 4 tires.
Vertical acceleration of the rider’s head.

R.M.S value of “a" is almost 2.7 (m/s^2). The mean frequency is 9.6 Hz.
Rider’s comfort according to ISO 2631.

- Depending on the R.M.S value of the vertical acceleration and the frequency of excitation we can find the time that a driver can drive before he looses comfort or harm his health.

For the case of bad road there is instant loss of comfort and 1h time period before health harm.
Input in “single line change” scenario.

- Rotation history of tires, during single line change scenario.

  0-4.9 sec: Acceleration on straight line.

  4.9-6.25 sec: Single line change with steady acceleration, with linear rotation history. Maximum rotation 5.7 deg.

  6.25-13 sec: Steady acceleration on straight line.

Outputs from “single line change” scenario.

- During single line change exist 2 turns. At first one left and then one right.
- Due to centrifugal force roll moment is generated to car and the car weight shifts to one side.
- That’s why the right vertical forces are higher on the first turn and the left vertical forces are higher on the second turn.

First turn at : 5-6.1 sec  
Second turn at : 6.1-7.2 sec
“Single line change” without anti-roll bar.

• If the anti-roll bar is not used, then car roll is bigger during turns. The result is that the shift of the car weight is bigger.

• Due to that, the difference between the left forces and the right forces is bigger.

• In the plot is visible that the force difference is bigger without antiroll bar.

Comparison of rear tire forces, with and without anti-roll bar. Green/purple with antiroll bar, yellow/gold without.
Chassis roll with/without anti-roll bar.

- Chassis roll is higher without antiroll bar.

Blue: Chassis roll without antiroll bar. Red: Chassis roll with antiroll bar.
Resultant forces upon the suspension arm.

- Forces from the 3 spherical joints of the suspension arm during the “bad road” excitation.
Optimization of suspension arm.

- At start we have an initial volume of the suspension arm.
- Then we insert the forces acted upon the attachment points on the suspension arm.
- Topology optimization with static case and minimization of Strain energy was used.
- Max mass, stress, sum of eigenvalues and volume fraction used as constraints.
- Inertia relief was activated.

Initial volume of the suspension arm and the 3 attachment forces.
Derivation of static forces from transient forces.

1. An assumption is made that during the bad road excitation the arm deforms in the same manner. For example, it deforms only with a bending motion around -z- axis clockwise and with a torsion around -x- axis counterclockwise.

2. A random time point is being selected and the resulting forces are selected for the static optimization.

3. At the time point selected is already known the maximum stress on the already designed arm. That value, with a safety factor, is being set as the stress limit on the optimization.

4. As a drawback of the assumption made, the arm will be optimized only for the deformation state that occurs in that time point. Let it be “bending around -x-c clock and torsion around -x- counter-clock” . In any other time instance with other deformation state it will not behave “that good”.
Optimization result.
Comparison of the 2 designs

- Strain Energy: 462.3 mJ
- Max Stress: 56.6 MPa
- Design space mass: 2.790 kg
  - 1<sup>st</sup> elastic Mode: 213 Hz
  - 2<sup>nd</sup> elastic Mode: 230
  - 3<sup>rd</sup> elastic Mode: 235
  - 4<sup>th</sup> elastic Mode: 246
  - 5<sup>th</sup> elastic Mode: 315

- Strain Energy: 1221.6 mJ
- Max Stress: 129.9 MPa
- Design space mass: 2.790 kg
  - 1<sup>st</sup> elastic Mode: 262 Hz
  - 2<sup>nd</sup> elastic Mode: 319
  - 3<sup>rd</sup> elastic Mode: 392
  - 4<sup>th</sup> elastic Mode: 439
  - 5<sup>th</sup> elastic Mode: 652
1. As expected the optimized arm performs better than the already designed, at this deformation state.
2. It’s almost 3 times more rigid than its substitute.
3. The max stress is less than the half compared to the other design.
4. They weight the same.
THE END!