Queen Mary University of London - September 15-17th 2003

Third European Conference on Constitutive Models for Rubber ECCMR

Dynamic analysis of rubber to metal devices using an unconventional numerical modeling for elastomers

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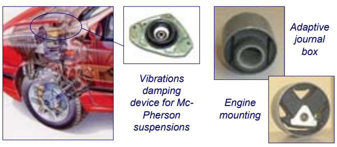
Context and Objective of the Research

This contribution deals with the searching of numerical models to be applied on rubber within an automatic code of calculus to simulate the static and dynamic behaviour of some rubber to metal devices used in the automotive industry.



This work can be placed within a wide research project intended to elaborate a methodology to characterise the dynamic behaviour of rubber to metal devices and, in a more general optics, of components made up of non-linear viscoelastic materials which are very sensitive to temperature, frequency and static pre-strain (or pre-load).

The proposed approach involves experimentation and may be thought as divided into three related stages.

1. The experimental analysis of the dynamic properties of viscoelastic systems: a first phase allows to characterise the behaviour of simple geometry test specimens, pointing out few parameters about the material viscoelasticity (those parameters are: the Young's modulus E and the shear modulus G); a second stage focuses on complex rubber to metal devices and characterises the overall mechanical dynamic behaviour of these. Dynamic response curves are estimated in different work conditions in terms of temperature, deformation level and static pre-load.

2. The searching of suitable models to consider the mechanical dynamic properties of elastomers, taking into account all the mentioned peculiar effects typical of these materials.

3. The implementation of a code of automatic calculus to simulate the behaviour of rubber to metal devices. The numerical simulation are made on theoretical systems (which try to approximate the real ones), given by the mechanical models delineated in the previous stage. The dynamic properties of these theoretical systems must be calibrated using those numerical values pointed out during the first stage about the properties of the used viscoelastic materials. The results of simulations can be compared with the ones coming from experimentation applied on devices.

The innovative point of view introduced by this work consists in modelling the elastomeric components using particle based concentrated parameters models: mass has to be considered as accumulated in a certain number of points, while elasticity and viscosity are not distributed characteristics of the continuous, but properties assembled in some link elements equipped with defined geometric properties, dependent from the particular treated system.

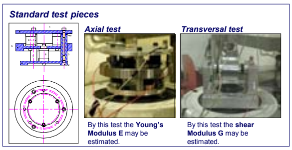
The current adopted approach models the mechanical behaviour of the elastomeric materials using a neural network, which makes possible to assign to each link (during the numerical calculus) a proper value of axial and shear stiffness (to be intended in terms of complex numbers, which implies viscoelasticity) starting from the experimental data represented by a cloud of non-ordered points in a multi-dimensional dominion (frequency, deformation, temperature, static pre-load or pre-strain).

At the present state of development for this research it may be said that a dedicated mean for the numeric simulation of the dynamic behaviour of rubber-to-metal devices has been proposed. This is a useful mean to be used in the design optimisation of those components, offering a CAD similar environment, by the use of which it can be investigated how modifications in geometry or material undertaken on the treated product affect its dynamic behaviour.

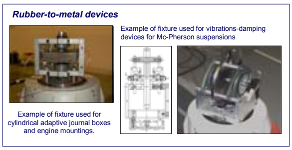
1. Experimentation

Experimental analysis has been performed by an elctrodynamic shaker.

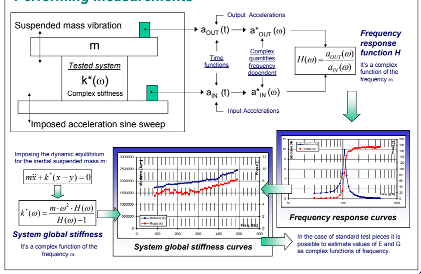
Standard test pieces



Rubber-to-metal devices



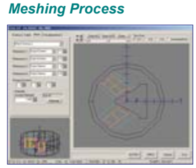
Performing measurements



2. Modeling

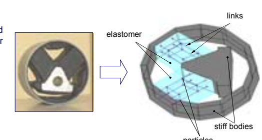
Modeling has been performed by particle based concentrated parameters models.

Meshing Process



- Mass is accumulated in certain number of particles
- elasticity and viscosity are considered as assembled in concentrated links (having both an axial and a shear complex stiffness)

The device is reduced to a mechanical vibrating system having a finite number of degrees of freedom.



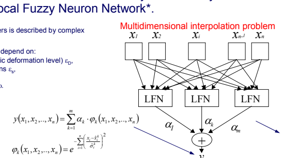
Numerical Modeling for Elastomers

Constitutive equations have been numerically modelled by a Neural Network named Local Fuzzy Neuron Network*.

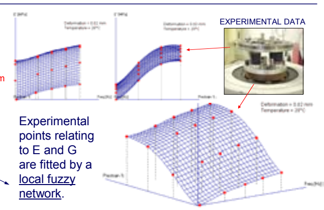
- Dynamic behavior of elastomers is described by complex numbers.
- Complex quantities (E and G) depend on:
  - strain amplitude (dynamic deformation level) ε_D,
  - static pre-strain conditions ε_S,
  - temperature T,
  - frequency of excitation ω.

$$E = E' + j \cdot E''$$
$$E' = f_{E'}(\varepsilon_D, \varepsilon_S, T, \omega)$$
$$E'' = f_{E''}(\varepsilon_D, \varepsilon_S, T, \omega)$$

$$y(x_1, x_2, ..., x_n) = \sum_{k=1}^{m} \alpha_k \cdot \varphi_k(x_1, x_2, ..., x_n)$$



Experimental points relating to E and G are fitted by a local fuzzy network.



3. Simulation

Simulation is performed by the Newton-Raphson method.

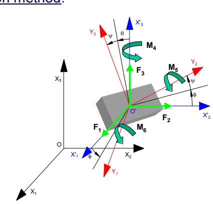
- The dynamic equilibrium is imposed on each mass element;

$$M \cdot \ddot{x} + K(x) \cdot x = F$$

LFN

x = vector of d.o.f. motion
K = stiffness of links
F = external loads vector

- A system of non-linear differential equations is obtained in the time domain;
- Making use of complex numbers these differential equations are reduced to algebraic;
- The system of algebraic non-linear equations is solved by the Newton Raphson iterative method. → The x vector is pointed out.

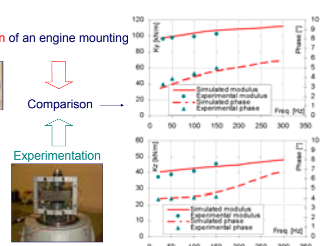


Results

Dynamic simulation of an engine mounting

Comparison

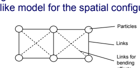
Experimentation



Improvements

- Bending effects

Bending effects could be taken into account by a trestle like model for the spatial configuration of links.



- Thermal effects

Thermal effects could be considered by the superposition of a thermal concentrated parameters model on the mechanical existing one. The simulation should be conducted by a time-frequency analysis.

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