NOVEL NONLINEAR LUMPED PARAMETER MODELS FOR ASYMMETRIC RUBBER BUSHING COMPONENTS

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In this work we present a lumped parameter modelling approach for accurately representing the non-linear behaviour of carbon-filled rubber bushing components. In particular, we analyse the behaviour of a flexible rubber-filled joint used as engine mount.
The key role of bushing elements is to create a kinematic joint between different components while attenuating their transmitted vibrations [1]-[2]. Accordingly, their application is largely spread across the mechanical industry, from machinery to the automotive sector. However, under large deformations the bushings exhibit strong nonlinearities influencing the overall system performances.
In the considered vehicle application, at low frequency regimes - which includes the longitudinal and lateral vehicle dynamics - the internal combustion engine is subjected to large displacements leading to large bushing deflections. Under these conditions, the bushing working regime is highly nonlinear and it is dominant for the whole mechanical system behaviour. As depicted in *figure 1.a*, the studied engine mount consists of three elements: a central rubber component representing the main bushing (in black), two rubber end-stops at its sides (in blue and grey) and a gap (indicated with b) separating the end-stops from the central part. The green and red rings represent the input-output interfaces.
In the fields of condition monitoring [3], model-based control [4] and virtual sensing [5], numerical modelling strategies able to efficiently and accurately capture the bushing element behaviours are needed.
The state of the art techniques [6]–[8] can be grouped in two main modelling approaches, being 1D lumped parameter models (**LPM**s) [9] and 3D nonlinear finite element models (**FEM**).
1D lumped parameter models offer flexible and modular modelling approaches - allowing the analyst to plug and play complexity in the final mathematical representation of the considered system and/or component. Moreover the physical properties of the rubber components, i.e. *elasticity, viscoelasticity* and *friction,* are uncoupled and represented through analytical formulations. Regarding their computational performance, LPMs generally have low computational cost making them eligible for real-time simulations by ensuring a good trade-off between solution accuracy and model complexity.
However for complex bushing design, it is not always possible to analytically describe the model geometry and material behaviour, thus, a priory assumptions need to be stated during the modelling stage. In certain cases, such assumptions may be questionable, especially when complex system designs and non-linear materials are involved.
On the contrary, the FEM strategy still represent the most general numerical approach since no geometrical assumptions are required. For this reason, FE models allow high solution accuracy in spite of high computational cost. Even if model order reduction techniques [10] are applied to reduce the simulation costs of the full order model, the usage of FEM is still too computationally demanding for system level simulations.
This work aims to overcome the limitations of state of the art techniques by introducing 1D modular bushing models which accurately represent the material and geometrical nonlinearities under large deflections and low-frequency conditions.

The proposed formulation allows the description of the friction force contribution by including geometrical properties of the bushing into the model. In particular, the novel bushing approach can be seen as an extension of the Berg model [11] accounting for the higher forces acting when the central bushing hits either the left or right end-stop. Furthermore, one of the Berg's friction parameters is adjusted in order to scale quadratically with the displacement due to the interaction between the main bushing and the end-stops.
The proposed models have been identified using a parameter optimization toolbox, available in Simulink. Similarly, the identification was carried out for the Berg model used as reference.
Finally the results are compared, showing a good correspondence between the novel approaches and the experimental data, and confirming the great potential of the integration of 3D geometrical information into the LPMs.

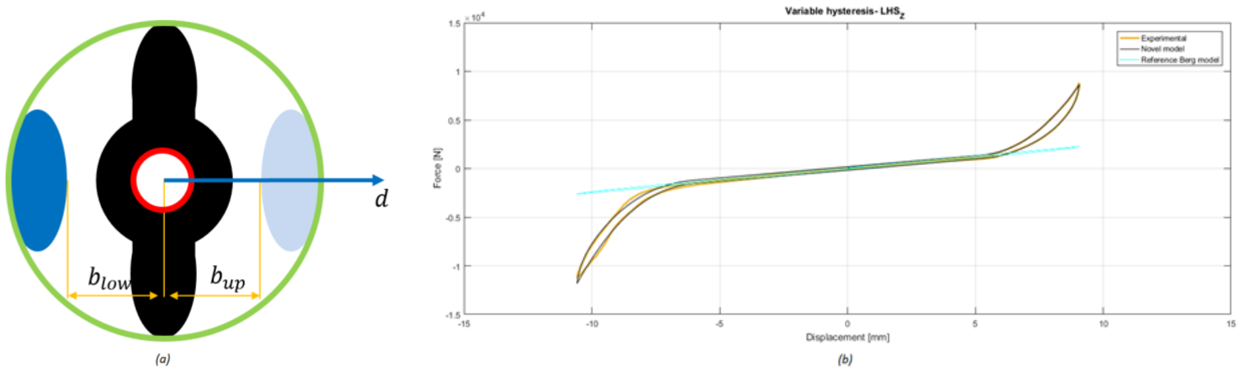

Fig. 1: (a) Bushing topology. (b) Experimental, Berg and proposed model hysteresis curves comparison.

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