Design and Analysis of Non-Pneumatic Tires With Hybrid Metamaterial Spoke: A Novel Approach

Shah, Siddhant (School: Bhagawan Mahavir International School)

As the market for Off-the-Road (OTR) tires grows (annual growth of 5.2%, valuing at $32 billion), consumers continue to demand driving efficiency and productivity, even as the equipment places additional stress and performance demands on tires. Although traditional pneumatic tires have dominated the market for years, they are easily punctured and require excessive maintenance, limiting their performance on rugged terrains. In recent years, non-pneumatic tires (NPTs) have posed a potential solution. NPTs replace air pressure with flexible-spokes, eliminating the risk of flats & rapid pressure-losses while increasing driving safety. In this research, different polyurethane (PU) spoke structures were studied under radial loading conditions. The Mooney-Rivlin 5 Parameter model was utilized to model the hyperelastic behavior of PU based on the uniaxial-test data obtained from the FEM test specimen. Based on the limitations of existing spoke structures, a hybrid metamaterial spoke design was created. The new spoke uses a negative-stiffness mechanism to increase recovery from deformation and maintain minimal stress levels compared to existing structures by 271.65%. The design is utilized in a tire assembly, which is covered with a tire casing, creating a closed tire design that prevents foreign debris from accumulating and causing vehicle imbalance—a problem identified with conventional NPTs. The project utilizes nonlinear finite-element analysis to evaluate tire performance based on static, modal, and dynamic roll-over bump analysis. Results showcased that the new structure demonstrates a 17% improvement in durability and handling precision compared to pneumatic tires. Additionally, it offers better vibrational stability while maintaining comparable contact-pressure.

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