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A STUDY ON VISCOELASTIC FLUID WITH APPLICATION

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Abstract

In industrial settings, including oil pipelines, propellant lines, & water distribution systems, viscoelastic pipes that transfer fluid, such as polymeric & rubber pipes, are frequently utilised. Several academics have been interested in the dynamics & stability analysis with viscoelastic pipes carrying fluid because of their numerous industrial uses. In light of wave media, a thorough analysis of these systems' dynamics is offered. The term "viscoelastic characteristics" refers to a material's combination between elasticity and viscosity, which is most frequently seen in elastomers and polymeric materials. These materials have molecular chains as part of their molecular structure. The tension needed to maintain the same amount of strain over time decreased, however, if indeed the viscoelastic material was subjected to a consistent level of strain; this is known as stress relaxation. When a viscoelastic material behaves in this way, it means that the material has memory and that the strain and stress that are created at any one time are related. In light of the aforementioned characteristics, several attempts have been made to develop appropriate mathematical models that are tailored to genuine viscoelastic material behaviour curves in the linear domain.

Keywords: Viscoelastic, Fluid, Model.

Introduction

There are many models available that simulate the behaviour of linear viscoelastic materials at this time. These models are made by connecting a number of springs and dashpots in series and parallel because the behaviour of viscoelastic materials is close to that of elastic and viscous materials. The viscoelastic classic models, which include the Maxwell, Kelvin-Voigt, and Zener models, are the most basic ones used here. These models use the first-order differential equation regulating the spring and dashpot sets to demonstrate the link between stress and strain. Although these patterns can somewhat depict the elastic and viscosity behaviour of a viscoelastic material, they are unable to accurately represent the behaviour of such materials. The Maxwell model's prediction of the creep phenomenon and the Kelvin-Voigt model's prediction of the stress relaxation phenomenon are both false. The behaviour of creep & stress relaxation has been adjusted to an appropriate level in the Zener model. Because to its simplicity, this model is helpful for analysing the quality of viscoelastic materials, but it is not exact enough to correctly forecast viscoelastic behaviour. The accuracy of the described patterns can be improved by connecting numerous springs and dashpots in parallel and series. The Prony series is more accurate than the differential equations of the classical models when larger stress & strain derivatives are added. To adjust to the experimental data, a significant number of experimental constants will be needed in these circumstances, it should be emphasised.

In the literature, several investigations have been conducted to anticipate the behaviour of viscoelastic materials in the linear domain, leading to a variety of methodologies such fractional derivatives. Bagley was the first to suggest fractional derivatives for materials that are viscoelastic. For viscoelastic materials, they were the first to present a frictional stress-strain relation.

This model can precisely forecast viscoelastic behaviour across a broad frequency range while only requiring a few empirical parameters to adjust to the experimental data. The molecular behaviour of viscoelastic materials in waves was investigated. They demonstrated how the molecular model of viscoelastic materials will eventually result in a fractional relationship amid stress and strain.

Literature Review

Soid (2017) [2] Considered is a steady flow of the boundary layer along a straight thin needle submerged in a nanofluid in two dimensions. In order to solve the partial differential equations that govern numerically for the copper-water nanofluid having Prandtl number Pr = 6.2 (water), the equations governing the partial differential equations must first be converted to a set of ordinary differential equations that are nonlinear. The velocity and temperature curves, as well as the relevant physical variables like the local Nusselt number and the skin friction coefficient, are shown. When the free stream and the needle travel in the opposing directions, two solutions are discovered.

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It can be seen that as the volume of the solid fraction parameter is increased, the solution domain shrinks. On the heat transfer and flow properties in addition to on the velocity as well as temperature profiles, the effects of the tip size as well as the solid volume percentage variable are examined. Due to its various technological and industrial uses, the study of flow as well as heat transfer over a submerged solid object has attracted a lot of research interest throughout the years. Examples include a hot wire anemometer with shielded thermocouple for monitoring wind speed, microscale cooling devices for applications involving heat removal, microstructure electronic devices that result in highly compact and efficient systems, etc.

(2002) Yurusoy [1] Third-grade fluid flow in a conduit including heat transfer is taken into account. Reynold's model viscosity, Vogel's model viscosity, and constant viscosity instances are all handled independently. For each scenario, reasonable analytical solutions are offered using perturbations. For the concerned dimensionless parameters, the criteria that determine whether the responses are valid are identified. The steady-state circulation of a third-grade liquid in a conduit including heat transfer is taken into consideration in this work. It is assumed that the temperature inside the pipe is higher compared to the temperature surrounding the fluid. The problem is presented with approximate analytical solutions, and the solutions' range of applicability is examined. The constant viscosity case, the Reynolds model case, and the Vogel model case are each given their own attention. Then, numerical comparisons between the available finite-difference solutions and perturbative solutions are made. Analytical and numerical solutions are consistent within the permissible parameter space.

Study on Viscoelastic Fluid

The fractional model was used to study the phenomenon of stress relaxation. They demonstrated that compared to the conventional model, this one could predict viscoelastic behaviour over a significantly wider frequency range. The loss and storage modulus were used in the study to compare the viscoelastic behaviour predicted by the variational model with standard models for a broad frequency range. As a result, only a limited frequency range of the viscoelastic behaviour of rubber & glass materials can be predicted by the conventional models. The pattern of fractional derivatives across a broad frequency range can reveal the viscoelastic properties of rubber materials. The results of the experimental tests are consistent with the storage modulus & loss modulus that were calculated from this model. They demonstrated that their model correctly predicts the viscoelastic behaviour of the materials over a broad frequency range. For a variety of viscoelastic materials, these coefficients of the fractional model were determined. He demonstrated that this model is reliable in predicting the viscoelastic behaviour of the materials across a broad frequency range. This was done by contrasting classical models using fractional models. They demonstrated how fractional models would converge with classical models with multiple spring and dashpot sets. The fractional model must be determined using a considerably smaller set of parameters. The fractional derivatives model on asphalt was generalised, and it was demonstrated that this model is more accurate in predicting the creep and relaxation behaviour of asphalt than traditional models. The fractional viscoelastic models can accurately model the behaviour of viscoelastic materials over a wide range of frequencies, whereas the classical models cannot accurately simulate the behaviour of viscoelastic materials, according to a recent comparison of classical and fractional models for viscoelastic materials. They also demonstrated that the fractional Zener model is the most accurate of the fractional models.

As previously mentioned, the fractional derivative models predict the elliptical stress-strain hysteresis loops for viscoelastic materials by using molecular theories that regulate viscoelastic media and meet the second law of thermodynamics. The fractional derivative models may correctly forecast viscoelastic behaviour across a wide frequency range while only requiring a few empirical parameters to adjust to the experimental data. It should be noted that strain-displacement simulations of nanostructures are another usage for fractional models. This was investigated using a fractional calculus-based nonlocal continuum model that included long-range forces betwee non-adjacent volume elements. The analytical formulation as well as finite element solution regarding fractional-order nonlocal simulation of an Euler-Bernoulli beam were presented, and they were based upon this fractional-order nonlocal continuum mechanics model. It is looked at how to improve the space-Fractional Euler-Bernoulli beam (s-FEBB) concept and analyse nonlocal bending in nanobeams. With a fractional formulation of cross-section rotations, they created new kinematics.

Conclusion

The behaviour of viscoelastic structures is examined in the published publications that use fractional derivative models. Using fractional viscoelastic models, a thorough analysis of the dynamic behaviour of viscoelastic structures is carried out. An overview of fractional viscoelastic models was given, and they were used to examine the creep, relaxation, as well as viscosity. Also, they include the analytical equations for the compliance, relaxation modulus, creep graphs, and viscosity of effective fractional models. In order to investigate the stability of a viscoelastic beam made of a fractional-order material that was travelling axially, the multi-scale method was utilised to solve the motion equation. Considered the dynamical behaviour of beams and rods sitting on such a fractional viscoelastic basis by using multiple-scale perturbation method. They took into account how the fractional-order parameter will affect the system's natural frequency & stability margin. The stability and linked bi-flexural-torsional vibration of fluid-conveying pipes rotating about an eccentric axis were presented. By using the extended Hamilton principle as well as the 4-term Galerkin method, they were able to construct the differential motion equations. With a fractional-order viscoelastic material description, the dynamic model of a simply supported Euler-Bernoulli beam is being examined. The beam is excited by the movement of the support. Moreover, the behaviour of a fractionally viscoelastic Euler-Bernoulli beam under quasi-static & dynamic loads is being examined. The vibrations of rotating, supported drill-string-like pipes subjected to internal & exterior annular flows were investigated in a three-dimensional (3D) environment. The extended Hamilton concept was used to generate the doubly gyroscopic system's governing equations. Considered the static behavior of such a viscoelastic beam modelled using fractional-order theory, based on Timoshenko beam theory. It was concerned with the dynamic analysis for composite beams incorporating elastic & viscoelastic layers through using Euler-Bernoulli beam element and the Timoshenko theory. For parameter identification of something like the Zener fractional viscoelastic models, they presented new techniques. For substantial deformation of a viscoelastic wall made of four viscoelastic layers joined by five parallel steel plates, a fractional-derivative Maxwell-Kelvin viscoelastic mechanical model has been created. A fractional Kelvin model and a fractional Maxwell model coupled in tandem made up the fractional-derivative Maxwell-Kelvin viscoelastic mechanical model. We explore the nonlinear steady-state vibration of harmonically stimulated beams. This uses the fractional Zener rheological model to describe the viscoelastic material of the beams. To resolve the equation of motion, they also used the harmonic balancing approach and the finite element method. Using classical and fractional Zener models, the researcher investigated the quasi-static behaviour of the simply supported viscoelastic beam submitted to evenly distributed load. This formulation involving twisted viscoelastic beams was derived analytically, using fractional calculus as capture the viscoelastic behaviour. With a fractional Zener model, the dynamic behaviour of a viscoelastic beam that is simply supported is explored. It is explored how a cantilevered column will behave under a finite hereditary foundation as well as a constant intensity follower force. The dynamic properties and steady-state response with fractional viscoelastic beam constructions are studied with the use of the wave approach. They took into account how wave transmission, reflection, and wave propagation are affected by fractional order.

Fractional viscoelastic mathematical models have been utilized recently to analyse the dynamic behaviour of fluid-conveying pipes. As an illustration, the nonlinear free movement of a fluid-conveying fractional viscoelastic pipe is investigated. They were able to derive the dynamic equations of linked planar motion for the pipe using the Euler-Bernoulli beam theory as well as the Hamilton's principle. Also, they directly used the multiple scales method for nonlinear vibration analysis and modelling. Using fractional-order constitutive laws, the dynamic properties of polymer-like pipes that transmit fluid while being excited by a supporting foundation are explored. For the situation involving primary resonances, they solved the model using the multiple scales approach.

The stability analysis of fluid-conveying pipes supported by a fractional Kelvin-Voigt foundation was taken into consideration in the study. They employed the partial Kelvin-Voigt model to predict the behaviour of the viscoelastic foundation and the Euler-Bernoulli technique described to model the non-viscoelastic pipe structure. On the basis of the viscoelastic fractional model for damping, the plug flow model for fluid flow, and the Euler-Bernoulli technique described for structural dynamics, we examine the divergence & flutter instability of pipes transporting fluid with the fractional Kelvin-Voigt viscoelastic model. Using the energy-phase approach for the first time, the researchers investigated the dynamical modelling, multi-pulse orbits, as well as chaotic dynamics with cantilevered pipe transmitting pulsating fluid using external harmonic force. Also, they took into account nonlinear geometric pipe deformation when using the pipe's material's Kelvin constitutive relation.

A cantilevered pipe that was transporting pulsing fluid under the influence of an external harmonic force was explored for its nonlinear resonant reactions, mode interactions, as multi-time-periodic and chaotic oscillations. To calculate the average equation of such cantilevered pipe conveying pulsing fluid under 1:3 internal resonance and main parametric resonance, they combined the Galerkin methodology with the multiple scales method. The time-dependent excitations exposed a fractional Kelvin-Voigt viscoelastic conduit carrying fluid to nonlinear forced vibrations. In this, the strain-displacement relation proposed by Von Karman and the Euler-Bernoulli beam theory were used to explain the nonlinear geometric partial differential equations resulting from the stretching effect. Investigations were made into the nonlinear vibration analysis of a fluid-conveying pipe with something like an across breathing crack during main and secondary excitations. They modelled the damping and fluid flow using the partial Kelvin-Voigt viscoelastic model as well as the plug flow assumptions.

While the Kelvin-Voigt fraction framework has been used to simulate the behaviour of viscoelastic materials throughout wave homogeneous conditions in all of the aforementioned articles, research suggests that the fractional Zener framework could also observe the behaviour of mechanical properties in a broad frequency range with greater accuracy compared to the other fractional models. The fractional Zener framework is used in this research to explore the divergence & flutter instability with viscoelastic pipes carrying fluid with varying boundary conditions because it is accurate in mimicking the behaviour of viscoelastic materials. In addition, wide conditions are taken into consideration to investigate the impact of this approach on the prediction of something like the stability margin of fluid-conveying pipes because the flutter & divergence instability depend on the boundary system circumstances. The pipe structure is treated as a free-free Euler-Bernoulli beam restricted by two lateral and rotating springs installed at the pipe's beginning and end.

The pipe structure is subject to distributed axial tangential & direct forces. The pipe's viscoelastic property is modelled using the fractional Zener model, which is a more thorough model. A scattered lateral load combining inertia, Coriolis, and centrifugal forces is used to represent the fluid flow. The extended Hamilton's principle is used to generate the governing motion equation, which is then translated to the Laplace domain. A collection of algebraic equations is created using the Galerkin method. The eigenvalues & stability margin of the system are produced by the roots of something like the determinant of such coefficients of the retrieved equations. The acquired results are verified by comparing them to other findings in the literature, after which it is looked into how the fractional Zener parameter estimates affect the stability margin for pipes that transmit fluid under various boundary circumstances.

Conflict of Interest

There is no conflict of interest by the authors in this manuscript.

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