Comparison of vibrational characteristics of aluminum and steel cantilever beam with Sandwich beam through modal analysis

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Abstract— The dynamic behavior of sandwich cantilever beam has not been extensively investigated, the application of cantilevers is found extensively in structural elements, supporting device for motors or engines and construction of bridges. Dynamic stresses will be induced on beams hence it is important to know the natural frequencies of beam-mass system. Present work involves comparison of dynamic behavior of aluminum and steel cantilever beam with sandwich beam of aluminum and steel both analytical and numerical analysis. The natural frequency calculated by using equations and it has been validated numerically and variation of 1 to 5 % noted difference between numerical and analytical analysis.

Keywords— Cantilever Beam, sandwich beam, Modal analysis, Frequency

1 Introduction

Beam is inclined or horizontal structural member casing a distance among one or additional supports, and carrying vertical loads across (transverse to) its longitudinal axis, as a purling, girder or rafter. Vibration testing has become a standard procedure in design and development of most engineering systems. The system under free vibration will vibrate at one or more of its natural frequencies, which is the characteristic of the dynamical nature of system. The natural frequency is independent of damping force because the effect of damping on natural frequency is very small [1].

Cantilever beam is considered as one of the most fundamental structure in the field of structural mechanics. Cantilevers are widely found in construction mainly in bridges and balconies. Detection of the natural frequencies of the structure is considered as the most important observation in the vibration analysis as it is needed to avoid resonant condition [2].

Structural Sandwich is a special form of composite comprising of a combination of different materials that are bonded to each other so as to utilize the properties of each separate component to the structural advantage of the whole assembly. Sandwich materials are frequently used wherever high strength and low weight are important criteria [3]. Sandwich structures have a wide application in different branches of industry, like the optical, biomechanical, microelectronics and highly resistant components, due to their high stiffness, superior strength, heat conductivity and small mass [4].

Every material in the nature is having different natural frequencies i.e. it vibrates on its own at highest frequencies. When these natural frequencies match with external excitation force body will vibrate at its maximum amplitude i.e. Resonance occur and due to this body gets damaged. This can be avoided if natural frequencies of materials are known. Various techniques can used to avoid resonance if it is already knowing the natural frequency. That's why this project is to calculate natural frequencies of various materials having various geometries. Different methods like, Formulation, Software and Actual Experimentation were used. After getting frequencies from all methods it's able to compare results from all methods and find out variations in them.

Vibration is a mechanical oscillation about a reference position. Any system has certain characteristics to be fulfilled before it will vibrate. To put in simple words, every system has a stable position in which all forces are equivalent and when this equilibrium is disturbed, the system will try to regain its stable position To remain stable, structure exhibits vibration at different magnitude when excited, the degree of vibration varies from point to point (node to node), due to the variation of dynamic responses of the structure and the external forces applied Therefore, vibration may also be described as the physical manifestation of the interchange between kinetic and potential energy [5].

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Modal analysis is a process of describing a structure in terms of its natural characteristics which are the natural frequency and mode shape it's a dynamic property. The change of modal characteristic directly provides force excitation of structure condition based on change in frequency and mode

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shape of vibration [7].

2 NUMERICAL METHOD AND MODEL DESCRIPTION

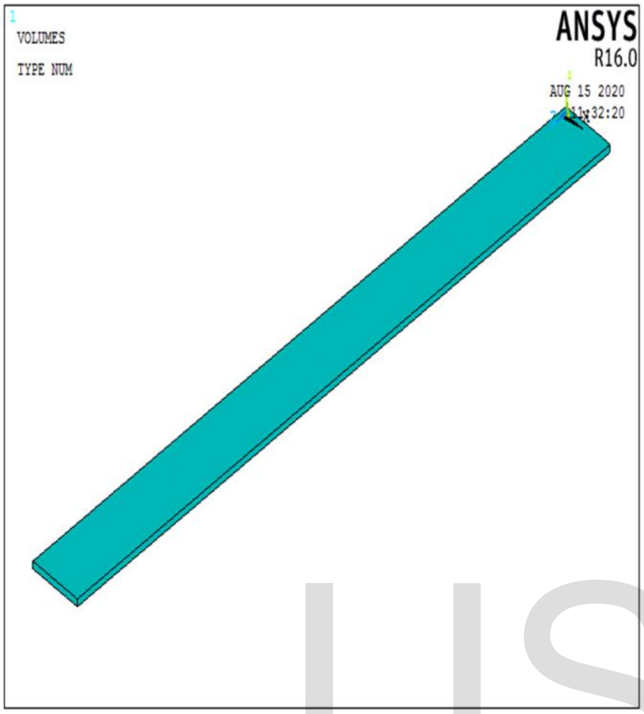


Figure 1: Geometry of steel and aluminum beam

The geometry is as shown in Figure 1, the rectangular cross section of width 50mm, height 5mm and length 600mm is chosen for modal analysis. The material chosen is aluminum and steel.

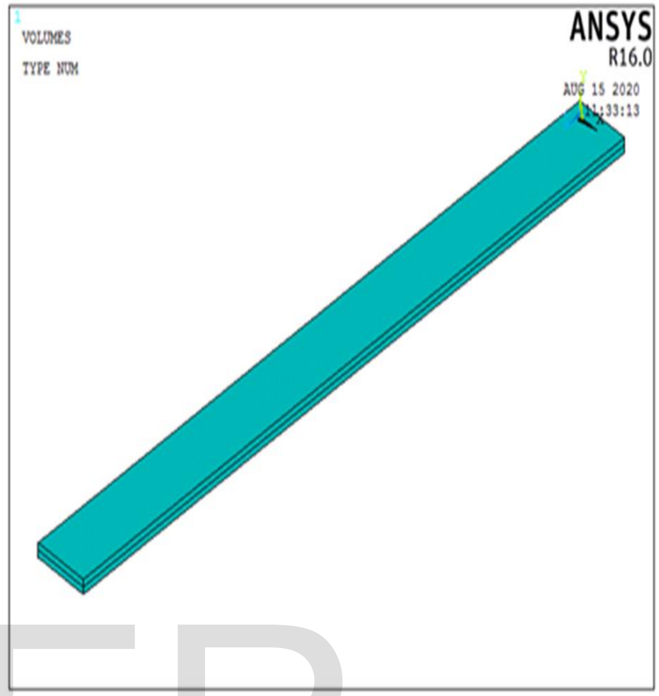


Figure 2: Geometry of sandwich beam

The geometry is as shown in figure 2, the rectangular cross section of width 50mm, height 10 mm and length 600mm is chosen for modal analysis. The material chosen is aluminum and steel.

2.1 Properties of material

Material used for the cantilever beam;

- **Mild steel**

Density	*7850kg/m³*
Young's Modulus	210 x 10^9 Pa
Poisson's ratio	0.303

- **Aluminum**

Density	*2700kg/m³*
Young's Modulus	69 x 10^9 Pa
Poisson's ratio	0.334

For sandwich beam first material at bottom aluminum has been taken and at top layer steel has been taken with above properties.

2.2 Analytical solution

For a cantitilever beam exposed to vibration, following equations has been deduced from Euler-Bernoulli beam theory is used in order to obtain natural frequencies [6].

Where E is the modulus of rigidity of beam material, I is the moment of inertia of cross section of beam, Y(X) is displacement in y direction at distance x from fixed end, ω is the natural frequency and m is the mass per unit length, m = ρA(x), ρ is the density of the material, x is the distance measured from the fixed end.

After applying boundary conditions for a cantilever beam [6];

From uniform beam under free vibration equation we get;

Where K is the constant obtained from Ranks formula for stress and strain table and n is the number of frequencies.

2.3 Numerical solution

Analysis carried out through Ansys with element type beam 2 node 188 with above material property. In modeling section we have created a volume of 50 mm width, 5mm height and 600mm depth for both aluminum and steel cantilever beam. For sandwich beam we have glued. We have restrained the degree of motion at one end of beam by fixing it through all degree of freedom.

We have selected modal analysis and to extract mode Block Lanczos method of mode extraction used which is a default method of mode extraction... The default is to extract first 5 natural frequencies.

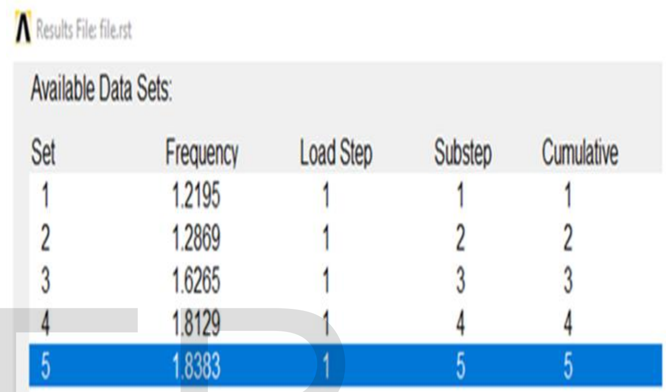
3. RESULTS AND DISCUSSION

The natural frequency obtained numerically and comparison between analytical and numerical results is shown in table 1,2,3,4 and 5. It has been observed that natural frequency of lighter material will be less than heavier material. When dynamic behavior compared between aluminum, steel and sandwich beam natural frequencies of sandwich beam is more than that of steel and aluminum. Hence due to above analysis we found when material reduces natural frequency will reduce.

One notable observation has been noted from the analysis is that deformation of sandwich beam is nearer to aluminum since bottom material of sandwich beam placed was aluminum. The geometrical arrangement of sandwich beam will have influence on deformation particularly for a cantilever beam.

The nodal solution indicating deformation, natural frequency for aluminum, steel and sandwich cantilever beam is as shown in figure 3, 4, 5, 6, 7, 8, 9, 10 and 11. From the figure natural frequency of lighter material is more that is for aluminum followed by steel and sandwich beam. Since sandwich beam has more frequency than that of aluminum and steel cantilever beam more resonance occurs hence some resistance needed in the form of damping material for sandwich beam.

Table 1: Natural frequencies obtained numerically for aluminum beam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Available Data Sets:

Set	Frequency	Load Step	Substep	Cumulative
1	1.2195	1	1	1
2	1.2869	1	2	2
3	1.6265	1	3	3
4	1.8129	1	4	4
5	1.8383	1	5	5

$$\frac{d^2}{dx^2}\left\{EI(x)\frac{d^2Y(x)}{x^2}\right\} = \omega^2 m(x)Y(x)$$

Table 2: Natural frequencies obtained analytically and numerically for aluminum beam

MODE	*Natural frequencies obtained analytically*	*Natural frequencies obtained Numerically*	*Error in %*
1	1.206	1.2195	1.10
2	1.270	1.2869	1.31
3	1.587	1.6265	2.42
4	1.768	1.8129	2.47
5	1.791	1.8383	2.58

$$\text{At } x = 0,\ Y(x) = 0,\ \frac{dY(x)}{dx} = 0$$
$$\text{At } x = l,\ \frac{d^2y(x)}{dx^2} = 0,\ \frac{d^3Y(x)}{dx^3} = 0$$

$$\omega = K\frac{n}{2\pi}\sqrt{EI/_{mL^4}}$$

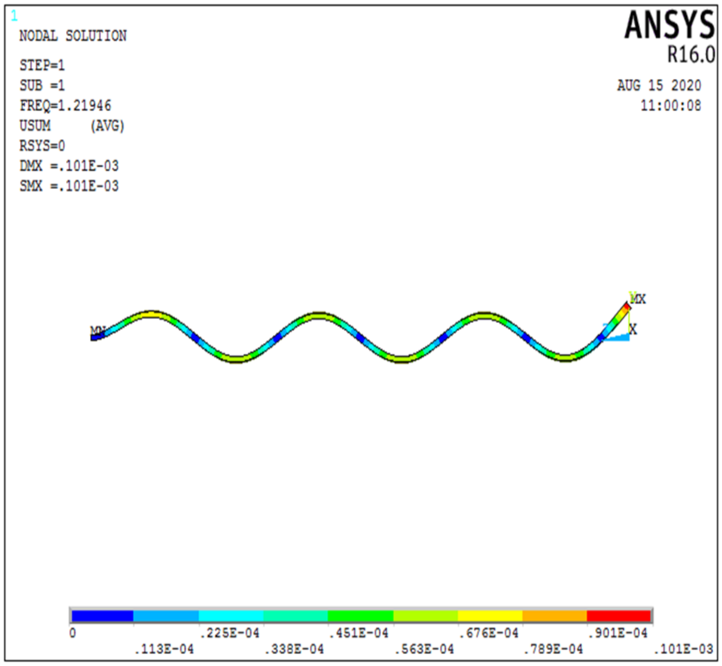

Figure 3: Nodal solution for aluminum at frequency 1.2195 HZ

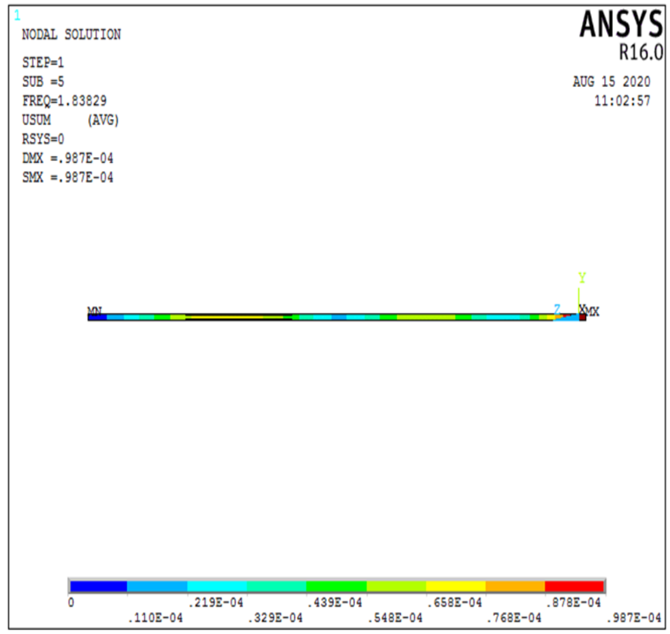

Figure 5: Nodal solution for aluminum at frequency 18382 HZ

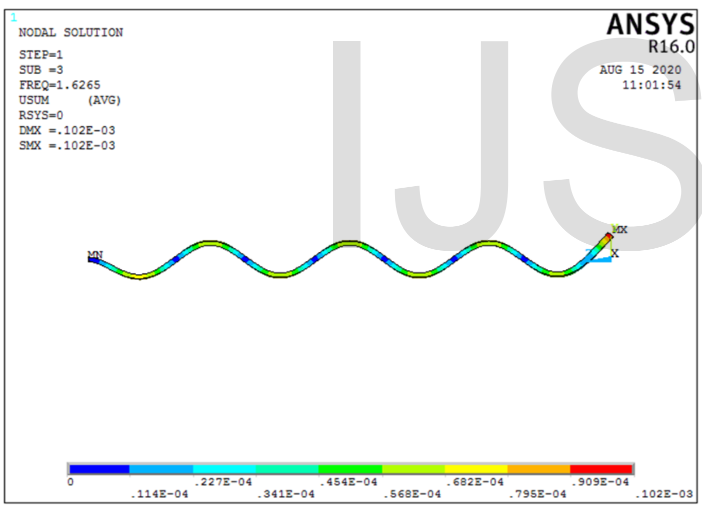

Figure 4: Nodal solution for aluminum at frequency 1.6265HZ

Table 3: Natural frequencies obtained numerically for steel beam

Results File: file.rst

Available Data Sets:

Set	Frequency	Load Step	Substep	Cumulative
1	1.2624	1	1	1
2	1.3323	1	2	2
3	1.6838	1	3	3
4	1.8768	1	4	4
5	1.8824	1	5	5

Table 4: Natural frequencies obtained analytically and numerically for steel beam

MODE	*Natural frequencies obtained analytically*	*Natural frequencies obtained Numerically*	*Error in %*
1	1.235	1.2624	2.17
2	1.301	1.3323	2.34
3	1.639	1.6838	2.66
4	1.810	1.8768	3.55
5	1.804	1.8824	4.17

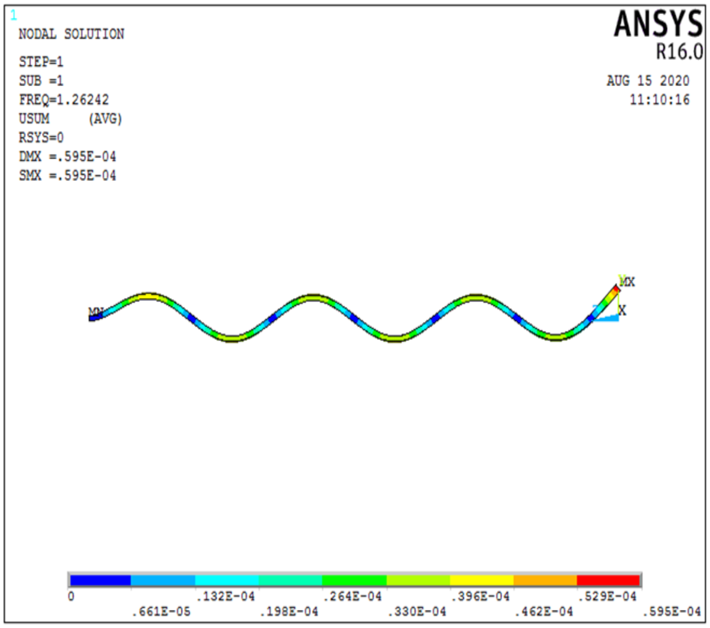

Figure 6: Nodal solution for steel at frequency 1.2624HZ

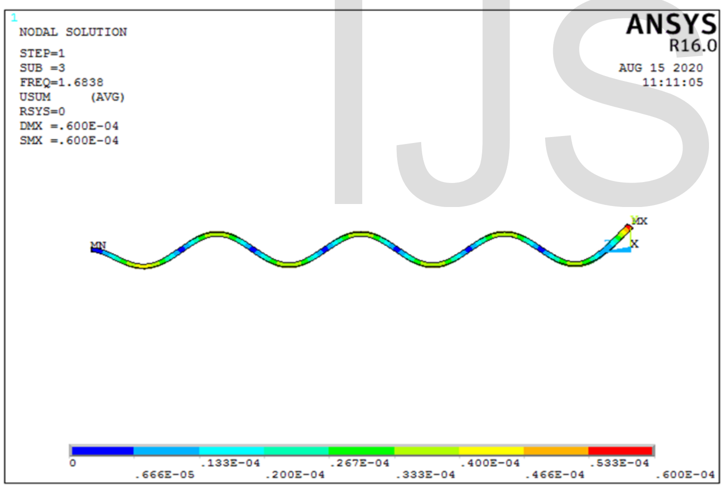

Figure 7: Nodal solution for steel at frequency 1.6838 HZ

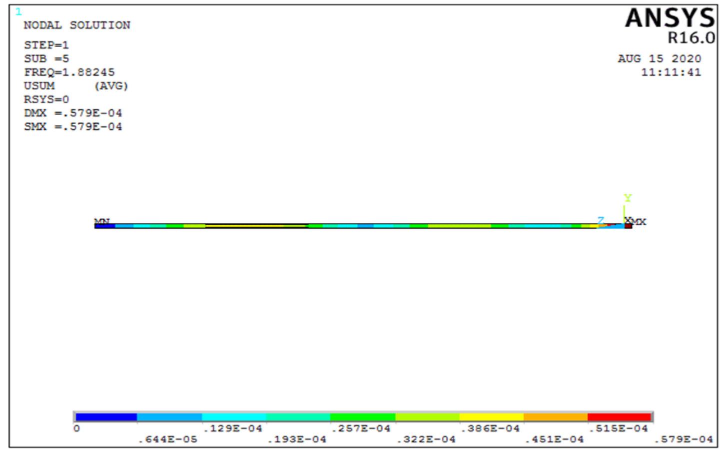

Figure 8: Nodal solution for steel at frequency 1.88245 HZ

Table 5: Natural frequencies obtained numerically for sand which beam

Results File: file.rst

Available Data Sets:

Set	Frequency	Load Step	Substep	Cumulative
1	1.3318	1	1	1
2	1.3643	1	2	2
3	1.8526	1	3	3
4	1.8984	1	4	4
5	1.9106	1	5	5

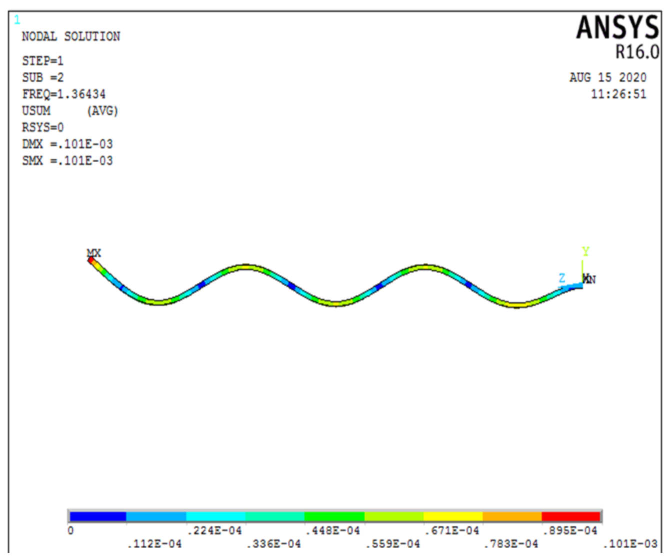

Figure 9: Nodal solution for sandwich beam at frequency 1.364HZ

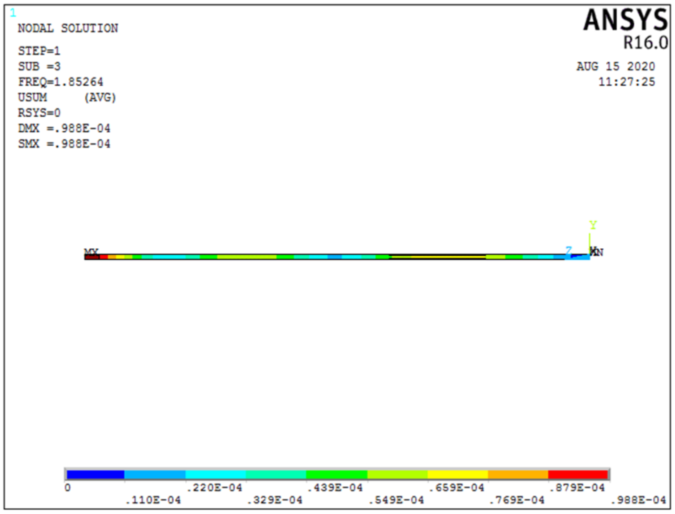

Figure 10: Nodal solution for sandwich beam at frequency 1.852HZ

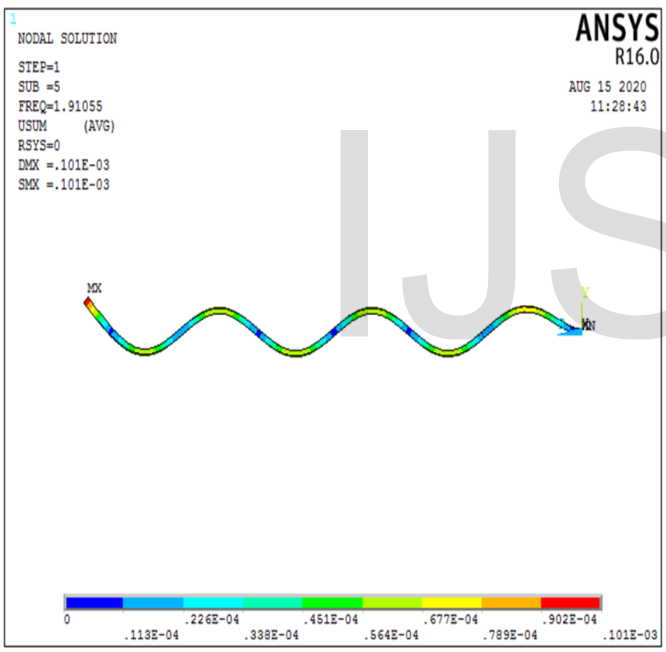

Figure 11: Nodal solution for sandwich beam at frequency 1.910HZ

CONCLUSION

- Has density of material reduces natural frequencies will reduce.
- Geometrical arrangement of lighter and heavier material for sandwich cantilever beam will have influence on dynamic property behavior particularly deformation.
- Due to increase of density of material, frequency increases leading to resonance, hence some resistance needed in the form of damping material.
- Natural frequency of sandwich cantilever beam found to be more than steel and aluminum.
- Natural frequency variation between analytical and numerical found to vary between 1 to 5 %.

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