

# Computational simulation of intelligent big data analysis under nanotube rotation

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**Abstract.** Economic investigation is one of the main issues regarding the design and production of small-scale structures. This paper concerns the creation, implementation, and economic aspects of the cross-section profile of small-scale structures regarding the dynamic response of the free and forced vibration behavior of spinning nanoscale beams based on big data analysis. According to the financial analysis, the three practical non-uniform functions of cross-sections are compared to the uniform beam in the same weight and the equal material used. The previous studies reported that the uniform beams are more stable and contain a better frequency response based on the mechanical analysis. Still, concerning the economic investigation, which means the considered structures should have equal length and have the same weight in the aspect of material used, the conclusion can be different from the mechanical aspect. Consequently, in the current paper, the dynamic response along with computer technology as well as the big data analysis of the free and forced vibration of the nanobeam regarding the economic shape of the cross-section is scrutinized.

**Keywords:** economic analysis; economy model; optimization; vibration analysis

## 1. Introduction

Economic systems are characterized by ongoing change and development, and explanations of the features of economic structures have piqued the interest of experts. Due to feedback effects, the design of a system and its dynamics may impact each other (Ebrahimi and Shafiei 2017, Ghadiri *et al.* 2017e, Mirjavadi *et al.* 2017a, Shafiei and Kazemi 2017a, Shafiei *et al.* 2017d, Azimi *et al.* 2018). In no way are economic systems uniform, stable, or homogeneous. The same can be said for the processes by which they evolve over time and space, presenting a wide range of patterns worth investigating, such as inhomogeneous development across countries and regions, sustained oscillations in aggregate output and growth, financial instability punctuating long periods of relative stability, spatiotemporal patterns of innovation and technological change, skewed distributions of wealth and income, evolving demand and constraint patterns, and skewed distributions of wealth and income (Habibi *et al.* 2016, 2018b, Ebrahimi *et al.* 2019a, Esmailpoor Hajilak *et al.* 2019). Although there are evident links between these patterns and economic fundamentals, understanding the particular processes that underpin their genesis is a complicated and ongoing research project (Venkatachalam and Kumar 2021).

The term “structure” has several meanings in various disciplines, and any economics-specific definition must incorporate the characteristics that distinguish economic

systems (Ehyaie *et al.* 2017, Ghadiri *et al.* 2017c, d, Mirjavadi *et al.* 2017d, Shafiei and Kazemi 2017b, Shafiei *et al.* 2017c). Among these are the irreversibility of changes over time and the complexity of their dynamics (Habibi *et al.* 2018a, 2019b, d, e, Pourjabari *et al.* 2019, Safarpour *et al.* 2019a). For instance, technological change is a disruptive force that has a cumulative effect on economic systems and is often unidirectional in nature (Ghadiri *et al.* 2017a, b, Mirjavadi *et al.* 2017b, c, Shafiei *et al.* 2017a, b). Economic systems progressively get more complex as they grow and adapt. They are neither wholly stable nor completely unstable, and their composition and organization undergo significant changes at moderate to rapid rates (Habibi *et al.* 2019a, Safarpour *et al.* 2019b, Alipour *et al.* 2020, Ebrahimi *et al.* 2020a, Chen *et al.* 2022). While the concept of structure is essential in general economic theory, the objective of structural change economic theories is to elucidate the underlying mechanisms and processes that sustain these patterns (Ebrahimi and Shafiei 2016, Shafiei *et al.* 2016d, c, f, Ebrahimi *et al.* 2017, Shivanian *et al.* 2017). Developing methods for comparing different structures, defining structural equivalence, determining the extent of self-emulating capabilities, comprehending structural stability, complexity, transformation drivers, and developing tools to study their potential and actual dynamics are just a few of the later aspects (Venkatachalam and Kumar 2021).

Small-scale structure design and manufacture are high-cost technologies, and the materials utilized in these structures are one-of-a-kind (Habibi *et al.* 2017, 2019c, Safarpour *et al.* 2018, 2020, Ghazanfari *et al.* 2020). The main effort overlooked by researchers is the optimization of these structures in the area of material utilized. The cross-section design is essential in the mechanical design of

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small-scale buildings since it may save a lot of material and money. However, the researcher overlooks this fact in their article (Azimi *et al.* 2016, Ghadiri and Shafiei 2016a, c, Shafiei *et al.* 2016a, e, g), for example: Huang *et al.* (2021c) scrutinized the cross-section impact on the nonlinear dynamic behavior of micro-scale tubes based on the classical beam theory that the economic production was neglected, it was shown the uniform beams are the more stable structure than the nonuniform. Hou and Wu (2021) studied the different functions of cross-sections involving uniform and three types of nonuniform sections in order to investigate the thermal impact on the stability of the microscale functionally graded tube, which the assumption was not based on the economic production. He and Cai (2021) examined the buckling behavior of a microtube made of functionally graded material to investigate the cross-section effect on it without equal tube mass. Hou *et al.* (2021a) presented the numerical modeling for the static analysis of the porosity-dependent micropipe made of functionally graded material in which the material properties varied along the pipe length. Li *et al.* (2021) worked on the nonlinear static behavior of the imperfect micropipe, including the porosity, in order to investigate the cross-section effect.

As reviewed, many studies have been presented for the cross-section impact on the stability of small-scale structures, the researchers usually assumed the uniform structures reformed to the tapered ones without the presumption of equal mass or material used (Ebrahimi *et al.* 2019b, c, Mohammadgholiha *et al.* 2019, Mohammadi *et al.* 2019, Ebrahimi *et al.* 2020b, Habibi *et al.* 2020, Shariati *et al.* 2020, Shokrgozar *et al.* 2020). The main reports of published studies indicated that the uniform structures are more stable, but the results can be different because of economic production. So, this paper presents the economic design of the cross-section function to study the stability of the nanoscale beam based on the mathematical simulation.

## 2. Mathematical modeling and formulation

A rectangular beam structure is considered in this paper that the thickness is not uniform and is a function that changes continuously along the beam length regarding the following equations.

$$h = h_0 \quad \text{Uniform section} \quad (1a)$$

$$h = 1.28571237h_0 \left(1 - 0.75 \frac{x}{L}\right)^{0.5} \quad \text{Convex section} \quad (1b)$$

$$h = 1.3\bar{h}_0 \left(1 - 0.5 \frac{x}{L}\right) \quad \text{Linear section} \quad (1c)$$

$$h = 1.359124h_0 \left(1 - 0.2928 \frac{x}{L}\right)^2 \quad \text{Exponential section} \quad (1d)$$

In the considered beam, shown in Fig. 1, the beam length and beam mass are the same, the presented thickness functions are for the beams with equal length and mass, so the thickness because of different types of them is various mentioned. The presented constants for other thickness

functions were given based on the equal beam volume.

According to the first-order shear deformation beam theory, the displacement component will be defined.

$$u_x(x, y, z, t) = z\varphi(x, t) + u(x, t) \quad (2a)$$

$$u_y(x, y, z, t) = 0 \quad (2b)$$

$$u_z(x, y, z, t) = w(x, t) \quad (2c)$$

'x' and 'z' are independent components, and 't' is the time. The movement along the 'x/-', 'y/-', and z-axis indicates by  $u_x$ ,  $u_y$ , and  $u_z$ . Utilizing the movement components, the strains equations are obtained as follows.

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} + z \frac{\partial \varphi}{\partial x} \quad (3a)$$

$$\varepsilon_{xz} = \varepsilon_{zx} = \frac{1}{2} \left( \varphi + \frac{\partial w}{\partial x} \right) \quad (3b)$$

According to the Timoshenko beam theory along with the nonlocal theory, the general nonlocal governing equations, as well as boundary conditions, are as follows.

$$\delta(u): Au_{,xx} = m_0 \ddot{u} - (ea)^2 m_0 \ddot{u}_{,xx} \quad (4a)$$

$$\text{Boundarycondition}(\delta(u)): Au_{,x} - (ea)^2 m_0 \ddot{u}_{,x} = 0 \quad (4b)$$

$$\delta(\varphi): D\varphi_{,xx} - B(w_{,x} + \varphi) = m_2 \ddot{\varphi} - (ea)^2 m_2 \ddot{\varphi}_{,xx} \quad (4c)$$

$$\text{Boundarycondition}(\delta(\varphi)): D\varphi_{,x} - (ea)^2 (m_2 \ddot{\varphi}_{,x}) = 0 \quad (4d)$$

$$\begin{aligned} \delta(w): Dw_{,xxxx} &+ (ea)^2 \left( N^R w_{,xxxx} + \frac{d^3(N^R)}{dx^3} w_{,x} \right. \\ &\left. + 3 \left( \frac{d^2(N^R)}{dx^1} w_{,xx} + \frac{d(N^R)}{dx} w_{,xxx} \right) \right) \\ &- B(w_{,xx} + \varphi_{,x}) - N^R w_{,xx} + N^D - \frac{d(N^R)}{dx} w_{,x} \\ &- (ea)^2 \frac{d^2(N^D)}{dx^2} = (ea)^2 m_0 \ddot{w}_{,xx} - m_0 \ddot{w} \end{aligned} \quad (4e)$$

$$\begin{aligned} \text{Boundarycondition}(\delta(w)): Dw_{,xxx} - B(\varphi + w_{,x}) + (ea)^2 \left( \frac{d(N^R)}{dx} w_{,x} + N^R w_{,xx} \right) \\ - (ea)^2 m_0 \ddot{w}_{,x} = 0 \end{aligned} \quad (4f)$$

where

$$(A, D) = \int_A E(1, z^2) dA \quad (5a)$$

$$B = \int_A K_S \frac{E}{2(1 + \nu)} dA \quad (5b)$$

$$(m_0, m_2) = \int_A \rho(1, z^2) dA \quad (5c)$$

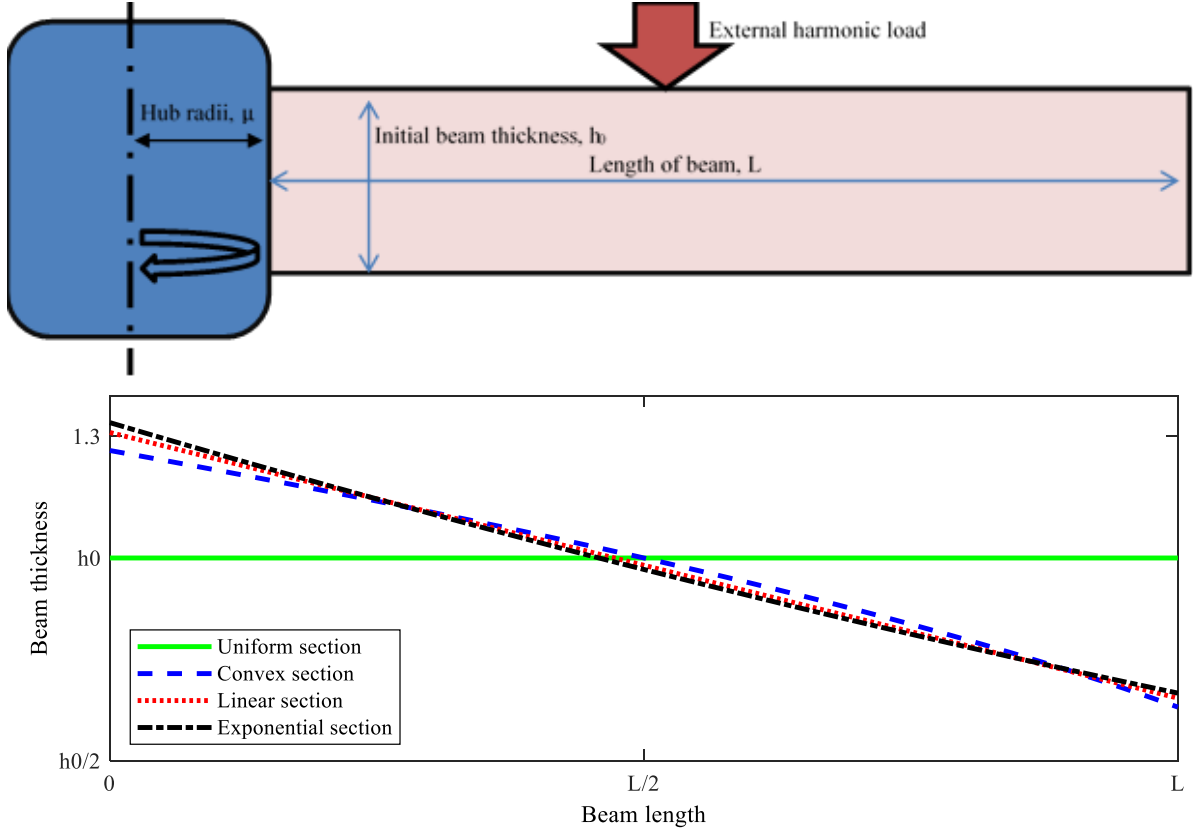


Fig. 1 Schematic of the spinning beam along with the various thickness functions.

In which ‘E’, ‘ $\nu$ ’, ‘ $\rho$ ’, and ‘ $K_s$ ’ are Young’s modulus, Poisson’s ratio, density, and shear correction factor. Moreover, the centrifugal force of rotation ( $N^R$ ), and the external dynamic load ( $N^D$ ) are defined as follows.

$$N^R = \int_x^L \int_A \rho \phi^2 (\mu + x) dA dx \quad (5d)$$

$$N^D = T \sin(\Omega t) \sin\left(\frac{n\pi}{L} x\right) \quad (5e)$$

where ‘ $\mu$ ’ is the hub radius, ‘ $\phi$ ’ is the rotation speed, and ‘ $T$ ’ is the external load (Ma *et al.* 2021, Hou *et al.* 2021b, Huang *et al.* 2021d, Liu *et al.* 2021d, Yu *et al.* 2022).

### 3. Methodology and solving procedure

A numerical approach is used to solve the time-independent eigenvalue problem, then, the time-dependent deflection results are computed based on the Newmark beta technique. According to the following assumption, the generalized differential quadratic method (GDQM) is utilized for the numerical method (Ghadiri *et al.* 2016a, b, c, d, Ghadiri and Shafiei 2016b, Shafiei *et al.* 2016b).

$$\bar{u} = u e^{i\omega t} \quad (6a)$$

$$\bar{w} = w e^{i\omega t} \quad (6b)$$

$$\bar{\varphi} = \varphi e^{i\omega t} \quad (6c)$$

For the eigenvalue problem, the following format will be used (Al-Furjan *et al.* 2020a, b, c, Bai *et al.* 2020, Li *et al.* 2020b, Zhang *et al.* 2020, Guo *et al.* 2021b, Liu *et al.* 2021b).

$$\omega = \frac{[K]}{[M]} \begin{Bmatrix} u \\ \varphi \\ w \end{Bmatrix} \quad (7)$$

where

$$[K] = \begin{bmatrix} A \frac{\partial^2}{\partial x^2} & 0 & 0 \\ 0 & D \frac{\partial^2}{\partial x^2} - B & -B \frac{\partial}{\partial x} \\ 0 & -B \frac{\partial}{\partial x} & [K]_{31} \end{bmatrix} \quad (8a)$$

$$[K]_{31} = D \frac{\partial^4}{\partial x^4} - N^R \frac{\partial^2}{\partial x^2} - \frac{d(N^R)}{dx} \frac{\partial}{\partial x} - B \frac{\partial^2}{\partial x^2} + (ea)^2 \left( N^R \frac{\partial^4}{\partial x^4} + \frac{d^3(N^R)}{dx^3} \frac{\partial}{\partial x} + 3 \left( \frac{d^2(N^R)}{dx^2} \frac{\partial^2}{\partial x^2} + \frac{d(N^R)}{dx} \frac{\partial^2}{\partial x^2} \right) \right) \quad (8b)$$

$$[K] = \begin{bmatrix} A \frac{\partial^2}{\partial x^2} & 0 & 0 \\ 0 & D \frac{\partial^2}{\partial x^2} - B & -B \frac{\partial}{\partial x} \\ 0 & -B \frac{\partial}{\partial x} & [K]_{31} \end{bmatrix} \quad (8c)$$

Table 1 Validity and comparison of the current study of the bending vibration frequency of rotating beam with the results of Fan *et al.* (2022),  $\phi \sqrt{\frac{L^4 m_0}{D}} \Big|_{x=0} = 2$

Present Timoshenko theory	Classic beam theory, Fan <i>et al.</i> (2022)	First-order beam theory, Fan <i>et al.</i> (2022)	Third-order beam theory, Fan <i>et al.</i> (2022)
4.1389182105	4.13737278	4.13613432	4.141702101

Table 2 The free frequency ( $\Xi$ ) of the spinning beam versus the rotating speed (Y) for the different functions of the cross-sections

	Uniform	Convex	Linear	Exponential
Y=0	2.805376157	5.37295981	5.542001059	5.573654832
Y=1	3.201494325	5.604995114	5.772041223	5.805265207
Y=2	4.160568168	6.245771613	6.40860761	6.445837828
Y=3	5.37346284	7.177846081	7.336947027	7.379238428
Y=4	6.690256525	8.293438446	8.450298921	8.497632242
Y=5	8.05202451	9.519233621	9.675152705	9.726981789
Y=6	9.43508375	10.81091671	10.96672709	11.02237037
Y=7	10.8292006	12.14266917	12.29883614	12.35765115
Y=8	12.2295703	13.49945555	13.65622037	13.717669
Y=9	13.63374365	14.87237466	15.02985182	15.09350293
Y=10	15.04037262	16.25602515	16.41426192	16.47977731
Y=11	16.44865635	17.64703498	17.80604124	17.87315649
Y=12	17.85808198	19.0432361	19.20300532	19.27150821
Y=13	19.26828622	20.44319409	20.60370542	20.67342827
Y=14	20.67898143	21.84593365	22.00716123	22.07796919
Y=15	22.08991262	23.2507755	23.4126904	23.48446777

On the basis of the GDQ methodology, the  $g$ -order derivative functions of ' $f$ ' should be reformed to the matrix form via the following equation (Zhao *et al.* 2021, Huang *et al.* 2021b, Jiao *et al.* 2021, Moradi *et al.* 2021, Xu *et al.* 2021).

$$\sum_{j=1}^q H_{ij}^{(g)} f(x_j) = \frac{\partial^g f(x)}{\partial x^g} \Big|_{x=x_q} \quad (9)$$

where

$$H_{ij}^{(g)} = g \left( H_{ij}^{(g-1)} H_{ij}^{(1)} - \frac{H_{ij}^{(g-1)}}{(x_i - x_j)} \right) \quad (10a)$$

$$H_{ij}^{(1)} = \frac{Y(x_i)}{(x_i - x_j) Y(x_j)} \quad (10b)$$

$$Y(x_i) = \prod_{j=1, j \neq i}^n (x_i - x_j) \quad (10c)$$

$$2x_i = L \left( 1 - \cos \left( \frac{\pi(i-1)}{(q-1)} \right) \right) \quad (10d)$$

The eigenvalues are the natural frequencies, which will be generated by assembling the boundary conditions into Eq. (7). Then utilizing the obtained frequencies, the time-

dependent dynamic response of spinning uniform and nonuniform beams will be calculated operating the Newmark beta approach (Liu *et al.* 2020a, Wang *et al.* 2020, Zhou *et al.* 2020, Dai *et al.* 2021, Guo *et al.* 2021a, Shao *et al.* 2021, Wu and Habibi 2021).

#### 4. Big data analysis

Big data analytics is the often-challenging process of analyzing massive volumes of data to find helpful information, such as hidden patterns, correlations, market trends, and customer preferences, that may aid businesses in making effective business decisions. Large-scale data analytics technologies and processes allow businesses to evaluate data collections and get new insights. Business intelligence (BI) queries give answers to essential questions about the operations and performance of an organization (Li *et al.* 2017, 2020a, 2022, Liu *et al.* 2021a, 2022, Lv *et al.* 2022, Wang *et al.* 2022a). Big data analytics is a kind of advanced analytics that entails complex applications powered by analytics systems that incorporate predictive models, statistical algorithms, and what-if analysis, among other elements. Scientific Organizations may apply big data analytics tools and software to make data-driven decisions that improve business outcomes. The benefits may include more efficient marketing, extra income opportunities, personalized customer service, and increased operational

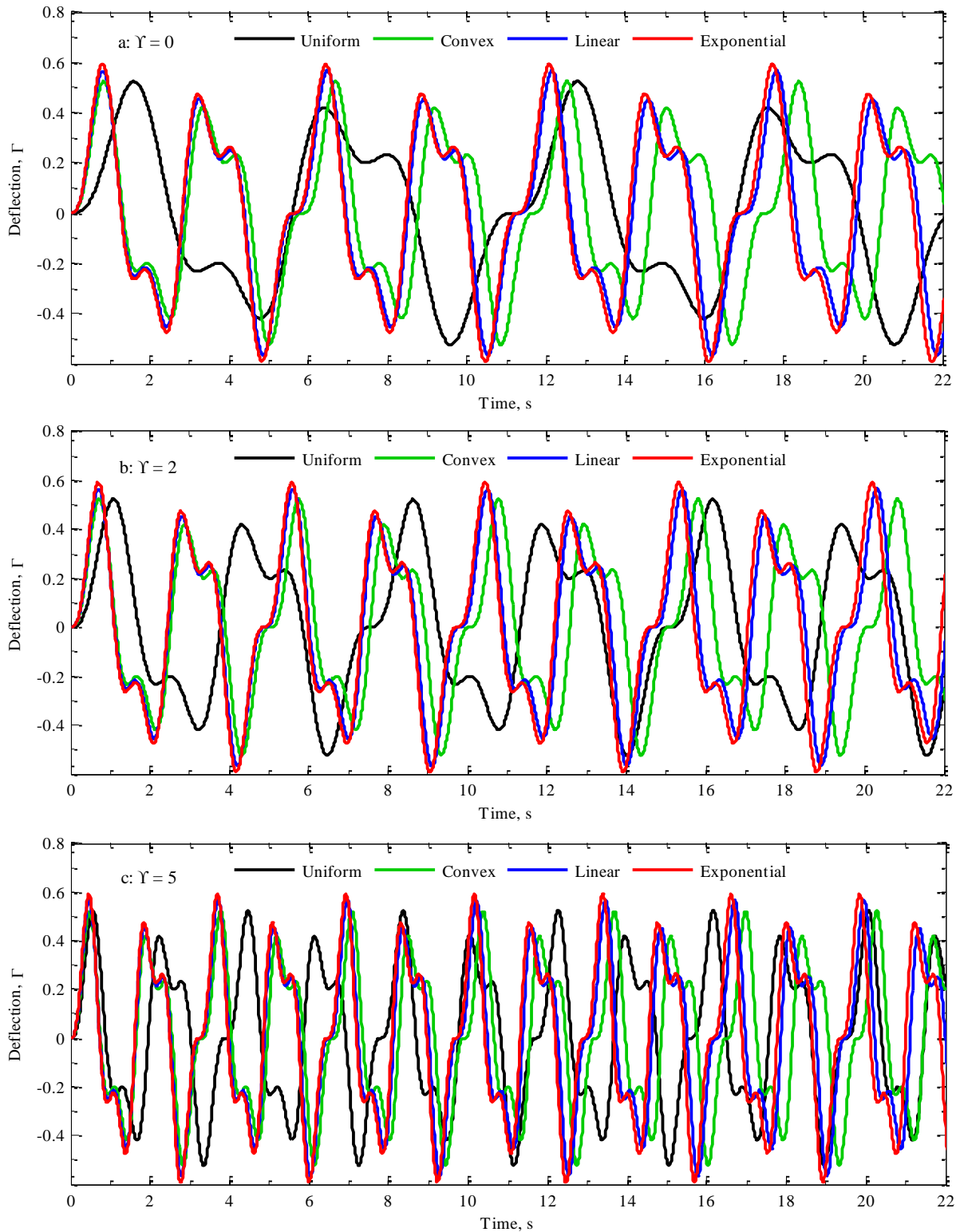


Fig. 2 The time-dependent dynamic deflection ( $\Gamma$ ) of the rotating-beam versus the angular velocity ( $Y$ ) along with the different cross-section,  $\Omega/\omega=0.4$

efficiency. When paired with a good plan, these advantages may offer a competitive advantage over rivals. Data from internal systems and external sources, such as weather data or consumer demographic data supplied by third-party information service providers, are often integrated into big data analytics applications. Furthermore, as customers want

real-time analytics on data fed into Hadoop systems using stream processing engines like Spark, Flink, and Storm, streaming analytics applications are becoming increasingly common in big data contexts. Primitive big data systems were generally deployed on-premises, particularly in significant organizations that collected, organized, and

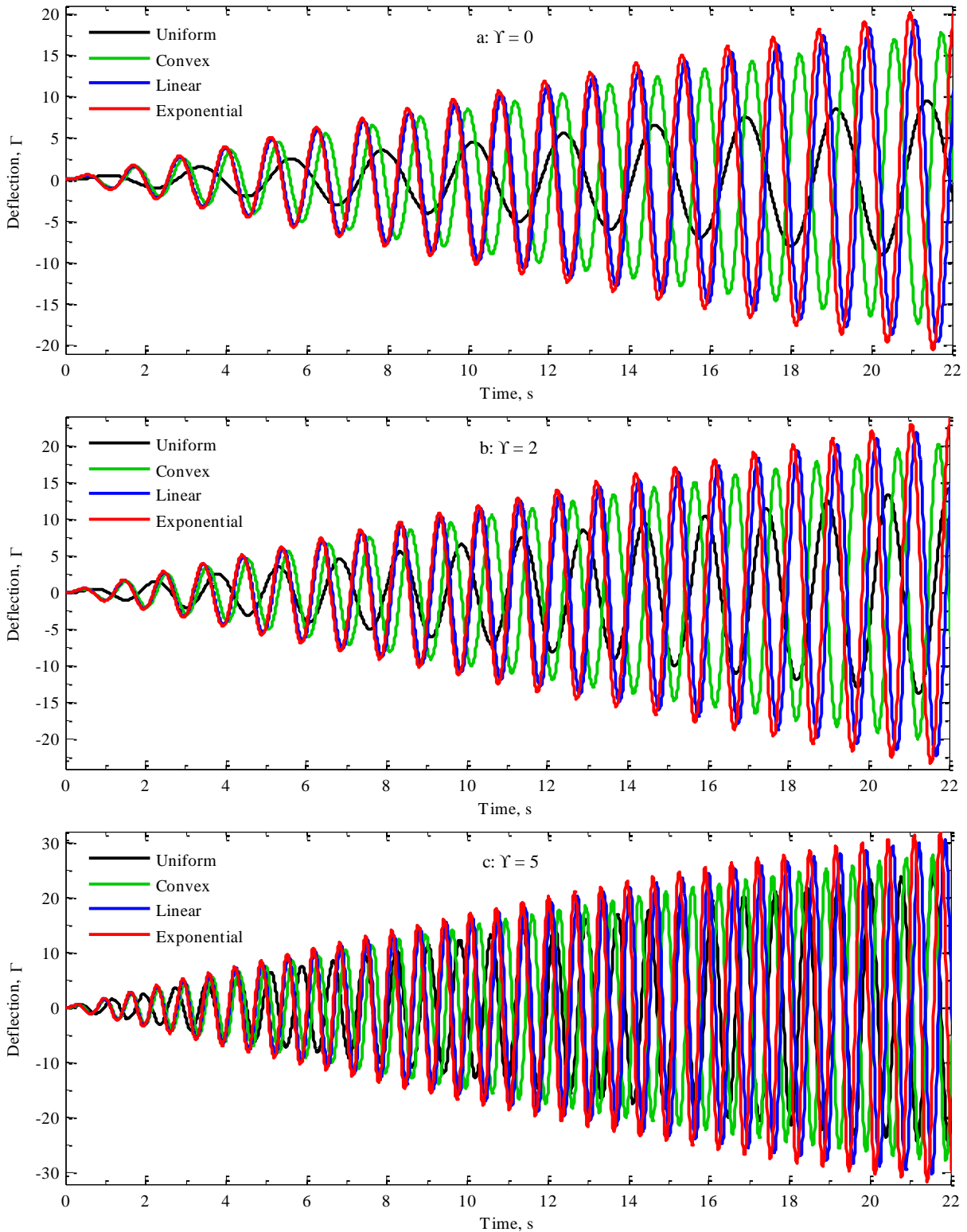


Fig. 3 The time-dependent dynamic deflection ( $\Gamma$ ) of the rotating-beam for different angular velocity values ( $Y$ ) and the different cross-section,  $\Omega/\omega=0.99$

analyzed massive volumes of data. Big data has become more helpful in supply chain analytics. Big supply chain analytics uses big data and quantitative methods to enhance supply chain decision-making. Big supply chain analytics expands data sets for better analysis beyond the conventional

internal data accessible in enterprise resource planning (ERP), and big data analytics for supply chains uses very effective statistical methodologies on both new and old data sources (Wang *et al.* 2022b, Xiao *et al.* 2022, Zhao *et al.* 2022, Zheng *et al.* 2022a, b, Zhong *et al.* 2022).

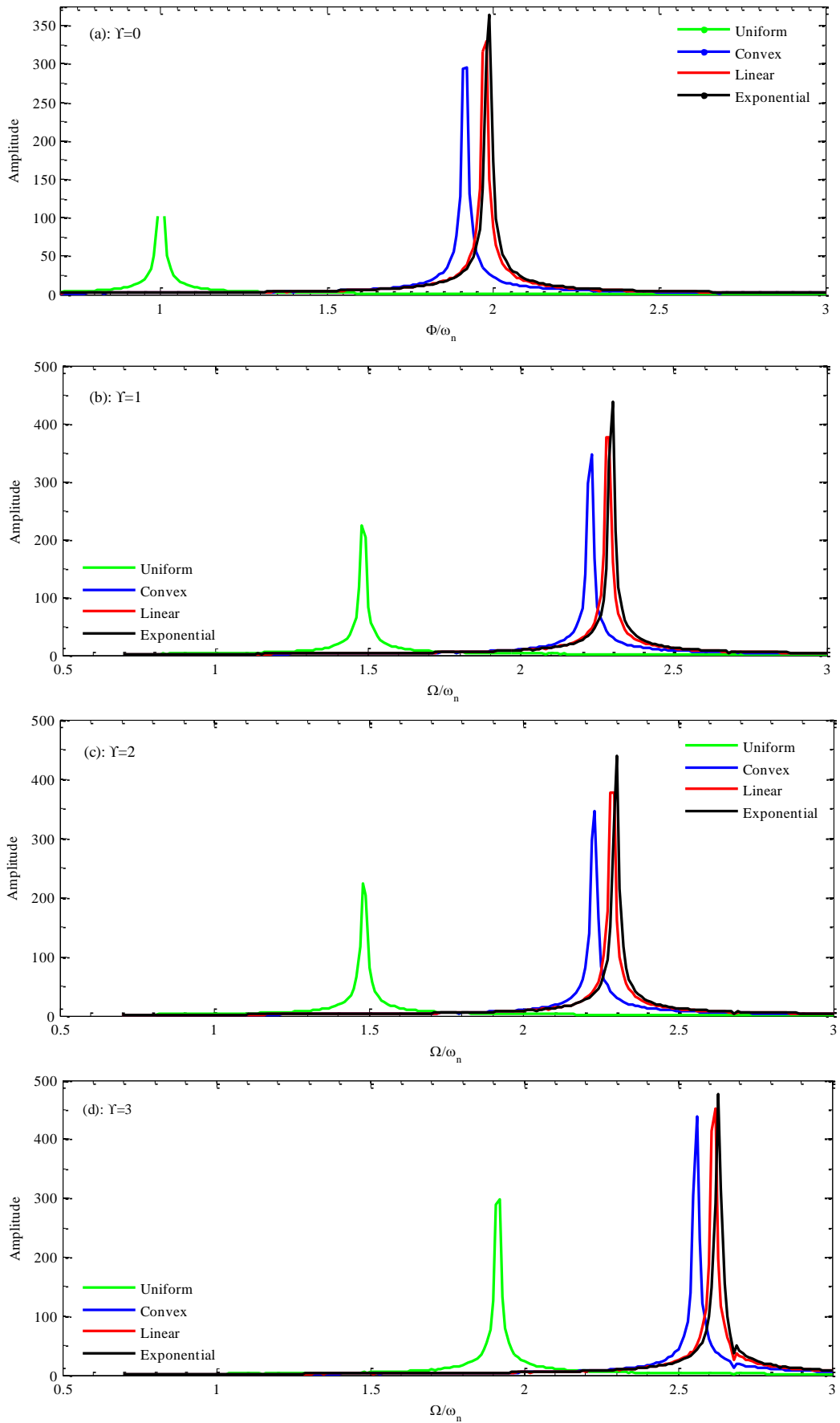


Fig. 4 The amplitude of dynamic deflection of spinning beams versus the rotating speed ( $Y$ ) and different function of the cross-section

Table 3 The fundamental frequencies ( $\Xi$ ) of the spinning propped cantilever beam versus the nonlocal parameter ( $\vartheta$ ) regarding the uniform and nonuniform cross-section beam,  $Y=1$

	Uniform	Convex	Linear	Exponential
$\vartheta=0$	12.53769718	13.57528514	13.9009615	14.09555434
$\vartheta=0.2$	12.53196992	13.56996371	13.89376558	14.08739156
$\vartheta=0.4$	12.51483362	13.55404261	13.87225136	14.06299468
$\vartheta=0.6$	12.48642374	13.52765046	13.83663669	14.0226351
$\vartheta=0.8$	12.44696282	13.49099852	13.78727837	13.96675632
$\vartheta=1.0$	12.39675573	13.44437603	13.72466217	13.89596017
$\vartheta=1.2$	12.33618336	13.38814401	13.64938984	13.81099007
$\vartheta=1.4$	12.26569491	13.32272789	13.56216411	13.7127099
$\vartheta=1.6$	12.1857991	13.24860895	13.46377137	13.60208153
$\vartheta=1.8$	12.09705462	13.16631496	13.35506376	13.48014082
$\vartheta=2.0$	12.00006026	13.0764109	13.23694059	13.34797377
$\vartheta=2.2$	11.89544465	12.97948903	13.11033054	13.20669344
$\vartheta=2.4$	11.78385654	12.87615957	12.97617464	13.05741884
$\vartheta=2.6$	11.66595519	12.76704165	12.83541085	12.90125564

## 5. Presentation of results

### 5.1 Mathematical results discussion

In this section, the numerical results of the mathematical simulation will be presented, but before the presentation, the validation of extracted equations as well as the numerical approach should be confirmed, the primary mathematical simulation of the current study is to investigate the vibrational response of the spinning nanobeam structures. So Table 1 provides the comparison between the present study with the results of Fan *et al.* (2022) for the free frequency of rotating cantilever beam. The comparison confirms the validity of the current generated equations and the operated numerical solution procedure.

To better describe the presentation of the results, the nondimensional parameters are presented as follows.

Dimensionless free frequency ( $\Xi$ ):

$$\frac{\Xi^2}{2} = \omega^2 L^4 \frac{m_0}{\pi D} \Big|_{x=0} \quad (11a)$$

Dimensionless rotating speed ( $Y$ ):

$$\frac{\pi Y^2}{L^4} = \phi^2 \frac{m_0}{D} \Big|_{x=0} \quad (11b)$$

Dimensionless deflection ( $\Gamma$ ):

$$\Gamma \times TL^4 = -w \times 10\pi D \Big|_{x=0} \quad (11c)$$

Dimensionless Hub radii ( $\eta$ ):

$$\eta L = \mu \quad (11d)$$

Dimensionless nonlocal parameter ( $\vartheta$ ):

$$\vartheta^2 L = (ea)^2 \quad (11e)$$

Table 2 provides the free frequency ( $\Xi$ ) of rotating

uniform and nonuniform beams for various velocities ( $Y$ ) along with the different functions of cross-section involving the uniform and nonuniform. Based on the presented results, the speed improves the beam frequency because of centrifugal force. Moreover, all rotating speeds, the nonuniform beams have a higher frequency, and they are more stable than the uniform beams. It is noted that the exponential type of cross-section provided the best frequency response among the nonuniform presented cross-section.

Fig. 2 shows the dynamic deflection of the rotating beam for various angular velocities as well as a different function of the cross-section when  $\Omega/\omega=0.4$ . The domain deflection of the uniform beam is lower than the nonuniform beams, while the uniform beam makes a higher period. The exponential beam provided the highest domain deflection and the most down period among the nonuniform beam sections. Also, it is noted that the angular velocity has no impact on the deflection domain, but the period of rotating-beam decreases via angular velocities.

Fig. 3 depicts the dynamic deflection of a rotating beam at various angular velocities, as well as a distinct function of the cross-section when  $\Omega/\omega=0.99$ . The uniform beam has a more negligible domain deflection than the nonuniform beams, but it has a more extended period. The exponential beam had the most significant domain deflection and the shortest cycle time among the nonuniform beam sections. It is also worth noting that although angular velocity does not affect the deflection domain, it reduces the spinning beam period.

Fig. 4 supplies the resonant response of the rotating beam for both uniform and nonuniform cross-sections regarding the different rotating speeds ( $Y$ ). It is shown that the nonuniform section delays the happening the resonant frequency. Also, among the nonuniform beams, the exponential section has the highest resistance concerning the resonance happening, and the convex type has the

Table 4 The first frequencies ( $\Xi$ ) of the rotating cantilever beam versus the hub radius ( $\eta$ ) along with the uniform and nonuniform function of the cross-section,  $Y=1, \vartheta=1$

	Uniform	Convex	Linear	Exponential
$\eta=0.0$	3.210052316	5.567957244	5.737845732	5.771007878
$\eta=0.1$	3.25892683	5.600106557	5.770557412	5.803666601
$\eta=0.2$	3.307067787	5.632069574	5.803081128	5.83613848
$\eta=0.3$	3.354506892	5.663849452	5.835420038	5.868426636
$\eta=0.4$	3.401273629	5.695449265	5.867573842	5.9005341
$\eta=0.5$	3.447395475	5.726872	5.899552424	5.93246382
$\eta=0.6$	3.492898088	5.758120672	5.931355152	5.96421867
$\eta=0.7$	3.537805459	5.789197883	5.962984849	5.995801444
$\eta=0.8$	3.582140078	5.820106495	5.99444427	6.02721486
$\eta=0.9$	3.62592307	5.850849184	6.025736093	6.058461571
$\eta=1.0$	3.66917426	5.88142856	6.056862927	6.089544156
$\eta=1.1$	3.711912345	5.911847163	6.087827316	6.120465133
$\eta=1.2$	3.754154937	5.942107464	6.118631739	6.151226953
$\eta=1.3$	3.795918671	5.972211876	6.149278611	6.181832007
$\eta=1.4$	3.837219267	6.002162752	6.179770287	6.212282627
$\eta=1.5$	3.878071606	6.031962383	6.210109067	6.242581087

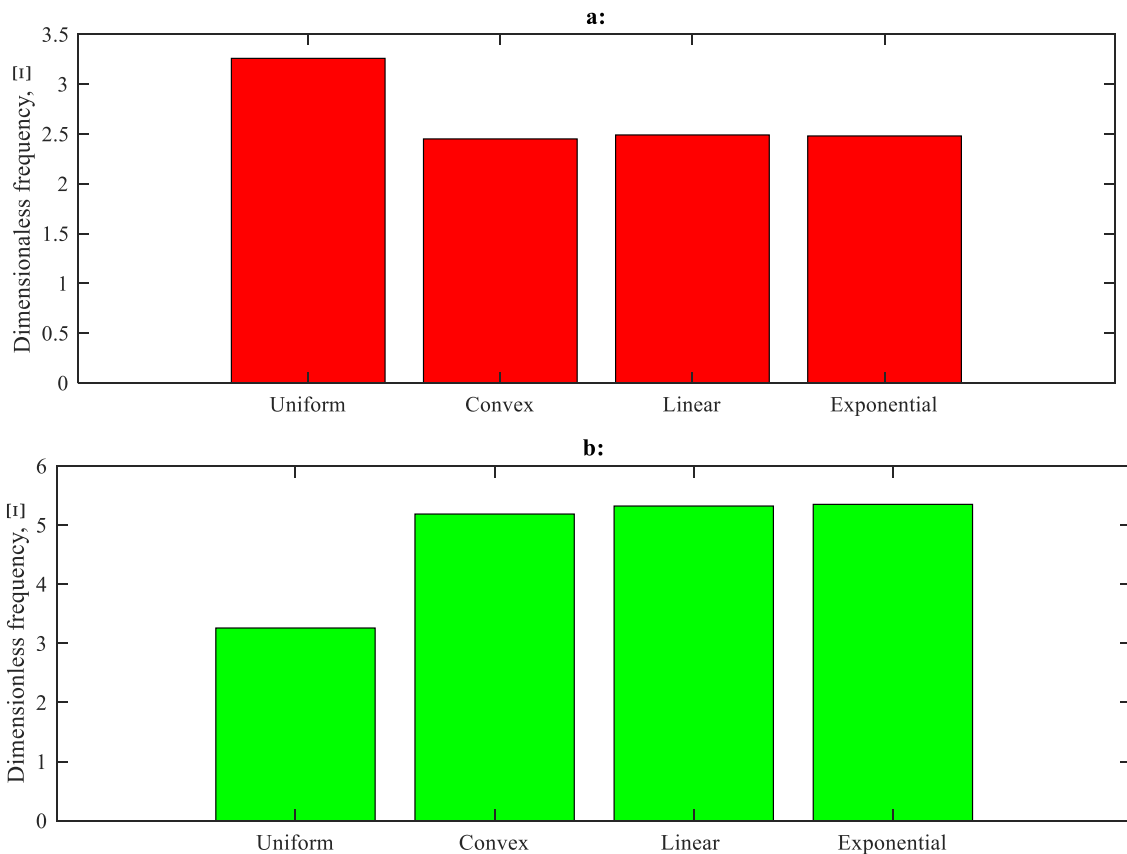


Fig. 4 The amplitude of dynamic deflection of spinning beams versus the rotating speed ( $Y$ ) and different function of the cross-section

lowest opposition regarding the resonance occurring. It can be seen that the resonant frequency delays via rotating speed in all shape functions of the cross-section.

Table 3 presents the nonlocal impact on the fundamental frequency ( $\Xi$ ) of propped cantilever rotating nanobeam for different nonlocal parameters ( $\vartheta$ ) concerning the cross-

section function, including the uniform, nonuniform convex, nonuniform exponential, and nonuniform linear section. The nonlocal parameter limits the frequency in all presented sections and decreases the stability of the beam. As was mentioned, the nonuniformity of sections improves the dynamic behavior of the rotating beam, and the nonlocal impact has no unexpected impact on the beam behavior, and the same response is seen in all presented nonlocal parameters.

Table 4 illustrates the nonlocal influence on the fundamental frequency ( $\Xi$ ) of a cantilever spinning nanobeam for various hub radii ( $\eta$ ) relating to the cross-section function, such as uniform, nonuniform convex, nonuniform exponential, and nonuniform linear sections. The hub radii improve the beam frequency by enhancing the centrifugal force and have no specific impact on the frequency response to the section change.

### 5.2 Economy description

This section is analyzed the obtained mechanical results based on the economic aspect. In order to have a better performance of the structures, especially in response to the thermal conductivity, fluid flow analysis, etc., the different cross-sections will be used, including the uniform and nonuniform sections. The nonuniform structures are usually operated by the thermal fins, fluid flow diffuser, fluid flow nozzle, thermal sensors, etc., including the linear, concave, or convex functions. Fig. 5 indicates the economic aspect of the present paper, which is shown the frequency response of the different spinning beam structures concerning the different cross-sections, where a: the economic aspects are neglected, b: the economic factors, including the same material production, are considered.

The economic aspect selects the best model regarding the finance view (Fig. 5b), nevertheless, by neglecting the economic characteristics (Fig. 5a), the uniform section predicts a higher frequency, however, it is not economical. In this view, the cost of production is neglected, and the aspect of the material used is the essential issue. As explained, both considered models have the same weight and equal length. The nonuniform nanobeam contains a higher frequency and predicts better stability than the uniform beams (Liu *et al.* 2020b, 2021c, Habibi *et al.* 2021, He *et al.* 2021, Huang *et al.* 2021a, Zhang *et al.* 2021). Also, the three practical functions of cross-section involving the nonuniform linear section, nonuniform convex, and nonuniform exponential section were used. Among the presented nonuniform sections, the convex section is more unstable than others, and the exponential section is the best function in response to the dynamic behavior of free and forced vibrational behavior of nanobeam.

## 6. Conclusions

The principal objective of this proposal was to explore the free and forced vibration behavior of rotating uniform and nonuniform nanobeams in terms of choosing the optimal economic model of cross-section using the same material. The precise weight and length of all anticipated

nanobeams were taken into account, which is the economic component of this research. Timoshenko theory of beams, as well as the nonlocal theory based on the Hamilton principle, were used to simulate the nanobeam. A numerical method combined with the Newmark beta technique is used to calculate the numerical findings. In the present research, a uniform beam as well as three actual nonuniform sections were investigated for all sections:

- The rotation speed decreased the period, improved free frequency, and delayed resonance happening.
- The nonlocal parameter limited the free frequency.
- The hub radii enhanced the beam stability.

In the economic view, the nonuniform sections provided a better stability and frequency response than the uniform section.

The nonuniform exponential section provided the higher frequency, and the convex section supplied the lower frequency than the other nonuniform section.

The resonance occurring in the nonuniform section is sooner than in the exponential section and is later than in the convex section.

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