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LOCALIZATION OF A LOCAL STIFFNESS DECREASE

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Abstract: *The article using an example of a FEM model describes decreasing tendency of natural frequencies in a context of a local reduction of beam stiffness for specific areas, named pliable regions. It is demonstrated that the drop in natural frequencies also depends on the location of the pliable region, because different curvatures of individual modes relate to a specific position on the beam, which are related to an extent of deformation during bending oscillation. Degree of curvature of modes has an effect on a degree of decrease of their corresponding natural frequencies. Based on these statements, the principle of locating the pliable region on the beam is formulated based on a comparison of drops ratio of natural frequencies of the considered model with the polynomially approximated ratios. This method of locating pliable regions can be used in practice to diagnose machines or structures using an impact test.*

Keywords: Natural frequencies, Modes, Diagnostics, Finite Element Method (FEM),.

1. Introduction

In technical practice, there are situations when in machines due to loosening of a connection, damage to integrity of a material, etc. there is a local decrease in a stiffness of the system. This local stiffness drop can serve as an indicator of damage or other deviation from the desired state of the device. Using of a simple FEM model in the ANSYS software and its analysis in MATLAB, the principle of localization of a pliable region with changed stiffness is described in a following chapters. (Musil et al., 2022) (Titurus et al., 2016) (Wei et al., 2011) (Zacharakis et al., 2023) (Huynh et al., 2005) (Musil 2003; 2006).

2. Description of a FEM model

The model consists of a straight beam made of BEAM3 elements, while the stiffness was reduced in certain regions of the beam using a change in Young's modulus of elasticity. These regions of the beam can be called pliable regions (PR) (Fig. 1).

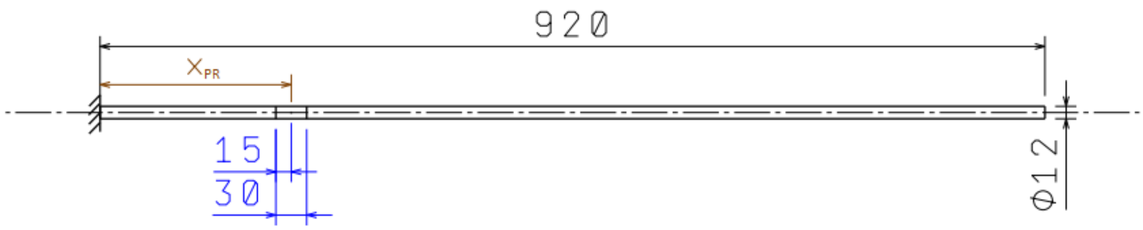

Fig. 1: Model with important dimensions and depicted PR.

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Young's modulus of elasticity related to PR represents a decrease in stiffness analogous to the diameter decrease Δd. This Young's modulus was derived based on the bending stiffness of the beam $k = 3EJ/l^3$. When the PR diameter is explicitly changed, the quadratic moment of the area would also be changed, which would affect the mass distribution in the system and that is not desirable. Therefore, the equivalent Young's modulus E_2 is expressed in (1).

$$E_2 = \frac{(d - \Delta d)^4}{d^4} E_1 \tag{1}$$

3. Principle of a localization of a region with changed stiffness

The method of locating PRs is based on three main assumptions:

1. The decrease of NFs is more significant if PR is located in an area with greater curvature of MSs,

2. The decrease of NFs with the increasing degree of loosening has a linear course or a course similar to a linear one for the considered model,

3. The similarity of assessed MSs to reference MSs is negligible.

Using the modal analysis of the model described above, 3.-8. bending NF and their associated MSs and modal characteristics were used in further analyses. When the local stiffness of the system changes, the modal parameters also change, specifically, the publication focuses on the decrease of NFs compared to the reference system without PR.

The possibility of PR localization is based on an assumption that if the PR is located in an area with a greater deformation during oscillation (a region with greater curvature), then the effect of a local stiffness change on the decrease of the NF belonging to a particular MS is greater than in an area with a lower deformation (a region with lower curvature). The curvature (c_{Nj}) obtained from the normalized MSs (v_{Nj}) is defined as:

$$c_{Nj} = \frac{d^2 v_{Nj}}{dx^2} = \frac{M_{Nj}}{EJ}, \qquad v_{Nj} = \frac{v_j(x)}{v_j(l)} \tag{2}$$

The 1st assumption is fulfilled, as the bending moment is directly proportional to the curvature.

For equivalent Young's modulus corresponding to small proportional reductions in the diameter of the considered beam, the decrease in NFs has a character similar to the linear Fig. 2. Therefore, the decreases of individual NFs will be in almost the same proportion to each other for a specific position of the beam for different rates of stiffness decrease.

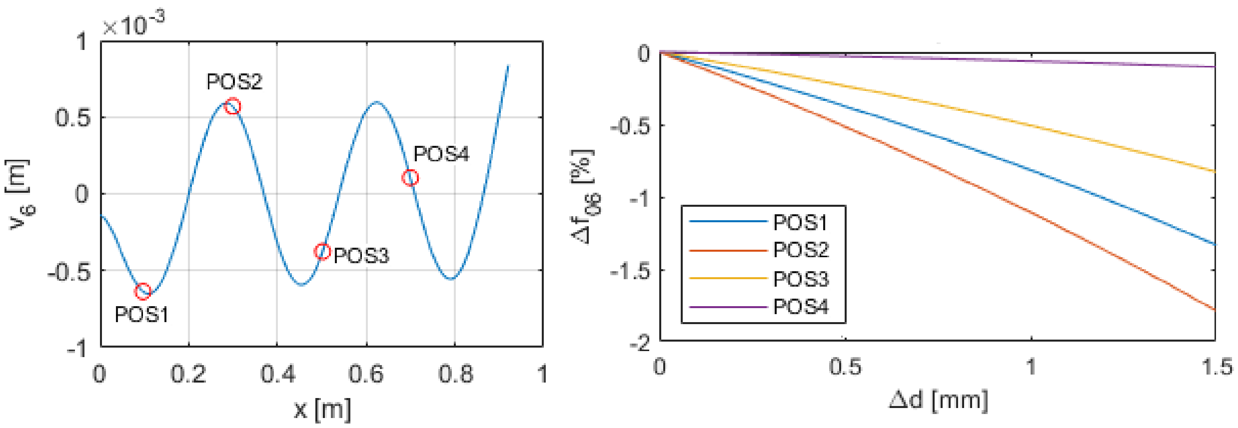

Fig. 2: 6th bending MS and corresponding NF decreases.

In the case of the beam under consideration, the similarity of the assessed MSs to the reference MSs is negligible. MAC criterion > 0.99 for all MSs with PR when compared to the MS model without PR.

Fig. 3 shows the course of the curvatures of the individual MSs and for the selected 10 positions, the NFs drops are assigned (Fig. 4).

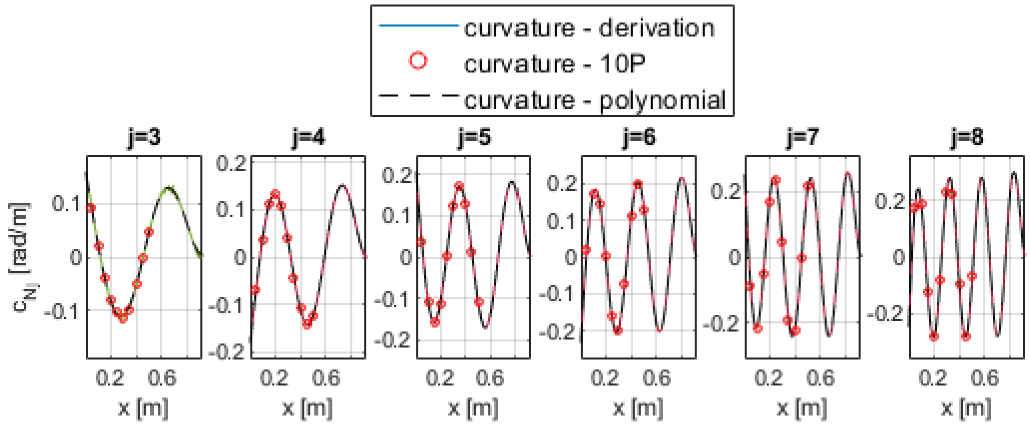

Fig. 3: Curvatures of MSs as functions of x.

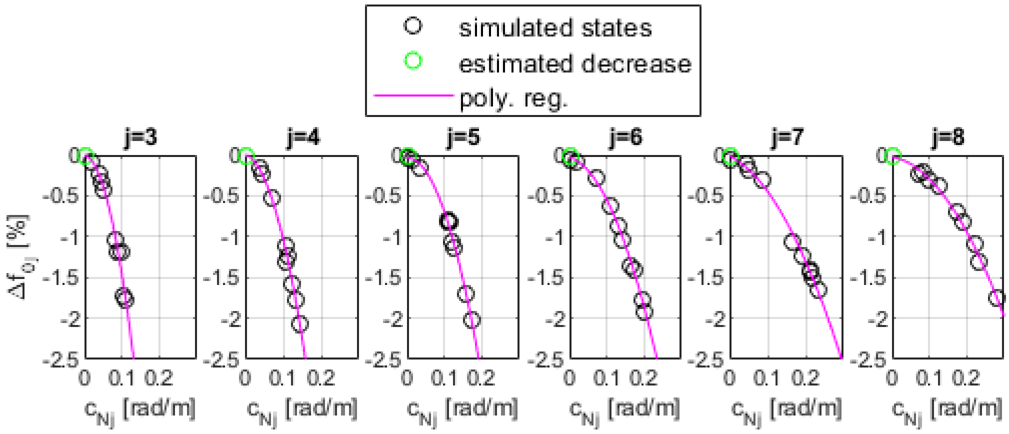

Fig. 4: Decreases of NFs as functions of a curvature.

Since it was possible to express the dependence between the curvature of the MSs with the position on the beam and also between the decreases in NFs and the curvature, it is possible to express the decreases in NFs as a function of the position on the beam (Fig. 5) according to relation (3), since the curvature is for this case defined as a 20th order polynomial ($n = 20$) of position and NFs drops are defined as a 2nd order curvature polynomial. There is an absolute value in the equation because only the amount of curvature affects the decrease of NFs, not the convex or concave character of the MS.

$$\Delta f_{0R\ j}(x) = A_j \left(\sum_{k=1}^{n} a_{kj} x^{n-k} \right)^2 + B_j \left| \sum_{k=1}^{n} a_{kj} x^{n-k} \right| + C_j \qquad (3)$$

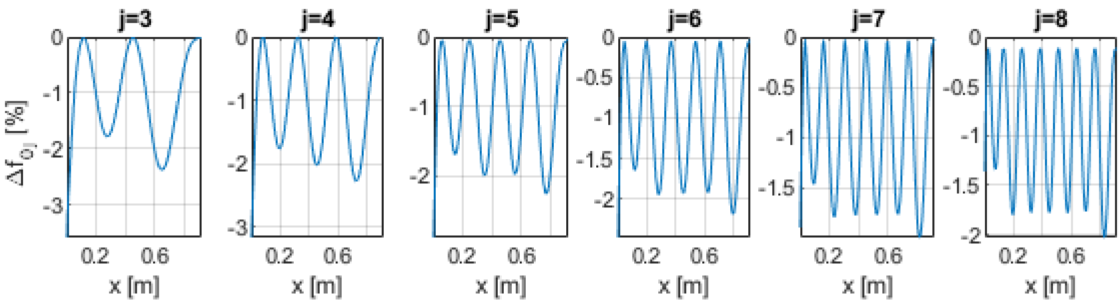

Fig. 5: Decreases of NFs as functions of x.

The relation (4) expresses the vector of the ratio of NFs drops for the reference model.

$$p_{Rj}(x) = 100 \frac{\Delta f_{0R\ j}(x)}{\Delta f_{0R\ 1}(x)} \qquad (4)$$

The vector of the NFs decrease ratio of the inspected model, which is obtained analogously, as well as the $p_{Rj}(x)$ vector, is compared with this vector. The relation (5) expresses the extent of differences between the ratios of these drops for all considered x of the system, and the value of x_{PR} in equation (6) expresses the position of the PR of the considered system.

$$p(x) = \left\| p_{Rj}(x) - p_{Ij} \right\| \tag{5}$$

$$p_{Rj}(x_{PR}) = \min(p(x)) \tag{6}$$

4. Conclusions

The output of the article is a creation of the localization method, which makes it possible to determine the location of damage or other form of local change in stiffness in the system. To demonstrate the correctness of the method, an example with release $\Delta d = 3mm$ in position $x = 0.7m$ is given. In Fig. 6 is a representation of the location function $p(x)$ as a function of position on the beam.

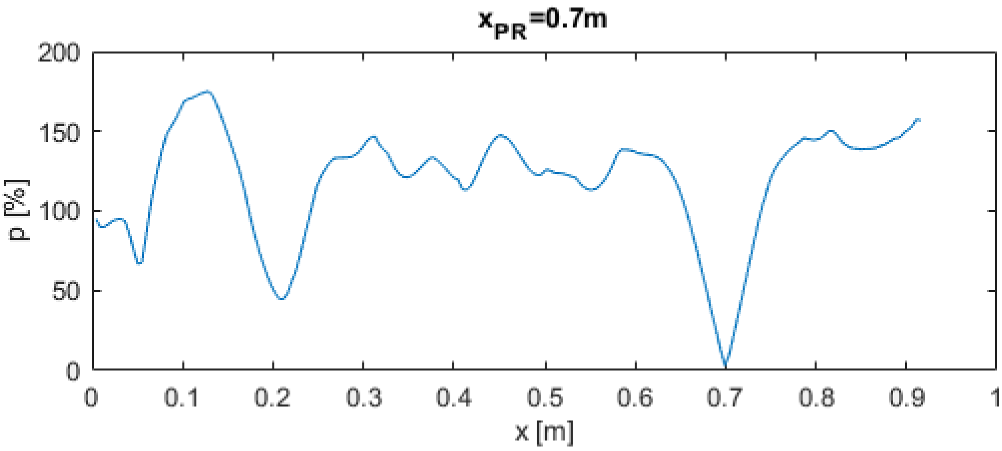

Fig. 6: Correlation function with respect to the reference model.

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References

Musil, M., Úradníček, J., Páleník, M. and Chlebo, O. (2022) Diagnostics of a Clamping Joint System, Strojnícky časopis - Journal of Mechanical Engineering 72(2):119-130, DOI: 10.2478/scjme-2022-0022

Titurus, B., Yuan, J., Scarpa, F., Patsias, S. and Pattison, S. (2016) Impact hammer-based analysis of nonlinear effectsin bolted lap joint. In Sas, P., Moens, D. and Van de Walle, A., eds., Proceedings of ISMA 2016-InternationalConference on Noise and Vibration Engineering and USD 2016-International Conference on Uncertainty inStructural Dynamics. Heverlee (Belgium) KU Leuven

Wei, F. and Pizhong, Q. (2011) Vibration-based Damage Identification Methods: A Review and Comparative Study, Structural Health Monitoring [1475-9217 (201101) 10:1; 83–29 10.1177/1475921710365419]

Zacharakis, I. and Giagopoulos D. (2023) Model-Based Damage Localization Using the Particle Swarm Optimization Algorithm and Dynamic Time Wrapping for Pattern Recreation. Sensors 2023, 23, 591. https://doi.org/10.3390/s23020591

Huynh, D., He , J. and Tran, D. (2005) Damage location vector: A non-destructive structural damage detection technique. Elsevier Ltd. All rights reserved. doi:10.1016/j.compstruc.2005.03.029

Musil, M. (2003) Crack localisation and quantification based on measured vibrations. In Tenth International Congress on Sound and Vibration, ICVS 10. Stockholm : KTH Royal Institute of Technology, 2003, s.nestr. In database: SCOPUS.

Musil, M. (2006) Localization and quantification of breathing crack. In Journal of Dynamic Systems Measurement and Control-Transactions of the ASME. Vol. 128, No. 2 (2006), s.458-462. ISSN 0022-0434 (2006: 0.658 - IF, Q3 - JCR Best Q, 0.640 - SJR, Q1 - SJR Best Q). In database: SCOPUS.