EAN 2012
50th annual coference on experimental stress analysis

Identification of the mechanical properties of the cervical implant material

Petr Henyš[1], Jan Škoda [2]

Abstract: The aim of this paper is the identification of mechanical parameters of cervical implant material and the mechanical structure. This mechanical structure was designed for measuring the biomechanical interaction between the implant and the surrounding bone. The main idea of this device is based on the dynamic response of connected structure. It is important to know how and how much the parameters of structure response depend on the boundary conditions which are represented by the surrounding bone or another support. Boundary conditions will be represented by two cases. In first case will be described linear model of boundary condition and in second case will be described non – linear model. It is necessary to know how the linearities or non-linearities influence the response of the structure and where the non-linearities can occur. Will be described the experimental device and its mathematical model. The cervical implant will be represented as a connection between the surrounding bone and the mechanical structure. By the comparison the numerical simulation and experimental data will be identified the parameters of simplified mathematical model. Experimental device will be put to the dynamic excitation and the response of system will be measured.

Keywords: Finite element analysis; Experimental analysis; Implant stability; Response function;

1. Introduction

The measure of the mechanical stability of cervical implant is crucial question still. The stability of spinal implant is one of most important conditions for successful surgery. Nowadays, there are not any ways how to describe the stability and give about it some information to surgeon. So, during the operation, surgeon can check the stability of implant only by his experience or he can try to guess it. For measure the stability of spinal implant was designed a simple device. The dynamic response is obtained from FFT. There is a relation between spinal implant stability and response progress of connected mechanical structure. We suppose there are several factors influenced the response function also. It mostly means the influence of non-linearities which can affect the dynamic response and accuracy of implant stability evaluation and different boundary stiffness and damping.

[1] *Ing. Petr Henyš; Department of Aplied mechanics, Technical university of Liberec; Studentská 2, 46117 Liberec 1, Czech Republic; petr.henys@tul.cz*
[2] *Ing. Jan Škoda.; Department of Aplied mechanics, Technical university of Liberec; Studentská 2, 46117 Liberec 1, Czech Republic; jan.skoda@tul.cz*

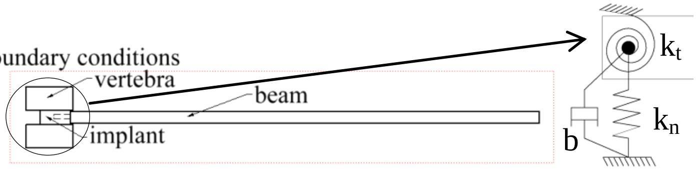

Fig. 1. The boundary conditions represented by the springs and damper

2. Composing the mathematical model

The boundary conditions are represented by the springs, which have properties according to used material. It is showed that the stability of implant affects the boundary stiffness and damping. Thus in the model is expected that the stiffness k_n, k_t and dumping b will be used as a function. The model is represented by the beam with different boundary conditions.

The boundary stiffness and damping represent the implant stability. If the stability is increasing the stiffness is increasing too.

Numerical model was created by finite element method. The model of beam with dependent boundary was created. There were used measured properties of material in support of the beam. In first case was simulated linear model. There were used a physical discretization. This method is suitable for linear system. We can get by this method the response at steady state vibrations.

2.1. Modal characteristic of the beam

In the graph 1 is showed a resonant frequencies.

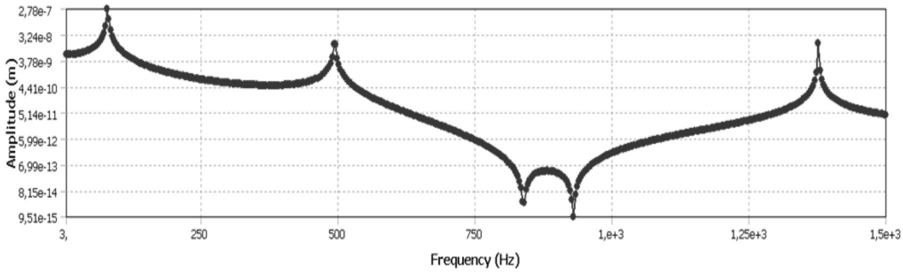

Fig. 2. Harmonic response created by finite element method

In the second step was created modal analysis for obtaining the response function (Fig. 3). We can see that resonance frequencies are very similar. First resonance is about 84Hz, second about 500Hz and third about 1480 Hz. In these three resonances we measure the dependence on the boundary stiffness and boundary damping.

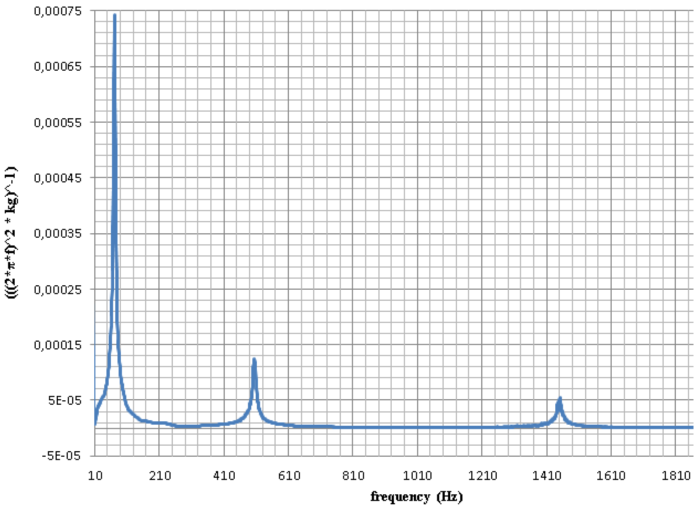

Fig.3. Frequency response function of the beam

2.2. Discrete model of the beam

The next was created the model of discretized beam and different boundary stiffness and damping were applied. The beam was divided to several parts (mostly used 12 for calculations) with 2 degrees of freedom (vertical translation and rotation) connected together by linear springs and dampers. Boundary stiffness and damping is represented by torsion and normal springs and dampers which connects one end of beam to the ground.

This model was used to derive the frequency responses with respect to different parameters of boundary conditions. As we can see in Fig.4, if we increase boundary stiffness than natural frequencies are moved to higher frequency. In the Fig. 5 there is illustrated the effect of change of the boundary damping, if the damping is decreased the amplitudes of the stable state vibrations are increased.

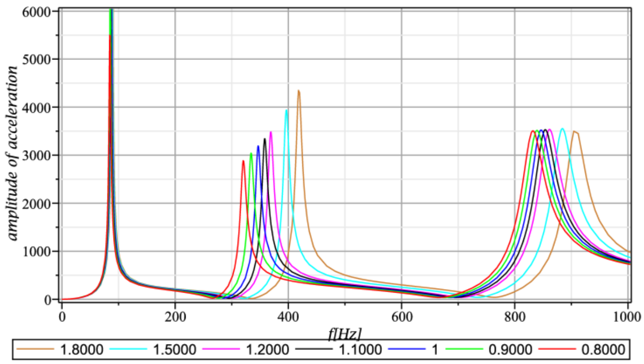

Fig.4. Frequency response function with respect to multiplication of boundary stiffness

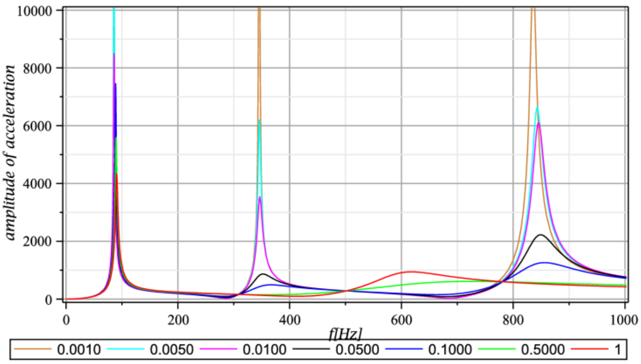

Fig.5. Frequency response function with respect to multiplication of boundary damping

3. Experimental results

In the Fig. 6 we can see, what happened when we applied the force in the support of beam. Dashed curve means the state after load. We can see that the resonance is moved to higher frequency and the amplitude is rapidly increased. In the graph is showed the frequency response for the sweep signal. The middle resonance (about 580Hz) is not beam resonance but it is resonance of the actuator. It is shown that the second and third measured resonances are moved to lower frequency if we use more elastic material in the support. First resonance was not measured because the excitation system is based on the inertia force and below 100 Hz exciting force was very small.

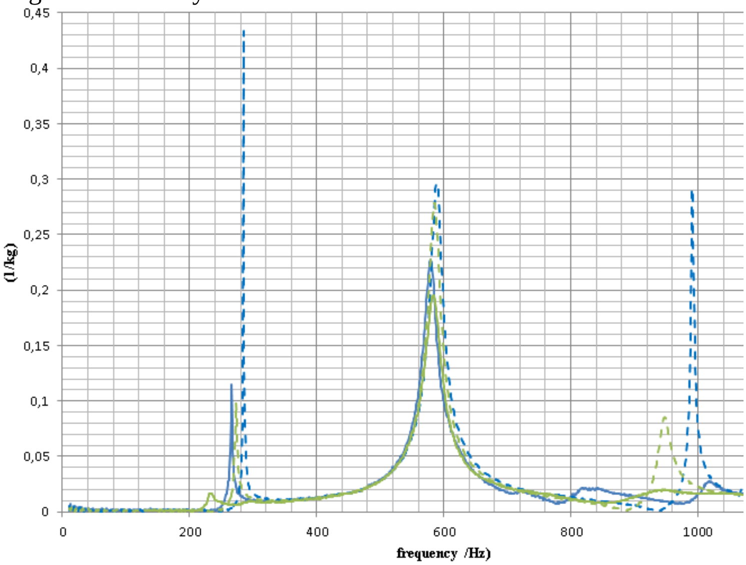

Fig. 6. Response function of the beam (blue: k = 45N/mm, green: k= 10N/mm).

Comparing the experimental results and frequency responses of the linear model we can say that preload of material in the beam support causes the small increase of its stiffness and decrease of its damping. It proves that the material behavior is nonlinear.

4. Nonlinear boundary conditions

In last step was created the situation with non-linear boundary. There were created simple model with nonlinear stiffness and damping presented by this formulation:

$$F_k = k_0 x + \varepsilon_1 k x^3 \text{ and } F_b = b_0 \dot{x} + \varepsilon_2 \tanh(c\dot{x}),$$

where F_k, F_b are forces in the boundary, variables k_0 b_0 are static values, parameters $\varepsilon_1, \varepsilon_2$ are small and parameter c = 1800. Damping characteristics has higher slope around zero velocity and slope equal to damping applied in linear case for higher velocities. In this model we study how this type of nonlinearity affects the natural frequency and if we should remember its effect when we measure implant primary stability. In figure 7 are compared spectra of the free vibration at transient state of linear model and model with applied nonlinear boundary condition described above.

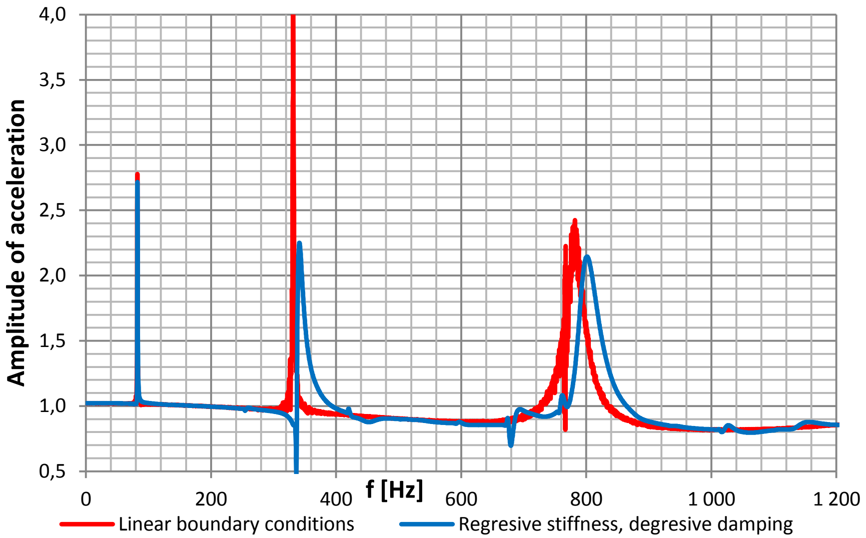

Fig.7. Acceleration spectra of the free end of beam on free vibrations

Fig. 7 illustrates that weak non-linearity of boundary conditions affect the amplitudes especially of second resonance also the magnitudes of second and third resonance frequencies are impacted. Bigger non-linearity of stiffness causes lower amplitudes of second and third resonance and higher frequency shift of the third resonance. Damping characteristic with lower linear part causes higher amplitudes of 2^{nd} and 3^{rd} resonance and lower amplitude of 1^{st} resonance.

5. Conclusion

In this paper were presented the base of measuring the implant primary stability by the modal and harmonic analysis. Similar method was already used in the case of hip replacement [2]. For the first time was created simple model with the elastic support and the stiffness in this support was changed in the percentage of k = 45N/mm. However can be the real stiffness non-linear, for the small amplitude of vibration we can expect linear behavior. But from the other hand, if we apply a force in support we change the stiffness but statically. Thus it means that in the model we can only change the value of stiffness, because it depends on the vibration displacement as a linear function. We can also measure amplitude dependence on the boundary damping. It seems to be that if apply a force in support, the boundary damping is changed. In the real model we can see that the resonant amplitudes increase if we apply the force. So, there are two ways how to associate stability of implant with evaluation of the response function. We suppose it is possible to find a relation between primary stability of the implant and the response function of the connected structure. In this paper we found the clear relation between boundary stiffness, damping and response function but in the real case (in vivo) we must use a statistical method for evaluating the relation between primary stability and the response function because we know that each patient is individual.

Acknowledgements
This work was supported by national financial resources of Ministry of Education of Czech Republic for specific university research.

References

[1] Gurgoze M., Erol H., “Dynamic response of a viscously damped cantilever with a viscous end condition,” ,*Journal of Sound and Vibration*, **298**, pp. 132-153 (2006)

[2] Elena V. , Ewa B. , Maurizio L. , Angelo C., Luca C., “Assessment if implant stability of cementless hip prostheses through the frequency response function of the stem-bone system”, Available from http://www.sciencedirect.com/science/article/pii/S0924424710003870, 2012 – 04 - 09