Non-linear dynamics of the temporomandibular joint disc

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Abstract. The paper presents issues related to the identification of a non-linear mathematical model of the temporomandibular joint disc. Laboratory tests consisted in reflecting the mechanical characteristics of the articular disc. Regarding the verified and optimized model, which very well reflects the results of the laboratory experiment, model tests were carried out. Numerical simulations included, among others, plotting a multi-colour map of distribution of the largest Lyapunov exponent, on the basis of which, the areas of occurrence of periodic and chaotic solutions were identified. Bifurcation diagrams of steady states were generated for sample sections of Lyapunov's map and phase flows of periodic and chaotic solutions were presented.

Introduction

The articular disc is an integral element of the temporomandibular joint, which is one of the most complex joints in the human body. These are two points of support, formed by the heads of the condylar processes, performing interconnected complex spatial movements in time, whose heads move on the shape-shifting sockets. The loads acting on the tissues of the articular discs, from a theoretical point of view, can be classified into two types of loads: static and dynamic. Static loads occur when the dental arches are clamped. On the other hand, dynamic loads take place during the act of chewing. The results of experimental studies indicate that, regardless of the deformation zone, the stress in the tissues of the articular disc decreases with each cycle. In addition, with each subsequent load cycle, the hysteresis loop decreases, which results in the loss of dissipation properties [1,2].

Model and experimental research

The results of the model research presented in the paper focused on the formulation of a mathematical model that reliably reproduces the behavior of the articular disc tissues subjected to cyclic loading. The disc model was mapped using a system with two degrees of freedom, consisting of a non-linear elastic element and two non-linear dissipation members. The measurement data were recorded in laboratory conditions, using the Zwick universal testing machine, through which the tissues of the articular disc were cyclically loaded.

The conducted numerical experiments indicate that the proposed mathematical model of the articular disc very well reflects the course of experimental research. The compatibility of the simulation results with the measurement data is at the level of approx. 98%.

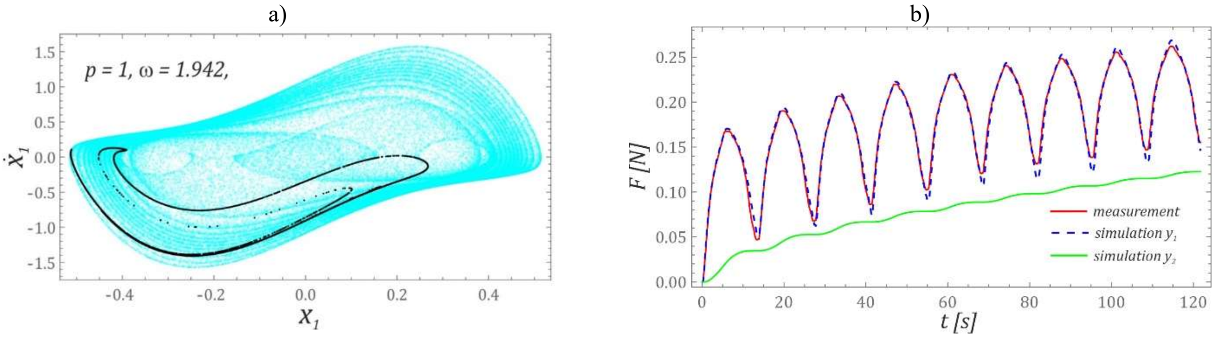

Figure 1: Exemplary results showing a) chaotic solutions, b) verification of mathematical models of temporomandibular joint discs.

At the beginning of the model research, we focused our attention on determining the zones of occurrence of chaotic solutions [3]. Then, for selected values of the amplitude of the external dynamic load acting on the disc tissues, steady-state bifurcation diagrams were plotted. We analyzed the effect of the frequency and the dimensionless amplitude of the external load acting on the tissues of the joint disc. The results of the numerical experiments are presented in the form of stable orbits against which the points of the Poincaré cross-sections are plotted. The last element, which was the subject of model tests included in the paper, was the identification of coexisting solutions. We proved that chaotic system responses and multiple solutions most often occur in the range of low values of the dimensionless amplitude of the external load.

References

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