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OPTIMAL STIFFNESS OF MECHATRONIC STIFFNESS

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Abstract: *The paper deals with the application of the concept of mechatronic stiffness for the design of a mechanism of aircraft wing that is capable to provide both morphing of aircraft wing profile and its aeroelastic control. It requires the wing structure to have both low stiffness for morphing with small forces and high dynamic stiffness with good aeroelastic properties. Such different demands can be satisfied by mechatronic stiffness. The development of mechanism for aircraft wing morphing and its aeroelastic control is briefly described. However, the optimal choice of stiffness of auxiliary construction and its possible deformation is formulated and solved. The optimal stiffness of auxiliary structure of mechatronic stiffness as the key result of the paper is described.*

Keywords: Dynamic stiffness, Mechatronic stiffness, Actuator force authority, Auxiliary structure, Morphing

1. Introduction

The concept of mechatronic stiffness Valasek (2014) has improved the dynamic stiffness of compliant mechanical structures Necas (2007). The advantage of this concept is the efficient use of actuator force when acting on a mechanical structure. The actuator force effect has a transfer ratio of one and higher. Therefore this concept has been extended towards the control of the deformation of the load-bearing structures Valasek (2024). And this extended concept has been applied for design of morphing mechanisms of aircraft wings. The space inside the wing for the construction of the morphing mechanism is limited and this opens the question of the optimal choice of mechatronic stiffnesses, which has not yet been addressed. This paper is devoted to that.

2. Mechatronic stiffness

The concept of mechatronic stiffness originated within a project for suppression of deformation of quill of machine tools. The quill (Fig, 1 left) is a beam with a cutting tool that machines in the cavity of the workpiece. The quill is deformed by gravity and cutting forces, i.e. disturbance forces. Traditionally, this deformation is compensated by a horizontal actuator at the quill root, but then the ratio of disturbance and actuator force is 10 and more. The ideal solution would be a frame support below the disturbance force, but that is not possible because the quill is inside the cavity. This contradiction is resolved by the concept of mechatronic stiffness (Fig. 1 right). The concept is following. Mechanical construction/structure is equipped with concurrent auxiliery structure and both structures are connected in connecting points by

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one or more actuators that are controlled based on deformation/motion of connecting points The ratio of disturbance and actuator force is 1 and less.

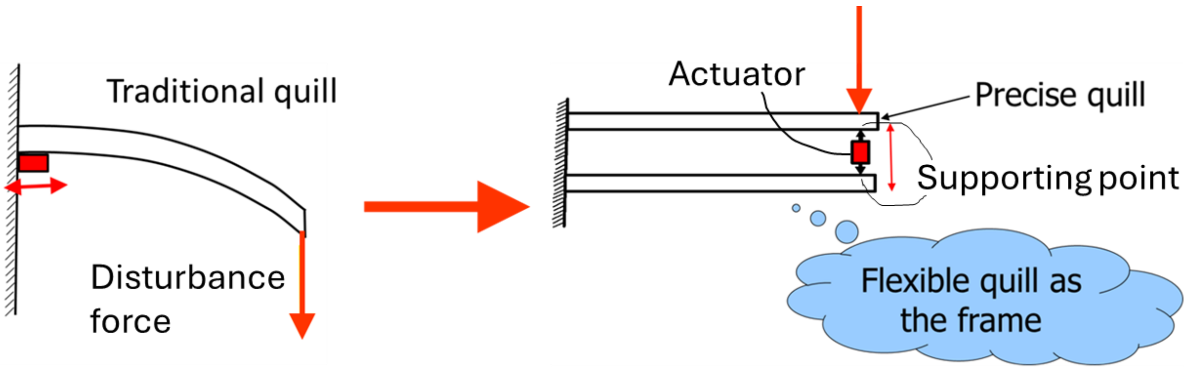
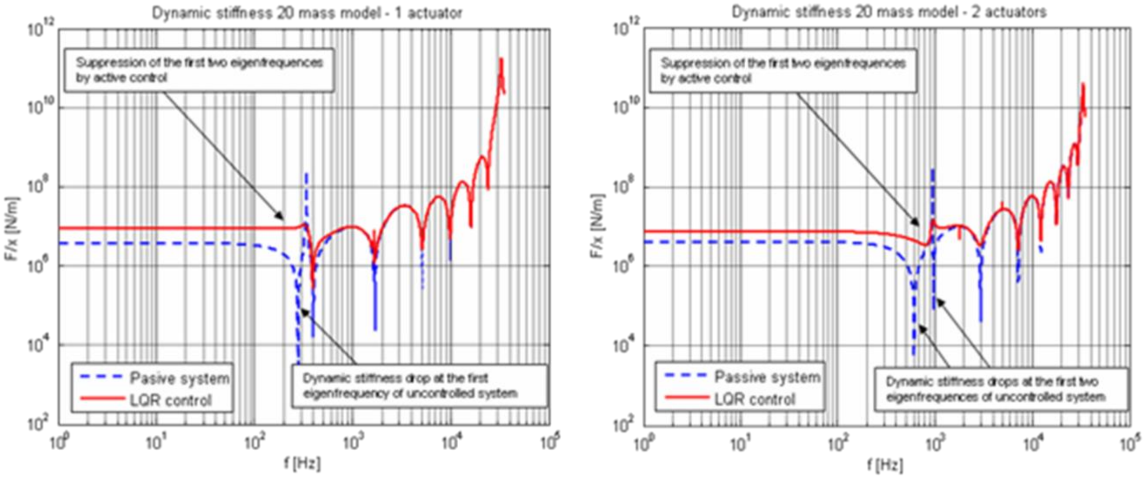


Fig. 1: Concept of mechatronic stiffness.

The comparison of frequency response of both structures from Fig. 1 is in Fig. 2. One actuator removes the influence of one eigenfrequency. Two actuators remove the influence of two eigenfrequencies. The resulting dynamic stiffness is increased by ten times.



One actuator

Two actuators

Fig. 2: Frequency response of mechatronic stiffness.

The mechatronic stiffness is advantageously made as a tube in tube (Fig. 3).

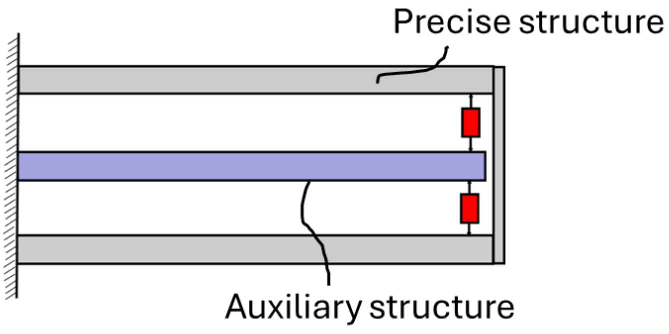


Fig. 3: Mechatronic stiffness as a tube in tube.

3. Mechanisms for control of deformation of structures

The change of shape of structures requires certain deformation force that is equivalent of disturbance force at mechatronic stiffness. The advantage of ratio of disturbance and actuator force being 1 and less is used for concepts of mechanisms for control of deformation of structures. The concept of mechatronic stiffness as a tube in tube in Fig. 3 can be immediately used for mechanisms for control of deformation of precise structure in Fig. 4. Based on that a morphing mechanism of aircraft wing trailing edge in Fig. 5 was developed. This mechanism provides not only morphing but also aeroelastic control capability.

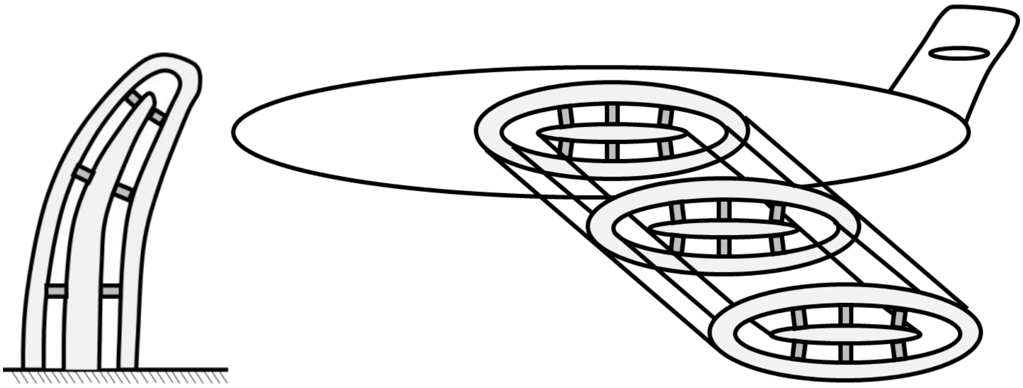


Fig. 4: The concept of mechatronic stiffness used for deformation of blades or wings.

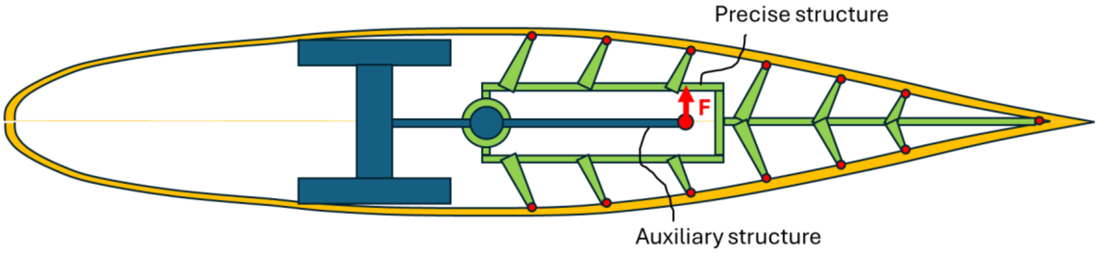


Fig. 5: The morphing mechanism of trailing edge of aircraft wing.

4. Optimal stiffness of auxiliary structure

Thus the mechanism from Fig. 5 has two functions: applying force F and morphing motion. The application of the force F creates the deformation of the auxiliary structure and this deformation is limiting the possible morphing motion (Fig. 6). The deformation of auxiliary structure is given by its thickness and available space for the deformation (Fig. 7).

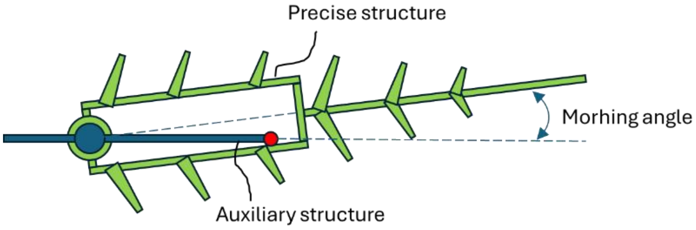


Fig. 6: Limited possible morphing motion.

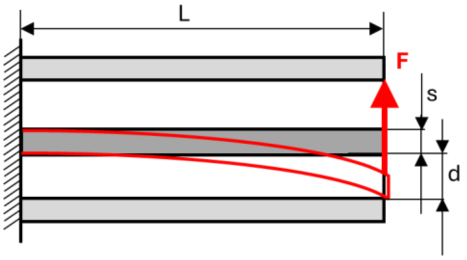


Fig. 7: Deformation of auxiliary structure.

For simplicity let us suppose that both precise and auxiliary structures are beams with rectangular cross sections. The sum of height of auxiliary structure s and the available height for deformation d is limited by the size Lim (Fig. 7)

$$s + d = Lim \tag{1}$$

The maximum possible deformation d of cantilever beam of length L by the force F with width b is

$$d = \frac{FL^3}{3EJ}, \quad J = \frac{1}{12} bs^3 \tag{2}$$

Substituting into (1)

$$s + \frac{4FL^3}{Ebs^3} = Lim \tag{3}$$

Expressing the force F and finding its optimum

$$F = \frac{Eb}{4L^3}(Lim\,s^3 - s^4) \tag{4}$$

$$\frac{dF}{ds} = \frac{Eb}{4L^3}(3Lim\,s^2 - 4s^3) = 0 \tag{5}$$

It gives the optimal size of height s and space d

$$s = \frac{3}{4}Lim, \quad d = \frac{1}{4}Lim \tag{6}$$

The dependence of force F on the thickness s and the extreme is in Fig. 8. It is evident that the optimal choice influences the accessible loading force significantly. The possible ratio <0,27> of optimal/non-optimal forces is quite large.

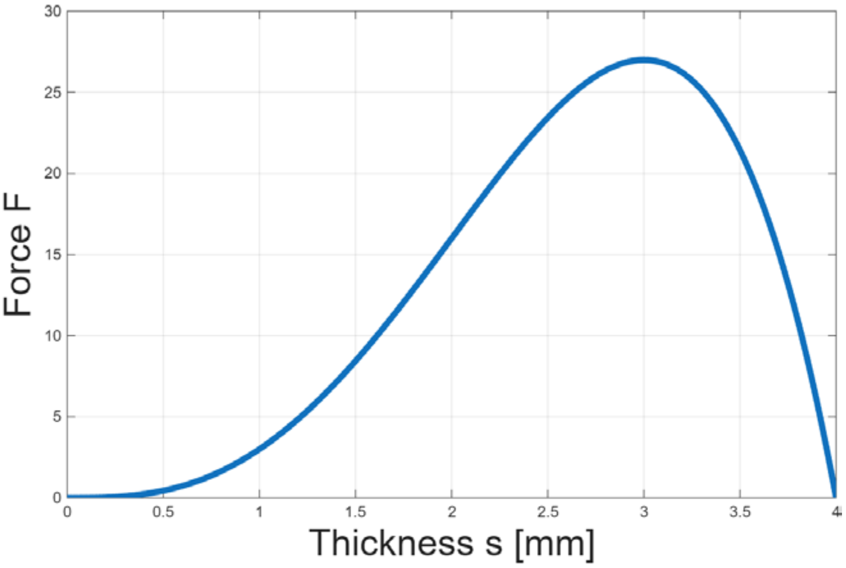


Fig. 8: Dependence of force F on thickness s.

5. Conclusions

The paper describes the optimal dimensions of mechatronic stiffness used for combined mechanism for morphing and aeroelastic control of aircraft wing. The contribution of the optimization is quite large, The development of such mechanism from the concept of mechatronic stiffness is included.

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