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Modifying the Shape of Blades of a Flexible Reed in a Vibration Beat-up Mechanism – Theoretical Investigation

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Abstract
The beat-up mechanism of a loom with exciters for vibrating motion of the reed is presented. With the placing of exciters at regular distances across the width of the reed, certain differences can be observed in the amplitudes of the vibratory motion of individual blades. Undercutting is proposed here as a method of reducing these differences. The permissible distance between the exciters was determined taking into account the undercut reed. The undulation of the reed in the process of thickening of the wefts is shown to be a consequence of undercutting. For a distance between the exciters of L = 200 mm and relative depth of the undercut h_0/h = 0.8, differences in the amplitudes of individual blades do not exceed 10%.

Key words: *vibration reed, reed blades' deflection, mode shapes, natural frequency, finite element modelling.*

Introduction

Vibration thickening of the wefts during the weaving process is one method of reducing the dynamic loading of the reed [1]. ***Figure 1*** shows a new vibration beat-up mechanism consisting of a sley (1), vibratory motion exciters (2), and a special flexible weaving reed (3). This mechanism uses a principal rotational reciprocating movement around the axis of the sley shaft (4). Additional vibratory motion of the blades is induced by the exciters through the buckle (5) and tube-shaped connector (6). The exciters are placed at regular distances along the width of the reed.

The amplitude of the vibratory motion of the individual reed blades is not the same; it is greatest in the area where the exciters operate, and decreases with the distance of the blades from the axes of the exciters. To reduce this negative phenomenon, more undercuts were made in the blades, as shown in ***Figure 2***. Circular undercuts are made in the lower parts of the blades, which are subjected to the most deflection. The diameter of the undercut corresponds to four depths of a full blade. The depth of the undercut depends on the position of the blades in relation to the axis of the exciters. The undercuts penetrate uniformly into the reed, starting from the blades situated in the exciter axis. In this way, the blades along the axis remain full, while those located exactly between the exciters undergo the strongest undercutting. The maximum depth of the undercut h_0 constitutes a specific part of the depth of a full blade h in the range $h_0/h = 0 – 0.8$.

During the thickening of wefts, the fabric fell presses against all reed blades with almost the same force [2]. The variable depths of the blade undercuts therefore result in their variable deflection, and consequently in the undulation of the connector and weft, which undergoes thickening.

The main objective of this study was the analysis of the undercuts of individual blades of the reed in order to reduce the differences in their amplitudes of vibratory motion. These variations increase with the distance between the exciters. Therefore an acceptable range of this distance was also defined, enabling practical application of the mechanism. Beyond this range, the differences in the amplitudes for individual blades are too large, despite undercutting the reed. The analysis takes into account several consequences

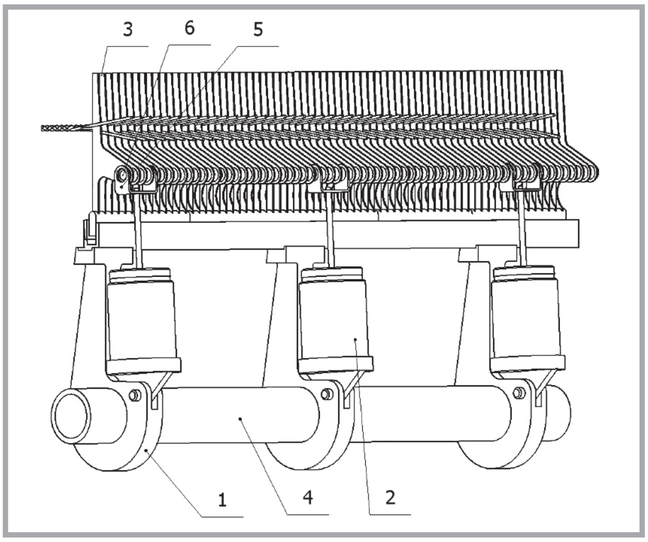

Figure 1. *Vibration beat-up mechanism: 1 – sley, 2 – vibratory motion exciters, 3 – weaving reed, 4 – sley shaft, 5 – buckle, 6 – connector.*

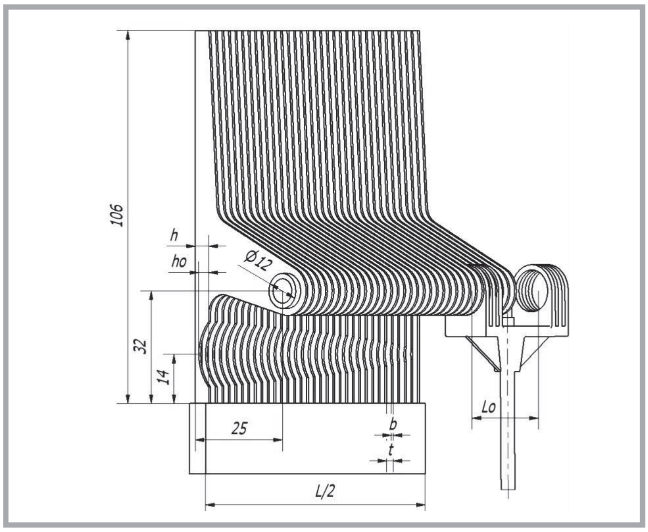

Figure 2. *Section of the new flexible reed: h_0 – max. depth of the undercut, h – depth of a full blade, L_0 – width of the buckle, L – disctance between the exciters.*

of undercutting the reed, such as undulation of the weft, an increase in rigidity, replacing the mass of the reed, and an a rise in the average deflection of the blades in relation to the shift of the connector.

Simulation model

The simulation study was based on the stress analysis module ANSYS Workbench. Due to the complex geometry of the reed, the automatically generated grid uses a tetragonal finite element solid 187 [3-5]. The corner nodes of the element possess three degrees of freedom in the form of possible displacements ux, uy & uz. Central nodes use average displacements from the corner ones.

The analysis used a repeatable section of the reed width corresponding to half the distance between the exciters. The basic dimensions of this section are shown in ***Figure 2***. It was assumed that the reed was made of stainless steel (R_e = 663 MPa) and fixed to the lower frame. The cross-sections of the fragment of the connector were defined as free sliding surfaces, as shown in ***Figure 3*** [17, 18].

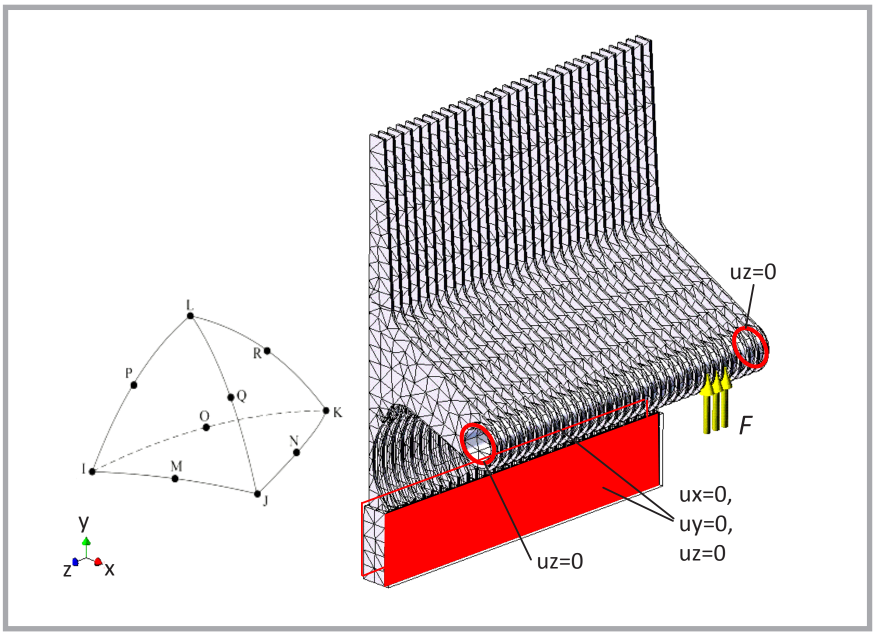

Figure 3. *Finite element solid 187, automatically generated grid, and initial conditions.*

In the manufacture of a fabric with a considerable degree of thickening, the phase of beating-up the weft takes 0.1 – 0.2 of the cycle [6-8]. During this time, the reed should hit the fabric fell between a few and over a dozen times [1, 9, 10]. Assuming an efficiency of the loom of 3 – 5 wefts/s, the average frequency of the vibratory motion of the reed was calculated as f_w = 400 Hz.

The vibrating system of the reed operates at its own natural frequency created by the stiffness of the reed blades [11-13]. The natural frequency was determined on the basis of modal analyses [14-16]. In these analyses, the masses of the buckle and moving part of the exciter (0.05 kg) were taken into account in addition to those of the reed blades and connector. The initial depth of the full blades of the reed was determined iteratively in order to obtain the constant modal frequency f_w, regardless of the depth of the undercut.

The average width of the buckle was taken as L_0 = 40 mm. The distance between the exciters was assumed to be in the range L = 200 – 300 mm. The range of the iteratively defined blade depths is h = 5.8 – 8.2 mm. Due to the risk of losing the stability of the full blade from bending, its width was taken to be b = 0.8 mm [19]. The pitch of the reed blades was assumed to be in the range t = 1.6 – 3.2 mm.

The deformation simulations carried out assumed a static line of the reed deflection, which corresponds to the resonance line. The peak static deflections of individual blades are therefore proportional to their resonance amplitudes.

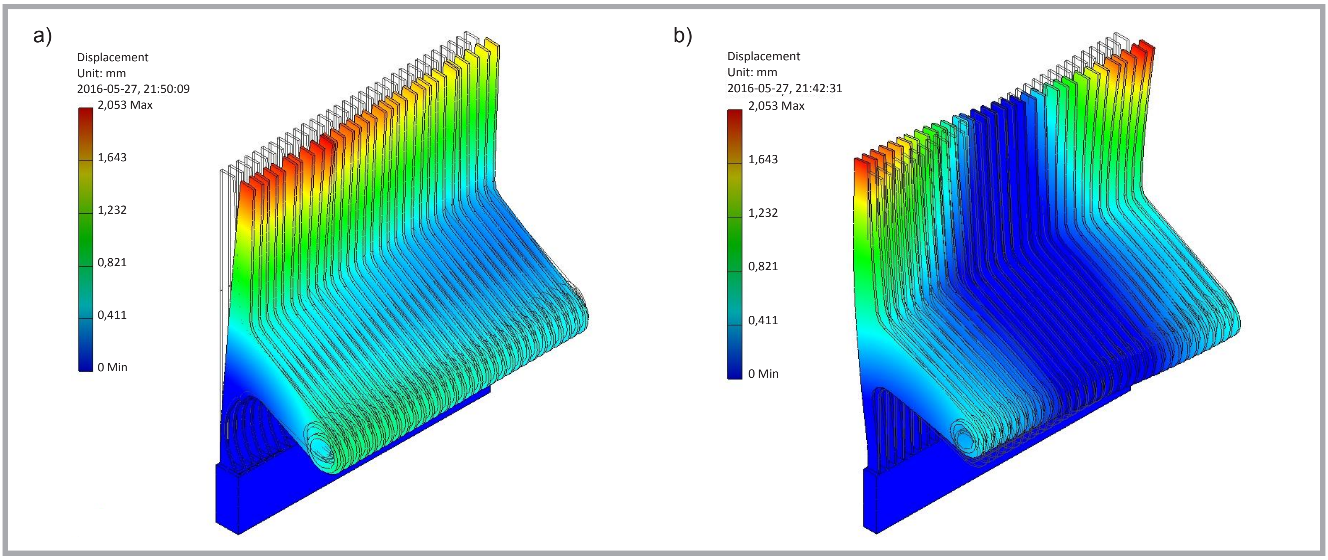

Figure 4. *Mode shapes of reed deformations at a) 400 Hz & b) 880 Hz.*

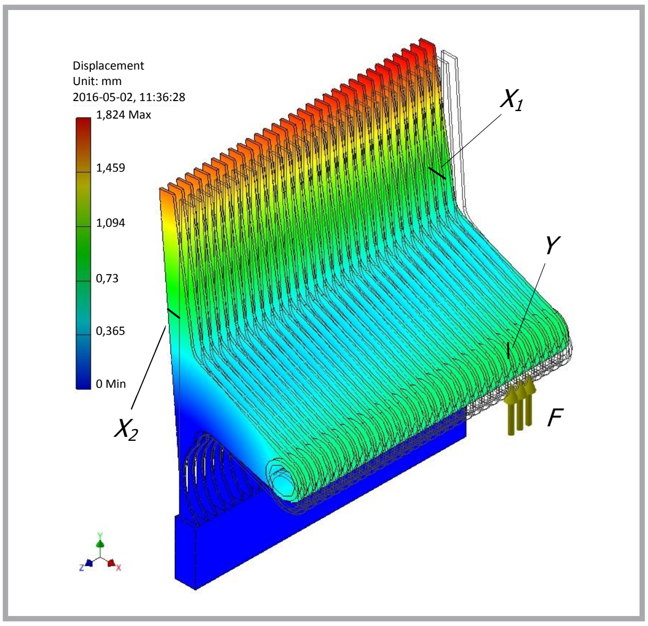

***Figure 5.** Deflections of reed blades loaded with force F.*

Results of the simulation studies

As a result of FEM analysis, the mode shapes of the deflection of the reed section were obtained. Some selected examples are shown in ***Figure 4*** from a frequency range of up to 1000 Hz, which enables the implementation of the vibration thickening of the wefts. Due to the construction of the reed, these are neither the first nor even the subsequent mode shapes. ***Figure 4.a*** presents the deflection shape which was assumed for realisation of the vibratory motion. There are no reports in the literature of vibration thickening by means of a reed equipped with full blades, which undergos deformation as shown in ***Figure 4.b***.

Figure 5 shows the results of simulation of the deflections of individual blades. The section of the reed tested was loaded with a force $F = 400$ N applied to the connector at a distance $L_0/2$ from the axis of the exciter. The force F generates maximal stress values close to half of the yield strength R_e value for the reed material. Further considerations are peak deflections of the extreme blades measured at the height of the fabric fell X_1 and X_2, as well as peak displacement of the connector in the area where the exciter Y operates.

Figure 6 presents simulation results for the deformations of an undercut section of the reed with different pitch values, for three distances between the exciters. An increase in the depth of the undercut and reed pitch compensates for the deflection of the blades. Undercutting improves the ratio of extreme deflections of the blades of the reed section by up to 20%. In general, the value of the ratio obtained in the simulation was in the range $X_2/X_1 = 0.25 - 0.94$. The optimal deflection ratio $X_2/X_1 = 0.9 - 0.94$ was observed for a relative depth of the undercut of $h_0/h = 0.8$, relative pitch of the reed $t/b = 4$ or 3 and relative distance between the exciters $L/L_0 = 5$. For a relative distance of $L/L_0 = 6.25$, the deflection ratio $X_2/X_1 > 0.8$ was only observed for a larger reed pitch $t/b = 4$.

The results of studies on the vibration thickening of wefts described in [9] show that under these conditions, the differences in the loading of individual blades do not exceed 5%. Due to the unfavourable ratio of extreme deflections of the blades – $X_2/X_1 = 0.2 - 0.6$, it is not advisable to apply the relative distance between the exciters – $L/L_0 = 7.5$ ($L = 300$ mm).

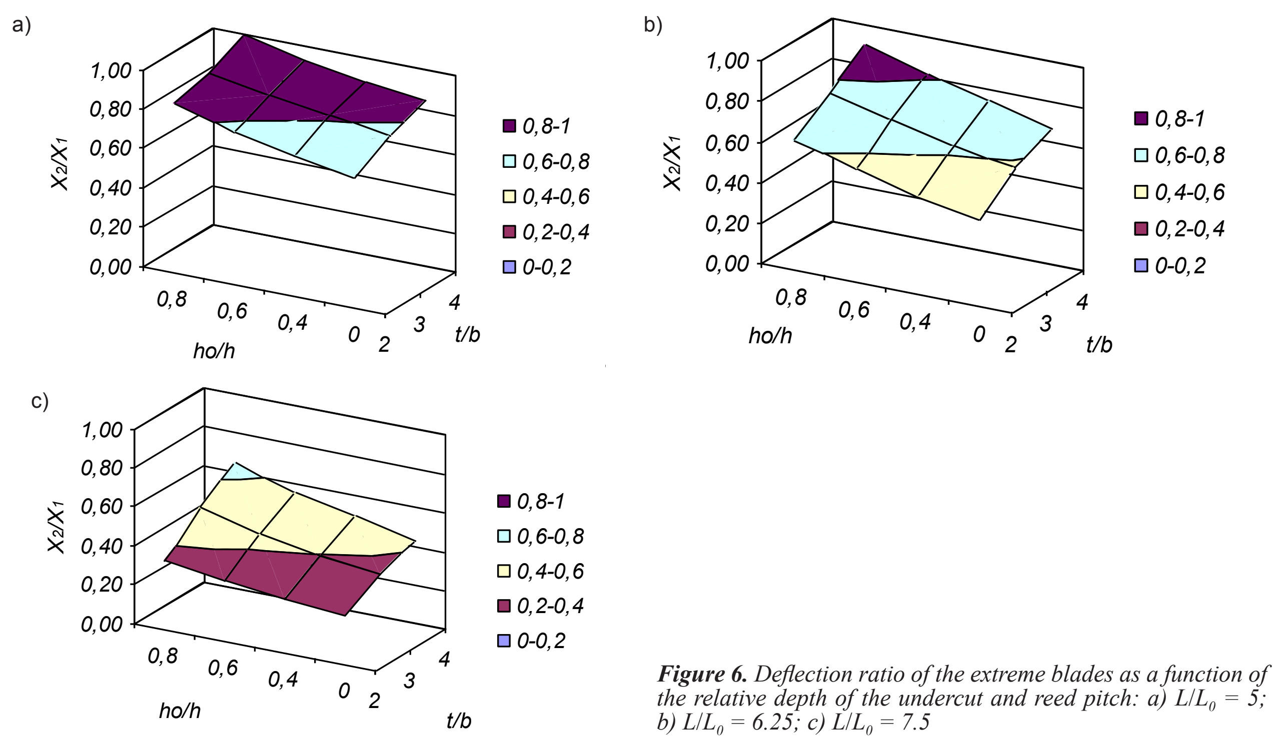

***Figure 6.** Deflection ratio of the extreme blades as a function of the relative depth of the undercut and reed pitch: a) $L/L_0 = 5$; b) $L/L_0 = 6.25$; c) $L/L_0 = 7.5$*

Figure 7 shows the ratio of extreme deflections of the blades of a section of the undulated reed under the influence of the fabric fell during weft thickening. In general, the range of values for this ratio is $X_2/X_1 = 1-2$. However, for relative distances between the exciters of $L/L_0 = 5$, the deflection ratio obtained was in the range $X_2/X_1 = 1-1.25$. Similarly for relative distances of $L/L_0 = 6.25$ and relative pitch of the reed of $t/b = 3-4$, the value of the deflection ratio obtained was in the range $X_2/X_1 = 1-1.3$.

The differences in the beat-up force resulting from the undulation of the reed are proportional to the ratio of stiffness of the fabric-warp system and the stiffness of the reed [8, 10]. This ratio should be less than 1/30, so that the vibration system maintains working conditions close to resonance during the thickening of the wefts [20]. Taking into account the range of the deflection ratio of the extreme blades – $X_2/X_1 = 1-1.3$, differences in the loading of the reed blades during the thickening process should not exceed 1%.

Due to the preferred ratio of extreme deflections of the blades of the reed section loaded with force F and the fabric fell, further analysis used relative distances between the exciters of $L/L_0 = 5$ ($L = 200$ mm) and $L/L_0 = 6.25$ ($L = 250$ mm).

Based on deformation simulations of the reed section loaded with force F, average deflections of all the blades measured at height X_0 of the fabric fell were determined. The average deflection, referring to the displacement of connector X_0/Y with respect to the depth of the undercut and distance between the exciters, is shown in ***Figure 8***. In general, an increase in the depth of the undercut and reed pitch causes an increase in the value of average deflection of the blades. For a relative distance between the exciters of $L/L_0 = 5$, the results obtained were in the range $X_0/Y = 0.95-1.13$. For a relative distance of $L/L_0 = 6.25$, the results were in the range $X_0/Y = 0.82-1.08$. However, there are conditions under which the average deflection of the reed blades at the height of the fabric fell is close to the connector displacement (e.g., $L/L_0 = 5$, $t/b = 2$, $h_0/h = 0.6$ or $L/L_0 = 6.25$, $t/b = 3$, $h_0/h = 0.8$).

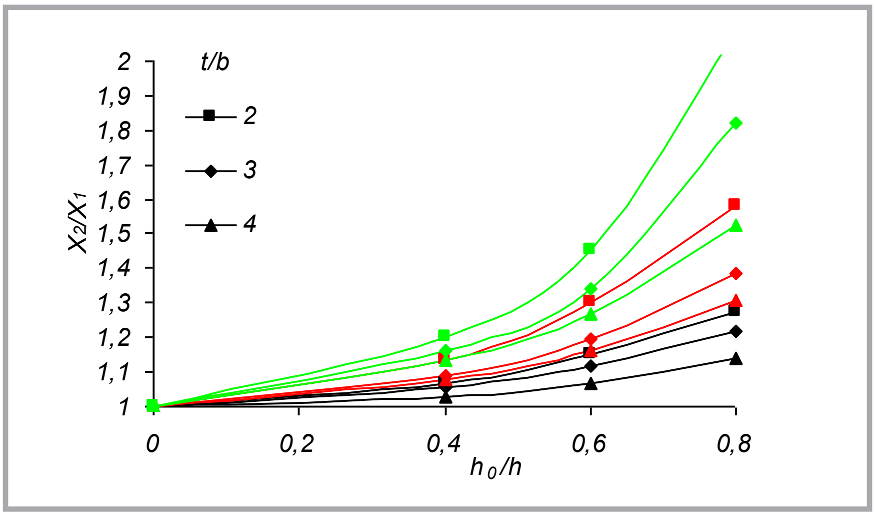

Figure 7. *Deflection ratio of extreme blades loaded with fabric fell as a function of the relative depth of the undercut and reed density ($L/L_0 = 5$ – black, $L/L_0 = 6.25$ – red, $L/L_0 = 7.5$ – green).*

In order to identify the mechanism of the reed as a vibrating system, described by equation of motion – ***Equation (1)***, its equivalent stiffness k_z and equivalent mass m_z were defined. The connector displacement values Y around the axis of the exciter resulted from the simulation carried out for deformations of the reed section loaded with force F. According to ***Equation (2)***, the equivalent stiffness was determined. The fixed natural frequency f_w determined from the modal analysis of the reed section allowed calculation of the equivalent mass according to ***Equation (3)***.

$$\ddot{y} + \frac{k_z}{m_z} y = 0 \qquad (1)$$

where: y – temporary connector displacement values around the axis of the exciter

$$k_z = \frac{F}{Y} \qquad (2)$$

$$m_z = \frac{k_z}{(2\pi f_w)^2} \qquad (3)$$

The results were referenced to equivalent masses, and stiffnesses were obtained for the full reed, as shown in ***Figure 9***.

In general, increases in the depth of the undercut and reed pitch cause an increase in the equivalent stiffness and mass of the system. The relative increase in these pa-

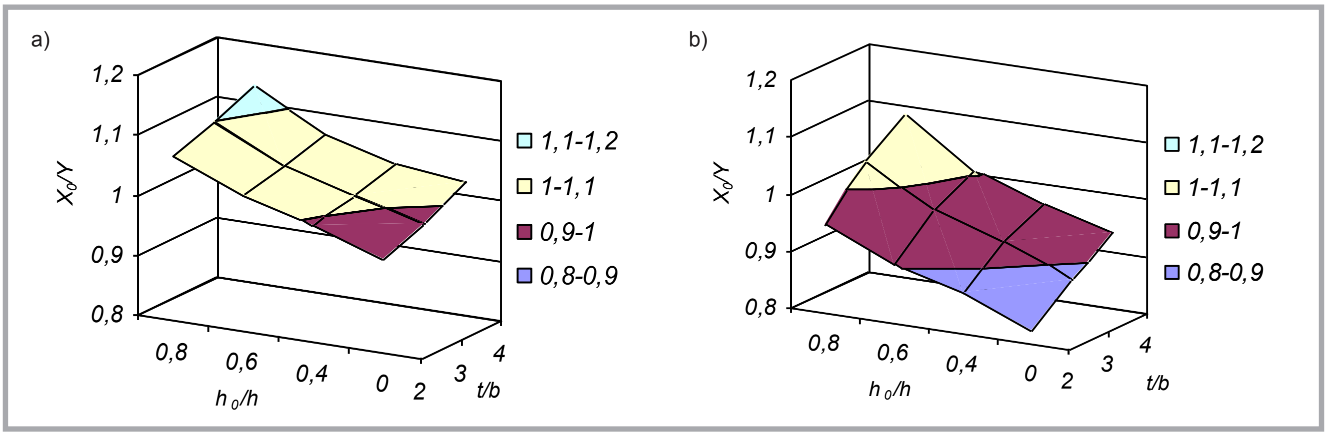

Figure 8. *Ratio of average deflection of reed blades to connector displacement as a function of the relative depth of the undercut and reed pitch: a) $L/L_0 = 5$; b) $L/L_0 = 6.25$*

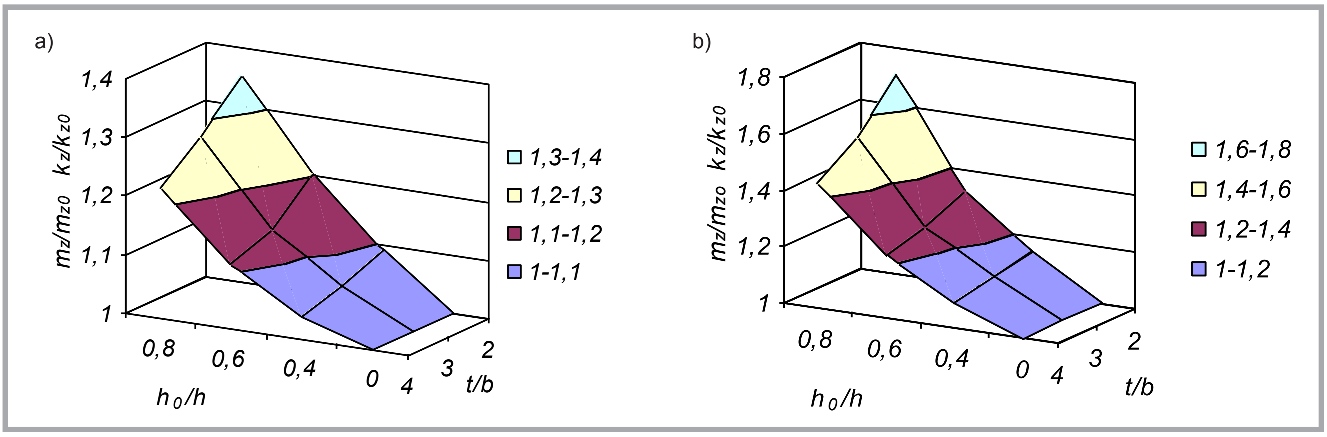

***Figure 9.** Ratio of equivalent mass or equivalent stiffness of a section of undercut reed to a full reed as a function of the relative depth of the undercut and reed pitch: a) $L/L_0 = 5$; b) $L/L_0 = 6.25$.*

rameters was obtained in the ranges k_z/k_{z0} $(m_z/m_{z0}) = 1 - 1.34$ and $1 - 1.68$ for relative distances between the exciters $L/L_0 = 5$ and $L/L_0 = 6.25$, respectively. The increase in equivalent mass and depth of the undercut are associated with the increased depth of the full blades. This depth results from maintaining a constant natural frequency of the system f_w.

Conslusions

In general, undercutting the reed diminishes differences in the deflections of the extreme blades of the section analysed by up to 20%. However, a measurable effect was achieved only for a relative depth of the undercut of $h_0/h = 0.6 - 0.8$. For the distance between the exciters $L = 200$ mm ($L/L_0 = 5$) and the reed with a blade pitch of t = 3.2 mm or 2.4 mm ($t/b = 3$ or 4), the ratio of extreme deflections of the blades X_2/X_1 is greater than 0.9. Under these conditions, as a result of loading the reed section with the fabric fell, the ratio of extreme deflections of the blades X_2/X_1 does not exceed 1.25. The distance between the exciters $L = 200$ mm is recommended for practical applications. The simulation results obtained conditionally allow the use of an exciter pitch of $L = 250$ mm ($L/L_0 = 6.25$). An exciter pitch of $L = 300$ mm is not recommended.

For a distance between the exciters of $L = 200$ mm, the average deflection of the reed blades at the height of the fabric fell with reference to the displacement of the connector around the exciters increases with the depth of the undercut in the range of $X_0/Y = 0.95 - 1.13$. There are geometrical conditions for which the average deflection is similar to the displacement of the connector.

The undercutting of the reed blades, assuming a constant natural frequency of the vibratory system, causes a relative increase in the equivalent mass and stiffness of the vibration system in the range $1 - 1.3$.

In addition to the typical deflected shape of the reeds, there is also an alternative mode shape of reed deformation which also enables vibration thickening of the wefts.

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