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The Model and Analysis of the Doffing Comb Device Vibrations in Carding Machines

Abstract

The paper presents a methodology for analysing mechanical doffing comb devices which take off the web in carding machines. A discrete model of the doffing device, worked out with the use of the FEM method, is presented. The results of an analysis of the calculation model are compared with the results of the experiment, affirming the correctness of the adopted assumptions. The criterion of the doffing comb device evaluation has been formulated while taking into account the permissible amplitudes of vibrations of the doffing blade. On the basis of the results of computer simulations, we described diagrams which may be helpful in selecting doffing comb devices to rework a given range of fibres. Directions of constructional changes contributing to an increase in the efficiency of doffing comb devices are presented.

Key words: carding machine, doffing comb, finite elements method, analysis of vibrations.

Introduction

In order to obtain the appropriate quality of yarn, a uniform layer of fibres (web) must be produced. The web cannot include any rubbish or inclusions, and fibres of the required length should be straightened, mixed and put in parallel directions (parallelisation). The technological process of preparing the web is carried out in a series of successive operations, the most important of which is carding. In the final stage of this process, the layer of fibres gathered on the doffer is taken off by means of the doffing device, so that it can undergo further technological processes.

The efficiency of the whole carding process is largely determined by quality and efficiency of the performance of the device which takes off the web. Because of large working widths as well as the rotational velocities of the rollers and working cylinders, the efficiency presently achieved makes great demands of doffing devices as to accuracy and rate of work. The biggest problems with the efficiency and quality of the taking-off process are encountered when applied to the wool and wool-like fibres taken off from the doffer's surface. These fibres show strong adherence to card clothing and to one another. Therefore, a solution is far more difficult to find than when considering cotton or smooth chemical fibres [2].

Constructors' work aiming at constructing a device which could fulfil the demands of textile technology has resulted in many solutions protected by numerous patents. Among the constructions, we

may note a number of solutions having common features, which makes it possi-

ble to systematise them. These are:

■ roller devices;

In such devices, the elements which take off the web are various types of smooth shaft systems, either fluted or with working or cleaning cloth on the surface [13, 15, and 17]. In the process of taking the web off the doffer, an aiding factor (air) is often used [9, 10, and 14].

■ multi-comb devices;

These devices may be classified as mechanical devices which take off the web by means of a series of blades (doffing blades). These are put in motion by various drives so that they take off the web off the doffer's surface. However, there are other solutions in which the blades are situated tangentially [12] or radially [8] to the doffer's surface.

■ doffing devices;

The constructional solutions of doffing devices presently used include:

- a) devices with an undivided comb,
- b) devices with a divided comb,
- c) devices with a comb shaft working in the area of resonance (with the torsional shaft).

So far there have been many varieties of mechanical and electromechanical doffing comb devices protected by numerous patents, e.g. [7, 11, and 16]. The changes in particular claims apply mainly to the solution of suspending the construction and power transmission system (camming drive, crank-and-rocker mechanism, drive mechanism with a flexible element, etc.)

However, most of these devices have not been used in practice in carding machines which rework wool. On the basis of the available literature from machine manufacturers and the review of the machines shown at the ITMA world exhibition of textile machines, we can conclude that card machines reworking wool only use doffing comb devices, among which classic mechanical doffing comb devices predominate. Owing to their simple structure, low price and reliability, and at the same time their satisfactory work parameters, the predominant group constitutes doffing devices with a mechanical drive. Such devices are the topic of the present paper.

At this point, it is worth drawing attention to an additional aspect resulting from the use of doffing devices. Carding units are frequently used in places with poor work conditions. The halls of such factories are not air-conditioned, there is much dustiness, high temperature and humidity. This makes it impossible to use expensive electronically-controlled devices. This is why a huge demand still exists for classic doffing devices which do not require special work conditions.

■ The object of research

The construction of a doffing comb device with an undivided comb (BEFAMA S.A., Poland) is presented in Figure 1.a. The crank-and-rocker drive mechanism built into the drive box (1) puts the shaft (3) into rotational oscillating motion. The doffing blade (2), which is linked to the shaft by means of columns (4), takes off the web from the doffer. The comb shaft is supported in ball bearings built into the

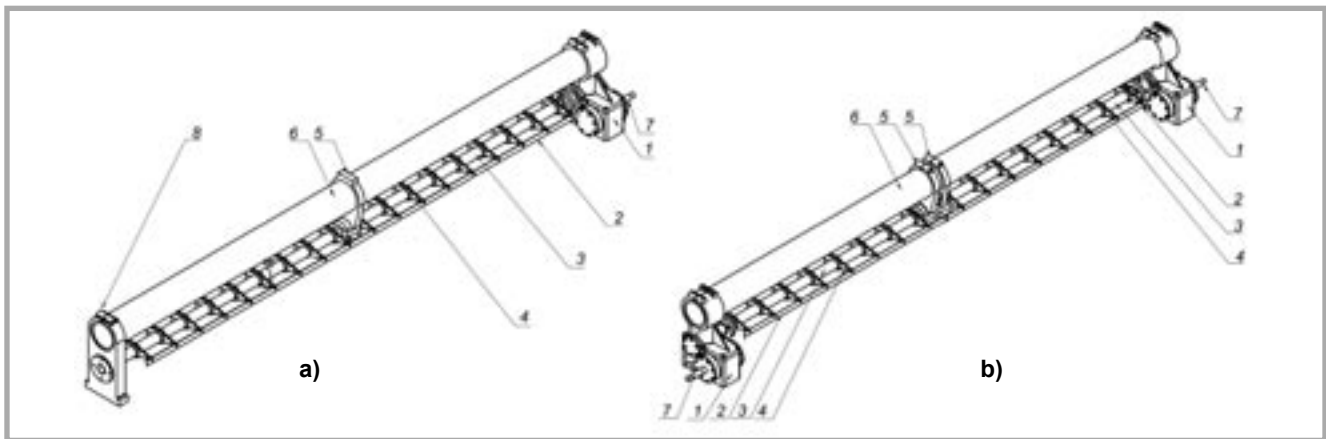


Figure 1. Doffing devices: a) with undivided comb, b) with divided comb; 1 - drive box, 2 - doffing blade, 3 - shaft, 4 - column, 5, 8 - supports, 6 - carrying pipe, 7 - shaft.

supports (5) and (8), as well as the drive box (1), which together with the carrying pipe (6) form the suspended construction. The drive to the device is transmitted from an electric motor.

A device with a divided comb (Figure 1.b) is different from the former because two drive boxes (1) are used, the other one is put in place of the support (8), and there are also two middle supports (5). The device has two comb

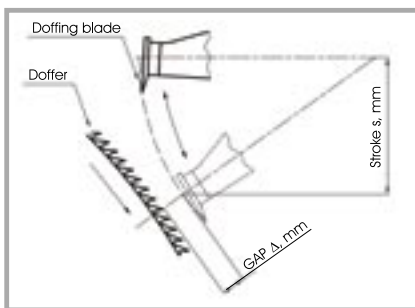


Figure 2. Doffing blade and the doffer system co-operation.

shafts, approximately half the length of the shaft shown in Figure 1.a.

There are high demands of the modern construction of doffing comb devices, connected with efficiency and quality of work. It is expected that the frequency of oscillations of the comb conditioning the efficiency of the card machine may be 2000-3000 cycles/min (33-50 Hz). Moreover, the buyers demand the working widths of the machines to be 2.5-3.5 (4.5) m. It is important to remember that the smallest distance between the blade and the doffer (the gap, Figure 2) should be $\Delta = 0.2-0.4$ mm, depending on the range

of the fibres. The stroke of the doffing blade should be between $S = 28-42$ mm.

The floating (working) motion of the comb shaft causes harmful vibrations to the shaft, columns and blade, which reduces the size of the gap Δ (Figure 2). Due to the small size of the gap, it is advisable to aim to reduce the amplitudes of harmful vibrations. The construction of the comb should not allow the blade and the doffer card clothing to collide throughout the whole range of frequencies of oscillations applied. It is a critical situation which cannot be allowed to take place in practice, as it would lead to the breakdown of the machine. In order to achieve the required uniformity of the web, excessive lateral (bending) vibrations of the blade are unacceptable. They lead to local attenuation or shouldering of the layer of fibres in the combed web.

■ The aim of the analysis

Despite using various types of mechanical doffing comb devices, it is difficult to make recommendations regarding the application of individual types. Their use in a specific carding unit and the range of fibres is usually a compromise between the expected efficiency of the card machine, the price, and the quality and availability of the service.

The essential aim of the following analysis is to work out a methodology for evaluating doffing comb devices and selecting the device for the required range of fibres, taking into account the minimal size of the gap between the blade and the doffer (Table 1) for the assumed working width of the carding machine and the expected frequency of oscillations. The recommended calculation model will also be used for analysis aimed at reconstructing the manufactured doffing comb devices and improving their work parameters as a result.

In order to achieve such results we took the following steps:

- a calculation model, used for simulating the doffing comb devices' motion with various parameters (working widths, frequency of oscillations) was worked out and experimentally verified,
- doffing comb devices were evaluated on the basis of a formulated criterion of permissible amplitude of vibrations, and the areas of application for the particular devices were determined on the basis of the adopted criterion, and
- the influence of constructional factors on the amplitude of vibrations of the blade was examined, and we have indicated the directions of constructional changes whose introduction will improve the work parameters of mechanical doffing comb devices.

Table 1. Recommended size of the gap Δ in mm in BEFAMA S.A. carding machines.

Raw material	Size of gap Δ , mm for carding machine		
	breaker	central	final
Thick wool (yarn Tex 250+700)	0.40	0.35	0.30
Medium-thickness wool (yarn Tex 100+250)	0.40	0.35	0.30
Thin wool (yarn Tex 50+100)	0.35	0.30	0.25

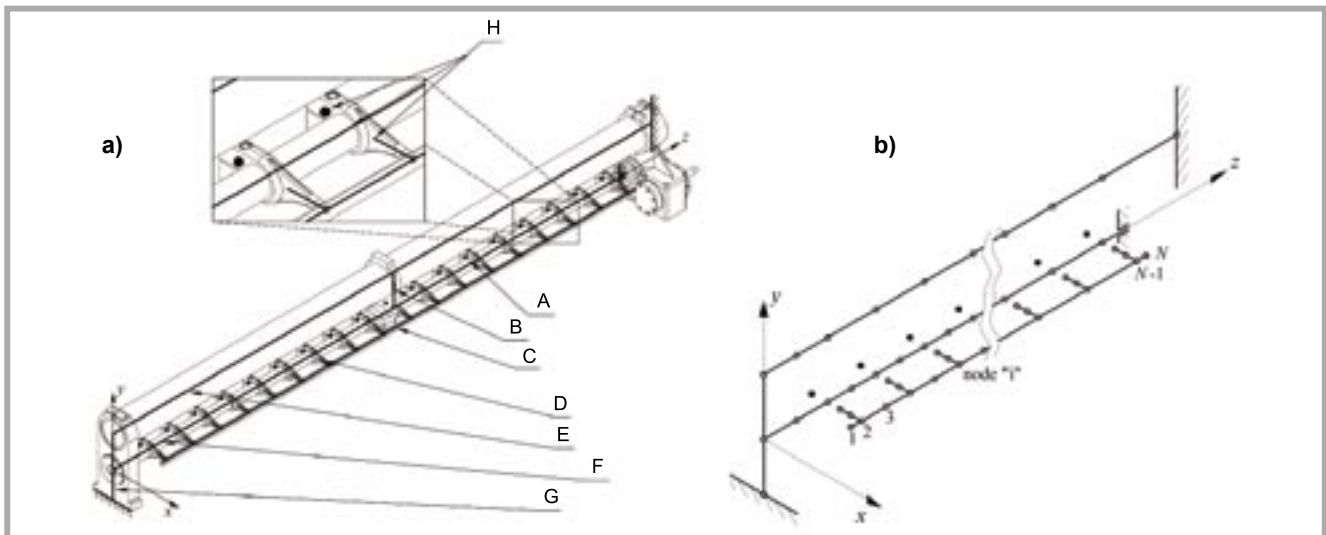


Figure 3. FEM model of the doffing device; a) scheme of the doffing device with beams modelling the particular elements of the device, b) discrete calculation-model of the doffing device; A - equivalent mass modelling inderformable part of column, B - beam modelling middle support, C - beam modelling doffing blade, D - beam modelling deformable part of column, E - beam modelling carrier pipe, F - beam modelling shaft, G - beam modelling left support, H - coupling.

Calculation model of doffing comb device

The Final Element Method (FEM) was used for the analysis [6]. The FEM model of the doffing comb device presented in Figure 3, when correctly made and experimentally verified, permits a variety of simulations of the machine in near-real conditions.

The necessity of the large number of numerical tests and the predicted long times of calculations led us to use mainly beam elements in its construction. This is a compromise between the expected accuracy of simulations and its calculation efficiency.

The model was built on the basis of the following assumptions:

- the doffing blade, shaft, supports, carrying pipe and deformable part of the column will be substituted with beam elements having a substitute stiffness calculated by means of the FEM with the use of ANSYS [1],
- the non-deformable part of the column, together with the balancing holes, will be substituted with the concentrated mass element located in its centre of gravity,
- the link of the deformable and non-deformable parts of the column with the comb shaft will be made while considering the compatibility of the displacements and the rotation of the joined nodes considering the floating motion (coupling),

- the comb box will be treated as non-deformable (ribbed cast iron construction).

The substitution of individual parts of the system with beams and concentrated masses requires that their substitute parameters be determined. The detailed methodology consists in structural analysis of auxiliary models resulting from dividing the doffing device into particular parts and the results are shown in [4].

The oscillating rotational motion of the shaft around the axis z (Figure 3) was obtained by setting rotation to the final element of the shaft at any subsequent moment of time. The adequate function is the result of kinematical analysis of the crank-and-rocker drive mechanism. The Newmark method with automatic time stepping, as recommended by the creator of ANSYS package for dynamic analyses, was used to integrate the system of differential equations of motion.

Methodology of evaluation of doffing comb devices

If we treat the doffing comb device as a system of flexible bodies put in working motion by the drive, all the deflections from the assumed (theoretical) trajectory of the points of the system should be considered undesirable, requiring elimination or at least reduction. The main cause of the deflections from the assumed trajectory of motion are the vibrations of component parts of the device induced by working motion. The vibrations cause the

reduction in the gap Δ size, which results in a lack of uniformity of the web, and in extreme cases, breaking off its continuity or the blade catching on the card clothing of the doffer, which in turn leads to the breakdown of the machine.

The main technical criterion for evaluating the doffer's taking off the web is the permissible amplitude of vibrations in the normal direction n to the assumed trajectory of points on the edge of the blade (Figure 4), as determined in the movable, local coordinate system Ont . It cannot exceed the value of the gap Δ between the blade and the doffer.

Having the displacements u_{n_i} ($i = 1 \dots N$) in all N points of discretisation of the doffing blade (FEM model nodes) (Figure 3), a formula may be stated which defines the maximum displacement (amplitude of vibrations) in the normal direction to the theoretical trajectory of motion:

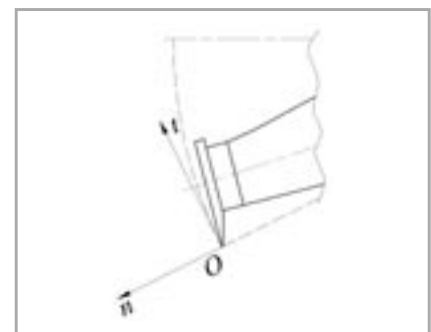


Figure 4. Movable, local Ont coordinate system.

$$A_{nMAX} = \max\{\max[u_{n_i}(\tau)]\} \quad (1)$$

where: τ - time.

It is clear that the value of the maximum amplitude of vibrations in the normal direction, determined in this way, cannot exceed the limit values from Table 1.

Experimental verification of the calculation model

Experimental research was performed in order to verify the calculation model. We carried out a series of measurements at an assembly stand of the doffing devices made available by the manufacturer, as well as a comparative analysis of the values measured and obtained by means of computer simulation.

The research programme assumed the measurement of accelerations in test points on the shaft of the device in the normal n and tangential t directions (Figure 4).

In order to test the compatibility of the results of computer simulation and measurements, the values of accelerations obtained in the domain of time and their transforms in the domain of acceleration were compared.

The detailed description of the experiment and the analysis of the courses determined and the values of estimates were presented in another paper [3]. The conclusions resulting from the presented analysis allow us to assume that the compatibility of the results of measurements and calculations is satisfactory, and the accepted calculation model is therefore correct. The errors calculated for the amplitudes of acceleration did not exceed 25%, and the errors determined for the amplitude of frequency of oscillations were smaller than 4%.

Nomogram for selection of the device

In order to determine the areas of application for the doffing comb devices, the calculation model, worked out and experimentally verified, was used by performing numerical tests for working widths consistent with the manufacturers' technical documentation and with the frequencies of constrained motion, such as:

- in the range of 1500=2500 rpm for the device with an undivided comb,
- in the range of 1500=3000 rpm for the device with a divided comb.

Figure 5 shows the isolines (obtained by means of computer simulation) of the maximum amplitude of vibrations of doffing blade A_{nMAX} versus the working width of the comb for the assumed frequency of oscillations. The isolines determine the areas of safe work for the device with an undivided comb. Thanks to this diagram, we can determine the permissible frequency of oscillations (efficiency of the machine) when we know the kind of raw material (and at the same dimension of the gap Δ – as presented in Table 1) and the working width of the carding machine.

As mentioned above, the value of maximum amplitude of vibrations in the normal direction cannot exceed the limit values. It is thus necessary to introduce a safety factor. This can be expressed by means of the following formula:

$$A_{nMAX} \leq x_B \Delta \quad (2)$$

where: $x_B \in \langle 0,1 \rangle$ – safety factor (usually $x_B = 0.5$).

For example, assuming that in order to card wool fibres of 150 tex on the breaker card (compare Table 1) with a wor-

king width of 2500 mm, the maximum amplitude of vibrations cannot exceed $A_{nMAX} \leq x_B \Delta = 0.5 \cdot 0.4 = 0.2$, the permissible frequency of oscillations is 1900 rpm for the device with an undivided comb (Figure 5), or about 3500 rpm for the device with a divided comb (Figure 6).

A similar nomogram was made for the device with a divided comb (Figure 6).

The choice of the doffing comb device (divided or undivided) was above all determined by the costs. If possible, a cheaper device with an undivided comb is used. If the device with an undivided comb does not meet the requirements, it is necessary to use the device with a divided comb.

Reconstructing the shaft of the doffing comb device

The discrete calculation model presented above allows us to consider a series of factors which can influence the blade's vibrations in computer simulations. These are the stiffness of the blade, the stiffness of the shaft, and the location of middle support.

For each of these factors, appropriate change ranges were determined, mainly by considering that the suggested potential modifications do not oblige significant changes to be introduced in the construction and technology of manufacturing particular parts of the doffing comb devices. Owing to the large number of cases to be considered, it was decided that the influence of each of these factors should be examined separately.

The doffing blade is linked to the shaft by means of columns. The stiffness of each section of the blade between the columns

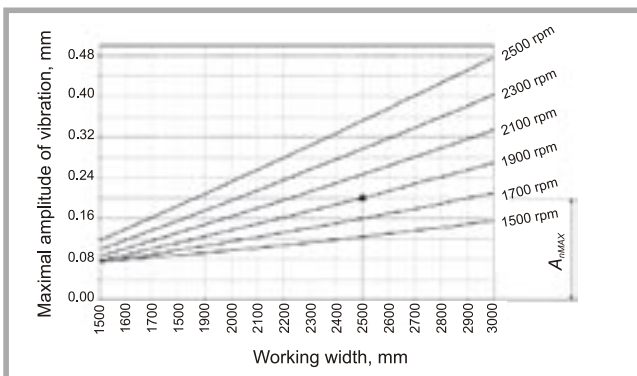


Figure 5. Nomogram for the selection of the device with undivided comb.

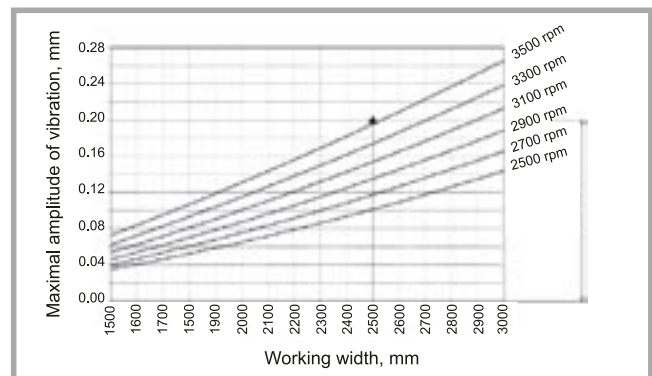


Figure 6. Nomogram for the selection of the device with divided comb.

may be modified in two ways: by changing the length of the blade section by increasing (or decreasing) the number of columns, or changing the parameters of the blade cross-section.

The number of columns for calculations was specified as the number of 16, 18, 20 or 22; where 22 is the border value at which it is possible to place the middle support between the columns. The blade is made of a steel strip of appropriate length. The change of its stiffness may then be carried out by changing its thickness; the thicknesses of 0.75, 1, 1.5, 2, 2.5, 3 mm were assumed for tests.

The stiffness of the shaft is determined by moments of inertia resulting from the size of the diameter: outer D and inner d . In the real construction, the shaft is made of a precision steel tube [18]. The outer diameters D and the inner diameters d were chosen for numerical tests in order to minimise working allowances (see Figure 7).

The observations of amplitudes of vibration of the doffing shafts show that as they get closer to the left support, the amplitudes increase. This phenomenon may be explained by the influence of the flexibility of the suspended construction (especially the middle and left supports). To evaluate the possibility of changing the situation, the following options for doffing the shaft support were considered:

- the middle support located halfway along the length of the shaft (a),
- middle support shifted by 1/4 (b) and 1/8 (c) length of the shaft to the left support,
- without middle support.

The real construction as suggested by the manufacturer, which is the reference in comparative analyses, is characterised by the following values: the thickness of the blade is 2 mm, the number of columns 18, $D = 45$ mm, $d = 38$ mm, and the middle support located halfway along the length of the shaft.

Figure 7 shows the influence of the selected factors on the value of the maximum amplitude of vibrations.

Analysing the results obtained, it was concluded that by introducing changes to the construction of the existing devices, we could achieve a significant decrease in amplitudes of the blade vibrations. The change of the shaft pipe from

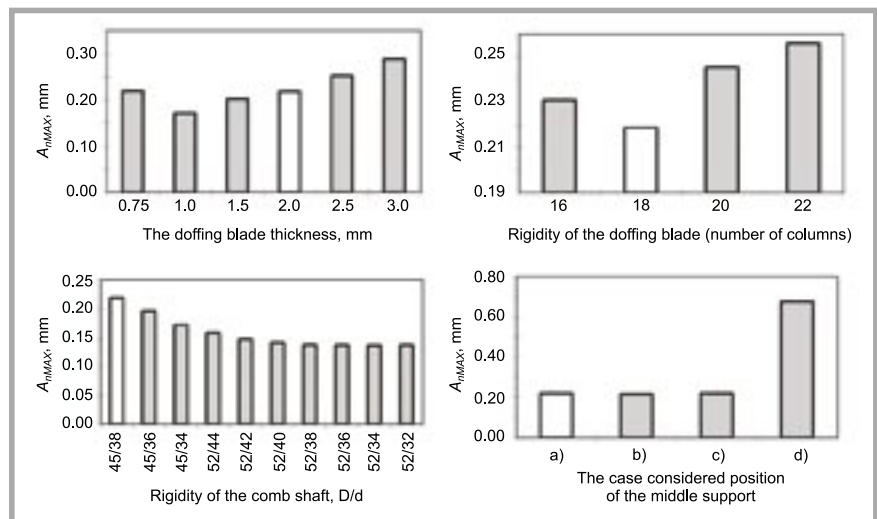


Figure 7. The influence of construction factors on the maximum amplitude of vibrations; - the reference construction.

$D/d = 45/38$ to $D/d = 52/34$ brings about a decrease in the maximum amplitude of vibrations in the normal direction to the assumed trajectory of motion A_{nMAX} at 37%, whereas reducing the thickness of the blade from 2 to 1 mm lets us decrease this factor to 22%. The change in the number of columns and the means of support of the shaft does not improve the existing state.

Summary

The developmental work on doffing comb devices which we have so far carried out was mainly based on the engineering intuition of the constructors and the users' experience of using the devices. Although the improvements suggested over the years were in most cases right, they have not so far been supported by complex calculation analysis. As shown by the research, the FEM model of the doffing comb device, as worked out and experimentally verified, allowed us to perform a series of computer simulations whose results formed a basis to determine the areas for the safe operation of the device.

The nomograms (Figures 5 and 6) are helpful for adjusting the doffing comb device to the textile technology's requirements. The conclusions drawn from the analyses may be used when reconstructing manufactured doffing comb devices, and the calculation models and methodology of research can be used for newly designed doffing comb devices.

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