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Non-destructive diagnostics of uniformity of loading of the sheet of paper

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Abstract

To ensure high quality of printing the paper in the printing machine is to experience uniform loading: the stresses are to be uniformly distributed across the width of the paper. For the diagnostics of the uniformity of loading the use of time averaged moiré analysis of transverse vibrations of the paper is proposed.

Orthotropic constitutive model is to be taken into account for machine made paper, while laboratory made sheets are usually isotropic. It is assumed that a paper in a printing device is loaded in its plane and thus a problem of plane stress is analyzed. Principal stresses are calculated and represented at the centers of finite elements. They substantially determine the vibration behavior and stability of the paper.

Keywords: optical diagnostics, non-destructive testing, machine made paper, orthotropic model, stress strain law, finite elements, experimental setup, projection moiré, time averaged moiré, paper vibrations, automatic control, printing device.

1. Introduction

To ensure high quality of printing the paper in a printing machine is to experience uniform loading: it is important to ensure that the stresses are uniformly distributed across the width of the sheet of paper. For a non-destructive diagnostics of the uniformity of loading of the sheet of machine made paper the use of the experimental method of time averaged moiré analysis of transverse vibrations is proposed.

Orthotropic constitutive model is to be taken into account for paper, while laboratory made sheets are usually isotropic. Stresses in isotropic paper were calculated in [1]. The effect of the defects of the modulus of elasticity and of the density to the eigenvalues of bending vibrations of a sheet of paper is analyzed in [2]. So this paper is a further development of the investigations described in the references [1, 2].

The model for the analysis of paper in a printing device is proposed on the basis of the material described in [3, 4]. It is assumed that a paper in a printing device is loaded in its plane. The static problem of plane stress by assuming the displacements at the boundary of the analyzed paper to be given is solved.

Papers [5 - 10] have a particular relationship with the problems analyzed in this article.

The principal stresses are calculated and represented at the centers of finite elements. They substantially determine the vibration behavior and stability of the paper.

When the sheet of paper in the printing machine is loaded non-symmetrically, the eigenmodes of vibrations of the sheet of paper change. Thus the influence of symmetric and a symmetric loading (schematic diagrams are presented in Fig. 1) and also the influence of the diagonal scratch to the eigenmodes of transverse vibrations of the sheet of machine made paper were investigated experimentally by taking the machine direction of the paper into account.

The a symmetric loading is the defect of the operation of the printing device and the diagonal scratch is the defect of the paper itself. Diagnostics of both types of defects is performed by the same experimental method.

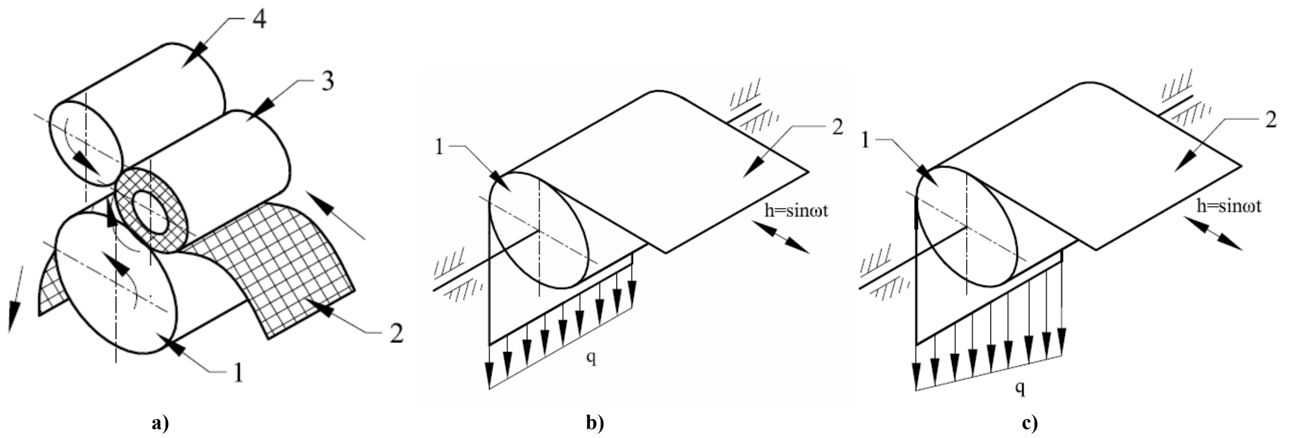

Fig. 1. **Offset sheetfed printing machine printing device kinematic and paper sheet loading schemes: a – printing device kinematic scheme: 1 – impression cylinder, 2 – paper, 3 – offset cylinder coated by offset rubber, 4 – plate cylinder with printing form; b – scheme of symmetric paper load, c – scheme of asymmetric paper load: *q* – vertical load**

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2. Procedure of analysis of stresses in paper in a printing device

Further x and y denote the axes of coordinates. The static problem of the plane stress is analyzed. The element has two nodal degrees of freedom: the displacements u and v in the directions of the axes x and y of the system of coordinates.

Paper is described by the modulus of elasticity in the direction of the x axis E_x, modulus of elasticity in the direction of the y axis E_y, Poisson's ratio ν_{xy} for strain in the direction of the y axis ε_y when paper is stressed in the direction of the x axis only, that is:

$$\nu_{xy} = -\frac{\varepsilon_y}{\varepsilon_x}, \qquad (1)$$

where ε_x is the strain in the direction of the x axis, the Poisson's ratio ν_{yx} for strain in the direction of the x axis when paper is stressed in the direction of the y axis only, that is:

$$\nu_{xy} = -\frac{\varepsilon_y}{\varepsilon_x}, \qquad (2)$$

The modulus of elasticity in the direction of the x axis is determined from:

$$E_x = E_y \frac{\nu_{xy}}{\nu_{yx}}. \qquad (3)$$

The matrix of elastic constants has the form:

$$[D] = \begin{bmatrix} \frac{E_x}{1-\nu_{xy}\nu_{yx}} & \frac{E_y\nu_{xy}}{1-\nu_{xy}\nu_{yx}} & 0 \\ \frac{E_x\nu_{yx}}{1-\nu_{xy}\nu_{yx}} & \frac{E_y}{1-\nu_{xy}\nu_{yx}} & 0 \\ 0 & 0 & \frac{E_x E_y}{E_x + E_y + E_x\nu_{yx} + E_y\nu_{xy}} \end{bmatrix}. \qquad (4)$$

The displacements at the boundary of the analyzed paper are given and they produce the loading vector. The vector of displacements is determined by solving the system of linear algebraic equations.

The stresses are determined at the centers of the finite elements. The principal stresses are calculated and their directions are represented inside the smaller circle, while their values are proportional to the black angle between the two circles. One drawing is produced for the representation of positive values and another drawing is produced for the representation of negative values.

3. Results of analysis of stresses under symmetric and a symmetric loading of paper in a printing device

The physical constants of the paper are: the modulus of elasticity in the machine direction E_{MD}= 4.4 GPa, the modulus of elasticity in the cross direction E_{CD}= 2.2 GPa, the Poisson's ratio ν_{MDCD}= 0.2 for the strain in the cross direction ε_{CD} when paper is stressed in the machine direction only, that is:

$$\nu_{MDCD} = -\frac{\varepsilon_{CD}}{\varepsilon_{MD}}, \qquad (5)$$

where ε_{MD} is the strain in the machine direction, the Poisson's ratio ν_{CDMD}= 0.1 for strain in the machine direction when paper is stressed in the cross direction only, that is:

$$\nu_{CDMD} = -\frac{\varepsilon_{MD}}{\varepsilon_{CD}}. \qquad (6)$$

The square piece of paper is analyzed. The following boundary conditions of symmetric loading are assumed: on the lower boundary it is assumed that u= v= 0; on the upper boundary it is assumed that u= 0 and v= 1×10^{-6} m.

For a symmetric loading the boundary conditions on the upper boundary are changed, that is on the upper boundary linear variation of the displacement v is assumed with v= 0.5×10^{-6} m on the left side of the boundary and v= 1.5×10^{-6} m on the right side of the boundary.

Problem 1. It is assumed E_y= 2.2 GPa, ν_{xy}= 0.2, ν_{yx}= 0.1.

For a symmetric loading the values of positive principal stresses at the centers of finite elements are presented in Fig. 2, while the values of the negative principal stresses at the centers of finite elements are presented in Fig. 3. For symmetric loading the values of the positive principal stresses at the centers of finite elements are presented in Fig. 4, while the values of the negative principal stresses at the centers of finite elements are presented in Fig. 5. The values of the negative principle stresses are much smaller than the values of the positive principle stresses. So the scale for the representation of the values of the negative principle stresses is forty times more sensitive than for the values of the positive principle stresses.

Problem 2. It is assumed E_y= 4.4 GPa, ν_{xy}= 0.1, ν_{yx}= 0.2.

For a symmetric loading the values of the positive principal stresses at the centers of finite elements are presented in Fig. 6, while the values of the negative principal stresses at the centers of finite elements are presented in Fig. 7. For symmetric loading the values of the principal stresses at the centers of finite elements are everywhere positive and are presented in Fig. 8. The scale for the representation of the values of the positive principle stresses is twice less sensitive than for the previous problem. The scale for the representation of the values of the negative principle stresses is four times more sensitive than for the previous problem.

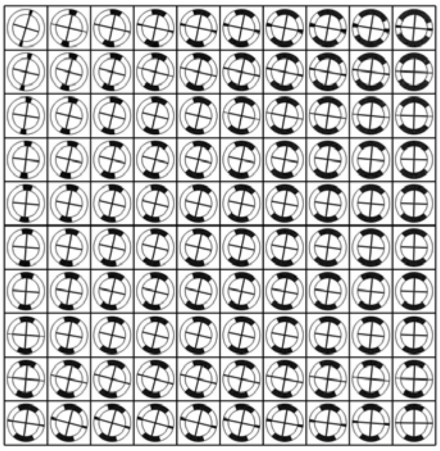


Fig. 2. **The values of positive principle stresses under a symmetric loading**

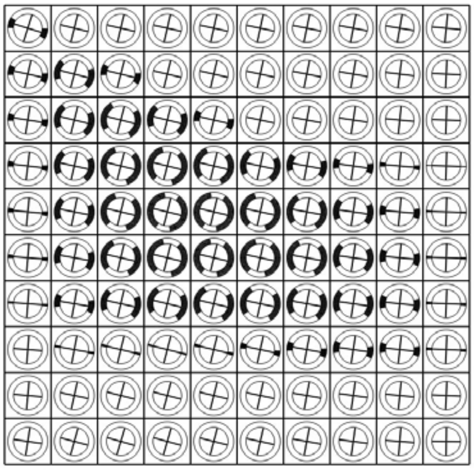


Fig. 3. **The values of negative principle stresses under a symmetric loading**

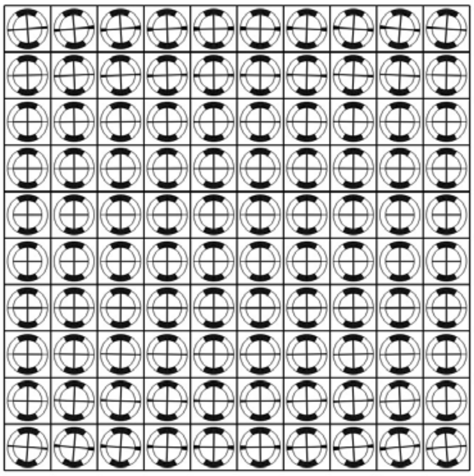


Fig. 4. **The values of positive principle stresses under symmetric loading**

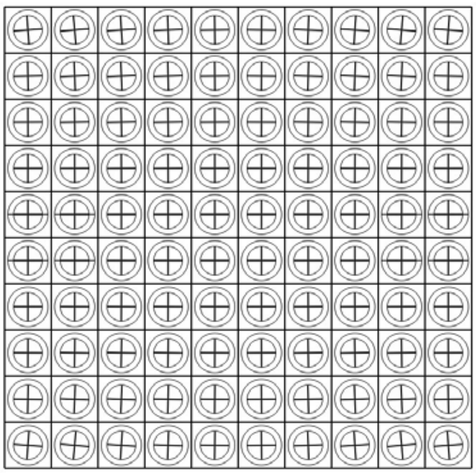


Fig. 5. **The values of negative principle stresses under symmetric loading**

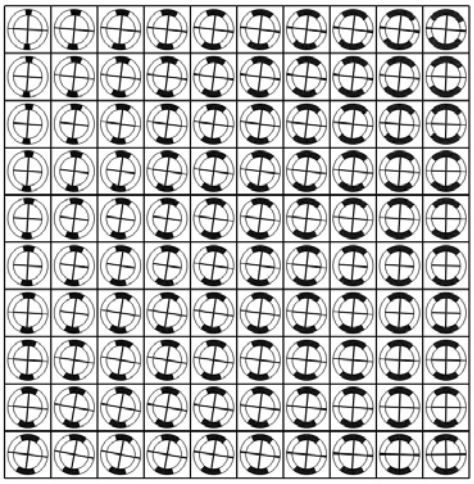


Fig. 6. **The values of positive principle stresses under a symmetric loading**

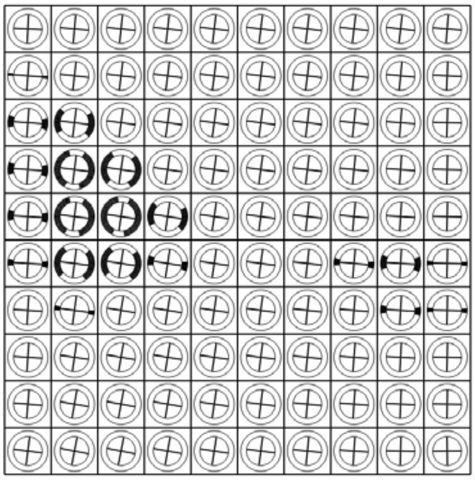


Fig. 7. **The values of negative principle stresses under a symmetric loading**

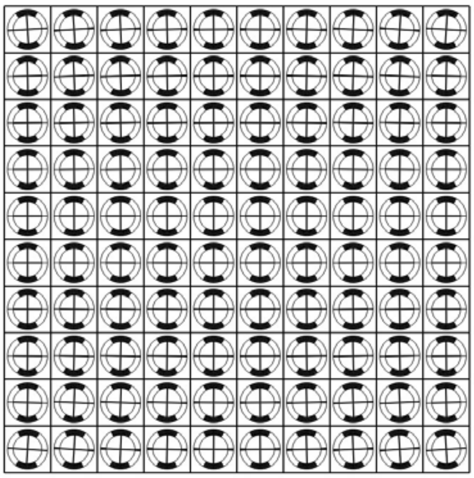


Fig. 8. **The values of principle stresses under symmetric loading.**

The stresses in the plane of the paper substantially influence the bending stiffness of the paper and thus its transverse vibrations. In the regions where there is a negative principle stress the loss of stability of the paper can be expected.

4. The method and the results of experimental investigation

In order to determine the dynamical characteristics of the paper a special setup for experimental investigation was developed and used [11, 12].

For the investigations the paper *"Plano Plus"* was chosen. Technical characteristics of this paper are: the surface density 80 g/m^2, the thickness 102 μm.

From the presented results it is seen that in the case of the paper with a symmetrical load the first eigenmode (see Fig. 9a and Fig. 10a) takes place at lower frequencies of the transverse vibrations of the sheet of paper. This is true for the machine direction as well as for the cross-machine direction of the sheet of paper, and the moiré image of the mode itself for those cases changes (for this case in the longitudinal direction of the sheet of paper near to the center two elliptically shaped nodal lines occure), when compared with the first eigenmode of the paper without defects (see Fig. 9c and Fig. 10c), where along the sides of the borders of the sheet of paper nodal lines of the shape of partial ellipse occure.

In case of the sheet of paper with a diagonal scratch in it the first eigenmode (see Fig. 9b and Fig. 10b) takes place at lower frequencies of the transverse vibrations of the sheet of paper. This is true for the machine direction as well as the cross-machine direction of the sheet of paper, and the moiré image of the mode is similar to the first eigenmode of the paper without defects (see Fig. 9c and Fig. 10c).

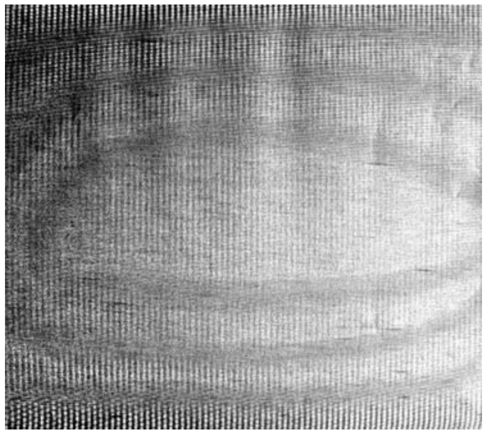
The proposed method of optical diagnostics of defects is applicable in the systems of automatic control of polygraphic materials (paper, cardboard and etc.) and of the quality of operation of the printing devices.

5. Conclusions

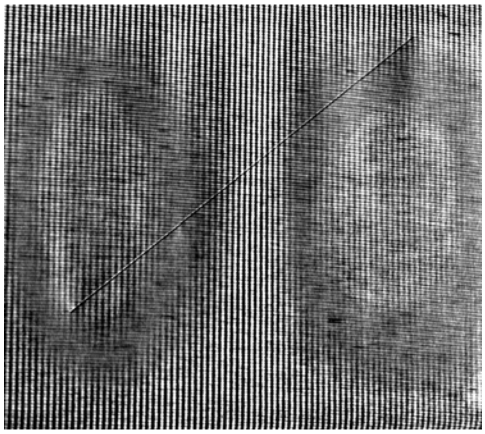
The proposed method of non-destructive diagnostics of uniformity of loading of machine made paper is based on the application of the time averaged projection moiré techniques for the analysis of the first eigenmode of transverse vibrations of paper. The non-uniformity of distribution of moiré fringes enables to diagnose this defect of loading effectively and in real time.

The model for the analysis of machine made paper in a printing device is proposed using the orthotropic constitutive relationship. It is assumed that paper in a printing device is loaded in its plane. The static problem of the plane stress by assuming the displacements at the boundary of the analyzed paper to be given is solved. The principal stresses are calculated and represented at the centers of finite elements. Symmetric and a symmetric loading of the sheet of paper, and the paper with a scratch are analyzed experimentally. The non-symmetry of loading and the scratch are considered as defects of operation of the printing device and of the paper itself. Both the machine direction as well as cross direction are considered as the directions of loading.

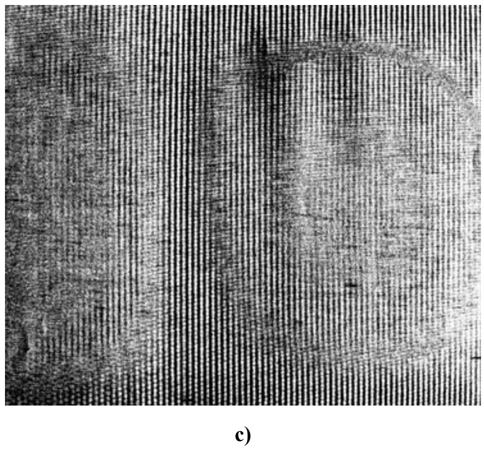
The analysis shows that when generating sinus-shaped vibrations of the paper *"Plano Plus"* in machine and cross-machine directions and having defects of the previously described types the first modes of different configurations are formed, compared with the first modes of quality paper.



a)

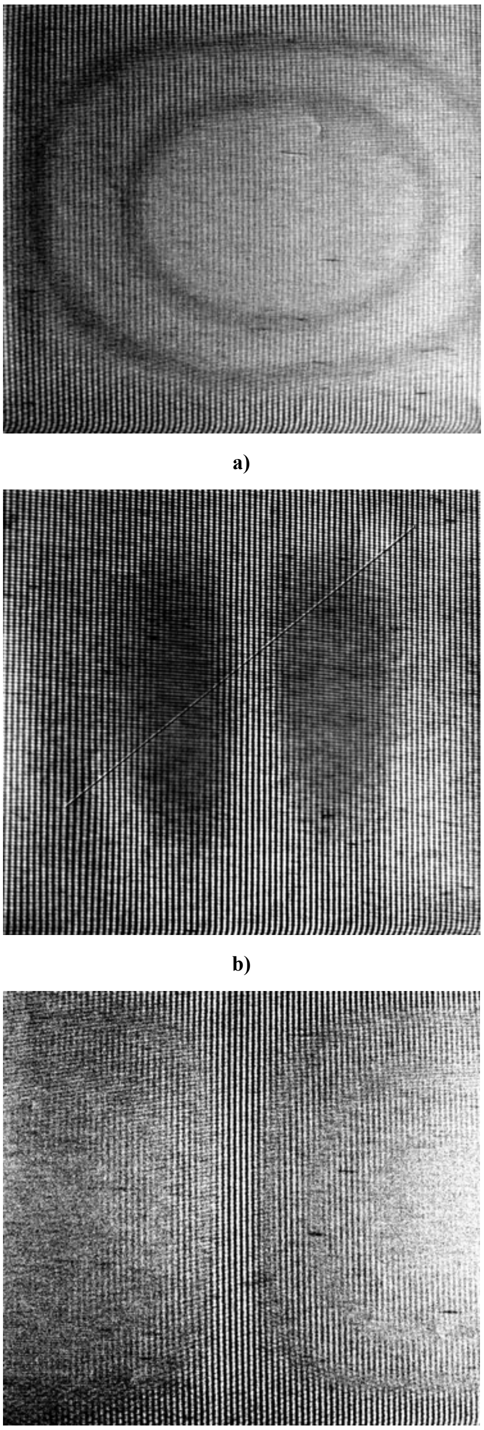


b)



c)

Fig. 9. **The first eigenmode of the paper "*Plano Plus*" 80 g/m^2 (machine direction of the paper): a – a symmetrical paper sheet load (frequency of vibrations 152 Hz, amplitude 2×10^{-6} m); b - diagonal scratch in the paper sheet of 18 cm length (frequency of vibrations 157 Hz, amplitude 2×10^{-6} m); c - paper without defects (frequency of vibrations 162 Hz, amplitude 2×10^{-6} m)**



a)

b)

c)

Fig. 10. **The first eigenmode of the paper "*Plano Plus"* 80 g/m^2 (cross-machine direction of the paper): a – a symmetrical paper sheet load (frequency of vibrations 146 Hz, amplitude 2×10^{-6} m); b - diagonal scratch in the paper sheet of 18 cm length (frequency of vibrations 154 Hz, amplitude 2×10^{-6} m); c - paper without defects (frequency of vibrations 163 Hz, amplitude 2×10^{-6} m).**

The proposed method of optical diagnostics of defects is applicable for automatic control of polygraphic materials (paper, cardboard and etc.) and of the operation of the printing device.

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Neardomoji popieriaus lapo apkrovos tolygumo diagnostika

Reziumė

Kad būtų užtikrinta gera spausdinimo kokybė, popierius spausdinimo mašinoje turi būti apkrautas tolygiai, tai yra įtempiai turi būti tolygiai pasiskirstę popieriaus lapo plotyje. Lapo apkrovos tolygumui diagnozuoti siūloma taikyti popieriaus skersinių virpesių analizę laike suvidurkinto projekcinio muaro metodu.

Mašininės gamybos popieriui taikomas ortotropinis modelis. Tariama, kad popierius spausdinimo įrenginyje apkrautas savo plokštumoje, todėl nagrinėjamas plokščios įtemptos būsenos uždavinys. Skaičiuojami pagrindiniai įtempiai ir atvaizduojami baigtinių elementų centruose. Šie įtempiai turi esminę įtaką popieriaus lapo virpesiams ir stabilumui.

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