

Analysis of Fibrous Web Dewatering in Roll Presses

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Abstract

In this study, results of total and hydraulic pressure measurements in a pressed paper web are presented. A large part of these measurements relates to the effects of technological and design parameters on total and hydraulic pressure values. Based on the results obtained, mathematical relationships allowing to calculate the maximum total and hydraulic pressure and vacuum in a paper web and felt are proposed.

Key words: fibrous web, web pressing, web dewatering press nip, total pressure, hydraulic pressure.

Introduction

The process of paper web pressing is very important because of the web properties and cost of paper manufacturing. The process is quite complicated, and up to the present this has not allowed to express the pressing process in a mathematical form.

Present theories of pressing are based on that proposed in 1960 by Wahlström, which was later enlarged by other researchers [1, 2]. He stated that the main driving force of water removal is the hydraulic pressure created in the web due to its compression in the press nip (*Figure 1*). The compressive force in the converging nip is balanced at each point of the nip by the sum of the structural pressure and hydraulic pressure created by the flow resistance of water in the fiber network. The structural pressure balanced by the mechanical stiffness of the solid structure dominates as long as the web is not saturated. When the web becomes saturated, the hydraulic pressure starts to rise and water flows into the felt, where its movements are determined by the press design and roll surface structure. In the outgoing nip there is a reverse flow from the roll structure into the felt and from the felt into the web. The reverse water flow from the felt to the web is called rewetting [3]. Kataja [4, 5] worked out a model of the wet pressing process on the basis of the hydrodynamics theory. These theories, however, up till now have not been completely confirmed experimentally.

Aim and scope of measurements

The aim of the measurements performed was the determination of:

- the value and characteristic of the total pressure distribution in the press nip,

- values and characteristic of hydraulic pressure distribution in the nip,
- the effect of technological and design parameters on the value of maximum hydraulic pressure,
- the interdependence of hydraulic pressure on the value and distribution of the total pressure in the press nip.

The study was carried out on an experimental semi-commercial press. The measuring line included:

- tension (*Figure 2*) and piezoelectric (*Figure 3*) sensors installed in a steel roll,
- feeding and amplifying system with analog-digital converter,
- computer for storage and conversion of measurement results.

During the measurements, the following parameters were applied:

- a) constant parameters
 - diameter of rolls $D = 700$ mm
 - elastic plain roll - rubber hardness $T = 16^\circ$ PJ
 - grooved roll - rubber hardness $T = 8^\circ$ PJ
 - thickness of rubber cover 20 mm
 - paper web temperature $t_p = 20^\circ$ C
 - kraft unbleached chemical pulp,
- b) variable parameters:
 - linear pressure: $\sigma_L = 10 - 90$ kN/m
 - linear velocity $v = 1 \div 10$ m/s
 - paper web grammage $q = 50 \div 1000$ g/m²
 - beating degree of the stock $Sm = 13 - 95^\circ$ SR
 - moisture content of paper web $w_p = 60 - 85\%$
 - moisture content of felt $w_f = 30 - 50\%$

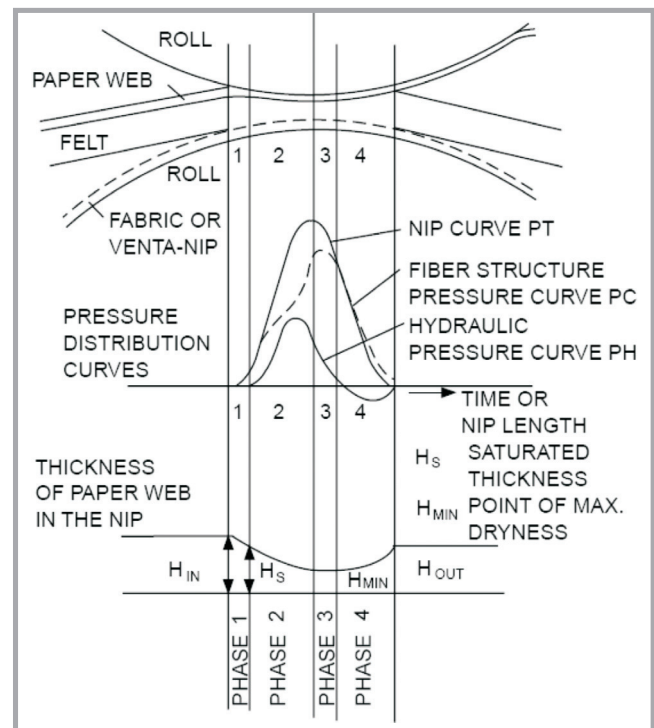


Figure 1. Single-felted transversal flow nip (2).

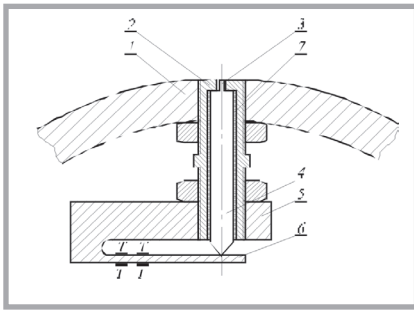


Figure 2. Sensor of total pressure: 1- press roll, 2,5 – body of the sensor, 3 – end (1x10 mm) of moving bar 4, 6 – beam with strain gauges T.

In the course of measurements only one parameter was changed, while the others were kept at a constant level, and they respectively amounted to: $\sigma_L = 30 \text{ kN}$, $q = 100 \text{ g/m}^2$, $v = 5 \text{ m/s}$, $S_m = 30^\circ \text{ SR}$, $w_p = 70\%$, $w_f = 40\%$, needled felt of 1000 g/m^2 of the batt-on-wire type (two layers wire, laminated), plain press.

Measurement results

Figures 4 and 5 show, as an examples, a diagrams of the total pressure in a pressed paper web. On this diagram the maximum value of the total pressure and press nip width are marked. As can be seen, the point of the maximum value of the total pressure is at a certain distance from the middle of the nip width, which is caused by the asymmetric deformation of the driven roll by the rubber cover. Based on the results of the measurements obtained, a relationship is proposed between the value of the nip width and the

parameters of the pressing process in the form of the following equation:

$$a = 0.42 \cdot \sigma_L^{0.28} \cdot D_z^{0.32} \cdot (k_T T_g)^{0.325} \cdot (k_f q)^{0.115} \cdot k \text{ in mm} \quad (1)$$

where:

σ_L – linear pressure, kN/m,

D_z – substitute diameter, mm,

$$D_z = 2 D_1 D_2 / (D_1 + D_2)$$

D_1 – upper roll diameter,

D_2 – lower roll diameter,

T_g – rubber hardness, °PJ,

q – basis weight of paper, g/m^2 ,

k – coefficient dependent on rubber cover thickness, felt wet-

ness, kind of felt, basis weight and number of felts,

k_4 – coefficient dependent on paper web dryness,

k_T – coefficient dependent on rubber cover temperature.

The value of the maximum total pressure can be calculated from the following equation:

$$P_{max} = \alpha p_m \quad (2)$$

where: mean value of the total pressure in the press nip

$$p_m = \sigma_L / a$$

Dependence p_{max}/p_m can be found using the diagram presented in **Figure 6** (see page 100).

Figure 7 (see page 100) shows, as an example, a diagram of the hydraulic pressure in a paper web being pressed in a

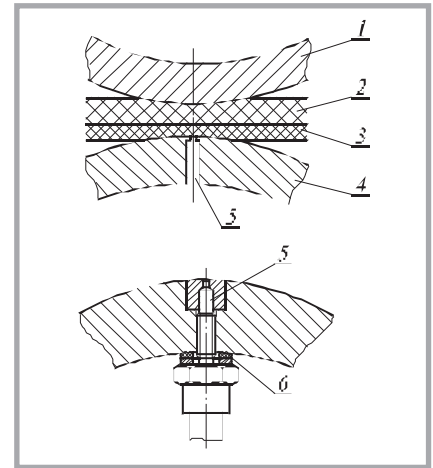


Figure 3. Location of hydraulic pressure sensor: 1 – elastic roll, 2 – felt, 3 – paper web, 4 – hard roll, 5 – sensor; 6 – gasket and adjusting washers.

felted press nip. As can be seen, the hydraulic pressure in the pressed paper web appears at a certain distance from the beginning of the press nip. The measurements performed indicate that the earlier the hydraulic pressure in the pressed paper web appears, the lower the dryness of the web entering the press nip is. During measurement of a web of about 15% dryness, hydraulic pressure appeared close to the beginning of the press nip, in a range of about 1 - 3 mm, depending on the width of the press nip, a . For an initial web dryness of about 40%, however, it amounted to 5 - 7 mm from the beginning of the press nip.

What is more, water flowing to the felt also causes its saturation, thus hydrau-

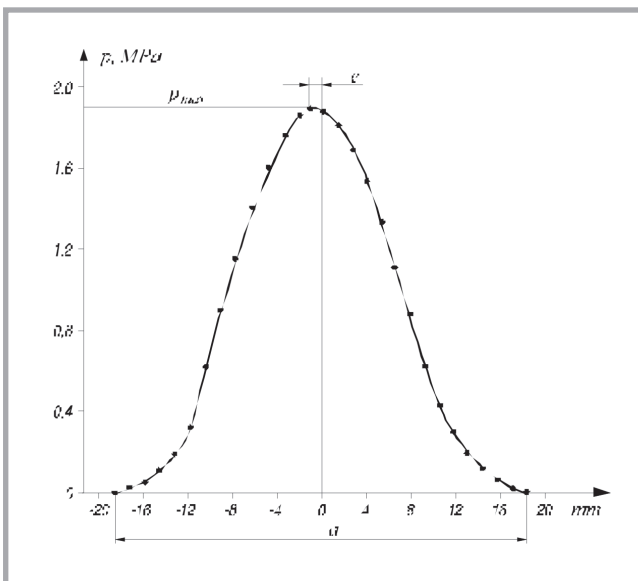


Figure 4. Distribution of the total pressure in the press nip ($\sigma_L = 30 \text{ kN/m}$).

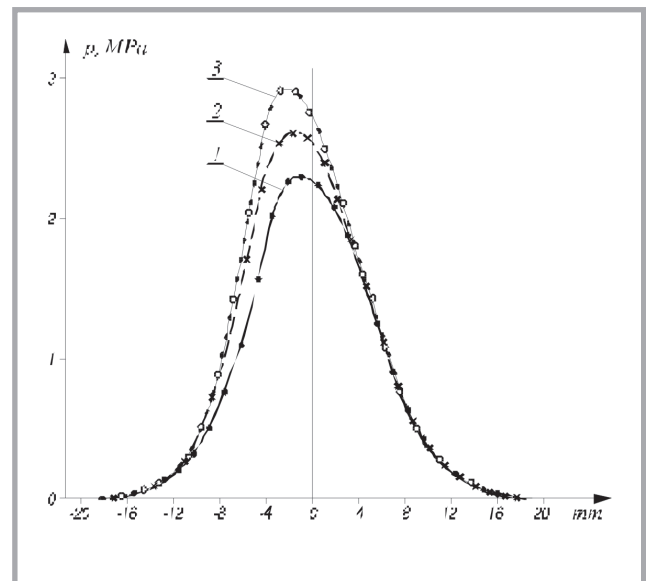


Figure 5. Distribution of the total pressure in the press nip; 1 – $\sigma_L = 45 \text{ kN/m}$, 2 – 60 kN/m , 3 – 75 kN/m .

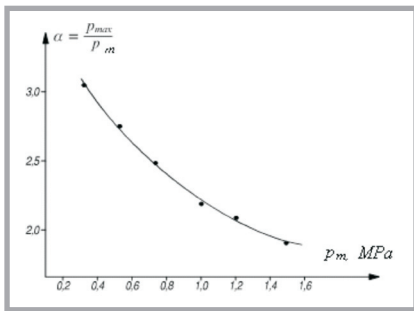


Figure 6. Effect of the mean total pressure value p_m , in dependence on p_{max}/p_m .

lic pressure occurs in the felt as well. The hydraulic pressure in the web and felt achieves a maximum value slightly before the middle of the press nip. The maximum values of hydraulic pressures in the felt are markedly lower than in paper web. The hydraulic pressure value in both the paper web and felt decreases and reaches zero. A zero value of hydraulic pressure appears in the area where the press nip widens. In this area both the paper web and felt expand, and a vacuum is created in them, which is higher in the paper web than in the felt, which induces water flow from the felt to the paper web (so called "rewetting"). The vacuum in both the paper web and felt reaches zero at the end of the press nip.

Most significant with respect to the possibilities of pressing process intensification (taking into consideration the phenomenon of web crushing as well) is the

maximum value of hydraulic pressure in the paper web and felt.

The measurements performed show that the maximum value of hydraulic pressure in the pressed paper web, p_{Hmax} , mostly increases at the maximum total pressure, web speed, web basis weight, beating degree of the stock used for making the paper web, and moisture content of both the paper web (Figure 8) and felt.

Based on the results of the measurements obtained, a relationship is proposed between the value of the maximum hydraulic pressure in the paper web being pressed, p_{Hmax} , and the parameters of this process in form of the following equation:

$$p_{Hmax} = k_1 \cdot p_{max}^{1.28} \cdot v^{0.75} \cdot q^{0.52} \cdot S_m^{0.42} \cdot w_p^{2.80} \cdot w_f^{0.22} \cdot d' \quad (3)$$

where:

- k_1 - numerical coefficient,
- p_{max} - maximum value of total pressure, MPa;
- v - web speed, m/s;
- q - paper web grammage, g/m²;
- S_m - beating degree of the stock used for making the paper web, °SR;
- w_p - moisture content of paper web, %;
- w_f - moisture content of felt, %;
- d' - coefficient relatively dependent on the number of felts, grade of stock, type and basis weight

of felt, type of press, condition of felts, and web temperature.

The maximum value of the vacuum in the paper web being pressed, p_{pmax} , increases together with an increase in the maximum value of the total maximum pressure and web speed. The value of the vacuum in the paper web depends, to a large extent, on the moisture content of the paper web, e.g. with an increase in the moisture content of the paper web from about 60% to about 80%, the p_{pmax} value increases approximately twofold. The high effect on the vacuum value in the paper web being pressed also has a beating degree of the stock used for making the paper web. In the latter case the highest increase in p_{pmax} was observed in the range of lower beating degrees (about 30 - 40° SR); at higher beating degrees this effect is lower.

On the basis of the measurement results, it was found that the dependence of the maximum vacuum value in the paper web being pressed, p_{pmax} , on the pressing process parameters can be determined in the form of an equation:

$$p_{pmax} = k_3 \cdot p_{max}^{0.76} \cdot v^{2.30} \cdot S_m^{0.31} \cdot f^3 \quad (4)$$

where:

- k_3 - numerical coefficient,
- f^3 - coefficient dependent on the grade of stock and temperature of the web.

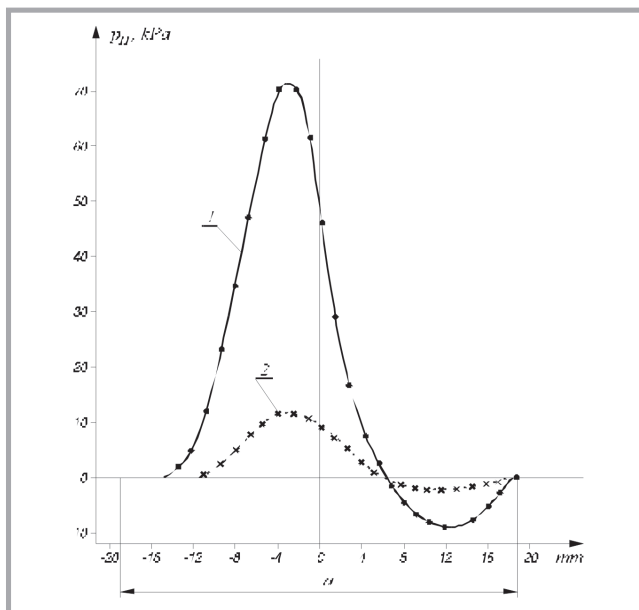


Figure 7. Hydraulic pressure distribution in the press nip; ($\sigma_L = 30$ kN/m, $v = 5$ m/s, $q = 100$ g/m², $S_m = 30^\circ$ SR, $w_p = 70\%$, $w_f = 40\%$, 1 needed felt 1000 g/m²), 1 - in paper web, 2 - in felt, a' - press nip width.

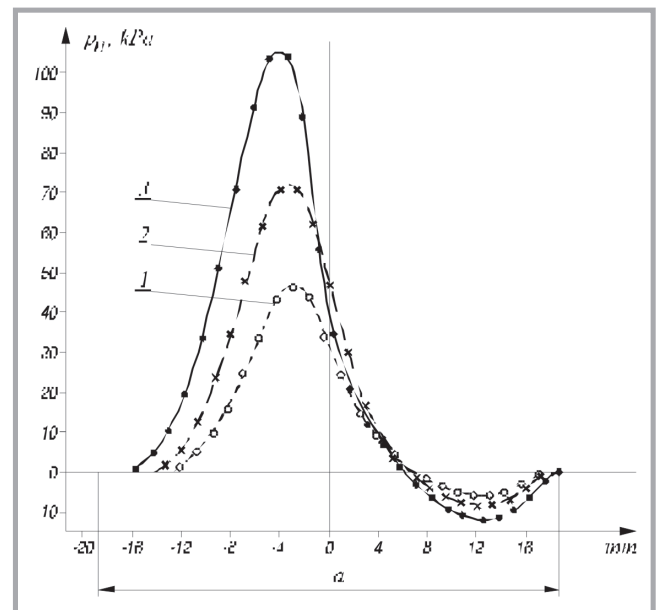


Figure 8. Hydraulic pressure distribution in the paper web; 1 - $w_p = 60\%$, 2 - $w_p = 70\%$, 3 - $w_p = 80.7\%$.

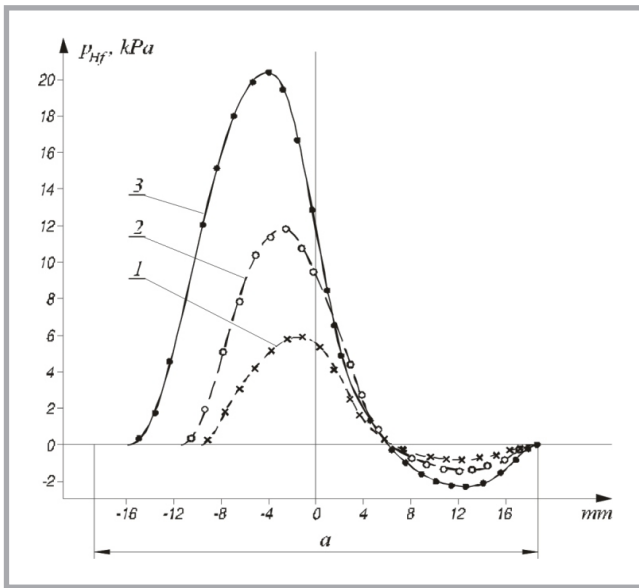


Figure 9. Hydraulic pressure distribution in felt; 1 - $w_f = 30,2\%$, 2 - $w_f = 40\%$, 3 - $w_f = 50\%$.

The results obtained during the pressing of the felt alone are presented, as an example, in **Figure 9**. These relationships show that the maximum total pressure exerts a similar effect on the value of maximum hydraulic pressure in a felt, p_{Hfmax} , as it is in the case of a paper web. The speed has a similar effect. However, the type of press has a much higher effect on the value of p_{Hfmax} , since in this case the presence or lack of storage space for water has a direct effect. If there is sufficient space for water storage, then the hydraulic pressure value on the surface between the felt and elastic roll may amount to zero or is not much higher. In the case of a plain press, however, there is a certain hydraulic pressure on the surface necessary for providing a flow of water in the felt in a direction parallel to the movement of felt in the press. It is obvious that the moisture content of felt has a direct and major effect on the value of p_{Hfmax} (**Figure 9**).

Based on the results obtained during measurements, the dependence of the maximum hydraulic pressure value in felt, p_{Hfmax} , on the pressing process parameters can be determined in the form of the following equation:

$$p_{Hfmax} = k_2 \cdot p_{max}^{1.28} \cdot v^{0.70} \cdot w_p^{2.50} \cdot d'' \quad (5)$$

where:

k_2 - numerical coefficient,
 d'' - coefficient relatively dependent on the type and grammage of the felt, type of press and felt condition.

The value of the maximum vacuum in the felt, p_{pfmax} , also increases together

with an increase in the maximum total pressure. The nature of this relationship is quite similar to that for paper web. It should be noted, however, that the values of the maximum vacuum in the felt during the measurements performed were mostly about 7 to 8 times lower than in the paper web. The vacuum in the felt also increases in a proportional way together with an increase in felt speed. At the same time it should be noted that there is a substantial difference in the vacuum in felt when it is pressed in a plain press or one with a lateral flow. In the case of pressing in a plain press, the p_{pfmax} value is 3.0 - 3.8 times higher than when pressing in a grooved roll press. The value of the vacuum in the felt also increases together with the moisture content of the felt. The dependence of the maximum vacuum value of the felt, p_{pfmax} , on the pressing process parameters can be determined using the following equation:

$$p_{pfmax} = k_4 \cdot p_{max}^{0.76} \cdot v \cdot w_p^{2.10} \cdot f'' \quad (5)$$

where:

k_4 - numerical coefficient,
 f'' - coefficient dependent on the type of felt, type of press and felt condition.

Conclusions

1. The press nip width can be determined from equation [1]. This width mostly depends on the linear pressure, roll diameter, rubber hardness and number of felts.
2. The maximum value of the total pressure can be determined from rela-

tionship [2], based on the known linear pressure and press nip width.

3. The maximum value of the hydraulic pressure in a pressed paper web decreases with a decrease in the maximum value of the total pressure, web speed, web grammage, beating degree of the stock and moisture content of the paper web and felt. This pressure is also lower during the pressing of two felts on a vented nip press, or when pressing a felt of higher permeability and grammage. The value of such pressure depends, to a greater extent, on the maximum value of their total pressure and moisture content of the paper web.
4. The maximum value of the vacuum in the pressed paper web increases with an increase in the maximum value of the total pressure, web speed, moisture content, and beating degree of the stock used for making the paper web. The highest variation of this vacuum value occurs when the web's moisture content changes.
5. The maximum value of hydraulic pressure in a felt decreases with a decrease in the maximum value of the total pressure, speed and moisture content of the felt. This pressure is lower during pressing on a vented nip press using felt of higher permeability.
6. The maximum value of the vacuum in a felt increases with an increase in the maximum value of the total pressure, felt speed, and moisture content of the felt. The vacuum is also higher during pressing in a plain press. The value of this vacuum depends, to a large extent on the moisture content of the felt and type of press.

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