Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

MODELLING OF WASTE-PAPER STOCK TREATMENT PROCESS IN DISC REFINERS

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Abstract

In the article problem of modelling and simulation in the range of refining devices of waste-paper industry were presented. Author have proposed own method of modelling of disc refiner work.

Keywords: *disc refiner, modelling of beating process, waste paper*

1. Introduction

The refining stage in stock preparation plays an important role in developing the properties of stock for paper production [4, 5]. Appropriate fiber treatment in the refiner greatly affects the runnability of the paper machine and quality of the end product. On the Figure 1 was presented mechanical treatment of fibers inside disc refiner.

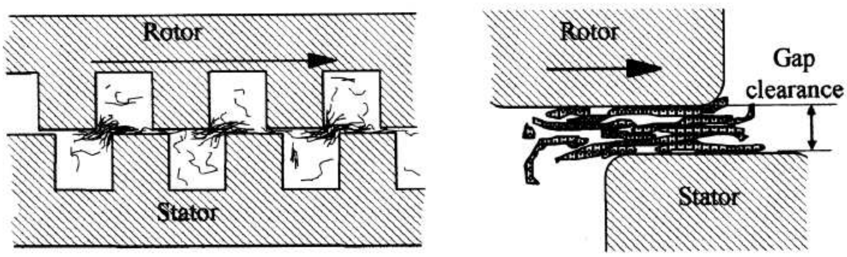

Fig. 1. Mechanical treatment of fibres inside a refiner[1, 3]

Bar configuration in refiner is probably the most important factor to achieve pulp properties. We have following plate design parameters, which are the key components of a refiner plate [1, 4]:

- Bar edge: Major working point of fibrillation (peeling action or pulling back of the primary wall along the fiber length) that increases fiber flexibility.
- Bar width: Narrower bars yield more bars for a given size plate which increases the total available bar edges and frequency of bar crossings, leading to a higher degree of fiber development while minimizing fiber shortening.

- Groove width and depth: Groove width determines flow through the refiner. Decreased groove width and depth brings the fibers to the bar edges, promoting refining action, restricting flow rate, and reducing hydraulic capacity. Excessive groove depth results in more stock passing through the refiner untreated.
- Bar angle: Increased bar angle gives more bar edge length, leading to enhanced refining and fiber development. This also increases pumping action, yielding more throughput capacity and higher pressure build-up, which uses more energy and lowers efficiency.
- Dams: Prevents the water-slurry mixture from channeling through the plate without being passed over the bar edges, but dams reduce throughput capacity. They are seldom used in low consistency refiners.
- Plate clearance: Distance between the refiner plates determines the amount of fiber cutting, as well as affects plate wear.

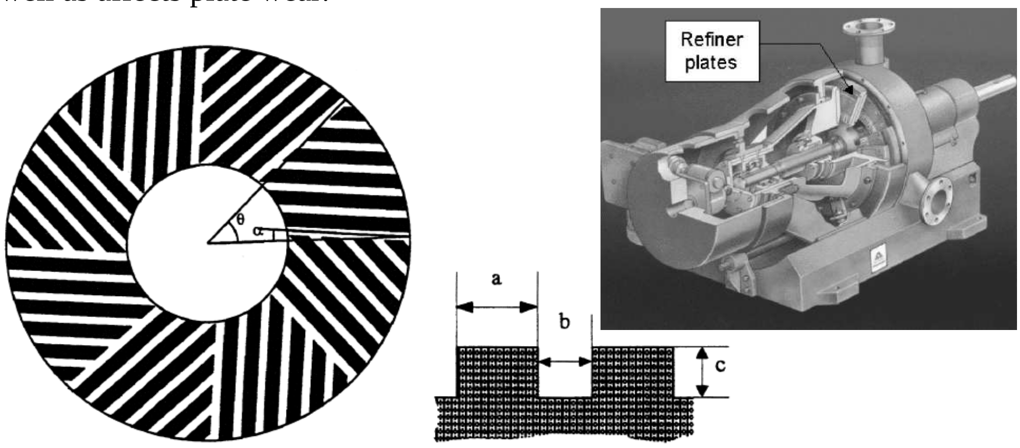

Fig. 2. Geometrical parameters of refiner fillings: a - width of bars; b - width of grooves; c - depth of grooves; θ - sectorisation angle; α - grinding angle [1]

Beating process, like in any other complex technological processes, depends on many factors, which we can divide into construction and system factors (connected with beating system and with its equipment) and technological factors. In the first group of factors there belong: using refining system (periodic, continuous), number of refining devices and their division into units (refining, proper beating, post refining), system of refiners connections and chests and characteristics of the used devices (kind, type, rotary speed, refining elements etc). We cannot change these factors during the exploitation of refiner or these changes would be complicated in practical realization.

To the most essential parameters of the second group (technological) we can accept [1, 3, 6]: properties of waste paper stock before refining, flow intensity by refiner, distance between disc, stock consistency and stock temperature.

2. Modelling of waste-paper stock treatment process in disc refiner

During the last two decades refining processes and the pulp produced with the refiners has been studied very intensively. However in many presented papers the refiner itself has been treated like a macro scale black box [5, 6]. In these studies, the effect of the major operating or input parameters such as refining consistency, refining pressure and production rate have been studied with different refining processes. The refiner mechanical pulps have also been categorized by the type of refiner used to produce them and in many cases it has been possible to differentiate between double disc, single flat disc and conical disc pulps [5]. At present, new refining processes employing high operating pressures and high refiner rotational speed are being compared to conventional refiner operation. A process model is a mathematical representation of an existing or proposed industrial (chemical) process. Process models normally include descriptions of mass, energy and fluid flow, governed by known physical laws and principles. In process engineering, the focus is on processes and on the phenomena of the processes and thus: A process model is a representation of a process. The relation of a process model and its structure to the physical process and its structure can be presented on the Figure 3 [5, 6].

Why modelling? Models, simulation and optimization in waste paper treatment are important because of the following [1, 5]:

- reduce manufacturing costs, reduce research, development and engineering times,
- increase efficiency of paper production,
- greater understanding of the waste paper stock treatment problem,
- decision support in production, knowledge management,
- ability to handle complex problems,
- improve the safety of the plants,
- bring new products to market faster,
- reduce waste in process development,
- improve product quality of paper.

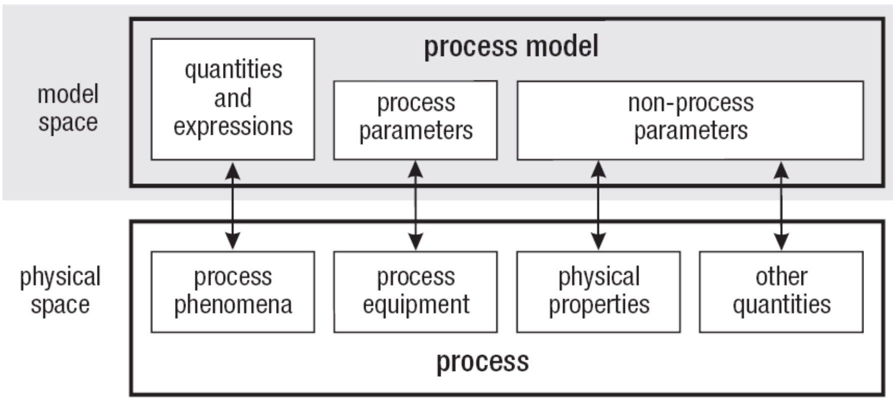

Fig. 3. Process and process model [1, 2, 3]

Different steps in the modelling of disc refiner unit processes can be presented in the following way:

1) Identification of the main purpose of the model.

2) Identification of different phenomena in the beating process:
- stock refining, fibers cutting, proper beating,
- mixed friction (beating friction and metallic friction of knives),
- procesy dodatkowe zakłócające (ciepło, drgania, zużycie itp.).

3) Identification of the most important phenomena and planning their experimental research:
- refining - mutual fibers friction and friction between fibers and working surfaces of knives,
- proper beating - treatment on the frontal surfaces of working discs,
- cutting - decohesion on the knife edges,
- mixed friction on the working surfaces of discs.

4) Selection of the theoretical basis from several competitive theories:
- friction theory,
- specific edge load theory,
- specific surface load theory.

5) Formulation of power consumption equations:
- balance of power consumption [4]:

$$N_c = \begin{cases} \text{for } x = x_4: & N_j + N_r + N_t + N_{esz} \\ \text{for area IV}: x_4 < x < x_3: & N_j + N_r + N_t + N_{sz} \\ \text{for area III}: x_3 < x < x_2: & N_j + N_r + N_b + N_t \\ \text{for area II}: x_2 < x < x_1: & N_j + N_r + N_b \\ \text{for area I}: x_1 < x: & N_r + N_j \end{cases} \qquad (1)$$

- cutting index, index of beating and refining, index of quality of paper stock,
- treatment intensity of fibers equations, component powers equations:

Power consumed on beating [4]:

$$N_b = k_b \cdot n \cdot p \cdot (D_Z^3 - D_W^3), \quad \text{(kW)} \qquad (2)$$

where:

k_b - solidity coefficient of beating,
n - rotational speed (rev/min),
p - beating pressure (Pa),
D_z - outside diameter of disc (m), D_w - inside diameter of disc (m).

Power consumed on refining [4]:

$$N_r = k_r \cdot n^3 \cdot (D_z{}^5 - D_w{}^5), \ \text{(kW)} \qquad (3)$$

where:
k_r - solidity coefficient of refining.

Power consumed on fibers cutting [4]:

$$N_t = P_t \cdot z_1 \cdot z_2 \cdot l \cdot k \cdot \tau \cdot n \cdot d_w, \quad \text{(kW)} \qquad (4)$$

where:
P_t - elementary cutting force (on knives length unit) (N/m),
l - average length of movable and non-movable discs knives,
z_1 i z_2 - knives number of movable and non-movable discs,
k - coefficient of length using of intersecting knives on cutting process,
τ - intensity of cutting,
d_w - width of fiber cutting layer (m).

Power consumed on metallic friction [4]:

$$N_e = \frac{\pi^2 \cdot b^2 \cdot p \cdot \alpha_t \cdot \sigma \cdot n \cdot (D_Z^3 - D_W^3)}{6 \cdot t^2}, \ \text{(kW)} \qquad (5)$$

where:
α_t - coefficient of knives metallic friction,

σ - summary coefficient of irregularity of frontal surface of knives, mechanical damages, angle of knives setting and knives material,
b - width of knives (m),
t - knives pitch (m).

6) Solution of the model

The solution of the model can be carried out in three basic ways: simulation, design and parameter estimation (Table 1). Optimization and experimental design could also added to the table. Process parameters refer to the parameters that are specific to the process. Non-process parameters refer to the parameters that are not specific to the process.

Tab. 1. Three ways to the solution of models

Solution mode	Calculated	Specifications
Simulation	output variables	input variables process parameters non-process parameters
Design	process parameters	input variables output variables non-process parameters
Parameter estimation	non-process parameters	input variables output variables process parameters

On the Figure 4 was presented example of disc refiner work simulation: dissipation of energy in disc refiner (application of J&L Fiber Services Inc.).

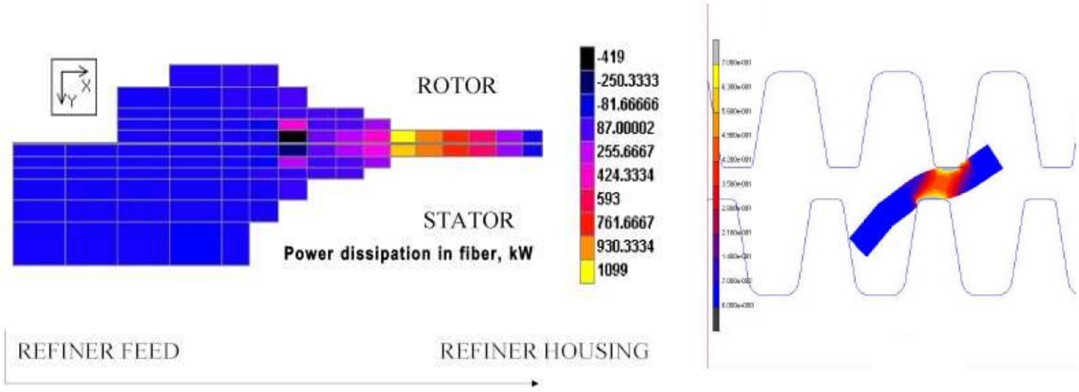

Fig. 4. Simulation: dissipation of energy in disc refiner - J&L Fiber Services Inc. [5]

7) Presentation and interpretation of the results

Parameter estimation and model validation based on experimental data, experimental data should be obtained using experimental design methodologies. On the Figure 5 was presented chart of total power consumption in function of the slot - x for disc refiner with regard of composition powers.

Beating of paper stock is one from basic processes of paper treatment and also is one from most energy-consuming processes. Power delivered on engine shaft in the time of beating changes in dependence on many factors. And in peculiarity from slot between discs refiner - x and from each composition powers. These powers are consumed on different processes, which occurred in disc refiner during beating. Total power consumption we can show by formula, in which are the basic processes [4]:

$$N_t = N_b + N_r + N_t + N_{sz}\,,\ \text{(kW)} \tag{6}$$

where:
N_b - power consumed on beating,
N_r - power consumed on refining,
N_t - power consumed on cutting of fibers,
N_{sz} - power consumed on metallic friction between beating surfaces.

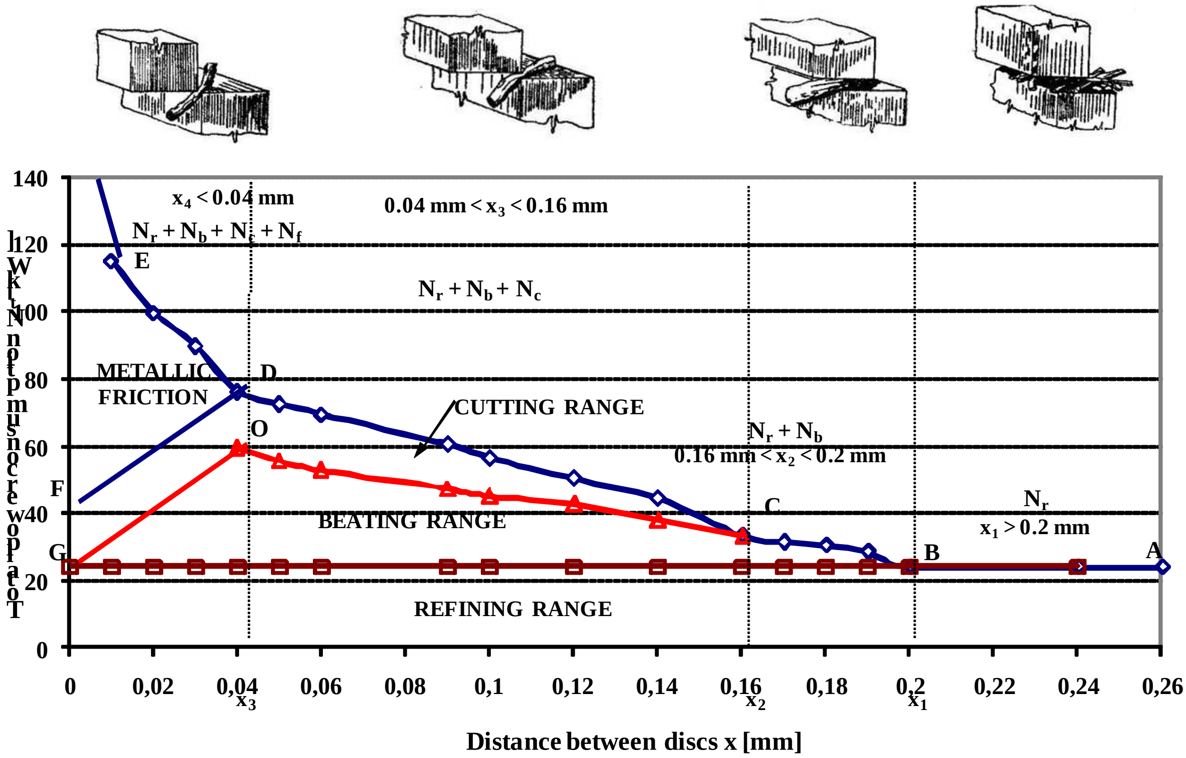

Fig. 5. Chart of total power consumption in function of the slot - x for disc refiner with regard of composition powers

Process powers were qualified by theoretical analyses of refining process [4, 5]. These powers are as follows:

N_c - Total power consumption, which depends on x – distance between disc, refiner construction and stock kind. This power is measured on engine shaft, which drives refiner;

N_j - Power consumed on idle run without stock for slot size greater than 0.2 mm;

$N_{jr} = N_j + N_r$ - Power consumed on refining with power consumed on idle run (with stock) for slot size x > 0.2 mm;

$N_r = (N_j + N_r)\text{-}N_j$ - Power consumed on refining, $N_{jr} - N_j = N_r$;

N_b - Power consuming on beating;

N_t - Power consuming on fibers cutting;

N_e - Power consuming on metallic friction (friction between frontal surfaces of knives);

N_{sz} - Power consumed on mixed friction (mixed friction consist of metallic friction and friction, which is connected with beating process): $N_{sz} = N_{msz} + N_{esz}$;

N_{msz} - Power consumed on beating which is a part of power consumed on mixed friction;

N_{esz} - Power consumed on metallic friction, which is a part of power consumed on mixed friction.

8) Documentation of the model
9) Integration of the model to the whole system or process
10) Further development of the model.

4. Conclusion

Presented conception of mathematical models elaboration enabled the comprehensive solution of the problem of mutual relations of power consumption components in relation to working conditions of investigated refiner grinding unit. Accepted assumptions and methods of logical proceeding resulted in elaboration of original work algorithm and finally led to the elaboration of the unique graph: (N_c, N_b, N_t, N_r) = f(x).

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