Information system for calculating paper-forming indicators of fibrous semi-finished products based on regression models

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Abstract. The paper presents an information system for calculating the main paper-forming parameters of the pulp for given technological and design parameters of the grinding plant. The operation of the system is based on mathematical regression models of the processes that were obtained in the course of experimental studies of knife sets of various types. As input parameters in these models, the rotor speed, knife gap, concentration and degree of grinding of the mass are used. The output parameters are the grinding time, water retention capacity and average fiber length. The developed information system is a network web application with a modular structure. The modules are united by the main interface for the user. Each module implements a regression model for a specific type of headset. At the moment, the system has two modules for calculating the parameters of a percussion type headset and a headset with a curvilinear shape of knives. In the future, it is planned to add the ability to calculate indicators for headsets of other designs. It will also add the ability to solve optimization problems by finding the minimum or maximum value of the output parameters.

1. Introduction

Digitalization is one of the main drivers of global economic growth. Digital transformation is, without exaggeration, the mainstream of industrial technological development. Modern industrial production uses digital and computer technology in all aspects of its work. Almost all processes, from direct control and management of the technological process to business planning and workflow, are currently carried out using digital data and digital infrastructure.

Despite this, the digital transformation process is still in its early stages. On the issue of digitalization, the Russian pulp and paper industry market has not yet left the initial stage of the process. This topic is relevant due to the accelerated development and qualitative changes in the state, economy and society. It is digital technologies that often become the basis of the increasingly complex situation with social relations and structures.

The introduction of digital technologies to solve problems of improving the grinding process of fibrous semi-finished products is also relevant. At present, many studies have been carried out to intensify the process of grinding a fibrous suspension in disk mills with a modification of the working bodies of grinding machines - a knife set [1-6].

One of the main tasks of processing experimental studies was to determine the numerical values of the parameters necessary for calculating the coefficients of mathematical models. The use of such models makes it possible to determine the optimal grinding mode, as well as to evaluate the efficiency of grinding when using various sets.
To build a mathematical model of the grinding process, regression analysis is used - a method that allows you to set the values of factors and the ranges of their variation at your discretion, without disrupting the course of the technological process, according to the technical characteristics of the equipment used, the requirements of standards for finished products, etc.

2. Regression mathematical models for calculating the parameters of the grinding process

The main technological and design parameters of the grinding plant, which have the greatest influence on the process of fiber grinding. Input and output parameters are presented in Table 1.

| Parameter | Designation |
|-----------|-------------|
| Input parameters (controlled factors) |
| Rotor speed, rpm | X₁ |
| Knife gap, mm | X₂ |
| Mass concentration, % | X₃ |
| Grinding degree, °SR | X₄ |
| Output parameters (controlled factors) |
| Grinding time, min | Y₁ |
| Paper-forming indicators when grinding pulp |
| Water-holding capacity (according to Jaime), % | Y₂ |
| Average fiber length, mm | Y₃ |

The following restrictions were imposed on the input parameters:

- 1000 rpm ≤ X₁ ≤ 2000 rpm;
- 0.1 mm ≤ X₂ ≤ 0.3 mm;
- 1% ≤ X₃ ≤ 3%;

Below are examples of the developed mathematical models for refining pulp using various designs of sets.

For a headset with a curvilinear shape of knives, the regression equations take the form [1]:

Grinding time:

\[ Y_1 = -34.13 - 5.6x_1 + 200.1x_2 + 0.038x_3 - 0.16x_4 + 24.72x_1x_2 + 0.105x_1x_4 - 566.67x_2^2 - 0.062x_3x_4 + 3.2x_2x_4 - 0.0000066x_3^2 - 0.0003x_3x_4 + 0.005x_4^2 \]  \tag{1}

Water holding capacity:

\[ Y_2 = 226.56 - 9.0012x_1 - 429.456x_2 + 0.01x_3 + 6.81x_4 + 95.9x_1x_2 - 0.0133x_1x_3 + 1686.08x_2^2 - 0.27x_3x_4 + 4.26x_2x_4 - 0.053x_4^2 \]  \tag{2}

Arithmetic mean fiber length:

\[ Y_3 = 0.64 + 0.32x_1 + 5.74x_2 + 0.00065x_3 - 0.0165x_4 - 0.72x_1x_2 - 0.000091x_1x_3 - 7.08x_22 - 0.00154x_2x_3 + 0.0276x_2x_4 \]  \tag{3}

For a percussion type headset, the regression equations take the form [2]:

Grinding time:
The presented regression models are used to solve optimization problems that require a lot of calculations. These calculations, as a rule, are carried out using specialized software, which requires the purchase of an expensive license. Thus, the authors decided to develop an information system for calculating the main parameters of the grinding process and solving optimization problems.

3. System for calculating the characteristics of the grinding process of fibrous semi-finished products

Within the framework of this study, the authors have developed an information system that allows calculating the paper-forming indicators when refining the pulp.

The system is a network web application with a modular structure. During development, the following technology stack was used: html+css (bootstrap 4.6), php+mysql, javascript. All developed modules are united by the main interface for the user. Each module implements a regression model obtained during an experimental study of the efficiency of a grinding plant with a specific type of set.

At the moment, the system has two modules for calculating the parameters of a percussion type headset and a headset with a curvilinear shape of knives. Figure 1 shows the main interface of the system. Here the user is asked to select a module for calculation, after which the page of the corresponding module opens (figure 2). At the top of the page, you must enter the input parameters in the appropriate fields. After clicking on the "Calculate" button, the output parameters are calculated using the regression model, which are displayed at the bottom of the page. In the example shown in figure 2, a set with a curved knife shape was chosen. The following values were used as input parameters:

- Rotor speed = 1000 rpm;
- Knife gap = 0.1 mm;
- Mass concentration = 1%
- Grinding degree = 32 °SR.

As a result of the calculation, we got:

- Duration of grinding = 12.48 min;
- Water holding capacity = 348%;
- Average fiber length = 1.36 mm.
4. Conclusion
The information system developed within the framework of this study allows calculating the main paper-forming indicators of the pulp for the given basic technological and design parameters of the grinding plant. The calculation is carried out using regression mathematical models obtained in the course of a large number of experimental studies of various designs of knife sets.

At the moment, the system implements two types of sets (percussion type and with a curvilinear shape of knives). In the future, it is planned to add the ability to calculate indicators for headsets of other designs. It will also add the ability to solve optimization problems by finding the minimum or maximum value of the output parameters.

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