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METHODOLOGY FOR IMPROVING THE EFFICIENCY OF PAPER PRODUCTION AT THE PRODUCTION FACILITIES OF UKRAINIAN ENTERPRISES

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Abstract - This paper highlights the current state of paper production in the current state of energy supply in Ukraine. Paper and cardboard production is an energy-intensive process. The author presents ways to solve the problem of backup power and steam supply to the enterprises, as well as shows the complexity of electronic control, regulation of the web tension between electric drives with the possibility of their precise correction and movement from drive to drive, their dependence on high-quality and reliable power supply.

Keywords: paper machine, gluing presses, paper calendering, drying cylinders, electricity and steam supply, transformer substation, turbine generators, automatic control system.

Introduction

There are major differences between paper mills, such as the use of raw materials and their grades, but the typical processes are similar across all mills (Figure 1).

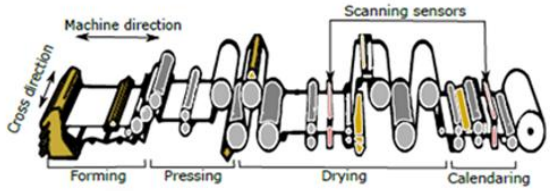

Figure 1: Schematic diagram of a Fourdrinier paper machine.

The paper and pulp industry consumes about 6% of the world's total industrial energy consumption, being the fourth largest consumer of industrial energy in the world.

As of 2024, there are 19 operating companies in the paper industry in Ukraine. The raw materials used by these companies are primary pulp and recycled paper.

Before the pulp and recycled paper pulp enter the paper machine, some processing steps are necessary, which include the preparation of the pulp from several processes, such as fibre disintegration, cleaning and storage and mixing steps, which are adapted to each other.

During the preparation of recycled paper and pulp, they must be cleaned of impurities, plastics and adhesives. Some types of paper made from primary fibres require a refining step to improve the properties of the fibre. Refining is carried out in refiners. The order of the raw material preparation operation may vary from mill to mill, and some steps may be repeated.

After the pulp has passed all the necessary stages of the pulping process, it is poured onto a sieve. In this area, most of the water is removed by gravity and vacuum. The paper pulp on the screen is dewatered by filtering. The rate of dewatering of the paper pulp affects the quality of the finished paper, for example, an increase in the dewatering rate leads to a deterioration in paper quality.

Dehydration of raw paper to a dryness of 30%-40% takes place in the press section through mechanical extraction of moisture using presses of various designs. During the paper's passage through the presses, the paper's moisture content is further reduced and compacted, which leads to a reduction in porosity and improvement of physical and technical characteristics [1, 4].

The paper is dried in the drying section of the machine. Here, the paper is finally dehydrated and brought to the moisture content specified by the standards for each type of paper [9]. In addition to final dehydration, the drying process also involves gluing the paper by hydrophobising the substances added to the paper pulp. The temperature regime of drying significantly affects the properties of paper (Fig. 2).

The paper is dried by convection. During the contact component, the heat of the heated solid surface of the cylinders, which are heated from the inside by heated steam, is directly transferred to the wet web [5-7, 9]. The temperature of the drying cylinders inside which steam is supplied depends on the type of paper and does not exceed 180°C.

This method of drying is quite economical and allows us to achieve high paper quality, namely the absence of warping and increased smoothness. The drying cylinders are heated by superheated steam supplied at a pressure of 0.5-1.0 MPa and a temperature of 120°C-165°C.

Convective drying is used to intensify the paper drying process [6].

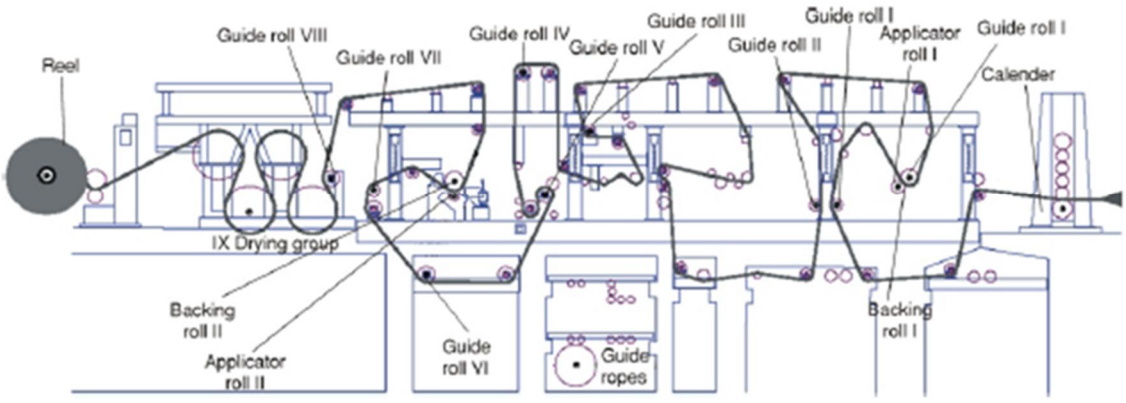

Fig. 2 Schematic diagram of the drive in the paper machine section.

The use of high-speed drying hoods allows for a higher degree of dryness compared to contact drying. In the case of the collective drying method, the paper is dried with heated air.

The technological processes of dehydrating, pressing and drying paper web complement each other. Drying paper is 10-12 times more expensive than pressing and 60-70 times more expensive than screen dehydration. At the final stage of paper production, a number of operations are carried out to improve its consumer properties.

Paper is glued to improve the closeness of its structure, increase its strength, smoothness and water resistance. The most common method of surface gluing is the use of gluing presses. Gluing presses are installed in the part of the machine where the dryness of the web reaches approximately 85%-94% and consist of two shafts. After gluing, the paper is dried.

Paper is calendered to make it stiff, soft and bulky, which is very important for sanitary, packaging and other types of paper. Finished paper is calendered on special calendering devices or directly on the paper machine.

The final step in the paper production process is rolling or cutting the paper into sheets of a certain size. The paper is then labelled and packaged.

An important structural element of the paper machine is the electric drive, which consists of motors, frequency converters and switching equipment, control panels with the integration of additional functions for controlling section speeds and activating serial input.

The equipment's automation system includes a programmable logic controller with software, a digital and analogue signal input/output module, and a digital data network controller.

The electric drive of the paper machine is selected based on an analysis of the leading characteristics of the working machine, it also takes into account the following operating features: environmental dependence, high humidity, and the presence of chemically active substances.

A variety of conductive characteristics of working elements is taken into account when selecting electrical modifications of motors and analysing transient processes of the motor-working part of the machine.

The choice of an electric drive for a working machine is based on its drive characteristics, which include: technological, kinematic, inertial, mechanical, load, and energy characteristics. The analysis of the technological characteristics makes it possible to formulate requirements for the electric drive control circuit (necessary interlocks, angular speed control, protection against possible emergency shutdowns, etc.) and select an electric motor according to the environmental conditions.

When designing an electric drive, the coefficient of inertia of the motor-working part of the machine is used. The mechanical characteristics of the machine's working parts make it possible to select electric motors according to their starting properties.

In recent years, when installing new paper machines and upgrading existing ones, there has been a trend towards the widespread use of variable frequency drives using asynchronous motors as the simplest, cheapest and most reliable electric drive that does not require special operating conditions or constant maintenance.

A variable frequency drive is a complex electromechanical system that, in addition to an induction motor, also includes a frequency converter (FC) and an automatic control system (ACS).

The paper manufacturing process requires the creation of a certain amount of tension. In the wet part of the machine (screen, presses), tension is created to remove the paper from one part and transfer it to the next section. In the drying groups and the final part of the machine, the paper must have some tension to avoid creasing. Therefore, tension control is one of the key conditions for paper production.

Fig. 3. Paper machine.

The tension of the paper web in the machine's inter-sectional spaces is created by the speed difference between the compatible sections, which is maintained with great accuracy by the automatic speed ratio control system, and the automatic control system is also used to compensate for process deviations in tension and maintain it at the desired level.

All existing tension control systems are closed-loop stabilisation systems and maintain tension with high statistical and dynamic accuracy. The main task of the electric drive system is to regulate the tension and elongation under conditions of variation of technological factors and external disturbances and to ensure uninterrupted operation of the machine.

Analysis of the current state of maintaining constant electricity and steam supply and functioning of control systems at paper mills.

Paper and board production requires a large amount of energy. Electricity consumption per machine ranges from 3 MW to 8 MW per hour. Process steam consumption is up to 15 tonnes per hour. Converting and cartoning machines require highly sophisticated electronic control. The speed setpoint must be maintained at a precise level, all drives must be synchronised and the speed cascaded from drive to drive, with precise correction [2]. In addition, the tension of the sensors must be controlled between the drives in the part of the production line where the web is formed, and the tension of the board must be controlled and the load distributed. A commonly used method is to use force sensors. Any fluctuation in the frequency voltage in the network leads to a paper web break. All the effort that was spent at the initial stage of pouring the mass onto the sieve table and guiding the paper web to the roll is wasted [4]. All energy expenditure at this level is wasted. The paper machine has to be stopped, the paper stock has to be removed at all production stages and the stock has to be fed from the pressure box onto the screen again.

In Ukraine, all paper mills do not have their own electricity generation, which makes them dependent on high-quality, reliable electricity supply. Having analysed the volume of paper production in Ukraine (Table 1), we can see that in 2020-2023, there will be a significant production decrease in paper products.

Table 1

Statistics on the volume of production of domestic cardboard and paper products

Production / ***Year***	***Paper, thousand tonnes***	***Cardboard, thousand tonnes***	***Corrugated box, million sq m***
2020 year	155,3	662,8	710,5
2021 year	161,5	735,4	754,8
% 2021 year in compare with 2020 year	104,0	111,0	106,3
% 2021 year in compare with 2021 year	100 %	100 %	100 %
2022 year (24.02.beginning of the war)	121,8	399,6	443,0
% 2022 year in compare with 2021 year	75,4 %	54,3 %	58,7 %
2023 year	110,4	467,9	529,4
% 2023 year in compare with 2021 year	68,4 %	63,6 %	119,5 %
% 2023 year in compare with 2022 year	90,6 %	117,1 %	70,1 %

There are various factors that influence this process. One of the most important factors is a stable and reliable power supply to the consumer. At the existing paper mills, steam is produced directly at the production site, while some consumers buy it from other consumers. All paper mills are supplied with electricity exclusively from the Ukrainian power grid (Figure 4).

To solve this problem, we propose to build a CHP plant (Fig. 5, proposed scheme) directly at the paper mill.

Figure 4. Electricity supply scheme of enterprises.

A combined heat and power plant (CHP) should provide combined heat and power to an industrial enterprise. Depending on the needs, CHPPs are equipped with special types of steam turbines of T, PT and R types. The project should provide for the capacity of steam boilers and turbine generators to cover 100% of the paper mill's process steam and electricity production needs. This will make it possible to be independent of emergencies in the energy market [1]. Wood or coal should be the main fuel for paper boilers. Gas should be the backup fuel. This will make it possible to choose the type of fuel depending on its availability on the market and price. The steam output of the boiler is selected depending on the choice of an electric generator and the process steam needs of the paper machines. A steam turbine with a generator should be selected depending on the installed capacity of the consumer.

Each turbine is matched to a specific type of generator. Turbines and generators are matched on a power scale. When choosing a turbine, it should also be borne in mind that industrial steam with a pressure of 0.3 MPa - 0.5 MPa is used for paper drying. Therefore, a turbine should be selected with condensation, industrial and heat recovery (PT type), taking into account that the heat load should also be provided for ventilation and heating of production facilities. Heating and ventilation and domestic needs are usually supplied with hot water with a temperature of 70°C to 180°C.

The combined generation of electricity and heat will significantly improve the efficiency of the power plant by reducing heat loss in the turbine condensers.

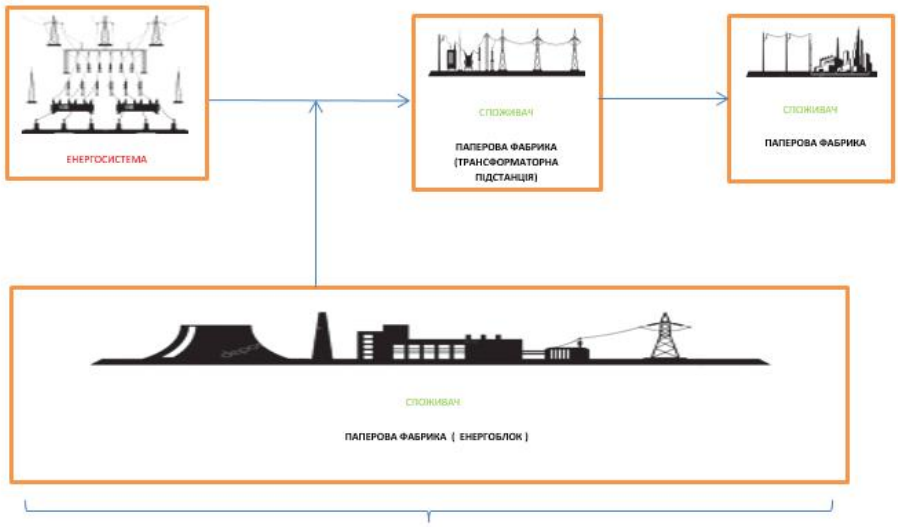

Figure 5. Proposed scheme for modernising electricity consumption with building of separate power block and possibility of operation in autonomous mode using own power source.

Structurally, they are made according to the modular layout principle in the size of a standard container (Fig. 6).

The module has an electric capacity of 6 MW, and if necessary, the single installed electric capacity can be increased to 25-30 MW.

It should be noted that the modernisation proposal does not affect the existing equipment at the existing plant. On the free territory near the boiler house and substation of the enterprise, turbine modules operating on organic coolant steam are installed and delivered to the construction site in full factory readiness, which significantly reduces the time for installing electrical

equipment. The modular device allows the installed capacity to be increased to meet the needs of the consumer.

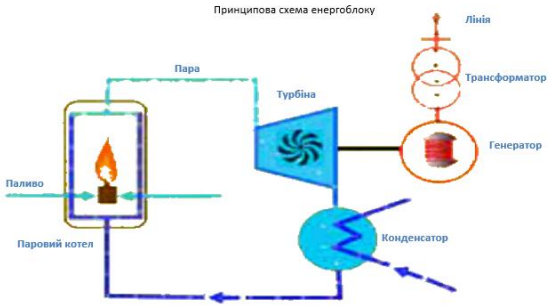

Fig. 6 Schematic diagram of the power unit.

Conclusions:

The construction of CHP plants will make it possible to reliably supply enterprises with electricity and steam.

The creation of new industrial steam and electric power plants opens up the possibility of optimising the parameters of interacting heat flows and the selection of organic coolant. When implementing the above proposals to improve the reliability of the enterprise's energy supply, the construction of a CHP plant does not affect the existing energy supply at the enterprise. This energy supply scheme will be both technologically and economically beneficial regardless of the state of external networks (electricity, steam, gas supply).

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МЕТОДИКА ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ВИРОБНИЦТВА ПАПЕРОВОЇ ПРОДУКЦІЇ НА ВИРОБНИЧИХ ПОТУЖНОСТЯХ ПІДПРИЄМСТ УКРАЇНИ

Степан Пакіж

У статті висвітлено сучасний стан виготовлення паперової продукції в існуючих умовах енергозабезпечення в Україні. Наведено способи вирішення резервного забезпечення папереробних підприємств електроенергією і паром, показано складність електронного керування, регулювання сили натягу полотна між електроприводами з можливістю їх точної корекції та переміщенню від приводу до приводу, а також їх залежність від енергопостачання.

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