Selected quality indicators and methods of their measurement

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Abstract. Since long time it's known that every enterprise or factory, to keep position on the market must constantly increase productivity, improve the quality of its product or introduce new features and functions or reduce costs production and after that decrease the price of the final product. Strong slogans: faster, better, cheaper they do not always go hand in hand. Today no one even dreaming about a spectacular jump by a dozen or several dozen percent. We are currently "fighting" by several percent and in some cases for percentage fractions that will allow you to stay ahead of the competition. The paper will attempt to identify the suitable parameters used to assess the quality and efficiency of production. Methods of measuring quality values and ways of reacting for their change. Their mutual dependencies and ranges of changes. Which parameters have a critical impact on the product and its suitability for sale.

1. Introduction
Since the year 105 when how it assumed the paper was invented, much has changed in its construction, manufacturing process and methods of measuring its features and quality [1,2,3,4]. Continuous control of the production process at each stage and control of raw materials used for production overall consists of the quality of the final product, which must meet with the criteria set by customers. Those criteria are increasingly tight tolerance range and the deviation or going beyond the specification can't take place. The continuous increase speed of production can't affect the quality of the final product. Furthermore, this production process cannot have negative impact on the environment, pollution emitted to atmosphere and groundwater should be reduced. Natural primary fibers (pulp) are still irreplaceable raw materials in the production of various types of paper. This is determined by the necessity of fulfilling the specific performance or meeting the specific quality requirements by the finished product [4,5,6]. The striving to reduce the share of primary fibers in the final product requires changes in the paper's composition, in additives used in its production, and what is more, also changes in measurement techniques and parameters that are measured. Every second thousands of data are generated in process and it gives the general overview of it. But to interpret it correctly, there is a need to acquire a deep knowledge about critical parameters of final product.

Machines built twenty years ago are currently working with 400 percent of their nominal designed capacity, machines built five years ago work on 115 percent of the original capacity. Manufacturers should cooperate (often simultaneously) on many levels of a complicated production process. Sometimes increasing productivity is not enough or the costs for it are not adequate to profit. Sometimes, to improve performance, it is necessary to change the features of the product so that it is possible to speed up the manufacturing process. They optimize the production process and, if possible,
the product itself or its subcomponents. After these operations, there is a need to modify the process control, change the instructions and manuals, service training and modification of production procedures. There is a need to change verification procedures of the final product. This increases the number of points to be controlled during the process itself as well as after its completion. Each high-performance production plant is controlled today by the automation system. The size of the system is measured at I / O points (inputs / outputs). The inputs or outputs can be binary or analog. Depending on the complexity of the process as well as its size, the system may have from 500 to 10000 I/O’s. The whole factory may have even 50 - 60 thousand I/O’s. Sixty thousand physical signals, including temperature, pressure, rotational speeds, current and voltage values, working statuses and many other parameters. Each I/O is more or less important, but each carries some information that needs to be processed, stored and analyzed and which may be relevant in certain circumstances. If we look locally only on one production machine, we can list at least 15 important parameters that we constantly measure in at least of ten places. With a efficiency of, for example 400,000 tons per year, this gives an effect of scale. We are currently overwhelmed by a huge amount of large numbers, so maybe it does not make such impression and it is difficult to imagine that. But if we assume that machine speed is 1200 m per minute and the product has a width of 4 - 6 m and every hour we produce 60 tons of product, then it is easier to imagine the scale of production. Included to this control measurements and measurements of additional parameters that are done out in laboratories. The choosing of relevant data that affects specific production parameters is a challenge for Industry 4.0. Information Technology [7,8,9,10] (IoT, Industry Ethernet, Big Data Center) allows to remember and transform such a huge amount of data. But there is still to needed look for new techniques and algorithms that the results developed by the computer system would be they are useful and can be used for overall process optimization.

To identify which components have major impact on the finished product’s quality, the mutual dependency between process’ parameters and other components participating in creation of the manufacture must be determined. The following paper is an attempt to show the most important indicators which affect the quality and attributes of the paper regardless its type and purpose. Nevertheless, paper as a product must meet all the requirements that are set with final customer.

2. Production and measurements

Each stage of the production of pulp and paper is strictly controlled by specialized employees. They rely not only on their knowledge, but also on complex computer systems for monitoring (QCS) and regulating the most important parameters at every stage of production. They are additionally supported by laboratory systems, performing a repeated check of control systems in the production process.

Paper as a product can be divided into several categories. In to groups: due to the type of raw materials of which it is made; due to the use; due to the production process and many more [11]. The properties that are obtained after the production process also differ as well. However, each of these products should be evaluated and controlled. However, any tests that are performed on paper require a measurement method and devices to carry it out. A classification is made of product quality indicators, which is paper. Of course, the specificity of the plant and above all and the client's requirements precisely specify which parameters and what values are to be met by the product. It must be checked the product does not deviate from the accepted requirements of the assessment already at the stage of raw materials during the preparation of the mass and during the manufacturing process and after its completion. Some measurements can be made already during the production process "ON-LINE" and some in the laboratory. ON-LINE measurements provide with continuous information not only about the current measured values, but also provide a source for the process control and control system (DCS) to verify current settings and change setpoints. Two groups of measurements and process control can be distinguished. So-called MD (Machine Direction) longitudinal and CD (Cross Direction) transversal [12]. The terms refer to the direction of web sliding in the paper machine figure 1.
Paper has different properties depending on the direction of measurement. The relationship between the directions is compiled and both lateral and longitudinal direction should be considered. On the major production stages, continuous measurements take place, which have a direct impact on the process control and measure the current parameters of the web. Appropriate detectors are placed in a measuring frame that moves the sensors head across (edge to edge) of the moving web [13].

![Figure 1. Direction of movement of the sensor head relative to move of web. own elaboration [13].](image1)

![Figure 2. The principle of operation of the weight meter. own elaboration.](image2)

### 3. Parameters and measurements

As the most important measured and controlled parameters can be mentioned: basis weight, thickness, moisture, strength, surface quality [14].

**BASIS WEIGHT** - this is the number of grams per square meter of product. Group paper by terms of basis weight, they can be divided into paper < 250 g/m2, including tissue paper < 28 g/m2 and cardboard weighing > 250 g/m2.

Can distinguish:
- tissue paper - a type of paper with a low weight, usually less than 20 g/m2; it is a paper with special functional properties that allow it to be used for sanitary and hygienic purposes; the main assortments of hygienic papers are: wipes, towels, napkins, toilet paper,
- papers for printing and writing - the assortment of papers in this group are xerographic, offset and other papers; the typical weight of this type of paper is 80 g/m2,
- special papers - paper varieties which, after production, can constitute a final commercial form or serve as a raw material to produce other paper assortments; examples of assortments of this group of papers are: decorative papers, acid papers, laminating substrates.

To measure the basis weight, absorption meters are most often used, based on the phenomenon of radiation absorption figure 2, because the accuracy of measurements made with such a device is more accurate in comparison with radio-isotopic scatter meters. To measure the basis weight during the production process, a weight gauge built into the measuring frame is used. The basic sensor is a contactless two-sided sensor designed to measure the mass per unit area of the paper web passing between the heads [15]. The package also includes sensor head software and application software in the quality measurement server (QMS). The sensor consists of a radiation source on one side of the paper web (referred to as the source head) and the detector on the opposite side (referred to as the detector head). The beta radiation emitted by the source is partially absorbed by the paper and collected by the detector. The detector, the ionization chamber, derives a current proportional to the intensity of the measured radiation, which then is the inverse function of the mass of the measured sample. Models of mass sensors differ mainly in the type of radioactive source used. The required range of measuring mass determines the source to be used.

**THICKNESS** - most often expressed in μm. It is also conditioned by the type of paper produced and its use. On the basis of the thickness measurement, the density of the substrate can be determined at individual points of the web. Even distribution of thickness over the entire surface is important for...
achieving good results, for example when printing, if considering printing paper. Depending on the type of paper used to measure its thickness, two types of measurements are most commonly used. Measurement based on magnetic induction and optical laser triangulation.

The principle of electromagnetic sensor operation is based on a kind of electromagnetic induction called self-induction. Each circuit with variable current changes the electromagnetic field. On the other side, the propagating electromagnetic wave induces a current in the conductor. If the conductive element is not a wire, the electromagnetic field generates circular currents (eddy) figure 3. The current generated by the magnetic field of the circuit is called self-induction. According to Lenz's law, the current induced in the conductor will be against the current change that causes the stream to change. The reduction of the current flow in the circuit as a result of induction is called inductive reactance. The value of self-induced current depends on the length of the conductor. To increase its length, the wire forms a coil. The sensor consists of two heads mounted on both sides of the measured sample and the sensor-specific software and application software located in the quality measurement server (QMS). The floating head (detector) generates a magnetic flux as well as detects changes in its strength. The button is made of a material with high magnetic permeability. During operation, the pneumatic controller lifts the button in the source head and presses slightly on the upper detector head assembly. The ribbon passes between the heads and its thickness changes change the distance between the button and the detector head that changes the magnetic flux. Changes in the magnetic flux are proportional to the distance between the coil and the button, and thus can be used to measure the thickness of the paper web.

![Figure 3. Technique based on the measurement of the electromagnetic field, [15].](image)

Optical thickness measurement uses the head shifting method figure 4, where one side of the sheet is measured by the laser, while the bottom side of the sheet is captured by the reference surface. A single device for measuring laser triangulation is simple. Accuracy and repeatability are comparable to contact type sensors and no difference in performance can be found between the laboratory, contact terminal or optical clamp. The distance measurement (Z) built into the sensor body is specially designed to match the laser resolution of the triangulation system. The combination of the reference surface, distance measurement and distance Z results in the measurement of the clamped paper. Additional devices are built into the sensor to support its calibration and standardization without the need to remove it for service [16].

![Figure 4. The principle of laser thickness measurement, [16].](image)
HUMIDITY - this is another important parameter of paper. Water is very important in the production process. At the initial stage, paper pulp is made up of 99% water and process additives and only 1% of fibers. Such a high-water content prevents flocculation. Flocculation involves striving fibers to connect with each other. If the flocculation would not be eliminated, the final paper would form an inhomogeneous surface. To prevent flocculation, the mass poured in the infusion is set in motion. The infusion distributes a precisely defined, even amount of paper pulp in the next dryer fabric section, where the paper web is formed. At the next stages of production, the water is removed from the web, so that at the end the paper contains from 5 - 10% of water depending on the range [13].

However, all the water cannot be removed immediately from the paper, because it would run uncontrolled and unpredictable. Depending on the side, the paper exhibits different moisture-generating properties, and consequently the deformation takes place differently figure 5 [17].

![Deformation of the paper relative to direction move of web](image)

**Figure 5.** Deformation of the paper relative to direction move of web, [14].

The moisture sensor uses the latest available technology. The measurement technique is based on the absorption of infrared radiation. The molecules (water or fiber) present in the paper can be identified by absorption at a specific wavelength. The choice of the wavelength of light is possible using narrowband interference filters. The mass of water can be determined based on absorption at a selected wavelength. The humidity measurement consists of the main source of the double head (lower head) and detector (upper head). The detector contains appropriate head, sensor and application software on a quality server (QMS). High-power halogen lamp - the source of light shines all the time in the source head and has an orange colour thanks to the reflective mirror coating in the upper part. Penetration takes place through paper and is collected by the detection head. Special sensor optics minimizes the effect of scattering, aligns the head, minimizes the effect of dust accumulation in the detector and the impact of environmental effects. Optics consist of lens systems and mirrors, located partly in the head and partly in the detector. The design helps in providing light from the source to the detector in a very efficient manner. The humidity algorithm is based on the intensity of four transmission signals measured at selected wavelength bands. The average value of each signal is corrected for the current and expressed in absorption units. The absorption of photons in paper increases drastically with the number of fiber layers that are proportional to the weight of the paper. Various elements that often occur in paper, such as clay, titanium, kaolin, starch or other chemicals, also affect total infrared absorption.

### 4. Conclusions

Beside the indicators which were mentioned above, there are many quality indicators defining the paper. The correct measurements are the base for correct process control in order to obtain stable parameters of the product requested by customers. Different kind of tests checking the appearance and characterizing the paper have been included in the international guidelines. These standards allow to standardize the obtained results, compare different products or make them in different factory or line. While comparing the obtained results, there is a need to compare also testing conditions. Continuous control of measuring devices and their calibration as well as verification of results in laboratories give certainty of the results obtained from the process.

This paper is the first part of the research to allow the analysis of the results obtained from production and to find a correlation between the dynamically changing production parameters. An
attempt will be made to change the current controls calculated by the control system in order to improve production. Production improvement can be understood as raising the quality, reducing the amount of raw materials used for it, increasing speed or reducing the number of failures. Continuous process control (DCS, QCS), many measurements combined with automation and advanced control give great results. Thanks to this, it is certain that the produced paper always meets the technical requirements.

Acknowledgments
This work has been supported by the Ministry of Science and Higher Education according to contract no 12/DW/2017/01/1.

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