ANALYSIS OF CONTROL SYSTEMS FOR THE APPLICATION OF DATA MINING METHODS

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Abstract: In high speed continuous production process the machine control system consists many controllers of different type and different level of complexity. Paper making is an example of such a high-speed continuous process. Can be listed PID, MPC, fuzzy controllers and a few others that are in use in different parts of the paper machine at different stages of production. The machine-directional (MD) and cross-directional (CD) control system includes loops that influence the paper properties in the cross and machine direction. However, PID regulators only look at a small part of the technology, and only account for one or at most cases two process parameters. MD and CD control reacts to deviations from the parameters determined by the technological requirements of the paper. However, these systems do not have the ability to analyse a wider range of the machine or to cover the whole machine area with its scope. Minimalization the time of production of the wrong product means multifarious profits for the production plant. The ideal situation would be to eliminate the wrong product at all. Finding new ways of detecting or prediction the emergence of defect areas and minimizing the time of adjusting the system to nominal conditions of a paper making process is the aim for research in this paper. The paper is an attempt to compile and analyse currently used control loops and the possibility of modifying them to improve the quality of the final product.

Key words: control system, process production, quality assessment, data mining, reliability assessment

1. INTRODUCTION

As part of the work, several research interviews to production plants were carried out and several conversations were held with employees at various levels. There is different awareness of employees about how the process is controlled. Which controller is responsible for which stage of production. Not from the technological side but from the control system side. Employees are divided into departments, e.g. technology, electrics, control and measurement equipment and system engineers. Sometimes there is a situation when workers from one department performed by some action and not reported to the second department e.g. an actuator replacement with theoretical the same type, but a newer model with another open/close time. It causes a change in the dynamic response of the object and thus deterioration of product properties because controller was tuned in other conditions. Then the operators saw the effect of deviating from the specifications or upsetting control. The situation is reviewed and directed to the appropriate department for resolution. Finally, the cause of the issue is found and removed, but the time spent on searching for it and producing the wrong product is treated as unprofitable and reduces the efficiency of the mill.

Priority in any manufacturing industry is minimalization the time of production of the wrong product means multifarious profits for the production plant. The ideal situation would be to eliminate the wrong product at all. Finding new ways of detecting or prediction the emergence of defect areas and minimizing the time of adjusting the system to nominal conditions of a process is the aim for research in this paper. Clear information for the service about the situation and indication of the location of the fault is the basis for modern production control systems and management of the whole plant. Correlation of various seemingly unrelated phenomena that occur on the machine is possible only by qualified staff with many years of experience or by a control system based on Statistical, Data Mining principles. Especially in paper making mills where paper goes through paper machine with 1200 meters per minute. However, man has limited perception and limited ability to simultaneously analyse several signals and measurements. On average, simultaneous analysis 5, 7 to 10 trends are very difficult. If it is necessary to extend the time horizon for the analysed range in order to detect various appearing symptoms preceding the deviation from the norm, then man is completely unable to handle with this problem.

We receive hundreds of thousands of data per minute. This creates a matrix of the hundreds of control loops interconnected with each other, whose change of one parameter at the beginning of the process may represent irreversible effects in the final product only

detected at the end of the process.
With such a large number of variables, it is obvious to use the data mining techniques (Milne et al., 1998). These methods have many advantages and they are very powerful tools, but they also have disadvantages. Some of these features under certain conditions they are unacceptable. First it is need to have a very high computing power so do not to create expensive local server clusters in most cases data are transported outside mill to external cloud where are calculated. So, a case of data security arises. Second data mining is not accurate in 100%. When inaccurate data is used for key production decisions, it will cause a consequence. If we use about neural networks, for example, there is a risk of overfitting the network and then it will show unbelievable results.
The paper is an attempt to compile and analyse currently used control loops and the possibility of modifying them to improve the quality of the final product.

2. MEASUREMENTS AND CONTROL

The output from the production process is a product that should meet the properties specified in its specification. The final product is influenced by many production and non-production factors. Those related to production primarily are the state of the machine and executive elements. Accuracy of valve movement, shaft balancing, amount of backlashes. Condition of drive sets and servos. Condition of machine clothing, including felt and driers (Hashemian and Bean, 2011). Production speed and variability as well, actual weight and type of product. Important is also the ability of the machine to follow on speed changes and basis weight. These parameters can save the amount of the final product directed to the fiberizer. Non-production parameters include everything that happens outside the paper machine, namely pulp, water, steam Figure 1. These conditions must be in the best state for production to run off without loss quality and unplanned downtime with highest possible efficiency (Linnala and Hämäläinen, 2011). The paper production process is a continuous and complicated production process. It combines mechanical, chemical and physical issues. The speed of the process and the impact of disturbances on its own, of course, should be taken into account. Paper machine is distinguished between CD and MD dimensions (Niemiec and Krenczyk, 2018). The properties of the paper are distributed relative to these directions. The properties of paper in these directions are not the same, so the further production process of paper products is subordinated to the direction of MD. Because the strength of the paper in most cases is greater in the MD direction (Pavithra, 2015).

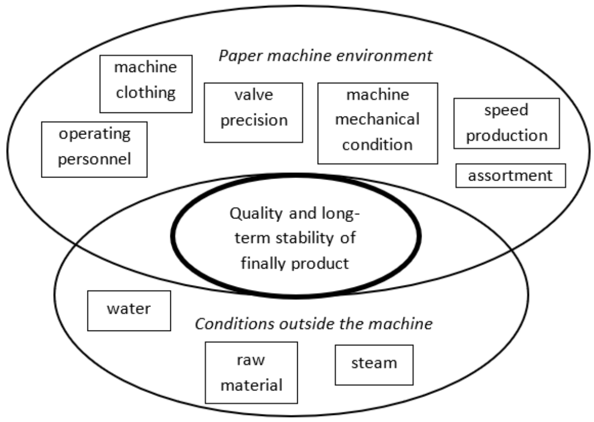

Fig. 1. Influence of factors on production quality

In addition to strength in the cross and longitudinal directions, other important parameters are basis weight, moisture and thickness. The specialized control systems (DCS, QCS) as well as personnel supervise of good parameters of process production and keep them in limits and specifications of finally product. The CD and MD parameters are different so the controls in these directions are separated (Rippon et al., 2019). In the control system, these are separate controllers, each of which is responsible for its designated parameters. Their divide is dictated to minimize temporary deviations in these areas. The target of paper production, from the quality point of view, is to control process to keep the efficient way of production of a paper web with consistent properties in accordance with customer specifications and equal over the whole width and length of reel (Bajpai, 2015). It is difficult because the width of the paper web can reach up to 10m and length of single reel can reach up to 50km. Dedicated MD and CD control systems are used for time and space changes. For implement feedback control, MD and CD controllers require measured output profiles, coming from a scanner sensor. Because of specifics of the measurement sampling trajectory, the obtained scanner signal contains a mixed signal coming from CD and MD. CD controller is responsible for cross profile of paper web. This controller controls the dilution valves located along the inlet (VanAntwerp et al., 2007). The degree of opening of the angular valve is calculated as feed forward individually considering the current settings and measurements coming from the traverse. MD controls the longitudinal profile. It controls the speed of individual drives and thus the speed of the whole paper machine. It also corrects the moisture content of the web by controlling steam and water boxes. MD and CD are built based on the MPC (Model Predictive Control) structure to get predict the process output over some future horizon and solve optimization issue with the control signals and many variables (HosseinNia and Lundh, 2016, Ammar and

Dumontc, 2015). At every moment of the control performance, the controller forecasts the process result and predicts the future state of field. Forecasts are made within a specified time horizon and are relay on built process models and known control history.
The MPC master controller calculates the main parameter settings and is connected to many controllers. So, we can list the function implemented by controller CD and MD:

- Mapping;
- Control algorithm and performance;
- Processing of scanner measurements;
- Aim calculation;
- Error predictor;
- Control actuator level;
- Graphical interpretation.

Single controllers maintain single flow or pressure values to maintain the overall product set point. Some of them are PID or PI type. This model is called SISO process (Single Input Single Output) and can have only one measurement (Input) value and one output (control) value. It can be described by the transition function of first – order model (1).

$$G(s) = \frac{K}{1+Ts} e^{-Ds} \tag{1}$$

where: D-delay, K-gain, T-time constant.

Each PID controller must be tuned to the system at start up. It is a laborious process, however, quite well recognized and its implementation is not difficult in simple systems. When work conditions or objects parameters have change then regulator should be retuned one more time. There are many tools for helping to tune of PID controller (Nisi et al., 2018), (Nagaraj and Vijayakumar, 2012).

$$G(s) = \begin{bmatrix} G_{11}(s) & \cdots & \cdots & G_{1q}(s) \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ G_{p1}(s) & \cdots & \cdots & G_{pq}(s) \end{bmatrix} \tag{2}$$

An MPC process is a system with multiple process inputs (measurement) and multiple process output (control) is call MIMO model (Multiple Input Multiple Output). Each process output is connected to several process input so value of each process output is influenced by several process inputs. It is impossible to separate the coupled variables. The MPC model can be described as a model matrix (2).
Standard PID or PI controllers are used for simple control loops, and MPC is used for advanced algorithms and for calculating multiple values. Some special control loops, such as basis weight can be done via the fuzzy controller (Bhatia et al., 2017). Fuzzification is the process of dissociate a system input and/or output into one or more fuzzy sets. The easiest way to interpreted of fuzzy is to show it as triangular or trapezoidal shaped functions because they are easier to represent in embedded controllers Figure 2.

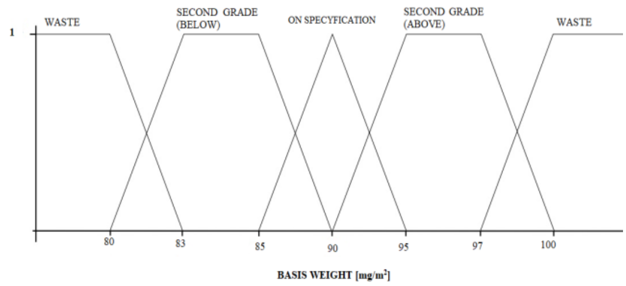

Fig. 2. Graphic representation of fuzzy functions

With this scenario, the input variable's state no longer jumps abruptly from one state to the next (https://en.wikipedia.org/wiki/Fuzzy_control_system, 2019).

3. SUPERINTENDENCE

In a properly functioning continuous technological process that is stable, a dynamic balance is established, which is generally called as technological balance. This balance is defined by indicators: physical, physic-chemical and chemical. These indicators call criterion indicators, which enable unambiguous characterization of the state of the technological process. These indicators usually also have a significant impact on the whole process. But the challenge in controlling the paper-making process is also the fact that a some of important indicators (parameters) of the final product can be measured only in the laboratory. As a test for tensile strength.
After production of the reel, control slices are taken, which are sent to the company's laboratory and serve first as verification of the measurements mounted on the machine and secondly provide information about parameters not measured on the machine. Also, measurements of raw material cannot be made directly but obtain value is as a result of indirect measurement - e.q. measurement of suspension concentration in the first sieve water. This introduces additional measurement uncertainty and the need to calculate control based on the final product. The time and material devoted to the measurement result in case of a negative effect should be calculated as a loss. Tensile strength is a very important feature of paper, which mainly depends on the orientation of fibers. It is important that the long fibers line up

along the paper production direction. Thus, the paper gains very high strength in this direction and it is easier to design e.g. a shopping bag or carton box. The arrangement of the fibers, however, depends to a process of the pulp is spouted out on a wire. The subsequent operations with the help of the control system bring slight changes to its formed properties. There are methods that allow approximation of paper web strength based on pulp composition analysis (Belle and Odermatt, 2016, Ahola, 2005). It's very important to be able to predict the features of paper on the reel. And then control the process in such a way to obtain the assumed parameters (Ekholmer, 2016, Bai et al., 2017). This helps to pre-calculate paper strength. It is very important to avoid breaks on the paper machine. Every web break on the machine reduces its efficiency. Depending on the place of occurrence on the machine the web break causes the production process to stop and it is more or less difficult to resume it. But this always slows down the machine and breaks the paper continuity on the reel. It causes interference in the steam flow and thus affects the temperatures inside the machine. This has an effect on product quality.

Therefore, automating web break detection and strengthening its reliability is of great importance during the production process. Important think of these solutions will be the ability to copy of detection system to another machine and increase the time window until a break occurs. Adding all the listed components: raw materials, machine condition, and control system there are affecting the quality of the final product.

But today's in mills it is not only the most important to keep production and keep the final product in high quality. Today is also important to meet the above assumptions and to run the process efficiently and economically with including also impact on the environment. Currently, the factory is seen as a source of profit, of course, but also strives to leave the smallest possible footprint for the environment. However, technological processes have become more and more sophisticated and their complexity has increased. The number of measured parameters of the final product and parameters during the process increased. We can say that today that there is no limit for the amount of data collected and saved to the system. Various statistics and calculations are used to obtain a reliable indicator of the overall process and thus try to keep them in good condition and good efficiency (Ma and Shen, 2019).

Good performance is the speed of the process itself as well as the number of production hours. Sometimes, due to technology, the process cannot be accelerated anymore, so there are still being sought the solution that can ensure longer machine operation. This means that downtimes or extended periods between shutdowns/maintenance or both can be minimized (Ahola et al., 2004, He et al., 2019). Predictive maintenance is the solution that is intended to indicate the place and time of the next failure. This will allow you to safely stop the process and control the repair or conduct the process on such parameters that will allow you to safely drive the process to planned downtime (Yihai et al., 2017). Trying to make an assumption for finally quality, energy consumption, consumption of raw materials, amount of impurities (Martin, 2013). Tools for estimating the results of ongoing production can also help when process going to deteriorating quality without a visible effect on the machine or process parameters. Sometimes the quality parameters deviate from the norm, it is not known why. This is especially the case for the production from recycled paper, whose market share is still increasing (Association of Polish Papermakers Bulletin, 2018). As a result, paper pulp gets less fresh, strong and long fibers. While they get into the pulp weak and short fibers. Then the pulp composition becomes unknown and unpredictable. In such cases when the control system cannot cope with the task then a man can help. People who are employed in the mill. Experience and knowledge of the process as well as human intuition are still irreplaceable in such cases. However, along with intuition, a man brings his ego to work, which should not affect his decision making, however, sometimes it happens. Sometimes there are immeasurable relationships between people which cause that the operators do not want to run the process well or do not want to improve it because it causes work to themselves or trouble for them if this operation fails (Sukdeo, 2017). Conviction of being superior and not replacing specialist sometimes has a negative impact on process control, because it’s a man makes the final decision to change production parameters and drive a process. The rivalry between shifts or between team members sometimes causes making a bad decision or making decisions for hinder or move own work on colleagues. Such conditions in the production team for sure have negative effects on the condition of the process and the quality of the product. But if the team is well-integrated and the relationships between the members are in good condition, the quality of the process and the quality of the final product can be very high. Any deviations from the norm can be noticed very quickly and corrected immediately by an experienced operator of line. High consciousness of the crew about the process and awareness of the impact of the quality of the final product on its sale and thus on the condition of the whole factory is a good basis for good process management. However, transferring the employee's knowledge and experience to the control system or advisory system and creating a database expert knowledge is still an important area of research and development of modern control systems. Especially in the new trend Industry 4.0 or IoT (Schmidt et al., 2015) of collecting information from various sources totally different types. Information that sometimes comes from various systems, e.g. production, financial, logistics and human resources. Data which have never been combined each other before. This allows you to create a data set that, when analysed, takes into account all of the above issues. This requires preparations of the structure for new data, but today there are many environments supporting such a process and running advanced calculations in publicly available tools (McKinney, 2010). This makes the performance of advanced analysis becomes available to everyone and can be repeated for many cases and variants. This makes it possible to obtain an answer e.q. why once under certain parameters the process of papermaking goes smoothly and later with the same parameters and speed of production the web break occurs.

4. CONCLUSIONS

Above in the paper, there was presented several techniques currently used to control and check the production process. Checking takes place at various levels and with varying degrees of detail and relevance. Depending on the level of control, i.e. how close the control loop is to the process, different methods of process control and optimization can be distinguished. Of course, the control methods are matched to the number of variables entering the control as well as the number of variables output as the control commands Figure 3.

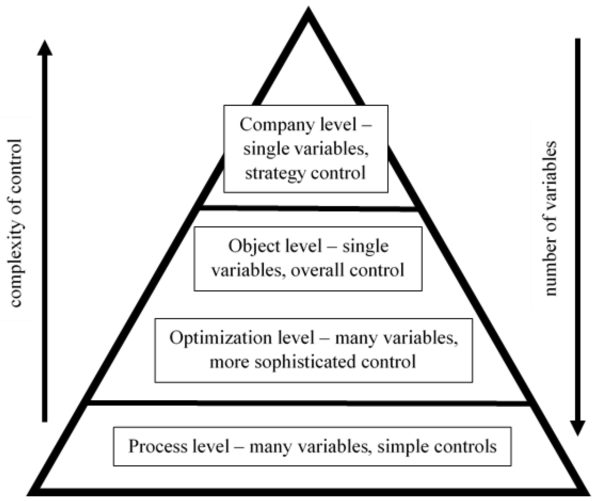

Fig. 3. Pyramid of control

Other methods and the degree of complexity of regulators are used in the lowest process layer, e.g. to control individual valves. Other methods are used to control CD or MD profiles. The article shows some methods to rank the number and complexity of controls occurring within a paper machine. It is also related to the different degree of preparation of given controllers for work. As was shown, PID is a simple regulator, easy to tune, giving a relatively quick response and good stability. But it never reaches the offset and action is instantaneous. MPC controller has good immune on disturbance, upcoming control action prediction and improved response to steady state. Disadvantages of MPC are high cost of implementation and are very dependent on the quality of the object model. While Fuzzy logic is able to deal with accurate or incomplete data, not so expensive to implement, its operation is similar to human reasoning. But requires a lot of data, is useful in middle size of variables sets and is has a lower speed of response. However, it should be emphasized that a common feature of all regulators is their constant need to supervise their work. Knowledge about their structure and operation to be able to comprehensively and precisely achieve the assumed goal. In each case, there is a need to change parameters or rebuild the model if the conditions change. None of these methods can work in extremely variable conditions and adapt themselves to new assumptions. The system status is assumed to change around 10% (Training. Advancing yourself, 2019) per year. It happens during normal production work and maintenance of machine and device elements. Minor replacements or repairs also have affected the change. Typically, every five years because of a major retrofit, the system changes by 25% (Training. Advancing yourself, 2019). This forces the need to adapt working controllers to new conditions. This requires experienced employees and qualified engineers who can perform this task. It takes time and introduces fluctuations in the process, however, it is necessary to restore the quality of the product and maintain its stability over time. So, every year there should be a control loop audit and needed adjustments should be done to the settings. However, it is necessary to pay special attention for loops that work in the area of e.g. an exchangeable element.

5. FUTURE WORK

It is planned to prepare a survey on the occurrence of failures and irregularities in the product specification but at employees of various levels. Because management staff, managers and normal employees have different perceptions about the situations and their causes. Sorting out the most common defects and trying to get information from the same employees about how to resolve them or predict next time. Finally, put this data into the control system so that it shows possible occurrences of the place of failure, finds situation before and proposes solutions of the problem as it was shown on Figure 4.

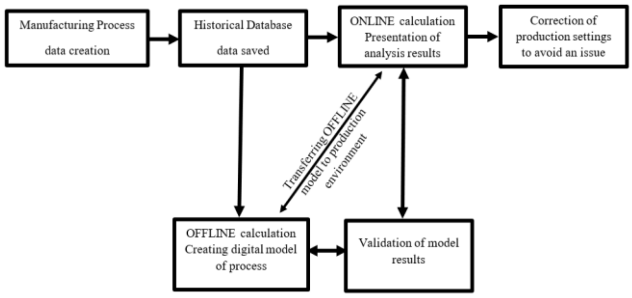

Fig. 4. Diagram of data flow through the model

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7. REFERENCES

1. Ahola, T., Kumpula, H., Juuso, E., (2004). *Prediction of paper machine runnability by identification of operating situations,* 2004 IFAC.
2. Ahola, T., (2005). *Intelligent estimation of web break sensitivity in paper machines,* Faculty of Technology, Department of Process and Environmental Engineering, University of Oulu.
3. Ammar, M.,E., Dumontc, G.,A., (2015). *Automatic tuning of paper machines cross-direction controllers via linear matrix inequalities,* Journal of Electrical Systems and Information Technology 2 283–295 http://dx.doi.org/10.1016/j.jesit.2015.11.006.
4. *Association of Polish Papermakers Bulletin* ISSN 1436-2517 Nr 11 2016-2018.
5. Bai, Y., Li Ch, Sun, Z., Chen, H., (2017). *Deep Neural Network for Manufacturing Quality Prediction* Prognostics and System Health Management Conference DOI:10.1109/PHM.2017.8079165.
6. Bajpai, P., (2015). *Green Chemistry and Sustainability in Pulp and Paper Industry*, Springer Cham Heidelberg New York Dordrecht London DOI 10.1007/978-3-319-18744-0.
7. Belle, J., Odermatt, J., (2016). *Initial wet web strength of paper,* Cellulose 2016 23:2249–2272 DOI 10.1007/s10570-016-0961-7.
8. Bhatia, A., Bansal, M. C., Mukherjee, S., (2017). *Fuzzy Modeling and Control of Basis Weight of Paper using Simulink*, Proceedings of the 10th WSEAS International Conference on Fuzzy Systems, pp. 97-103.
9. Ekholmer, H., (2016). *Prediction and Optimization of Paper Quality,* Degree project in mathematics, Second cycle, KTH Royal Institute of Technology SCI School of Engineering Sciences, pp. 5-45, Stockholm, Sweden.
10. Hashemian, H. M., Bean, W. C., (2011). *State-of-the-Art Predictive Maintenance Techniques,* IEEE transactions on instrumentation and measurement, **60**(10), DOI:10.1109/TIM.2009.2036347.
11. He, Y., Liu, F., Cui, J., Han, X., Zhao, Y., Chen, Z., Zhou, D., Zhang, A., (2019). *Reliability-oriented design of integrated model of preventive maintenance and quality control policy with time-between-events control chart,* Computers & Industrial Engineering 2019, DOI: https://doi.org/10.1016/j.cie.2019.01.046.
12. HosseinNia, S. H., Lundh, M., (2016). *A general robust MPC design for the state-space model: application to paper machine process,* Asian Journal of Control, **18**(5), DOI: 10.1002/asjc.1252.
13.https://en.wikipedia.org/wiki/Fuzzy_control_ system, Accessed: 31/03/2019.
14. Linnala, M., Hämäläinen, J., (2011). *Improvement of cost efficiency in papermaking with optimization tools,* Journal of Science & Technology for Forest Products and Processes, **1**(2), 71-76.
15. Ma, W., Shen, T., (2019). *Analysis and Optimization of the Relationship Between Operating Parameters and Energy Efficiency of Press Section in Tissue Paper Machine*, Transactions of China Pulp and Paper, **34**(2), 47-52, DOI: 10.11981/j.issn.1000-6842.2019.02.47.
16. Martin, M. P., (2013). *Economic Model Predictive Controllers in a Micro-grid with Hydrogen Storage,* System Engineering and Automation Department School of Engineering, University of Seville, Seville, Spain.
17. McKinney, W., (2010). *Data Structures for Statistical Computing in Python*, Proc. of the 9th Python in science conf. (SCIPY), 51-56.
18. Milne, R., Drummond, Renoux, M., (1998). *Predicting paper making defects on-line using data mining,* Knowledge-Based Systems, **11**(5–6), 331-338, available at: https://doi.org/10.1016/S0950-7051(98)00061-6
19. Nagaraj, B., Vijayakumar, P., (2012). *Tuning of a PID Controller using Soft Computing Methodologies Applied to Moisture Control in Paper Machine*, Intelligent Automation & Soft Computing, **18**(4), 399-411, DOI: 10.1080/10798587.2012.10643251.
20. Niemiec, K., Krenczyk, D., (2018). *Selected quality indicators and methods of their measurement*, IOP Conf. Ser.: Mater. Sci. Eng., **400**, 022039, DOI: 10.1088/1757-899X/400/2/022039.
21. Nisi, K., Nagaraj, B., Agalya, A., (2018). *Tuning of a PID controller using evolutionary multi objective optimization methodologies and application to the pulp and paper industry*, International Journal of Machine Learning and Cybernetics, DOI: https://doi.org/10.1007/s13042-018-0831-8.
22. Pavithra, R., Gunasekaran, S., Sailatha, E., Kamatchi, S., (2015). *Investigations on Paper Making Raw Materials and Determination of Paper Quality by FTIR-UATR and UV-Vis DRS Spectroscopy*, ISSN: 2347-3215, **3**(11), 42-59.
23. Rippon, L., Lu, Q., Forbes, M. G., Gopaluni, B.,

Loewen, P. D., Backstrom, J., (2019). *Machine Direction Adaptive Control on a Paper Machine*, Industrial & Engineering Chemistry Research, DOI: 10.1021/acs.iecr.8b06067.
24. Schmidt, R., Möhring, M., Härting, R. Ch., Reichstein, Ch., Neumaier, P., Jozinović, P., (2015). *Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results*, W. Abramowicz (Ed.) LNBIP **208**, 16–27, DOI: 10.1007/978-3-319-19027-3_2.
25. Sukdeo, N., (2017). *The effect of the working environment on employee satisfaction and productivity: a case study in a clothing manufacturing factory*, Proceedings of the International Conference on Industrial Engineering and Operations Management Bogota, Colombia, pp. 1112-1121.
26. *Training. Advancing yourself* Available from: https://businessdocbox.com/Human_Resources/69857379-Training-advancing-yourself.html
Accessed: 31/03/2019.
27. VanAntwerp, J. G., Featherstone, A. P., Braatz, R. D., Ogunnaike, B. A., (2007). *Cross-directional control of sheet and film processes*, Automatica, **43**, 191–211, DOI: 10.1016/j.automatica.2006.07.025
28. Yihai, He, Changchao, G., Zhaoxiang, Ch., Xiao, H., (2017). *Integrated predictive maintenance strategy for manufacturing systems by combining quality control and mission reliability analysis*, International Journal of Production Research, DOI: 10.1080/00207543.2017.1346843

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