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INTELLIGENT MANAGEMENT IN THE AGE OF INDUSTRY 4.0 – AN EXAMPLE OF A POLYMER PROCESSING COMPANY

Katarzyna Łukasik[1], Tomasz Stachowiak[2]

[1] *Czestochowa University of Technology, Faculty of Management, Poland*
[2] *Czestochowa University of Technology, Faculty of Mechanical Engineering and Computer Science, Poland*

Corresponding author:
Katarzyna Łukasik
Czestochowa University of Technology
Faculty of Management, Department of Enterprise Management
Aleja Armii Krajowej 19 B, 42-200 Czestochowa, Poland
phone: +48 34 3250397
e-mail: katarzyna.lukasik@wz.pcz.pl

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Abstract
In the article, the significance and essence of management of intelligent manufacturing in the era of the fourth industrial revolution has been presented. The current revolution has a large impact on the operation of the company. Through the changes resulting from the application of modern technologies, production processes are also undergoing revolutions, which results in changes in such indicators of business development. Management of intelligent manufacturing is also a challenge for socially responsible activities; due to solutions of Industry 4.0, enterprises directly and indirectly influence environmental protection, which results in benefits for all mankind. In the article, the analysis and assessment of management of intelligent manufacturing, using modern technologies during the production process, has been carried out, with particular emphasis on the components of management such as: monitoring, control, autonomy, optimization. Moreover, the impact of the above components of management on changes in the following indicators (KPI – Key Performance Indictors) has been evaluated, i.e. (1) quality, (2) rapidity of the production process implementation, (3) performance and (4) productivity, (5) decrease in waste generated during the technological process and (6) amount of consumed electricity. For the purposes of conducting the research, a case study has been used, developed due to the information shared by the company manufacturing machinery and equipment for the polymer processing industry, in which intelligent solutions of Industry 4.0 are being applied. The presented article is a significant contribution to the current development of knowledge in the field of implementing Industry 4.0 solutions for polymer processing. The article is a combination of theoretical and practical knowledge in the field of management and practical industrial applications. It refers to the most current research trends.

Keywords
Intelligent manufacturing, Industry 4.0, modern technologies, the polymer processing company.

Introduction

Whereas some industries introduce new technologies very slowly, others rapidly respond to changes, using intelligent technologies to reduce waste and minimize costs in millions per year. The contemporary industry has unique opportunities to optimize performance with intelligent sensors that provide feedback to the automated infrastructure. Devices receive and send feedback in the cloud and artificial intelligence helps to find appropriate solutions to emerging problems. These are just some of the advantages of Industry 4.0, which causes that the more efficient system, through feedback and optimized results, is becoming a reality for a smart factory. Since the beginning of the 21st century new generation technologies have shown a sharp increase. The emerging fourth industrial revolution, the development of which is being witnessed, poses a range of challenges for production companies from the technological and organizational point of view as well as from the point of view of management [1, 2], and thus the subject matter of Industry 4.0 has become one of the most popular in recent years [3].

The beginnings of Industry 4.0 were initiated by the German government in cooperation with the industry and academia in 2011 as a high-tech strategy of 2020, which eventually leads to the creation of intelligent manufacturing [4–6]. Intelligent manufacturing is a new form of production, its main technologies include the Internet of Things (IoT), Cyber-Physical System (CPS), Cloud, Artificial Intelligence (AI) etc., which integrate production resources with sensors, cloud computing, communication technology, control, simulation, intensive data modelling and predictive engineering. The essence of intelligent manufacturing can be summarized in its six pillars: (1) technology and production processes, (2) materials, (3) data, (4) predictive engineering, (5) sustainable development, and (6) sharing resources and networks [7]. The use of new technologies and process transformation contributed to the creation of modern production systems, imposing new requirements on employees, e.g. in terms of possession and development of new competences but also bringing positive effects for the company's environment, including the natural environment and the society [8, 9].

The mentioned CPS digitization leads to the implementation of tools and solutions by the production company that enable the integration of manufacturing processes, machinery, people and products, and thus the company operates within the framework of the integrated network, it is able to manage its own resources better and more efficiently and make better decisions, favorable for the company's development [10]. As presented by the research (Report by McKinsey [11]), advanced technologies create the potential for a significant increase in performance of production, e.g. the transition from conventional production to automated production 4.0 may improve performance even by 45–55%. Can such effects be actually expected and what other factors, being the evidence of enterprise development (i.e. productivity, performance, time of process implementation, consumption of materials and waste generation), change after the use of the Industry 4.0 technology? The authors will aim to prove this while analyzing the example of the polymer processing company as the industry most frequently reaching for intelligent modern technologies.

Literature review

Industry 4.0 Intelligent Technology

The concept of Industry 4.0, which is fairly widely interpreted, is associated with a number of forms of intelligence, e.g. intelligent machines, intelligent production processes, intelligent devices, intelligent engineering, intelligent technologies, intelligent logistics, intelligent networks etc., which to a large extent characterizes a smart factory or, in approximate translation, intelligent manufacturing (Table 1).

Table 1
Intelligent technologies of Industry 4.0.

Typical forms of industry intelligence	Main contributions	Exemplary literature
Intelligent machines	Intelligent machines are devices equipped with technologies of the machine-to-machine (M2M) type and/or cognitive processing technologies, such as artificial intelligence (AI), they are characterized by fast learning, which is used for reasoning, problem solving, decision-making and operations. Intelligent machines include robots and other cognitive processing systems (cognitive computing systems), which are designed for task operations, often without human intervention.	[12, 13]
Intelligent production processes	They include dynamic, efficient, automated and process communication in real time in order to manage and control the highly dynamic production environment implemented through the Internet of Things.	[14]
Intelligent devices (Internet of Things)	Interconnection of various digital devices for collecting and exchange of data (information). This enables communication of devices and interactions between them and, if required, with the more centralized controller. This also decentralizes analyses and decision-making, allowing for responding in real time. IoT is also created by sensors and their readers, e.g. applied in industry, transport or trade.	[15, 16]
Intelligent engineering	It is mostly the product design and development, product engineering, production as well as after-sales service.	[17]
Intelligent technologies Smart Grid technology	It can be defined as the combination of the communication and IT technology with a traditional energy network to combine production subsystems, transfer, distribution and consumption in an electrical network.	[18, 19]
Intelligent logistics	They include intelligent tools and logistics processes. Self-organizing logistics is an example of intelligent internal logistics, it responds to unexpected changes in production, such as bottle necks and shortages of materials.	[20, 21]

The most desired form of Industry 4.0 is Smart Factory, which is the creation of both virtual and real world, using CPS systems [22, 23]. The solutions most frequently applied by Smart Factory (Fig. 1) are modern digital technologies, e.g. advanced robots and artificial intelligence, technologically advanced sensors, cloud computing, the Internet of Things, Big Data, 3D printers [24–26]. Digitization and combination of all of the production units leads to the fully automated assembly line where machines are able to communicate with each other, analyze data and even independently solve problems with minimum human involvement [27, 28].

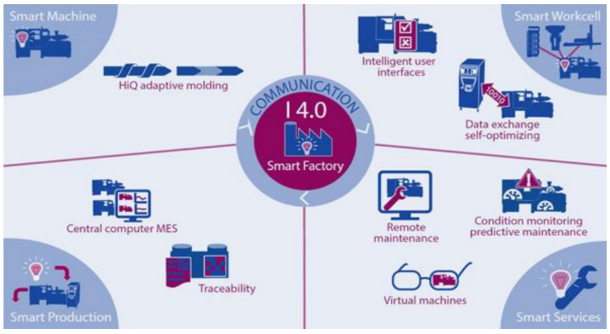

Fig. 1. Smart Factory and its intelligent environments.

Intelligent Manufacturing (IM)

Intelligent manufacturing (IM), using intelligent machinery, by which autonomization of manufacturing processes ought to be understood, allows the adjustment of products to the market needs. Due to increased complexity of modern production systems, particularly after integrating all the units/components in a common system, process decisions have become much more difficult, therefore, there is a strong need for the use of a vast amount of product data as well as the use of intelligence computational power to streamline the decision-making process in manufacturing. This intelligent capability relates to three functions that act similarly to the human body: (1) sensing, (2) decision-making and (3) operating. Due to the technological progress, detecting errors and production control seem to be easier since sensors or actuators are not missing in production systems. The challenge, however, consists in how to process information and knowledge so as to make the computer automatically make the right decision at the right time and at the right location, with little or no human intervention. Therefore, some new technologies have emerged in these areas, such as big data analysis, machine learning (ML) and cloud computing, which provide a huge potential for an increased intelligent production capacity [29]. The use of robots enables greater automation of production processes, which significantly unburdens employees in their work and increases their performance. Overall benefits resulting from the application of robots include, among others, increasing rapidity and efficiency of production, performance, optimization of production processes or possibility of self-optimization of robots, adjusting to current conditions [30]. Therefore, the results of automation and the use of robots are mostly important for internal and external customers, but also for the natural environment, e.g. through effective reduction in consumption and waste of resources and energy [31].

The other possibilities of Industry 4.0 can be grouped in six major areas [32]:

- flexibility of production which occurs during the production of small batches;
- rapid prototyping;
- higher output capacity;
- reduced configuration costs, fewer errors and less machine downtime;
- higher quality of products and less rejected production;
- better opinions of customers on products.

Looking at the historical development of the technological production system, the basic three measurements are used: quality, performance and costs [33], but also the following benefits from the use of IM can be observed: (1) reduced demand for materials; (2) less waste due to fewer materials consumed; (3) increased possibility of reusing and recycling waste; (4) reduced demand for energy; (5) greater integration of the supply chain; (6) improvement in operational performance [34, 35].

For the purposes of the article, the following KPI will be analyzed: (1) quality [29] and (2) rapidity of production process development [36–38], (3) performance and (4) productivity [39–42], (5) decrease in waste generated during the technological process, and (6) amount of electricity consumed, however, the first four have been broadly discussed and studied in the literature, whereas the last two require further verification.

Industry 4.0. in the area of management

Modern solutions of Industry 4.0 challenge various companies to find appropriate applications of new methods in the area of management and production. In the case of some organizations, access to management information near real time may be of great importance for enterprise management [43]. However, differences mostly relate to management at the operational level in enterprises which need to currently analyze data of large variability in time and keep track of constant changes in various parameters, and not just use the information on the level of these parameters obtained with some delay. In particular, this situation affects companies with great complexity of processes and high personalization of the offer [44].

It is very important for intelligent management of Industry 4.0 to perform managerial functions: monitoring, control, optimization, autonomy (more extensively discussed in another point, from the perspectives of management of the technological process in the polymer processing company) [35] (Fig. 2).

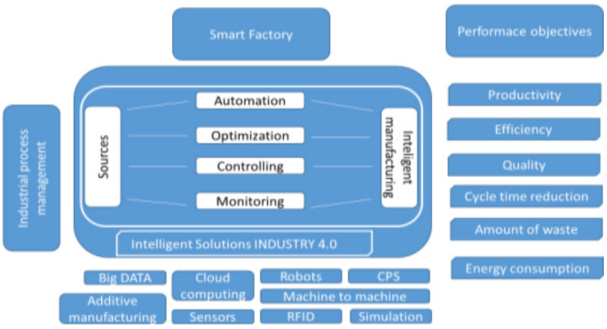

Fig. 2. Management skills of Smart Industry in the era of Industry 4.0.

Mentioned managerial functions:

- Monitoring: the performance of this managerial skill/function is facilitated by the global monitoring of the production system and its environment, which can be obtained due to combined various objects, i.e. the Internet of Things [45], e.g. for real-time value stream mapping by setting sensors along the assembly line; Radio-frequency identification (RIFD) system is used to tag goods, raw materials and products for their registry in the course of the process.
- Control: fully integrated control at each stage of the technological process and also monitoring the product parameters with the customer [46]. This system requires the interaction of machinery and equipment with humans [47].
- Optimization: on the basis of the monitored and controlled data, using the Internet of Things, artificial intelligence, simulation systems, the process can be optimized in real time [48, 49].
- Autonomy: the possibility of real-time monitoring, control and optimization of current systems due to algorithms and neural networks, communication of machinery and equipment, [50] and their capabilities of self-learning and improvement [51].

Intelligent Manufacturing in management of the polymer processing company production process

Research methodology

To conduct the research, a case study will be used, developed due to the information shared by the company manufacturing machinery and equipment for the polymer processing industry, in which intelligent solutions of Industry 4.0 are applied. The data for the research were transmitted via direct contact and e-mail from the Wittmann Battenfeld company, which is one of the leading manufacturers of robots and peripheral equipment for the plastics worldwide.

The research was conducted on the basis of information and materials provided by the top level manager of Wittmann Battenfeld Poland. The received materials were analyzed by the authors of the article in November 2019. Wittmann Battenfeld conducts independent research on the performance and productivity indicators of their machines, which were used in the article, and also uses the results of tests performed by companies using their products. The construction of the research instrument has been created in one step data collection.

Monitoring, control, optimization and autonomy of the production process of plastics

Monitoring (monitoring the technological process through the analysis of settings of machinery and equipment) will be presented on the example of control and supervision systems implemented by the Wittmann Battenfeld company, the world leader in the market of manufacturers of injection molding machines and auxiliary instrumentation (Fig. 3).

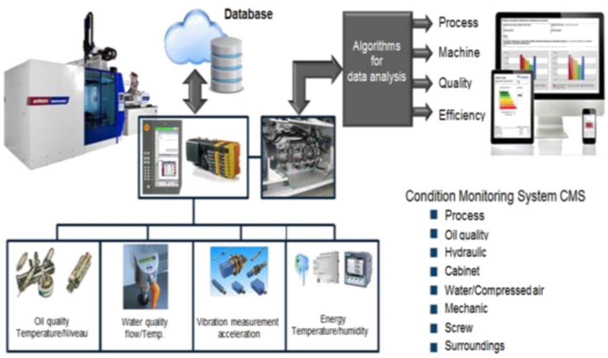

Fig. 3. Condition monitoring system.

The operations conducted currently in the field of management and optimization of manufacturing processes are moving towards autonomous systems, being able to independently make even complicated decisions without the operator (maximum elimination of the human factor). The systems implemented by manufacturers can be divided into the ones aimed at monitoring the technological process as well as the monitoring and control of selected parameters of the finished product (color, gloss, shrinkage, molding geometry etc.).

Monitoring the technological process consists in determining the group of selected technological parameters or the parameters directly affecting technological parameters and being able to influence the quality of the finished product and productivity, and subsequently determining the tolerance in which its variability may take place (Fig. 4). Monitoring is aimed at improving the quality of conducted technological processes, improving the quality of manufactured details, reducing downtime or manufacturing defective products [52, 53].

Fig. 4. The automated processing cell – injection of thermoplastics.

In order to improve productivity, avoid troublesome and extremely costly downtime and to maintain machinery and equipment in the best possible condition, in the case of the discussed injection molding technology, the following parameters of the machinery itself can be monitored:

- mechanical parameters associated with the proper operation of individual moving parts, their protection, the level of generated and transmitted vibration, which can adversely affect the course of the production process,
- technological parameters of the device itself, such as pressure and temperature of oil and/or other liquids required for the proper operation of the machine, voltage and electrical current essential for the control and proper operation of the device.

A range of factors associated with the course of the technological process is also subjected to monitoring, in the case of technologies of injection molding of thermoplastics, the following parameters may be subjected to monitoring:

- temperature of polymer melt – monitored both in terms of the plasticizing system and in terms of the tool (injection mold),
- pressure of the processed polymer – monitored both in terms of the plasticizing system and in terms of the tool (injection mold),
- screw rotation speed in the plasticizing system with the speed of its travel,
- speed of injection of polymeric material into molding cells of the injection mold,
- clamping force of the injection mold,
- parallelism of the injection mold plates,
- temperature of the surface of the molding cell,
- characteristics of the material processed with details of parameters of its preparation, such as temperature and drying time,
- flow rate of the cooling medium in the thermostating system of the injection mold.

Monitoring selected technological and machinery parameters allows managerial staff and technologists for constant surveillance of the conducted process and prevention related to excessive deviation of selected parameters from the assumed tolerance, and thus manufacturing defective products.

The control of selected technological and machinery parameters offers the possibility of their automatic correction in the case of the occurrence of discontinuity of the process. The above-mentioned values are subjected to the process of continuous and even remote monitoring combined with the acquisition and storage of the obtained data.

The data acquired during the monitoring process are used not only for supervision of the proper course of the production process but also serve the process of recreation and full traceability of the product (it is possible to fully recreate the course of the process of manufacturing the molding with the possibility of identification of the applied material, whether it was dried or not, etc.).

Moreover, it is possible to use the monitoring process, by the combination with the technological process, to tag the molding so that it is possible to replace it with another detail of the same shape (originality of parts).

The control with the possibility of adjustments in the autonomous and automatic mode is to implement changes in selected machinery and technological settings aimed at triggering specific effects in the course of the process itself or aimed at triggering specific changes in characteristics of the material processed, and thus the characteristics of the product already formed. A range of process parameters may undergo the control. The main factors affecting the quality of the finished product and its structure include the temperature and pressure of the material processed. At the stage of material preparation in the plasticizing system, the temperature and pressure of the polymer affect its lightness and the process of homogenizing plastics with excipients and fillers (uniform dispersion of fillers and homogeneity of the material is critical for the proper course of the injection process but also translates into the quality and mechanical properties of the finished product. At this stage, the monitoring and control of these two parameters takes place continuously and is repeated depending on in which zone of the system the material prepared for injection is.

In the tool zone, temperature and pressure can be monitored and controlled optionally due to the use of sensors of pressure and temperature and data acquisition may take place by the machine itself or the management system (constant monitoring and supervision of the course of the process and the analysis of the distribution of selected factors/ parameters in relation to the tolerance field established for them).

In the case of the occurrence of non-compliance and exceeding the assumed values, the solution used currently is not to stop the technological cycle. Such a situation was observed in the case when the process was only monitored. For the system monitored, in the case of exceeding the assumed values, there was the stopping of the technological device and calling the operator through a sound or light signal or combination of both.

At present, due to the application of algorithms of feedback loop and neural networks, programmable machines and enormous computing speed as well as greater knowledge about the characteristics of polymeric materials processed, the machinery (the injection molding machine) is able to independently make a decision correcting the selected settings in order to achieve the desired effect and eliminate the source of formation of defects.

Growing demands concerning the quality of moldings manufactured but also the areas of their application force processors to use increasingly narrower tolerance, increasingly shorter processing time but most of all achieving/manufacturing details with increasingly better mechanical and utility properties. Without knowledge, without being able "to look into molding cells", using sensors, the operator remains blind and may only refer to their knowledge and experience. Moreover, some defects of injection moldings can be visible only after several hours since the completion of the technological process (already at the stage of storage or delivery to the customer, which is often the reason for complaints and entails significant costs – following the principle of 1-10-100).

Indirect control and quality assurance systems

In indirect control systems, the measurement of the selected value is carried out indirectly. Temperature measurement systems using thermal imaging cameras should be mentioned here. The thermostating of injection molds is a task requiring great skills and knowledge from not only the operator but most of all from the constructor and manufacturer of the tool. Continuous measurement of temperature of the coolant in the injection mold thermostating system is conducted by the thermostating device but high thermal inertia of the device (related to its weight and the way and amount of performed cooling channels) often prevents proper reaction. The introduced thermal imaging solutions aim at error elimination of the device temperature measurement (which may differ by tens of degrees from the temperature assumed, which significantly affects the properties of the finished product). Moreover, they are to analyze the temperature field distribution and not selected points on the molding as in the case of using thermocouples. In the course of thermal imaging measurement, the picture of the injection molding is taken after removing it from the molding cell. The obtained thermogram is compared with the pattern. In the case of compliance with the pattern, the molding is transferred to further technological operation (transport, packaging etc.). In the case of non-compliance, the molding is considered as non-compliant and rejected (Figs 5 and 6).

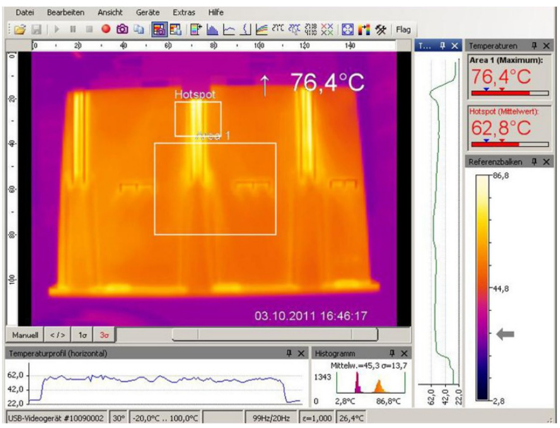

Fig. 5. Thermographic image – the control of the molding.

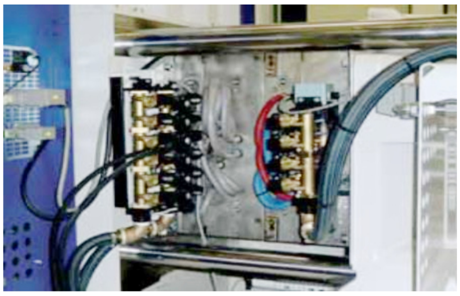

Fig. 6. Thermographic control of the injection molding process – the injection mold.

The control of the operation of thermostating devices

The data from other peripheral devices, among others, flowmeters, rotameters and thermostating devices are subjected to a similar analysis. The injection molding machine controls the operation of all of these devices according to the implemented program, taking into account the specificity of the material (the tool temperature, cooling rate). In the case of non-compliance in terms of the value of the required mold temperature, the thermostat settings are corrected by rotameters and flowmeters, there is a change in flow rate, thermostating liquid rate, and thus the value of molding cell surface temperature (Figs 7 and 8).

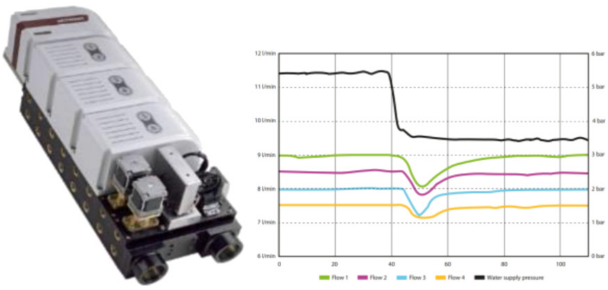

Fig. 7. The flowmeter with the system of control and measurement data acquisition.

Fig. 8. The injection molding machine with thermostating devices.

Moreover, this system can be used to analyze the wear and contamination of the thermostating system itself. Modern thermostating devices are equipped with ultrasonic sensors of the coolant flow rate. Thermostating systems that, in the overwhelming majority, are filled with water (from the water supply system), during constant operation, undergo corrosion and scaling in a short time, which leads to a reduction in the diameter of channels, and thus in cooling efficiency.

Due to such solutions, the system "recognizes" a decline in the efficiency of the cooling system and may inform the operator about that before the manufactured moldings are non-compliant (the arising defects can generate significant residual stresses or lead to obtaining a different than assumed structure of the molding, which affects its mechanical properties).

The control of the material flow

For the proper course of the material flow, the supervision of the material preparation (its drying) is also required as well as dosage while taking into account excipients required for the process or the molding (pigments, fillers, regranulates or regrinds and others – Fig. 9). Also, in this case, it is possible to monitor, control and automatize the system of polymer preparation, its drying (drying time, drying temperature, air flow rate, dew point should be taken into account) and then feeding into the hopper of the injection molding machine.

Fig. 9. The automatic dispenser and the drier.

For material feeding systems, sensors analyze either weight or volume of the plasticizing material fed into the system, with pigments and excipients. This is extremely important from the point of view of the accuracy of dosing the material (this process affects the weight of the obtained moldings, the dispersion of fillers and pigments in the polymeric mass) and the quality of the finished product. The control of the correctness of dosing affects the process of plasticizing the processed material, the process of its transport and characteristics of the cell filling. The lack of control of dosing may lead to changes in viscosity of the material, lack of adequate degree of mixing or, in the worst case, lack of fillers affecting mechanical properties in some moldings (the defect impossible to determine without laboratory tests).

Viscosity control

The primary objective of any kind of production is to achieve the best possible qualitative indicators, production ones, often economic ones, while maintaining the lowest possible energy input and emerging shortages. One of the control systems, characterized by a high degree of autonomy and the optimization potential is the control-measurement system placed in the plasticizing system, due to which the viscosity control of the processed material is possible (Fig. 10). On the basis of these measurements and the pressure distribution pattern in the plasticizing system, it makes the current correction of the value of injection time, holding pressure or both these parameters at the same time. The changes resulting from differences in the processed polymeric materials are compensated automatically and immediately by the system, due to which the obtained products are characterized by high quality and repeatability, which is crucial for current production standards.

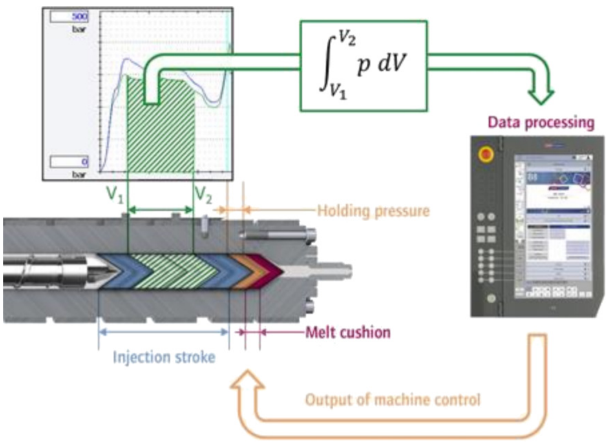

Fig. 10. The viscosity contol system of polymer melt in the plasticizing system.

In order to introduce greater *autonomy* of machinery and equipment as well as in order to optimize the injection molding production, vision systems (Fig. 11) are also implemented, not only enabling the visual control but also equipped with systems allowing for decisions concerning the use of the molding (correct moldings, incorrect moldings).

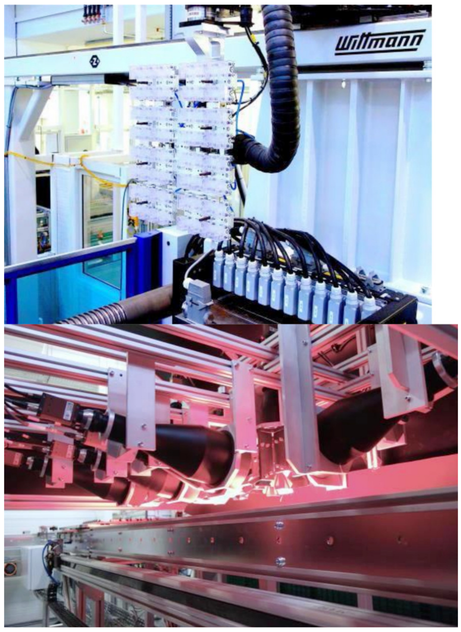

Fig. 11. Vision systems – the quality control of manufactured moldings, production optimization.

Such systems introduce a new quality to the issues of the quality control and optimization of production. They allow the control of 100% of the manufactured details. The moldings produced are photographed several times in high resolution and the obtained pictures are analyzed in real time. Depending on the demand of the specific type of production, the system may analyze the molding in terms of even tens of parameters. In the case of recognizing non-compliance, the information is introduced to the system concerning the nature of the defect and, subsequently, the decision is taken autonomously, aimed at its elimination without the operator. The system is equipped (depending on the demand and quantity of the values controlled) with one to even several cameras.

Discussion and conclusions

The implemented solutions of Industry 4.0 in the branch of industry such as processing of thermoplastic polymer materials allows for a substantial increase in the parameters/indicators pointed out in the introduction to the article. Current technological solutions allow for significant robotization and automation of processing with a simultaneous increase in autonomy of the production process. Learning machines are able to automatically optimize the production process in order to manufacture lighter, more durable moldings, characterized by very good mechanical, thermal, optical, visual properties, while using a much smaller amount of material and electricity for this purpose. The last factor seems to be the most significant in the era of overexploitation of natural resources.

Due to the implementation of these solutions, KPI for the specific product become significantly improved. The key parameters defined for the purposes of this article have changed in the following areas (Fig. 12): for productivity, an increase by 400% has been recorded, with an increase in production performance from 70 000 pieces per year (the data prior to the introduction of the Industry 4.0 solutions) to 400 000 pieces manufactured at present (the implemented solutions of Industry 4.0). Moreover, it should be noted that efficiency of production has increased due to the application of a different construction of injection molds. Over the years, their geometry has evolved from one-cell, simple tools to multi-cell (64-fold injection molds) or double system 2×48 (which gives a total of 96 cells manufacturing details).

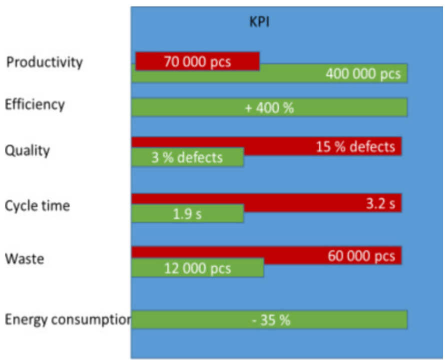

Fig. 12. Changes in the key parameters (KPI).

In relation to the indicator, the overall qualitative approach is the following, prior to the launch of the solutions proposed in the fourth industrial revolution, the quantity of generated waste amounted to about 15% of production, due to the adaptation of modern solutions, defects have been reduced to the level of only 3%. Defects and the issue of significant improvement in the quality of manufactured moldings are correlated with the quantity of waste generated in the production process (fewer errors, greater repeatability and quality of manufactured details), which translates into a decrease in the quantity of generated waste (in the injection molding production, only in exceptional cases, it is possible to fully eliminate waste). Waste reduction is the following: the success consists in reducing the quantity of defective units from 60 000 to the level of 12 000.

The cycle time (for the analyzed case) should be understood as the overall injection molding time with the holding and cooling stage, in that case, production was started with the cycle time of 3.2 s and, due to the implementation of innovative solutions, this time has been reduced to 1.9 s.

In relation to electricity saving, in the global approach to the injection molding, using modern machinery and instrumentation (and using the KERS system), it is possible to reduce energy input by 35%.

Production flexibility has been significantly improved due to the introduction of solutions such as automation and robotization of individual technological processes while reducing production cycle time and reducing the amount of electricity used and errors generated during production. In addition, the system was designed in such a way that it would be possible to connect further production sockets and to acquire data from them. This facilitates supervision of the current production process and facilitates the introduction of further system solutions.

The analysis of the solutions of Industry 4.0 in the field of plastics processing, presented in the article, allows for better understanding of processes and relationships occurring in the course of implementation of innovative solutions based on automation and computerization of production machinery and equipment. Injection molding machines manufactured currently as well as their accessories are autonomous devices and are adjusted to broadly understood communication as well as acquisition and exchange of data. The knowledge in this field allows for better understanding of the technological process and its better control, which leads to improvement in productivity and manufacturing high-quality products. Better understanding of these mechanisms leads to the more effective use of the potential of Industry 4.0.

It should also be noted that the solutions proposed are not without drawbacks. The first of the limitations one faces while introducing the fourth industrial revolution is the issue of economic justification of such a purchase (when implementing a new project, these costs can be determined and accepted, in the case of the already launched projects, contractors do not trust any changes). Another issue is the awareness and technical culture of users. Lack of understanding of the requirements and objectives associated with various levels of the operation of Industry 4.0 may lead to generating a greater number of errors or a loss of control over the technological process. One of the most important limitations and issues to consider is safety of use and communication; processing machines stop being anonymous, they begin communication using various aspects of the Internet. Ensuring safety of this communication is crucial to ensure the continuity of production and maintain the company's secrets.

Further directions of the research will focus on the analysis of the issue of Industry 4.0 from the point of view of individual management layers and communication in combination with e.g. ERP systems.

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