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COMPUTER-AIDED MAINTENANCE AND RELIABILITY MANAGEMENT SYSTEMS FOR CONVEYOR BELTS

SYSTEMY INFORMATYCZNEGO WSPOMAGANIA EKSPLOATACJI I ZAPEWNIENIA NIEZAWODNOŚCI PRZENOŚNIKÓW TAŚMOWYCH

Operational reliability of conveyor transport systems is a problem that relates to the provision of an adequate level of availability of a continuous transport system, which in the case of belt conveyors depends not only on their usability, as determined by their design and manufacture, but also on the appropriate level of their use, understood, among others, as the degree of sophistication and effectiveness of the methods and tools applied in industrial diagnosis of those devices. The present article describes the most popular diagnostic systems used in the maintenance of internal transport conveyor systems. Also a new method of computer-aided maintenance of such systems is presented.

Keywords: *Computer-aided Maintenance Management Systems, belt conveyors, maintenance.*

Niezawodność eksploatacyjna systemów transportu przenośnikowego, to zagadnienie dotyczące zapewnienia odpowiedniego poziomu gotowości systemu transportu ciągłego, który w przypadku przenośników taśmowych zależny jest nie tylko od ich walorów użytkowych, determinowanych zastosowanymi rozwiązaniami konstrukcyjnymi i wykonawstwem, ale też zależy w istotnym stopniu od właściwego poziomu ich użytkowania, rozumianego między innymi jako stopień zaawansowania i skuteczności zastosowanych metod i narzędzi diagnostyki przemysłowej. W artykule scharakteryzowano najpopularniejsze systemy diagnostyczne stosowane w eksploatacji przenośnikowych systemów transportu wewnątrzzakładowego. Zaprezentowano również nową metodę komputerowego wspomagania w utrzymaniu ruchu tego typu systemów.

Słowa kluczowe: *Computer Aided Maintenance Management Systems, przenośniki taśmowe, eksploatacja.*

1. Introduction

Modern transport systems based on belt conveyors are often very complex, in terms of both technology and design, which translates directly into their costliness. At the same time, the performance of a conveyor-based system determines not only the efficiency of a company's entire transportation system, but also the efficient and effective operation of other, cooperating subunits of a company's production system. In many cases, belt conveyor transport and cooperating subsystems have a serial structure. This means that a failure of a belt conveyor, which is one of the basic components of a transport system of this type, brings all other machinery and equipment to a stall. Therefore, the problem of ensuring an adequate level of availability of a continuous transport system is extremely important. Availability, in the case of belt conveyors, depends not only on their usability, as determined by their design and manufacture, but also on the proper level of utilization, understood, among others, as the degree of complexity and effectiveness of the methods and tools employed for their industrial diagnosis.

2. Diagnostic systems in the maintenance of conveyor systems for internal transport

The application of methods of technical diagnosis in the maintenance of belt conveyors is becoming an important issue from the point of view of effective utilization of those machines. However, methods of technical diagnosis are still underused in the case of belt conveyors and internal transport systems based on them. This is particularly important as modern means of information transfer make it possible to effectively monitor the state of machinery and equipment, and other computer-aided methods and techniques enable processing of the data collected using inference and prediction methods.

Typical monitoring of the condition of a machine involves measurement of the physical parameters of the work process that guarantee correct and safe operation and user safety. In the case of belt conveyors, monitoring typically encompasses the following parameters or characteristics: belt speed, belt run-off, belt wear, temperature of the elements that cooperate with the belt, the filling status of the transfer section, detection of metal components in the material conveyed, rotational speed of the drum, and conveyor performance. In general terms, then, monitoring of belt conveyors relates to diagnostic symptoms and technological, operating and safety parameters [2, 5]. The current condition of a belt conveyor, in the context of effective management of this means of transport, and especially its belting, can be determined using a variety of methods, tools and systems. The most effective and efficient among those is diagnosis of the elements of a belt transport system. Therefore, in modern conveyor systems, the parameters that characterize the operation of the whole system, the conveyor, or the belt itself are usually monitored continuously using mobile or stationary measuring systems. In the case of mobile systems, the results of measurements can indicate that the conveyor operates properly, but they may also point to errors in design assumptions, calculations and selection of conveyor components, which result in decreased durability of the conveyor and its components as well as a lower reliability of the whole structure [7]. Another group of diagnostic methods make use of computer techniques to control a single parameter or component whose condition has a significant impact on the reliability of the whole device and the entire belt conveyor system. A good example is a method used for monitoring the core of a steel cord conveyor belt [15] that utilizes an apparatus for magnetic monitoring of damage. This system is used to monitor the condition of the belt core directly on the conveyor belt, and it works by measuring and recording changes in the magnetic field resulting from discontinuities in the belting, i.e. locations at which the steel cords of the core have been damaged. Another system that works in a similar manner is a system for monitoring and detection of damage of reinforced conveyor belts [8]. The system generates a static magnetic field with a circuit that is closed by the reinforcing cords at the measuring sections along the belt and in the plane perpendicular to its surface. The system works by measuring magnetic field strength, processing the measurement signal, and analyzing the damage by means of an electronic data processing technique. Other diagnostic methods include radiographic examinations of fabric and steel cord belting for breaks and corrosion and ultrasonic rip detection.

One of the few methods that have so far been developed to prevent the occurrence of some of the types of belt failures is one in which special sensors are installed in the belting which signal belt damage or wear; these sensors work on the premise of transponders – electronic devices used in active radar systems. A transponder receives radio signals from one (transmitting) system and then collects, processes and amplifies them to transmit to another (receiving) system. A system that works in a similar way is Sensor Guard [13]. However, it only serves to protect belting against extensive rip damage and signals lateral movement and excessive slippage of the belt. In modern transport systems, it is a common trend to install complete computer-assisted monitoring systems. One such system is ZEFIR NT that is used to monitor a system for transporting rock materials [6]. Its task is to collect, analyze and visualize data related to the operation time of the individual devices, the number of start-ups, the length of outage periods, etc. Unfortunately, this system does not perform any diagnostic functions, and the data it generates can only be analyzed with a considerable delay.

The systems described above and other, similar ones, are used to control certain parameters related to the failure rate of conveyor belts, but they do not protect belts against sudden breaking in the area of the splice. They do not represent comprehensive monitoring and control systems, and the data collected with their help are often analyzed manually. For these reasons, it is necessary to develop appropriate, fully automated systems for controlling internal transport, including conveyor-based transport. A number of types of damage that may be incurred by a conveyor belt and its joints necessitate the use of advanced and maximally versatile diagnostic systems. Efficient and effective diagnosis of belt conveyors is also essential for continuous assessment of the state of belting aimed at preventing major failures and thus prolonging the conveyor's service life.

This means that it is necessary to implement into industrial practice a fully automated system for diagnosing internal conveyor transport, especially that the costs incurred as a result of losses due to belt damage are still very high. The use of simplified, manual analyses is time consuming and inefficient, especially in the era of the dynamic development of computer maintenance management systems (CMMs). Inefficient diagnosis may lead to reduced availability of a transport system, extend repair and maintenance time and increase maintenance costs. This is especially important when a conveyor belt breaks at the splice. Research on the design of belt conveyors and the structure of their load-bearing elements pays insufficient attention to conveyor belt splices, whose strength significantly affects the durability and reliability of conveyors, and even the entire systems that they are part of. For this reason, the present author has devoted the past several years to research and implementation work [9–13] aimed at analyzing the strength properties of bonded joints and developing and implementing a concept of a system for monitoring the condition of such joints during operation of a conveyor belt. As a result of this work, a monitoring system (Fig. 1) was designed and built, which consists, among others, of a magnetic field sensor and a pulse counter that make up a computer measuring system. A modem, RAM, and a microprocessor constitute its control system. The data transmission and processing system comprises a personal computer and phone lines or network cabling. Measurement points are marked with permanent magnets embedded in the conveyor belt on opposite sides of each splice. The location of the magnets during conveyor movement is identified by a semiconductor magnetic field sensor.

Fig. 1. Measuring–diagnostic system [13]

The principle of operation of the system is based on the appropriate use of the magnetic sensor located under the moving conveyor belt. Magnetic field strength increases as the magnet approaches the sensor; and when the magnet passes the sensor, the sense of magnetic field strength changes. At this point, the strength of the magnetic field changes the most in the shortest time. A pulse registration method that works in this way makes it possible to measure the time between two measuring points at a high accuracy. The measurement data obtained are sent to a computer equipped with suitable software for acquisition and analysis of data and visualization of results. The original monitoring system designed on this premise can signal in advance the occurrence of conditions that normally accompany an impending break in a belt splice. The monitoring system is designed in a way that endows it with powerful data analysis capabilities and offers additional benefits, allowing a specialist to:

- analyze those maintenance parameters of the belt conveyor that contribute to frequent failures due to belt breaks and to develop an appropriate intelligent system for monitoring the operating conditions of the device and for its automatic control aimed at eliminating critical situations;
- analyze, on the basis of the results of measurements conducted under actual conditions of use, the durability of different types of bonded joints used in conveyor belts to enhance the quality of the joints and develop or modify the technology of their manufacture;
- carry out analyses of the causes of defects in the manufacture of belt splices;
- and make a practical comparison of the peel strength and shear strength properties of adhesive materials used for splicing belts.

Measurement of the length of a conveyor belt splice begins when the magnetic field sensor sends a message that it has detected a reference point. This point marks the beginning of the measurement section and it resets the pulse counter. Splice length is measured indirectly. The moving belt turns a roller which is located under the upper section of the conveyor belt in such a way that there is permanent pressure between the roller and the moving belt, which prevents slippage between these two elements. Attached to the roller is a disk with evenly spaced indentations around its circumference. The pulse counter system uses a slotted optocoupler, which is a system that consists of two photoelements. One of them emits light beams (this is usually an LED), and the other is a photodetector, which converts the incoming light beams into electric voltage. The photodetector is a photodiode or a phototransistor. One of the disk slots is positioned between the two elements of the optocoupler. If the element that finds itself in the slot of the disk is impervious to light beams, a change in the voltage at the photodetector occurs (the voltage may rise or fall, depending on the electric system in which the photodetector operates). The moving belt turns the roller, which has a defined, constant diameter. The disk mounted on the roller has 200 holes (slots) around its circumference. This allows one to determine the distance travelled by the conveyor belt over the time when the disk has rotated by an angle equal to the rotation of the disk by one slot.

The optocoupler is used to count the passing holes (slots). The impulses start to be counted when a signal is received from the magnetic field sensor that the reference point has been detected. The counter starts counting the impulses coming from the optocoupler. Measurement ends when the magnetic field sensor sends a signal that it has detected a second reference point, which marks the end of the measuring section, i.e. the joint or section of the belt measured at a given time. The value of the counter is stored in the RAM of the control system and the counter is reset to zero. A microprocessor located in the pulse counter circuit controls the flow of data between the optocoupler, and the control system.

An important element of the discussed computer-assisted measurement system is its control system. The control system of the measurement system for monitoring instantaneous changes in the length of conveyor belt splices consists of three components – a microprocessor, RAM and a modem. The microprocessor controls data flow between the measurement system and the control system. Data incoming from the pulse counter circuit are transferred to RAM. Each measurement is stored according to a specified pattern. Readout of the pulse counter is saved along with the hour, minute, second and the date of receipt of the data by the control system. The control system has been equipped with a large storage capacity because of the substantial amount of incoming data and the high rate of transfer of these data by the user to a PC. The large number of measurement data recorded is a consequence of the high-speed at which the conveyor belt moves and the large number of splices, whose passage through the measuring system is recorded many times a day.

For measurements of this type, a separate analysis of static and dynamic errors has to be conducted. Static error is independent of the time-varying nature of the value measured and it is not associated with transient processes in the device. Since ideal static conditions do not exist in practice, it is assumed that changes in the value of the parameter measured are at the level of resolution of the measuring instrument. Static error of digital measurement is comprised of quantization error and analog error. Quantization error is a consequence of mapping an infinite set of continuous (analog) values onto a finite set of quantized digital values. Analog error is more complex. It consists of the threshold error of the system which is unable to respond to infinitely small changes in the parameter measured. Reference source error is usually the main component of analog error and it results from the imperfect nature of the reference. The last component of analog error is the error associated with noise and other types of interference in the measurement circuit [1, 3, 14].

Dynamic error arises when the value measured changes over time. Dynamic errors are the difference between the value measured and the actual value. The main components of this error are quantization errors associated with sampling, and transient states of the measuring instrument. Dynamic error is produced when a continuous value is averaged to discrete time intervals, when the sampling frequency is too low, i.e. lower than the frequency of changes of the analog signal, and when the instrument is in a transient state, for example, as a consequence of a change in the direction of the magnetic field in the magnetic field sensor.

Digital filters used in the proposed measurement system are designed to smooth out the signal, separate the relevant components of the frequency spectrum, and determine parameters in different frequency ranges. When designing a digital filter, care should be taken that the sampling frequency of the filter is higher than any component frequency of the signal at the input of the ADC. Another assumption is that the sampling period must be shorter than any time constant in the filter. This is to prevent a situation in which the analog signal ceases to be approximated by the digital signal. A digital filter must be sufficiently precise, i.e. it must have a low degree of quantization. If the degree of quantization of a filter is greater than the input of the ADC upstream of the filter, some information will be lost due to slower data-processing upstream of the filter. An unwanted effect in digital filters is clipping of the signal. It can lead to oscillation in the filter, which is a cause of errors [1].

Another problem related to measurement are the distortions arising from the nature of the environment in which the measurement system works. They give rise to signals in the measurement circuit that are not the result of the measurement process. The distortions are formed as a result of electromagnetic fields acting on the measuring system. Systems that are most liable to disturbances are those located in the vicinity of large electrical machines and those that are surrounded by a dense network of electric wires, as is usually the case with measurements made in industrial environments. Particularly sensitive to disturbance are analog systems. The continuous output signal can easily be deformed, especially when the voltage in the analog circuit is low, e.g., several millivolts. In this case, a distortion of the order of one millivolt can lead to an error between 10% and 20%. Measurement systems can be protected against this type of interference by shielding.

3. Computer-assisted analysis of measurement data and computer-aided maintenance

As noted, among others, by Kaźmierczak [4], the decision-making process for maintenance activities can and should be effectively aided by using appropriate computer tools. One type of such tools are Computer-aided Maintenance Management Systems (CMMS), which are developed to perform functions that go beyond typical database maintenance. An optimal CMM system should also encompass elements of the decision making process, including, among others [4]:

- effective collecting, processing and sharing of data stored in database systems using diagnostic methods for evaluating the state of an object,
- development of a knowledge base to complement the diagnostic data,
- designing an advisory system tool to support decisions on the state of the object using the information stored.

Identical assumptions were adopted for the design of software modules for the measuring system described in this article. The main functions of this software are recording and processing of process data, control of measuring equipment and communication with the user. This is why in this program the tool changing column has been placed beside the data window. The tool buttons are used to activate various functions of the program, such as setting the compensation of the magnetic sensor or importing data to the user's computer. The program that supports the measurement system described in this article offers, among others, the possibility of visualizing changes in the length of a particular splice during operation of a conveyor, visualizing changes in the length of each section of the belt between the joints and collective presentation of these values for all (or selected) splices of the conveyor and all sections of the belt between the splices. It also enables statistical analysis of the values recorded and export of measurement data, graphics, etc.

The measurement data and their analysis using the proposed computer program allow to visualize and comprehensively analyze measurement results, and the data obtained in this way allow to continuously monitor the status of all splices and sections of the belt between them. The program can signal an alarm condition and helps evaluate the operating conditions of the conveyor, identify a single splice any time during the operation of the conveyor belt, and assess the effectiveness of maintenance work – for example, strengthening of a joint with mechanical components. This means that the measurement system can signal in advance the occurrence of conditions that normally accompany an impending break in a belt splice. The appropriate design of the system and the dedicated program for data analysis also afford additional benefits arising from the application of the system, which include, among others:

- continuous measurement of changes in the length of all splices and belt sections between them to within 1 mm;
- about 1500 measurements per day for each conveyor, depending on the number of its splices;
- real-time visualization of changes in splice length,
- identification of splices and pinpointing of their exact location on the conveyor any time during its operation;
- analysis of historical data – the possibility of collecting information on each splice and belt section (date and place of manufacture, manufacturer's identity, operation time, load, place of operation, etc.);
- the possibility of integrating the system as a module into other diagnostic–visualization systems, especially in self-management systems (Fig. 2);
- availability of accurate information on the operating time of the conveyor, its instantaneous speed values, downtime periods, number of stops and times of restart, and the precise length of the conveyor belt at any time of its operation;
- data processing enabling predictive control of the operation of the conveyor belt.

It is due to these features that the system can be classified as a diagnostic system of the second level of security of the transport process, which is a higher level compared to the previously described conventional systems of locks and guards that perform the tasks of a lower level of security. Not without significance is also the possibility the system gives of long-term analysis of historical data for every single joint that forms part of the conveyor belt from its manufacture until the end of its useful life.

According to the concept of CMM, the monitoring device can also be transformed into an intelligent machine that has the ability to independently respond to the changing operating conditions and to eliminate conditions that cause belt breaks by anticipating future operating parameters and the consequences of their occurrence.

As it follows from previous analyses, both quality- and quantity-oriented knowledge of changes (a decrease) in the value of strength parameters of belt sections and splices during the entire maintenance cycle is indispensable when it comes to choosing a belt for a given conveyor and predicting the optimum time point for performing maintenance, based on the precisely specified operation time and load distributions. It may also be useful for the assessment and verification of newly developed mathematical models of operation time distribution.

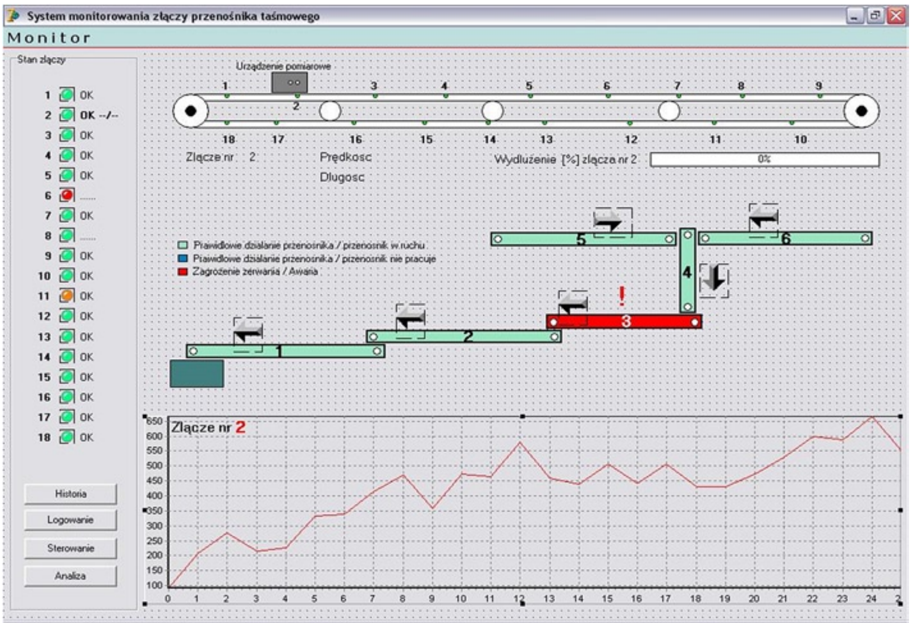

Fig. 2. A conception of a method for visualizing data from a system for monitoring conveyor belt joints

Therefore, bearing in mind that conveyor belts are commonly used in internal transport systems, and that there are no effective monitoring and control systems for preventing failures of these devices caused by splice breaks, it can be concluded that the results of the present study will not only increase the knowledge and experience of industrial use of diagnostic and monitoring systems, but will also reduce losses associated with downtime due to unexpected failures.

It can thus be stated that the objective of the present study is to design not only a comprehensive dispatching monitoring system, but also a smart actuator, which, when integrated into currently used transport monitoring and control systems, will allow to effectively expand them and make fuller use of diagnostics in self-management systems. The measurable benefits of implementing this concept of monitoring and controlling of belt conveyors include, among others:

- the possibility of constant surveillance of all conveyor belt splices during operation, using a non-invasive method;
- identification of joints and assessment of their durability and reliability throughout their operating life, regardless of their current location;
- real-time data mining of monitoring data along with a comprehensive analysis of historical data, which are especially useful in belt management;
- simple design and easy operation that does not require outsourcing;
- the possibility of assessing the effectiveness of maintenance activities.

The conception of a system for monitoring conveyor belt joints developed in this study corresponds, in accordance with the theory of diagnosis, to real time diagnosis of an object with simultaneous signalling and visualization of its state. Implemented in this way, the monitoring method yields a real-time diagnostic system for conveyor transport. This system collects during its operation a considerable amount of different types of data, which provide information on the object being diagnosed. This excess of information, which operators have to analyze using visualization of the current parameters characterizing the analyzed object, may eventually lead to an information overload, often resulting in ignoring the relevant information or a failure to use the potential that measurement data collected by the system over a long time have. The monitoring system itself, then, despite a number of undeniable advantages, is not, in the long run, a sufficient solution to the optimal use of information it generates.

That is why it has to be expanded to become a fully automated computerized system for supporting the diagnosis of belt conveyors. Its primary role should be to process collected data and analyze them to support the decisions made by supervisory personnel or to take such decisions automatically, as far as possible, and to utilize them for current or temporary control of the transport system.

In this way, the system for monitoring conveyor belt splices and the belting between them would become a system of continuous surveillance (supervision and safeguarding) of the state of the analyzed object. Depending on its application, it could be used to support decision-making to ensure proper operation of the object (Fig. 3) or to control the object to prevent its failure and the consequences thereof (Fig. 4).

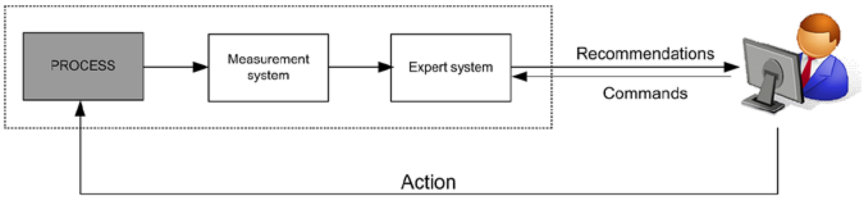

Fig. 3. The concept of an expert decision support system for conveyor belt transport

This is in line with diagnostic terminology, in which supervision stands for monitoring of an object and taking steps to maintain its proper operation, and safeguarding means the actions and technical measures taken to eliminate a potentially dangerous course of a process or to prevent the effects of such a course.

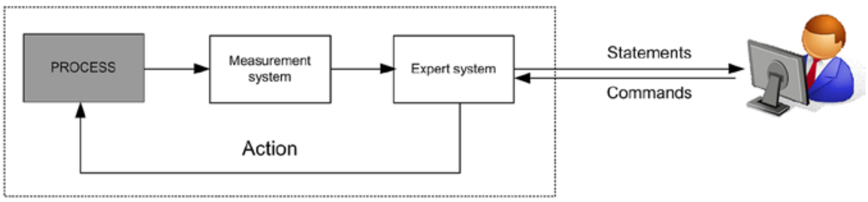

Fig. 4. The concept of a preventive control system for conveyor belt transport

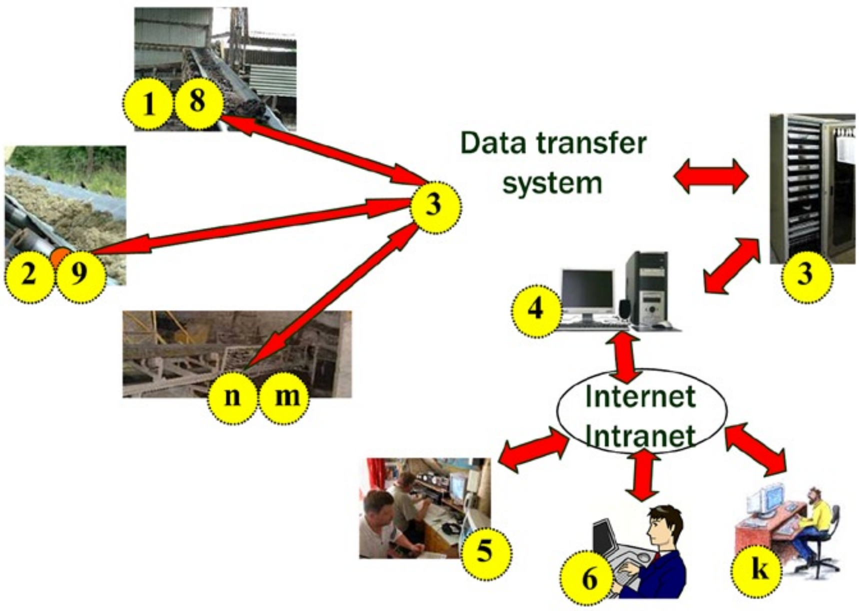

Fig. 5. A schematic diagram of the concept of a comprehensive system for monitoring belt conveyor transport: 1, 2, ..., n – measuring devices; 3 – a long-distance data transmission system; 4 – software for real time analysis and collecting of measurement data, processing of historical data and controlling the system; 5, 6, ..., k – end-user interfaces compatible with the company's dispatching system; 8, 9, ..., m – signalling devices.

Therefore, based on the results of the work carried out so far, it is also possible to build a comprehensive system of continuous surveillance of conveyor belts that could be used in company transport systems (Fig. 5). Such a system would combine diagnostic equipment for analyzing the reliability-relevant operation parameters of the individual conveyors with elements of a computer-based advisory and control system.

The primary objective of the system will be to automatically monitor the status of all bonded joints to prevent their rupture, and to track the operation history of all belts and their individual sections. A system of this kind is versatile in that it can be used in different types of companies, in accordance with their specific branch-related characteristics and requirements. Thanks to its versatility and the flexibility of its software modules, the system can be combined with other dispatching diagnostic and monitoring systems.

One problem related to operating this type of system is that it requires collection and processing of various types of data, which are often difficult to describe or analyze in real-time. It would therefore be important to expand the proposed splice monitoring system to a diagnostic advisory system forming part of a comprehensive diagnostic system based on intelligent tools.

4. Conclusions

The substantial amounts of data and accompanying information generated by a measuring system, particularly in the case of a large number of monitored bonded joints located on several, even up to 20, conveyors of a complex transport system, lead to numerous complications associated with the interpretation of collected data, making it difficult for supervisory personnel to make effective decisions. In such cases, the operator is faced with the necessity for constant decision making, having to analyze a large data set, observe changes in the data or predict their future values (the trend of changes on a safety scale of safe / emergency / above alarm level, which corresponds to the potential states of the analyzed object). In other words, the decisions have to be made under uncertainty [235, 237]. A conveyor transport system is an example of a system that is affected by many factors which have not been clearly defined or which are characterized by significant randomness and unpredictability. Objects of this type are difficult to describe.

Maintenance diagnosis of a single belt conveyor or an entire transport system conducted with the help of the described monitoring system enables effective assessment of the current state of bonded joints. When first symptoms indicative of reduced strength, and, hence, potential rupture of a joint, are registered, however, a monitoring system should additionally be able to predict for how long the joints will retain the characteristics that ensure proper operation of the conveyor. An ideal, newest-generation system should not only be able to collect and process current and historical measurement data and generate on their basis justified alarm signals, advisory information and guidelines for personnel, but also take corrective actions on its own. In other words, a distinguishing feature of such a monitoring system would be the ability to carry out an inference process with the use of expert systems, that would automatically generate and verify diagnoses to be used by the operator, and that would also have the ability to take action independently of the operator. To create a system of this type, it is important to develop diagnostic methods based on decision support systems and the latest developments in the field of intelligent techniques, which is also a significant challenge for the diagnostic system described in this paper.

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