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Challenges of Maintenance, Repair and Overhaul in Hazardous Areas

ABSTRACT

Service, repair and maintenance are fundamental areas of every company. These functions have special significance for production operations, since they represent important components for ensuring the value-added chain. The importance of maintenance has continually increased in the last few decades. Maintenance strategy concepts have been continually further developed, while their requirements and influence on added-value also is increasing. Maintenance has developed from reactive to preventative tasks. With the new applications of Cyber Physical Systems and the Internet of Things, even the methods of maintenance are experiencing new development. Experience-based maintenance becomes projected maintenance, since data is determined in real time, evaluated and actions can be initiated. Maintenance of systems in explosion-hazardous areas also has safety-relevant conditions in addition to the conventional requirements. For this reason, this area presents a very high challenge for maintenance. Along with the production-related aspects, regulations of guidelines and standards must be met. This leads to very high expenditures of time and costs. The processes of maintenance in explosion-protected areas can also be optimized and the necessary expenditure minimized through the new data-based starting points of maintenance. To test this option and to develop goal-oriented methods, it is necessary to analyze current procedures in the maintenance of explosion-protected areas with the aid of questionnaires and expert interviews. The specific requirements that are necessary to fulfill projected maintenance must be characterized during this. Results show that the integration of the maintenance approach is only possible through explosion protection compliant adaptation of the equipment and can result in progress for the entire product life cycle of explosion protected operating equipment and systems.

Keywords: maintenance, design methodology, explosion protection, hazardous area.

Introduction

Unexpected downtimes of production systems often lead to financial losses, which are accompanied by high time and cost intensive expenditures. Every producing company attempts to avoid these types of exceptional situations. The maintenance area is often the jurisdiction for this responsible task.

The task is expanded to maintain explosion protection during the manufacture of products in a potentially explosive atmosphere, which can be generated by the raw materials used for example. Reliability of the safety measures must be guaranteed in this area of safety technology, so that no danger exists for humans and the environment.

The strategy and methods used in maintenance have changed dramatically. Currently Cyber Physical Systems and the Internet of Things change the focus and methods of maintenance. In Germany, the overall development is now designated "Industry 4.0" due to the new aspects.

Explosion protection and handling with this safety area are characterized very traditionally. Due to specific requirements that are defined by guidelines and laws, the implementation of innovative ideas requires comprehensive testing. The advantages of the new strategies in the area of maintenance can lead to a general advancement in explosion protection. Thus it is necessary to analyze the current status of the branch and to define options for further development using the mentioned aspects.

Development of Maintenance

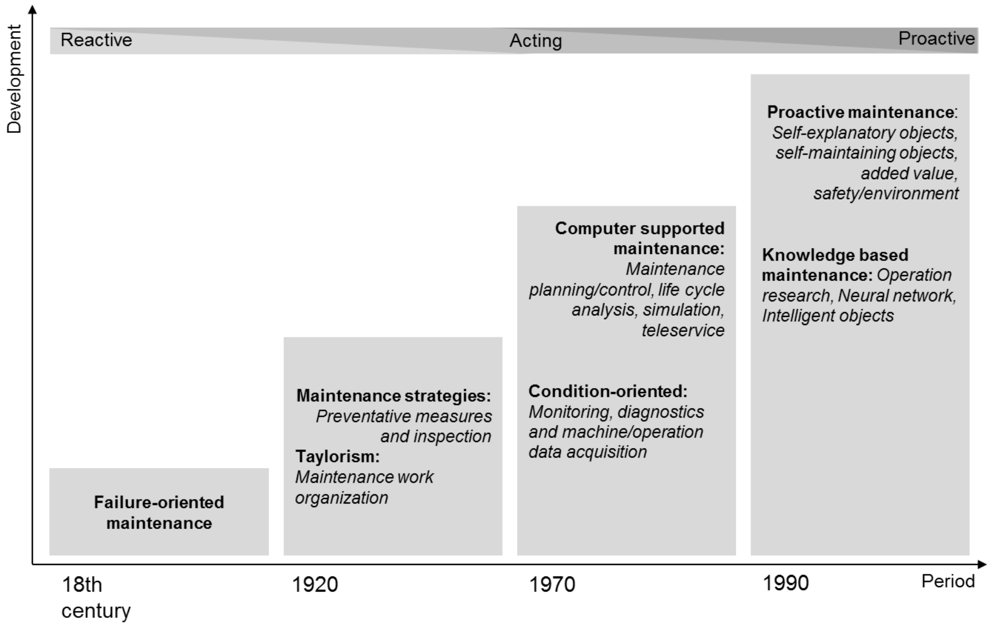
History

Development of maintenance is coupled with changes in the industry. The field of maintenance has transformed from a reactive to a proactive business process. Maintenance is an essential area for every producing company.

Up to and including the first industrial revolution in the 19^{th} century, maintenance of systems was done as a reaction to malfunctions or breakdowns. At that time the top objective was to get the machine functioning again as fast as possible and to keep company downtimes as short as possible. Initiation of maintenance as an independent company area was done with the integration of Taylorism into the production industry. Large facilities emerged with a comprehensive machine park and, due to the division of labor in the production process, individual manufacturing steps could be performed with less qualification and training. However, special tradesmen were required for maintenance of the facilities. Furthermore, it was recognized that the strategy of reaction through repairs incurred high costs. Preventative measures and regular inspections were introduced in order to optimize the reliability of the machines. This became even more significant as time went on, since functionality was required due to the linking and automating of the production sequences. Additionally, safety consciousness also increased in the production shops, which had to be ensured.

Due to increasing cost pressure, indirect company areas, which did not participate directly to the added value, appeared in the focus of optimization to create these more efficient and effective. In addition, the state of technology developed faster, while the technical obsolescence of the machine came quicker. Consequently, the expenditures of the system over the entire product life cycle had to be considered. Due to these requirements condition-based maintenance developed, which is partially used today. With the aid of a wide variety of resources, parameters can be monitored whose evaluation give feedback on the current condition of the machines. In this way, preventative measures can also be carried out. The newest developments include these basic concepts and expand them around the new capabilities of Cyber Physical Systems and the Internet of Things. For example, one idea is the evaluation of the measured data in real time, which could control a self-maintaining process. Figure 1 summarizes development of maintenance schematically (Pawellek, 2016, pp. 1-4; Schenk, 2010, pp. 1-4).

Figure 1. *Development of Maintenance*

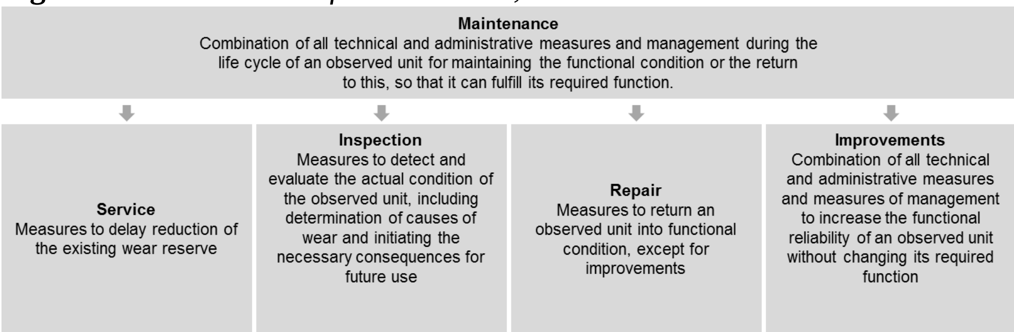


Current Tasks

Based on the history, requirements for maintenance have permanently expanded. Correspondingly, the task area also increases. Four different partial areas can be formed according to DIN 31051[1], see Figure 2.

[1]DIN 31051 is often referenced in literature to represent the partial areas. Also on the European level there exists a standard, DIN EN 13306, that is used for definition of the terms.

Figure 2. *Partial Areas of Maintenance, acc. to DIN 31051*



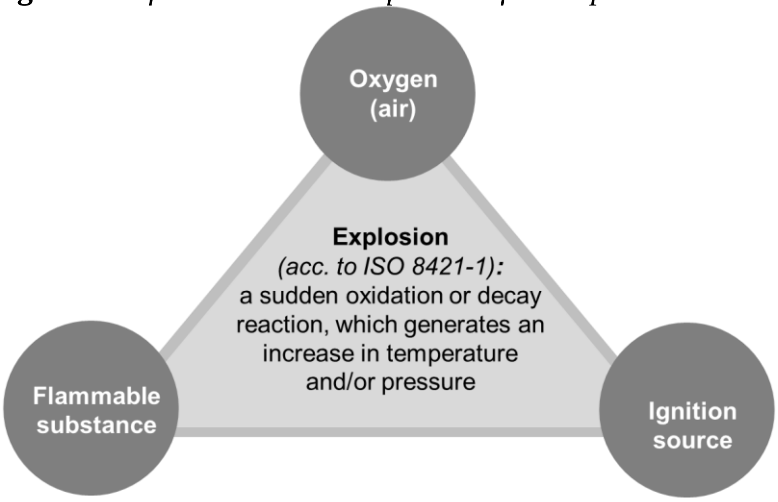
This covers the maintenance, service, inspection, repair and improvement of systems and machines. Requirements are fully met according to preventative and corrective activities. Therefore the contribution to the added value for reduction of use and increase of various resources can be defined. For example, maintenance lowers the use of resources by preventing malfunctions and breakdowns which affects the system, environment and process reliability, optimization of maintenance strategies and preservation of the system value. An increase of resources results, for example, by increasing the time/function utilization and ensuring all functions required by a technical system in regards to time duration and quality (Kuhn, 2004).

Maintenance in Hazardous Areas

Explosion Protection

Various materials are used for the manufacture of products. This can also include flammable substances, for example during the production of flour for baked goods or the fabrication of pharmaceutical products. Handling these flammable substances is influenced by special requirements, since a flammable substance forms an explosive atmosphere with oxygen in the air, which can explode if a source of ignition arises (see Figure 3).

Figure 3 *Definition and Prerequisites of an Explosion*



Actions are created with the aid of explosion protection to prevent the occurrence of an explosion, the results of which can be catastrophic for humans and the surroundings. Lack of knowledge and experience can lead to huge catastrophes in this field. For example in 2008, a hot-running bearing on a conveyor belt lead to an explosion in the sugar refinery in Port Wentworth (USA) with 14 fatalities (CSB, 2009). Also in Germany and Europe such catastrophes occurred, such as 2009 in Iserlohn (Lehmann et al., 2009) or more recently in October 2016 in Ludwigshafen (Zeit, 2016).

As a consequence, explosion protection is seen as a partial area of safety technology that is characterized by universal requirements and specifications from guidelines and standards. In 2003 in Europe, the overall regulation was done by the implemented EC-Guidelines for explosive atmospheres, the so-called ATEX Guidelines. Now there are two guidelines to further reduce the risk of an explosion in the affected areas. One is the EC Directive 94/9/EC (ATEX 95) as manufacturing guidelines and the other is the EC Directive 1999/92/EC (ATEX 137) as operator guidelines. On April 20, 2016 the EC Directive 94/9/EC was replaced by EC Directive 2014/34/EC (ATEX 114), which contained no fundamental changes of the product requirements, however includes new obligations for distributors and importers.

Compliance to the required safety in the directives is supported by standards. There exist proven active structures, the so-called ignition protection types. These generalized technical solutions resulted from the history of explosion protection and facilitate an expedient explosion protection compliant design of operating equipment. However, the basic approach to protection of the individual ignition protection types can be very different. Requirements and procedures for compliance or implementation of the ignition protection type are defined in the standards of the various ignition protection types. In this manner, the designer receives instructions for a targeted explosion protected design of the products when using an ignition protection type. Furthermore, a comparable safety level can be guaranteed when the standard specifications are complied with, which can also be controlled without increased effort through notified test sites.

Presently a differentiation of the ignition protection types is done in regards to their application for electrical and non-electrical equipment. In view of the high importance of electricity at the beginning of explosion protection, the ignition protection types for electrical equipment are presented in detail and transparent. The area of explosion protection for non-electrical equipment was first characterized about 20 years ago by explicit requirements in standards, however mechanical operating equipment has been used for over 150 years.

Specific Requirements and Tasks of Maintenance

In addition to preserving the function, maintenance for hazardous areas must also guarantee a high degree of safety. In order to achieve this, standards and specifications to be met were also created for this task area.

During this, a differentiation must be made between electrical and non-electrical equipment based on historical data. On an international level there are specifications for electrical equipment through the standards of IEC, which are also accepted on the national standard level. They include instructions for project planning, selection and installation of electrical systems (IEC 60079-14), inspection and maintenance of electrical systems (IEC 60079-17) and equipment repair, overhaul and regeneration (IEC 60079-19).

Furthermore, the specific requirements of the equipment manufacturer must be taken into account, which are noted in the operating manual, among others. These are of especially high importance for non-electrical equipment. Compared to the largely standardized implementation of ignition protection types of electrical operating equipment, the technical realizations of non-electrical ignition protection types are designed very uniquely. International standards for non-electrical equipment can be found in ISO 80079-36 and ISO 80079-37, valid since December 2016. However, these only encompass requirements for design, construction, testing and identification.

Requirements of the previously mentioned ATEX Directives must be met in Europe. In Germany, these guidelines are implemented through the Industrial Safety Regulations (Betriebssicherheitsverordnung (BetrSichV, 2017)) and the Hazardous Substances Ordinance (Gefahrstoffverordnung (GefStoffV, 2017)). Fully anchored in this is that the operating company is responsible for the safe operation of a system in hazardous area. The safety of the system is verified by inspections. For example, it must be checked whether seals are damaged, if there are open potential equalizations, whether the bearing lubrication is sufficient, or if unauthorized system changes or modifications were made. Here a differentiation is made in the assessment between inspections before the first start-up, periodic inspections and inspections after changes in the system. In addition, the mentioned laws stipulate inspection of the explosion safety to be done every six years and inspection of the technical explosion protection measures every three years. Fundamentals of all inspections form the risk assessment, a part of which is the explosion protection document, which presents the explosion protection concept.

This must, among other things, establish the risks of explosion, the corresponding actions and the intended inspection cycles. In general, inspections must be set by the operating company. The legal specifications and standards of the IEC require qualified personnel for performing the inspections, so-called competent persons. For this external companies can also be authorized for the inspection or in-house personnel can be trained.

Due to the high risk, areas there is the possibility that insurance companies and professional associations can increase the already mentioned tasks and requirements to create preventative measures for minimizing the risks. (Pepperl+Fuchs, 2017)

Analysis of the Current Procedures

Methods

Procedures in the maintenance of explosion-protected systems are characterized through required and individual company-specific tasks. To get an overview of the current maintenance concepts and their methods in the industry, various methods were used for analysis. In the first step, participants at an event for maintenance processes in hazardous areas were surveyed. Due to the low number of participants, the goal was the recognition of tendencies. With this knowledge, interviews with those responsible for the maintenance of potentially explosive systems in the process industry were carried out. The results of the individual case analyses could then be compared with the tendencies.

Tendencies of Current Maintenance

All participants in the tendency survey were working in the area of maintenance of potentially explosive systems and thus entrusted with the requirements of a high level of safety. With the aid of five questions, the current tendencies in regards to tasks and expenditures in maintenance should be explored.

The results show that carrying out repairs and inspection or visual inspections are the largest portion of the measures to be carried out, see Chart 1. The most frequent errors are electrical malfunctions and defective components, see Chart 2.

Chart 1. *Actions of Internal Maintenance*

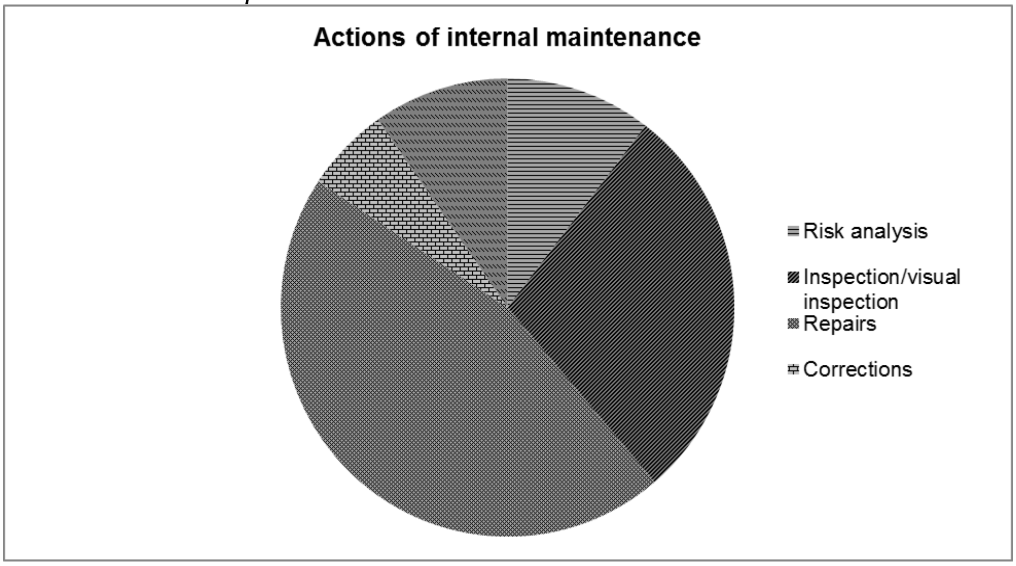


Chart 2. *Most Frequently Occurring Errors*

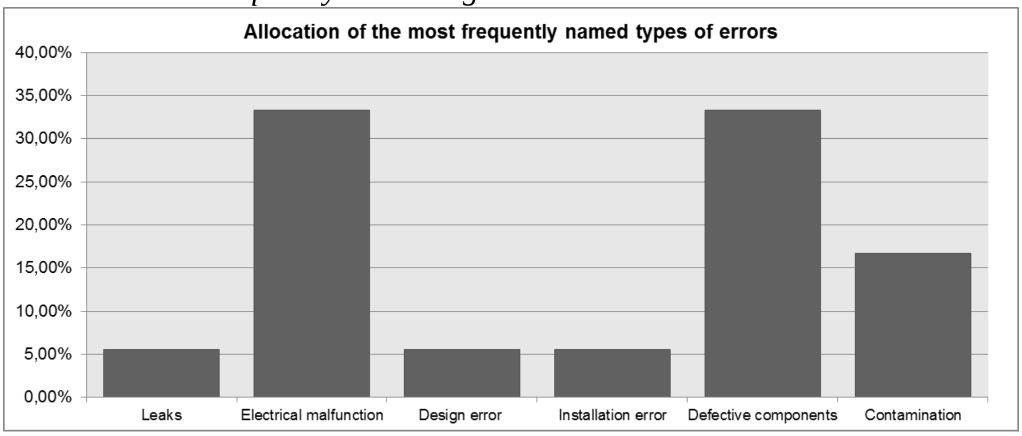
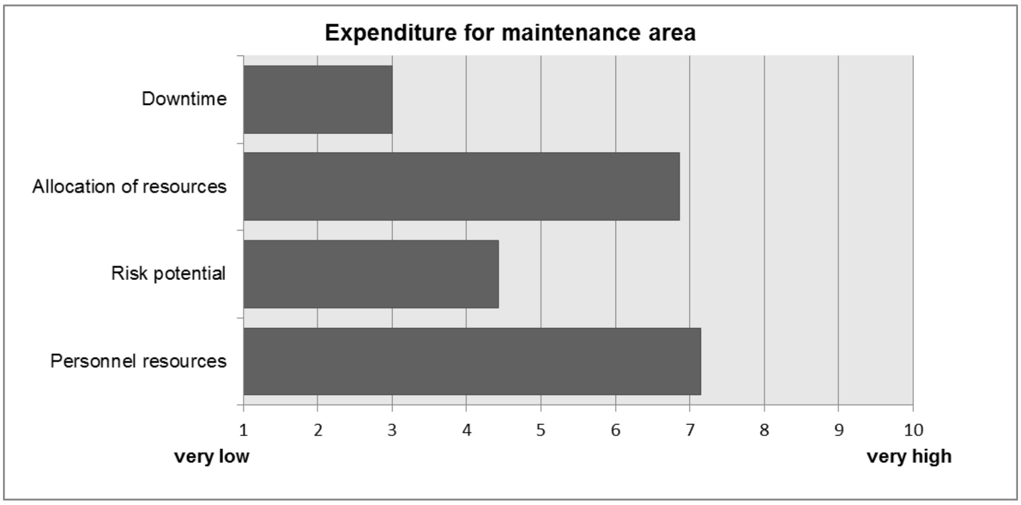


Chart 3. *Expenditures in Maintenance*



As shown in Chart 3, the expenditures for personnel and use of resources were estimated the highest by maintenance. As possible optimization points for reducing expenditures, aspects such as the use of preventative and event-oriented service, intelligent instrumentation, more efficient technology, standardization and better planning were mentioned. Furthermore, around 70%, and especially small and medium sized companies, see the future of maintenance in the perspectives of Industry 4.0. The largest companies observe outsourcing of maintenance tasks as future-oriented.

Expert Interviews

The first expert interview was carried out with employees at a refinery. Maintenance of the large system, which has potentially explosive zones in a wide variety of areas, is done with the aid of condition-oriented procedures, which, among other things, is implemented through rounds on each shift for visual inspection, vibration measurements on selected machines and online monitoring. Detected damage is repaired, depending on the priority - immediately, on the same day or in the same week. Here any conceivable damage can occur. Often leaks, bearing damage or defective components occur. The required legal inspection cycles are also shortened as needed. Therefore the refinery is shut down every five years for four to five weeks to carry out all inspections. Preparation for this phase begins three years in advance. Accessibility to this system is very good. However, at times the use of lifting platforms, cranes or scaffolding is necessary. Only qualified personnel are used in maintenance. Furthermore, external companies take over specific tasks or simple activities for reasons of capacity.

The second expert is working for a manufacturer of pharmaceutical products in the area of process reliability. This facility handles many raw materials and its production area is mainly located inside of buildings and includes hazardous areas. Maintenance measures are scheduled according to legal specifications. Visual inspection presents the largest scope of the inspections. Most of the deficiencies are detected through daily control rounds. In addition to visual inspection, employees also detect damage to components through unfamiliar sounds. Currently inspections are mainly done without technical devices. The idea of digital readouts of data could not be implemented. However, it was noted that the integration of error-detection sensors including wireless transmission and automatic evaluation could be a closer implementable solution.

Discussion of Results

Analysis of the current tasks and procedures for maintenance in hazardous areas shows that the scope of work of the specific area covers that of the maintenance for a safe system. However, comprehensive parts of maintenance in explosion protection are the inspections and repairs.

Inspections take a significant part of the scope of work, since these are also required by the legal and standard specifications. Here there are also higher expenses for work materials, since standard aids, such as cranes or lifting platforms must be used. Furthermore, it must be considered that the employee goes into areas with increased risk due to the required inspections and must be equipped appropriately. For example, in hazardous areas only low-spark or spark-free tools may be used. Furthermore, the employee must have a separate qualification, which must first be achieved in part through training courses. This also increases the costs for personnel.

Errors which occur that negatively affect the function of the machine often result from malfunctions or defective components. These cannot be detected in the visual inspection, since looking into the components is not possible. In hazardous areas assemblies cannot be opened or disassembled without preparation, for example by emptying supply pipes of substances, to prevent a potentially explosive atmosphere. This can only be done at essential downtimes that, for example, are done every six years for the inspection of the explosion safety. However, components are also often replaced at that time without assessing the condition, which is necessary for safety reasons.

The examination shows that currently concepts for hazardous areas a mix of reactive and proactive measures is done in maintenance. The approach of condition-oriented maintenance is used with large components in large companies. However, in general there is the desire and hope of the operating company, especially from small and medium sized companies, to integrate proactive maintenance using new technical options.

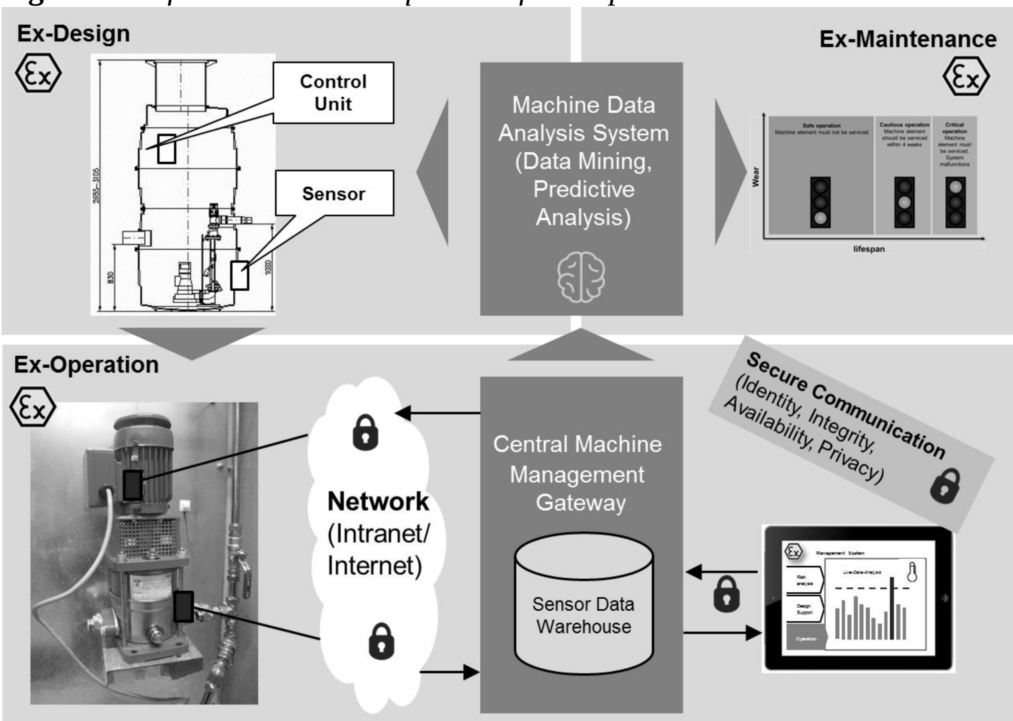
Future Challenges

The future challenges for maintenance of hazardous areas are oriented to the idea of Cyber Physical Systems and the Internet of Things. Through technical options, such as appropriate sensor technology, the condition of the system can be controlled in real time.

The greatest challenge, however, is here in the technical capability of the machines and systems for these maintenance concepts. Only components with appropriate explosion protection capable dimensions and design may be used in hazardous areas. It is at times required to verify this protection through complex certification processes. Thus the technology must already be taken into account from the first steps of product development. However, this also presents difficulties, since the parameters to be checked must be known. Consequently, knowledge of the change of conditions of machine elements and components during their service life must be established. If this step is successful, if necessary safety-relevant information can also be derived from the maintenance-related parameters. For example, pitting damage on a bearing can occur during operation. This can increase during continuous operation and thus negatively influence the resulting surface temperatures. In addition to the possible failure of the bearing, a hot surface in potentially explosive areas is also a huge hazard, since it can act as an ignition source. Furthermore, it is possible to optimize the products continually using the collected data and experience.

With such a system, the assessment, prognosis, preservation and improvement of the reliability of explosion-protected system can be realized. Nevertheless, the security aspects of information technology must also be taken into account in order to prevent possible influences through third parties. Figure 4 illustrates the relationship of a proactive maintenance concept between product development, operation, maintenance and IT security.

Figure 4. *Definition and Prerequisites of an Explosion*



Along with this further development, the capability of other auxiliary aids must also be checked. For example, drones for visual inspection can also be used. However, these must also be further developed for use in hazardous areas. This option could reduce the expenses for cranes and lifting platforms and risks for employees.

Approach to Research

The discussed fields of action offer a wide range of approaches for research projects. Non-electrical explosion protection has a multitude of specific and individual solutions compared to electrical explosion protection. Thus, a correspondingly special form of maintenance processes also results. Mechanical components and parts are designed according to the general fundamentals of mechanical engineering. These already meet a high degree of safety; however do not completely correspond to the specific requirements of explosion protection. Accordingly, further adaptations are absolutely necessary for the explosion protection capable design. The explosion protected design can only be partially implemented through specific technical solutions. If the use of standardized machine elements is done, the guarantee of explosion protection is often only possible through a reduction of operating hours or service intervals. Frequently these are specified shorter than needed. This leads to high downtimes and thus to high costs for the machine elements to be serviced, which in many cases are still functional. Minimizing of service intervals is done using knowledge that exists for the condition of machine elements during use in safe areas. The cause of this is that at present there are no clear instructions to be found in literature that cover the topic of possible interactions between existing wear or other occurring errors and the occurrence of active sources of ignition, such as hot surfaces or mechanical sparks in potentially explosive areas. Consequently, machine manufacturers and operators can only define or adapt on the basis of their experience. Therefore there exists very high optimization potential for the maintenance process of mechanical components and assemblies that are used in non-electrical explosion protection.

A demonstrator is established under these aspects in order to explore the requirements for explosion protection capable design and maintenance of non-electrical explosion protection. With the aid of this demonstrator, the application of frequently used mechanical machine elements is simulated. Correspondingly, life cycles, the influence of damage and other parameters can be researched. These experimental studies represent an efficient and effective method for generating knowledge.

The demonstrator includes a drive and a fast change system through which various machine elements can be quickly and safely integrated. Furthermore, the demonstrator is equipped with necessary external sensors that guarantee internal machine status monitoring, as well as implement the recording of signals. In addition, more sensors are made available for independent monitoring of the machine elements. These are, for example, thermal cameras, force sensors or acceleration sensors.

With this structure, it is possible to investigate the influence on explosion protection from various parameters which can change during the product life. With roller bearings, damage to the bearings can occur during its product life, such as pitting damage. This causes micro-crack formation and material fracture on the material surface. In the initial stages, these do not lead to a failure; however they can influence the occurring surface temperatures, among other things. With the aid of the demonstrator and thermal imaging, using a thermal camera, this possible influence can be investigated and limit values can be defined. Using this knowledge the maintenance and service processes can be planned optimally. Components can be replaced oriented to the condition. Furthermore, through this knowledge conditions of maintenance can be taken into account during product development. This knowledge can completely optimize the product development process, since new bases for dimensioning can be created using the limit values. Correspondingly, auxiliary design aids for implementing active structures and explosion protected design can also be optimized.

The quality and suitability of the signals for condition monitoring should be checked using the data redundancy integrated in the demonstrator. This means during the tests investigation is done as to whether the machine data, which was recorded by the external sensors, shows correlations to the conditions of the machine elements. If this is available, the possibility exists to use these primary data for monitoring explosion protection. For this, the primary data must be validated afterwards. Thus no additional sensors are required. Here various results for the individual machine elements are possible.

Possibilities of Cyber Physical Systems and the Internet of Things can also be investigated with the demonstrator through the integration of further information technology. Data recorded through the sensors should be sent to an internal server via a local network. The on/off operation of the device must also be enabled via the network, in order to simulate that the server decides in the network as to whether the device stops when reaching a specific limit value. In this manner, the development of an ignition source can be prevented. Furthermore, it can be investigated which effects possible hacking attacks (e.g. intercepting messages in the network and manipulating the contents) could have and how these can be influenced by the use of IT security technologies.

Through these comprehensive investigations, the first fundamental findings of the maintenance processes in explosion protection can be gained. Furthermore, comprehensive progress in non-electrical explosion protection can be generated. Along with the conversion of experience-based maintenance to condition-oriented or predictable maintenance, there are other optimizations possible. Using the findings gained, an interactive knowledge platform is built up, which comprehensively accompanies the product development process from non-electrical components for use in hazardous areas. The design engineer gets current information on explosion protection capable dimensioning and design via the knowledge platform. This also encompasses, along with the current requirements of the guidelines and standards, information on the determined limit values. The equipment is networked with this knowledge platform in order to carry out continuous data transfer. The limit values can be continually verified using the availability of this volume of data. A wide base of data from the field is thus available for the design engineer, which can significantly simplify calculation of the service life. Furthermore a transparent evaluation of the data is possible in real time, which can be called up at any time. Using this data, the wear and other influences can be analyzed over the service life. A targeted reason for actions can be realized. Through this on the one hand the costs for the machine elements can be significantly lowered, and on the other hand the service intervals lengthened or service work combined practically, resulting in a reduction of downtime. Time and cost savings can be made in the central phase of the product life using the knowledge platform and then all resources can be applied more effectively and more efficiently.

The guarantee of security presents a comprehensive challenge with the implementation of this idea. Loss, manipulation, blocking or external control must not be possible. Therefore in this area the highest requirements of IT security must be met and regularly updated. Without securing this requirement, such a system cannot be realized in the areas of security technology. Thus this is also a field of action which will be discussed in Germany during research for Industry 4.0. More fields of action which were named by the Industry 4.0 workgroup are real time availability of production key figures and use of predictive maintenance (Kagermann et al., 2013). All these topics can be taken into account with this approach to research.

Conclusions

The study shows that the approaches of proactive maintenance can be carried over into areas of explosion protection and can also be required. However the challenges here must not only be implemented by the system operator. Progress can only be made by a change in thinking of the component manufacturer. The required technology must be integrated into the products and also certified for use in hazardous areas. Safety of the explosion protection must be guaranteed. Using the options of continuous data acquisition, knowledge about the individual products can be collected, which currently can only be achieved by estimating and laboratory trials. This could be overall progress for explosion protection.

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