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The pipe – the basis for a computer aided pipeline management

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Abstract

Maintenance, seen from economic aspects, is a factor that cannot be underestimated by any network operator. Nowadays, steel pipelines combined with cathodic corrosion protection (CCP) create the basis for applying condition based maintenance concepts. That means meanwhile the network condition, which is linked with the data gained through the periodical monitoring performed by the CCP specialist, the object-related documentation, the individual manufacturer's pipeline data and the geographic position of each pipe in a system's pipework routing can be compiled. We would like to examine this form of maintenance, which can be implemented at this time, in more detail.

Zusammenfassung

Aus wirtschaftlicher Sicht ist der Unterhalt ein Faktor, der von keinem Netzwerkbetreiber unterschätzt werden kann. Heute ist die Verbindung von Stahlleitung mit einem kathodischen Korrosionsschutz die Basis für ein Zustandsbasiertes Unterhaltskonzept. Der Zustand des Netzwerks kann aufgrund von Informationen abgeschätzt werden, welche aus periodischen Überwachungsmessungen, objektspezifischer Datenerfassung, Rohrhersteller-informationen und geografischen Unterlagen stammen. Diese Methode des Unterhalts, welche aufgrund der verfügbaren Technologie heute verfügbar ist, wird im Detail diskutiert.

Introduction

Maintenance tasks can be roughly divided into the areas of inspection, service and corrective maintenance. The corrective maintenance area covers not only repairs but also rehabilitation, i.e. reconditioning and replacing line sections (Fig. 1)

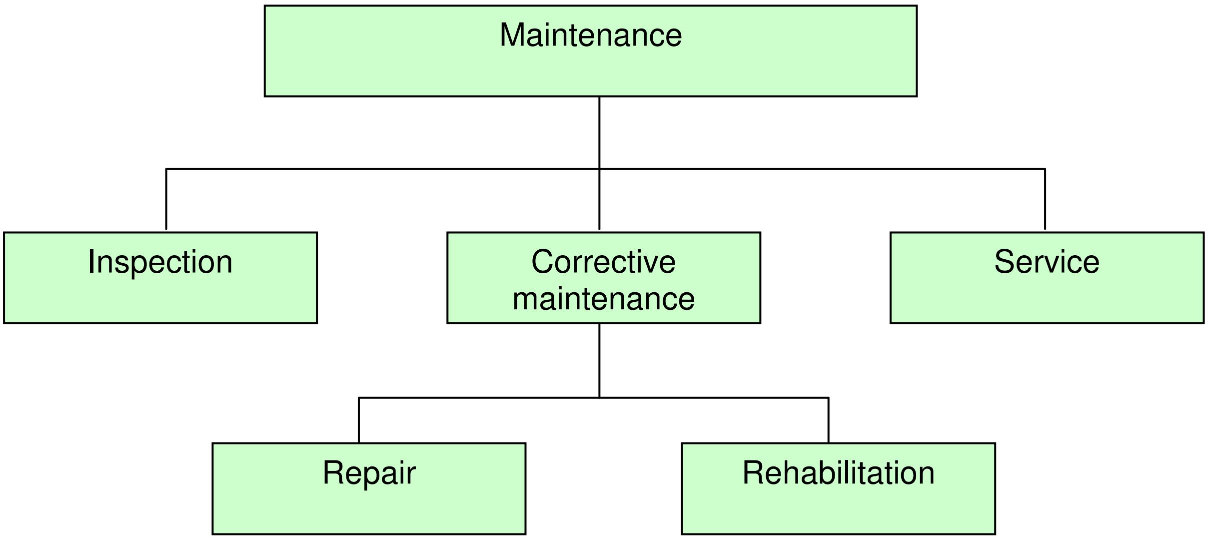


Fig. 1: Types of network operator maintenance tasks

One can differentiate between three different maintenance strategies (Fig. 2). Failure-related maintenance is a form of maintenance that cannot be planned. As no one knows when and where repair might be required, prognostic cost planning is also hardly feasible. This form of maintenance has asserted itself in pipeline construction for components that, depending on the operating conditions, do not underlie any material-related breakdown such as loss of flexibility and strength. That includes pipes made of concrete, stoneware, steel and cast pipes. The modern, planable concepts that are generally striven for nowadays include preventive and condition based maintenance. Whereas preventative maintenance is based on statistical factors and failure probabilities, condition based maintenance depends on measured quantities that supply information about the condition of a plant.

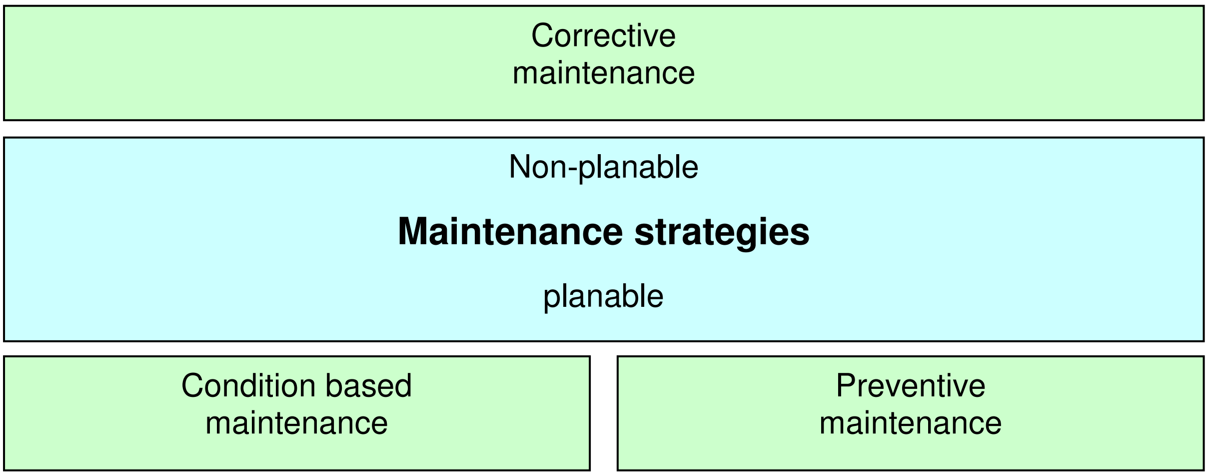


Fig. 2: Maintenance strategies

Condition based maintenance, with its associated utilisation of a component's capacity design margins, is finding increasing use in industrial production plants. Condition based maintenance has found its place meanwhile even in the private sector. That includes, for example, the monitoring of the rate of brake-lining wear now common in many automobiles. If the thickness of the brake linings reaches a critical limit, an indicator light on the instrument panel signals that the linings need to be replaced.

In public utilities, cathodic corrosion protection can be deployed with comparatively little effort for lines and line networks to fully utilise the benefits of condition based maintenance. The condition oriented form of maintenance according to the German VDI Directive 2888 for example is given when the measured data on the condition of a component can be permanently accessed [1]. When evaluating damage-data dependent on types of soil, condition assessments made with camera inspections etc., the term "maintenance condition monitoring" is often used ambiguously. Remaining with the example of brake pad monitoring used in the above, such component information, which in the final analysis is used in a network operator's rehabilitation planning as a statistical factor, can be compared with the quarterly wheel disassembly to monitor the degree of wear. While doing so, one can, for example, with the additional documentation of the kilometres driven on the motorway or in the city and, in this case, considering the resulting wear, limits the uncertainties in a service life prediction. Still, in the final analysis this procedure corresponds to a preventative maintenance concept. The expenditure for the documentation and evaluation of such statistical data along with the required validation of the results on the component involved is, considering the remaining uncertainness, disproportionate when compared with remotely readable measurement instrumentation.

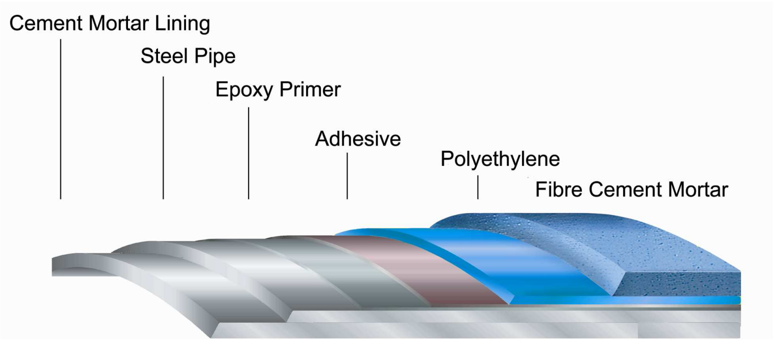
In the case of pipelines, cathodic corrosion protection cannot be considered to be an unavoidable extra cost for steel pipelines; rather, when operated correctly, it is a powerful tool for condition based maintenance [2]. This technology now enables the network operator to use software-supported pipeline management systems that not only centrally save all information on lines and line networks, but, based on the measurement data available from the cathodic corrosion protection monitoring, also facilitate concrete recommendations.

The development of the steel pipe

In the over 100-year history, from the aspect of maintenance of lines and line networks it is above all the development of steel pipes up through steel line pipes that need to be taken into consideration. From structural pipe aspects, the steel line pipes in the distribution networks are still usually over-dimensioned nowadays.
The functionality is decisively determined by the wall-thickness reduction of the eroded corrosion. It was realised early on that the component made of ferrous materials is exposed to material removal under environmental conditions. Seen historically, in steel pipe, two fundamentally different concepts in component design need to be considered here:

- Corrosion is considered a system-related factor during the design process
- Coatings are applied to separate the environment from the base material

Accordingly, in steel pipes with a lack of or with only insufficient corrosion protection, one must figure corrosion allowance into the wall-thickness design which was to be adjusted to the environmental conditions. See [3] for example. That means every pipe was inevitably given a planned service life. When damage is found on such pipes today, the damage cannot be attributed to the corrosion already considered during the design but to exceeding the planned service life associated with this design. Exceeding the planned service life is therefore not to be judged as negligence while planning the service life; rather in the case of failure-oriented maintenance it is systematically caused. The lines are operated until they fail. The problem lies in the decision as to whether the occurring damages are to be assessed as individual cases or as a sign of overall damage and thus as the failure of a line section.



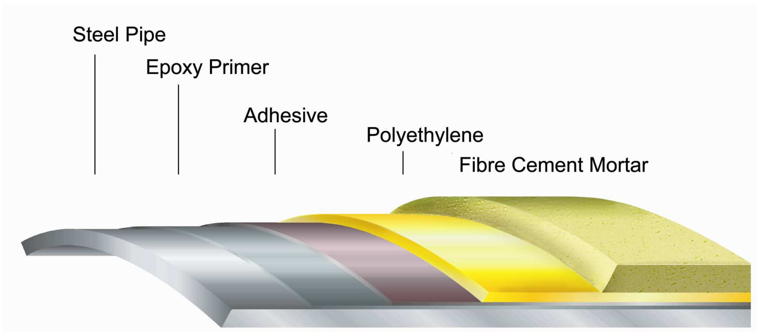


Fig. 3: The steel pipe - a material composite for underground gas and water lines

Steel line pipe, having now been manufactured for several decades, is a material composite pipe (Fig. 3) that differentiates itself from steel pipes in design already in that according to the technical code, a corrosion allowance does not need to be taken into consideration when designing the wall thickness. See, e.g., [4]. Corrosion processes are only possible here in cases of external effects as long as the plastic materials normally used as thick layer systems or the cement lining in the water-sector do not totally lose their barrier properties. Under the external influences, during this all the factors are compiled, which, in the final analysis have nothing to do with the system-related service life of the piping, such as third party activities, lack of care while installing the pipes, soil setting, etc. Independent of the corrosion likelihood of a soil, the time of damage is first of all determined by the time of such external influences - an aspect that is not statistically ascertained independent of the raw materials used. Even in the case of a possible corrosion rate of 1 mm/a, conceivable due to a combination of aggressive soils and external current effects, the question of time is decisive for the damage which leads to local failure. Here lies the main weakness of the damage statistics, which today are included in the sense of preventative maintenance for rehabilitation planning.

Another weakness in many statistics on service life evaluation is the use of corrosion as the cause of damage, which is normally applied for pipes made of ferrous materials (Fig. 4). The corrosion is a type of damage that can be attributed to external impacts, soil movements, a lack of care during installation, material defects, etc. It is not difficult to understand that when registering corrosion as the cause of damage in such statistics, assessing the execution-related service life is precluded from the rehabilitation planning. A necessary separation of the damages arising through external impacts from the system-related damages and therewith the acquisition of the damage attributes relevant to ascertaining a theoretical service life is not even possible under these circumstances.

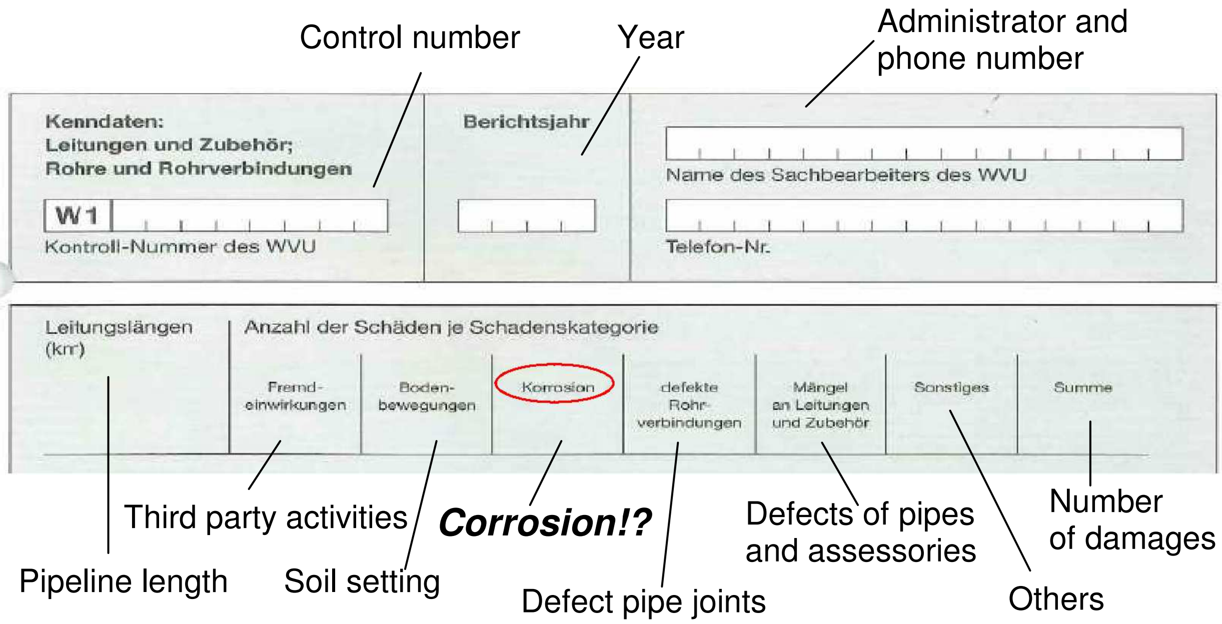


Fig. 4: Extract from the damage logging for rehabilitation planning for water supplies in Germany [5]

Another problem arises when for example in DVGW damages statistics various assessment periods, which are used as the basis, are combined (Fig. 5). That makes such statistics not merely misleading; the inevitable comparative view between the raw materials associated with this type of representation is impermissible and has no validity. This will be illustrated using the figures in the damage statistics for the distribution lines from the years 1997 and 2003 as an example.

Figure 5 shows a usual representation method of the DVGW damage statistics from 1997 and 2003. In this form of illustration, the following aspects are to be taken into consideration:

- The data in the case of cast iron and steel pipes involves an installation period of more than 100 years, whereas for the plastic pipes only a mere about 50 years of installation experience is available

- In the cast iron pipes, the technological progress of grey cast iron to ductile cast iron is cleanly separated. Even if after the introduction of the ductile cast pipes grey cast pipes were still being installed, they would unavoidably fall into the category of the pipes that correspond to the earlier state of the art

- In steel pipes, all supplied executions ever delivered are currently composed in one category. The pipes that, due to the lack of or insufficient corrosion protection over the corrosion allowance, were prepared for a service life must be differentiated from the versions with thick coatings

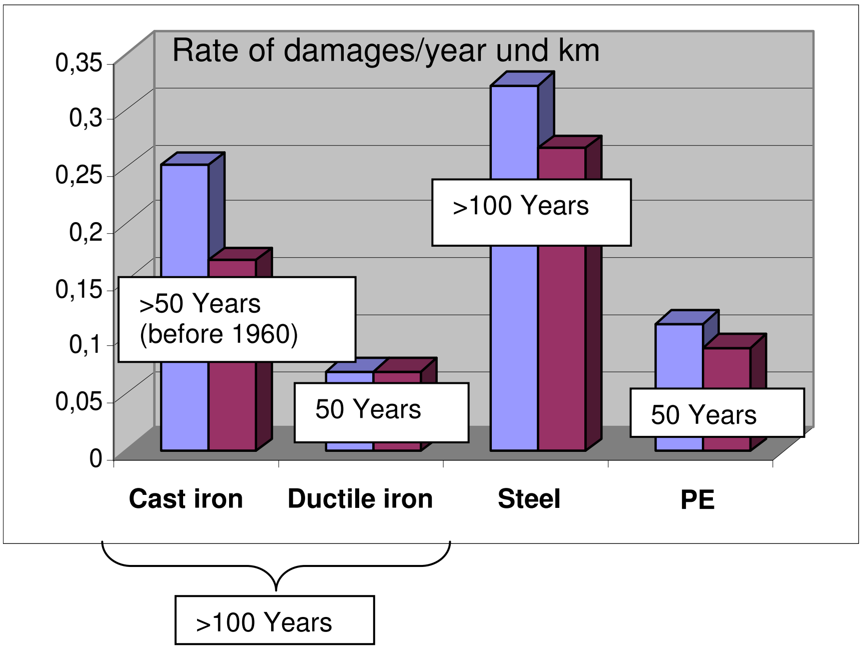


Fig. 5: DVGW damage statistics for water for 1997 and 2003 [6]

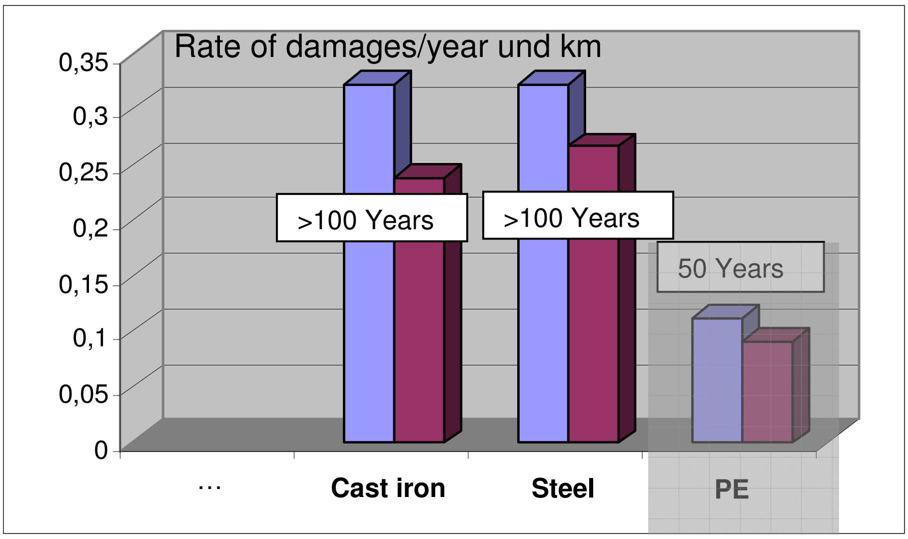


Fig. 6: DVGW damage statistics, water, with a reference time period > 100 years

When considering the one-hundred year installation history, a comparison between cast iron and steel pipes is certainly possible. While doing so, naturally no separation can be made based on technological developments (Fig. 6). A difference in relation to the types of damages can hardly be ascertained here in the frame of statistical fluctuations.

Also the examination of the 50-year installation history is feasible with the aid of some global considerations based on the extant data inventory (Fig. 7). In the case of cast iron pipes, the technological separation of the grey cast und ductile cast iron pipes executions is performed once again. Plastic pipes can also be taken into consideration correspondent to the available data. Considering such published statistics for steel pipes, there is apparently no data available. The following assumptions however can in fact be made based on the cast iron pipe data.

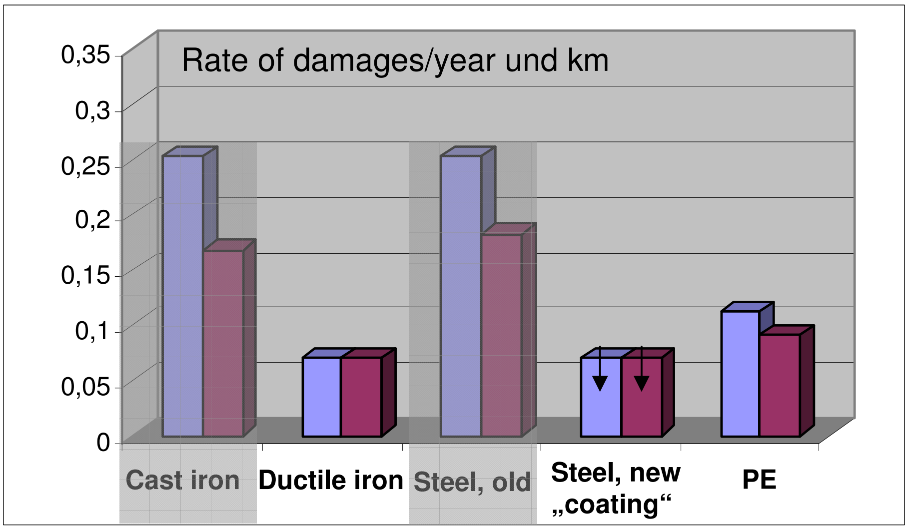


Fig. 7: DVGW damage statistics, water, with a reference time period of 50 years

The current damage rate of ductile cast iron pipes includes a considerable number of damages, which can be attributed to the missing of a adequate corrosion protection in the 60's and the beginning of the 70's [7]. It was believed that the ductile cast iron pipes, just as with the grey cast iron pipes, did not need an additional corrosion protection. With the materials modification from grey cast iron to ductile cast iron pipes however, the more ductile material had assumed the same corrosion behaviour as steel pipes. Correspondingly, nowadays identical corrosion protection measures are provided for cast and steel pipeline pipes [8], [9].
The corrosion behaviour in steel line pipes was never underestimated, so the thick coatings (cement grout linings, glass-fibre reinforced bitumen sheathing, PE sheathing) during the past 50 years in steel line pipe technology belong to "state-of-the-art". The damage rates in steel line pipes must therefore inevitably turn out smaller in comparison to cast iron pipes. Steel pipe versions from the former GDR with insufficient or missing corrosion protection are part of the older category, so they cannot falsify the statistics [10]. Furthermore, during the past 50 years in public utilities, the steel line pipes were predominantly welded, respectively since the 80's were provided with a spigot and socket joints comparable to the cast iron pipe system so that, for example, also the caulked sleeve problems known from the older steel pipe versions belongs into the earlier damage category.

Seen from a material-neutral perspective however, in the result for pipes made of ferrous materials compared with the plastic pipes, the balance is clearly more positive. Considering the fact that 80 to 90% of the damages can in reality be attributed to external impacts, the increased damage rate due to lower strengths in plastic pipes is also plausible. The "pickaxe" does not discern if it is dealing with a pipe made of PE 63, PE 80 or PE 100. The new generations are even more highly endangered as the wall thicknesses have been significantly reduced. With a correct reading of these statistics, one must urgently question how, based on this data trials can be justified in which plastic pipes are used for non-conventional pipe laying or even in the high-pressure gas sector, especially as steel line pipes in safety-relevant applications are to be additionally provided with cathodic corrosion protection.

In the 50's of the last century, cathodic corrosion protection was developed in order to exclude damages by external impacts in steel pipelines particularly in cases where they are statistically non-weighable and for this reason is specified for safety-relevant applications with the corresponding success. Here, the corrosion as an electrochemical process is an advantage because it can be recorded from the earth's surface and can be influenced by the protective current. Imperfections can be localised and the material removal in the exposed steel surfaces in such imperfections can be reduced to a negligible amount. For rehabilitation planning based on such data, it is of significant meaning that on the one hand the material has sufficient strength to resist external influences and on the other that the cathodic corrosion protection forms an independent corrosion protection to, in case of damage, still allow sufficient time to plan structured repair measures medium or even long-term [11]. Nowadays, not only the facility for technical-code based monitoring measurements exists; with the help of remote data transmission, the condition of a line or a line network can also be registered [12].

The WinKKS Classic

With the development of cathodic corrosion protection for steel pipelines, in the 50's the basis for condition based maintenance of buried pipelines was created. Cathodic corrosion protection helps create the facilities for monitoring lines and line networks and for precisely localising imperfections. As cathodic corrosion protection is an independent corrosion protection process, in case of local damages the repair and/or rehabilitation measures can be planned medium or long term. With the new developments in the area of telemetry and remote monitoring technologies, the facilities of cathodic corrosion protection in the area of maintenance condition monitoring has been significantly expanded [12]. These advantages of cathodic corrosion protection are important reasons why today this electrochemical protection method for all lines harmful to groundwater that transport media and for gas lines is always specified above 4 bar.

With the improvement of metrological facilities in the non-contact evaluation of buried systems, the possibility of a software-supported organisation of the tasks in the network and line operator departments responsible for cathodic protection was already contemplated early on [13]. One result of such contemplations is the WinKKS, which is focussed on covering all functions required for cathodic corrosion protection. The program has the facility to save all the master data of a pre-defined line section. In the CCP departments, these line sections however were primarily defined under metrological aspects such as protection sections, sections between two isolation pieces, etc. Here also, important attributes were already stored which in the end are also interesting for other departments responsible within the network company. These are, e.g. details about the pipe geometry such as the nominal width, wall thickness, length and material quality along with the delivery terms. Furthermore, details on the media flowing through, the operating pressure and the sheathing are saved in the database. Details on the network topology and the GIS, which is optionally linked using an intelligent interface, already turn the line section, which if applicable can also affect the individual pipe, into a "smart pipe" in the original version of WinKKS. Illustration 8 provides an overview of the pipe information saved as the default.

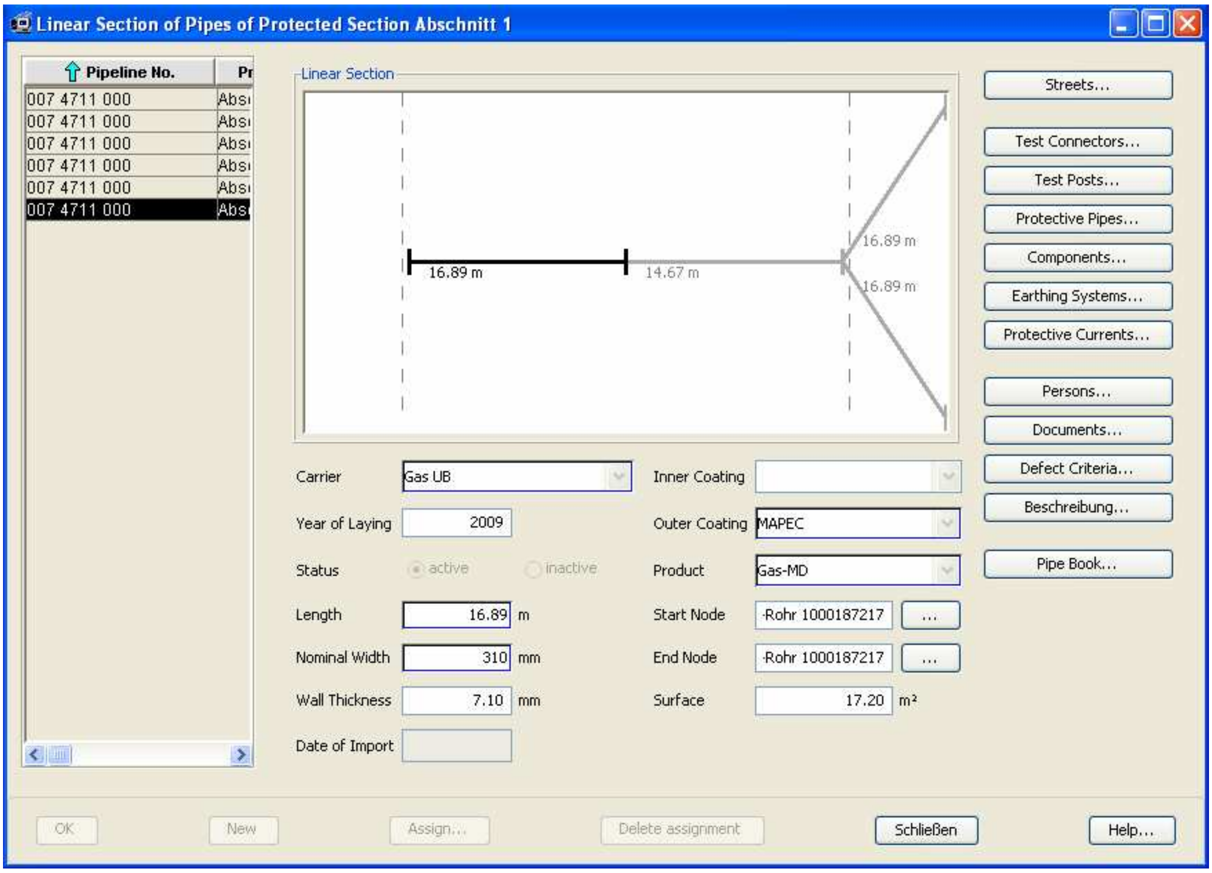


Fig. 8: Illustration of a line section to a protected structure

The pipe number — the key to pipe data

At the end of the production process, every single pipe number provides information about the origin and/or the properties of the raw materials and the test results, which have been acquired on the way from the black finish pipe up to the final product per batch. Thus the process of quality monitoring during line construction already starts with the raw material manufacture for the pipes, runs through the tests specified in the standards and delivery terms (e.g., bend, tensile, test, notched-bar impact test, etc.), to the final acceptance of each individual pipe with the agreed test certificate and on through factory quality assurance or external acceptance. The production facilities are to secure the traceability of the finished product back to the base material. That means the history of the finished product is concealed in every pipe number.

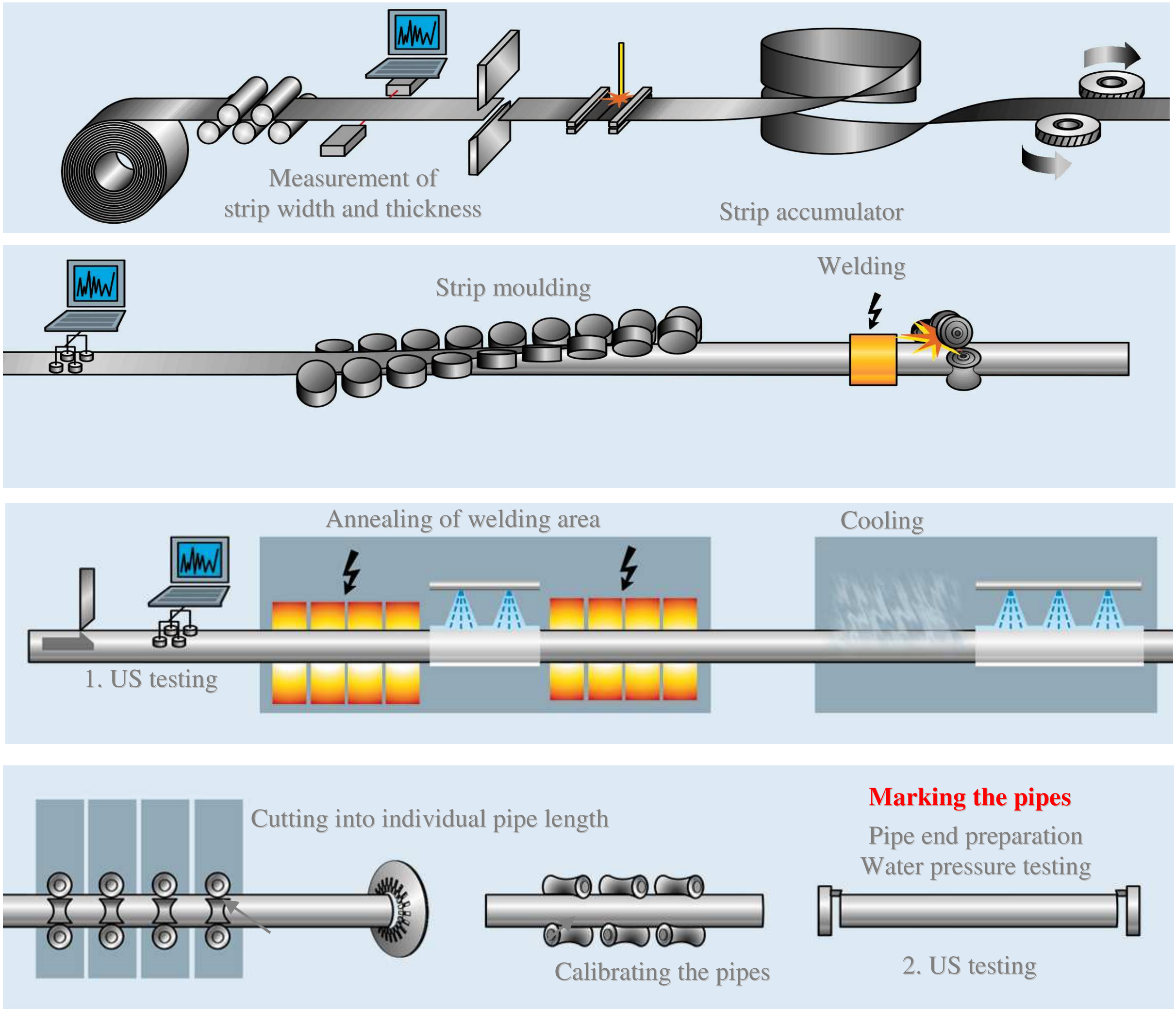


Fig. 9: Schematic sequence of pipe production

HFI longitudinally welded steel pipes are made from hot-rolled wide strip. From the steel melt, continuous plate slabs are cast in the steel mill. The continuous plate slabs are processed as individual slabs in the rolling mill into hot-roll wide strips. The supply of the roll material at the pipe manufacturer takes place in the wound form as coils. To manufacture the pipes, the continuous band is constantly moulded into a pipe and welded (Fig. 9). After cutting the continuous pipe conduit, which arises during this process, into the desired individual lengths, every pipe is given its identity in the form of pipe numbers.

Corresponding documentation is also required during installation. Suggestions for setting up pipe records are described in the DVGW technical code, for example [14]. These pipe records document details about the installation process (e.g., weld number, executing welder and sheathing guy along with the corresponding inspection process). Proper execution is certified with a TÜV certificate. It is exactly during installation when the pipe numbers can be recorded corresponding to the position in the route, facilitating the continuous allocation of all relevant data. Barcode scanners can be used in this process to record the pipe numbers to provide the exact position of each individual pipe in the route area, supplying the main prerequisites for using a pipeline management system. The documentation of the data and documents feasible via the individual pipe numbers in combination with the cathodic corrosion protection virtually suggests itself as a permanently accessible line-condition acquisition option for a pipeline management system.

WinKKS with expansion to a Pipeline Management System (PMS)

The pipe network operator is responsible for the planning, construction and maintenance of the lines or line network. A great deal of data and analogue documents are provided here which need to be resorted to back in case of need. That does not only involve the data material from manufacture and installation of the pipes; after installing and commissioning, the lines underlie continuous quality monitoring. That includes: onsite inspections, driven inspections, aerial surveillance, following up on messages and, if applicable, the use of intelligent pipeline pigging systems. In addition, the previously mentioned facilities are used for area corrosion protection. During these quality monitoring measures during line operation, in turn enormous amounts of data accrue both in digital and paper form. It was obvious to optimise the WINKKS program structure matched to the CCP operation into a pipeline management system by using corresponding expansions and to organise the data jungle so that, in case of a malfunction or line damage all necessary information and documents are available in the shortest possible time.

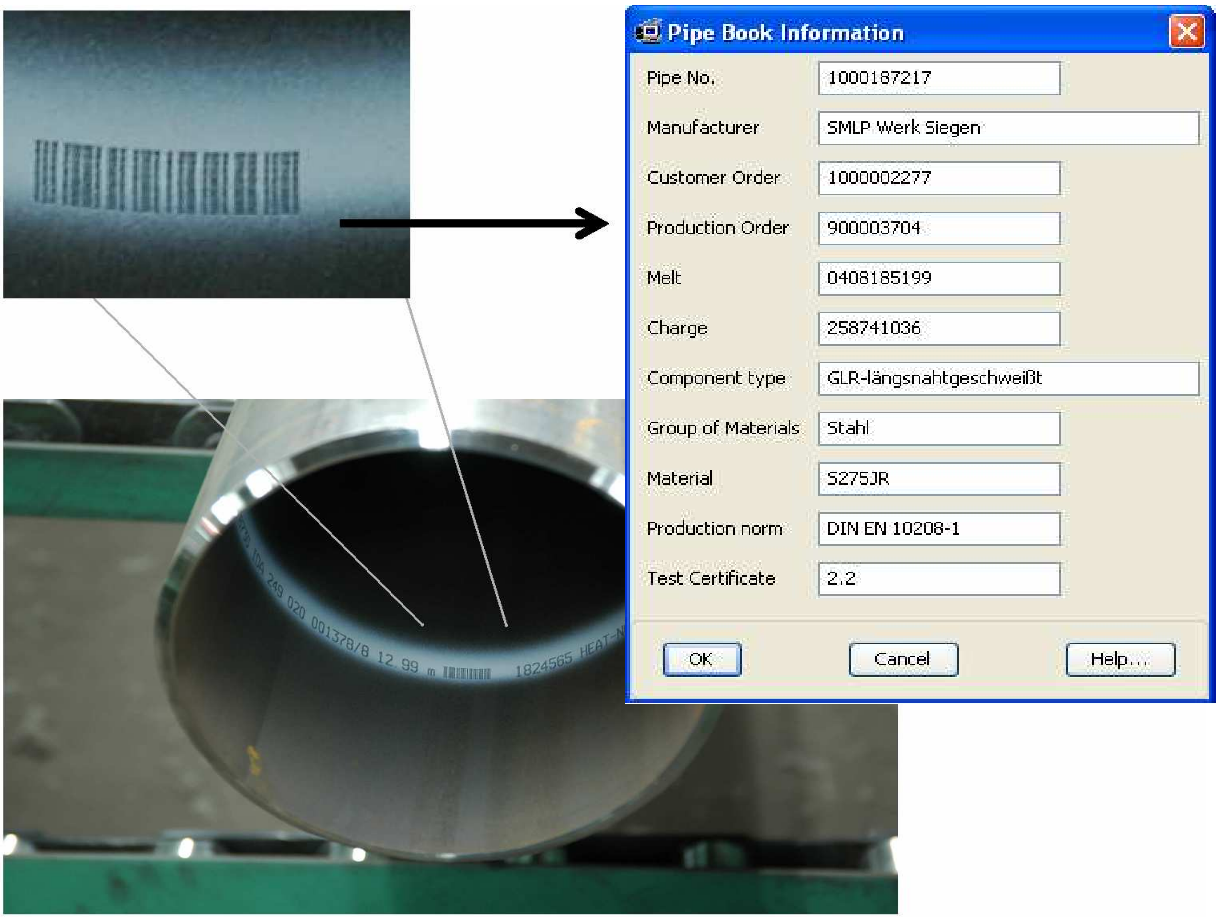


Fig. 10: Acquisition of the pipe data from the pipe identification barcode

If the definition of a "line section" in WinKKS is left up to those responsible for the CCP operation, in a pipeline management system this hierarchy can be expanded to registering every individual pipe. By scanning the pipe numbers at the construction site, all attributes saved from the production process about each individual pipe are archived for the entire life cycle. Along with the unique pipe number, that includes, for example, information about the manufacturer, order, smelt, batch, type of component, pipe geometries, material group, etc. (Fig. 10). This information is partially in the form of a pipe label as a barcode, attached to the pipe itself. When installing the pipe, the barcode can be read with a scanner so the information is merged together with the installation of the pipe and its position in the location. This information is transferred into the WinKKS database in an automatic process chain. The pipe attributes can be retrieved as "Pipe record information details". With the retrieval facilities provided to the user with the ORACLE database system, any piece of pipe information can be linked and presented in the form of lists or printed out.

Furthermore, there are also facilities to store additional documents such as TÜV certificates from the manufacturing process, which are available on paper, as PDF files in the database and they can also be linked with the pipe numbers.

So, for example, all individual data can be allocated for the stress pressure test as K*S values (the product of strength and wall thickness). For the stress pressure test, a distribution of the pipes with higher and lower K*S values adapted to the topography is needed, so by combining the pipe numbers with geographic data through WinKKS, the route planning can be coordinated and monitored. Later on in service the real K*S data is also a help to give a first impression how critical a local damage of the pipe can be.

Another example is the simplification of tracing documents at the network or line operator. The documentation duties require an amount of archiving of data and documents that cannot be underestimated. On the one hand, the pipe numbers including all the relevant documents can be linked and, if applicable, the documents originating from the manufacturer can be electronically retrieved in the factory. Using the predefined standard queries to the database, the decision-makers in the company are provided with the data for inspections, repairs or replacement actions. The now available functionality of the expanded WinKKS provides an IT tool that furthermore meets many requirements in terms of comprehensive asset management for underground steel pipelines and thus also meets the requirements placed on pipeline management.

Conclusions

The steel pipe, based on its more than 100-year history, disposes over not only the most varied pipe versions, but also underlay the various strategies of maintenance at the operators. Maintenance was conducted focused on failures for many decades. Meanwhile, one tries to gain expected service life evidence by using statistical methods.

The evaluation of the ageing and corrosion process in the line networks however requires a highly differentiated consideration, depending on the materials and the pipe execution. In plastics, the corrosion, accounted for here preferentially as material ageing, becomes noticeable long before the reduction in material strength through the embrittlement of the material. The stones under a plastic line only lead to damage if the material becomes brittle [15]. The useful service life can be calculated based on the strength development only with prudent and strain-free bedding of such lines.

In pipes made of ferrous materials, the material-removing corrosion forms need to be taken into consideration. If we consider the steel line pipe executions of the past 50 years, it is ascertained that during this time thick coatings are included in the state of the art which, as long as the corrosion protection is not completely degraded as in the case of the plastic pipes, can only be damaged by external influences. Under the external influences during this, all the factors are compiled that in the final analysis have nothing to do with the system-related service life of a pipe execution, such as third party activities, lack of care while installing the pipes, soil setting, etc.

For the assessment of the theoretical service life of a pipe version, damages caused by external influences are not statistically relevant. Damage can arise during the pipe installation and just as well only after 100 years of line operation. Nevertheless, 80 to 90 % of all damages to pipelines are based on these statistically-intangible damage causes. This is one main reason why without effective monitoring of exactly this form of damage, the maintenance by a public utility with all the expenditure that is invested in the determination of the execution-relevant service life of the raw materials will always remains predominantly failure-focused.

From economic aspects, in industrial reality nowadays one increasingly relies on condition based maintenance. In the public utility sector, as opposed to all other raw materials, it is only with steel line pipe where such concept for the lines and line networks can be realised. It is exactly the decreasingly available personnel capacities of the network operators for the increasingly important construction-site monitoring that requires an instrument which supplies evidence such as the cathodic corrosion protection for quality assurance in pipeline construction. The advantages of cathodic corrosion protection can be summarised as below:

- Quality assurance in pipeline construction
- Reliability through permanently available measurements
- Monitoring activities of third parties in the route area
- Localisation of imperfections
- Long-term plan of repair measures
- Recording conditions of pipelines and line networks

The data associated with the cathodic corrosion protection will be transferred and processed early-on in a planning tool, the WinKKS. The program is also capable of managing additional manually entered data or documents. For that reason, it was only a small step - by registering additional data - to generate a pipeline management system that provides support to all posts responsible in network operations. The main advantage of this planning tool is the fact that this system does not rely on statistical measurements that are tainted with probable quantities, but relies on genuine measurements. WinKKS thus increases not merely the safety and reliability of pipeline systems, but, based on the condition-focused individual pipe monitoring and the associated optimised utilisation level of the lines, also provides significant savings potentials. From the point of view of managerial economics, that exhausts not only the system-conditional expected life reserves of the steel line pipe by minimising the external influences, but also supports the organisational processes during network operation.

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