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Operation and maintenance of steel pipelines

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Operation and maintenance of steel pipelines

For all utility companies, maintenance represents a cost factor that must not be underestimated. The expenses to be expected for operating and maintaining a pipeline or a pipeline system should be determined as early as the planning stage. Utility companies should not restrict themselves to benchmarking only the costs for material and construction, but also consider and make appropriate allowance for the consequences of subsequent operation as determined by the choice of material. The very diverse types of steel pipe available for buried pipelines allow an optimum maintenance strategy for each application. The maintenance strategies employed are discussed in this article as they apply to steel pipe application areas.

Introduction

Pipeline networks are exceedingly complex systems subject to the most stringent demands with respect to availability and operational safety. Correspondingly high demands are placed on a utility company's maintenance activities, whether in the supply or waste management spheres. Maintenance can be broken down roughly into inspection, servicing and repair work [1]. Repair activities cover both repair and rehabilitation, i.e. reconditioning and renewing line sections (**Figure 1**).

The scope and hence the cost of subsequent maintenance are already roughly determined at the planning stage [2]. Thus the DVGW study on cost-cutting potentials in the water supply sector published in 1999, for instance, shows that prolonging the service life of pipelines by means of rehabilitation measures such as relining or subsequent cement-mortar lining is a factor of considerable economic significance [3]. Since pipeline rehabilitation is normally only possible where the system's statics and strength are unaffected, pipes with a limited service life can hardly be expected to make the realization of such cost-cutting potential possible.

The strategic approach to a maintenance concept must be taken into account right from the planning stage. Maintenance strategies can be divided into three different main types (**Figure 2**). A non-plannable form is corrective maintenance in response to failure; since nobody knows where or when repair work will be required, anticipatory cost budgeting is, obviously, hardly possible. Corrective maintenance has proved its worth with components not subject to wear and tear under operating conditions. Methods which can be planned include preventive maintenance and condition monitoring (predictive maintenance). Whereas preventive maintenance is based on statistical values, condition monitoring relies on measured values that provide information on the condition of a facility.

Steel line pipe, with its diversity of types, can accommodate any of these maintenance strategies. When cathodic corrosion protection is in place, condition monitoring can be implemented with relatively low input. Condition monitoring is increasingly establishing itself as the method of choice in industrial production facilities, due to the leeway it allows for exploiting a component's performance reserves. But condition monitoring can also be found in the private consumer sector. For example, many cars now feature brake-lining wear monitoring: if the thickness of the brake lining reaches a critical limit, an indicator on the dashboard lights up and shows that the linings must be renewed.

Condition monitoring is described in the VDI Guideline 2888 [4]. The use of this maintenance concept for buried steel pipelines has been widened thanks to the possibility of teletransmitting measured data from cathodic corrosion protection installations and processing them with specially developed software, such as WinKKS [5-7]. Without cathodic corrosion protection, steel pipe, like every other pipe material, is subject to preventive or corrective maintenance.

Corrective maintenance

Corrective maintenance was standard practice in utility companies for many years. This type of maintenance was geared to pipe materials whose mechanical and thus static properties do not change over time, irrespective of the length of the service period. These materials include ductile iron and steel as well as concrete and ceramics, which are widely used in wastewater systems. Functional impairments here are mostly attributable to outside interferences or subsidence. Pipelines in these materials are designed in such a way that their mechanical and hence their static properties do not change.

Figure 3 is an idealized plot of the service life of such pipelines. Deliberately, there are no numerical values assigned to the time axis. This is because problems can arise at the start of a pipeline's service life, e.g. due to defects in the pipe material or a lack of care in pipe laying. Once these faults have been eliminated, the pipeline can operate for a long time without problems until, depending on the frequency of

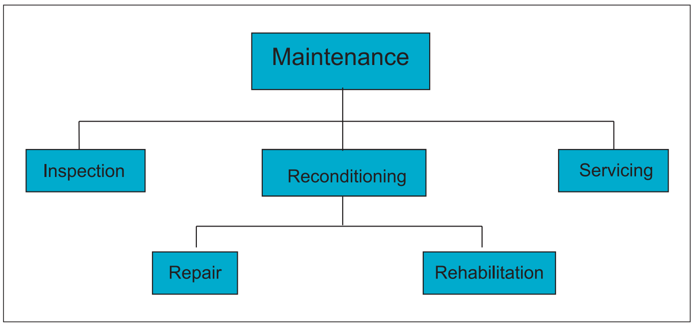

Fig. 1: Maintenance tasks required of a utility company

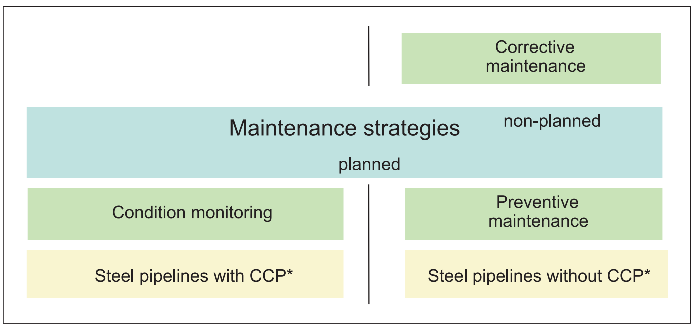

Fig. 2: Maintenance strategies

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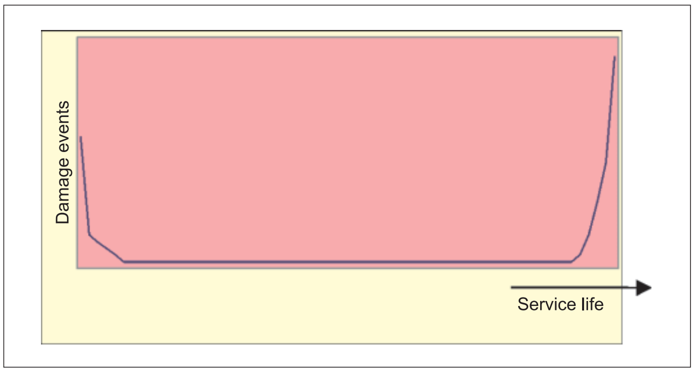


Fig. 3: Service life of pipes with stable mechanical properties

damage events, rehabilitation or even renewal is called for. The critical point here is whether a damage event is to be assessed as an isolated incident or as a sign of incipient major problems.

In the case of gas pipelines, in particular, cathodic corrosion protection was therefore employed very early, not only to supplement passive corrosion protection measures (coatings) but also for monitoring pipelines. The measured results of cathodic corrosion protection deliver the desired basis for assessing a steel pipeline's condition.

With the introduction of pipes whose mechanical properties by their very nature weaken over their service life, a completely new situation has arisen. Utility companies are now forced to consider the period for which such a pipeline is designed to function, and document painstakingly all the factors that influence its service life under operating conditions. The person responsible for operations then has to decide at some point whether a pipeline section must be replaced or can continue remain in use. While the risk involved is calculable in wastewater management and drinking water supply, a wrong decision by the operator of a gas pipeline can place human life in jeopardy. With the introduction of pipe materials that lose their strength over the course of their service life, adopting corrective maintenance as standard practice would be irresponsible, at least where gas supply pipelines are concerned. This is one of the main reasons why utility companies today build up a database for preventive maintenance.

Preventive maintenance

Preventive maintenance involves planning rehabilitation measures or renewal in good time, based on a statistical evaluation of the useful life of a pipeline. The framework for preventive maintenance for gas and water supplies is the DVGW Code of Practice G 401 and the DVGW Technical Information, Note W-401 [8, 9]. The appendices to these data sheets contain examples of service life expectations according to specific pipe types (**Figure 4** and **5**).

However, such service life assumptions can only provide a starting point for a comprehensive network analysis. The life spans covering several decades each are quoted as a function of the pipe material and design. For example, a useful life of between 80 and 120 years is anticipated for polyethylene-coated steel pipe with a top coat of fibrous cement mortar (see Figure 5).

While a pessimistic pipeline operator would renew such a pipeline after 80 years, to be on the safe side, a more optimistic one would gladly make use of a tolerance period of up to 40 years, depending on how prepared he is to take a risk. These facts show with the utmost clarity that decisions as to whether or when a pipeline needs to be rehabilitated can never be based on statistical data alone but require much more, and more specific, information. Factors such as:

- stray current effects
- the care taken during pipe laying
- soil conditions
- traffic loads
- pipe design
- activities along the pipeline route

all have an impact on the service life of a pipeline, and must be duly considered and documented for each section along the route. A minimum service life of 50 years means at least 50 years' documentation and maintenance of such data. Apart from the pipeline-specific information, other activities and measurements must also be analysed when assessing the condition of a complete pipeline or a pipeline section. These include, but are not limited to:

- turbidity measurements
- camera surveys
- damage documentation
- leakage detection, and
- loss measurements.

The data gained in this way can be processed into statistics which, in conjunction with network-specific factors, allow more accurate conclusions to be derived regarding the condition or residual service life of a pipeline. This is even considered as part of condition monitoring in some cases, an approach which, in terms of the example of the brake linings, would mean dismounting the wheels at regular intervals in order to measure the brake lining thickness. Although it makes the point clear, the comparison is lame in light of the continuous flow of data available to the pipeline operator for condition monitoring as per VDI 2888.

Damage statistics must be broken down by pipe materials and designs. Given the multiplicity of technical advances in steel pipe, it is difficult to allocate such data to a grid system that is meaningful yet not too

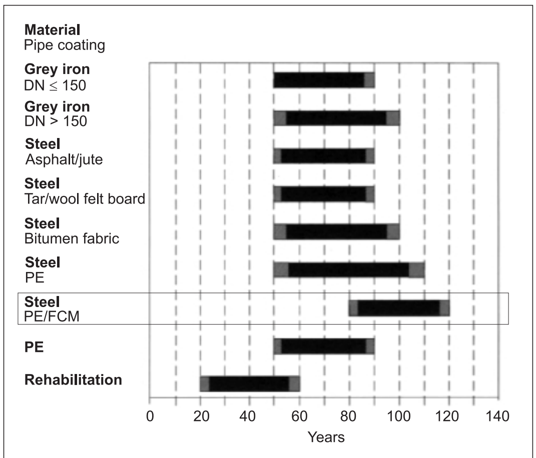


Fig. 4: Service life according to DVGW Code of Practice G 401 [8]

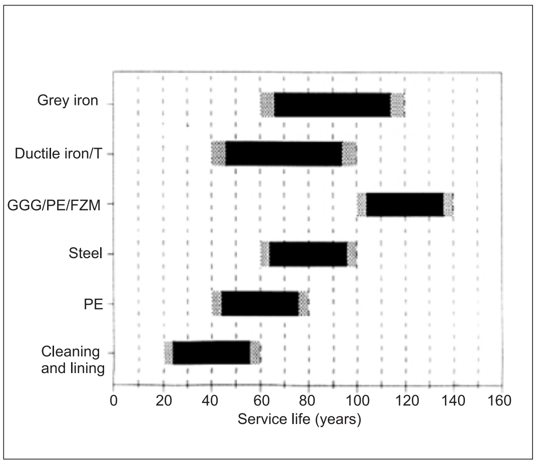


Fig. 5: Service life acc. to DVGW Note W 401 [9]

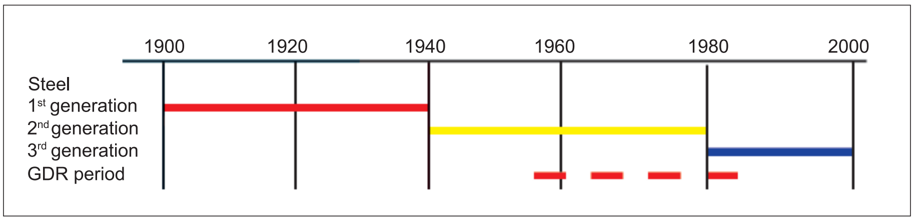


Fig. 6: Steel pipe generations according to Roscher [10]

complex. Since the service life of a pipeline made of ferrous materials is largely determined by the quality of the corrosion protection used, such a grid system should be aligned to the generational development of corrosion protection for steel pipe (**Figure 6**).

According to Roscher, service life or damage statistics of pipe networks and/or pipeline sections have to distinguish between three steel pipe generations [10]:

- **1st generation:** Pipes were coated and lined to protect them against corrosion as early as the 19th century. This does not necessarily mean that all the pipelines laid then were adequately protected for the intended application, at least not in terms of today's state of the art. It was not until the 1930s that buried pipelines were generally protected against corrosion by bitumen coatings and, particularly in water and wastewater systems, bitumen lining. Steel pipe up to 1940 therefore typifies the 1st generation of steel pipelines, i.e. inadequately – or not at all – protected against corrosion.
- **2nd generation:** Steel pipelines laid between 1940 and 1980 incorporate new developments and advances which distinguish them as the 2nd generation. The commonly used bitumen coatings had improved considerably by then, with the change from jute and corrugated cardboard wrappings to more durable fibreglass materials.
- **3rd generation:** From about 1980 onwards, high-grade polyethylene coatings were finally in general use for external corrosion protection of buried steel line pipe. Cement mortar linings were by now standard for steel pipelines transporting water and wastewater. The period after 1980 marks the 3rd and, to date, latest generation of steel pipelines for gas and water supplies.

Steel pipe laid during the GDR period is classifiable as 1st or 2nd generation, because of the partly inadequate corrosion protection.

Damage statistics from the water supply systems submitted so far do not take account of these steel pipe generations [11-13]. Such statistics, as a result, often yield a picture which is disadvantageous to steel pipe in comparison to more modern materials, such as polyethylene or ductile iron. Yet these data serve as the basis on which decisions are taken on the rehabilitation of pipeline networks in keeping with the DVGW directions Note W 401 and the DVGW Code of Practice G 401. Thus, in September 2001 at the Bregenz Pipeline Conference, Girsberger and Jaccard presented comparative damage statistics from various utility companies, which led to the expectation that the frequency of damage is significantly higher in steel pipelines than in polyethylene or ductile iron pipe (**Figure 7**). These statistics were primarily intended to document the divergences, in part very grave ones, in the data collected by the utility companies, but they also invite false conclusions from a comparison of the pipe materials.

The danger in evaluating statistics compiled in the course of rehabilitation programmes and published especially for the water-supply industry is that, apart from the above divergences in assessing damage frequency due to lack of differentiation between steel generations, false conclusions can also be drawn regarding safety-relevant properties. This holds especially in the context of the DVGW damage statistics, because it was repeatedly emphasized in the past that these were intended to provide assistance in the selection of pipe materials [11; 14].

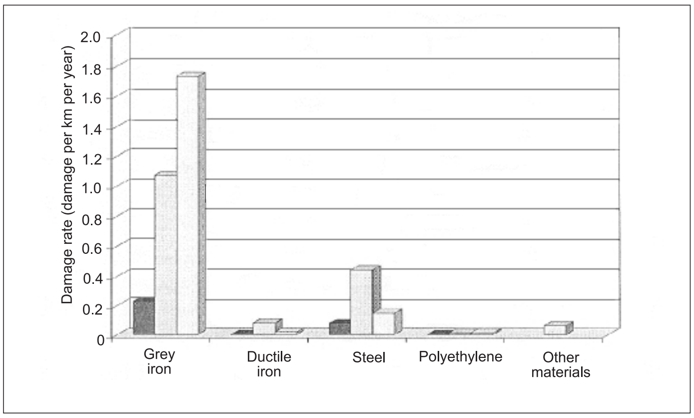
The DVGW Code of Practice G 401 defines the damage or leakage point as "a locally limited unacceptable impairment of functional efficiency – as a rule linked with a gas leak – which usually leads to immediate reconditioning by repair" [8]. Damage by third parties is excluded here, since this is irrelevant to rehabilitation measures. It is assumed that the perpetrator of such damage is usually known and is responsible for its elimination.

DVGW Code of Practice G 401 also requires that "damaged pipe coatings" and "external corrosion" be recorded in the context of a network condition analysis. This covers damage which, although affecting the steel pipe directly and exclusively, was originally caused by a third party [8]. In practice, such damage is usually discovered very late and it is close to impossible to trace it back to the responsible party. This means that pipeline operators have to allow for damage of this type in the context of pipeline rehabilitation planning.

Yet this highly differentiated recording of externally caused damage renders statistics compiled as part of rehabilitation planning in line with DVGW Code of Practice G 401 unsuitable for evaluating safety-relevant aspects in the context of materials selection, because these statistics exclude precisely those outside interferences that are essentially important from the point of view of pipeline safety. Statistics compiled from Internet-based research into gas pipeline coverage in German daily newspapers reveal that outside interference or tampering is the leading cause of damage events (**Figure 8**).

This refers not only to gas accidents but also to cases where fire services had to turn out because of gas smells or even where houses had to be evacuated. An evaluation of 89 reports on damage to gas pipelines published between June 2001 and June 2002 revealed that 63 cases were due to outside interference.

Fig. 7: Damage analysis results from diverse utilities [13] (Paper presented by Girsberger/Jaccard at the Bregenz Pipeline Conference 2001)



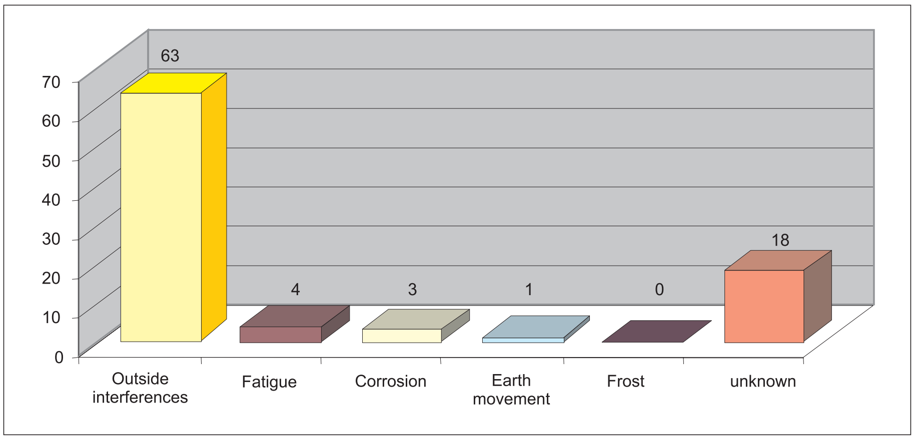


Fig. 8: Causes of damage to gas pipelines as reported in the press in the period June/2001 – June/2002

Needless to say, most of the incidents concerned pipelines made from materials with low strength reserves.

In summing up, the following statements can be made regarding the use of statistics as the basis for decisions on rehabilitation measures and thus as the basis for preventive maintenance:

1. Statistics compiled as part of rehabilitation planning provide no basis for the selection of pipe materials, because most of the types of pipe considered there are no longer produced today. They also lack information on current pipe materials and designs which is indispensable for a relevant assessment of pipeline safety.
2. Statistical pronouncements on service life will always contain a considerable element of uncertainty because of the very diverse pipe designs and stages of technological development, as well as the very different site conditions (traffic loads, care in pipe laying, soil conditions, etc.).

Service life statements are an essential prerequisite for preventive maintenance. In light of their uncertainties, however, it is condition monitoring which emerges as particularly suitable for pipeline maintenance, both for economic and safety considerations.

Condition monitoring

According to VDI 2888, condition monitoring is suitable for all production facilities which require maintenance to ensure efficient and/or safe operation. The objective of condition monitoring should be to optimise the time, quality and cost factors in the planning and implementation of maintenance.

The following advantages are mentioned:

- Wear-and-tear reserves are fully exploited
- The average maintenance-free (plant) operating time is increased
- Unnecessary repairs and dismantling of facilities are largely avoided and spare-parts inventories can be reduced
- Worn-out components can be exchanged at plannable down-times since adequate lead times can be ensured for repairs
- Awareness of the state of wear and tear contributes to operational safety and reliability
- Installed safety monitoring releases machine operators from checking work and is beneficial to safety and to the environment
- The possible quality and quantity output can be deduced from the current condition of the plant.
- The actual condition is documented by suitable instrumentation and measurement technology.

The development of cathodic corrosion protection for steel pipelines in the 1950s provided an important tool for condition monitoring of buried pipelines. Thanks to cathodic corrosion protection, it is possible to monitor pipelines and pipeline networks and precisely locate defects. Since cathodic corrosion protection is an independent anti-corrosion measure, repair work or even rehabilitation projects can be planned well ahead in the event of local damage. The combination of CCP and welded steel pipelines has gained acceptance above all for safety-relevant facilities, such as pipelines for transporting media which are flammable or hazardous to groundwater, but also for water and wastewater transportation. These advantages are fully exploited in the case of the welded-steel pipelines of our cities' gas-supply networks. Their condition can now be constantly monitored and recorded thanks to new developments, particularly in data communication.

The possibility of measuring, recording and evaluating above ground the condition of a buried pipeline or a complete network provides considerable benefits in terms of operational safety but also from an economic point of view. With cathodic corrosion protection, it is now possible to precisely assess the condition of a pipeline, independent of its design service life (**Figure 9**). The economic advantages follow as a matter of fact, because performance reserves can be fully exploited and a high pipeline utilization rate attained. The expenditure for installing and operating cathodic corrosion protection is insignificant in relation to the total outlay for a pipeline.

Conclusion

This contribution has looked into the spectrum of maintenance concepts for pipelines currently in use. At present, steel pipe alone is suited to all of these approaches. With a view to pipe materials with a limited useful life, discussions today focus on the change from corrective to preventive maintenance strategies. For preventive maintenance, assured and thus transferable statistical data in line with DVGW directions Note 401 and the DVGW Code of Practice G 401 are indispensable. There are many and varied network-specific parameters, such as the varying care taken in pipe laying, different soil conditions, or traffic loads, which generate inaccuracies. These should not be underestimated

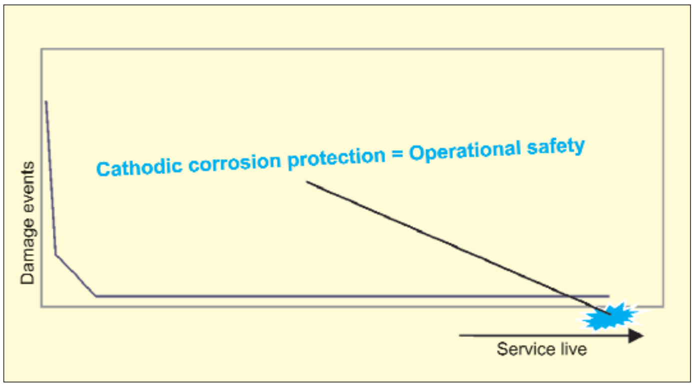


Fig. 9: Service life of a steel pipeline with cathodic corrosion protection

when considering statistical pronouncements on the length of a pipeline's service life. Even the approach of basing materials selection on these damage statistics, which has been frequently proposed in the past, is not viable. These data refer to long-since obsolete technologies, yet fail altogether to differentiate between old and new methods and materials where safety-relevant aspects are concerned.

For economic reasons, industrial practice today relies increasingly on condition monitoring. With steel pipe, in contrast to all other pipe materials, condition monitoring is feasible and is currently practiced via cathodic corrosion production installations. In light of the drop in capacities available to utility companies for the increasingly important surveillance of construction sites, a meaningful instrument such as cathodic corrosion protection is indispensable for quality assurance in the construction of pipelines.

The advantages of cathodic corrosion protection can be summarized as follows:

- quality assurance in pipeline construction
- operational safety through constantly available measured data
- monitoring third-party activities in the area of the pipeline route
- defect localization
- long-term planning of repair measures
- logging of the condition of individual pipelines and complete networks

Considering the decisive technical and economic advantages of condition monitoring, utility companies with cathodic protection installations already in place for their steel pipelines must be urgently advised to further develop and extend them. The higher material and pipe-laying expenditure for welded steel pipe in combination with cathodic corrosion protection is more than offset by the substantial technical benefits and cost savings attainable throughout the pipeline's service life.

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