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CCP-supported condition-oriented maintenance of gas distribution systems

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Abstract

A central component of a condition-orientated maintenance for steel pipes is the cathodic corrosion protection (CP). The aim of CP supported condition orientated maintenance is to optimize maintenance activities in accordance to quality aspects and expense. The strategy is based on constant monitoring of the network or system state by appropriate sensors. A remote monitored Cathodic corrosion protection systems helps to answer the question "What has to be done when, where, to monitor how and with what?"

Corrosion damage is generally caused due to lack of care when installing or external influences during operation. Since the corrosion of steel based on electrochemical processes, these types of injury are specifically monitored and influenced from a central position/system. In addition an evaluation and precise localization of the defects of buried pipelines and of the pipe network without excavations are possible. Suitable measurement methods are described in national and international standards and in technical literature.

These forms of maintenance are characterized by the fact that in case of contingency measures, there is yet more or less life reserve. In the case of condition orientated maintenance by CP this life reserve is limited to the technically necessary and is therefore necessarily being classified as more economic than a preventive maintenance approach. It will be illustrated how to realize in practice condition orientated maintenance of gas distribution systems supported by cathodic corrosion protection systems (CP) and give an example respectively a guideline of use.

Zusammenfassung

Ein zentraler Bestandteil einer zustandsorientierten Wartung von Stahlrohren ist der kathodische Korrosionsschutz (KKS). Das Ziel der durch KKS unterstützten zustandsorientierten Wartung ist, die Wartungstätigkeiten im Einklang mit Qualitätsaspekten und Kosten zu optimieren. Die Strategie beruht auf einer ständigen Beobachtung des Netz- oder Systemzustands durch geeignete Sensoren. Ein fernüberwachtes kathodisches Korrosionsschutzsystem hilft, die Frage zu beantworten: „Was muss wann und wo getan werden; wie und womit ist zu überwachen?"

Korrosionsschäden werden im Allgemeinen durch mangelnde Sorgfalt bei der Montage oder durch äußere Einflüsse während des Betriebs verursacht. Da die Korrosion von Stahl auf elektrochemischen Prozessen beruht, werden diese Arten von Schäden spezifisch überwacht und von einem zentralen System beeinflusst. Außerdem ist eine Beurteilung und genaue Lokalisierung von Defekten an unterirdischen Rohrleitungen und am Rohrleitungsnetz möglich, ohne zu graben. Nationale und internationale Normen und die technische Literatur beschreiben geeignete Messmethoden.

Diese Formen der Wartung sind dadurch gekennzeichnet, dass bei Notmaßnahmen noch mehr oder weniger Haltbarkeitsreserve vorhanden ist. Im Falle der zustandsorientierten Wartung durch KKS ist diese Reserve auf das technisch Notwendige beschränkt. Sie wird deshalb notwendigerweise als wirtschaftlicher angesehen als ein vorbeugender Wartungsansatz. Es wird gezeigt, wie eine zustandsorientierte Wartung von Gasversorgungssystemen, unterstützt durch kathodische Korrosionsschutzsysteme (KKS), umgesetzt werden kann. Außerdem werden ein Beispiel und ein Anwendungsleitfaden vorgestellt.

Résumé

Un composant central de la maintenance orientée selon l'état des tuyaux en acier est la protection cathodique (PC) contre la corrosion. L'objectif de la maintenance orientée selon l'état équipée de PC est d'optimiser les activités de maintenance en fonction du coût et d'aspects qualitatifs. La stratégie est basée sur une surveillance constante de l'état du réseau ou du système par des capteurs appropriés. Un système de protection cathodique contre la corrosion surveillé à distance aide à répondre à la question : « Que faut-il faire, quand et où pour surveiller comment et avec quoi ? ».

Les dommages dus à la corrosion sont généralement causés par un manque de soin à l'installation ou par des influences externes durant l'exploitation. La corrosion de l'acier étant basée sur des processus électrochimiques, ces types de dégâts sont spécifiquement surveillés et influencés à partir d'un lieu/système central. De plus, il est possible d'évaluer et de localiser précisément les défauts de canalisations enterrées et/ou du réseau de tuyauterie sans excavations. Des méthodes de mesure adaptées sont décrites dans des normes nationales et internationales ainsi que dans la littérature technique.

Ces formes de maintenance sont caractérisées par le fait que, dans le cas de mesures d'urgence, il subsiste plus ou moins de durée de vie en réserve. Dans le cas d'une maintenance orientée selon l'état via protection cathodique, cette réserve est limitée à ce qui est nécessaire techniquement, ce qui la classifie par conséquent nécessairement comme une approche davantage économique que de maintenance préventive. Nous illustrerons comment réaliser en pratique la maintenance orientée selon l'état de systèmes de distribution de gaz équipés de systèmes de protection cathodique contre la corrosion (PC) et nous fournirons respectivement un exemple et une directive d'utilisation.

Introduction

The objective of condition-oriented maintenance is to plan and carry out maintenance measures which have, based on the systems' conditions, been recognised as necessary at the optimum time, quality and costs. The strategy is based on the constant monitoring of the network or system condition by means of suitable sensor technology. In the case of gas distribution systems, the question "What has to be monitored when, where, how and with what?“ can be solved by cathodic corrosion protection.

In Germany the DVGW Code of Practice G 402 (draft) "Network and damage statistics – Recording and analysis of data for the development of maintenance strategies for gas distribution systems" [1] forms the basis for the development and application of condition-oriented maintenance of gas distribution systems.

Maintenance strategy

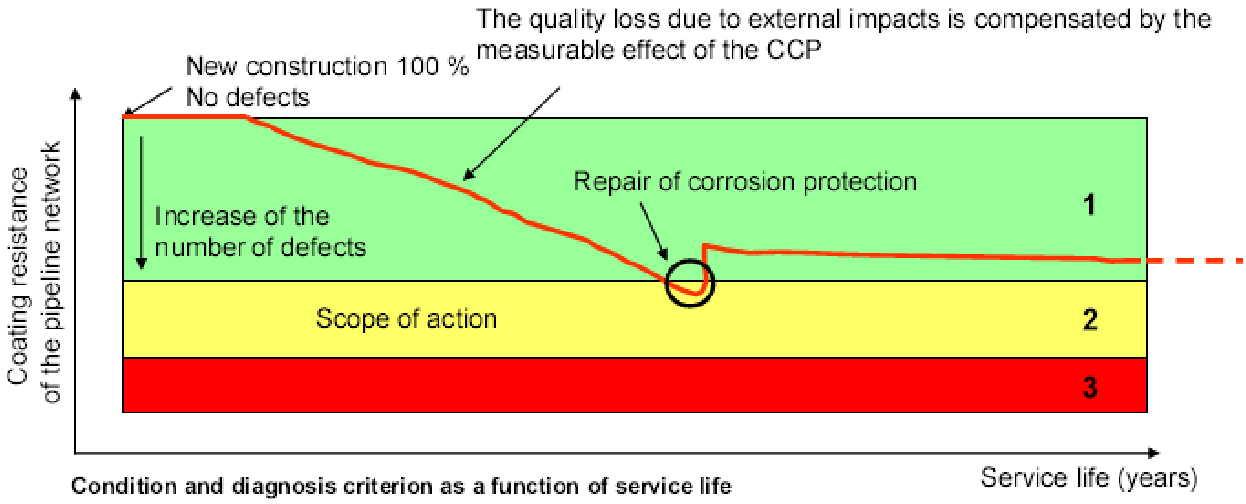
There are three basic types of maintenance strategies. Concepts permitting scheduling include condition-oriented and preventive maintenance. These types of maintenance are characterised by the fact that if equipment needs to be replaced, there is as a rule still a more or less extensive service life reserve left. In case of condition-oriented maintenance, this service life reserve is restricted to the technically necessary extent and must therefore necessarily be rated as more cost-effective than is the case with a preventive maintenance concept.

A type of maintenance that cannot be scheduled is the event-oriented maintenance, where one waits for failures or malfunctions requiring maintenance measures to occur. For gas pipe systems, which must guarantee a high level of safety, event-oriented maintenance is not a sensible strategy.

CCP-supported condition-oriented maintenance

Central component of condition-oriented maintenance of steel pipes is the cathodic corrosion protection (CCP). Corrosion damage can usually be ascribed to a lack of diligence during pipeline laying or external impacts during operation. As the corrosion of steel is based on electro-chemical processes, this type of damage can be purposefully monitored and influenced from a central position. In addition, the localisation of defects with utmost precision and thus the assessment of the soil-covered pipeline network are possible without excavation. Suitable measurement methods are listed in EN 13509 [2] and described as well as in the technical literature.

Conceptually, steel pipe designs in combination with cathodic corrosion protection that are in common use today, are designed for a service life far in excess of 100 years. The phases during the operation of steel pipelines to be taken into consideration are depicted in Figure 1.



1. Technically negligible material abrasion <10 µm/a
2. Critical phase, increasing material abrasion >10 µm/a.
   Scope of action for corrective maintenance at the optimum time, quality and cost
3. Occurrence of damage

Figure 1: Condition and diagnosis criterion as a function of service life

An essential requirement for a safe operation of the pipeline network during phases 1 and 2 is the combination of effective passive and active protective measures. Within the limits of phase 1, the pipeline operating company can concentrate on its scheduled tasks. During phase 1, damage events range at a minimum level. Operational experience shows that the coating resistance of a pipeline network reduces in the course of time due to an increase in coating defects caused by external impacts. By measuring the CCP it is possible to monitor if and when the quality of corrosion protection drops into phase 2 (warning limit). During phase 2, an assessment of the pipeline sections is carried out in cooperation between network operating company and CCP experts and priorities for the required maintenance measures are defined. As a rule, pipelines that are subject to such condition-oriented maintenance do not reach phase 3.

Phase 3 is reserved for networks with no or only insufficient cathodic protection. As soon as corrosion damage has occurred in a pipeline network, it must be assigned to phase 3 until the actual reason has been determined. In case of damage due to a lack of diligence during laying, further defects may be expected. Here, depending on the soil's corrosiveness or even external current influences, defective areas are subject to metal abrasion which may sooner or later cause leaks. Such pipeline sections necessarily must continue to be assigned to phase 3. Damage which can demonstrably be ascribed to later excavations are usually of a local nature, limited as to their extent and require repair. After a corresponding inspection, such a network section can possibly be returned to phase 2 or 1.

Preventive maintenance concept

From today's point of view, a lacking cathodic corrosion protection in a pipeline network does not necessarily lead to deterioration into phase 3. Within the scope of the systematic assessment of the pipeline networks, the pipeline condition should be recorded, thus implementing a preventive maintenance concept. In case of networks without cathodic protection, the coating resistance criterion is lacking for phase 2. However, in this case it is possible to determine a reaction time by assessing the pipeline condition (corrosion abrasion, condition of the coating, environmental conditions, etc.) and with that the usually existing wall thickness reserve, and to thus implement rehabilitation planning in terms of a preventive maintenance concept.

Such condition assessments can be carried out at exposed pipeline sections while pipeline integration or relaying operations or the establishment of service connections are under way. However, as this method does not necessarily record the condition of the entire network, an uncertainty in the assessment of a distribution network remains. Such a network will thus within certain limits necessarily be operated in an event-oriented manner. However, it is basically possible even for pipeline sections that have already reached phase 3 to be returned to phase 1 by means of cathodic corrosion protection and corresponding purposeful repairs. Experience shows that the retrofitting of CCP in existing gas distribution systems can be implemented in a cost-effective manner.

Assessment of the pipeline condition by CCP

The assessment basis for condition-oriented maintenance results from the mode of operation of cathodic corrosion protection. The signal light model acc. to Figure 1 on which the assessment is based explains and substantiates the current density potential curve of steel in vented and unvented soils (Fig. 2).

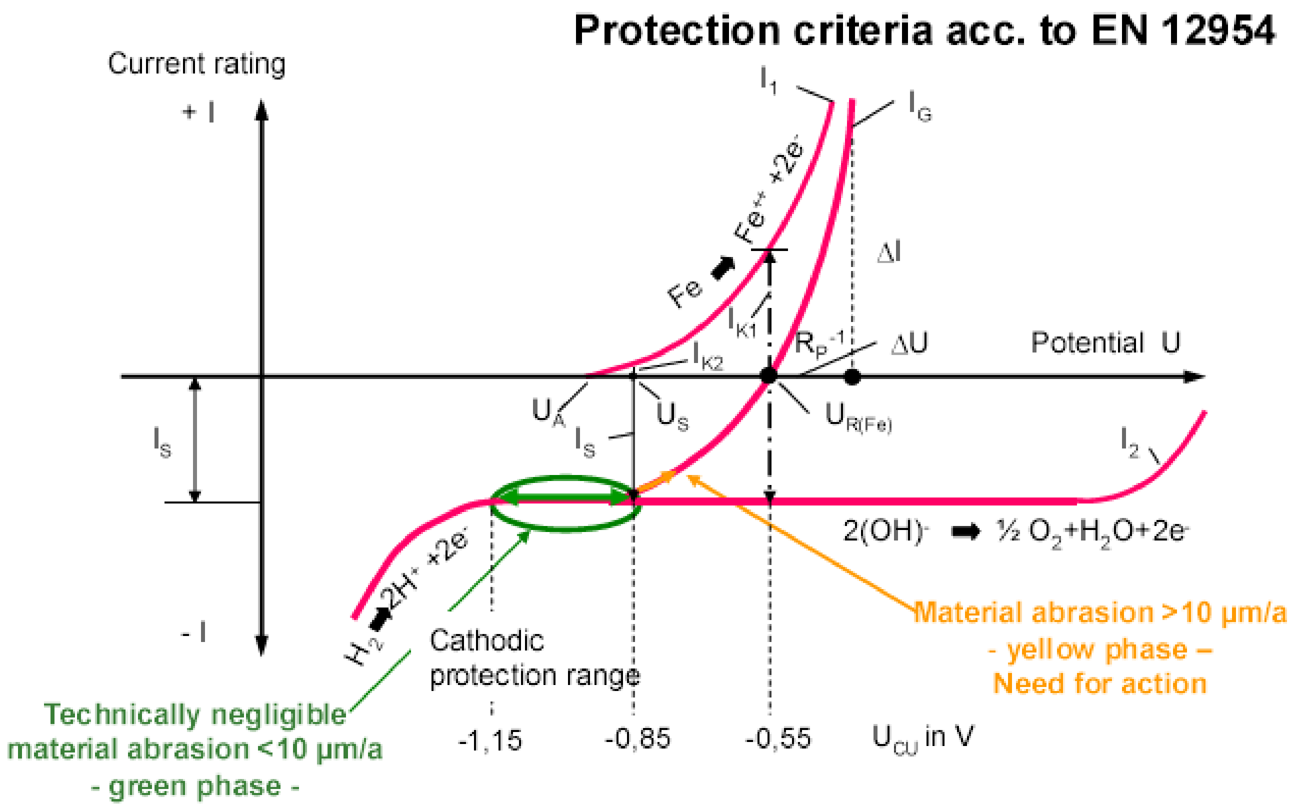


Figure 2: Current density potential curve of steel in vented and unvented soils

The green area of the signal light model (phase 1) characterises the protection range for cathodic corrosion protection, which in vented soils ranges between -0.85 V and -1.15 V (measured against the copper sulphate electrode; Cu/CuSO4). By means of the measurements according to EN 13509 [2], the effectiveness or quality of CCP can be monitored and the reaching of the yellow range (phase 2) detected. From this point in time, the protective effect of the CCP is no longer sufficient, consequently there is need for action as far as the planning and implementation of maintenance measures is concerned.

CCP-supported maintenance process

A compulsory requirement for "condition-oriented maintenance" is the availability of readily retrievable measuring data providing information about a component's condition. On the basis of these measuring data, failures and damages are recognised in good time, thus ensuring an optimum network operation. In case of prompt indication, it may also be possible to determine the reasons for or originators of damages, for example in the case of external influences. Figure 3 depicts the progression of the CCP-supported maintenance process.

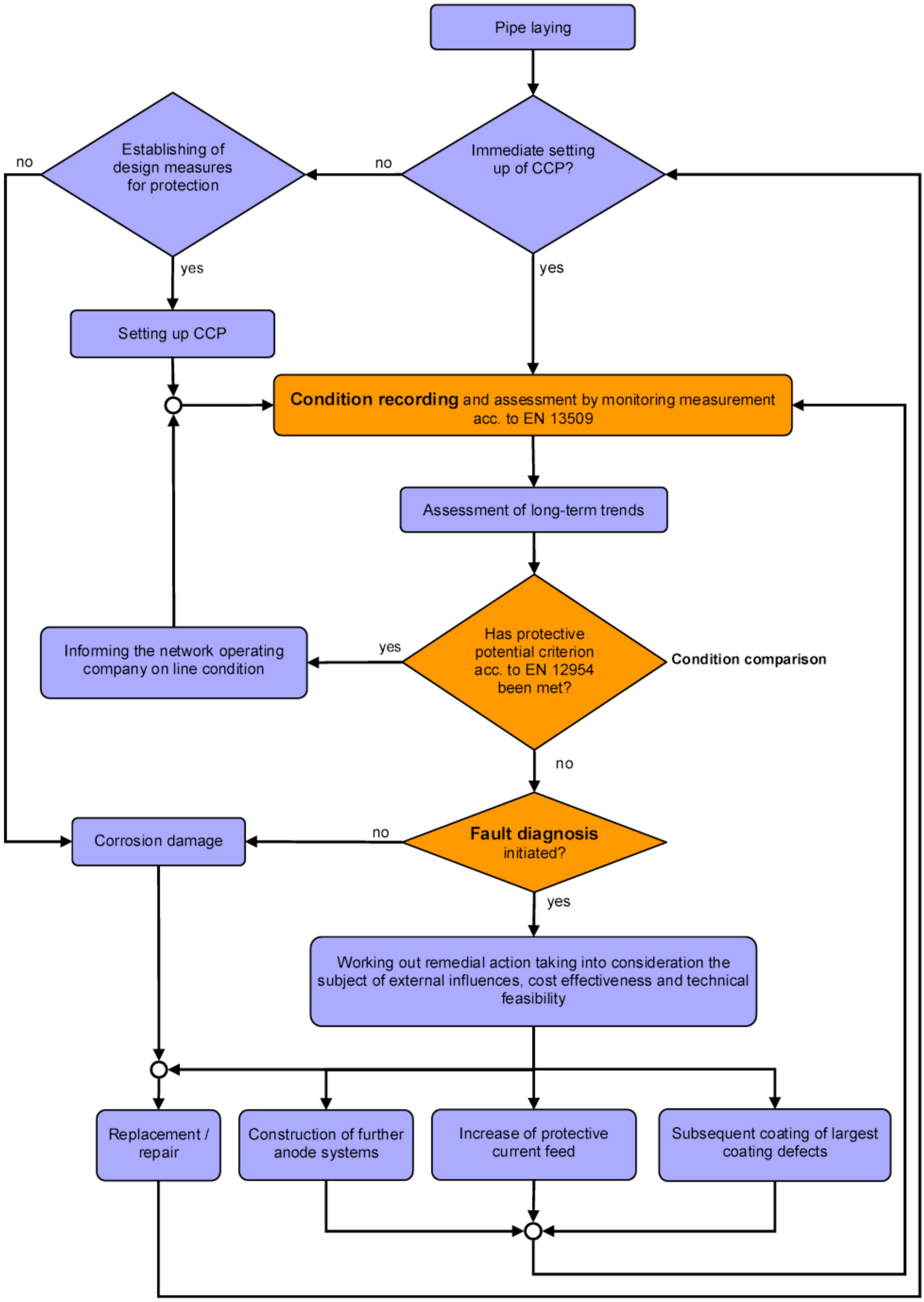


Figure 3: CCP-supported maintenance process

Condition monitoring is made up of the sub-steps condition recording, condition comparison and diagnosis.

Condition recording

Condition recording takes place via the measurement and documentation of parameters in connection with corrosion protection mirroring the current state of the pipelines. Based on the structure described in DVGW Code of Practice G 412 [3] (Fig. 4), the implementation of a condition-oriented maintenance concept involves comparatively little expenditure as the required measuring data are already available due to the monitoring measurements required according to EN 13509 [2].

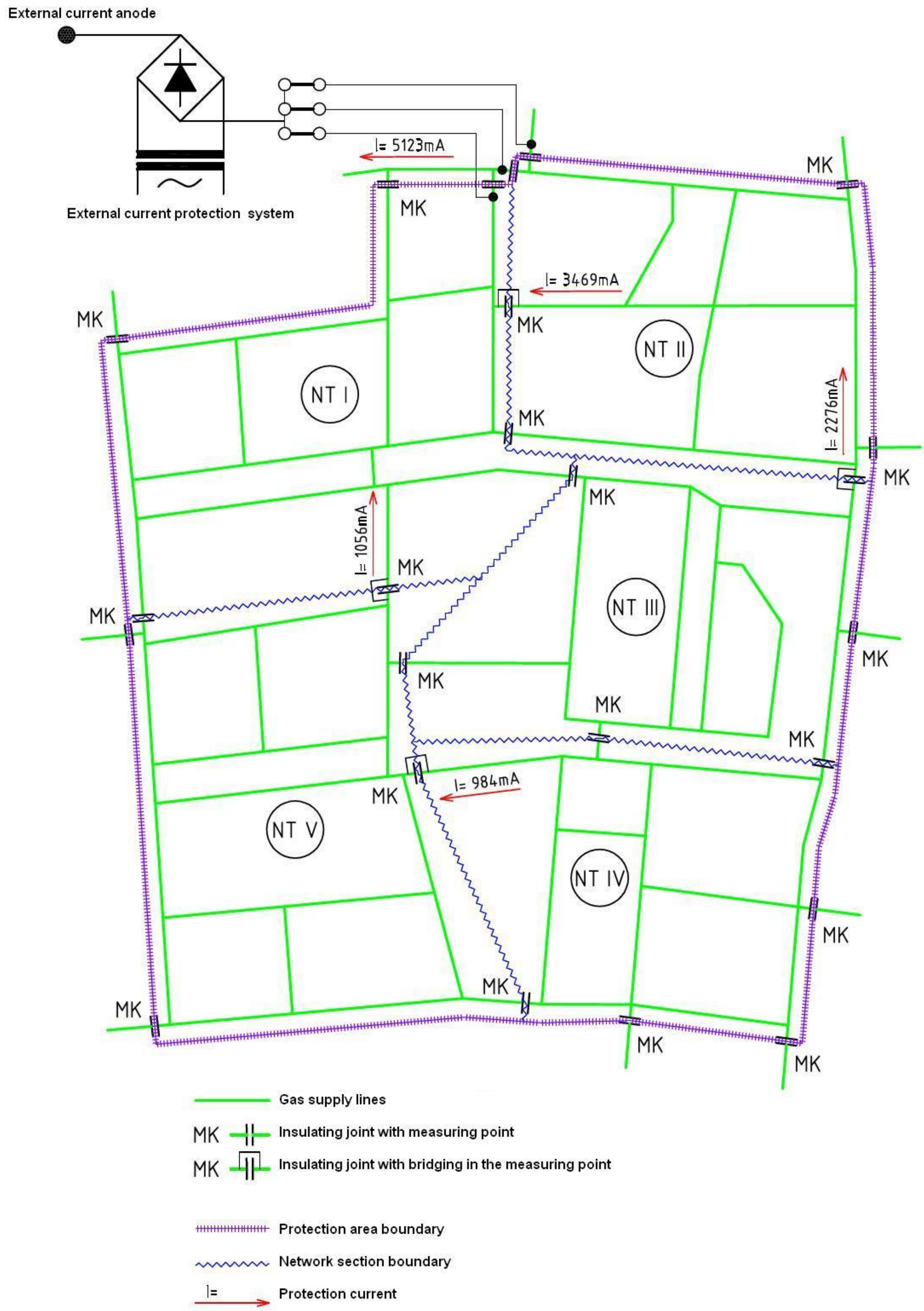


Figure 4: Schematic representation of a protection area inside a gas distribution system

Condition comparison

The condition comparison constitutes a comparison of the as-is state with a specified reference value. When cathodic corrosion protection is applied, this reference value is the limit of the protective potential criterion according to EN 12954 [4], which in vented soils amounts to -850 mV (measured against the copper sulphate electrode). Condition recording and condition comparison essentially correspond to the inspection according to EN 13306 [5].

Diagnosis

The diagnosis serves to locate any possible faults as early as possible on the basis of the results of the condition comparison and if necessary, to determine their cause(s) so as to be able to plan and implement necessary maintenance measures in an optimum manner (time, quality, costs).

Rehabilitation planning on the basis of CCP data

The following aims at explaining the question as to how a condition assessment is performed on the basis of the measuring method of cathodic corrosion protection and how as a result the correct time for upcoming replacement, repair and rehabilitation measures can be determined.

Measurement-based condition assessment

So as to keep the scope of the measurement-based condition assessment as narrow as possible and the acceptance for ongoing maintenance as high as possible, only the protective potential criterion according to EN 12954 [4] and the average protective current density are drawn on for the assessment. At the same time, the recording of measuring data does not require any additional expenditure as these are already available from the monitoring measurements according to EN 13509 [2].

The assessment systematics presupposes the establishment of electrically delimited protection areas according to DVGW Code of Practice G 412 [10] (Fig. 4) [3]. The development of a measurement-based condition assessment merely requires the following inventory and condition data:

- On-, off-potential and protective current consumption according to EN 13509 [2]
- Length and surface of the pipelines (inventory data from the GIS).

The mobily recorded measuring data according to EN 13509 [2] and the inventory data from the GIS are saved in a spread sheet application or database. Subsequently, the corrosion protection parameters "average protective current density" and "specific coating resistance" are calculated from these (table 1).

Pipeline	Eon [mV]	Eoff [mV]	Ip [mA]	Line length [m]	Sur-face [m^2]	Commis-sioning of pipeline	CCP since	Ka [%]	ip [µA/m^2]	rco [k□m^2]	Protection criterion met(y/n)	Coeffi-cient	Condition rating (1 - 5)
SB 77 NT I	-1360	-940	598	3666	1431	1954-2001	1989	58	418	1,01	**Yes**	42	3
SB 77 NT II	-1280	-860	1.193	3601	1501	1952-1999	1989	41	795	0,53	**Yes**	79	4
SB 77 NT III	-1350	-780	2.276	2998	2551	1969-2009	1971	83	892	0,64	**No**	114	5
SB 77 NT IV	-1260	-920	984	3755	1972	1954-1999	2005	27	499	0,68	**Yes**	50	3
SB 77 NT V	-1260	-860	72	2431	988	1954-1999	2001	82	73	5,49	**Yes**	7	1

Explanation of table and rating example

Pipeline:	Cathodically protected network section
Eon:	On-potential
Eoff:	Off-potential
Ip:	Protective current consumption
Line length:	Cathodically protected line section
Surface:	Surface of pipelines as a function of dimension and cathodically protected line length
Commissioning of pipeline:	Year of commissioning of the oldest and youngest line section
CCP since:	Year of commissioning of the cathodic corrosion protection in the network section concerned
Ka:	Percentage portion of pipe coating made of plastic in the network section concerned
ip:	Average protective current density
rco:	Specific coating resistance
Protection criterion met:	Protection criterion for the CCP of non-alloy and low-alloy ferrous materials, e.g. -850 mV "yes" => 0 points "no" => 25 points
Coefficient:	The coefficient results from the sum of the points of the parameters "Protection criterion" and the average protective current density "Ip". The number of points of the average protective current density in µA/m^2 results from multiplication of the value with 0.1. The result is shown as integer without unit (at least 1 point).
Condition rating:	School grade 1 - 5 depending on the coefficient: Grade 1 => coefficient 1 - 7 Grade 2 => coefficient 8 - 24 Grade 3 => coefficient 25 - 60 Grade 4 => coefficient 61 - 100 Grade 5 => coefficient > 100
Example:	ip amounts to 14 µA/m^2 => 1 point Protection criterion "no" => 25 points Coefficient = 26 => grade 3

Table 1: Measurement-based condition assessment

The results are transferred into a coefficient system and rated with grades ranging from 1-5. Additional information, such as the dates the pipelines were commissioned, the year the CCP was commissioned and the percentage portion of pipelines with bitumen and plastic coating (Ka), increase the significance of the resulting assessments. The complete layout including all coefficients as well as the determination of the school grade system is also explained in table 1.

Prioritisation and rehabilitation

The grades ensuing from the condition assessment directly result in the required work sequence. If several network sections are rated with the same grade, the coefficient must also be drawn on for the purpose of prioritisation. The pipeline sections to be rehabilitated are determined by means of measurements according to EN 13509 [2], e.g. by means of intensive measurement technique IFO[1] (Fig. 5).

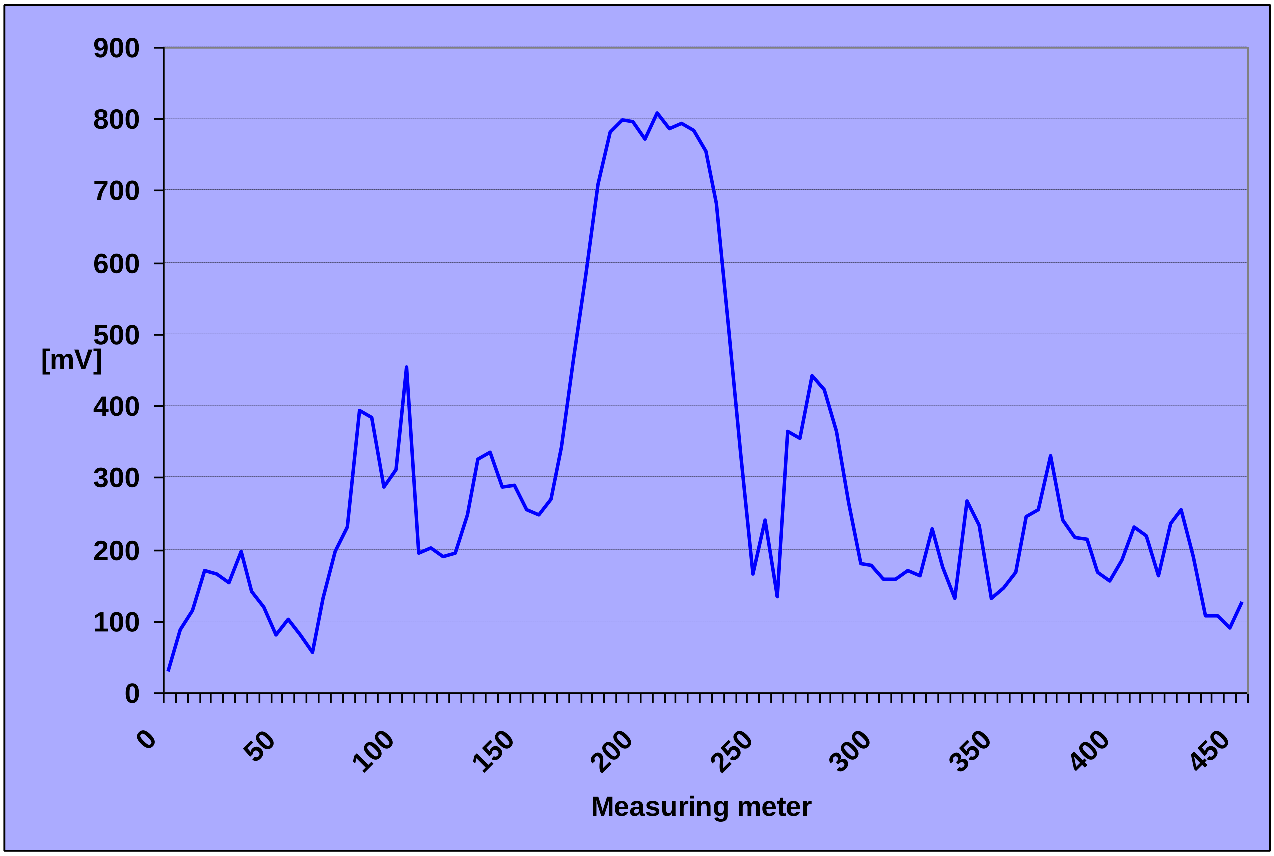


Figure 5: IFO measurement diagram

Assessment of the individual pipeline sections is performed on the basis of these measurements. Pipeline sections which do not meet the protective potential criterion according to EN 12954 [4], or pipeline sections causing an undue influencing of other objects must be rehabilitated in the short to medium-term.

[1] IFO = German acronym for "intensive Fehlstellenortung" ≈ Intensive defect location

Further initiating projects for repair and rehabilitation

This type of rehabilitation of pipeline sections comprises the coordination of rehabilitation measures with other initiating projects. In cooperation with the planning divisions and responsible building and construction departments, road construction projects, track construction projects, underground construction measures or new installation measures of other branches such as water, power or district heating can be used to rehabilitate pipeline sections concerned cost-effectively and thus economically.

To ensure a professional and target-oriented approach, it is first of all necessary to identify the pipeline sections which are located in the project area concerned.

It can be assumed that the damage frequency of pipeline sections which were cathodically protected since their installation tends towards zero. In these cases there is no need for action with regard to rehabilitation measures. In other cases, where pipeline sections were only cathodically protected several years after their installation, the assessment is performed on the basis of the measurements according to EN 13509 [2]. As additional decision criterion, long-term damages which have occurred still more recently should be taken into consideration. The development of long-term damages can be traced back to the period during which the pipeline section was not yet integrated in the CCP. If a need for action arises from this, a decision as to bringing the repair and rehabilitation measures forward must be taken.

Example of CCP-based rehabilitation planning

In the present example of a gas distribution system, the grade "5" for network section III ensues on the basis of the measurements (Table 2).

Pipeline	Eon [mV]	Eoff [mV]	Ip [mA]	Line length [m]	Sur-face [m²]	Commis-sioning of pipeline	CCP since	Ka [%]	Jp [µA/m²]	rco [kΩm²]	Protection criterion met (y/n)	Coeffi-cient	Condition rating (1 - 5)
SB 77 NT III	-1350	-780	2.276	2998	2551	1969-2009	1971	83	892	0,64	**No**	114	5

Table 2: Measurement-based condition assessment prior to rehabilitation

Analysis of the IFO measurements (Fig. 6) shows that the coating on a 400 m long pipeline section is no longer able to meet the requirements to achieve an adequate electric barrier effect (Fig. 7).

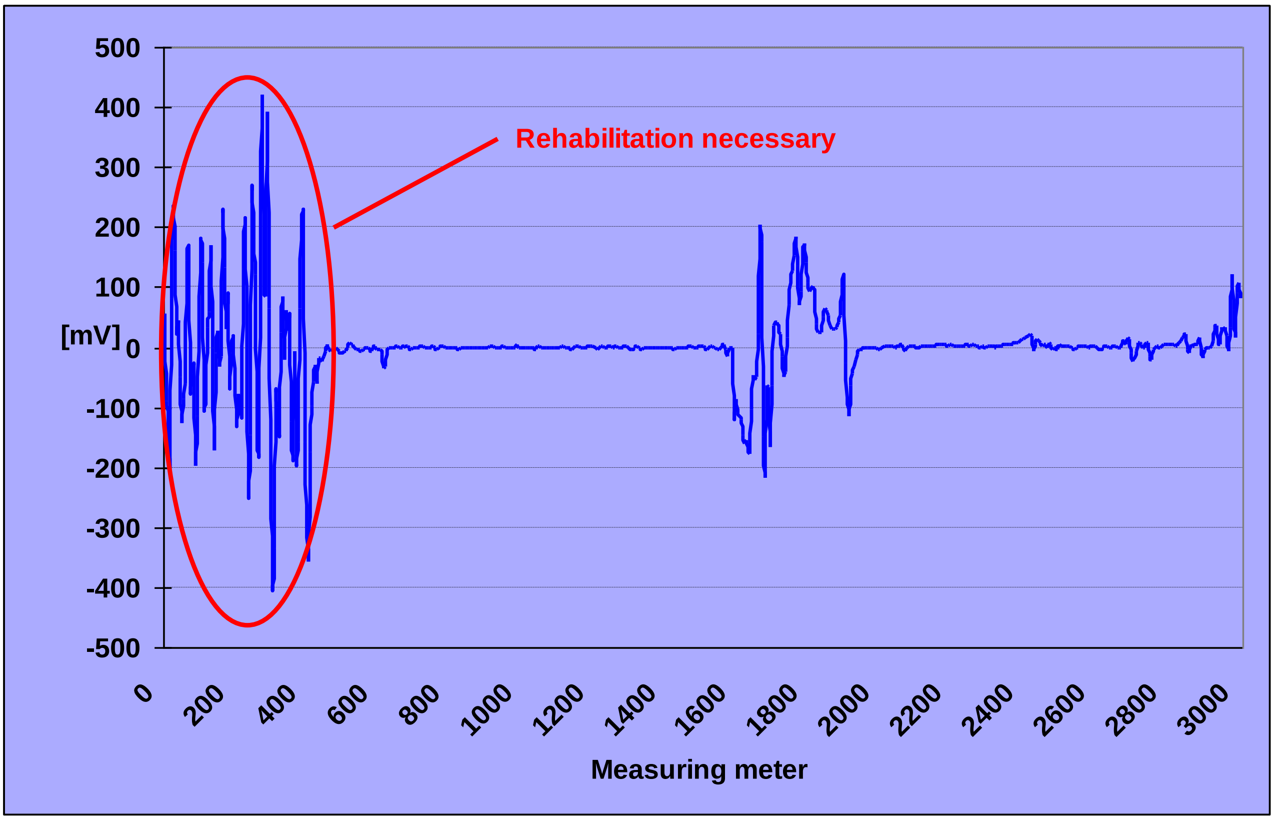


Figure 6: IFO measurement diagram prior to rehabilitation

Figure 7: Desolate condition of pipe coating

This section was repaired on the basis of the condition assessment, after an adequate consideration of the options of a construction site repair of the corrosion protection versus the complete replacement of the pipeline section. Decisive for this decision was on the one hand an undue influencing of an external metal line combined with the inadequate protective potential and on the other hand the line condition found (Fig. 7).

The control measurement after the implementation of the rehabilitation measures shows the reduced protective current requirement (table 3). The protective potential criterion according to EN 12954 [4] has been met and as a result, the grading changes.

Pipeline	Eon [mV]	Eoff [mV]	Ip [mA]	Line length [m]	Sur-face [m²]	Commis-sioning of pipeline	CCP since	Ka [%]	Jp [µA/m²]	rco [kΩm²]	Protection criterion met (y/n)	Coeffi-cient	Condition rating (1 - 5)
SB 77 NT III	-1350	-780	2.276	2998	2551	1969-2009	1971	83	892	0,64	**No**	114	5

Table 3: Measurement-based condition assessment after rehabilitation Conclusion

In the past, the outstanding importance of cathodic corrosion protection for repair and rehabilitation planning in the public utility industry went almost unnoticed. This becomes particularly clear by the fact that strategic documents rarely mention cathodic corrosion protection.

The actual significance of cathodic corrosion protection in rehabilitation planning is mirrored by today's revised technical rules or draft technical rules. The possibilities offered by cathodic corrosion protection for condition-oriented maintenance are not merely wishful thinking, but are put to good use in practical applications. Cathodic corrosion protection data can be processed in such a manner that even persons who are not familiar with the matter will understand them and thus be able to take into consideration the findings especially in medium and long-term strategic planning for pipeline networks.

The decision for or against the application of cathodic corrosion protection should no longer be taken solely on the basis of the necessity described in the technical rules for the construction of pipelines. Taking into consideration the advantages for long-term planning and maintenance of pipelines and pipeline networks yields completely new factors for decision making. With a view to today's extended measurement and assessment possibilities and based on the fact that the data of the object to be protected are readily accessible, CCP in principle forms the basis of any adequate pipeline management system.

The advantages are by no means only accessible for networks which have grown along with this technology over the decades. Especially for distribution networks which are maintained without cathodic corrosion protection, usually on the basis of statistical data, a high level of planning reliability comes within reach with the retrofitting of CCP. Looked at from an economic point of view, this planning reliability offers a wide basis for generating savings potentials during network operation. Thus, based on measurement-based condition assessment, the measuring methods of cathodic corrosion protection ensure that only such parts of the system are being rehabilitated which do in fact require rehabilitation. Service life reserves can be optimally exploited, which is an important advantage especially in view of the increasing cost pressure arising in the course of the regulation of gas networks. The systematics of measurement-based condition assessment introduced in this article is in particular characterised by the fact that only few, but comprehensively meaningful parameters are required. This again provides for a correspondingly low expenditure and large degree of acceptance in network operation. Thus, a coherent and consistent, effective and efficient course of action for rehabilitation planning based on the revised guidelines is available for cathodically protected steel networks.

Literature:

[1] DVGW G 402 *Network and damage statistics - Recording and analysis of data for the development of maintenance strategies for gas distribution networks*

[2] EN 13509 *Cathodic protection measurement techniques*

[3] DVGW G 412 *Cathodic corrosion protection (CCP) of buried gas distribution networks and gas distribution pipelines*

[4] EN 12954 *Cathodic protection of buried or immersed metallic structures - General principles and application for pipelines*

[5] EN 13306 *Maintenance - Maintenance terminology*