Experience and solutions for the installation of spark gaps for use in potentially explosive atmospheres to protect insulating pieces / joints against damages in case of overvoltages due to lightning according to AfK recommendation No. 5

Abstract

Insulating pieces / joints are used to electrically isolate pipeline systems or to divide high-voltage-interfered pipelines into sections. Cathodically protected systems are electrically isolated until the dielectric strength of the insulating piece is reached. Surges caused by a lightning strike, into exposed parts of a pipeline system, may lead to the dielectric strength of insulating pieces / joints being exceeded. As a result, sparking may occur or the insulating piece may be destroyed.

The function of isolating spark gaps for use in potentially explosive atmospheres (ExFS) and their connection elements is to protect the insulating piece (insulation) against lightning-induced surges and to discharge the lightning energy in a hazardous potentially explosive atmosphere without sparking. During normal operation and after the discharge process, the ExFS is supposed to ensure safe electrical isolation. Based on practical experience, AfK recommendation No. 5 (1986 edition) **[1]** was adapted to the latest lightning current parameters according to EN 62305 **[2]**. The new version, which includes the inspection of ExFS and notes on the selection of ExFS and adequate connection elements, is described below.

1. Field of application of AfK recommendation No. 5 [3]

This document describes measures to prevent ignition-related hazards to insulating pieces / joints and to ensure cathodic corrosion protection in potentially explosive atmospheres. The recommendation applies to stations of natural gas pipeline systems and – under consideration of the relevant regulations valid in the country of installation – also to other product pipelines.

In these systems, insulated couplings or insulating flanges can be used as insulating pieces / joints.

Other protection measures may be taken when transporting or handling hazardous liquids in harbours and waterways.

Protection measures against other risks such as discharging injected alternating currents or protection measures against electric shock are described in EN 50443 [4].

2. Necessity of ExFs

For explosion protection reasons, the primary goal in potentially explosive atmospheres is to avoid sources of ignitions (e.g uncontrolled spark-over on insulating pieces / joints).

ExFS do not have to be used outside of potentially explosive atmospheres (e.g. in case of buried insulating pieces / joints), however, faulty insulating pieces / joints basically interfere with cathodic corrosion protection. If pipelines are interfered by external voltage, shock protection is no longer provided. Faulty insulating pieces / joints must therefore be replaced. This involves high repair costs and considerably affects system availability. For these reasons, it may be useful to install ExFS and adequate connection elements even outside of potentially explosive atmospheres.

3. Selection, installation and testing of ExFS

The selection of adequate ExFS and their connection elements depends on the

- Lightning protection level (LPL) ,

- Dielectric strength of the insulating piece,
- Distance of the connection points (cable length),
- Technical data of the ExFS,
- Place of installation (Ex zone) and
- Insulation coordination (insulating piece with the connected ExFS)

3.1. Determination of the lightning protection level (LPL)

The lightning protection level (LPL) is determined by means of a risk assessment according to EN 62305-2 **[2]**. Based on this parameter, the maximum lightning current (lightning current distribution according to EN 62305-1 **[2]**) flowing through the ExFS is determined by means of different strike scenarios (S1 – S4). For example, the maximum lightning current (LPL I) flowing through the ExFS in the event of a lightning strike into an aboveground pipeline would be 100 kA (10/350 µs) (see Figure 1).

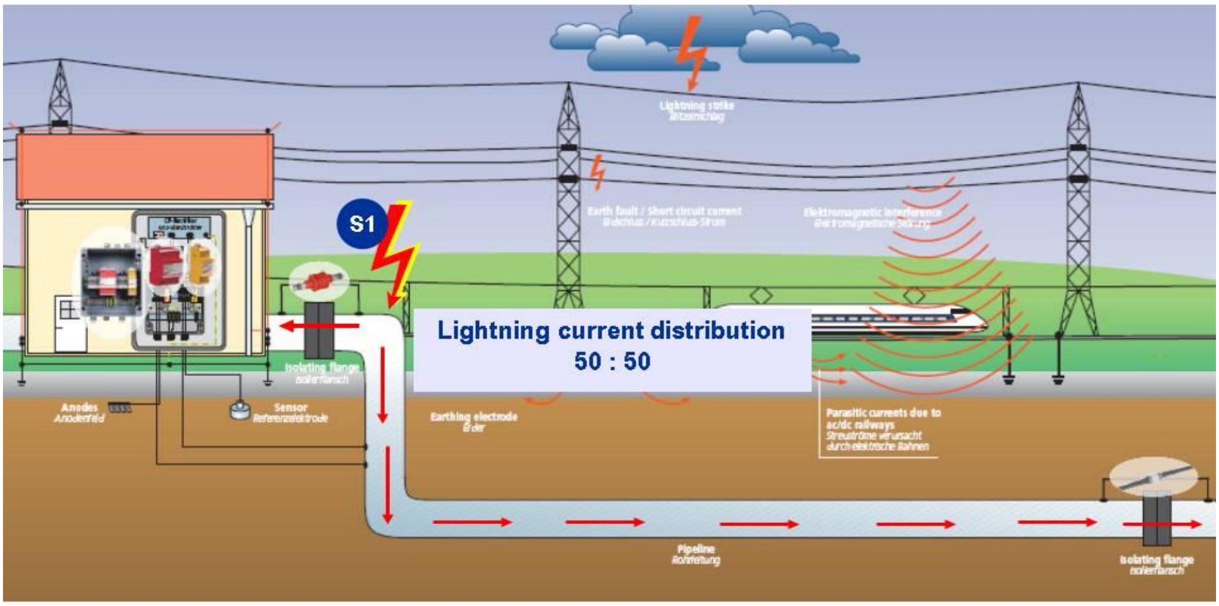


Figure 1 worst case lightning current distribution in case of lightning strike S1

Table 2 of AfK, recommendation No. 5 **[3]** specifies the maximum parameters of the first short stroke depending on the LPL for ExFS and their connection elements. The maximum values for the negative subsequent stroke are not considered.

3.2. Dielectric strength of the insulating piece

After insulating pieces / joints have been manufactured, they are tested with an a.c. test voltage U_{PW} of 50 Hz according to the relevant test class. There are two test classes:

Class 1: $U_{PW} \geq 5\ kV_{rms}$

Class 2: $U_{PW} \geq 2.5\ kV_{rms}$

The manufacturer of the insulating pieces / joints will provide information on the test classes of the insulating pieces / joints. Higher test voltages (e.g. 10 kV) may be tested if requested by the customer.

3.3. Distance of the connection points (length of the connecting cable)

Depending on the maximum current steepness of the partial lightning current determined in 3.1 and the length of the connecting cable, the dielectric strength of the insulating piece may be exceeded due to a voltage drop on the connecting cable (during the discharge process).

This may already be the case (based on a class I insulating piece and class of LPS I) for a cable length of more than 300 mm. If the length of the connection elements (S_L+ 2*H according to Figure 2) can be limited to ≤ 400 mm (length of the ExFs + cable length in case of a class I insulating piece), a further risk assessment (coordination of the ExFS with the insulating piece) is not required.

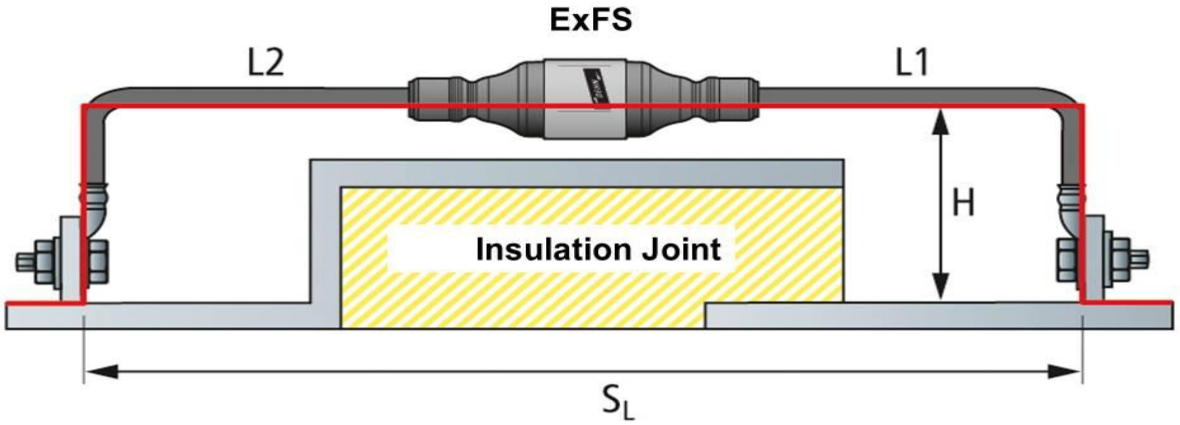


Figure 2 Length of the connection elements

In addition, all connection elements must

- Be capable of carrying lightning currents,
- Not produce ignition sparks (in case a hazardous potentially explosive atmosphere is present at the same time),
- Be arranged directly in parallel and close to the insulating piece,
- Be connected with the shortest possible distance,
- Be protected against accidental bridging (e.g. by tools).

Adequate connection points to pipelines are:

- Welded lugs, pins

- Threaded holes in the flanges for fixing screws

Note: Connection via a clamp is only permitted if it has been verified in tests that no ignition sparks occur in case of lightning currents.
All screws are to be prevented from becoming loose, for example, by inserting a spring washer. Toothed washers have not proven very effective in practice (sparking in case of lightning currents).

3.4. Minimum requirements on ExFS

Adequate ExFS should have the following technical data and approvals:

- Tested to EN 50164-3 **[5]**
- Lightning current carrying class: H or N
- d.c. sparkover voltage: > 600 V 1)
- 100 % lightning impulse sparkover voltage (1.2/50 µs): ≤ 1.25 kV
- Nominal discharge current (8/20 µs): 100 kA
- Lightning impulse current I_{imp} (10/350 µs): 100 kA (H), 50 kA (N)
- Rated impulse withstand voltage (50 Hz): 250 V 1)
- Rated a.c. discharge current (50 Hz): 500 A / 0.5s 2)
- ATEX certification in compliance with 94/9/EC directive [10] according to the Ex zone on the place of installation

  1) As a rule > Û at the place of installation
  2) Max. discharge current if interfered with by external voltage at the place of installation

3.5. Coordination of the ExFS with the insulating piece

Coordination between the insulating clearance of the insulating piece and the spark gap bridging this clearance is required to ensure that the lightning discharge is compensated via the ExFS and not the insulating clearance of the insulating piece. Thus, the ExFS serves as point of flashover that prevents a discharge process with uncontrolled sparking. The ignition of an ignitable atmosphere is equally prevented.
Coordination under the conditions of a lightning discharge is basically ensured if the voltage on the insulation of the insulating piece caused by the discharge process does not reach the value of its dielectric strength.

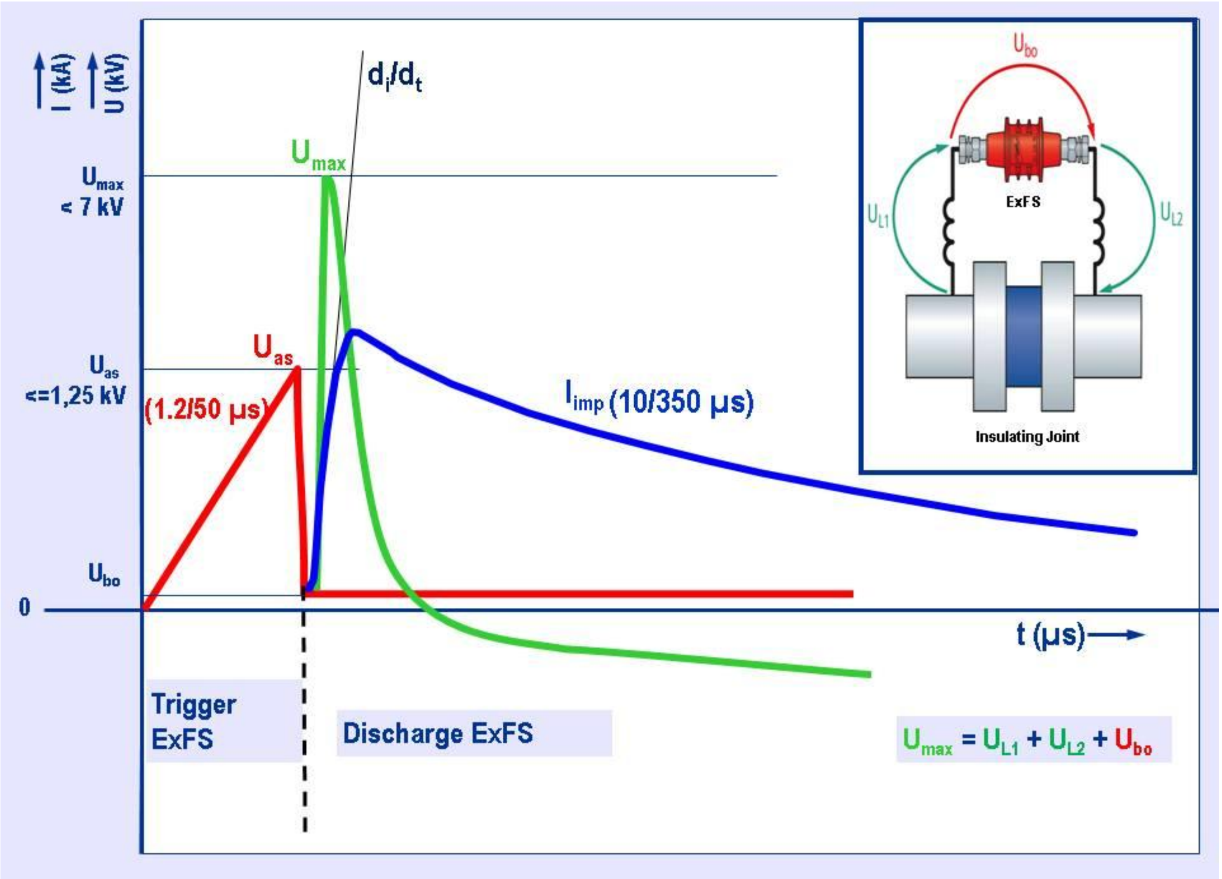


Figure 3 Schematic voltage characteristic of the insulating piece in case of a lightning strike

As can be seen from Figure 3, the tripping behaviour of the ExFS and, after the ExFS has tripped, the behaviour of the voltage drop on the connecting cable must be compared with the insulation strength of the insulating piece for coordination.

3.5.1. Trigger of the ExFS

The impulse sparkover voltage U_{as} (1.2 / 50 µs) of an ExFS must be 50% smaller than the rms value of the a.c. test voltage U_{PW} of the insulating piece (according to AfK 5).

Requirement: U_{as} <= U_{PW} / 2

e.g. class 2 insulating piece: U_{PW} = 2.5 kV
Impulse sparkover voltage of the isolating spark gap: U_{as} ≤ 1.25 kV
Note: When using ExFS with U_{as} ≤ 1.25 kV all (class 1 and 2) insulating pieces / joints can be protected by the triggering of the ExFS.

3.5.2. Discharge of the ExFS

The electric voltage load on an insulating piece does not only depend on the impulse sparkover voltage of an isolating spark gap connected in parallel with the insulating piece. After the isolating spark gap has ignited, an impulse current flows, causing a voltage drop on all connection elements. The voltage drop is significantly influenced by the impedance of the connection elements and may reach values which could

exceed the dielectric strength of the insulating piece (greater than the impulse sparkover voltage U_{as}).
The max. voltage drop on all connection elements (U_{max}) of a spark gap arrangement at the max. current steepness must be smaller than the peak value of the test voltage of the insulating piece $\hat{U}_{PW}$ (practice-oriented comparison according to AfK 5).

Requirement: $U_{max} < \hat{U}_{PW}$

e.g. class 1 insulating piece: U_{PW} = 5 kV
peak value of U_{PW}: $\hat{U} = U_{PW} * \sqrt{2} = 5 \text{ kV} * \sqrt{2} \Rightarrow \hat{U}_{PW} = 7 \text{ kV}$.

The max. voltage drop U_{max} can be determined using the following formula:

$$U_{max} = U_{bo} + I_{imp} * R_L + L * di / dt$$

U_{bo}: Arc voltage of the ExFS, depending on the type

3.5.3. Case study

The installation of a spark gap by means of an insulating piece (according to Figure 2) with the following parameters is to be assessed with the goal of “protecting the insulating piece“ in all phases of the lightning-induced discharge process:
Average installation height H of the ExFS: 10 cm
Spacing of the connection points S_L: 80 cm
ExFS: U_{bo} = 30 V; U_{as} <= 1.25 kV
Connecting cable: 25 mm², Cu, round;
ρ = 0.0178 Ω mm² / m
R_L = 0.712 mΩ / m
L = 1 µH / m
l = S_L + 2H = 1 m
Insulating piece: class 1 (U_{PW} >= 5 kV; $\hat{U}_{PW}$ = 7 kV)
Max. lightning current I_{imp} : 75 kA (10/350 µs)

a) Trigger

Requirement: $U_{as} <= U_{PW} / 2$;
⇒ 1.25 kV <= 5 kV / 2
1.25 kV <= 2.5 kV (requirement fulfilled)

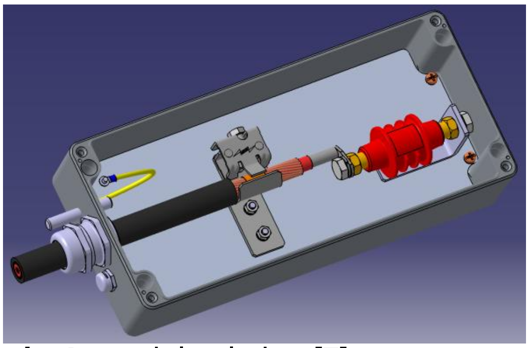
b) Discharge

Requirement: $U_{max} < \hat{U}_{PW}$

$U_{max} = U_{bo} + I_{imp} * R_L + L * di / dt$
= 30 V + (75 kA * 0.712 mΩ) + (1 µH * 7.5 kA/µs) = 30 V + 53.4 V + 7.5 kV = <u>7.50834 kV</u>

<u>7.50834 kV < 7 kV (requirement not fulfilled!)</u>

Additional measures are to be taken since the goal of protecting the insulating piece cannot be reached in all phases of the discharge process.



pic 4 coaxial solution [7]

Other possible measures:

- Increase of the dielectric strength of the insulating piece
- Reduction of the inductance L of the connecting cable, e. g. coaxial cables (see pic 4)

- Detailed assessment of the current distribution according to EN 62305-1 or risk analysis according to EN 62305-2

3.6. Testing of ExFS

If ExFS are used in potentially explosive atmospheres, they have to be tested at least every three years according to EN 60079-17 **[6].** Testing an ExFS and its connecting cables always requires visual inspection and measuring.
The ExFS and its connection elements are visually inspected for

- Damage of the ExFS housing
- Installation position according to the manufacturer's installation instructions
- Insulation of the connecting cables
- Tightness of the connecting cable
- Contact stability
- Pollution of the ExFS installation
- Suitability for installation in potentially explosive atmospheres
- Connecting cable length > 300 mm ➔ proof that the ExFS is coordinated with the insulating piece
- Other test criteria (see 3.3)

Short-circuits and sufficient insulation strength must be measured according to the relevant manufacturer's and test instructions. Electrical tests may only be carried out on removed ExFs outside of potentially explosive atmospheres. If an electrical test is to be carried out in a potentially explosive atmosphere, close consultation with the operator is required.

4. Summary

The AfK recommendation No. 5 **[3]** now makes it possible to assess the installation of ExFS to achieve the goal of protecting the insulating piece in all phases of the lightning-induced discharge process. Compared to [1] the user can choose from a variety of technical measures that can be taken depending on the installation environment.

5. Symbols and abbreviations

di/dt: steepness of the lightning impuls
H: height of the installation
I_{imp}: lightning impulse current
$U_{bo:}$ arcing voltage of the ExFS
R_L: ohmic resistance of the connection cable
S_L: distance between the connection brackets
L: inductive resistance of the connection cable
U_{max}: max. voltage drop after triggering the ExFS
U_{PW}: AC test voltage (rms)
$\hat{U}_{PW}$: AC test voltage (peak)
U_{as}: lightning impulse spark over voltage
l: cable length of the installation
ρ: specific resistance of the used material (e.g. Cu: 0,0178 Ω mm² / m)
ExFS: isolating spark gap

6. References

[1] AfK recommendation No. 5, February 1986 (replacement for AfK recommendation No. 5 of November 1973): “Kathodischer Korrosionsschutz in Verbindung mit explosionsgefährdeten Bereichen“ [Cathodic corrosion protection in potentially explosive atmospheres]

[2] EN 62305-1: 2011; Protection against lightning – Part 1: General principles
EN 62305-2 : 2011; Protection against lightning – Part 2: Risk management
EN 62305-3 : 2011; Protection against lightning – Part 3: Physical damage to structures and life hazard
EN 62305-4 : 2011; Protection against lightning – Part 4: Electrical and electronic systems within structures

[3] AfK recommendation No. 5, July 2010 (replacement for recommendation No. 5 of February 1986): “Kathodischer Korrosionsschutz in Verbindung mit explosionsgefährdeten Bereichen“ [Cathodic corrosion protection in potentially explosive atmospheres]

[4] EN 50443: 2012, Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction Systems and / or high voltage a.c. power supply systems;

[5] EN 50164-3 : Lightning Protection Components: Requirements for isolating spark gaps: 2006 with corrigenda 1: 2007

[6] EN 60079-17 : Explosive atmospheres
Part 17: Electrical installations inspection and maintenance

[7] data sheet and installation manual for the coaxial solution from pic 4 (DEHN + SÖHNE GmbH + Co.KG.; mail to: Manfred.Kienlein@dehn.de)

Author
Manfred Kienlein
Market Manager for Process Systems
DEHN + SOEHNE GmbH+Co.KG
Hans-Dehn-Str. 1
92318 Neumarkt
Telephone: 09181/906-401