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Assessment of isolation between a metallic casing and a pipeline by means of remote monitoring and coupon

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ABSTRACT:

Steel casings are installed to provide additional mechanical protection for pipelines crossing sites with possibility of significant mechanical stress (like roads, railways or watercourses) or areas with high population densities.

To guarantee that the CP applied to a pipeline in presence of a casing could work in an effective way, it is fundamental that no contact (electrical or electrolytic) would exist between pipe and casing. In the presence of a contact, the CP could still work, but an assessment will be required using an effective technique from the different options that can be used for this purpose.

In this paper, the technique proposed in Annex 2 from Cefracor Recommendation PCRA n. 10 has been applied to check the presence and the type of contact between a pipe and its casing in a real field experience by means of remote monitoring and coupons. Furthermore, the technique has been integrated with the ON/OFF cycling of the TR and different electrical resistive contacts have been simulated to check the conditions where the technique can give proper results.

INTRODUCTION

Underground pipelines, once buried, are generally not subjected to significant mechanical stress, unless they are in an area with a recognized risk of ground movement, like earthquake or landslide.
Nevertheless, there are some specific sites where, if pipeline cross them, mechanical stresses are expected almost continuously: railways and main roads with the vibrations generated by trains and heavy vehicles passing on them, or watercourses with the continuous movement of the water flowing are the most common examples.
In these cases, pipelines need an extra mechanical protection to avoid that this continuous stress could lead to damage over time: the carrier pipe is installed inside a larger pipe section, a casing, which will be the one "in charge" to transfer to the below ground the mechanical stress coming from the above, thus avoiding the carrier pipe to be affected.
While, on a mechanical point of view, casings work very well, they have been always a problem in terms of cathodic protection assessment, since corrosion of the carrier pipe inside the casing may happen when insulation between the two metallic structures is compromised either by electrolytic contact (water or soil entering the annulus, i.e. the space between carrier pipe and casing, thus creating a path for current to move from one to the other) or by direct metallic contact (if some metallic object or scrap metal creates a direct metallic contact between the two pipes).
This is the reason why a periodic surveillance on casing installation is requested by means of potential surveys[1] to determine the electrical status.
There are different methods suggested for checking the electrical status between carrier pipe and casing: cycling the transformer rectifier on one side is normally the most common method used whenever a contact between two metallic structures is suspected.
In this paper the technique proposed in Annex 2 from Cefracor Recommendation PCRA n. 10 has been applied to check the presence and the type of contact between a pipe and its casing in a real field experience by means of remote monitoring and coupon, and its results compared and combined with the ones obtained from cycling the transformer rectifier. After a first evaluation, different electrical resistive contacts have been forced to check the limits up to which the technique is able to provide reliable results.

ANNEX 2 FROM CEFRACOR RECOMMENDATION PCRA N. 10 [2]

In Cefracor PCRA n.10 "Protection contre la corrosion des canalisations aux passages en fourreaux - Prévention et contrôle", in the annex 2 is described a method to assess the isolation between a metallic casing and a pipeline by means of coupon and by analyzing their polarization.

Installation setup

Coupon and associated reference electrode are placed next to the pipeline to be assessed and their position shall be kept the same during all test long (Fig.1).

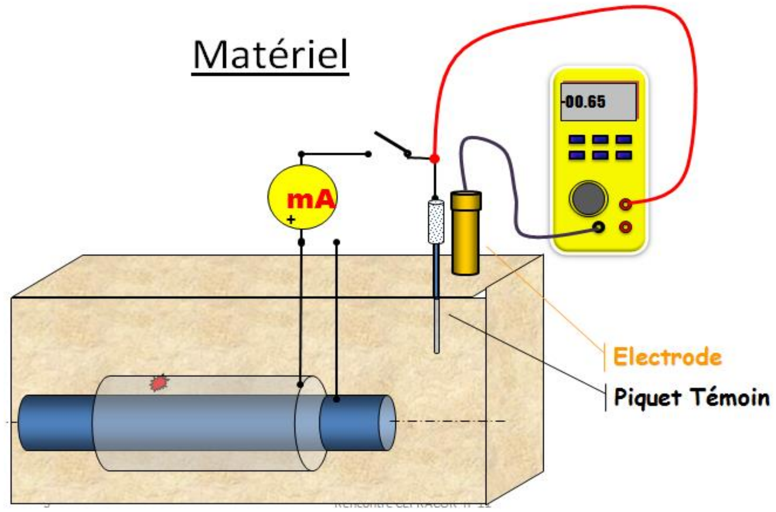

Fig.1: installation setup from Annex 2 of PCRA n.10

The measurements that will be taken are the followings:

- E_{on}: coupon potential when connected to the metallic structure (pipeline or casing),
- E_{off}: coupon potential when disconnected from the metallic structure,
- I_T: current through the coupon when connected to the structure (note: according to the scheme in Fig.1, the cathodic current through the coupon has negative values as the coupon is connected to the negative terminal of the datalogger).

The whole method can be summarized in three main steps:

Step 1: casing measurements

The following actions (Fig.2) must be taken to perform the measurement on casing:

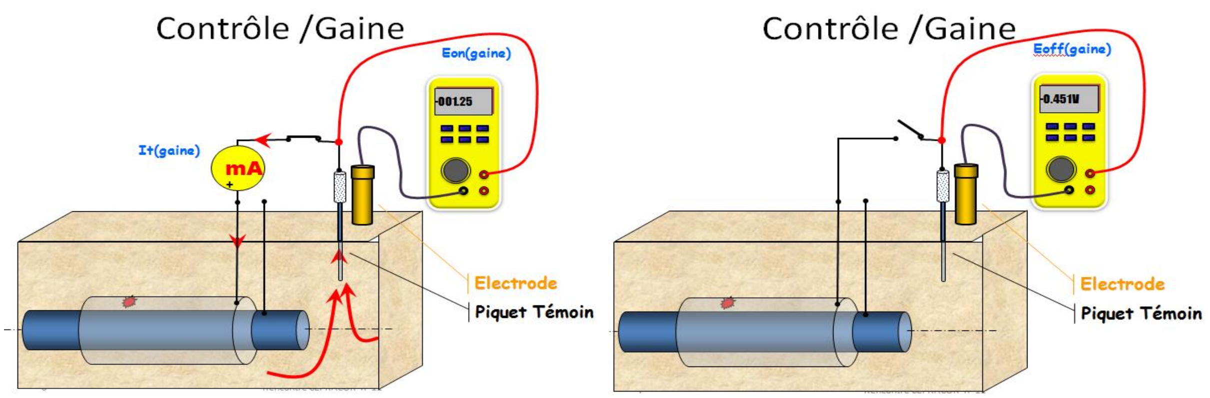

Fig.2: casing measurements

- Connect the cable from the casing to the data logger on the right terminal.
- Record for 15 minutes Eoff, Eon and I_T through the coupon and read the results of the measurements.

Step 2: pipe measurements

The following actions (Fig.3) must be taken to perform the measurement on pipe:

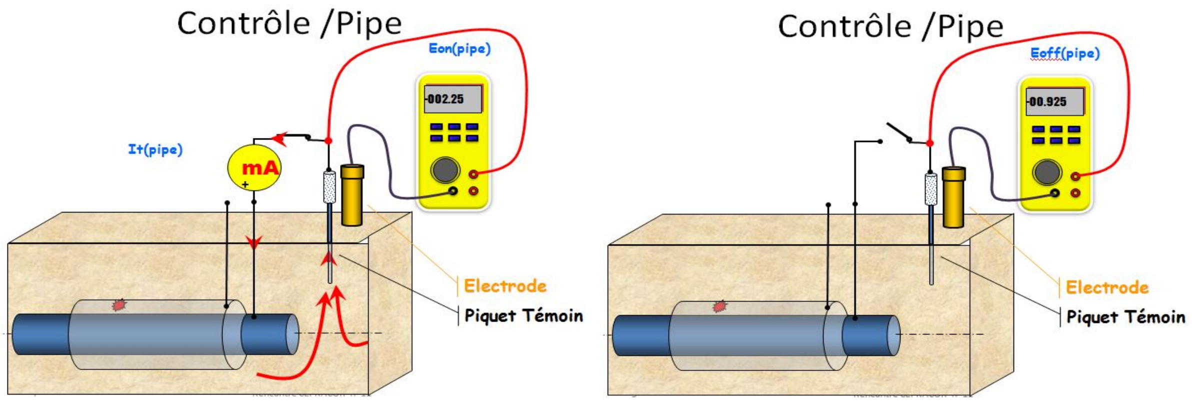

Fig.3: pipe measurements

- Connect the cable from the pipeline to the data logger on the right terminal.
- Record for 15 minutes Eoff, Eon and I_T through the coupon and read the results of the measurements.

Step 3: data analysis

The measurement taken must then be analyzed according to the scheme in Fig.4 to determine the presence of a direct contact, an electrolytic contact or the absence of any contact:

	Measurements analysis			Conclusion
	E_{on}	E_{off}	I_T	Direction if the current through the coupon
Case 1	E_{on} pipeline = E_{on} casing	E_{off} pipeline = E_{off} casing	I_T pipeline = I_T casing	**Direct contact**
Example	E_{on} pipeline = -2,5 V E_{on} casing = -2,5 V	E_{off} pipeline = -1 V E_{off} casing = -1 V	I_T pipeline =-1,0 mA I_T casing = -1,0 mA	Itg
Case 2	E_{on} pipeline ≈ E_{on} casing	E_{off} pipeline < E_{off} casing	I_T pipeline < I_T casing	**Electrolytic contact**
Example	E_{on} pipeline = -2,5 V E_{on} casing = -2,0 V	E_{off} pipeline = -1 V E_{off} casing = -0,7 V	I_T pipeline =-1,0 mA I_T casing = -0,2 mA	Itg
Case 3	E_{on} pipeline < E_{on} casing	E_{off} pipeline << E_{off} casing	I_T pipeline << I_T casing and I_T casing ≈ 0	**No contact**
Example 1	E_{on} pipeline = -2,5 V E_{on} casing = -1,0 V	E_{off} pipeline = -1 V E_{off} casing = -0,5 V	I_T pipeline =-1,0 mA I_T casing = -0,1 mA	Itg $E_{Casing} < E_{coupon}$
Example 2	E_{on} pipeline = -2,5 V E_{on} casing = -0,6 V	E_{off} pipeline = -1 V E_{off} casing = -0,3 V	I_T pipeline =-1,0 mA I_T casing = +0,1 mA	Itg $E_{Casing} > E_{coupon}$
Legend		Pipeline + casing	Coupon	Cable between pipeline and casing

Fig.4: interpretation of the results in relation to the risk of contact

FIELD TEST SETUP

To test the method and compare it with cycling of the transformer rectifier, a location in the UK along the CLH-PS pipeline network has been chosen, in the vicinity of a railway crossing, with a bare steel casing protecting the pipe.
The idea is to perform a parallel monitoring on both casing and pipeline at the same time by means of 2 remote monitoring devices, in order to manage both coupon to pipe and coupon to casing connection.

A permanent reference electrode with 10 cm^2 coupon was already present on site, a second coupon of 10 cm^2 was installed in order to use the same permanent reference electrode for all the measurements to be carried on in the test.

The final setup of the installation has been represented schematically in Fig.5:

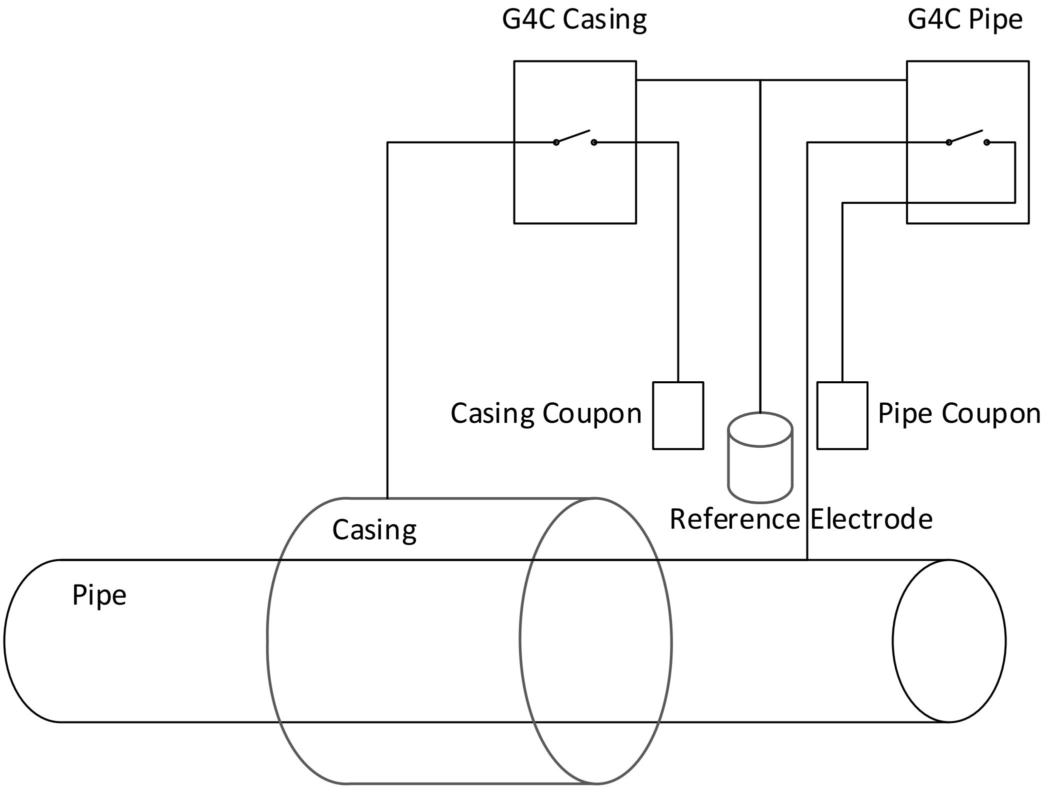

Fig.5: field test setup

Elements installed at the test site:

- 1 Permanent reference Electrode (CSE) (the same for pipe and casing)
- 2 permanent coupon 10cm^2
- 2 remote monitoring devices (G4C) to manage each one a different coupon.

The measurements performed at 1Hz frequency (1 measure per second) on each device are the following:

- Eon.dc: DC On potential;

- Eoff: continuous instant off on coupon, 1ms waiting, 20ms measurement, every second;
- mIon: coupon polarization current, the same as I_T in the Annex 2 of PCRA n.10 but, according to the setup in Fig.5, the current is **cathodic** in presence of **positive** values.

The continuous instant off measurement on coupon has been performed as shown in Fig.6:

Instant off timing setup	Time to wait	1 ms
	Time over which carry out the measure:	20 ms
	Time the interrupter is kept open:	22 ms
Total coupon ON/OFF timing	Total time coupon OFF during 1s:	22 ms
	Total time coupon ON during 1s:	978 ms
Measure frequencies	Eoff (Coupon instant-off potential)	1 s
	Eon.dc: (Pipe On potential)	1 s
	mIon: (Coupon polarization current)	1 s

Fig.6: timing setup of the measurements

In the pictures in Fig.7, a view of the test post before and after the installation of the materials required by the test is shown:

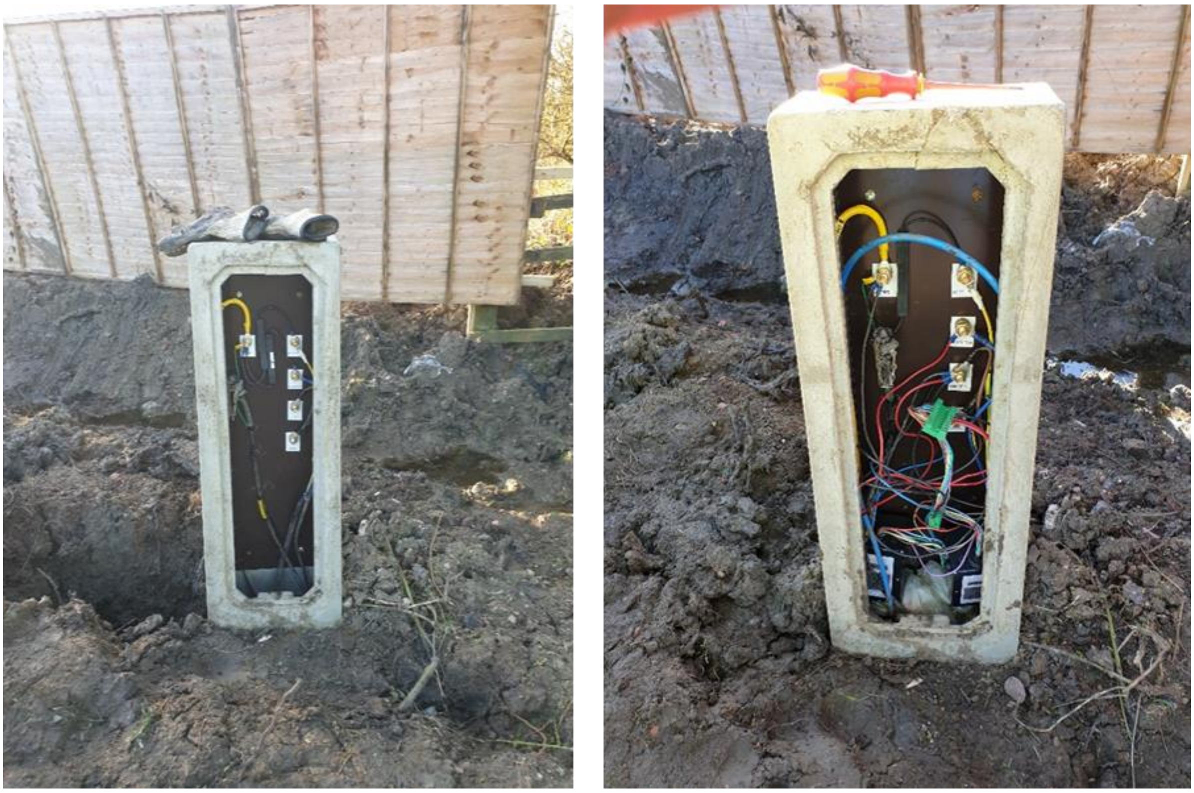

Fig.7: test site before and after test preparation

The tests were divided into two steps:

- In a first step, an assessment of the isolation between casing and pipe as they were found has been performed both by applying the Annex 2 PCRA n.10 method and by cycling the transformer rectifier, and the results have been compared;

- In a second step, different types of contact have been forced between casing and pipe, from direct contact to resistive contact with different resistance values, and, for each one of these conditions, they were checked both by applying the Annex 2 PCRA n.10 method and by cycling the transformer rectifier to better understand up to which condition these methods are able to provide reliable results, on their own and also combined.

The tests have been performed after some days from the installation, to allow the recently installed second coupon to polarize properly.

The tests have been performed in the following order:

- Casing and pipeline in their original state
  - **Test #1a**: assessment of the isolation by applying the Annex 2 PCRA n.10 method.
  - **Test #1b**: assessment of the isolation by cycling the transformer rectifier (Ton=12s and Toff=3s).

- Forced direct electrical contact between casing and pipeline
  - **Test #2a**: Compare results obtained by both methods, with shorted pipeline and casing.

- Forced different resistive bonding between casing and pipeline with R = 0,4Ω - 1,1Ω - 2Ω - 3Ω - 4Ω - 5Ω - 10,1Ω - 33Ω
  - **Test #2b**: Compare results obtained by both methods, with resistive bonding between casing and pipeline.

FIELD TEST

Test #1a

In this test, the assessment of the isolation between casing and pipe as found has been performed by applying the Annex 2 of PCRA n.10 method.
The assessment has been performed taking the measurement from a significative moment of the day, as shown in Fig. 8 (measured values are almost stable during the whole day): Eon from pipe and casing, Eoff from the different coupon connected to pipe and casing and polarization current mIon from both coupons have been measured.

It is important to underline how with respect to the table in fig.4, the polarization current relationship is reversed due to having, in the field setup, cathodic polarization current with positive values.

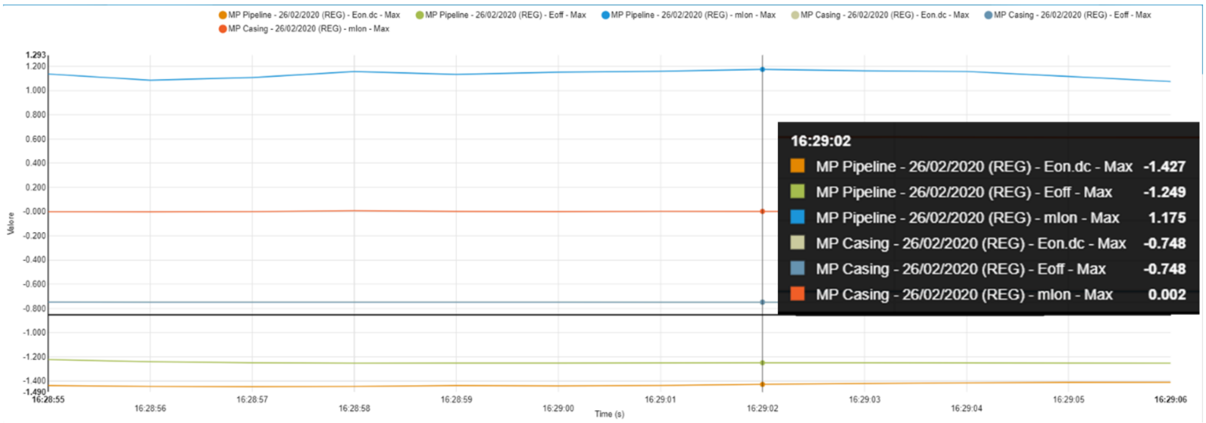

Fig.8: measures for test #1a

	Eon	Eoff	mIon	Conclusion
Pipeline	-1,427 Vcse	-1,249 Vcse	+1,175 mA	
Casing	-0,748 Vcse	-0,748 Vcse	0,002 mA	
Case 3	Eon pipeline < Eon casing	Eoff pipeline < Eoff casing	mIon pipeline >> mIon casing mIon casing ≈ 0	**NO CONTACT**

According to Cefracor recommendation, the data correspond to Case 3, so there is no contact between pipeline and casing.

Test #1b

In the same conditions of Test #1a, a cycling on the transformer rectifier with Ton=12s and Toff=3s has been performed.
In Fig. 9-11 the effects of cycling transformer rectifier on Eon, Eoff and mIon are shown, in order to confirm that also with this method, it can be assumed that there is no contact between casing and pipe, as expected.

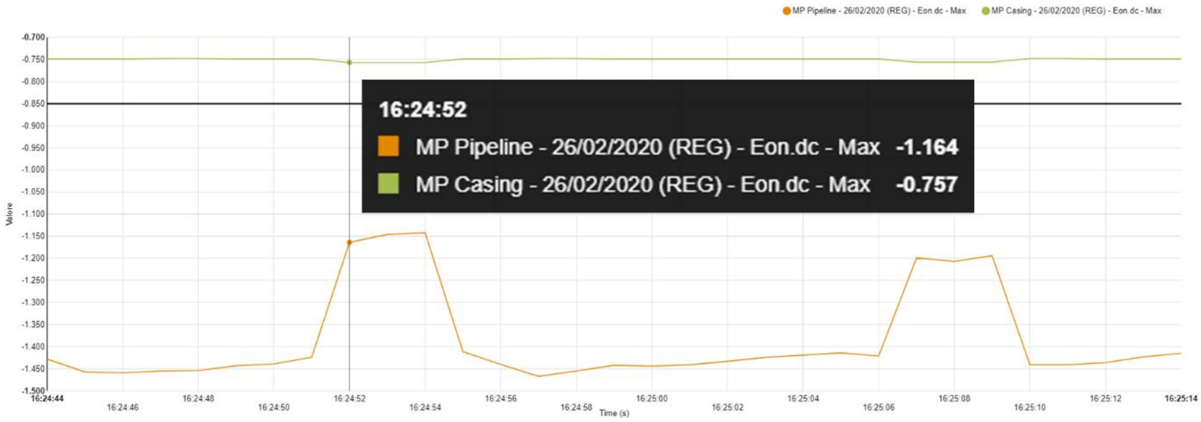

Fig.9: cycling effect on ON potentials

Fig.10: cycling effect on coupons instant-off potentials

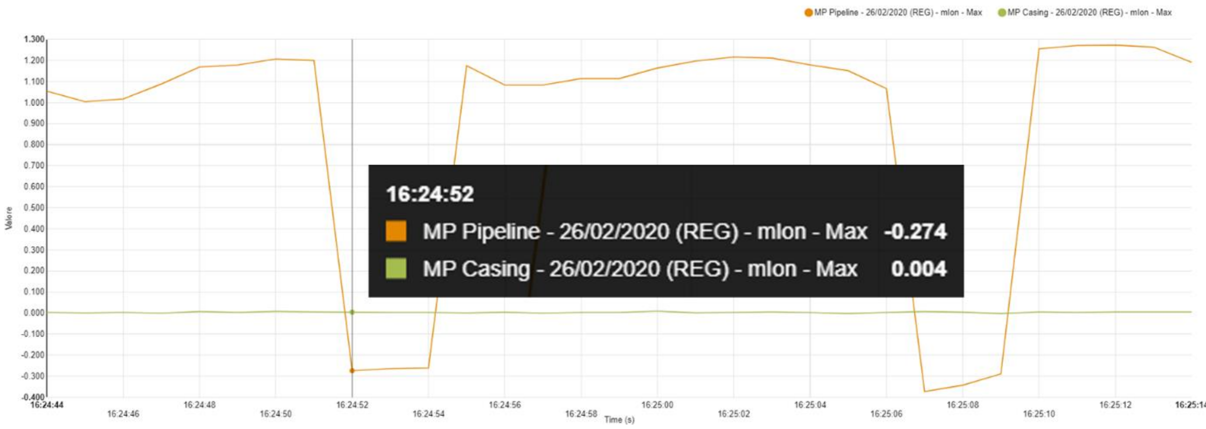

Fig.11: cycling effect on coupons polarization currents

Test #2a

After assessing that there is no contact between casing and pipe, a direct contact has been forced inside the test post, to verify that both methods are able to properly identify this condition.

The test 2a and 2b have been performed almost 24h after the bonding: this is because a real assessment is performed after a contact is already present, so the casing will result polarized according to the received current. Having polarized the casing for almost 24h, the test performed by forcing direct contact and different resistive contacts is expected to be less affected from polarization/depolarization transients and closer to a real field condition.

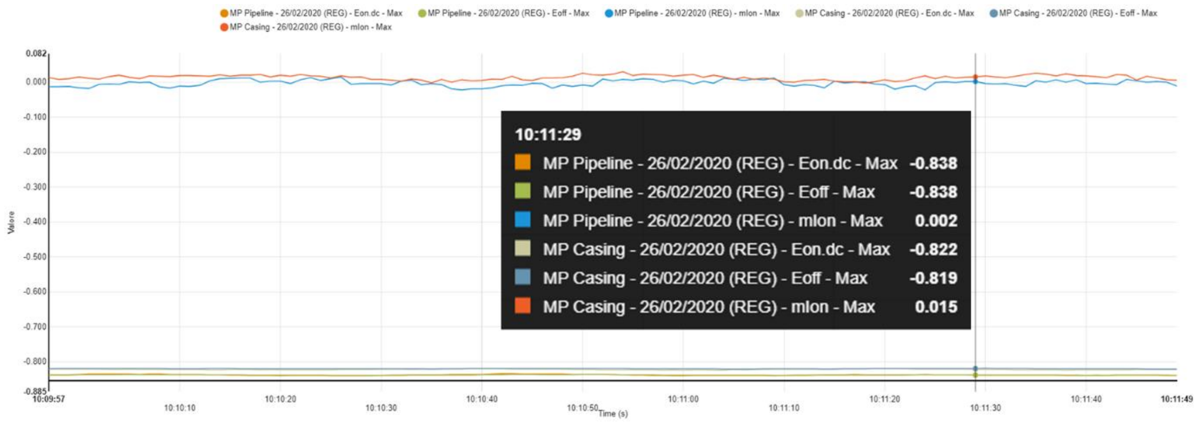

Fig.12: measures for test #2a (PCRA n.10)

	Eon	Eoff	mIon	Conclusion
Pipeline	-0,838 Vcse	-0,838 Vcse	+0,002 mA	
Casing	-0,822 Vcse	-0,819 Vcse	0,015 mA	
Case 1	Eon pipeline = Eon casing	Eoff pipeline = Eoff casing	mIon pipeline = mIon casing	DIRECT CONTACT

According to Cefracor recommendation, data correspond to Case 1, so there is direct contact between pipeline and casing.

The same result is obtained by cycling the transformer rectifier, since an evident effect is detected on casing potential, as shown in Fig.13

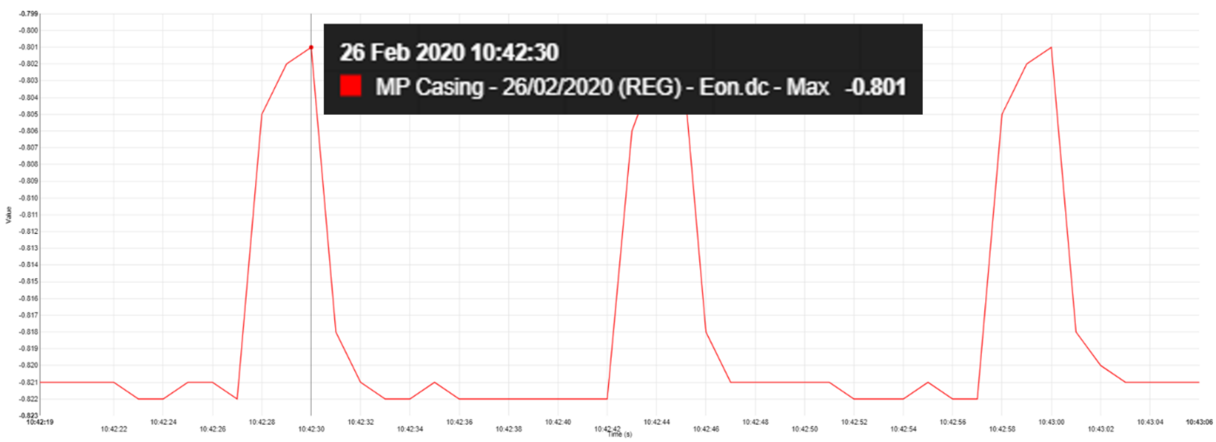

Fig.13: measures for test #2a (cycling transformer rectifier)

Test #2b

Through variable resistors, different resistive connections between casing and pipe have been simulated, and for each resistance value both Cefracor recommendation and cycling of the transformer rectifiers were used to assess the connection.

The resistance values used are the following: 0,4 Ohm - 1,1 Ohm - 2 Ohm - 3 Ohm - 4 Ohm - 5 Ohm - 10,1 Ohm - 33 Ohm.

The full set of data is described in the paragraph "Data Analysis", in Fig. 14-17 the data from the test with resistive bonding with 1,1 Ohm resistor are shown as example.

Already at 1,1 Ohm bonding resistance value, both methods start to seem unable to come up with a certain outcome:

- With Annex 2 from PCRA n.10 method (fig. 14), due to the difference between potentials starting to be significant, but casing potentials are still too negative to be considered as a "no contact" condition, coupon polarization currents values are still very close between them and the casing coupon polarization current is still different from 0 mA. Furthermore Annex 2 method doesn't indicate clearly when to consider the ON potentials no more "almost equal", since in the example in Fig.4, for Case 2 with 0,5 V difference still consider them very close.

- With cycling the transformer rectifier, the On-Off swing (Fig. 15) on casing potential starts to be very little (only 8 mV), so it can be detected only with accurate measuring instruments.

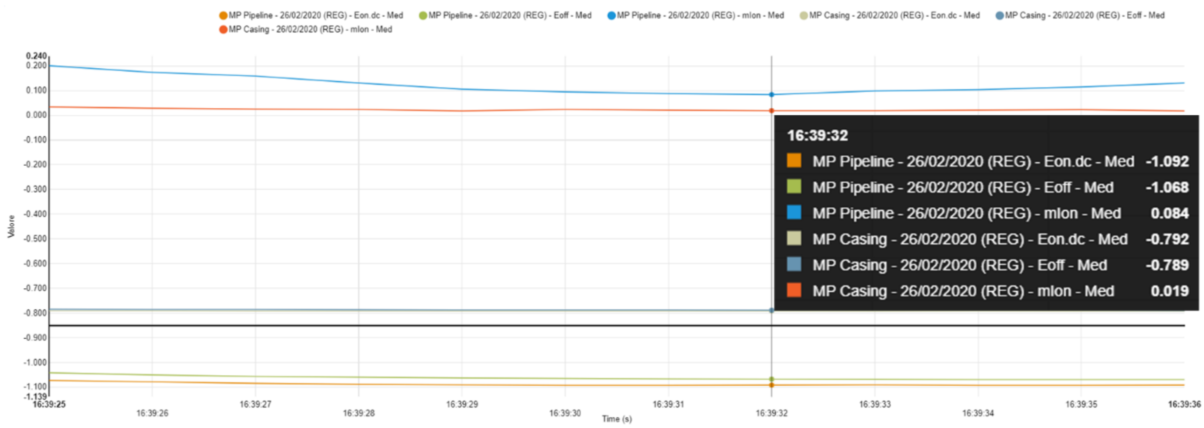

Fig.14: measures for test #2b @ 1,1 Ohm (PCRA n.10)

	Eon	Eoff	mIon	Conclusion
Pipeline	-1.092 Vcse	-1,068 Vcse	+0,084 mA	
Casing	-0,792 Vcse	-0,789 Vcse	+0,019 mA	
Case 2	Eon pipeline ≈ Eon casing	Eoff pipeline ≈ Eoff casing	mIon pipeline > mIon casing	**ELECTROLYTIC CONTACT**

Fig.15: cycling effect on ON potentials @1,1 Ohm

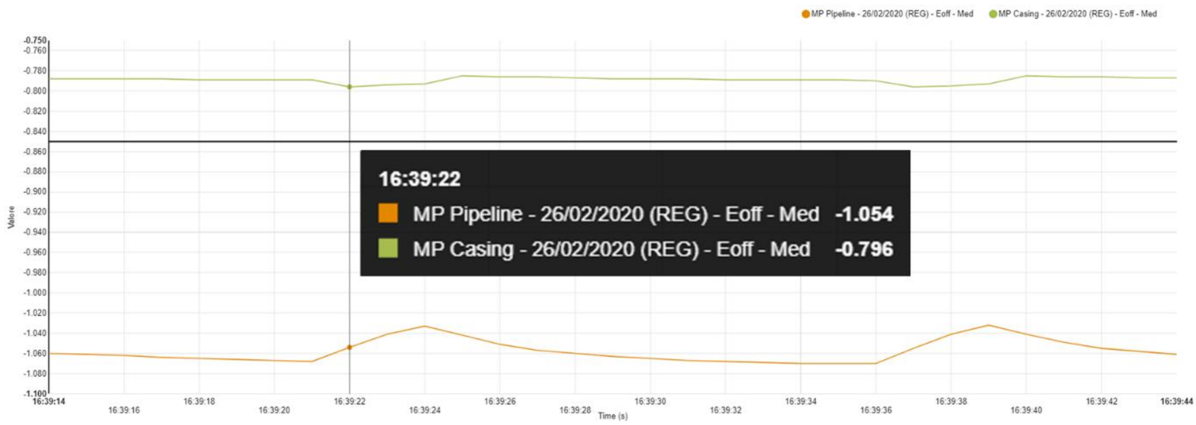

Fig.16: cycling effect on coupons instant-off potentials @1,1 Ohm

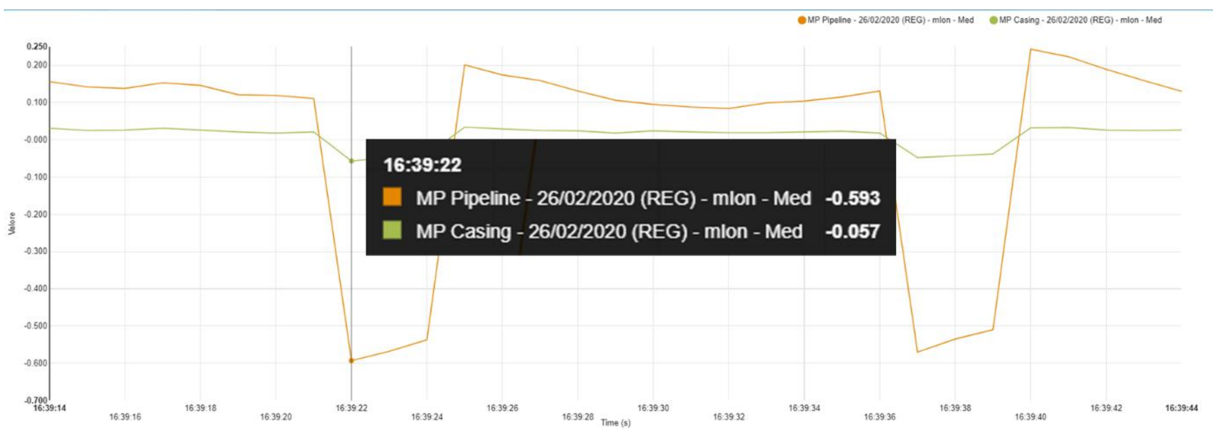

Fig.17: cycling effect on coupons polarization currents @1,1 Ohm

DATA ANALYSIS

Data from all the tests done and their reference values have been summarized in the following tables.
Data obtained from testing according to Annex 2 of Cefracor PCRA n.10:

Cefracor	Disconnected	shorted	0,4 Ohm	1,1 Ohm	2 Ohm
Eon pipeline	-1,427	-0,838	-0,952	-1,092	-1,183
Eoff pipeline	-1,249	-0,838	-0,988	-1,068	-1,137
mIon pipeline	1,175	0,002	-0,267	0,084	0,244
Eon casing	-0,748	-0,822	-0,808	-0,792	-0,782
Eoff casing	-0,748	-0,819	-0,801	-0,789	-0,780
mIon casing	0,002	0,015	0,034	0,019	0,022
RESULT	NO CONTACT	DIRECT CONTACT	ELECTROLYTIC CONTACT	ELECTROLYTIC CONTACT	ELECTROLYTIC CONTACT

Cefracor	3 Ohm	4 Ohm	5 Ohm	10,1 Ohm	33 Ohm
Eon pipeline	-1,248	-1,265	-1,304	-1,353	-1,420
Eoff pipeline	-1,180	-1,197	-1,214	-1,238	-1,255
mIon pipeline	0,443	0,494	0,531	0,690	0,876
Eon casing	-0,775	-0,769	-0,766	-0,757	-0,749
Eoff casing	-0,772	-0,767	-0,764	-0,756	-0,749
mIon casing	0,018	0,015	0,014	0,010	0,001
RESULT	NO CONTACT	NO CONTACT	NO CONTACT	NO CONTACT	NO CONTACT

Looking at all the data together and their evolution obtained with the different bonding conditions, it can be assumed that, until a value of 2 Ohm, reliable results can be possibly obtained by this method.
On the other hand, considering a single measurement performed in the field with no knowledge of the historical values, a bonding with equivalent resistance of 1,1 Ohm can be already difficult to detect properly.

The most significant value able to give some proper indication even in a single measurement, seems to be the casing coupon polarization current, but this means that the coupon needs to be installed for a sufficient period to be properly polarized.
Anyway, monitoring over time (by frequent field measurement or by remote monitoring), could better help to recognize a contact when this occurs.

Checking the data obtained by cycling the transformer rectifier, in a first instance no coupon measurements have been considered, since for this method they are not needed.
In the table below, the values shown correspond to the average swing measured considering the last On value (at time T) and the first Off (at time T+1 second) value obtained on casing and pipe potentials during the test ($\Delta = Off_{T+1} - On_T$, calculated on the Eon channels), to better evaluate the variation:

T/R ON-OFF Δ (V)	Disconnected	shorted	0,4 Ohm	1,1 Ohm	2 Ohm
Eon pipeline	0,251	0,026	0,070	0,127	0,160
Eon casing	-0,007	0,019	0,014	0,008	0,005
RESULT	NO CONTACT	CONTACT	CONTACT	???	NO CONTACT

T/R ON-OFF Δ (V)	3 Ohm	4 Ohm	5 Ohm	10,1 Ohm	33 Ohm
Eon pipeline	0,190	0,206	0,210	0,206	0,244
Eon casing	0,002	-0,001	-0,001	-0,004	-0,007
RESULT	NO CONTACT	NO CONTACT	NO CONTACT	NO CONTACT	NO CONTACT

According to the data, it can be assumed that reliable results can be possibly obtained by this method until a value of only 0,4 Ohm.
Still at 1,1 Ohm some correct conclusion can be drawn, but only if using high accuracy measurement instruments which are able to clearly measure few mV variations.

At this point, the measurements performed on coupon (both instant-off and coupon polarization current) during the cycling of the transformer rectifier have been analyzed in the same way.
As before, for the Eoff channel (instant off potentials on coupon) the average swing measured considering the last On value (at time T) and the first Off (at time T+1 second) value obtained is shown.
The mIon current value (mA), is the first value measured after T/R off, at T+1 (at time T, the value was cathodic > 0mA).

T/R ON-OFF	Disconnected	shorted	0,4 Ohm	1,1 Ohm	2 Ohm
Eoff pipeline Δ (V)	0,027	0,004	0,009	0,014	0,020
mIon pipeline	-0,229	-0,125	-0,659	-0,593	-0,668
Eoff casing Δ (V)	-0,008	-0,006	-0,007	-0,007	-0,006
mIon casing	0,003	-0,097	-0,073	-0,057	-0,038
RESULT	NO CONTACT	DIRECT CONTACT	ELECTROLYTIC CONTACT	ELECTROLYTIC CONTACT	ELECTROLYTIC CONTACT

T/R ON-OFF	3 Ohm	4 Ohm	5 Ohm	10,1 Ohm	33 Ohm
Eoff pipeline Δ (V)	0,023	0,023	0,023	0,022	0,028
mIon pipeline	-0,624	-0,695	-0,685	-0,591	-0,354
Eoff casing Δ (V)	-0,007	-0,008	-0,007	-0,007	-0,007
mIon casing	-0,024	-0,022	-0,019	-0,005	0,000
RESULT	ELECTROLYTIC CONTACT	ELECTROLYTIC CONTACT	ELECTROLYTIC CONTACT	???	NO CONTACT

In Fig.18 an example of the casing coupon polarization current is shown during an ON-OFF transition @5 Ohm.

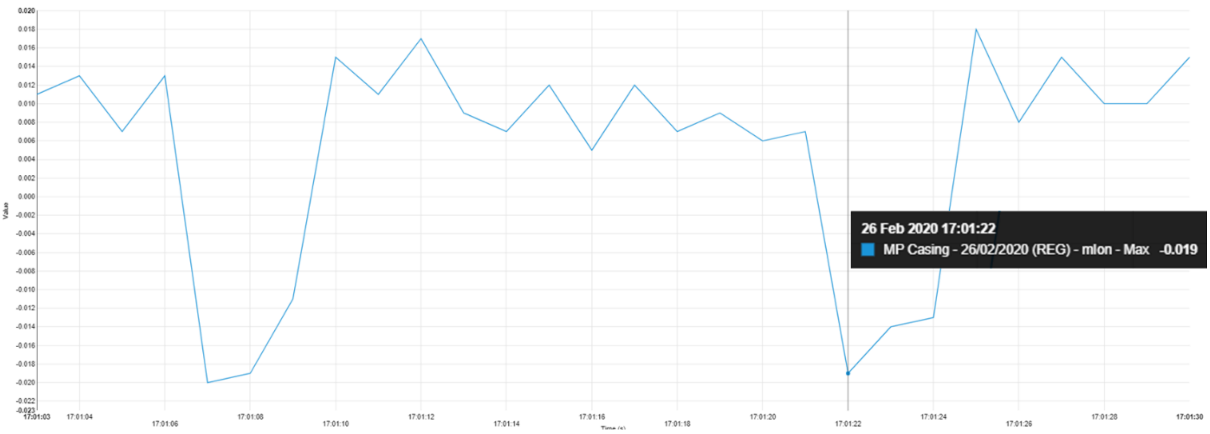

Fig.18: cycling effect on casing coupon polarization current @5 Ohm

While coupon instant off potentials swings seems to add no further information with respect to the data previously analyzed, it is very interesting what is shown by the casing coupon polarization current during the on-off transition: the presence of a resistive contact can be clearly assessed up to a resistance value of 5 Ohm, and even at 10,1 Ohm it can still be detected with accurate measurement instruments, allowing

to assess the presence of a contact between pipe and casing in a really wider range with respect to both Annex 2 method and cycling transformer rectifier.
Furthermore, the assessment can be done even in absolute absence of historical data.

CONCLUSIONS

The Annex 2 from Cefracor PCRA n.10 describes a method to assess the presence of a contact between a pipe and its casing by means of coupon: one of the biggest advantages of this method is the possibility to perform a test limited to the casing site without involving the whole cathodic protection system, like when performing cyclic switch on the transformer rectifiers.
The field test performed shows how, in the conditions described and considering a range of possible contacts (no contact, direct connection, different resistive connections), on a punctual assessment (i.e.: use of portable coupon and no historical data available), this method gives at least the same results from cycling the transformer rectifiers, detecting properly a no contact and direct contact condition, and resistive contact up to a resistance value of 1,1 Ohm.
Considering a frequent monitoring (by field measurement or better by remote monitoring), through comparing historical data the Cefracor method can also cover a little bit wider range up to a resistance value of 2 Ohm.
Among the different parameters observed, absolutely the most significant one appears to be the polarization current measured on the coupon connected to the casing: both with and without contemporary cyclic switch on the transformer rectifiers, its value seems to be able to determine the presence of a contact of almost any type (even up to 10,1 Ohm with good accuracy measuring instruments).
In order to obtain the best results, installing a permanent reference electrode with coupon and a remote monitoring device is a good option to be considered.

[1] ISO 16440:2016 "Petroleum and natural gas industries — Pipeline transportation systems — Design, construction and maintenance of steel cased pipelines"
[2] Recommandation PCRA 010 "Protection contre la corrosion des canalisations aux passages en fourreaux - Prévention et contrôle", Cefracor