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**JOINTS ON TRANSMISSION
LINE CONDUCTORS:
FIELD TESTING AND REPLACEMENT
CRITERIA**

**Working Group
22.12**

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JOINTS ON TRANSMISSION LINE CONDUCTORS: FIELD TESTING AND REPLACEMENT CRITERIA

Prepared by R. KLEVEBORN on behalf of
Working Group 12 of Study Committee 22

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1. FOREWORD

Transmission lines equipped with aluminium-based conductors have been in service around the globe for more than a half a century. On those lines strung with steel-cored conductors, two-piece joints (steel-aluminium) are used to make in-span joints. For the last decade numerous failures of these joints have been reported, the reasons for which have included asymmetrical installation of the aluminium sleeve as well as accelerated ageing and deterioration of the contact surface in the joint due to an increased electrical load. There is, therefore, a need for a document describing the failure mechanisms and the methods for determining the reliability of the existing joints.

2. PURPOSE

The purpose of this document is to describe the tests currently available to determine the condition of joints in order to establish their quality and ability for a reliable and continuing service, especially when an increase in electrical load is expected. For example, when increasing the operating temperature of a line. It should be noted that this is not exclusive to ACSR joints.

3. SCOPE

The scope of this document covers current-carrying joints compressed around the conductor using hexagonal- or concentric- shaped dies (intermittent or overlapping), or so-called "explosive" joints. Conductor types considered include AAC (All

Aluminium Conductor), AAAC (All Aluminium Alloy Conductor), ACAR (Aluminium Conductor Aluminium Reinforced), and ACSR (Aluminium Conductor Steel Reinforced) types.

The helical and wedge types of joint are not covered in this document.

4. INTRODUCTION

Properly designed, manufactured and installed joints should perform well at both high and low operating temperatures. However, it is often not known whether the joints were made in accordance with the design specifications in all cases. This is especially true for joints on lines that are over 20 years old. Records of the initial tests (if any) may not exist. Even joints which have been manufactured and installed in accordance with an appropriate specification can be affected by degradation and ageing during their time in service.

With the de-regulation of the industry and limited available financing, it has become imperative that utilities fully utilise their assets. This often means increasing the flows along existing power corridors, using methods such as real time line monitoring by measuring conductor temperature, sag or tension. In this case, it is very important that the components of a line can be relied on not to fail under the more onerous conditions.

5. FAILURE MECHANISMS OF JOINTS

The failure of a joint is usually as a result of an increased resistance due to corrosion, leading to an unacceptable increase in temperature and unstable mechanical conditions. Very few joints have been reported to

display failure resulting purely from mechanical loads.

The reported events involving basically mechanical failures have occurred on joints that have been asymmetrically installed, where the ingress of the aluminium layers of an ACSR at one end of the joint has been less than 2,5 times the conductor diameter.

Detection of asymmetrically installed aluminium sleeves on ACSR conductors can be performed by a reluctance test. Detection of asymmetrically installed aluminium and steel sleeves on ACSR can be performed by a radiographic test.

Mechanical failures of ACSR joints caused by corrosion of the steel core on ACSR conductors, causing mechanical failure of joints, have not been reported so far. However, intense corrosion of the steel core has been detected in the vicinity of the steel sleeve. Detection of this corrosion can be performed with a boroscope test.

5.1 Main Reasons for the Failure of Joints

The main reasons for the failure of joints have been identified as follows: corrosion of the aluminium contact surfaces, improperly cleaned conductors, and asymmetric installation of the aluminium sleeve and steel sleeve (on ACSR). All these reasons for failures can be attributed to an increased resistance across the joint. The total resistance across the joint consists of the conductor resistance, the sleeve resistance and the contact resistance. Only the latter will change with time in ser-

vice.

Since the stranding creates a non-homogenous conductor and the compression of the joint does not completely eliminate the voids between strands, water, sometimes contaminated, will penetrate the joint. The water will then remain in the cavities until it evaporates through the air gaps inside the conductor. This will take time, depending on the temperature in the joint and the humidity in the surrounding atmosphere.

The water will, during the time inside the joint, change the oxygen content along the route, creating differences in potential. The difference in potential will create crevice corrosion in the aluminium, inside the joint. The time it takes for the water to dry influences the severity of the crevice corrosion.

Corrosion of the steel core is generally a result of galvanic corrosion. It has been observed that when the temperature of the galvanised steel core rises above 60°C, the protective role of the galvanising with respect to the steel can be reversed. The steel then “protects” the galvanising.

5.2 Distribution of Resistance Along a Compressed Joint

The resistance of a compression-type joint has been found, by laboratory measurements, to be distributed in the following way:

- The first part of the resistance, the entrance of the joint (marked as L1 on Figure 1), includes a portion of the conductor, a portion of the aluminium sleeve and the contact

resistance.

- The second part of the resistance, the compressed part of the joint (marked as L2 on Figure 1), includes a portion of the conductor and a portion of the aluminium sleeve resistance.
- The third part of the resistance, the uncompressed part of the joint (marked as L3 on Figure 1), includes a portion of the aluminium sleeve and the steel sleeve. The resistance of the steel sleeve can be neglected in the calculation, in the same way as the steel core resistance can be neglected in an ACSR conductor due to its very high resistance.

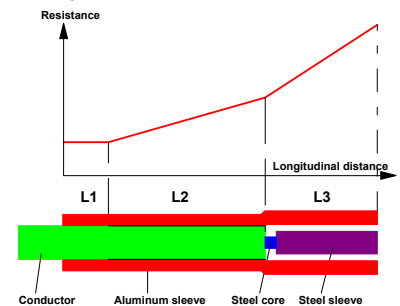


Figure 1 Distribution of Resistance in Joints

5.2.1 Calculation

The following empirical model for calculation can be used.

$$R_s = \frac{1}{\frac{1}{R_c \cdot 2(L_1 + x)} + \frac{1}{R_{asc} \cdot 2 \cdot L_1}} + \frac{R_{con}}{D} \cdot 2 \cdot L_2 + \frac{1}{\frac{1}{R_c \cdot 2 \cdot L_2} + \frac{1}{1,08 \cdot R_{asc} \cdot 2 \cdot L_2}} + R_{as} \cdot 2 \cdot L_3$$

Where

- R_s = joint resistance [$\mu\Omega$]
- D = conductor diameter [m]
- L_1 = length of entrance [m]
- L_2 = length of contact area [m]
- L_3 = length of uncompressed part [m]
- x = length of conductor outside joint [m]
- R_c = conductor resistance [$\mu\Omega/m$]
- R_{as} = aluminium sleeve resistance, uncompressed [$\mu\Omega/m$]

R_{asc} = aluminium sleeve resistance, compressed [$\mu\Omega/m$]

R_{con} = contact resistance [$\mu\Omega$]

The contact resistance (R_{con}) is dependent on the type of compression used, e.g. hydraulic or impulsive, intermediate or continuous, hexagonal or concentric. It can be determined experimentally.

5.2.1.1 Example

The following calculation example is given for an ACSR ZEBRA conductor joint having the following dimensions; $D = 0,0286$ m, $L_1 = 0,075$ m, $L_2 = 0,155$ m, $L_3 = 0,132$ m, $x = 0,005$ m, $R_c = 67,4 \mu\Omega/m$, $R_{as} = 19,5 \mu\Omega/m$, $R_{asc} = 21,4 \mu\Omega/m$, $R_{con} = 60$ n Ω ;

$R_s = 13,76 \mu\Omega$ and the conductor resistance for the joint length will be: $R_c = 49,54 \mu\Omega$.

The calculations show that this new joint has a resistance of 28% of that for the same length of conductor.

6. FIELD TESTING METHODS OF JOINTS

The electrical resistance of a joint is the main factor for assessing its condition. It can be determined using temperature measurement methods, resistance measurement methods or both.

It is not possible to detect the asymmetrical installation of joint sleeves using a temperature measurement method since the temperature distribution in the aluminium will be too uniform.

When using a resistance measurement, an asymmetrical installation of the aluminium sleeve results in too small a difference in the obtained resistance value to be detectable. Calculations of the change in resistance over a joint indicate that an asymmetry of 20 mm will give the same increase in the resistance as a temperature increase of 1°C and a doubling of the contact resistance gives an increase of 10°C at maximum conductor design temperature.

Detection of asymmetrical installation of the aluminium sleeve on ACSR conductors can be performed by a reluctance test.

Detection of asymmetrical installation of the aluminium sleeve on AAC, AAAC and of the steel sleeve of ACSR conductors can be performed by a radiographic test.

Detection of steel core corrosion in the vicinity of a steel sleeve can be performed by visual inspection with a boroscope.

These **different test** methods are described in detail in the following sections.

6.1 Temperature Measurement Tests

The reliable measurement of joint

temperature is highly dependent on the current flowing through the joint. For example, a current of $0,4 \text{ A/mm}^2$ gives a temperature difference of only 7°C between the conductor and the joint when the joint has a contact resistance 65 times larger than the contact resistance of a new joint (Figure 2). Since the thermal conductivity of aluminium is very high, the temperature will be equalised along the joint. It would therefore be difficult to detect joints that have an unacceptable contact resistance at one end, but a lower resistance at the other end. Also, the higher resistance at one end will not be detected if the resistance is measured across the entire joint. To increase the chance of detecting defective joints, the current flow in the overhead line should be increased as much as possible. The temperature detection along the joint gets more difficult under some ambient conditions when the heat generated in the joint is transferred to the surroundings e.g. rain, snow or high wind velocities.

Figure 2 shows conductor and joint temperatures taken from an existing transmission line that has been in service for 40 years, obtained during indoor laboratory tests with direct currents. The labels on Figure 2 indicate the resistance of the used joints (R_j) as compared to the resistance of a new one (R_{j0}).

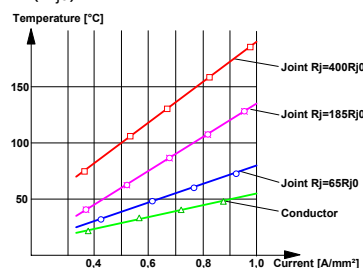


Figure 2 Joint Temperature as a Function of Phase Current

6.1.1 Infrared Photography

Infrared photography detects heat radiated in the infrared spectrum [1]. Detected temperatures at the joint are compared with detected temperatures at the conductor. The resolution is normally 1°C . Infrared photography can be performed from the ground or from a helicopter. In the following subsections both methods are described.

Measurement of temperature by infrared photography can be a time-saving method enabling a utility to get a good

indication of the condition of the joints along a line.

The infrared energy measured by the instrument pointed at the object of interest is the sum of the energy emitted, in a specific wavelength window, by the object itself and of the ambient energy radiated by the surroundings and reflected by the object towards the instrument. The latter, in the case of very reflecting objects (with low emissivity coefficient), can be a considerable proportion of the total measured energy and it is essential to accurately determine its value in order to determine the actual amount of energy emitted by the object. The surface structure will also influence the radiated energy.

A joint over-temperature is usually detected by comparing the brightness of the joint, with the unaided eye, on the screen with a suitable reference. This reference is usually the ground, the other half of the joint or the conductor when airborne surveying is used. In order to detect the over-temperature, the joint must appear brighter than the reference on the screen. Due to the lower emissivity of the joint compared with the ground, a fault-free joint appears darker than the ground, because the radiation from the cold sky is partly reflected from its surface. The colder the appearance of the sky and the lower the emissivity of the joint, the darker the joint appears on the screen. Therefore the less overcast the sky, or the higher the cloud ceiling, the higher the over-temperature needed for the joint to appear bright. Consequently a defective joint becomes more difficult to detect without making point measurements. This relationship is shown in Figure 3. In order to generalise the diagram the radiation temperature of the sky is plotted on the horizontal axis as an under-temperature when compared with ambient or the ground. The plotted curves show the critical joint over-temperature above ambient that is needed for the joint to appear brighter than the ground, on the screen, for different emissivities. One advantage of this plot is that the results are more or less independent of the ambient temperature even though this specific diagram is plotted using an ambient temperature of 0°C . The diagram shows that when a thermo-

graphic inspection is made under good conditions, e. g. emissivity of 0,5 and under-temperature of the sky of -15°C , the critical joint over-temperature is approximately 8 to 12°C . This means that the temperature of the joint will be an average of 10°C higher than that of the conductor.

NOTE: The relationship between temperature and emissivity is given by the Stefan-Boltzmann law.

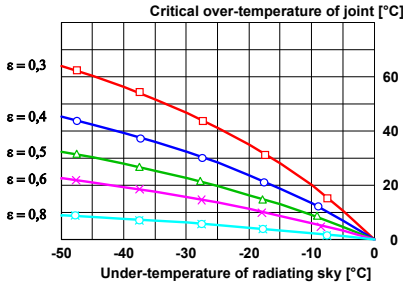


Figure 3 Critical Over-Temperature Needed for a Faulty Joint to be Detected

When a thermographic inspection is performed from the ground, the situation is different. The joint is always shown on the image as brighter than the background. Therefore it is not possible to visually detect joints with an over-temperature. Instead, the temperature of every joint must be measured with a camera having a sufficiently high resolution [1] and compared with other joints.

6.1.1.1 Effect of Weather Parameters

It has been observed that the results of infrared photography are not only highly dependent on the weather conditions but also on the interpretation of the image. Most of the atmospheric interference, e.g. background light, light reflection, solar heating (e.g. overcast), should be reduced to a minimum. As far as meteorological conditions are concerned, measurements carried out with different conditions of solar radiation (from cloudy to clear sky) have indicated that the infrared cameras that operated over a wave length range of 8-12 μm are less influenced by illumination conditions. Further, the wind velocity has a strong influence since the projected surface of the joint is approximately twice the surface of the conductor. The objective should be to make the measurements under the following weather conditions:

- Overcast sky.
- Wind velocity less than 1 m/s.

- No atmospheric precipitation.

6.1.1.2 Emissivity Coefficient [1]

Figure 4 shows the error of measurements (the average error obtained with different infrared cameras), as a function of the emissivity coefficient assumed for the joint [1]. The measured temperature is particularly influenced by the assumed emissivity, especially for low values. It should be noted that the emissivity is dependent on both the length of time that the joint has been in service and the amount (and type) of pollution prevailing at the line section being studied.

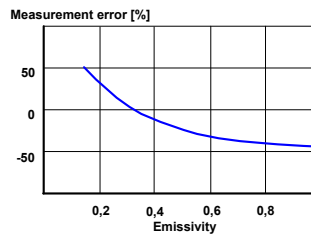


Figure 4 Measurement Error as a Function of Emissivity [1]

Measurements performed on ACSR conductors [2] that had been in service for different periods, indicated that both the emissivity and the absorptivity reach a high level over a period of five to ten years. Figure 5 shows a typical profile of the change in absorptivity and emissivity of a joint over time in service. It should be noted that the actual speed of increase depends on the environment.

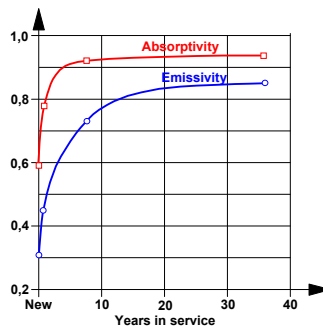


Figure 5 Typical Absorptivity and Emissivity as a Function of Time [1]

6.1.1.3 Distance to Detected Object

The average errors as a function of the distance to the joint for different infrared cameras are indicated in Figure 6 [1]. The results show that, in general, instruments with a smaller field of view and better resolution allow more accurate measurements to be obtained at longer distances. In particular an infrared camera with a zoom lens

showed that the use of the zoom increased the measuring performance at greater distances. However, the use of this narrow type zoom for measurements by helicopter is not recommended because of difficulties in focussing on the objects.

One infrared camera offered the possibility of automatically changing the objective, which is particularly useful for measurements made from a helicopter. Initially, a wide lens objective is used and once a hot spot is located it is possible to measure its temperature with a high precision using a 5° window.

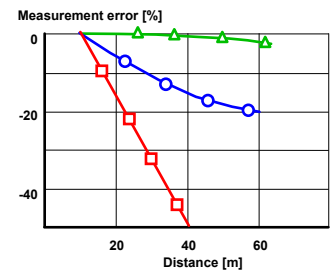


Figure 6 Measurement Error as a Function of Distance to the Object for Different Infrared Cameras [1]

6.1.1.4 Temperature Rise

In order to obtain reliable values with the infrared method, the current loading of the overhead transmission line should be such that the temperature rise in the conductor would be at least 20°C above ambient. At lower temperature rises, detection of problematic joints will be more difficult or even impossible.

6.1.1.5 Data to be Recorded

The following data should be recorded during the infrared inspection:

- Temperature of the joint.
- Temperature of the conductor or the temperature difference between conductor and joint.
- Ambient temperature.
- Electrical load in the conductor.
- Wind velocity and direction.
- Ground/sky radiated temperature.

The interpretation of the results is difficult since the infrared measurement is influenced by so many parameters. It is recommended that the test records should include well-documented weather and loading data for the individual joints being assessed. A low over-temperature under some weather and load conditions

may give a high over-temperature under other service conditions.

6.1.2 Thermocouples

The thermocouples to be used should be either of the Pt-detector (resistance) or the K-detector (bimetallic) type. The contact shape, measuring range, accuracy and the measurement time for the thermocouple should be appropriate for the purpose of the test.

6.1.2.1 Effect of Weather Parameters

It has been observed that the results of temperature measurements of joints are highly dependent on weather conditions. Most of the atmospheric interference e.g. background light, light reflection, solar heating, as well as the absorptivity and emissivity factors do affect the results. In addition, the wind velocity has a strong influence since the projected surface of the joint is approximately twice the surface of the conductor. Also atmospheric precipitation has a very strong influence on the obtained results. Since no studies have been carried out on the effect of rain, it is recommended that the use of any formulae that are available for temperature calculation with rain or other precipitation be avoided.

6.1.2.2 Temperature Rise

The current loading for the overhead line should be such that the temperature rise in the conductor would be at least 20°C above ambient, to increase the probability of obtaining reliable values. At low temperature rises the probability of detecting faulty joints will be lower.

6.1.2.3 Data to be Recorded

The following data should be recorded during an inspection with thermocouples.

- Temperature of the joint.
- Temperature of the conductor.
- Ambient temperature.
- Solar radiation.
- Absorptivity coefficient for the joint.
- Absorptivity coefficient for the conductor.
- Wind velocity and direction.
- Electrical load in the conductor.

6.1.2.4 Contact Points for Measurements

The temperature of the joint should be measured at each crimped contact part of the joint where the heat is gen-

erated (Figure 7).

The temperature of the conductor should be measured at a sufficient distance from the end of the joint such that the conductor temperature will not be influenced by the joint (Figure 7).



Figure 7 Temperature Measurement

6.1.3 Interpretation of Results

The temperature measured under actual weather conditions should be translated to that which would be measured under more typical ambient conditions. For example: 20°C ambient temperature, 1 m/s wind velocity, 45° wind angle to the conductor, sea level, and solar noon, in order to improve the interpretation of the obtained data from different test conditions.

The calculation procedure for the translation of the measured temperature for the purpose of this comparison should take into consideration the heat distribution along the joint and towards the conductor. It should be noted that the steady state model for the heat balance calculation in conductors introduced in [5] does not deal with joints.

From the calculated temperature values for the joint, the maximum value should be used for comparison with the appropriate acceptance criterion (see Section 7.1.1).

6.2 Resistance Measurement Method

The resistance should be measured from the conductor, in the vicinity of the joint, to the centre of the joint (Figure 8). The resistance measurement should be taken for each half of the joint since the degradation along the joint could be different. It has been observed that out of all joints with an increased resistance, around 10% have unacceptable degradation over just one half of the joint.

It is worth noting that the calculation method given in Section 5.2.1 allows the contact resistance to be measured without measuring all parts of the material involved in the joint, and that the user will be mainly interested in the incremental increase of contact resistance.

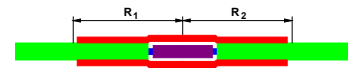


Figure 8 Resistance Measurement Method

6.2.1 A.C. Resistance Measurement on a Live Line

In order to obtain a meaningful value of the measured voltage drop, the level of current in line should be appropriate for the resolution of the measuring instrument used [3]. It should also be noted that since resistance is a function of temperature, it is also necessary to measure the conductor and joint temperatures.

The following measurements should be made.

- Temperature of the conductor.
- Temperature of the joint.
- A.C. voltage drop over each half of the joint.
- Electrical load in the conductor.
- The position of the measuring points.

6.2.1.1 Contact Points for Measurements

The contact points should be such that they give good contact with at least one of the conductor strands. The distance between the end of the joint and the contact point should be as equal as possible for all measurements.

The temperature of the joint should be measured at each crimped contact part where the heat is generated. The thermocouples to be used should be in accordance with Section 6.1.2.

The temperature of the conductor should be measured at a sufficient distance from the end of the joint such that the conductor temperature will not be influenced by the joint.

6.2.2 D.C. Resistance Measurement on a Non-Energised Line

To derive a reliable value of the voltage drop, at least four different D.C. currents should be applied in sequence. The current-feeding contacts should be installed on the conductor at a distance of at least half a meter from the end of the joint in order to have the current distribution equalised in all strands. It should also be noted that since resistance is a function of temperature, it is also necessary to measure the conductor and joint tempera-

tures.

The following measurements should be made.

- Ambient temperature.
- Temperature of the joint.
- D.C. voltage drop over each half of the joint.
- Current load in the conductor.
- The position of the points of measurement.

There are instruments available on the market, which display a calculated resistance rather than the voltage drop. When using this instrument the measurement of the current load in the conductor could be neglected.

The measurement of the D.C. voltage drop should be made from the conductor, in the vicinity of the joint, to the mid-point of the joint from both ends in order to obtain the resistance over each half of the joint.

6.2.2.1 Current-Feeding Contacts

The current-feeding contacts should be such that they give good contact and distribution of the current in all strands of the conductor. A recommended minimum distance between the joint or measuring contact and the feeding contact is 0,5 metres.

6.2.2.2 Measurement Contacts

The measuring contacts should be such that they give good contact to at least one of the conductor strands. The distance between the end of the joint and the contact should be as equal as possible for all measurements.

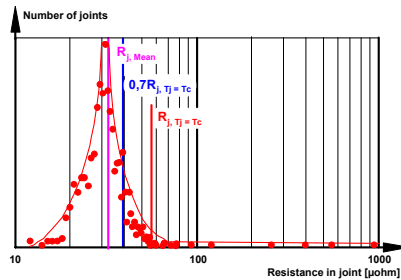
The temperature of the joint should be measured at each crimped contact part where the heat is generated. The thermocouples to be used should be in accordance with Section 6.1.2.

6.2.3 Interpretation of the Results

The ratio of joint- to conductor resistance is widely spread over the range of conductors used, even for the same design of joint, e.g. 10 to 45% for one type of joint. These circumstances indicate that it is not practical to use the ratio of joint- to conductor resistance as a criterion for the interpretation of results.

It is recommended that the joint resistance R_{joint} , is classified according to three reliability levels for each combination of conductor and joint using the same parameters as in the current carrying capacity calculation for con-

ductors, (see Figure 9). For the interpretation of results, all resistance values should be translated to the same temperature, for example 20°C. Out of the calculated resistance values for the joint, the maximum value should be used for comparison with the appropriate acceptance criterion (see Section 7.1).



Where: R is resistance, T temperature, j joint and c conductor

Figure 9 Distribution of Resistance in a Population of Joints

Figure 10 illustrates the effect of the joint resistance at different temperatures and loading, for ZEBRA conductor.

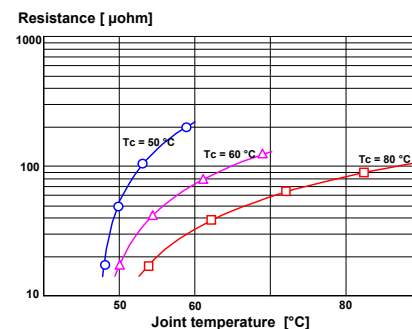


Figure 10 Joint Resistance Versus Temperature

6.3 Reluctance Tests

The aim of the reluctance test is to detect the asymmetrical installation of the aluminium sleeve on ACSR conductors by measuring the magnetic resistance (reluctance) of the joint.

6.3.1 Set-up of the Reluctance Test Equipment

The asymmetry of the aluminium sleeve versus the steel sleeve should be detected by the use of a magnetic detector. The detector should be thoroughly calibrated for the actual type and size of joints with the aim of giving a proper detection of each end of the steel joint. It should be taken into consideration that the compression joint might be bent so that the steel core is not concentric inside the alu-

minium sleeve. Furthermore, the increased distance from the outer surface to the steel sleeve should be taken into account when the aluminium sleeve has an uncompressed section in the middle.

The transducer should slowly be carried along the joint axis and when the ends of the steel joint are detected, those points should be marked.

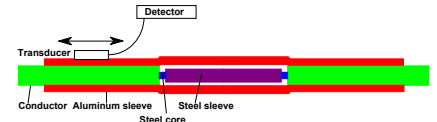


Figure 11 Reluctance Test Set-up

6.3.2 Interpretation of the Results

The ratio of joint- to conductor depth of engagement ($\Sigma L1+L2$ in Figure 1) is widely spread for the same type of conductor, due to the use of different crimping factors. In turn, the depth of engagement is a factor of both mechanical and electrical behaviour. This indicates that the ratio of joint- to conductor depth of engagement should be used as a criterion for the interpretation of the asymmetry.

Out of the calculated asymmetry values for the joint, the maximum value corresponding to the appropriate acceptance criterion should be used (see Section 7.1).

6.4 Radiographic (X-ray) Tests

The aim of the radiographic test is to detect asymmetrical installation of the aluminium sleeve on AAC, AAAC, ACAR, and ACSR conductors as well as the asymmetrical installation of the steel sleeve on ACSR conductor cores.

6.4.1 Set-up of the Radiographic Equipment

The X-ray film should be placed on the top of the joint. The exposure should be selected in such a way so as to allow the detection of the end of the steel core within the steel sleeve. Because it may be difficult to detect the ends of the aluminium sleeve, the ends of the aluminium sleeve should be marked with straps of lead.

The X-ray tube should be hung beneath the conductor at a distance such that a suitable exposure time and beam angle will be maintained.

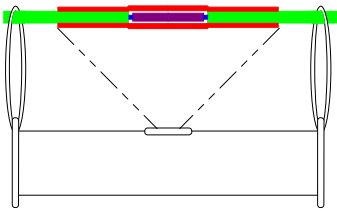


Figure 12 Set-up of Radiographic Equipment

6.4.2 Interpretation of the Results

Since there are different types and dimensions of joints on the market that may result in different image effects at the radiogram, the interpreter should be familiar with the particular type of joint under consideration.

The ratio of joint- to conductor depth of engagement is widely spread for the same type of conductor, due to the use of different crimping factors. In turn, the depth of engagement is a factor of both mechanical and electrical behaviour. This indicates that the ratio of joint- to conductor depth of engagement should be used as a criterion for the interpretation of the asymmetry.

Out of the calculated asymmetry values for the joint, the maximum value corresponding to the appropriate acceptance criterion should be used (see Section 7.1).

6.5 Boroscope Test

The aim of the boroscope test is to detect corrosion of the steel core in ACSR conductors, in the vicinity of the steel sleeve.

If the joint has been filled with grease during installation, the boroscope test is not useful.

6.5.1 Set-up of the Boroscope test

Before detection, a hole, with an appropriate dimension for the lens, should be drilled through the aluminum sleeve in the immediate vicinity of each end of the steel joint. It should be noted that the wire strands of the steel core must not be damaged by this procedure.

The detector should be equipped with an internal light for illumination of the zone to be inspected.

After the inspection has been performed, the drilled holes should be sealed with aluminium plugs.

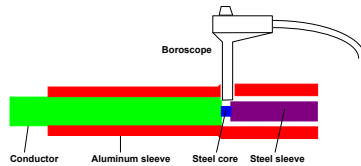


Figure 13 Set-up of the Boroscope Test

6.5.2 Interpretation of the Results

The interpreter should be aware that the image of the surface of the steel core will depend on the type of corrosion protection applied to the steel sleeve, i.e. red lead paint, zinc-rich paint, hot dip galvanising, oil rich paste, or other treatments.

From of the images of the corrosion of the steel core, the worst-case image should be used, corresponding to the appropriate acceptance criterion (see Clause 7.1).

7. REPLACEMENT OF JOINTS

This section covers the acceptance criteria for joints as well as the methods of replacing joints that do not meet the requirements specified in this paper.

7.1 Acceptance Criteria

To reach a higher degree of confidence in the joints on an old transmission line, a set of acceptance criteria should be determined. The criteria could be given for three levels of reliability, reflecting the importance of the line in terms of its sensitivity to outages, the occurrence of line crossing points and the risk to people beneath the line. The transmission line owner should state the requirements for the reliability of the particular section of the line where the joints are installed.

Since there is the ability to run standard conductor types (ACSR, AAC, AAAC and ACAR conductors) at temperatures up to 100°C and many countries assume a maximum normal design temperature of less than 75°C the resistance of the joint will be the triggering value for immediate replacement. In that case the expectation of future increases in current loading should be taken into account.

7.1.1 Criterion Levels for the Resistance or the Temperature of the Joint

The three recommended criterion levels for resistance or temperature are:

- 1) For joints where a failure and a drop of the conductor have a high influence and endanger the reliability of the line: $R_{joint} < 0,7R_{j,Tj=Tc}$
- 2) For joints where a failure and a drop of the conductor have an influence and jeopardise the reliability of the line: $R_{joint} < R_{j,Tj=Tc}$
- 3) For joints where a failure and a drop of the conductor have a low influence on the reliability of the line. $R_{joint} < R_{j,Tj=Tc+10K}$

Note: 1 The first level expresses in other words that the joint resistance should be less than 70% of the calculated resistance value at which the joint and the conductor would be at the same temperature.

Note: 2 The third level represents approximately the limit of possible detection by infrared photography under very good conditions (see section 6.1.3).

Figure 14, [5] illustrates a typical graph of the three levels of acceptance criteria calculated for hydraulically compressed Zebra conductor joints.

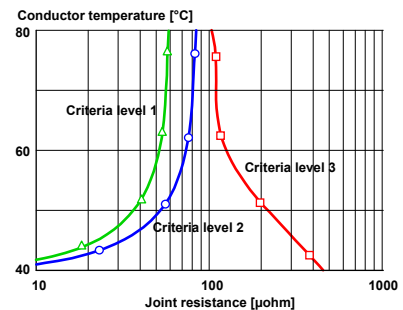


Figure 14 Acceptance Criteria for Joints

Example, taken from figure 14, of acceptable joint resistances at the three different criterion levels.

| Criterion level | Joint resistance [$\mu\Omega$] at conductor temperature | |
|-----------------|---|-------|
| | 50 °C | 80 °C |
| 1 | 36 | 58 |
| 2 | 52 | 83 |
| 3 | 216 | 102 |

7.1.2 Criterion Levels for the Asymmetry of a Joint

The recommended criterion levels for asymmetry are:

- 1) For joints where a failure and a drop of the conductor have a high

influence and endanger the reliability of the line: Asymmetry < 7% of the intended depth of engagement

- 2) For joints where a failure and a drop of the conductor have an influence and jeopardise the reliability of the line: Asymmetry < 12% of the intended depth of engagement
- 3) For joints where a failure and a drop of the conductor have a low influence on the reliability of the line: Asymmetry < 18% of the intended depth of engagement

7.1.3 Criterion Levels for the Corrosion of the Joint

The recommended criterion levels for corrosion are:

- 1) For joints where a failure and a drop of the conductor have a high influence and endanger the reliability of the line: No signs of corrosion, "rust strain"
- 2) For joints where a failure and a drop of the conductor have an influence and jeopardise the reliability of the line: No signs of severe surface corrosion, "layer of rust"
- 3) For joints where a failure and a drop of the conductor have a low influence on the reliability of the line: No signs of pitting corrosion, "deep-seated rust"

Note: If surface corrosion has been detected, the joint may not require replacement if the joint will be filled with grease.

7.2 Repair Joints

Two types of repair joints could be used: one type for mechanical reinforcement and one type for electrical reinforcement.

7.2.1 Mechanical Reinforcement

The mechanical reinforcement type of repair joint consists of preformed armour rods. The repair joint is intended to be installed over the existing joint to enhance its mechanical performance.

It should be noted that a resistance measurement after installation might not give the appropriate information about the electrical performance.



Figure 15 Joint Repair - Mechanical Reinforcement

7.2.2 Electrical Reinforcement

The electrical reinforcement type of

repair joint consists of a length of conductor and two parallel groove clamps. The repair joint is intended to be installed over the existing joint to enhance its electrical performance.

The preparation of the contact surfaces should include mechanical cleaning in order to obtain a low contact resistance. It is also recommended that protective grease be applied. This should be brushed on with a steel brush at these surfaces before installation.



Figure 16 Joint Repair - Electrical Reinforcement

7.3 Extended Joint

When the replacement of a joint must be performed by the use of an extended joint, the old joint and approximately 50 mm of the conductor should be cut out. The length of the extended joint should be such that the middle section has the same length as the cut out part and with adequate length at both ends to take care of the mechanical and electrical loads (Figure 17).

The preparation of the old conductor should include mechanical cleaning of the contact surfaces intended to be inserted in the aluminium sleeve in order to obtain a low contact resistance. It is also recommended that protective grease be applied. This should be brushed on with a steel brush at these surfaces before compression. Also, the contact surfaces of the aluminium sleeve should be prepared in the same manner.

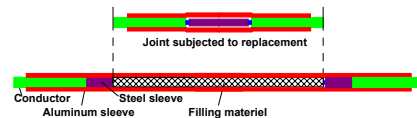


Figure 17 Extended joint

After installation of the extended joint a resistance measurement in accordance with Section 6.2 should be performed.

7.4. Two Joints with an Insert of a Length of New Conductor

When the replacement of a joint must be performed by the use of two new joints and a section of new conductor (Figure 18) the new conductor should have a length of at least 1000 times the conductor's outer diameter. In this case it should be noted that the temperature of this inserted length would

not be the same as for the old blackened conductor. Even the difference in mechanical behaviour such as creep should be taken into account for conductors with a high creep rate in short spans.

The preparation of the old as well as the new conductor should include mechanical cleaning of the contact surfaces intended to be inserted in the aluminium sleeve in order to obtain a low contact resistance. It is also recommended that protective grease be applied. This should be brushed on with a steel brush at these surfaces before compression.

Also the contact surfaces of the aluminium sleeve should be prepared in the same manner.



Figure 18 Two joints with a section of a new conductor

After installation of the joints a resistance measurement in accordance with Section 6.2 should be performed.

8. REFERENCES

- [1] F. Tavano et al. "Diagnostics of compression joints of conductors for HV overhead lines", CIGRÉ Session 1998, paper 22-206.
- [2] A. Davidson et al. "Thermal ratings for bare overhead conductors", IEEE/PES Winter Meeting, New York, January 27 – February 1, 1974.
- [3] J. Örmín, J. Bartsch "Hot line inspection and control of joints", CIGRÉ Session 1998, paper 22-203.
- [4] "The thermal behaviour of overhead conductors, Section 1 and 2: Mathematical model for evaluation of conductor temperature in the steady state and the application thereof", Electra No 144, SC22 WG12.
- [5] H. E. House, P. D. Tuttle "Current-Carrying Capacity of ACSR", AIEE Transactions, February 1959.