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STUDY OF CONTACT AREA AND RESISTANCE IN CONTACT DESIGN OF TUBING CONNECTIONS

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ABSTRACT

Within offshore installations, making pipe couplings to conduct electricity is a developing interest. Being able to use tubing structures to carry the drive electric power, that is necessary downhole, helps to avoid installation of cables and lines. The challenge is to be able to make the connection good enough so that the necessary power is transferred to the connected piping dowhole with minimum possible loss. At the same time, the connection has to secure the transfer of the voltage at the output side of the piping without any danger of overheating the connection. An overheating can eventually result in a welded connection between the mating piping.

As the capability of the connection to transfer power through the piping is based on the size of the contact area, the material type, the surface topography and most importantly, the connection strength, contact resistance is a limiting design factor in electrical contact design. This paper presents the result of a study performed on the electrical contact resistance of pipe couplings intended for offshore installations. The objective of the study is to investigate the influence of contact pressure (level of press fit) and contact area on the contact resistance.

Keywords: Contact resistance, surface roughness, press fit, conductivity, contact design

1. INTRODUCTION

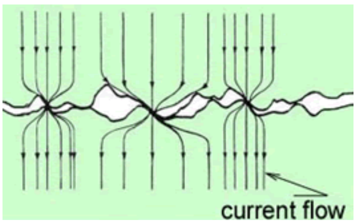
Within offshore installations, making pipe couplings to conduct electricity is a developing interest. This drives from the need to be able to use tubing structures to carry the drive electric power necessary downhole and to avoid installation of cables and lines. The challenge in this attempt is to make the connection good enough to transfer up to 100 A and 1 kV while the pipes are centered. The connection should transfer the necessary power to the connected piping dowhole with minimum possible loss and at the same time, the connection has to secure the transfer of the voltage at the output side of the piping without any danger of overheating the connection. An overheating can eventually result in a welded connection between the mating piping.

The capability of the connection to transfer power through piping connection is based on the size of the contact area, the material type and most importantly, the connection strength. The contact area and the connection strength are influenced by the level of the press fit, the surface roughness and mechanical properties of the surfaces. These parameters indicate that the level of electrical resistance is a limiting design factor in electrical contacts of many engineering systems and applications. Designing effective electrical contacts with optimized resistance or minimized power loss requires research both at the macro, micro and nano level. Research shows that the major portion of electrical contact resistance comes from the lack of ideal mating between surfaces where the surface roughness is the primary causes of this problem. A study by Holm [1] indicates that the actual contact area of two mating surfaces may be much smaller than the apparent contact area. Further, the result from a study by Avsarala and Haldar [2] shows that surface topography has a significant impact on the contact resistance of composite bipolar plates.

This paper focuses on effect of contact pressure (contact force and area) on contact resistance of pipe couplings designed for use within the offshore field so that the couplings can transfer electric power for the downhole installations. Among others, the study attempts to get answers on the voltage drop for each coupling and the variation as a function of type of current source (AC and DC) and the contact pressure.

2. FUNDAMENTAL THEORY OF CONTACT RESISTANCE

According to Mroczkowski [3], an electrical connector is an electromechanical system that provides a separable interface between two sybsystems of an electrical system without an unacceptable effect on performance of the system. As the schematic diagram in Figure 1 (adapted from Timsit [4]) illustrates, the electrical connection between the two mating surfaces takes place at discrete solid spots, also known as α-spots or asperities, based on the roughness of the surfaces. These spots determine the true size of the contact area that can be as small as only a fraction (about 1%) of the nominal contact area.



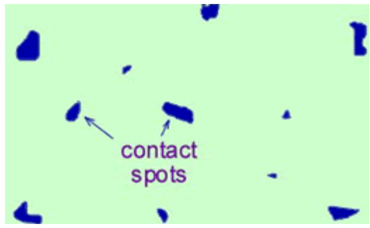


Figure 1. Schematic diagram of current flow (left, top view) through contact spot (right, top view)

The size of the true area of contact with respect to the apparent contact area affects not only the contact resistance, but also the mechanical property of the surfaces because α-spots must support local mechanical pressures that are larger than the yield strength of the materials in contact. The consequence of this high mechanical pressure is that contacting asperities deform permanently and the deformation level depends on their mechanical hardness. Thus, the deformation mode of contacting asperities allows an evaluation of contact resistance in terms of hardness and contact force. For monometallic contact surfaces that are free of insulating contaminants, the contact resistance (R) is given as [1, 3, 4];

$$R = \rho\sqrt{\frac{\pi \cdot H}{4F}} \qquad \text{.......... (1)}$$

where ρ is the electrical resistivity of the contacting materials, H is the Vickers' hardness of the softer of the contact surfaces, and F is the contact force.

The number of contact spots (Figure 2 right) increases when the two materials are polished. This increases the size (the diameter if the α-spots are assumed circular) of the α-spots. Accordingly, the resistance in one contact spot (R_c) can be calculated from the following relation:

$$R_c = \frac{1}{2a}\left(\rho_1 + \rho_2\right) \qquad \text{.......... (2)}$$

where a = diameter of asperity and ρ_I is the electrical resistivity of material *i*.

3. EXPERIMENTAL SETUP

3.1. Materials and equipment

The experiment requires the following easily available equipment: power source (AC and DC), an ammeter, a voltmeter, plates of steel AISI 1330 and aluminum 6082 T6, and some wires. The materials have he following properties:

Material	Hardness, Vikers	Electrical resistivity [ohms-cm]	Thickness [mm]
Aluminum	15	$2{,}7\text{x}10^{-6}$	5
Steel	271	$1{,}74\text{x}10^{-5}$	5

3.2. Experimental method

The goal of this study is to decide the contact area needed to transfer the voltage and current required through the tubing connector. This experiment thus targets to find the required contact pressure that is a function of the contact area and the contact force. The study focused on two contact pairs: aluminum to aluminum contact pair and steel to steel contact pair. The setup of the actual tubing connection is as shown in Figure 2(left) where one pipe slides perfectly into the other with a certain level of press fit given by the contact force.

To make the experiment easier however, the setup in the right hand figure (Figure 2) was used where the contact area was generated by "rolling out" the tubes into two plates. This made the contact area flat plate instead of circular tubing. Among others, this last mentioned setup simplifies the way the contact loads and the contact area are varied. As shown below, the contact area was gradually varied from a large size to a smaller one by sliding the plates with respect to each other. The contact force due to press fit was then simulated by putting different loads (1 kg, 5 kg and 10 kg) on top of the two plates.

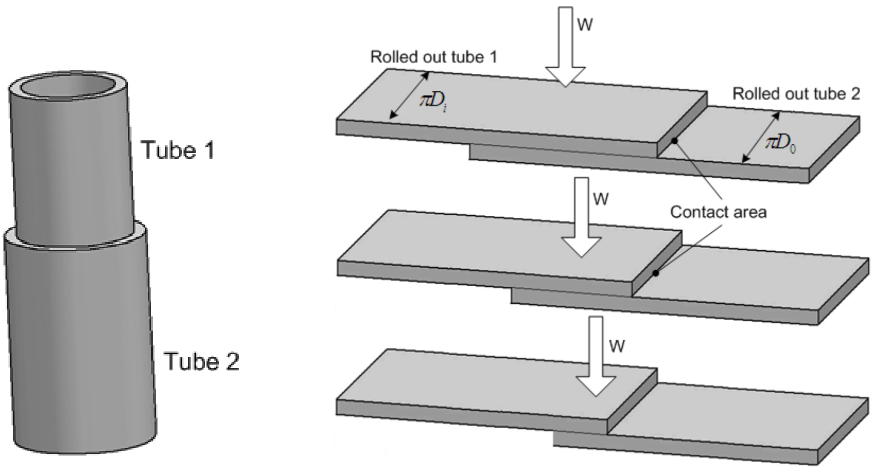


Figure 2. Test setup, two tubes in press fit (left), rolled out tubes into flat contacts (right)

4. DISCUSSION OF RESULTS

Figure 3 shows graphical plots of test results for Al-Al contact pairs for the two power sources, AC (LH figure) and DC (RH figure). Recalling Equation (1) it is simple to observe that the contact resistance decreases with increased contact force. The results in

Figure 3 also confirm this fact for all contact areas. When the contact force increases from 1 kg (10 N) to 5 kg and then to 10 kg, we observe that the voltage needed to get 100 A current decreases for all contact areas and power sources.

A decreasing voltage in other words indicates a decreasing resistance because the current was maintained at constant level. Ideally, the decreasing tendency of contact resistance with increasing contact force indicates that the contact takes place at several asperities when the contact force increases. Higher contact forces for the same contact area give higher contact pressure that can lead to an increased actual area of contact at the interface.

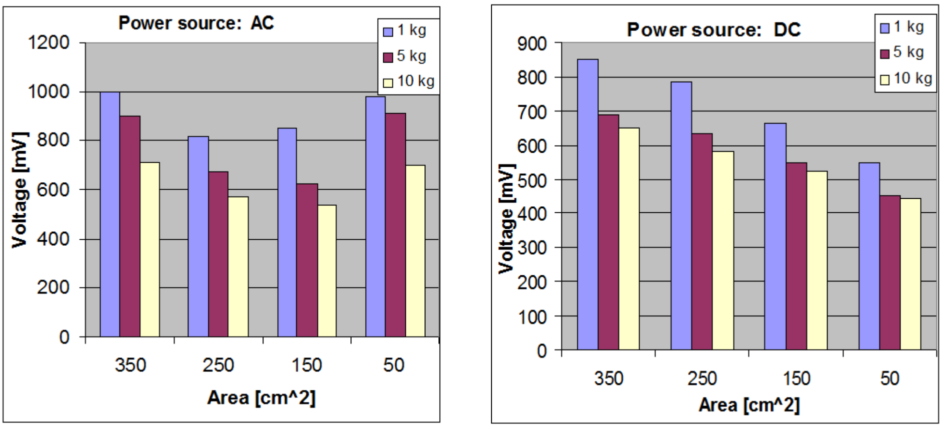


Figure 3. Plots voltage variation with contact area

Figure 4 shows plot of voltage drop as a function of contact area. The results for both Al – Al and steel – steel contact pairs are plotted only for one load case (10 N). These results show a general tendency of increasing contact resistance with contact area. The required voltage (1 kV) can be transmitted with contact area of about 350 cm^2 for aluminum pair while the needed contact area for steel pair is lower.

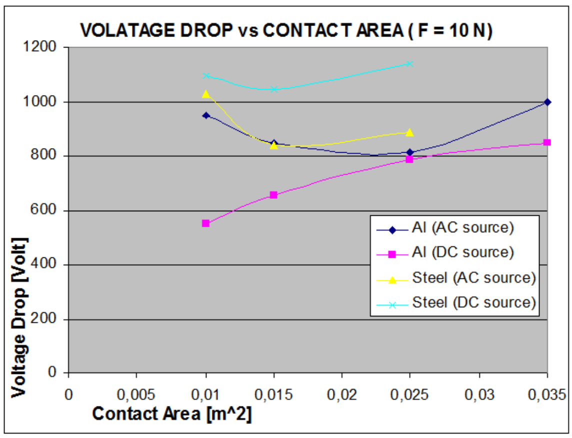


Figure 4. Plot of voltage drop for F = 10 N

5. CONCLUSION

The results of this study show a significant impact of the contact force (level of press fit) and contact area on the contact resistance. Though the results indicate that a contact area of 350 cm^2 is sufficient for aluminum pairs and lower values for steel pairs, these results are still subject to further verification. Further work in this direction includes a more controlled test and analytical calculations.

6. REFERENCES

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