Contact Resistance versus Pressure of Electrical Connections Used in Aluminium Smelter Potlines

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Abstract

The contact resistance of electrical connections used in aluminium smelter potlines are a source of wasted energy consumption. This excess energy consumption depends on initial contact surface cleanliness, contact pressure, contact area, and long term corrosion. The variability of contact resistance between the anode rod and anode beam (known as 'clamp drop'), and between the collector bar and flex connectors can cause uneven current distribution across the reduction cell which negatively impacts process performance. This research studies the correlation of contact resistance to contact pressure with different surface cleanliness and with nickel plating. The materials studied include aluminium and steel connections which are predominantly used in modern smelter anode and bus connections. The nickel plating is studied as a surface treatment to lower contact resistance of normally fast oxidizing surfaces such as aluminium, and to reduce long term corrosion between the contacting surfaces.

Keywords: Electrical contact resistance; energy consumption; clamp voltage drop; anode rod; anode beam.

1. Introduction

Approximately 160 mV [1] to more typically 300 mV of total voltage drop, depending on line amperage, or 4 - 7 % of total smelting power is consumed in the electrical resistance of the bus bar materials and interfaces, measured as external voltage drop from the collector bar/flex connection to the anode beam/rod stem interface. The contact resistance between the anode beam and rod stem is part of this total, however it demonstrates high variability due to poor rod surface condition, uneven clamping pressure and unpredictable contact area. The resulting voltage drop, also known as clamp drop as measured during smelter operation, may add over 35 mV to the total cell voltage drop [2].

This paper details laboratory research on contact pressure versus contact resistance for a range of aluminum and steel materials with varying surface conditions and the use of Hatch's nickel plating application for rod stems [3]. The results presented herein demonstrate the potential reduction in electrical contact resistance that may be obtained by either improving surface condition, increasing contact pressure or by nickel plating of these interfaces.

2. Electrical Contact Conditions

The electrical contact resistance between two surfaces, shown in Figure 1, is well known to be primarily a function of:

- Contact pressure: the higher the contact pressure ~ the lower the contact resistance.
- Contact area: the larger the contact area ~ the lower the contact resistance.
- Surface condition: the cleaner the contact surface ~ the lower the contact resistance.

These factors are generally independent of the contact materials, although the hardness and strength of the materials will limit the achievable contact pressure before they deform.

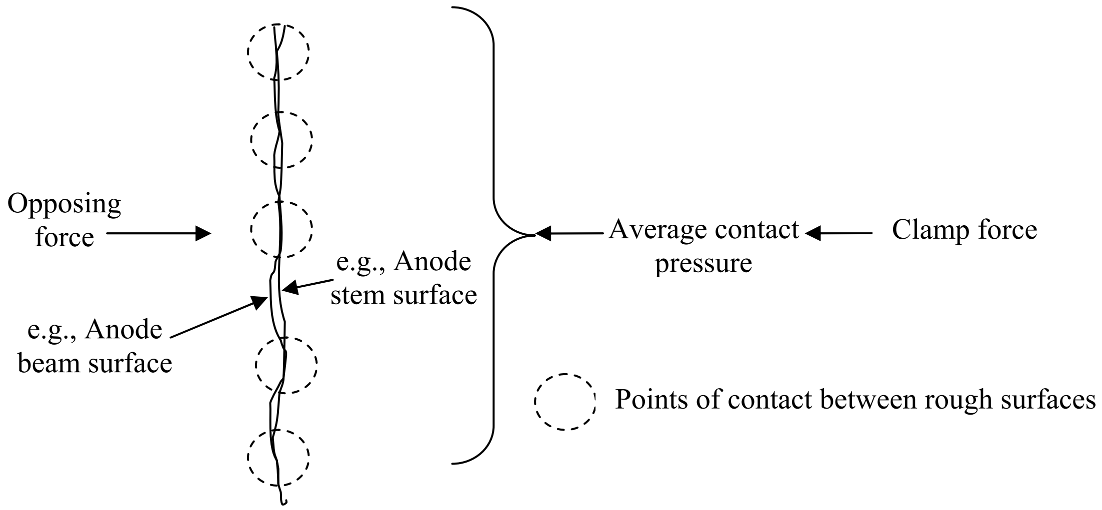

Figure 1. Closeup of electrical contact area between two surfaces.

The inverse conditions also apply to increase resistance. Any increased electrical resistance is a source of wasted power that does not contribute to the production of aluminum.

2.1. Rod stem and anode beam conditions

Rod stems are typically formed by direct chill continuous casting, without machining to a flat surface. During operation the stems are subject to local deformation from the anode beam clamps and the beam raiser machine clamps, oxidation, pitting from electric arcs, physical abrasion during beam raising, and uneven wear from repetitive rod brushing.

Anode beam contact surfaces are machined during manufacture, however during use the contact surface may be exposed to oxidation, physical abrasion against the rod stem, and pitting from electric arcs. Rod stems are clamped to the anode beam either across the entire anode beam/rod stem area, or on top of 'buttons' welded to the anode beam. Clamping the stem on the flat anode beam surface provides a large contact area, but results in low and uneven contact pressure. The use of contact 'buttons' typically used with copper rods and manually applied stem clamps can provide a higher contact pressure but only over a small contact area.

2.2. Anode beam clamp pressure and stem/beam contact pressure

The typical modern screw actuated stem clamp exerts two horizontal lines of contact pressure on the surface of the rod stem which are adequate to support the weight of the anode assembly and bath cover. This clamping force also provides the contact pressure of the rod stem to the anode beam to provide an acceptable electrical connection.

The ANSYS symmetric model shown in Figure 2 illustrates the transfer of clamp force from the clamp/stem interface to the stem/beam interface. The model used a typical clamp force of ~ 89 kN, resulting in a clamp contact pressure on the rod stem up to a maximum of 343.6 MPa over the very small area of the line of contact, while assuming contact over the full width of the stem.

- The relationship of the cleanliness of the surface for aluminum/aluminum connections.
- The use of nickel plating on aluminum showed similar behavior to that of 100 % cleaned aluminum; significantly lower contact resistance than that of 75 % clean aluminum.
- The nickel plated aluminum demonstrated significantly less increase in contact resistance versus 100% clean aluminum, after simulated aging by boiling in NaCl brine.
- The use of nickel plating on clean steel was shown to only introduce additional resistance.

The results of the nickel plating on the aluminum stem indicate a potentially significant reduction in contact resistance, and therefore potential power savings. Field tests are suggested to determine if the nickel plating is durable enough to minimize contamination risk of the aluminum in the pots. Field tests may also indicate if the process of brush cleaning of the rod stems can be avoided with nickel plating to further save operational costs.

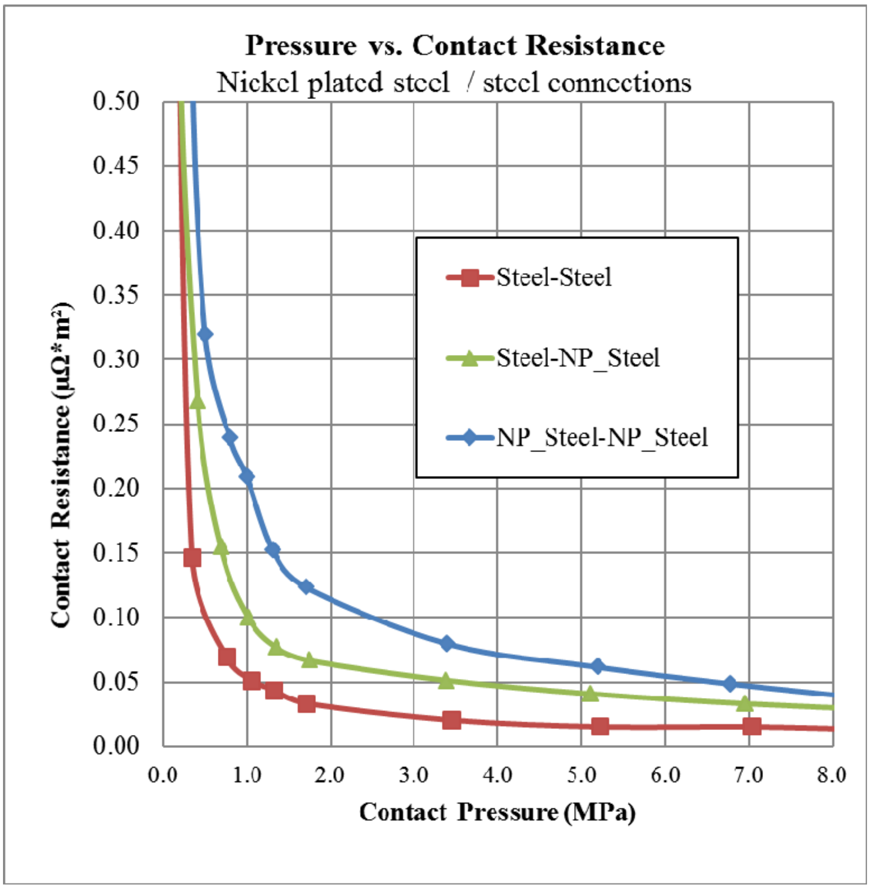

Figure 10. Contact resistance versus contact pressure of steel versus nickel plated steel.

8. References

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