“Advantages and Limitations of Mathematical Asperity Models and Testing in Connector Technology,”

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Contents

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Connections in the Electrical Installations

> Connections between two conductive metals are present throughout an electrical system at every voltage level and in every piece of conductor, equipment and appliance.

> Significant amount of modelling, design and testing is carried out on connections by researchers, test labs, users and manufacturers.

> Connectors also degrade over time.

> Performance under natural degradation is only simulated in tests at manufacturing stages mostly through accelerated ageing techniques, but cannot be exact .

Examples of Connections

(not showing connections inside switchgear, circuit breakers, relays and contactors)

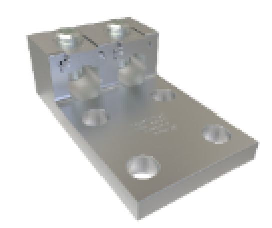


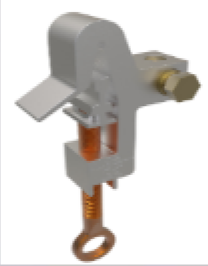
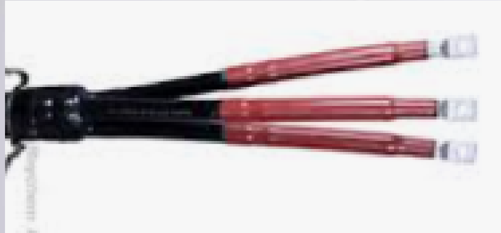






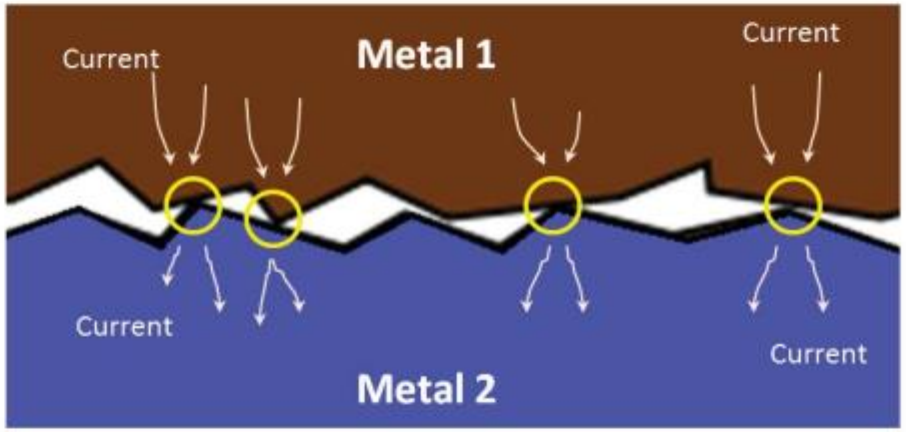


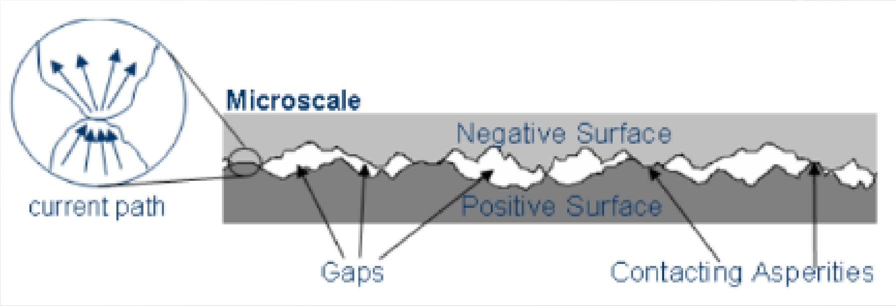




Asperity Model

- When two metals are in contact with one another in a connection, a perfect connection is never possible.
- These imperfections can be seen at microscopic level
- The asperity contact points (or A-Spots) are very small, of the order of microns in diameter. These points are distributed across an apparent contact area. The electrical current across the contact interface must flow through the asperity contact points, resulting in a resistance called constriction resistance. [2]
- Constriction Resistance is also called electrical contract resistance or ECR



Contact occurs only at the asperities of the contacting surface, leading to high contact resistance. [7}



Schematic of "bottlenecked" current flow [1]

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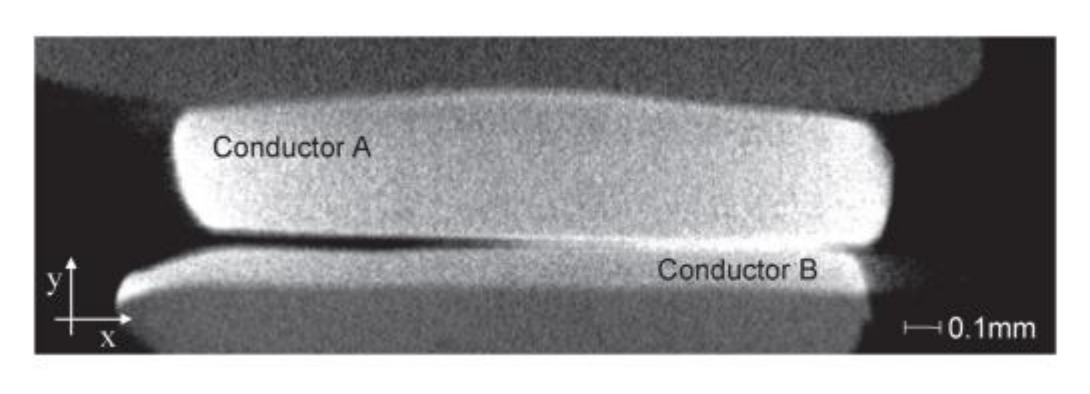
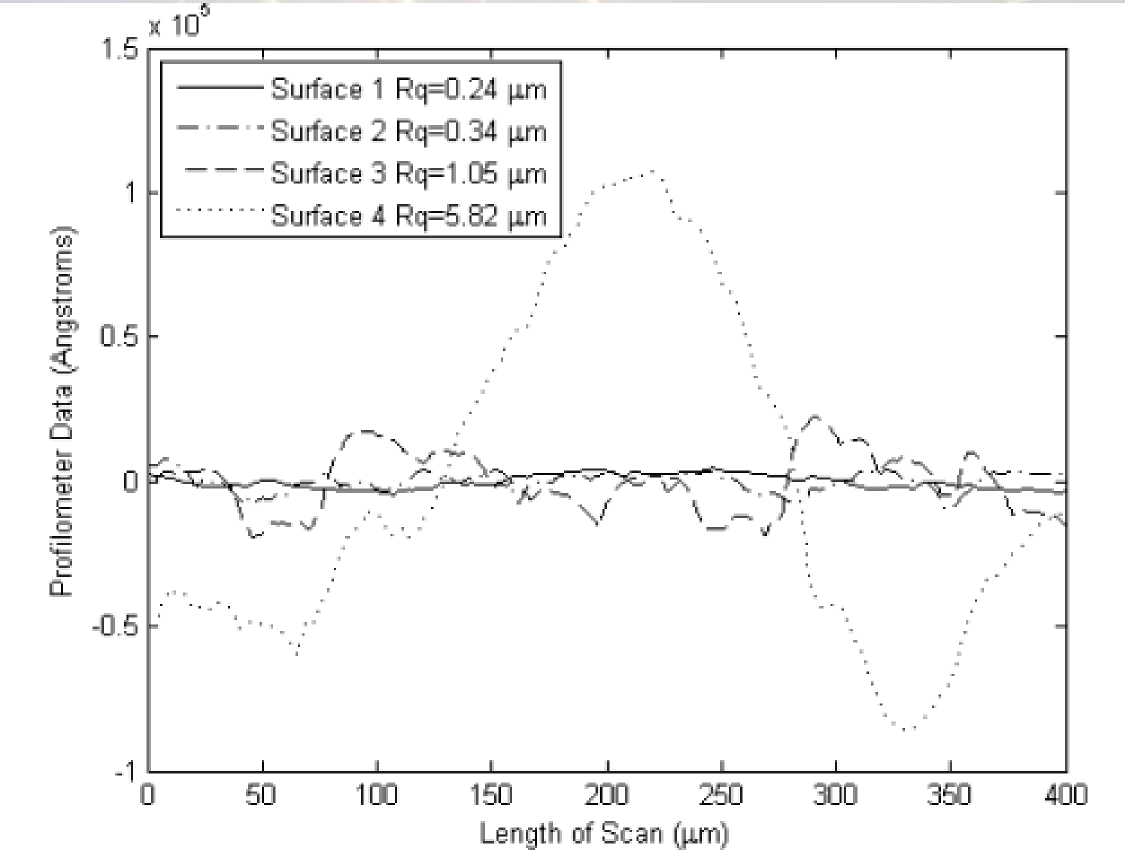
Asperity Model

- These imperfections can be seen at microscopic level using microscope or X-Ray equipment
- They can also be measured for experimental purposes using a stylus profilometer





Results from a stylus profilometer [1]

Mathematical Models

> Various Mathematical Model Exist to predict Electrical Contact Resistance

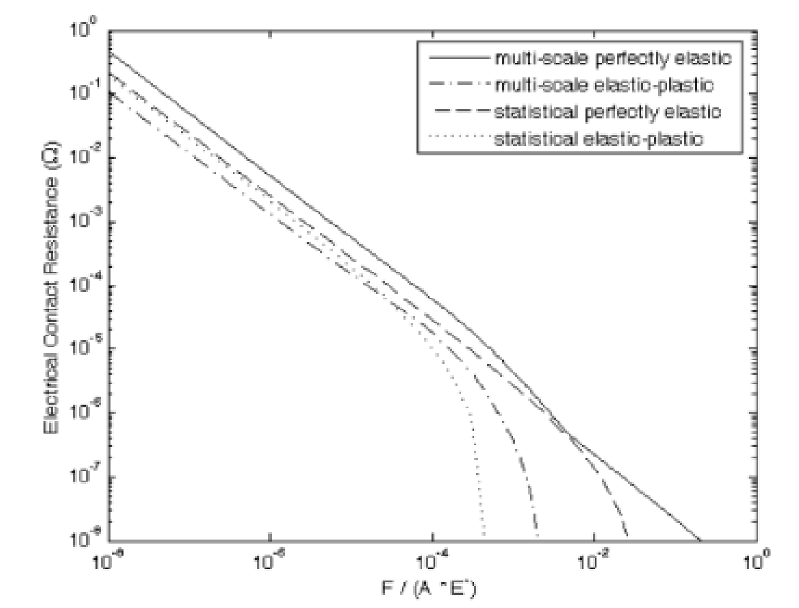
> **Multi-Scale Perfectly Elastic Contact**. The multi-scale model derived by Jackson and Streator [9] provides a method that can be easily applied to real surfaces[1]

> **Multi-Scale Elastic-Plastic Contact** . However, many of the asperities at the different frequency levels undergo plastic deformation. Therefore, an elastic-plastic sinusoidal contact model is needed to consider this effect. The equations used in the current work to calculate the elastic-plastic contact are derived from FEM results by Krithivasan and Jackson [10][1]

> **Statistical Perfectly Elastic Contact**. To compare and contrast the results of the multi-scale sinusoidal models, statistical contact models are also calculated using the same surface parameters and profilometer results. For the perfectly elastic case, this work employs the Greenwood and Williamson [11] approach for asperity contact. This method idealizes each asperity's contact as a single case of Hertz contact [1].

> **Statistical Elastic-Plastic Contact**. Similar to the multi-scale model, some of the asperities will undergo plastic deformation as loads increase past the critical values. This work uses the methodology of Jackson and Green (JG) [12] which replaces the Hertzian contact solution in the GW model with equations suited for plastic deformation after critical values have been reached [1].

- All Models Predict that ECR Reduces with LOAD /FORCE
- Better Models Predict the non-linearity



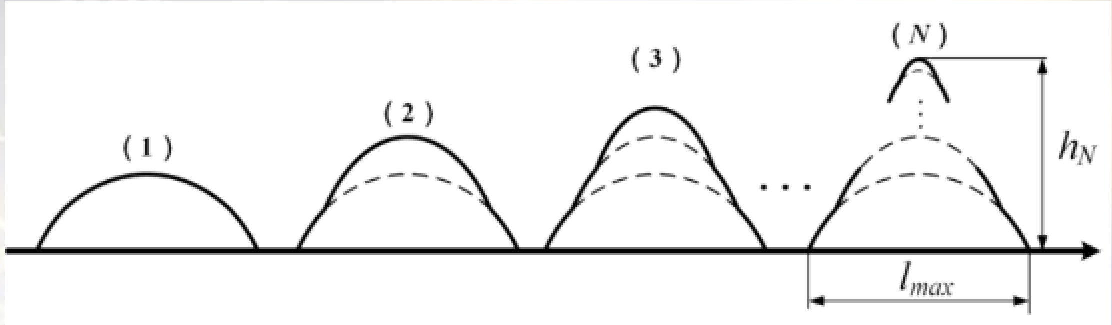
F= Force

A = Material, Surface Contact Area

E= Elastic Modulus of Tin

Limitation of Mathematical models

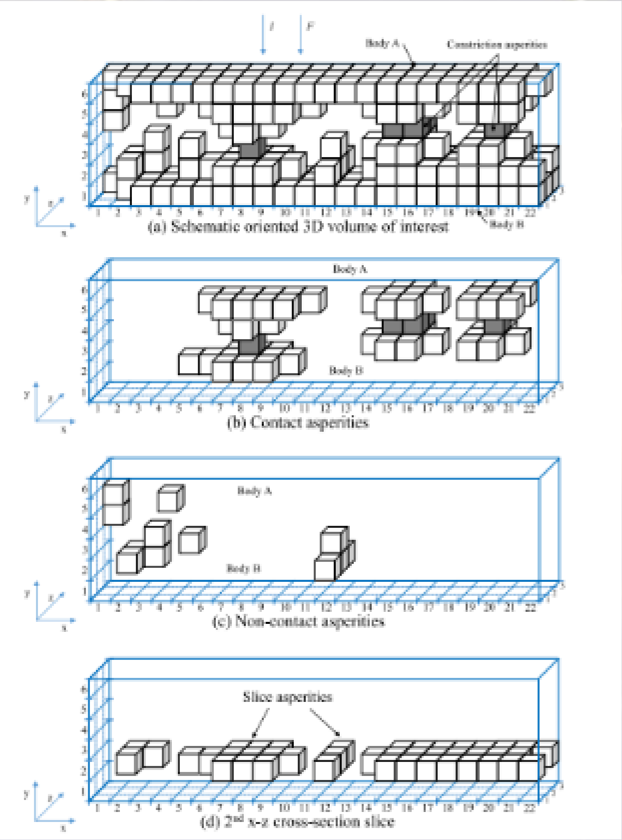
- The imperfections may be modelled as perfect shape
- May not account for elastic behaviour at higher forces
- Difficult to apply to products of non-flat shape being developed
- Difficult to apply to finished connections in the field
- Cannot Model future behaviour due to corrosion, thermal fatigue & fretting



Asperity Modelling (Simplified) in Mathematical Modeliing [4]

Other Mathematical Models

- In the paper "A 3D contact analysis approach for the visualization of the electrical contact asperities Constantinos C. Roussosa and Jonathan Swingler School of Engineering and Physical Sciences, Heriot-Watt University,Edinburgh EH14 4AS, United Kingdom" a new model using 3D Analysis is demonstrated [8]
- This model shows promise as it can be readily applied and changed in comparison with other models
- The X-ray CT method can be on close-open contacts without the need of dismantling the sample.[8]



Is Connector Testing The Answer?

- Mathematical models greatly help us understand how connectors will behave.
- To get a good assessment of a particular connector design they have to be tested using the right connectors, the correct configuration, the correct tools, correct torque or forces
- Ageing is normally simulated in many of the test using heat cycle testing, and exposure to alkaline and acidic conditions
- Examples of standards that have a test procedure for connections are IEEE 837-2014, UL 467, IEC 62561-1:2023, AS/NZS 4325, IEC 1238-1, UL486A, UL486B and ANSI C119.4

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Limitations of Connector Testing

- Mechanisms of corrosion in connectors include
  - Surface corrosion [2]
  - Motion-induced corrosion, or fretting corrosion [2]
  - Thermal fatigue
- While testing regime have methods to simulate some of the above, the corrosion or degradation effects when the connections are placed in the field will differ
- The installation of the connection in the field will differ to the installation during testing and will almost always be compromised
- For example, NO tests for buried connections in standards actually test a buried connector over its extended life

Making of a Crimp Connection

- The point of crimping is to make a connection with the lowest possible resistance. A permanent mechanical crimp involves forcing conductors together so that electricity can flow from A to B. Macro-structurally, good crimps occur when the connector is deformed past the yield point of the metal, and there is uniform deformation of the wires. [3]
- This bulk deformation is not the reason for low resistance, but the residual stresses between the conductors and the connector are responsible for keeping the system together. [3]
- If you look at the micro-structure of a crimp connection under a scanning electron microscope, the surfaces are quite rough, and there are only a few spots that actually make contact with each other. [3]
- The high-profile places where contact actually occurs, called asperity spots or a-spots in materials science — are the real indicators of resistance rating. [3]

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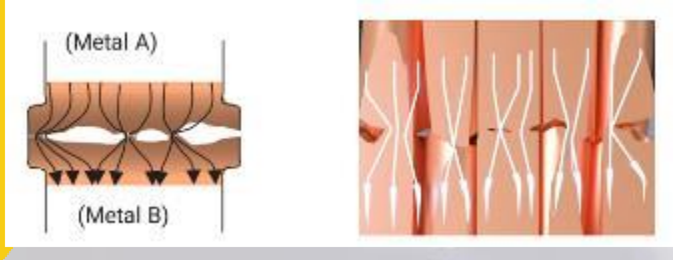
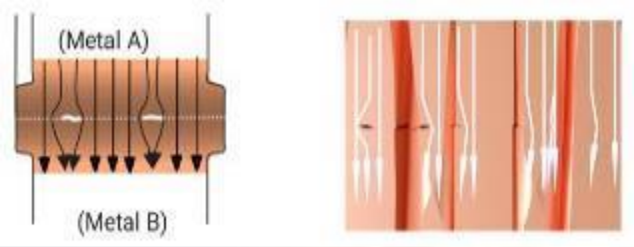
Comparison of Connectors Using Asperity Model



Typical mechanical connections with poor or some torque control.

Poorly made Crimp connections / Or Crimped with inadequate force or incorrect tools .

Poorly made exothermic connection e.g. with contaminants or water



Crimp connections made with correct tooling and correct force.

Correctly applied compound that inhibit corrosion and improve A-Spots. Compression connections with heat applied during compression or specialized shear lock or other connectors used inside termination kits of HV Cables

Typically exothermic connections.

Specialized connections with heat applied during compression or specialized connections used inside termination kits of HV Cables

Comparison of Connectors using Asperity Model

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Connector Degradation Mechanism – Surface Corrosion

- Direct surface corrosion on connectors occurs when the environment that the connector is installed in, exposes the connection to moisture, oxygen, contaminants, alkaline or acidic conditions
- These conditions are created by naturally occurring oxygen, salts and sulphur and other chemicals
- In some chemical manufacturing or mining environments there may be presence of additional corrosive materials as an outcome of materials being handled at the site
- In many of corrosion mechanisms the attack by external elements on the oxidised layer on the connector metal and subsequently on the bare metal is what causes surface degradation
- In every case of surface corrosion the connection asperity will change from the initial installed asperity

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Connector Degradation Mechanism – Thermal Fatigue

- Even if corrosion and contamination was not present, the electrical contact resistance can also increase over time in grounding connection due to application of repeated fault currents and in live line connections due to the currents flowing continuously and concentrating at these A-spots.
- This ECR increase over time occurs due to localized heating or thermal fatigue and mechanical stresses, that can loosen the connector and further reduce the number of A-spot or contact points.
- Connection failures will be minimized if connections selected provide the greatest possible Asperity spots.
- Conversely poor connections with less A-Spot will degrade faster from these electrical current concentration effects.

Summary

- Understanding Asperity model of contacts made during connections help us understand connection better
- Asperity impacts Electrical Contact (Constriction) Resistance
- Many mathematical models exist to model asperities found in connector surfaces
- Testing is practical approach to validating connector performance
- Both mathematical models and testing have limitations and benefits.
- There are several degradation mechanisms that will impact asperity over the lifetime of a connector (Surface Corrosion, Thermal Fatigue, Fretting)

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