Tin Whisker Observations on Tin-Coated Copper Bus Bar Obtained from “A Large Paper Mill in Sweden”

Jay Brusse/Dell Perot Systems at NASA Goddard Space Flight Center
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Jay.A.Brusse@nasa.gov
Background

• Since 1997 a large paper mill in Sweden has experienced three major arcing events (1997, 2000, 2009) involving tin-plated bus bars in power distribution cabinets. In the first two events, the root cause of the arcing was not determined.
  – Applied Voltage = 500 Volts AC between adjacent bus bars
  – Distance between bus bars ~20-mm

• After the third arcing event (2009), the paper mill representative, Anders Johansson, contacted Jay Brusse and Henning Leidecker (NASA Goddard Space Flight Center) to share images and to ask about the potential for metal whiskers to produce metal vapor arcs.
  – Images of bus bars showed features suspected to be metal whisker formations
  – NASA offered to perform materials analysis on a segment of one bus bar provided by the paper mill
  – Original manufacturing date of bus bar was reported to be circa 1988
Images from 2009 Arcing Event
@ Paper Mill in Sweden
Photos Provided by Anders Johansson

Bottom of Cabinet

Top Cabinet
Images from 2009 Arcing Event @ Paper Mill in Sweden
Photos Taken by Anders Johansson

Cabinet stripped from feeder groups. Vertical bus bars visible

Top of cabinet removed. Top of vertical bus bars visible.
Images from 2009 Arcing Event @ Paper Mill in Sweden
Photos Taken by Anders Johansson

Top of vertical bus bars.
Suspicious filaments visible in gap between bars

Distance between bars is ~20-mm
Image from 2000 Arcing Event @ Paper Mill in Sweden
Photos Provided by Anders Johansson
Images from 1997 Arcing Event @ Paper Mill in Sweden
Photos Provided by Anders Johansson

Cabinet Disassembled

After Arcing

Arcing Damage
Analysis of Bus Bar

• Lyudmyla Panashchenko (University of Maryland) provided lab services for the analysis of the Bus Bar provided to NASA Goddard

• Analyses included:
  – Determination of material composition of rail and surface finish
    • X-ray Fluorescence (XRF) Spectroscopy
    • Energy Dispersive X-ray Spectroscopy (EDS)
  – Measurement of surface finish thickness
    • XRF
  – Confirmation of tin whisker growths from the surface finish
    • Optical Microscopy
    • Scanning Electron Microscopy (SEM) + EDS

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Bus Bar Sample Cut by Anders Johansson and Sent to NASA for Analysis Herein
NASA Findings

• Bus bar base metal = Copper (Cu)
• Surface Finish = Tin (Sn)
• Surface Finish Thickness = variable along length of bus bar
  – Range from 1.26 - 26.2 microns in areas examined
  – Thinner Sn coating is located at the uncut end of the bus bar (by XRF)
• **TIN WHISKERS:**
  – Extensive tin whisker formations were confirmed by these inspections
  – Many whiskers are longer than 1-mm, some whiskers >3-mm.
  – Tin whisker density (# per area) is non-uniform
    • Very high density nearest the uncut ends of the bus bar (where plating is thinner)
    • Very low density near the cut end of bus bar
• Localized darkening, blistering and flaking of the tin surface finish was observed
  – Most noticeable in region with highest tin whisker density.
  – Discoloration looks like charring of the surface, but cause has not been determined
    • Might occur during localized heating of the bus bar (e.g., possible arcing event), but supplier does not believe sample provided for analysis had been involved in any arcing events
    • EDS of this region shows only Sn and O (i.e., no C). May be very thick tin-oxide layer.
X-Ray Fluorescence Spectroscopy (XRF)

XRF is a non-destructive method for measuring both the thickness and the elemental composition of thin surface finishes and the underlying base material.

Analysis by Lyudmyla Panashchenko
XRF Spectrum of Bus Bar Confirms Tin Over Copper Construction
Tin thickness vs. Position on Shoulders of Rail
(Measured by X-Ray Fluorescence)

Thickness of Sn vs Length of Rail

- Left Side of Rail
- Right Side of Rail

Position on rail (from the cut to "Blackened" region) [in]

Sn Thickness (um)

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Tin Whiskers on Bus Bar
Optical Microscopy

Inspections by Jay Brusse
Tin Whiskers on Bus Bar
"Blackened" End of Bus Rail with High Density (#/area) of Tin Whiskers
Tin Whiskers on Bus Bar
Tin Whiskers

5-mm
Tin Whiskers on Bus Bar
Scanning Electron Microscopy/
Energy Dispersive X-ray Spectroscopy
(SEM/EDS)

EDS is a non-destructive method for measuring the elemental composition of a surface.

Analysis by Lyudmyla Panashchenko
Blistered Tin Surface
In "Blackened" Region of Rail
Tin Whisker

Tin Whiskers on Bus Bar
Tin Whiskers on Bus Bar
Tin Whiskers on Bus Bar
Tin Whiskers
In "Blackened" Region of Bus Rail
Tin Whiskers
In "Blackened" Region of Bus Rail
Tin Whiskers
In "Blackened" Region of Bus Rail
Tin Whiskers
In "Blackened" Region of Bus Rail
"Blackened" Region of Bus Rail with Large Areas of Material Flaking Off
Tin Whiskers In "Blackened" Region of Bus Rail

Back Scatter Electron (BSE) view – difference in contrast represents different materials. Lighter colors are elements higher on periodic chart (in this case – tin), darker colors are elements lower on the periodic chart (in this case small debris, probably carbon)

Secondary Electron (SE) view – topographical image
Tin Whiskers
In "Blackened" Region of
Bus Rail
Tin Whiskers
In "Blackened" Region of
Bus Rail
Note: there seems to be flaking off of some tin coating. BSE image shows that most of flaked-off region exposes more tin underneath, but there is one area that exposes copper (Cu). See next slide for EDS analysis of this region.
EDS Analysis of an Area Where Tin Coating Has Flaked Off

Sn = Tin

Cu = Copper

Tin Whiskers on Bus Bar

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Tin Whiskers In "Blackened" Region of Bus Rail

The smoother regions in the picture are from a top layer of tin, while rougher regions are an exposed layer of tin from top layer flaking off.
Tin Whiskers
In "Blackened" Region of Bus Rail
Tin Whiskers
In "Blackened" Region of Bus Rail

Tin Whiskers on Bus Bar
Tin Whiskers

BSE view – difference in materials

SE view – topographical image
**Tin Whiskers in area with high density of ‘blisters’**

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<th>HV</th>
<th>WD</th>
<th>Mag</th>
<th>Spot</th>
<th>Sig</th>
<th>Tilt</th>
<th>X:</th>
<th>Y:</th>
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<tbody>
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<td>25.0 kV</td>
<td>10.7 mm</td>
<td>100x</td>
<td>3.0</td>
<td>SE</td>
<td>-0.1</td>
<td>-16.4</td>
<td>-11.3</td>
<td>---</td>
</tr>
</tbody>
</table>

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---500.0μm---
Blistered Tin Coating
In "Blackened" Region
Blistered Tin Coating In "Blackened" Region

BSE view – difference in materials

SE view – topographical image
Area with a piece of top tin coating flaked-off, and more tin exposed underneath

BSE view – difference in materials

SE view – topographical image

Area of Sn exposed after flaking of top layer
Tin Whiskers In "Blackened" Region of Bus Rail where Material has Flaked Off

Area of Sn exposed after flaking of top layer

BSE view – difference in materials

SE view – topographical image

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Tin Whiskers on Bus Bar
Tin Whiskers In "Blackened" Region of Bus Rail where Material has Flaked Off

Area of Sn exposed after flaking of top layer

BSE view – difference in materials

SE view – topographical image

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"Blackened" Region of Bus Rail where Material has Flaked Off

Area of Sn exposed after flaking of top layer

BSE view – difference in materials

SE view – topographical image

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Tin Whiskers on Bus Bar
"Blackened" Region of Bus Rail where Material has Flaked Off

BSE view – difference in materials

SE view – topographical image

Area of Sn exposed after flaking of top layer

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Very Few Whiskers; Mainly Nodules
In the Thicker Tin Coated Region
Contact Information

Jay Brusse
Dell Perot Systems at NASA Goddard Space Flight Center
Jay.A.Brusse@nasa.gov

Acknowledgment:

Lyudmyla Panashchenko
University of Maryland
Lyudmyla@calce.umd.edu