RELIABILITY OF POWER CONNECTIONS

Dr. Milenko Braunovic

MB Interface

5975 Place de l'Authion, Suite 503

Montreal, QC, Canada, H1M 2W3

E-mail: mbinterface@yahoo.com

MBI

RELIABILITY OF POWER CONNECTIONS

- Reliability requirements
- Basic feature of electrical contacts
- Connector design
- Degradation of electrical contacts
- Mitigating measures
- New trends in electrical contact design

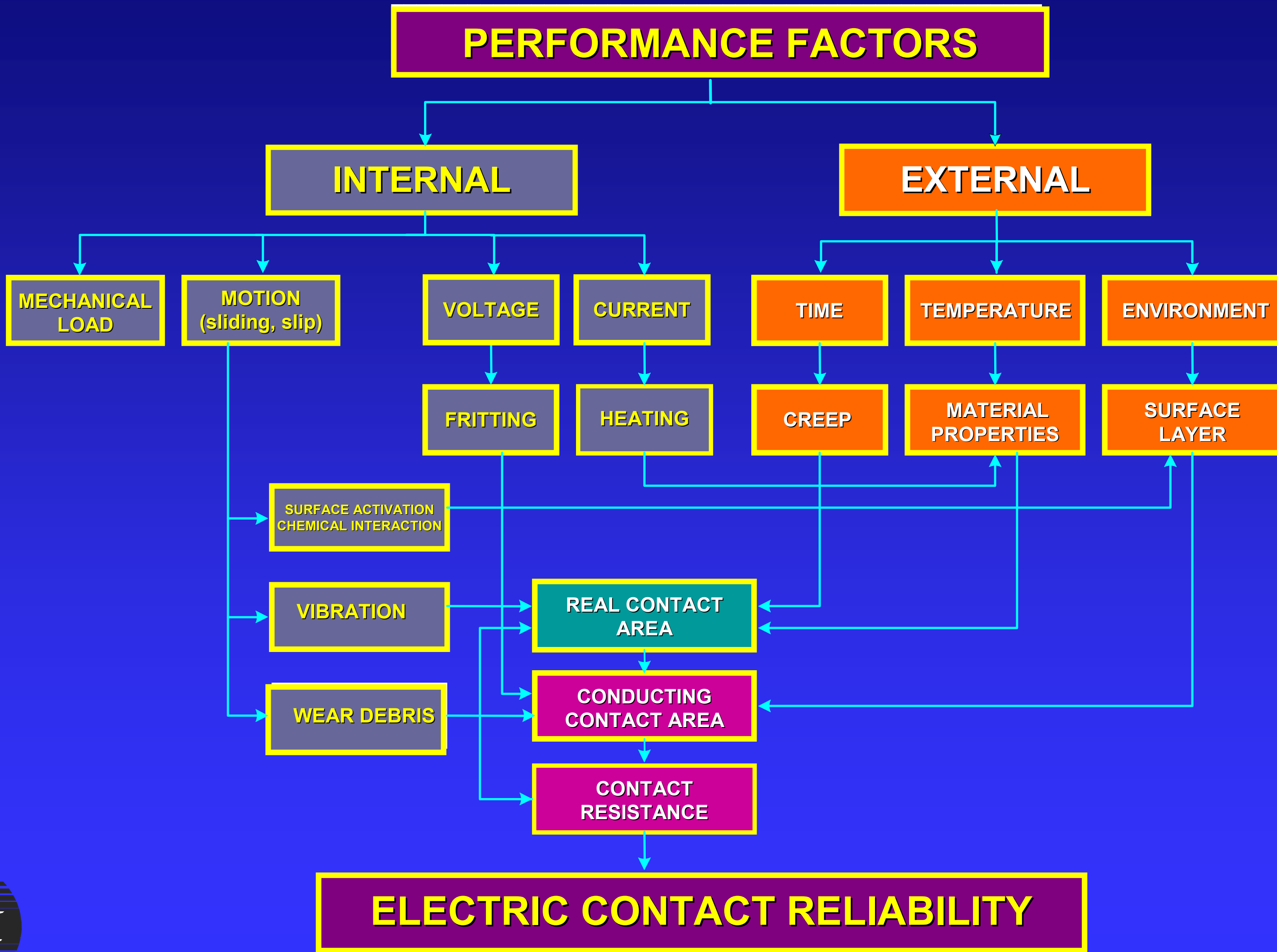
MBI

ELECTRICAL CONTACT REQUIREMENTS

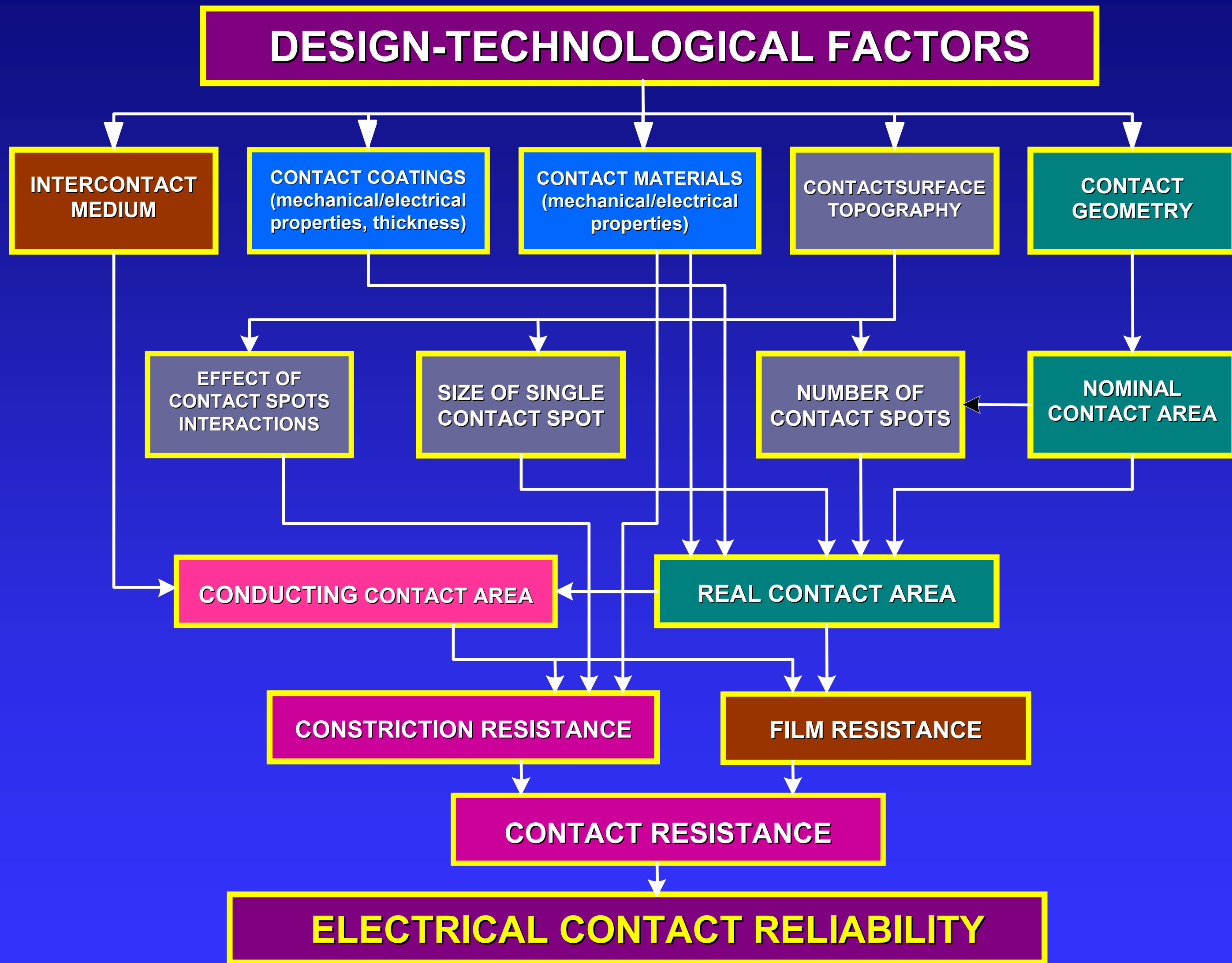
- ***Electrical:*** **low power losses, no signal distortion, no overheating;**
- ***Mechanical:*** **stable contact force during closing and opening, high wear resistance;**
- ***Ecological:*** **resistance to environment factors, minimal pollution to the environment under fabricating, operating, and recycling conditions;**
- ***Ergonomic:*** **simplicity of design and fabrication, simple maintenance repair and replacement, possibility of combining units;**
- ***Economical:*** **minimal content of noble and deficient non-ferrous metals.**

MBI

FACTORS AFFECTING CONTACT RELIABILITY



FACTORS AFFECTING CONTACT RELIABILITY



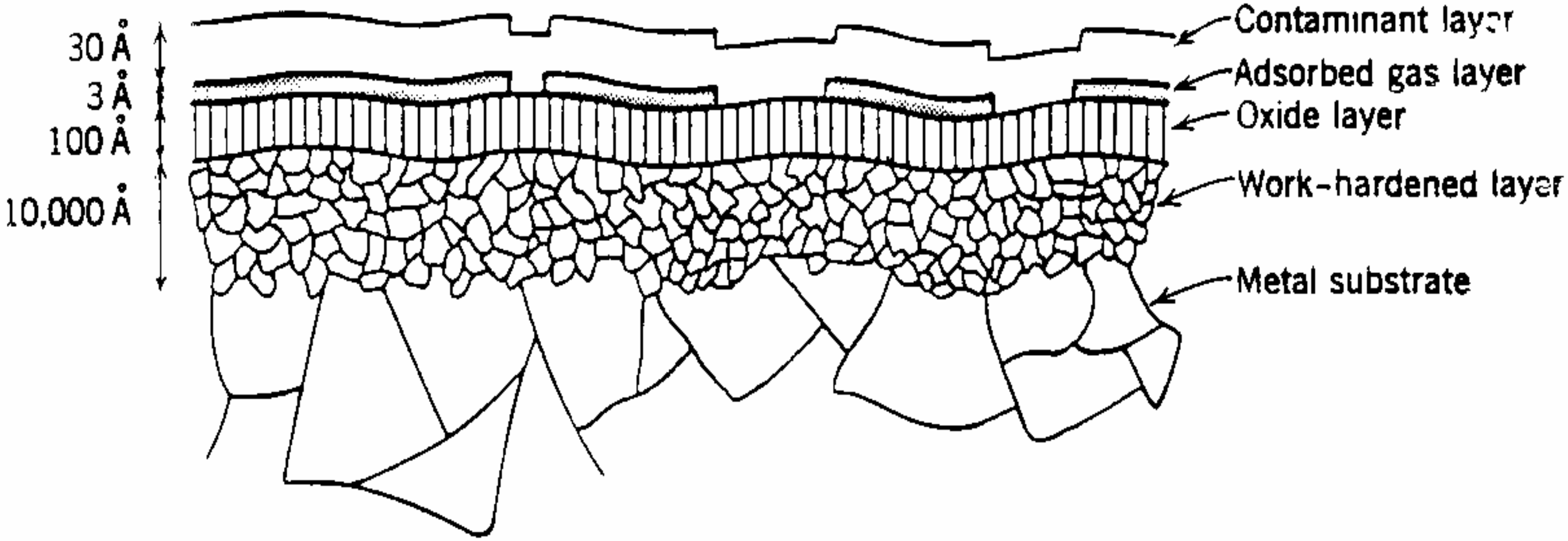
BASIC FEATURES OF ELECTRICAL CONTACTS

- Surface Topography
- Contact Area
- Electrical Current at an Interface
- Constriction Resistance
- Influence of Mechanical Load
- Effect of Surface Roughness on Contact Resistance

MBI

BASIC FEATURES OF ELECTRICAL CONTACTS

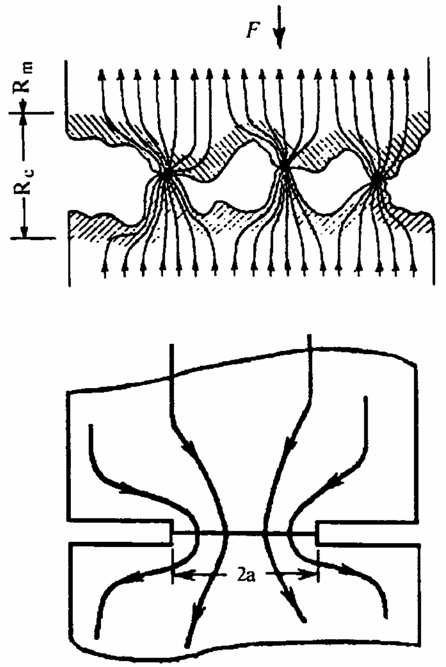
- **Surface Topography**



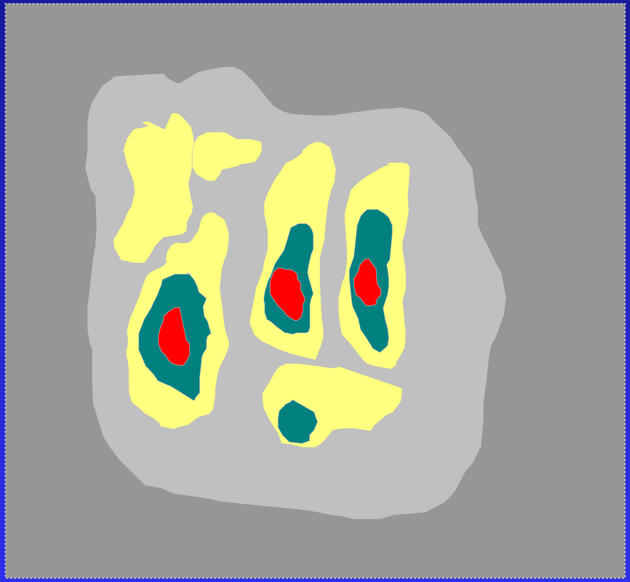
MBI

BASIC FEATURES OF ELECTRICAL CONTACTS

- Electrical Current at Interface



Rm CONDUCTOR RESISTANCE
Rc CONSTRICTION RESISTANCE
a DIAMETER OF A-SPOT

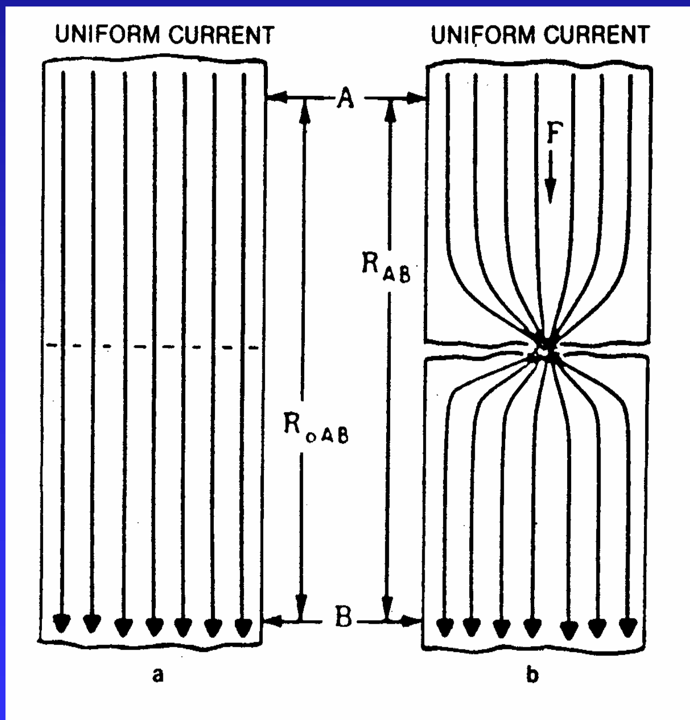


EXPECTED CONTACT AREA
ACTUAL CONTACT AREA
LOAD-BEARING AREA
QUASI-METALLIC CONTACT AREA
CONDUCTING CONTACT AREA

MBI

BASIC FEATURES OF ELECTRICAL CONTACTS

- **Constriction Resistance**



$R_{ab} = R_c + R_f + R_b$

R_c = CONSTRICTION RESISTANCE = $\rho/2a = \rho\sqrt{H/F}$

R_f - FILM (OXIDE) RESISTANCE = $\sigma_f / n \pi a^2$

R_b - BULK RESISTANCE

$T_s^2 - T_b^2 = U^2 / 4L$

T_s - SUPERTEMPERATURE (Temperature of a-spot)

T_b - BULK TEMPERATURE

L - Wiedeman-Franz Lorenz Number = 2.45^{-8} (V / k)

CONNECTOR DESIGN

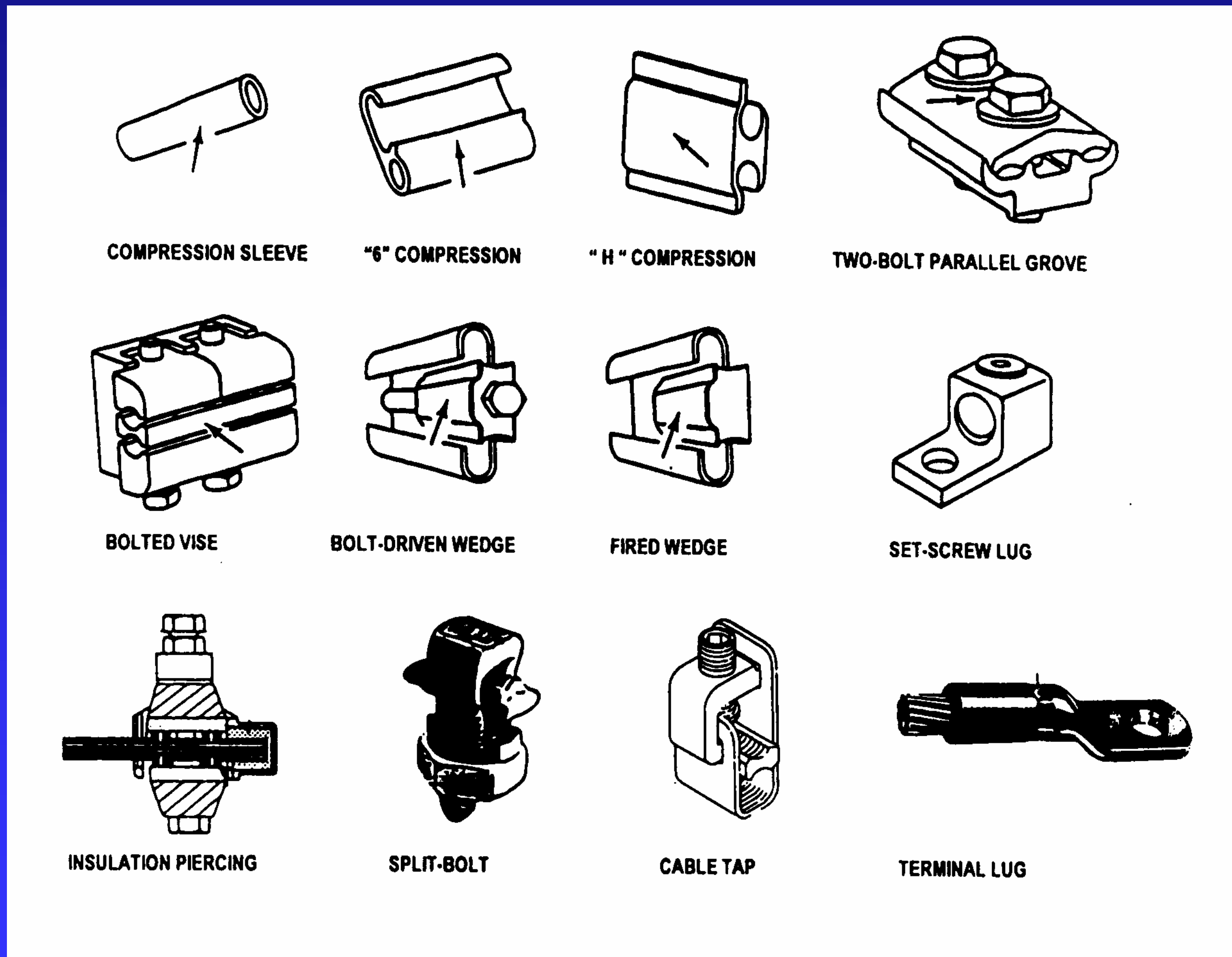
Types of Power Connectors

- **Mechanical Connectors**
  - *Split Bolt Connector*
  - *Parallel Groove*
  - *Bolted Wise Connector*
  - *Set Screw Lug*
- **Compression Connectors**
  - *H-Tap Connector*
  - *Compression Sleeve*
  - *Terminal Lug*
- **Insulation Piercing**
- **Wedge Connectors**
  - *Fired Wedge*
  - *Bolt Driven Wedge*
- **Bolted Connectors**
- **Welded Connectors**
  - *Exothermic*
  - *Friction Welded*

MBI

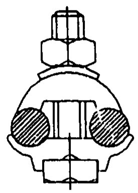
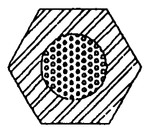
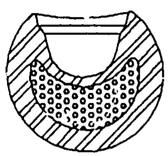
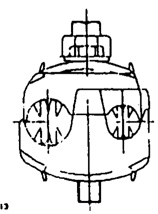
CONNECTOR DESIGN

Types of Power Connectors



CONNECTOR DESIGN

Comparison of different connection techniques

TYPE OF CONNECTION	MECHANICAL PROPERTIES	ELECTRICAL PROPERTIES	INSTALLATION	REMOVAL	APPLICATION
	+	+	+	+	OVERHEAD UNDERGROUND TAPPING
	++	+	±	-	OVERHEAD UNDERGROUND
	±	++	-	-	UNDERGROUNG
	+	++	++	+	OVERHEAD UNDERGROUND TAPPING

MBI

CONNECTOR DESIGN

Mechanical Connectors

Advantages

- Inherent resilience of the connector components permits follow-up of creep and reduces the stresses due to thermal expansion that tend to cause excessive creep.
- Ease of installation (sockets, wrenches, screwdrivers, etc) and removal, simple to use, require minimal training to install properly.
- Can be disassembled without damage to the connection components and may be reusable if in good condition
- Electrical performance of mechanical connectors meets or exceeds the industry requirements for which they are designed, thus not compromising the performance.

MBI

CONNECTOR DESIGN

Mechanical Connectors

Disadvantages

- Specific torque requirements must be followed to provide the proper clamping force needed for a sound electrical connection.
- Inconsistency of forces applied over identical mechanical installations is not generally repeatable due to use of uncalibrated torque wrenches.
- Because of relatively low mechanical holding strength, these connectors can not be used as full tension connections and in areas of high vibration; more maintenance and periodic inspection may be required.
- Owing to their geometry, installing mechanical connectors on insulated conductors is usually difficult and awkward.

MBI

CONNECTOR DESIGN

Compression Connectors

Advantages

- Low cost, relatively reliable performance, use of recommended tools and/or dies removes the human element during installation.
- Connector construction provides better conductor encirclement while retained oxide inhibiting compound protects the contact area from the atmosphere, thus assuring a maintenance free connection.
- High localized and consistent forces imparted by the installation tool break down the oxides and establish contact points (*a*-spots) for reduced contact resistance and electrically and mechanically sound connection.
- The softness of compression connector material relative to the conductor prevents spring back and contact separation.
- Due to their geometry, compression connectors are considerably easier to insulate or tape than mechanical connectors.
- These connectors are most suitable in areas of wind, vibration, ice build-up and other stress-associated tension applications.

MBI

CONNECTOR DESIGN

Compression Connectors

Disadvantages

- Proper installation tooling for a compression system program involves potentially high capital investments due to a large variety of different types of compression tooling to select from.

- Accurate die and tool selection is essential for proper installation of a compression connection.

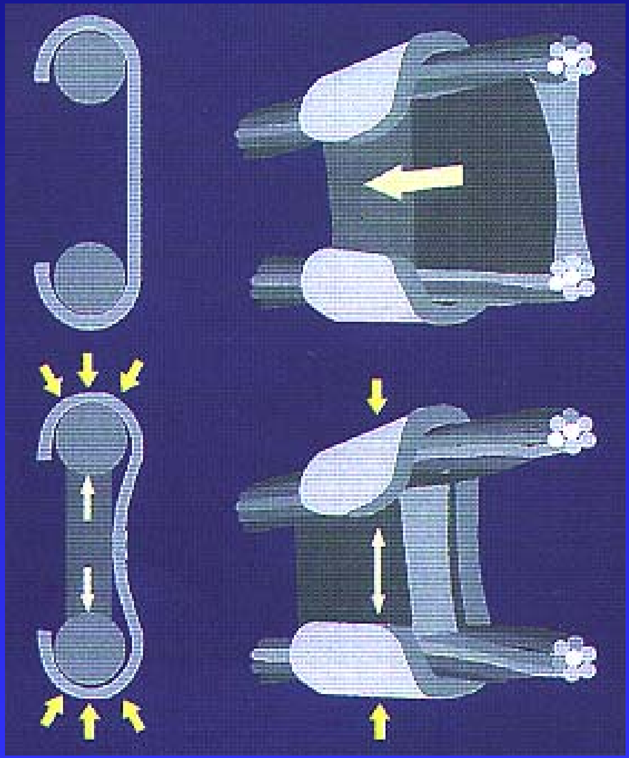
- Due to the need for specific tools and dies to install a compression connection, installers must be trained how to use the proper techniques and maintain these tools.

- In some compression connections, manually operated tools require greater physical exertion to install, thus when installing numerous connections, installers can become fatigued and possibly not complete the specified number of crimps.

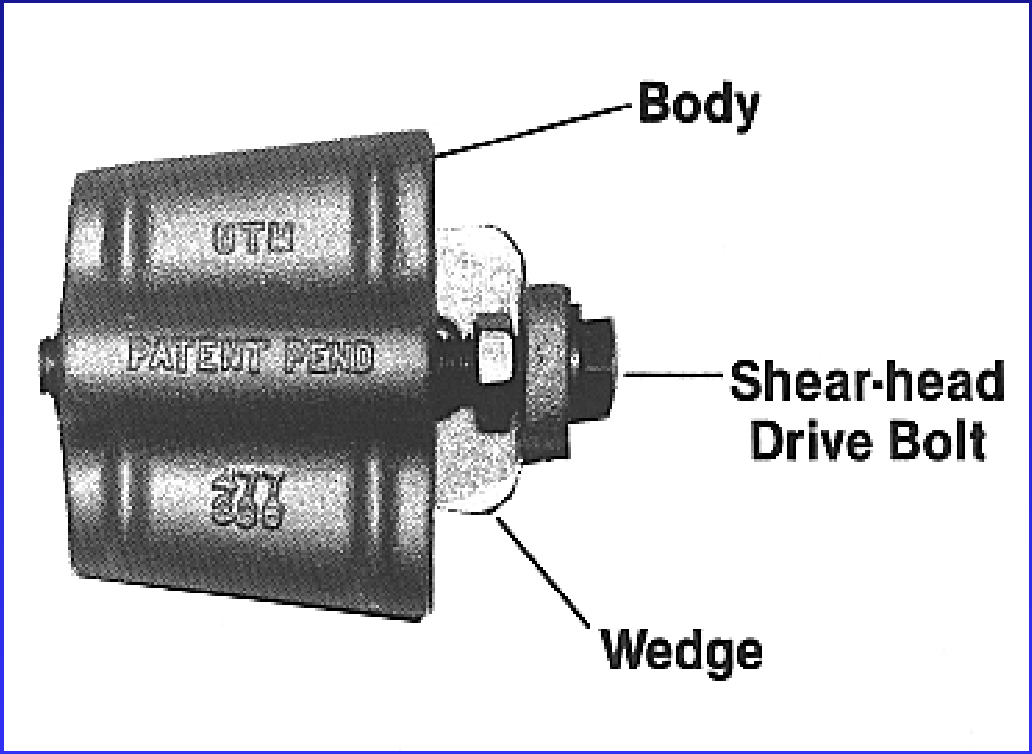
MBI

CONNECTOR DESIGN

Wedge Connectors



FIRED WEDGE CONNECTOR



MECHANICAL WRENCH LOCK CONNECTOR

CONNECTOR DESIGN

Wedge Connectors

Advantages

- Powder actuation provides consistent, uniform performance and requires low physical exertion from an operator to complete a connection.

- Rapid mechanical wiping action as the wedge is driven between the conductors breaks down surface oxides and generates superior contact points thus reducing overall contact resistance.

- Installation is accelerated with the use of lightweight, portable tooling with simplified loading and engaging mechanisms.

- The spring effect of the 'C' body maintains constant pressure for reliable performance under severe load and climatic conditions whereas a large connector mass provides better heat dissipation.

- Electrical performance of fired-on wedge connectors are excellent due to the low contact resistance developed during installation.

MBI

CONNECTOR DESIGN

Wedge Connectors

Disadvantages

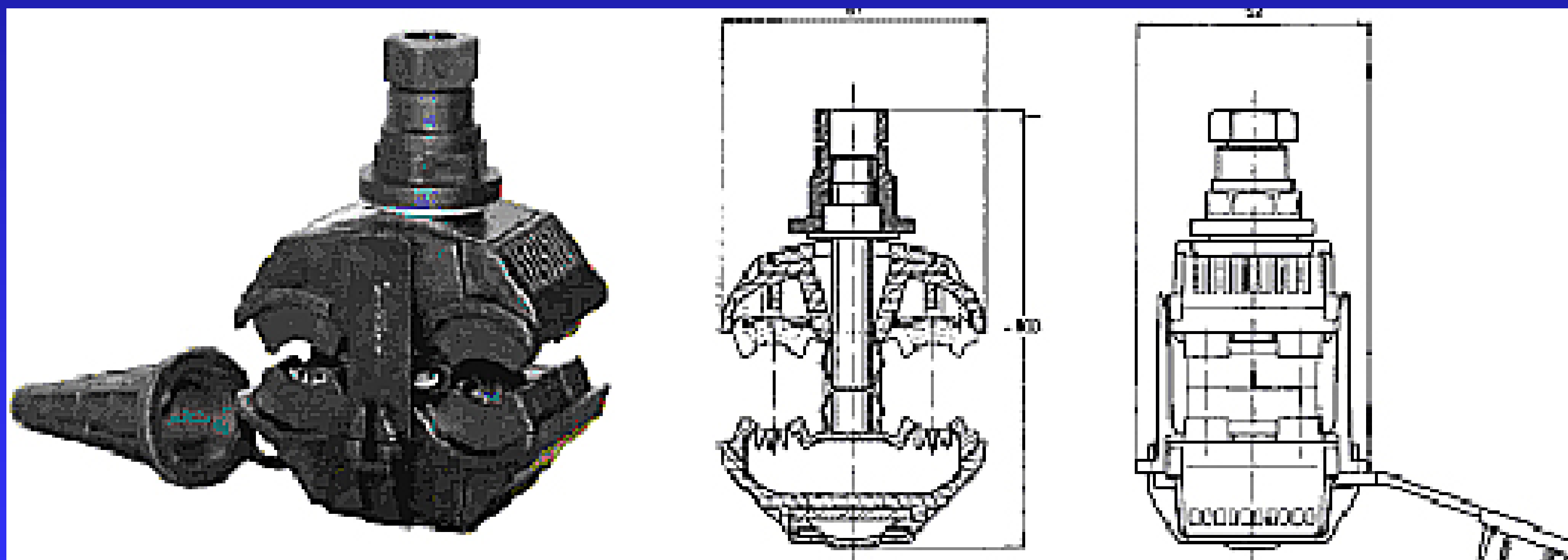
- Dedicated nature of powder actuation require full support from the user in terms of training, maintenance and service.
- Precautions and specially trained and qualified installers are required for safe and proper installation of wedge connections.
- Mechanical wedge connectors installed with wrenches, require more physical exertion for installation, show more inconsistent performance due to discrepancies caused by contaminants on the hardware and wide tolerances of shear-off bolts.
- Mechanical wedge spring bodies are typically manufactured by casting which produces much less spring action to maintain the connection.
- Wedge connectors are restricted to non-tension, out-door applications and suited only for a limited range of conductors.

MBI

CONNECTOR DESIGN

Types of Power Connectors

INSULATION PIERCING CONNECTOR



MBI

CONNECTOR DESIGN

Insulation Piercing Connectors

Advantages

- Low installation costs since no special tooling is required as they can be installed with a basic wrench.

- No insulation stripping or application of oxide inhibitor is required when making connections to insulated conductors.

- These connectors incorporate contact teeth designed to penetrate conductor insulation and make electrical contact, and are pre-filled with an oxide inhibiting compound to fill voids where contamination may enter.

- Insulation piercing connectors are insulated and require no tape or special cover once the connection is made.

- Relatively safe and easy installation on energized conductors.

MBI

CONNECTOR DESIGN

Insulation Piercing Connectors

Disadvantages

- Limited scope of applications; recommended for low voltage (600V and below) secondary distribution applications where insulated conductors are employed.

- The nature of the connection device limits their application to functions such as taps, although some parallel splices can also be made.

- These connectors are intended for use in non-tension applications only and should never be used on bare conductors.

- These connectors may not be suitable for conductors with very thick, very thin, or very hard insulation materials as they could damage the conductor or not make electrical contact at all.

MBI

CONNECTOR DESIGN

Exothermic (Thermite) Connectors

- **Exothermic welding is a process in which an electrical connection is made by pouring superheated, molten copper alloy on and around the conductors to be joined.**
- **The process requires no external source of heat or current and is completed within few seconds in a semi-permanent graphite mold in which the molten copper alloys causes the conductors to melt.**
- **The result of a reaction between a metal oxide and aluminum is liquid metal that acts as the filler metal and flows around the conductors making a molecular weld.**
- **The following chemical reaction occurs in the welding of copper conductors:**

$$3Cu_2O + 2Al = 6Cu + Al_2O_3 + Heat\ (1060\ kJ)$$

- **The thermite welding is extensively used for making grounding connections between copper conductors.**

MBI

CONNECTOR DESIGN

Exothermic (Thermite) Connectors

Advantages

- **Excellent current-carrying capacity equal to or greater than that of the conductors, high stability during repeated short-circuit current pulses, excellent corrosion resistance and mechanical strength.**

Disadvantages

- **Cost, lack of repeatability, numerous mold requirements, potential down-time caused by inclement weather or wet conditions, safety risks to personnel and equipment.**
- **The intense heat damages both the conductor and its insulation, anneals the conductor so that exothermic connections can not be used in tension applications.**
- **The resultant weld material exhibits lower conductivity and physical properties than the conductor, being similar to cast copper.**

MBI

CONNECTOR DESIGN

Friction Welded Connectors

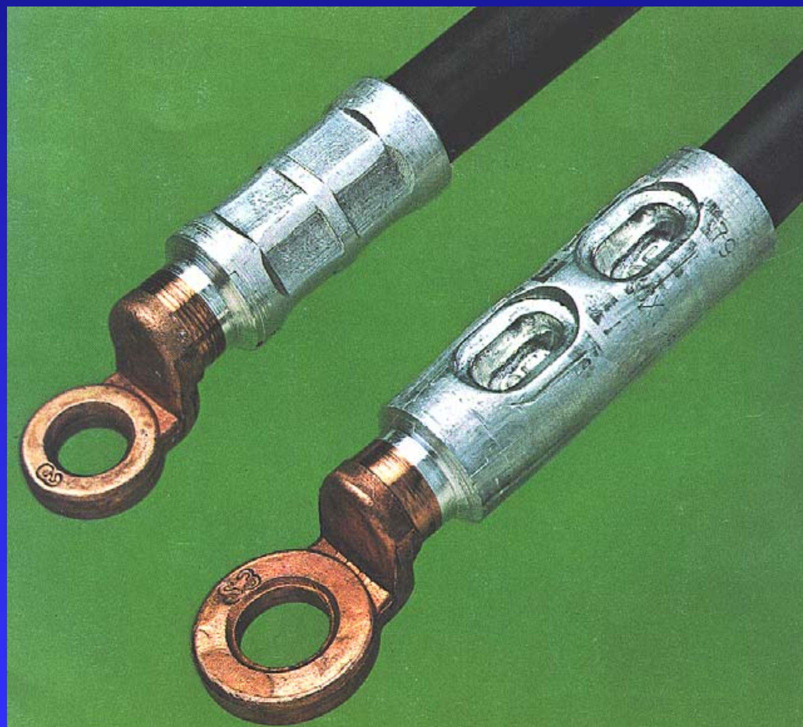
- **Friction welding is a solid-state welding process in which the heat for welding is produced by direct conversion of mechanical energy to thermal energy at the contact interface without the application of external electrical energy or heat from other sources.**
- **Friction welds are made by holding a non-rotating work-piece in a contact with a rotating work-piece under constant or gradually increasing pressure until the interface reaches welding temperature and then the rotation is interrupted to complete the weld.**
- **The frictional heat developed at the interface rapidly raises the temperature of the work-pieces, over a very short axial distance approaching but bellow the melting range.**
- **During the last stage of welding process, atomic diffusion occurs while the interfaces are in contact, allowing a metallurgical bond to form between the two materials.**

MBI

CONNECTOR DESIGN

Friction Welded Connectors

FRICTION WELDED HEXAGONAL COMPRESSION



FRICTION WELDED DEEP STEPPED INDENTATION CONNECTOR

DEEP STEPPED INDENTATION

DEEP STEPPED INDENTATION CONNECTOR

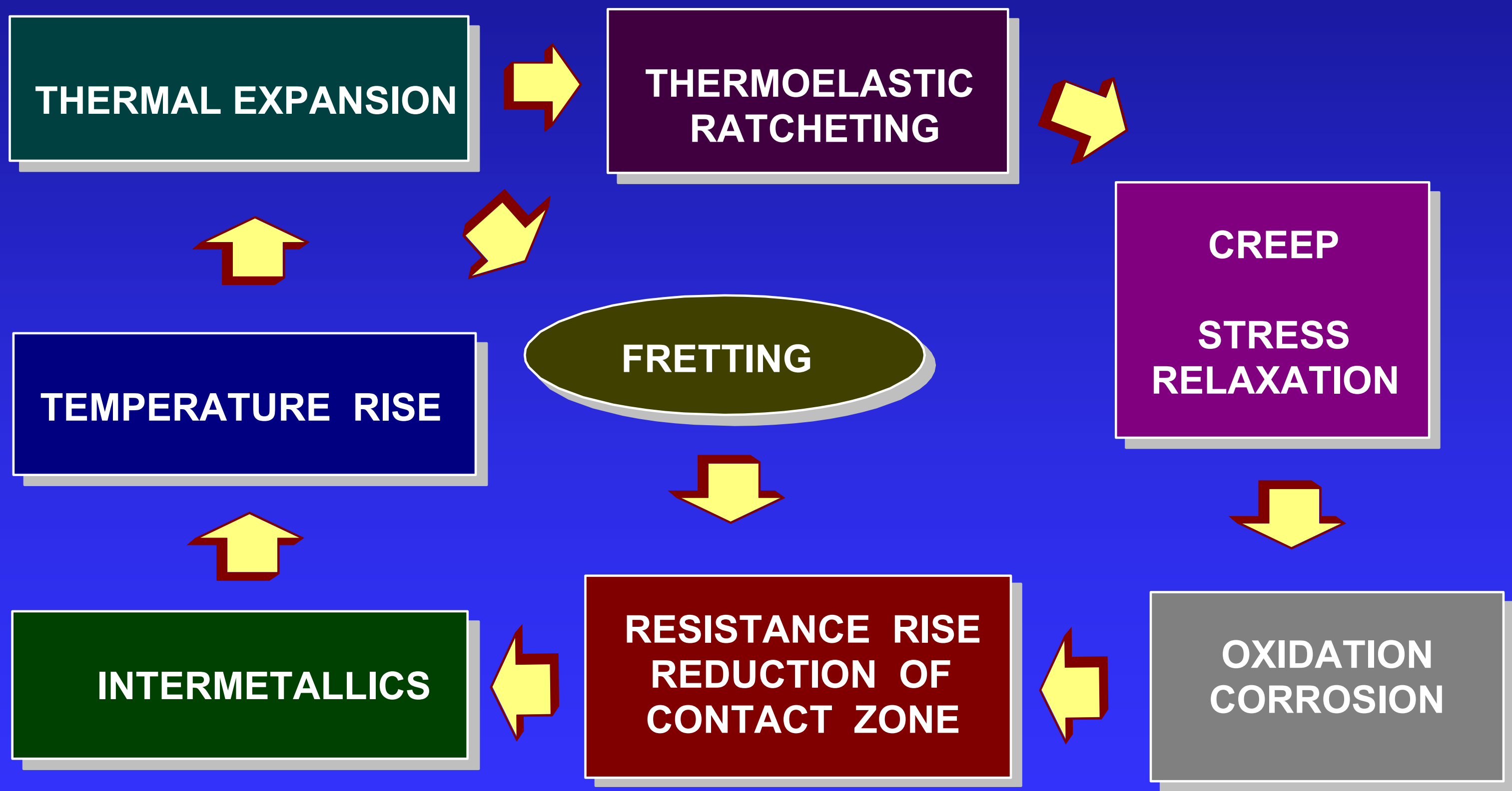
DEGRADATION OF ELECTRICAL CONTACTS

- Oxidation
- Corrosion
- Fretting
- Stress Relaxation / Creep
- Differential Thermal Expansion
- Formation of Intermetallics

MBI

DEGRADATION OF ELECTRICAL CONTACTS

Degradation Mechanisms



MBI

DEGRADATION OF ELECTRICAL CONTACTS

Oxidation

METAL	AMBIENT	PRODUCT	CHARACTERISTI FEATURES	THICKNESS (nm) AT		
					10^3h	10^5h
Cu	Air	Cu_2O	• Oxide forms immediately • Temperature-dependent	20°C 100°C	2.2 15.0	4.0 130.0
Sn	Air	SnO	• Initially slow growth rate • Weak temperature-dependence	20°C 100°C	4.2 25.0	6.1 36.0
Ni	Air	NiO	• Self-limiting • Weak temperature-dependence	20°C 100°C	1.6 3.4	15.0 34.0
Al	Air	Al_2O_3	• Oxide forms immediately (2nm in secs) • Humidity & Temperature-dependent	• Self-limiting growth • Very hard & insulating		
Ag	Sulfur Ozone	Ag2S Ag2O	• Depends of sulfur-vapor concentration • Remains thin and decomposes at 200C	• Humidity-dependent • No effect on contact		

MBI

DEGRADATION OF ELECTRICAL CONTACTS

Corrosion

- Atmospheric corrosion
- Crevice Corrosion
- Pitting Corrosion
- Galvanic corrosion

MBI

DEGRADATION OF ELECTRICAL CONTACTS

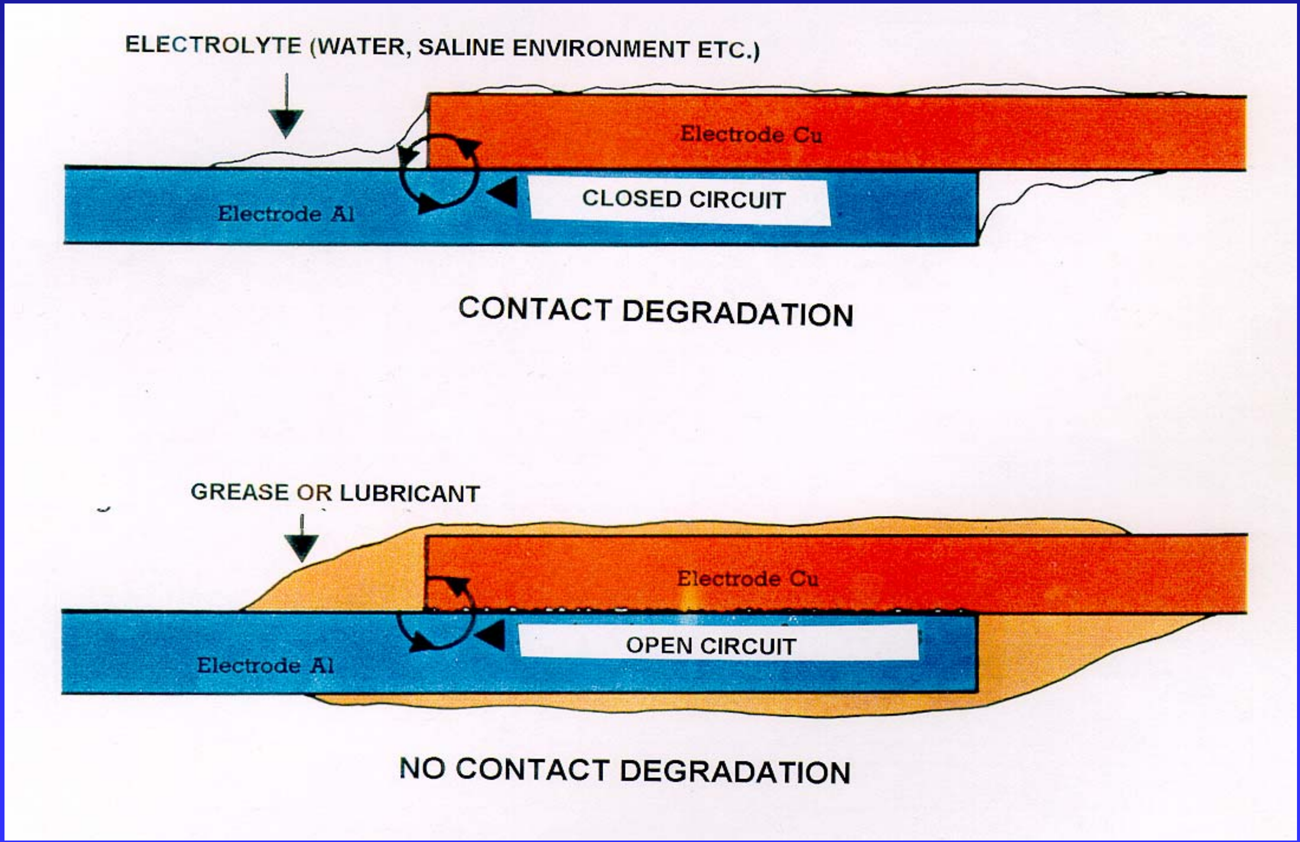
Galvanic corrosion

- Galvanic corrosion is one of the most serious degradation mechanisms.
- In case of Al*Cu joints, Al (anodic component) dissolves and deposits on Cu electrode forming complex hydrated Al oxide with evolution of hydrogen at the Cu cathode.
- Humidity is the most important parameter influencing corrosion

MBI

DEGRADATION OF ELECTRICAL CONTACTS

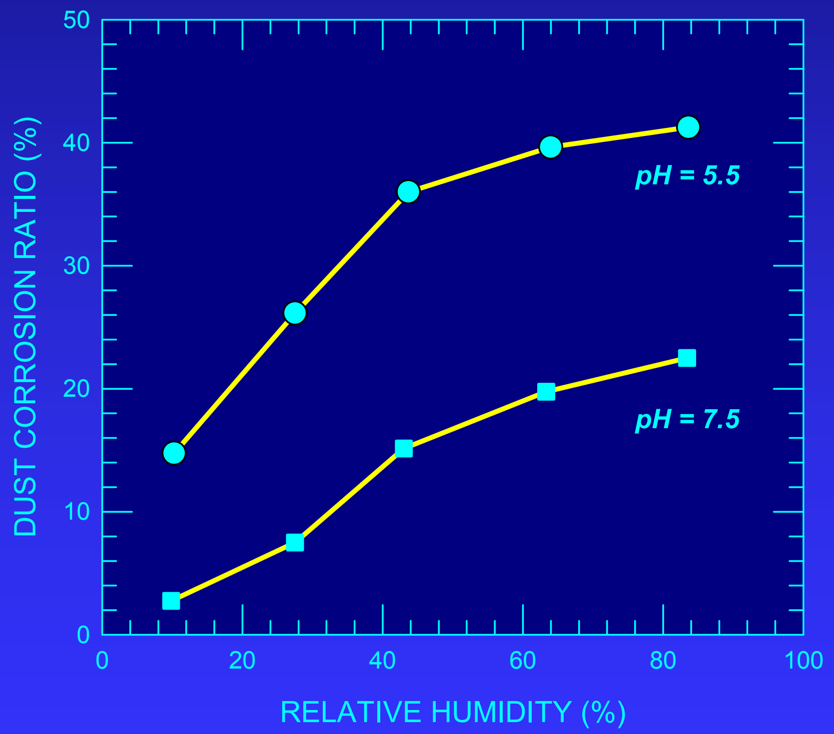
Galvanic corrosion



MBI

DEGRADATION OF ELECTRICAL CONTACTS

Dust Corrosion



DEGRADATION OF ELECTRICAL CONTACTS

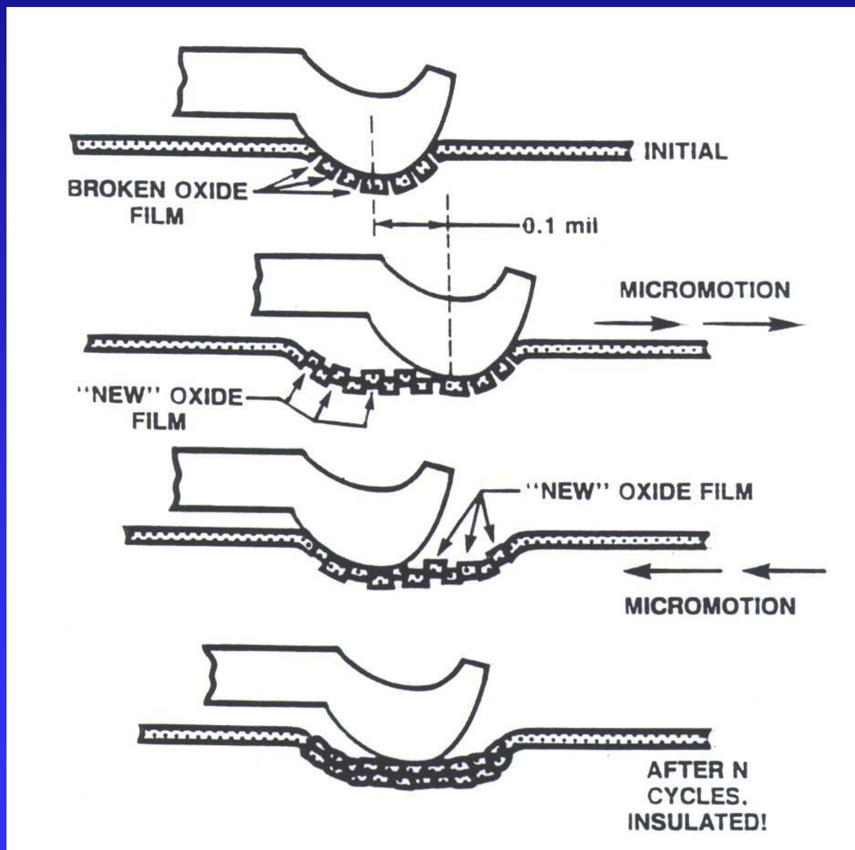
Fretting

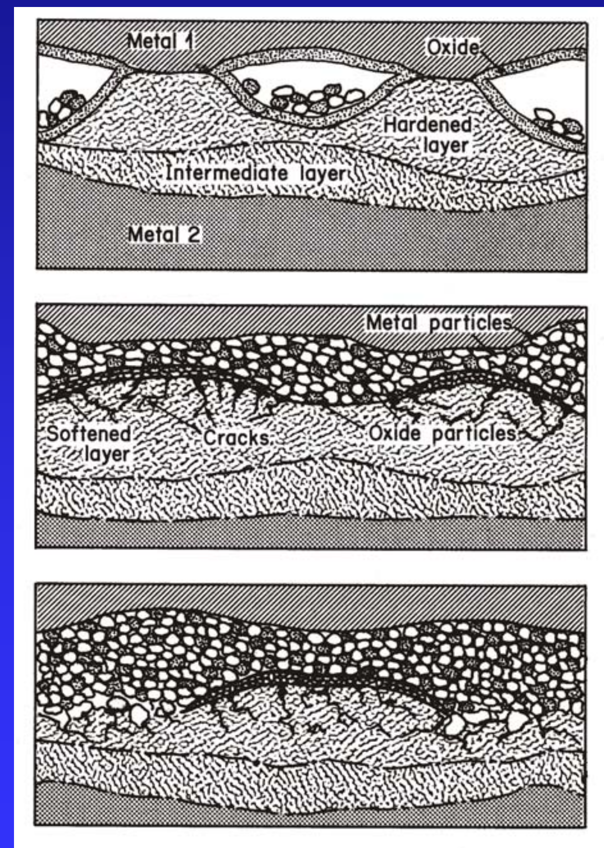
- Fretting is an accelerated surface damage occurring at the interface of contacting materials subjected to small oscillatory movement.
- The motion can be produced by mechanical vibrations, differential thermal expansion, load relaxation, junction heating etc.
- Due to limited amplitude of fretting, wear debris and oxides accumulate in the contact zone forming a thick insulating layer which leads to a dramatic increase in contact resistance

MBI

DEGRADATION OF ELECTRICAL CONTACTS

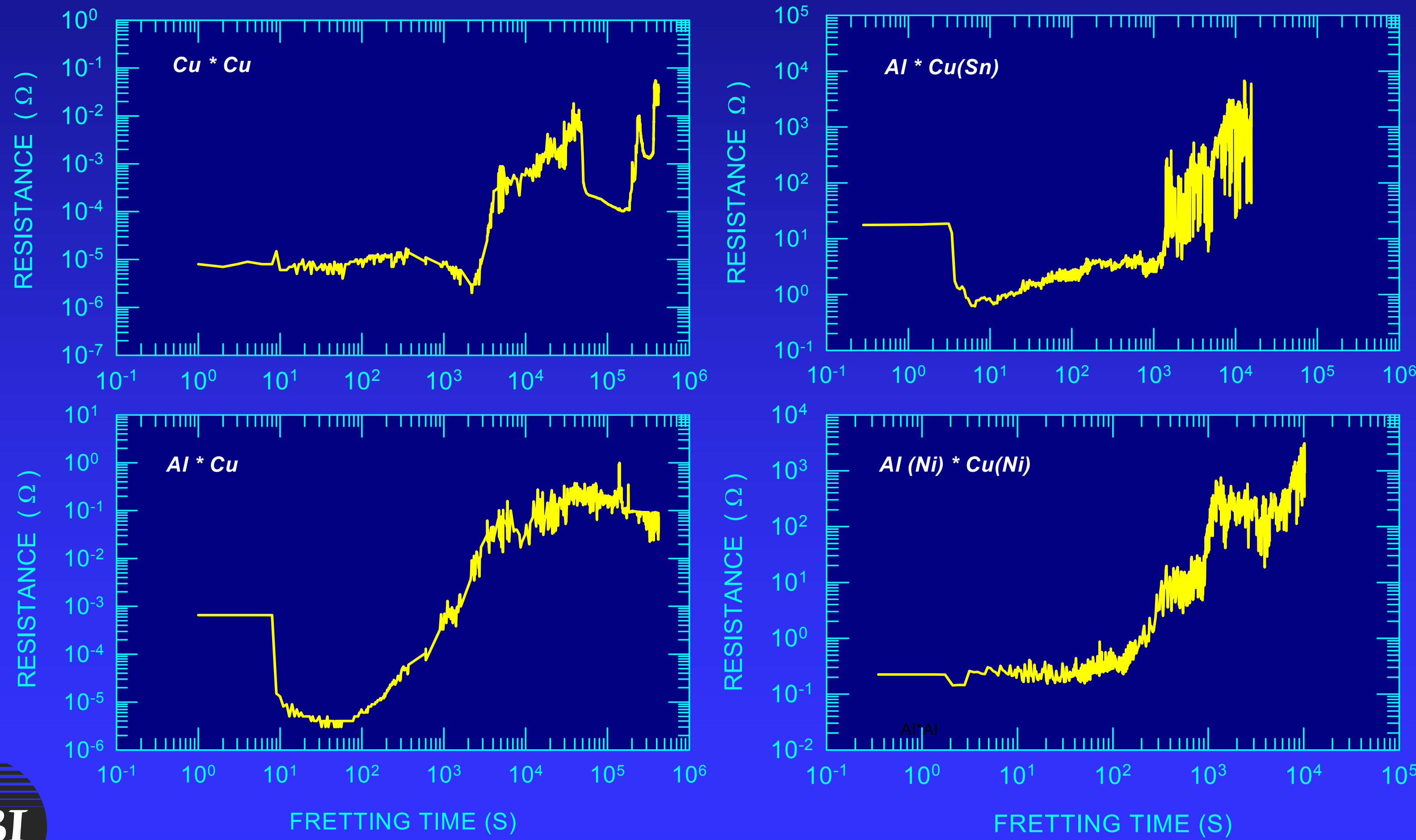
Schematic of kinetics, initiation and spreading of fretting damage





DEGRADATION OF ELECTRICAL CONTACTS

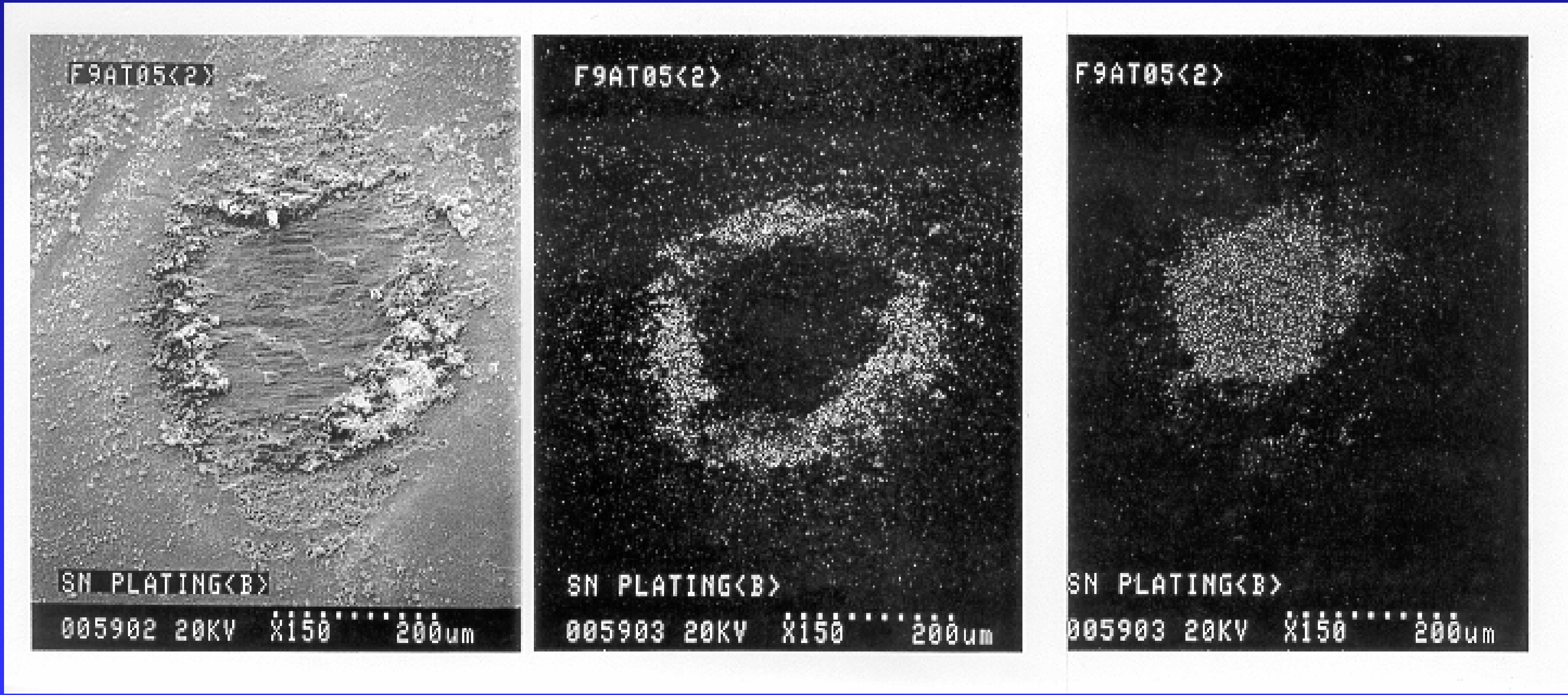
- **Effect of Fretting on Contact Resistance**



DEGRADATION OF ELECTRICAL CONTACTS

- **Examples of Fretting Damage of Contact Zone**

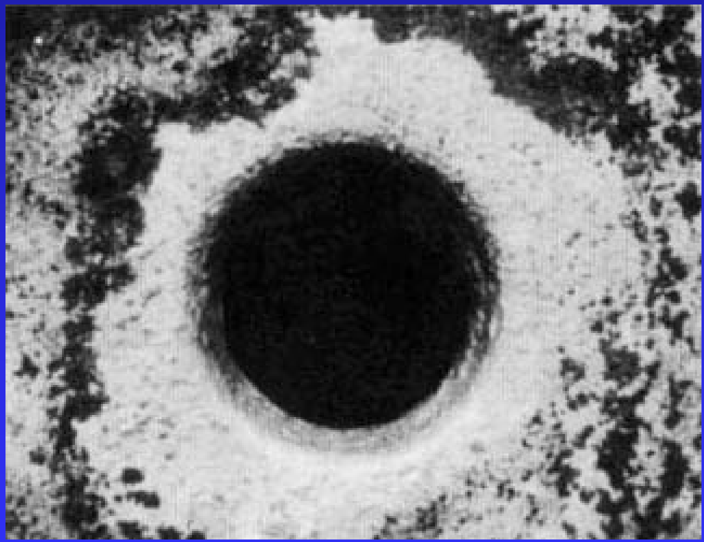
Al (wire) – Sn Plated Cu Plate Side

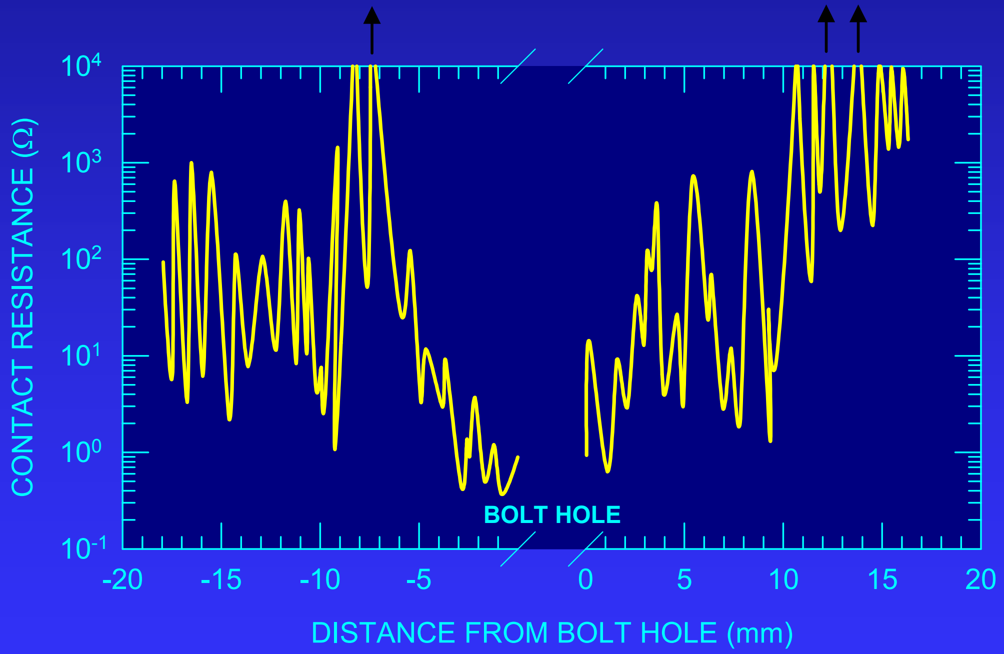


MBI

DEGRADATION OF ELECTRICAL CONTACTS

- **Examples of Fretting Damage in Electrical Connections**

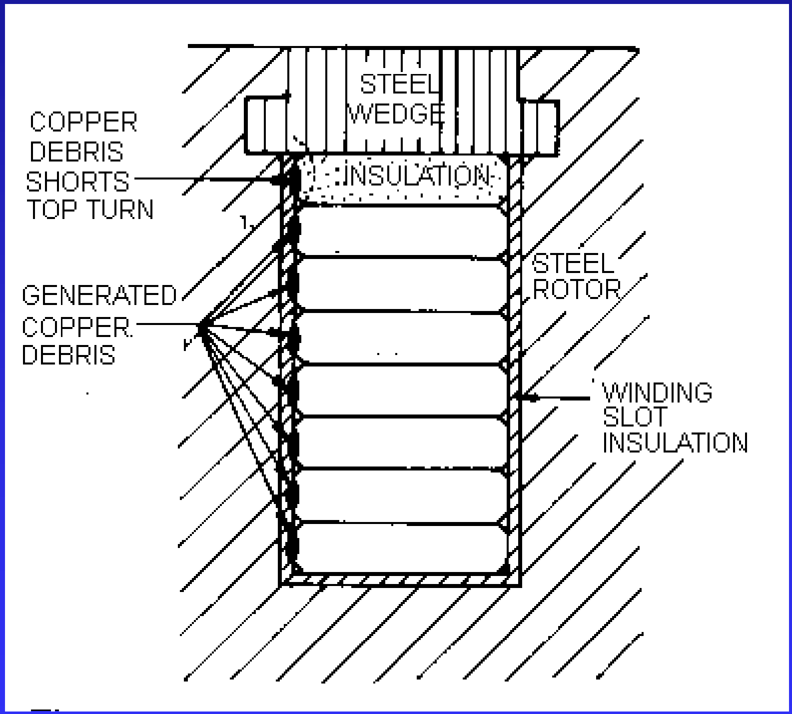




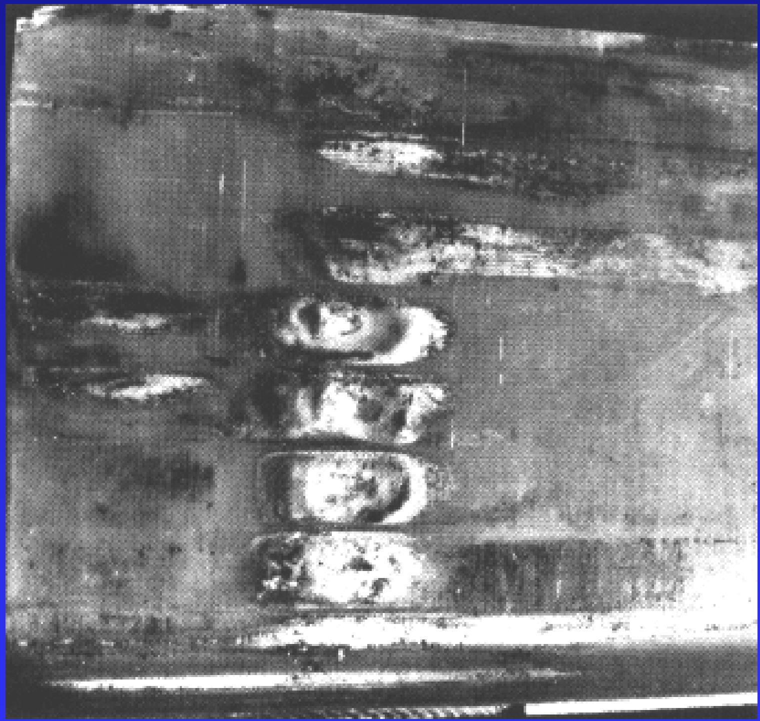
MBI

DEGRADATION OF ELECTRICAL CONTACTS

Examples of Fretting Damage in Electrical Connections



Cross section of a typical rotor slot

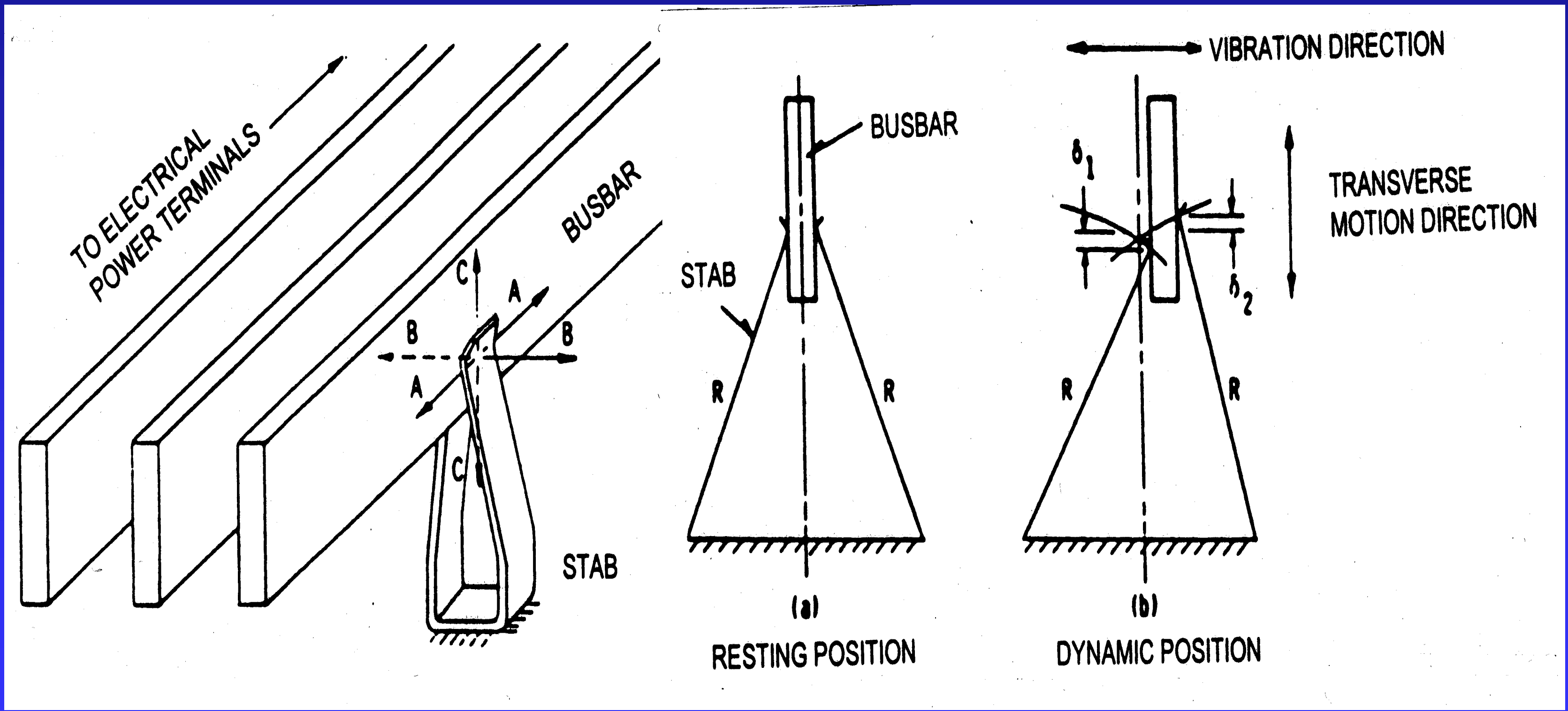


Fretting wear damage of rotor slot insulation

MBI

DEGRADATION OF ELECTRICAL CONTACTS

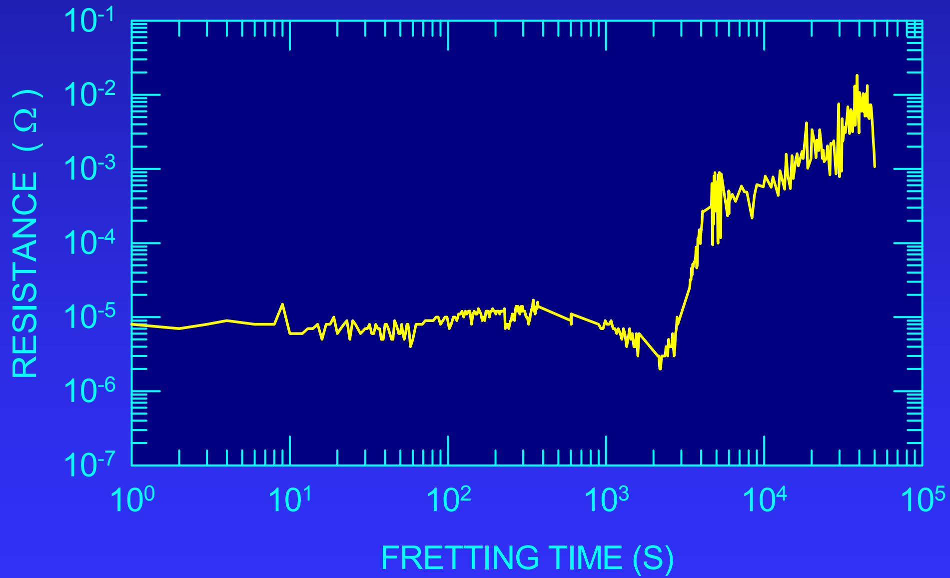
Examples of Fretting Damage in Electrical Connections



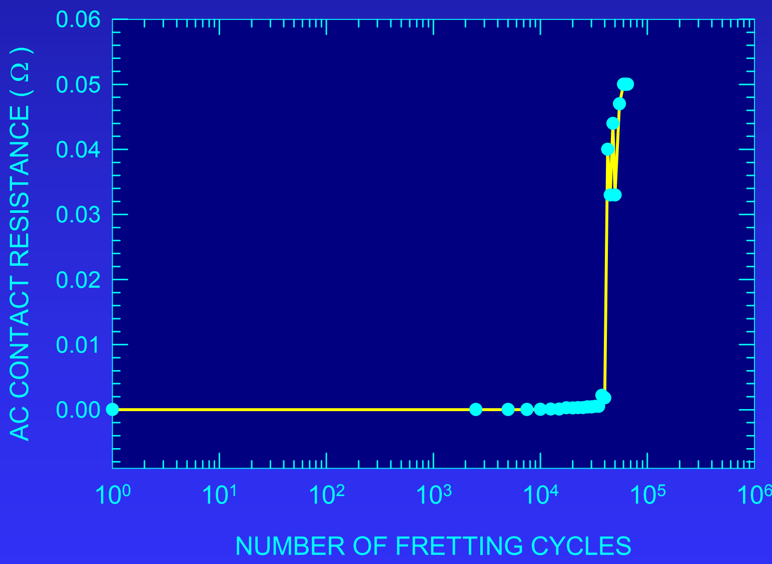
DEGRADATION OF ELECTRICAL CONTACTS

- Fretting Damage in Electrical Connections

DC CURRENT



AC CURRENT

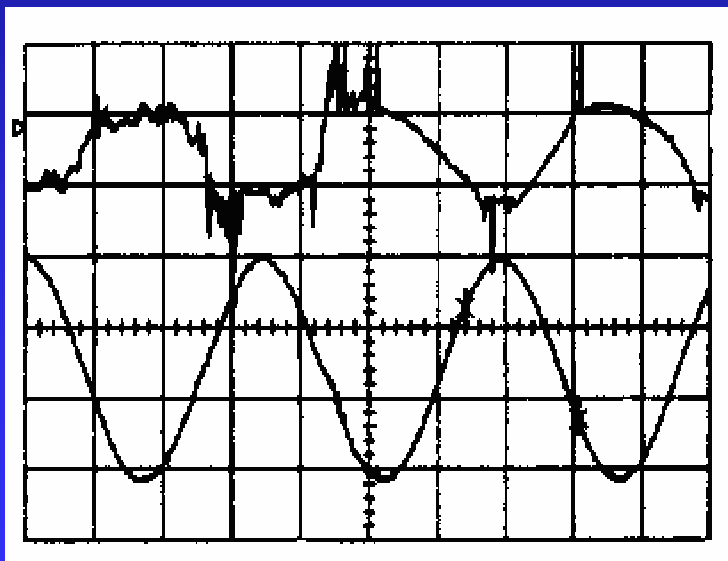


MBI

DEGRADATION OF ELECTRICAL CONTACTS

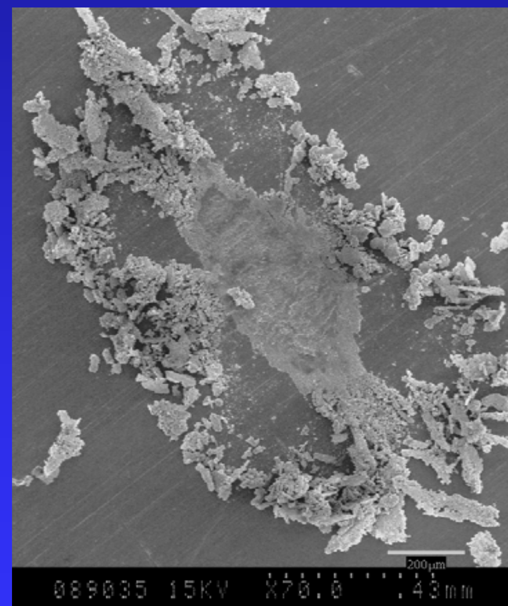
- **Fretting Damage in Electrical Connections**

AFTER 40 000 CYCLES

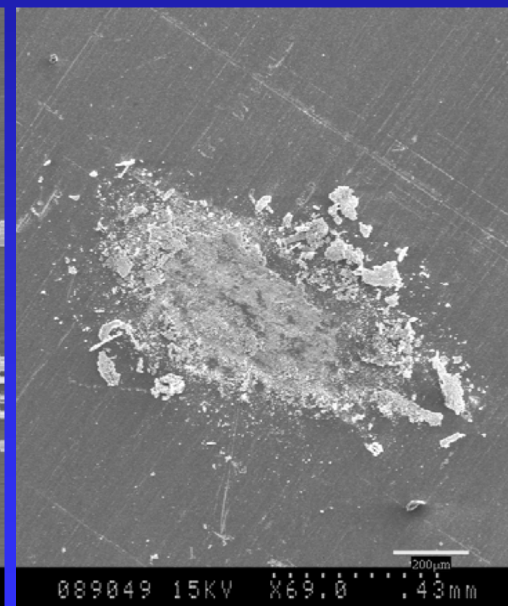


INITIAL

AC CURRENT

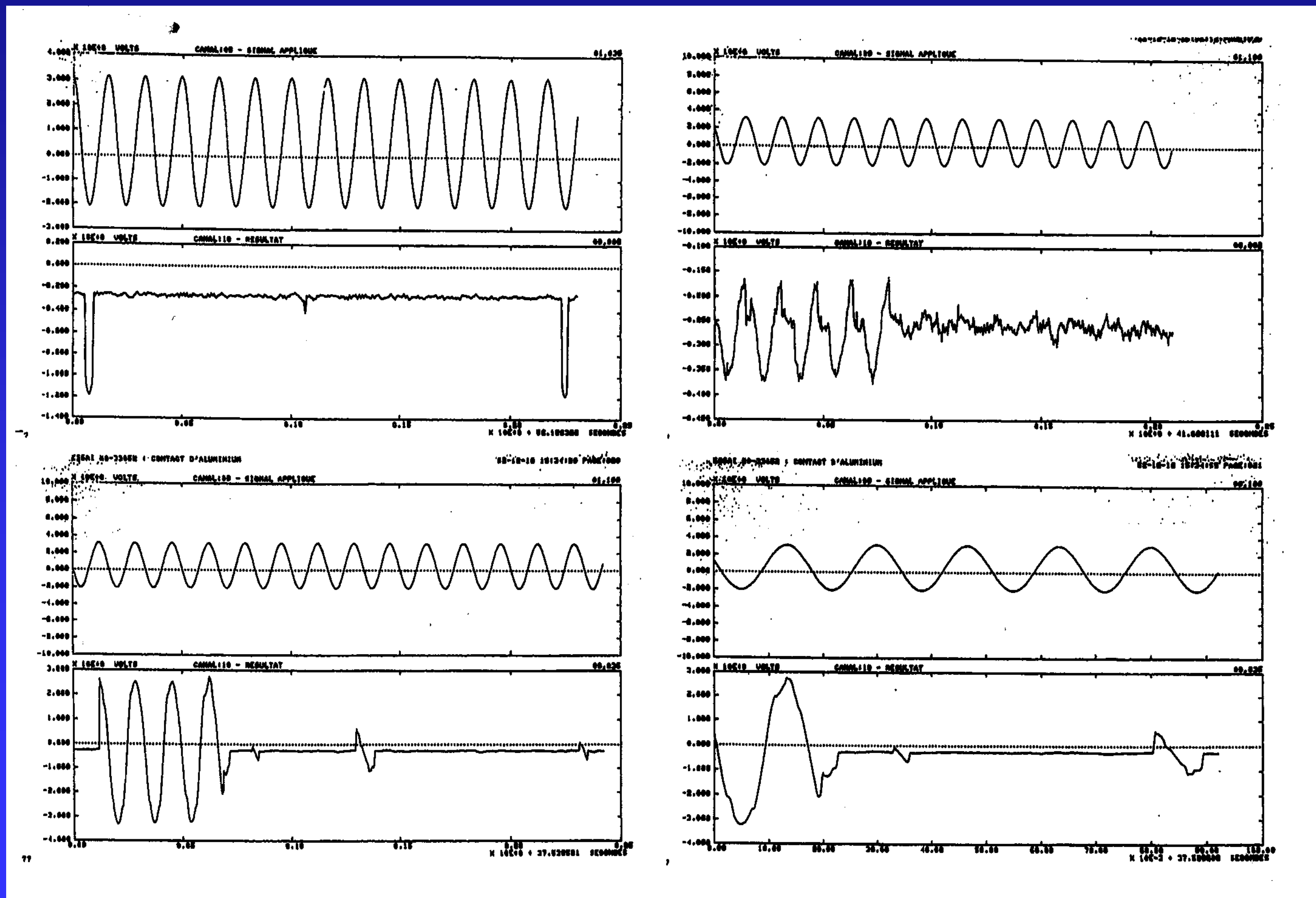


DC CURRENT



DEGRADATION OF ELECTRICAL CONTACTS

Effect of Fretting on Power Quality



DEGRADATION OF ELECTRICAL CONTACTS

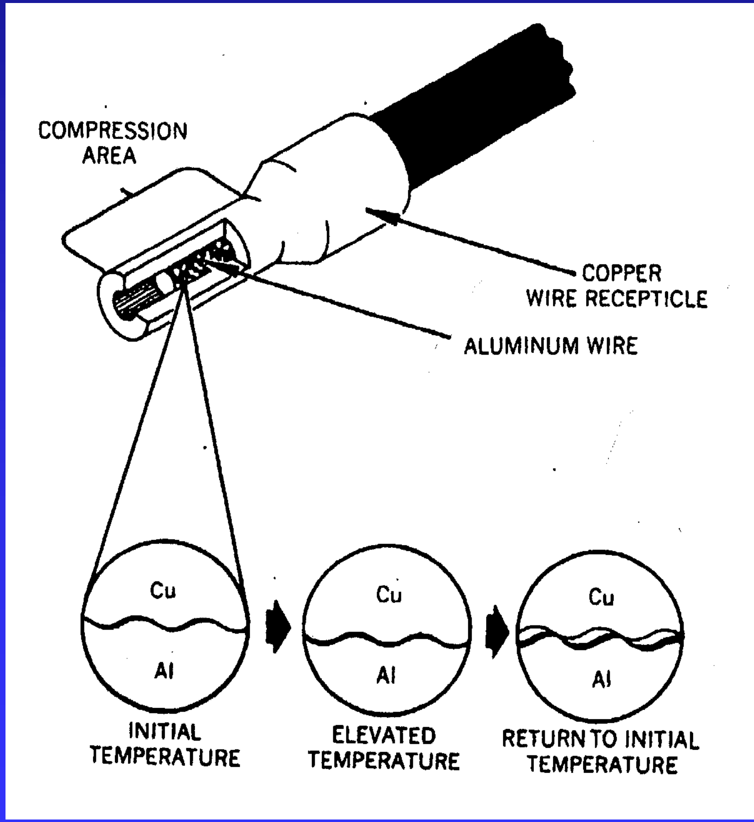
Differential Thermal Expansion

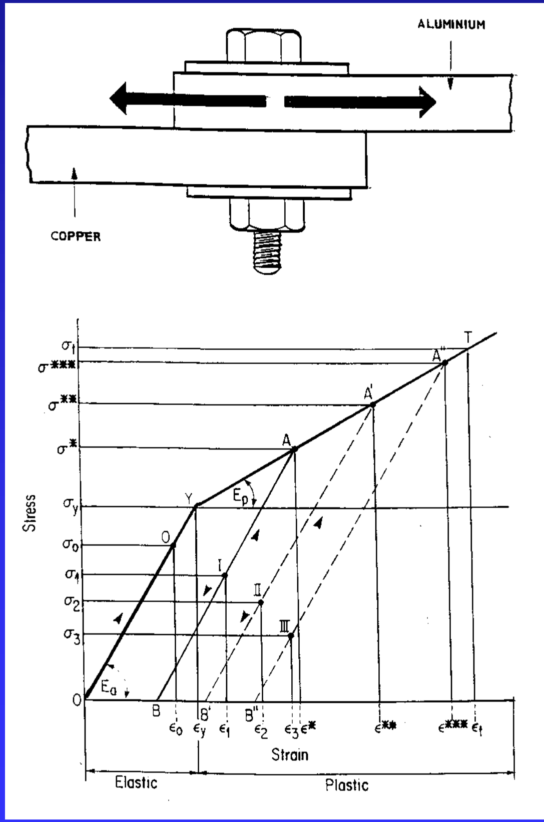
- **Aluminum expands at a greater rate than Cu or steel when exposed to higher temperatures resulting in the shearing of metal-contact bridges or plastic deformation.**
- **Thermoelastic ratcheting occurs in a bolted Al-Cu joint with a steel bolt due to excessive tightening of the bolt which causes plastic deformation of Al.**
- **Repeated heating-cooling cycles loosens the joint, increases the contact resistance and joint temperature.**

MBI

DEGRADATION OF ELECTRICAL CONTACTS

Differential Thermal Expansion





DEGRADATION OF ELECTRICAL CONTACTS

Formation of Intermetallics in *Al*Cu* Joints

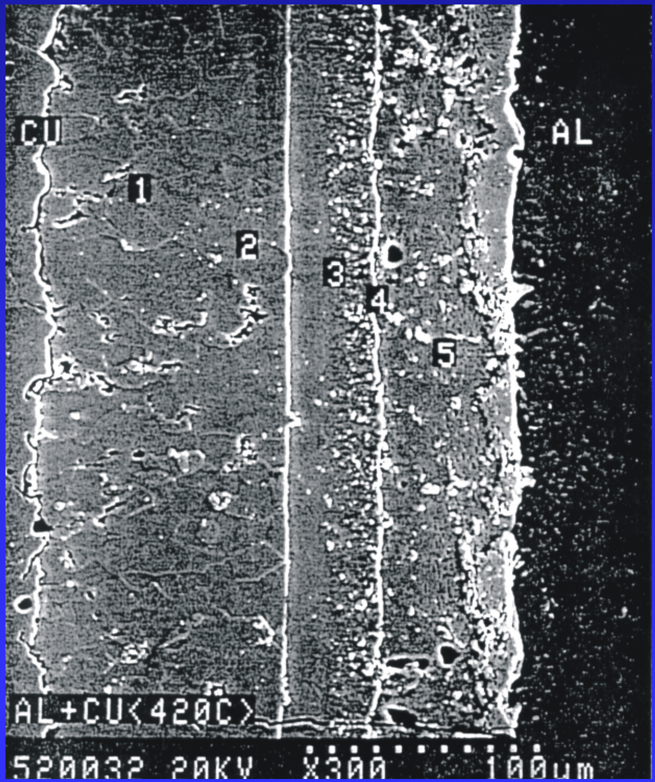
- In Al-Cu joints intermetallics can form relatively rapidly at temperatures generally accepted as normal operating and overload temperatures on the network.
- Electrical and mechanical properties of Al-Cu contact are significantly impaired by formation and growth of intermetallics.
- Intermetallics increase the significantly brittleness and the contact resistance of a joint.

MBI

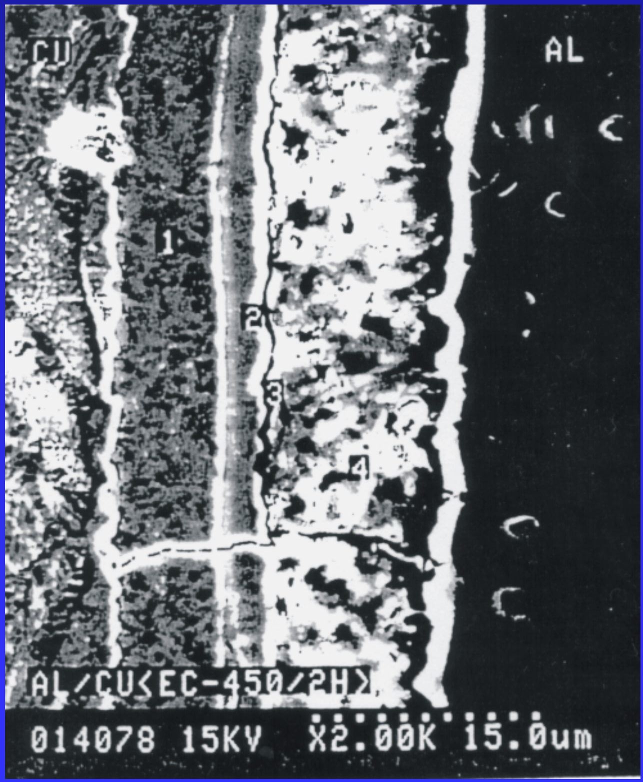
DEGRADATION OF ELECTRICAL CONTACTS

- **Formation of Intermetallics in *Al*Cu* Joints**

Thermal Gradient

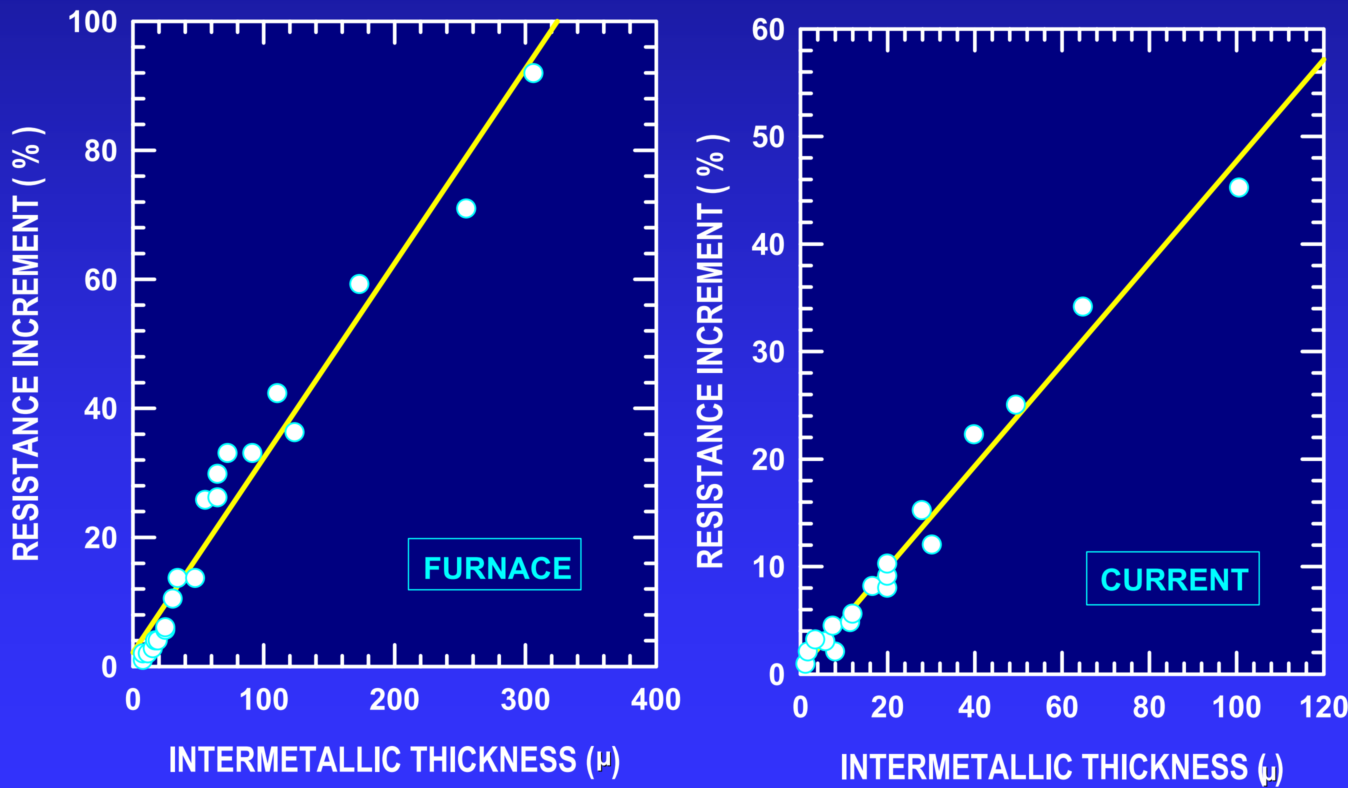


Electric Field Gradient



DEGRADATION OF ELECTRICAL CONTACTS

- **Deleterious Effect of Intermetallics**



MBI

DEGRADATION OF ELECTRICAL CONTACTS

- **Deleterious Effect of Intermetallics in Tin-Plated Cu**

MBI

DEGRADATION OF ELECTRICAL CONTACTS

Creep (Cold flow)

- Occurs when a metal is subjected to a constant external force
- Manifested by a dimensional change
- Higher for aluminum than for copper
- Stress-, time- and temperature-dependent

Stress relaxation

- Manifested by a reduction in the contact pressure
- Higher for aluminum than for copper
- Stress-, time- and temperature-dependent

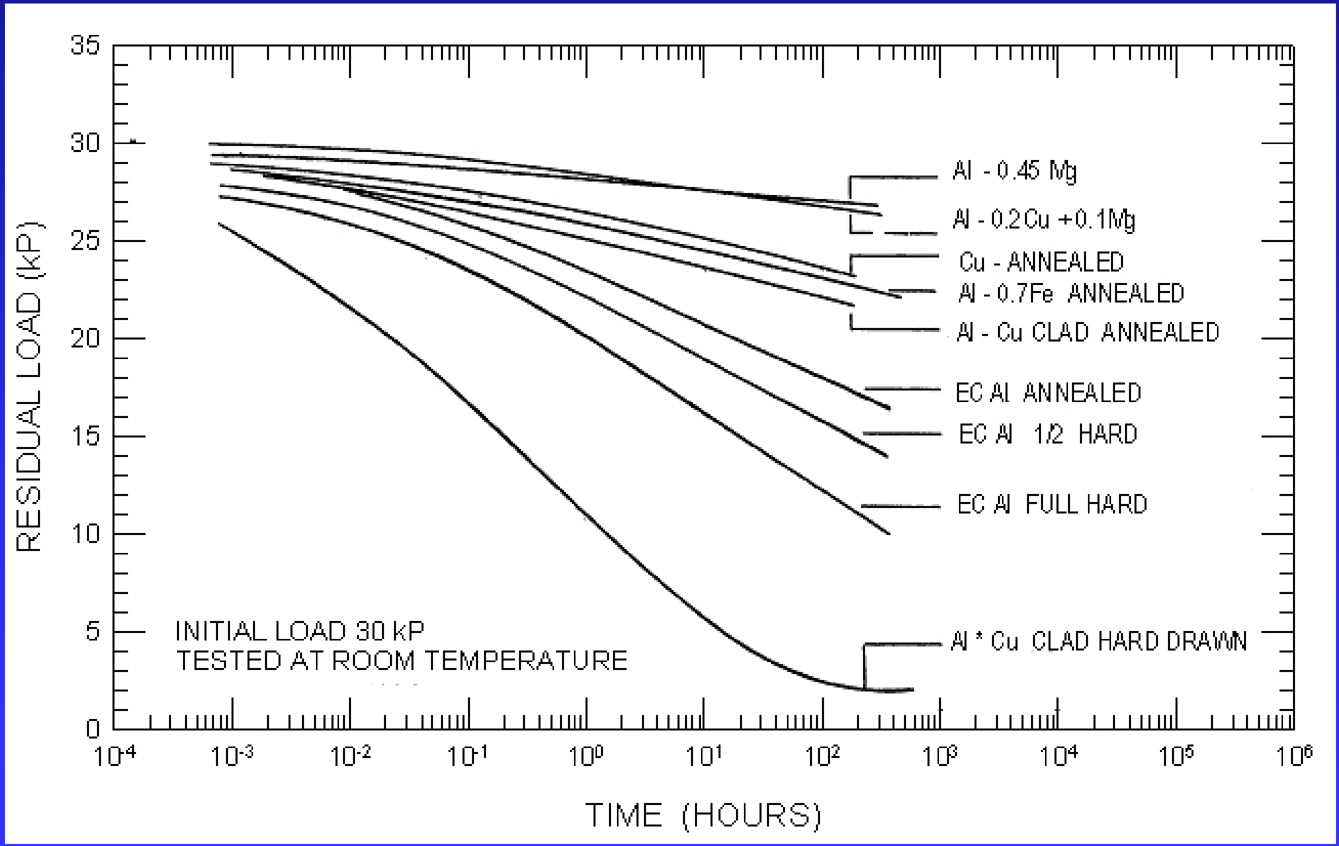
Electroplasticity

- Manifested by an increased ductility
- Increases creep / stress relaxation rates

MBI

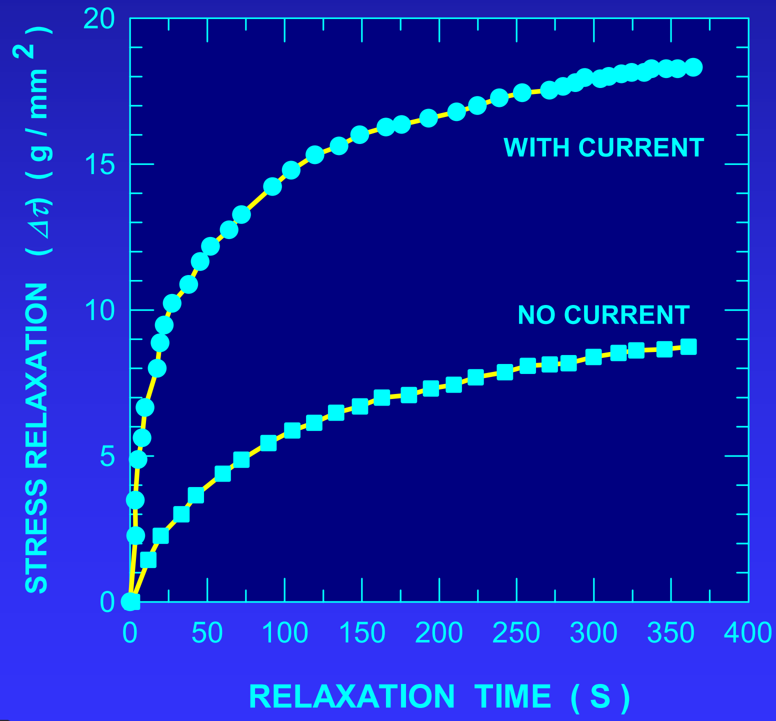
DEGRADATION OF ELECTRICAL CONTACTS

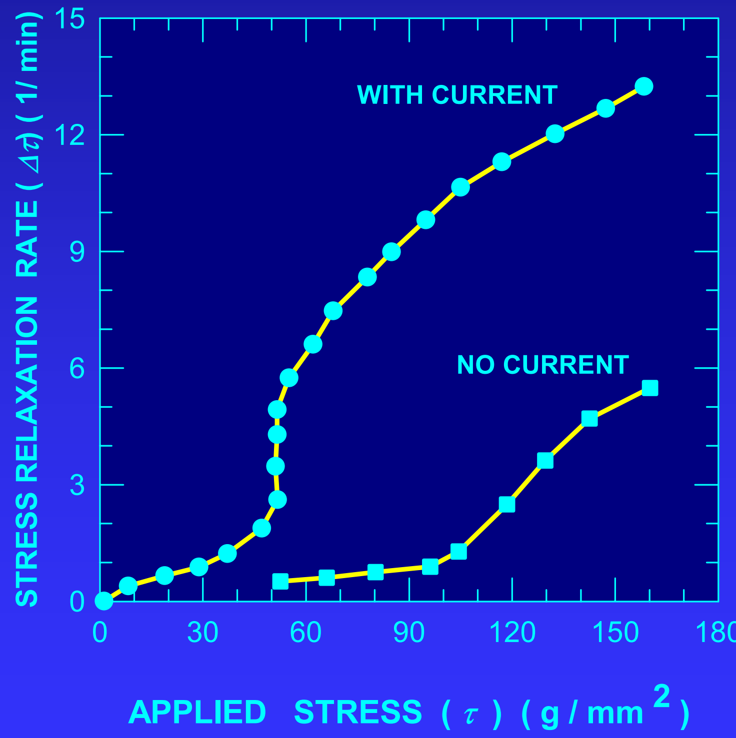
Stress Relaxation / Creep



DEGRADATION OF ELECTRICAL CONTACTS

Stress Relaxation / Creep





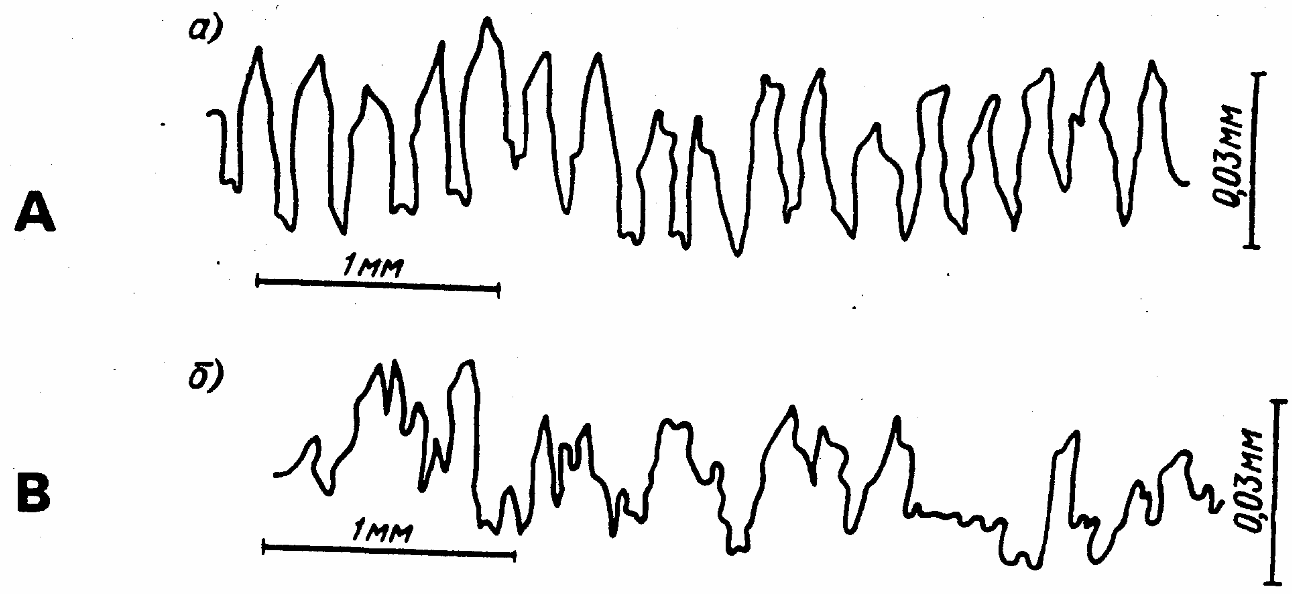
MBI

PALLIATIVE MEASURES

- Surface Preparation
- Connector Design
- Contact Area / Pressure
- Mechanical Contact Aids
- Coating / Plating
- Lubrication
- Installation Practices

PALLIATIVE MEASURES

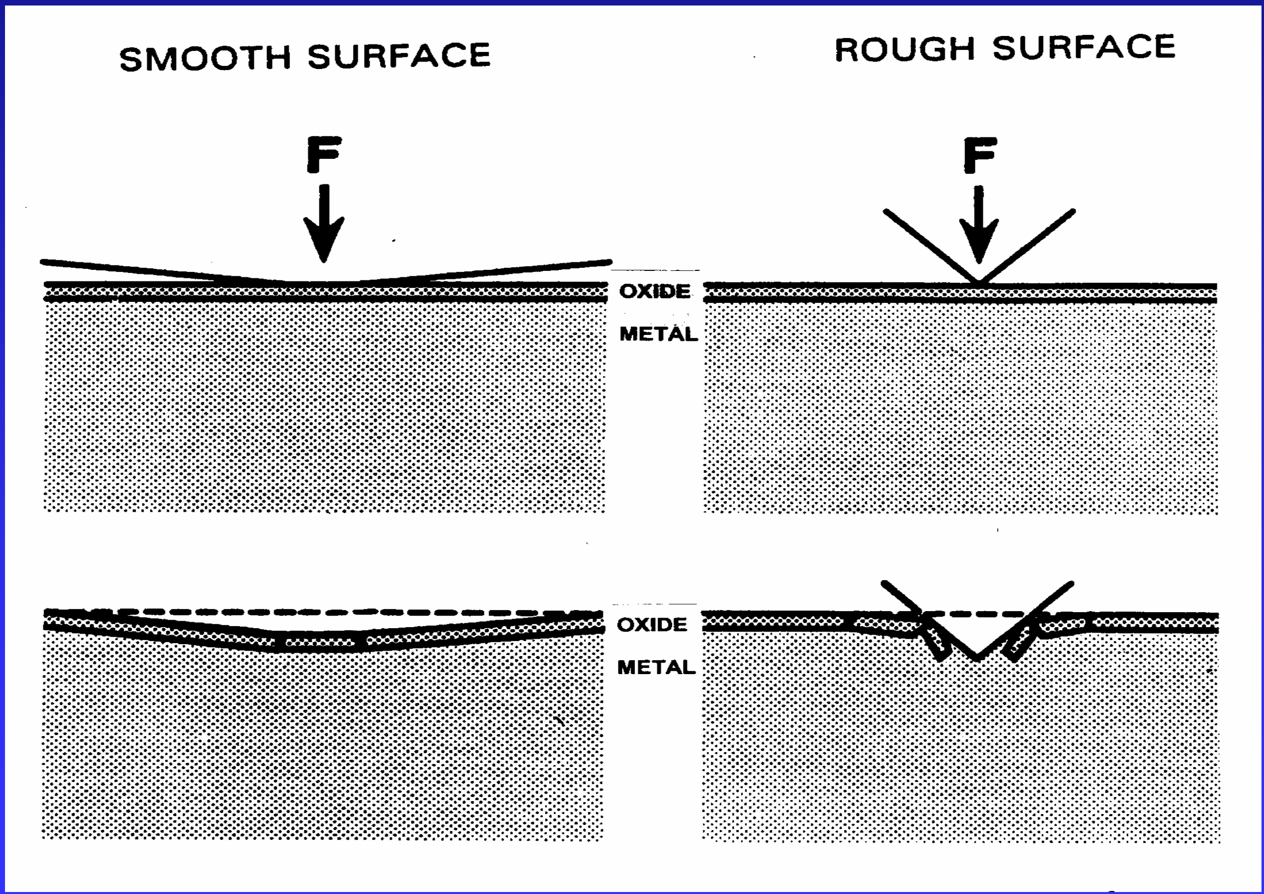
- **Surface Topography**



Surface topography of a metal abraded by a file (A) and a metal brush (B)

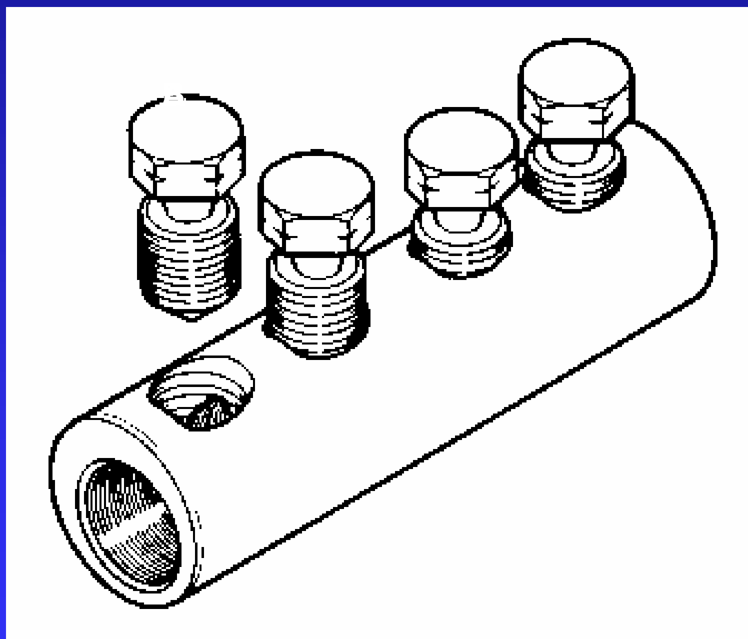
PALLIATIVE MEASURES

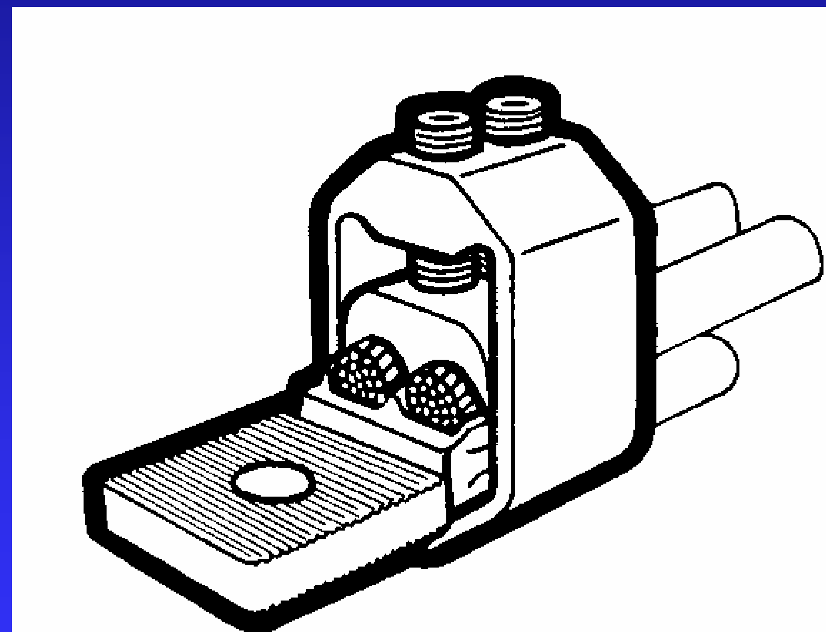
- Effect of Surface Roughness



PALLIATIVE MEASURES

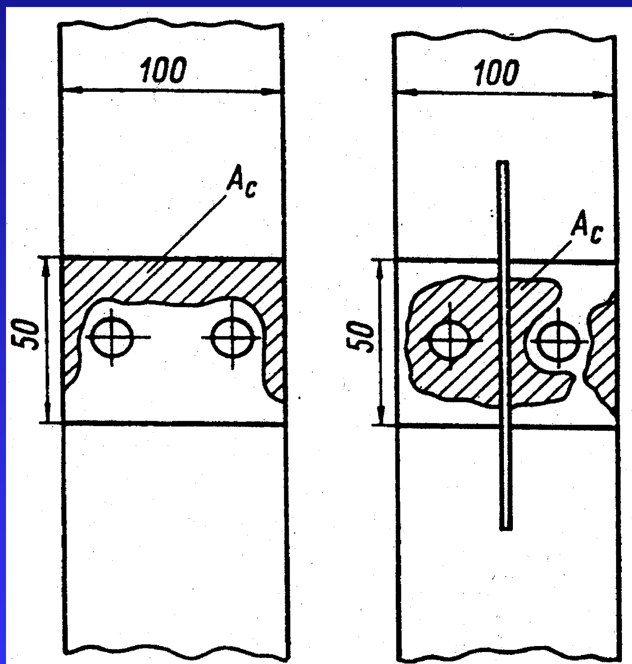
- Effect of Contact Area (Serrations)



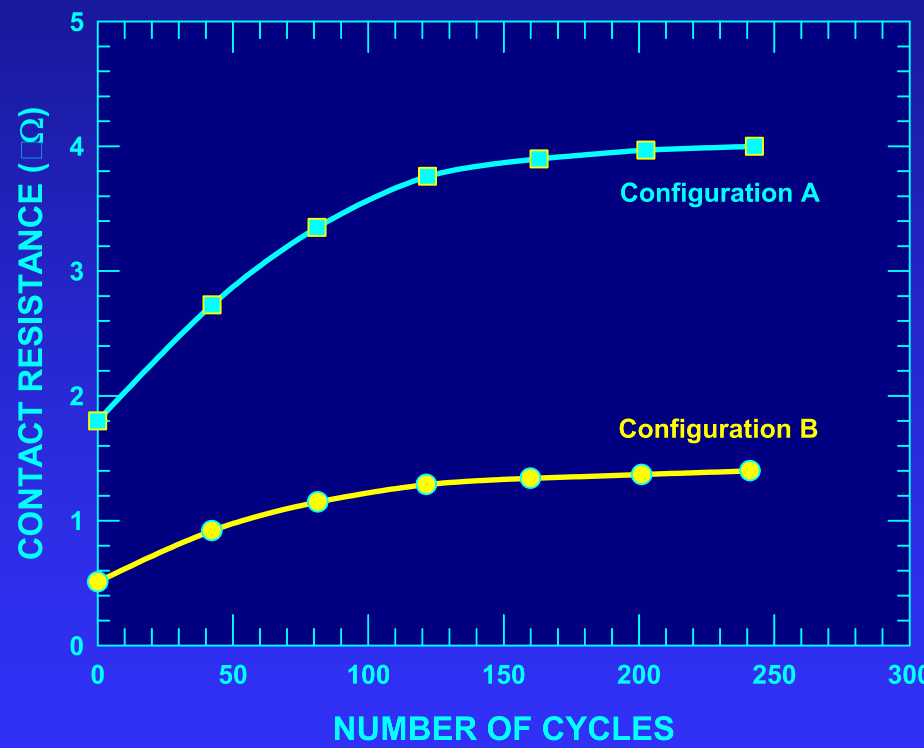


PALLIATIVE MEASURES

- **Effect of Contact Area**



A B

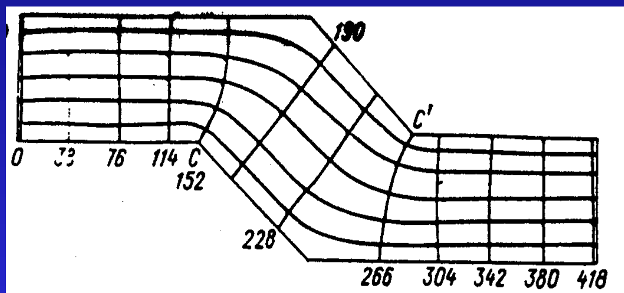


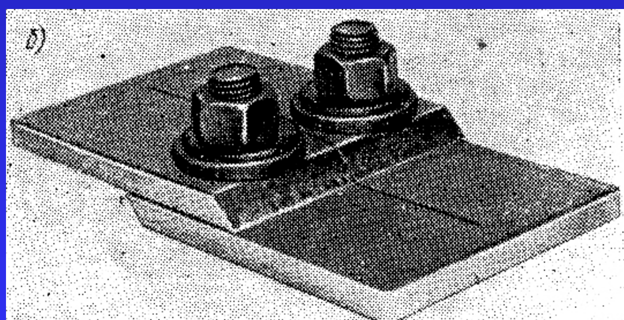
Contact resistance of joint configuration (B) is 20-30% lower than that of (A) and is mechanically more stable

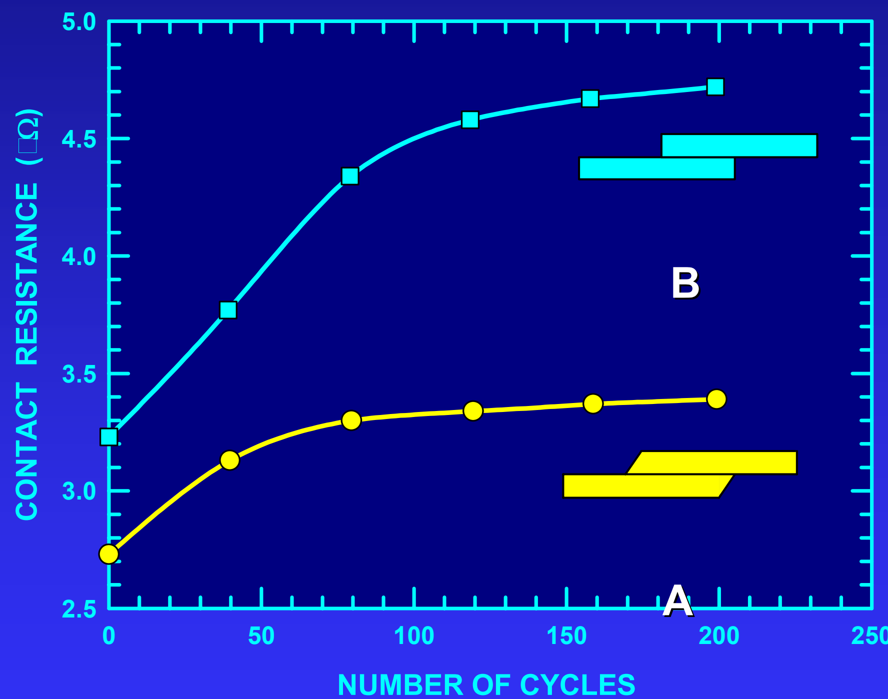
MBI

PALLIATIVE MEASURES

- **Effect of Contact Area**





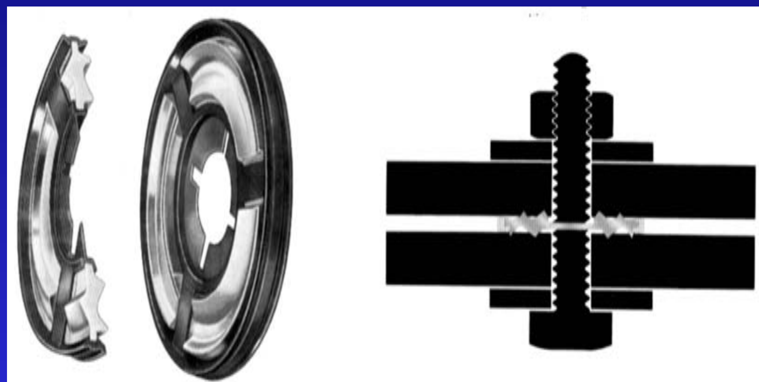


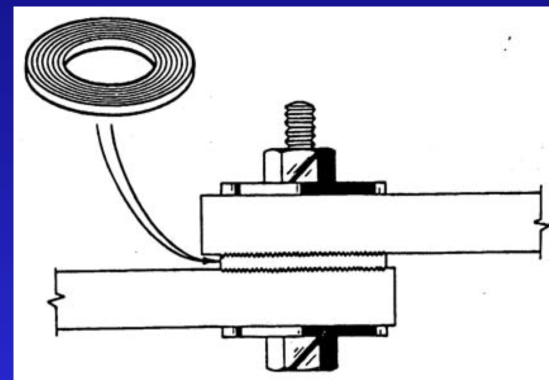
Contact resistance of slanted busbars (A) is 1.3 – 1.5 times lower than that of non slanted busbars (B).

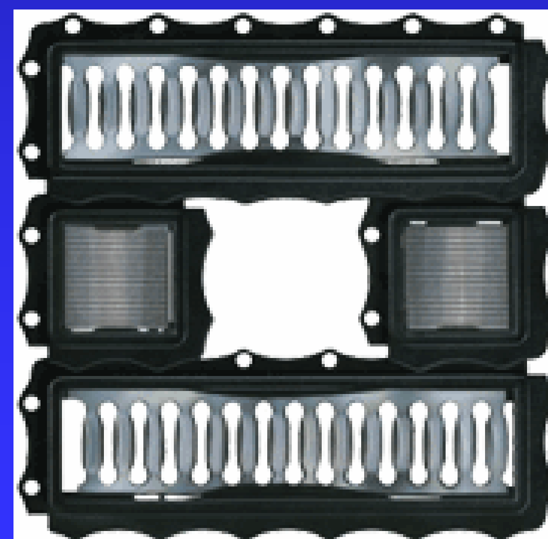
MBI

PALLIATIVE MEASURES

- **Use of transition washers**

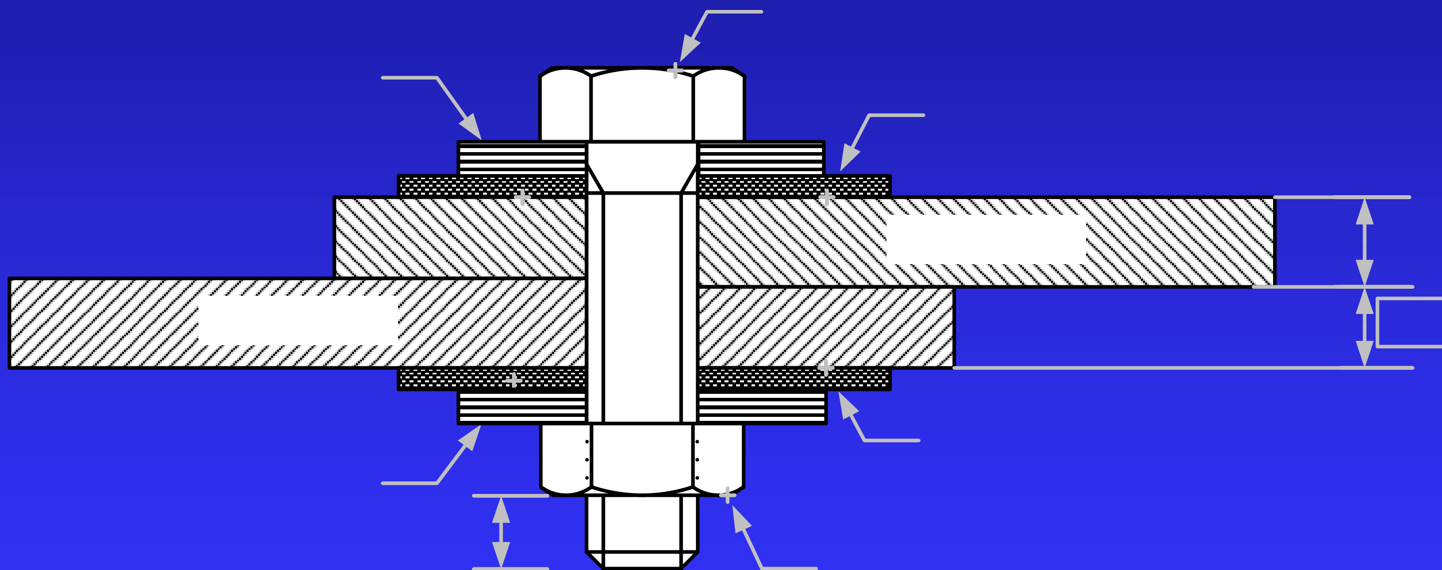






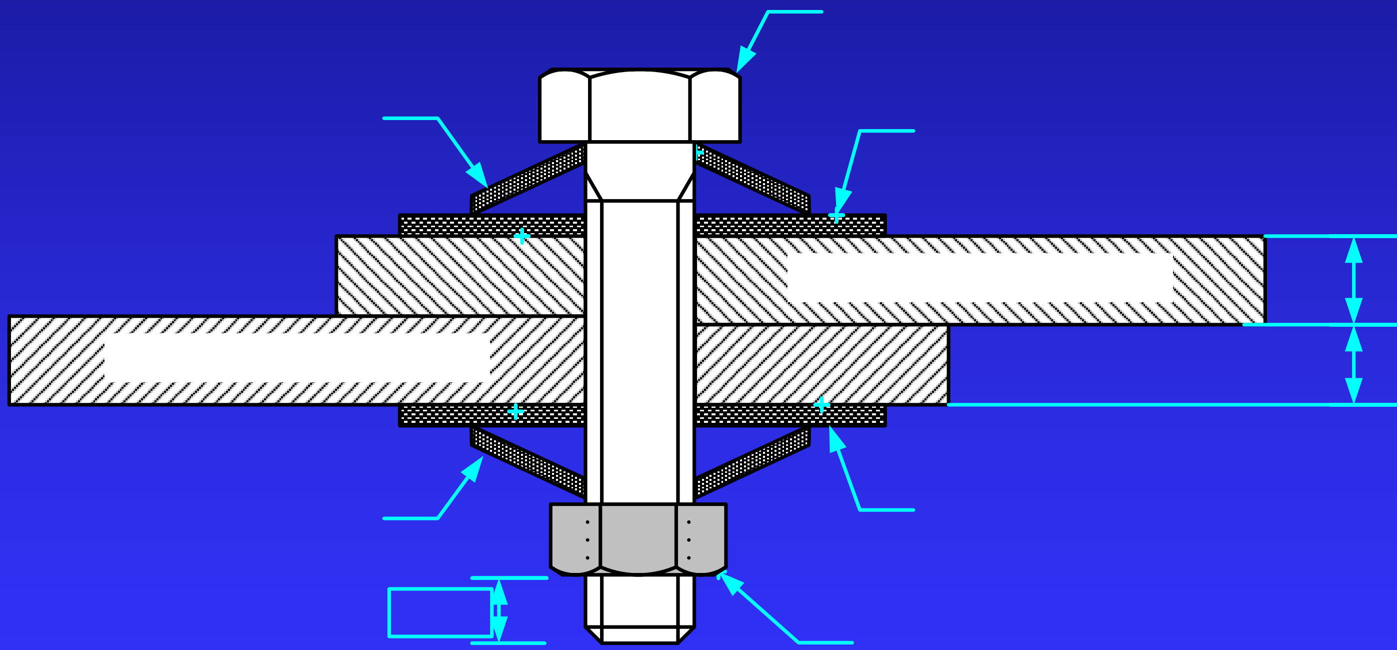
INSTALLATION PRACTICES

Recommended installation practice for bolted Al-Al joints with all aluminum hardware



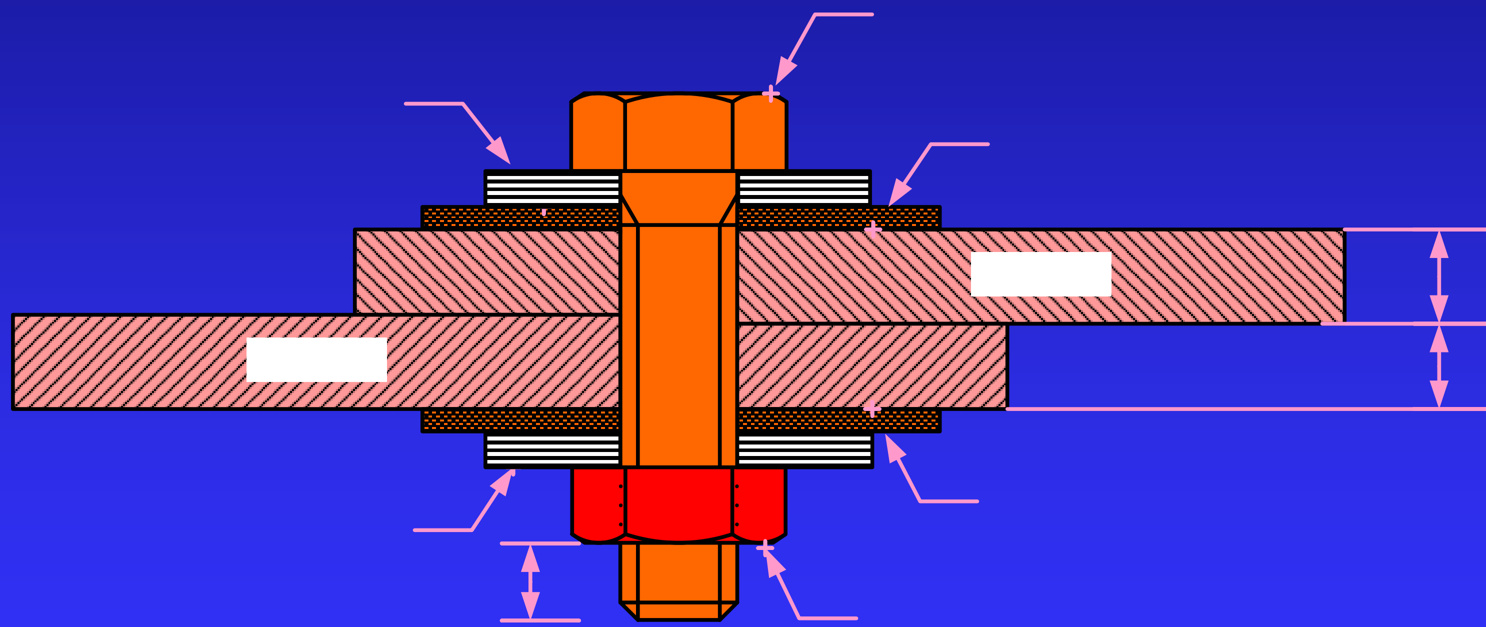
INSTALLATION PRACTICES

Recommended installation practice for bolted joints Al-Al, Cu-Cu, Al-Cu with steel hardware



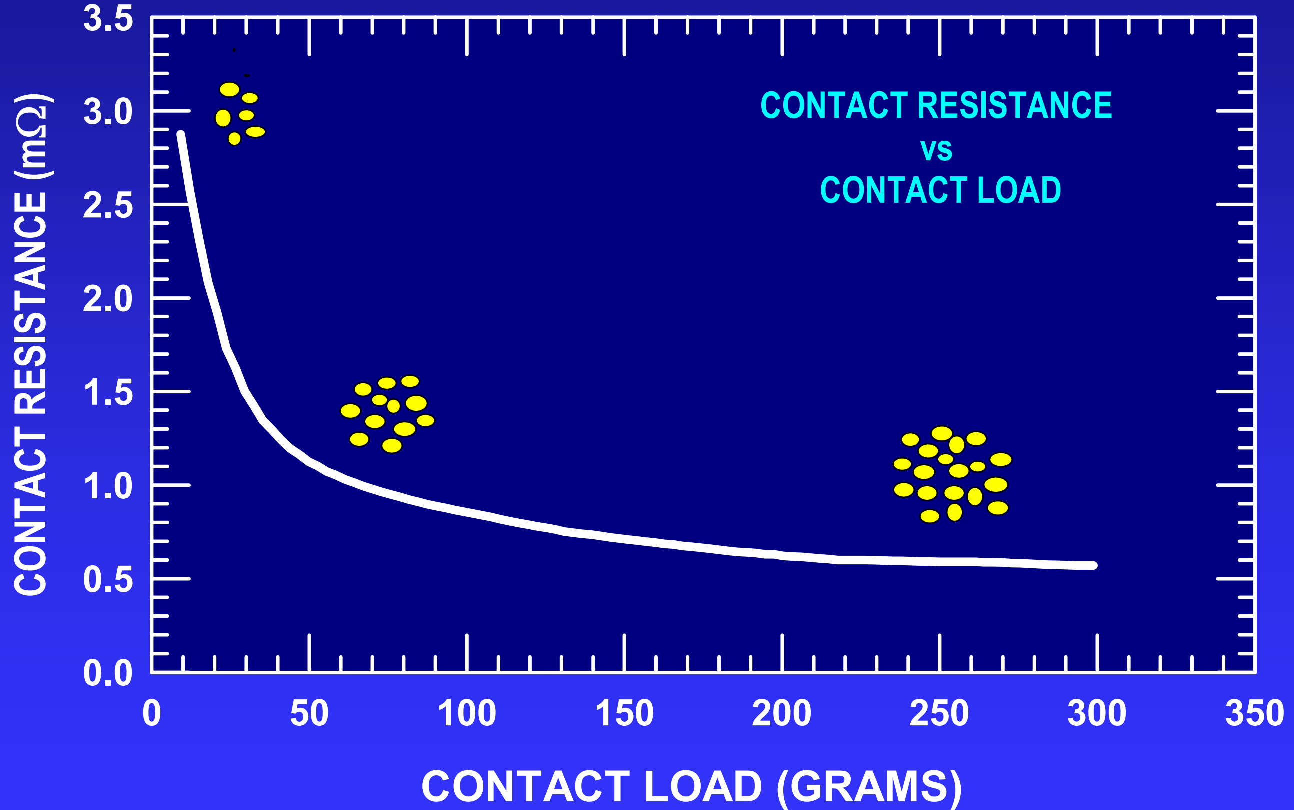
INSTALLATION PRACTICES

Recommended installation practices for bolted Cu-Cu joints with all copper hardware



PALLIATIVE MEASURES

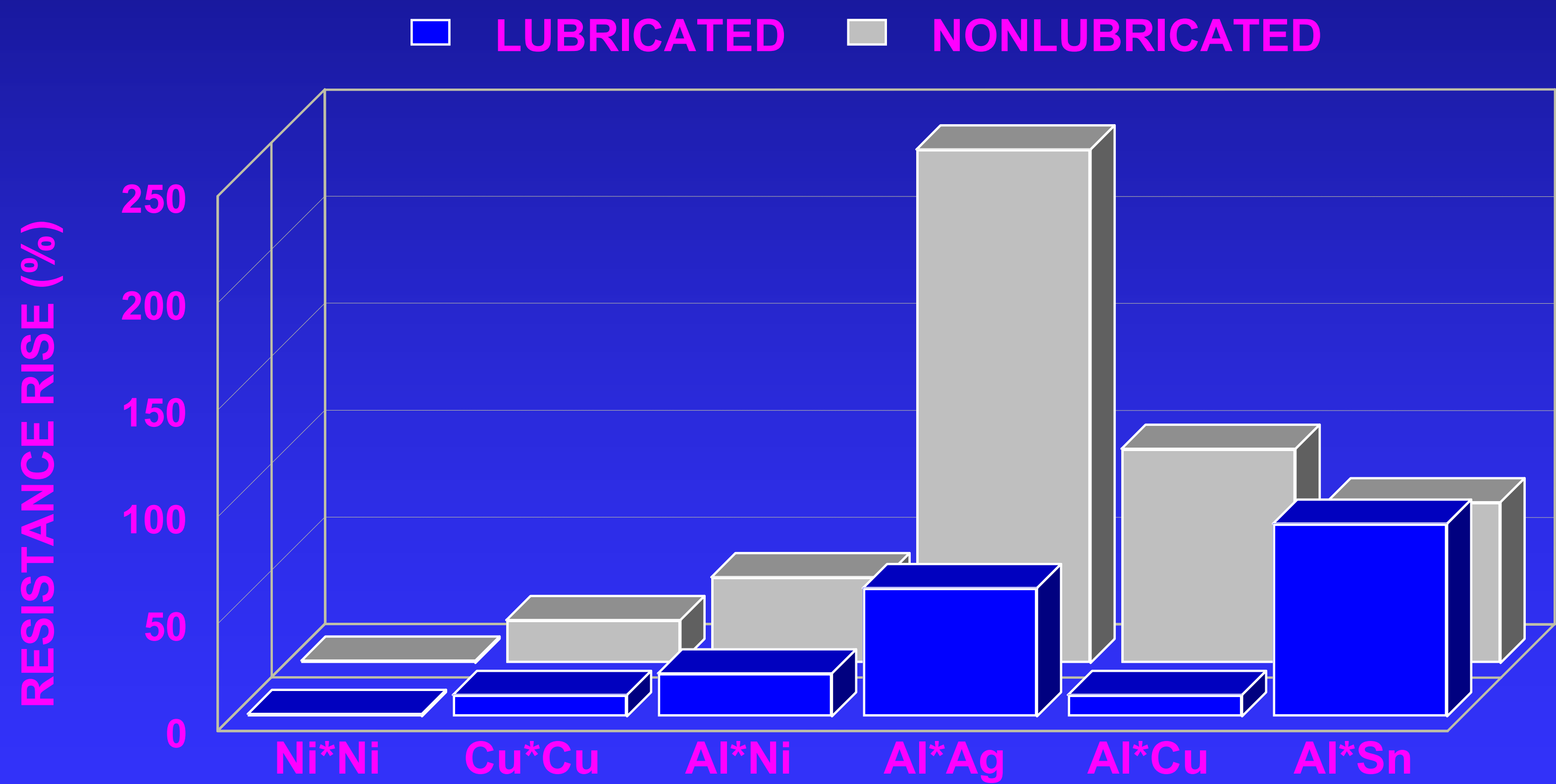
- **Effect of Mechanical Contact Load**



PALLIATIVE MEASURES

- **Coatings / Plating**

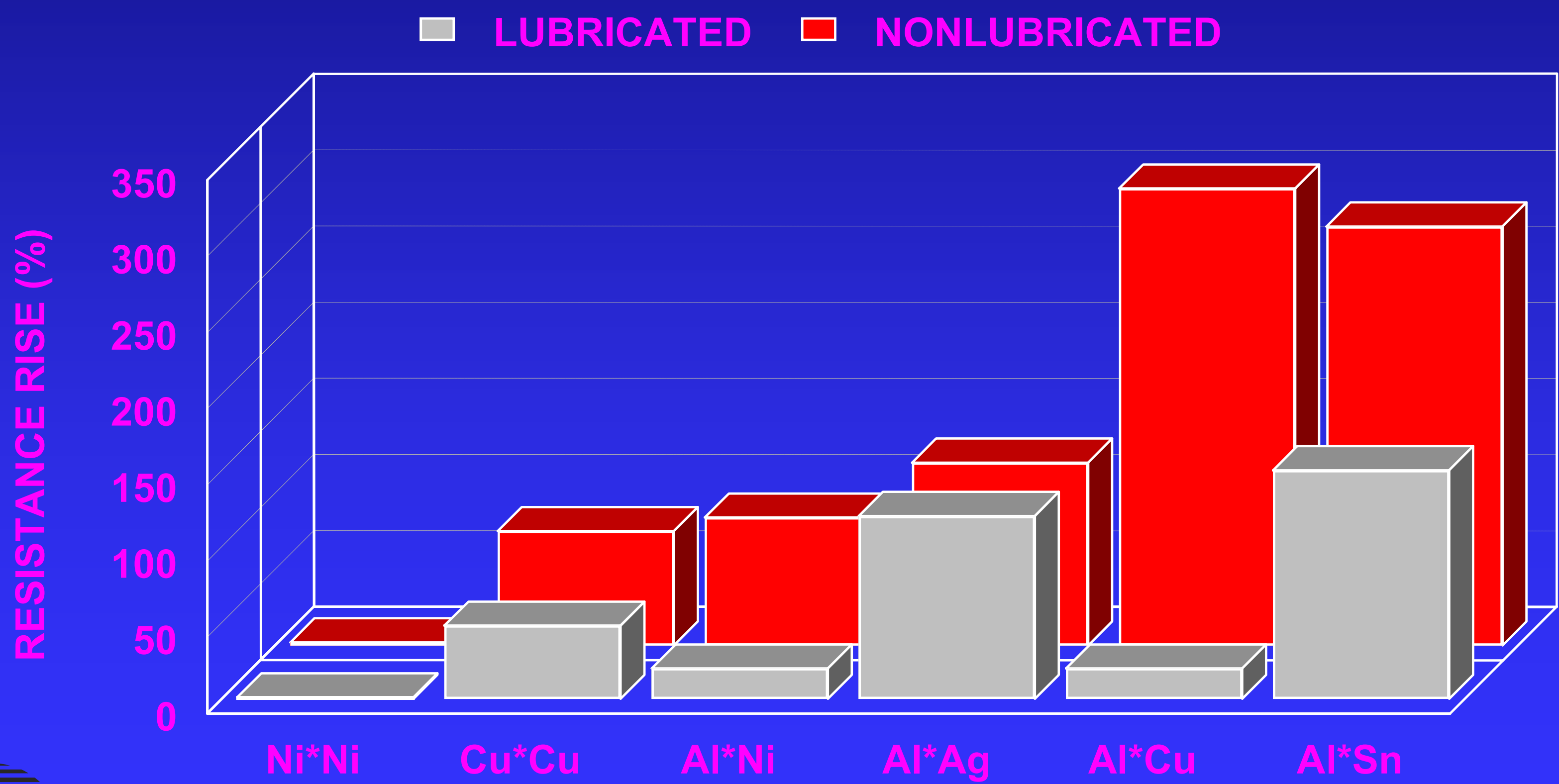
Industrial Pollution



PALLIATIVE MEASURES

Coatings / Plating

- Saline Environment



MBI

PALLIATIVE MEASURES

Lubrication

Basic Properties of Lubricants Intended for Electrical Contacts

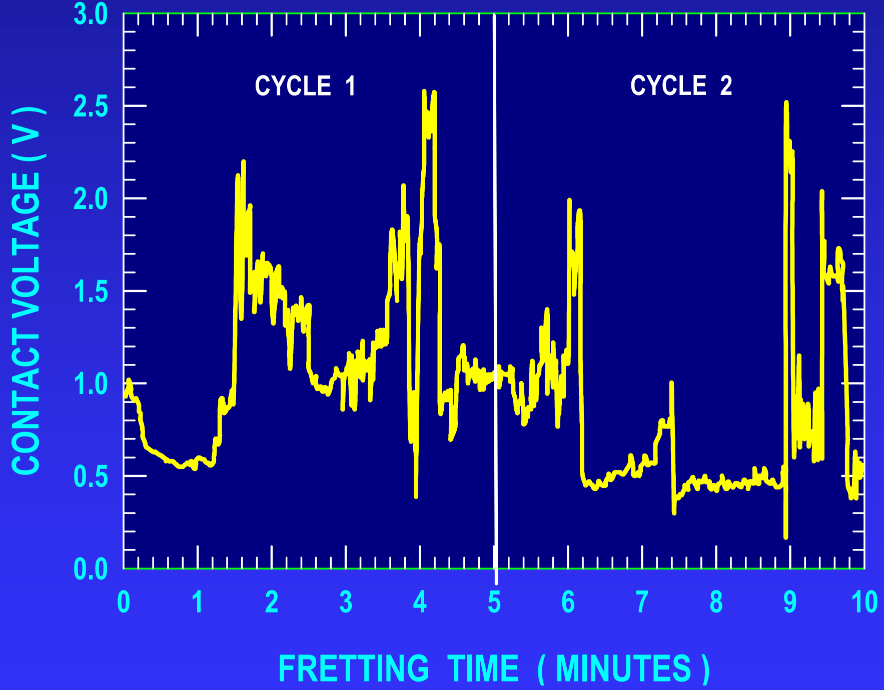
- Thermal Stability
- Spreading Tendency
- Resistance to Oxidation
- Resistance to UV Radiation
- Ability to Protect Contact Zone
- Corrosion Inhibition
- Dispensability for Dust and Wear Particles
- Applicability
- Stability to Polymerization
- Reactivity with Ambient Vapors
- Viscosity

MBI

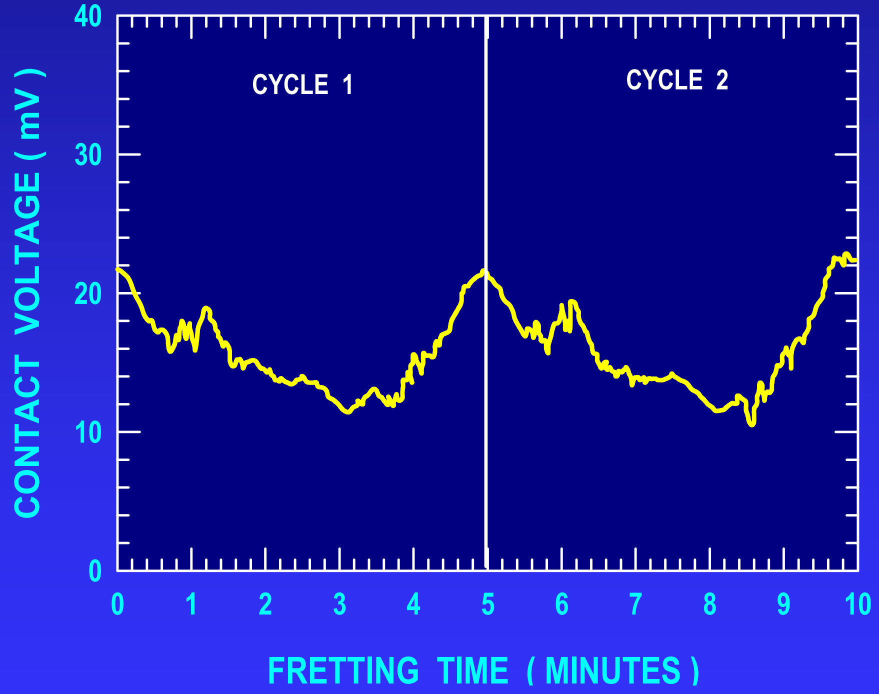
PALLIATIVE MEASURES

Effect Lubrication on Contact Voltage of Al-Cu Contacts Under Fretting Conditions

NON-LUBRICATED



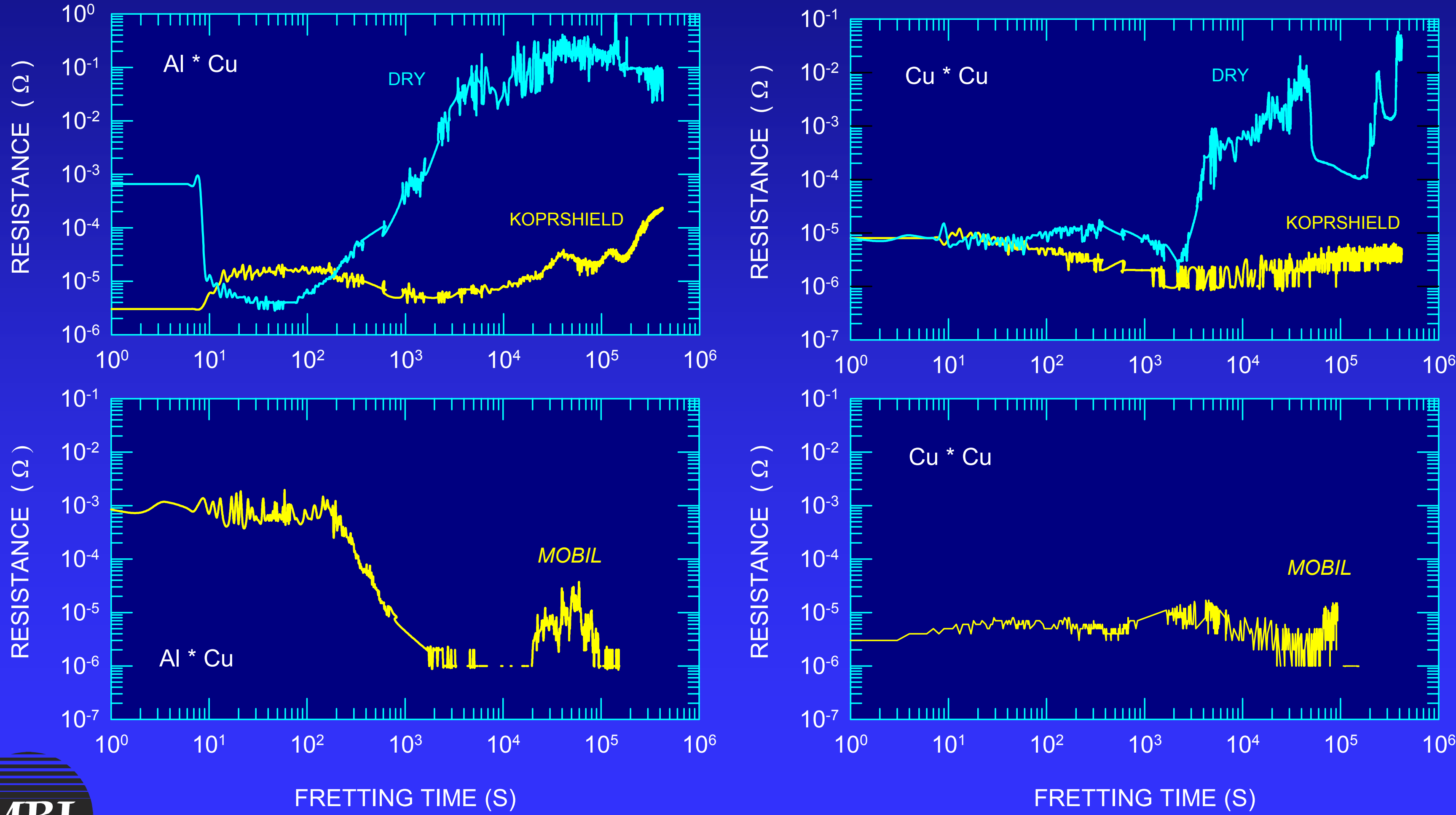
LUBRICATED



Slip Amplitude: ***25 microns*** **Frequency:** ***0.0033 H*** **Load: 2 *N***

PALLIATIVE MEASURES

Lubrication



MBI

MONITORING AND DIAGNOSTIC TECHNIQES

- **Ageing is the continuous time dependent degradation of materials due to normal service conditions.**
- **All power equipment materials undergo ageing and lose, partially or totally, their designed function.**
- **Ageing degradation of power components, such as connectors and disconnect switches, if not effectively monitored and controlled, may impair their performance characteristics and thus a reduction of the reliability of associated power systems.**
- **Effective control of ageing degradation of power components requires timely detection and mitigation of the degradation.**

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Monitoring and diagnostic techniques should:

- **Detect deterioration or damage affecting structural integrity of power equipment.**
- **Determine and characterize the extent and severity of deterioration**
- **Assess the deleterious effect of deterioration on the performance of the power equipment.**
- **Initiate mitigating or corrective actions to restore the operational capabilities of the power equipment.**

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Techniques and methods used to monitor and diagnose the condition of power components

- **Thermal measurements**
- **Resistance measurements**
- **Force measurements**
- **Torque measurements**
- **Ultrasonic measurements**

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Thermal measurements include:

- Infrared thermal systems
  - Infrared thermometers
  - Infrared focal plane area cameras
- Temperature stickers
- Remote temperature sensors
- Shape-memory alloy indictors

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Infrared thermometers

Handheld IR thermometers

Fixed-type IR thermometers

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Infrared focal plane area cameras

Mikron MikroScan
7600 PRO

FLIR ThermaCAM®
P60 IR Camera

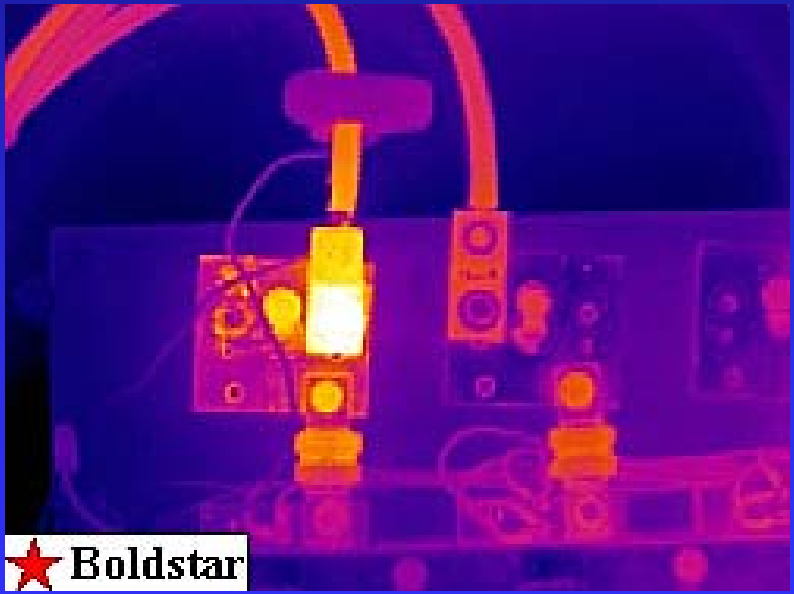
Electrophysics
EZTHERM PRO

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Examples of of overheated power components

(Courtesy of Boldstarinfrared)



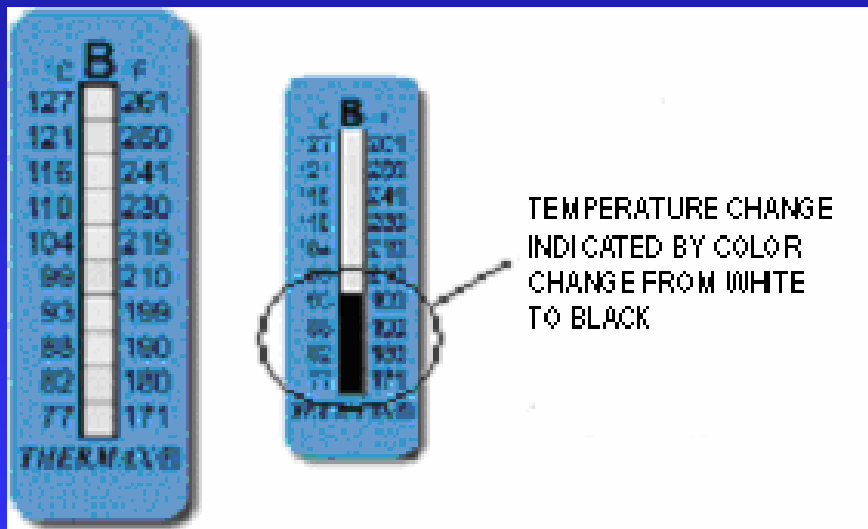
Overheated bolted connection

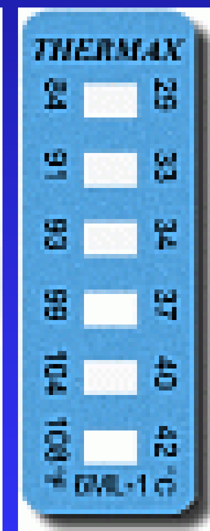
Overheated of disconnect switch

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Temperature stickers (Labels)



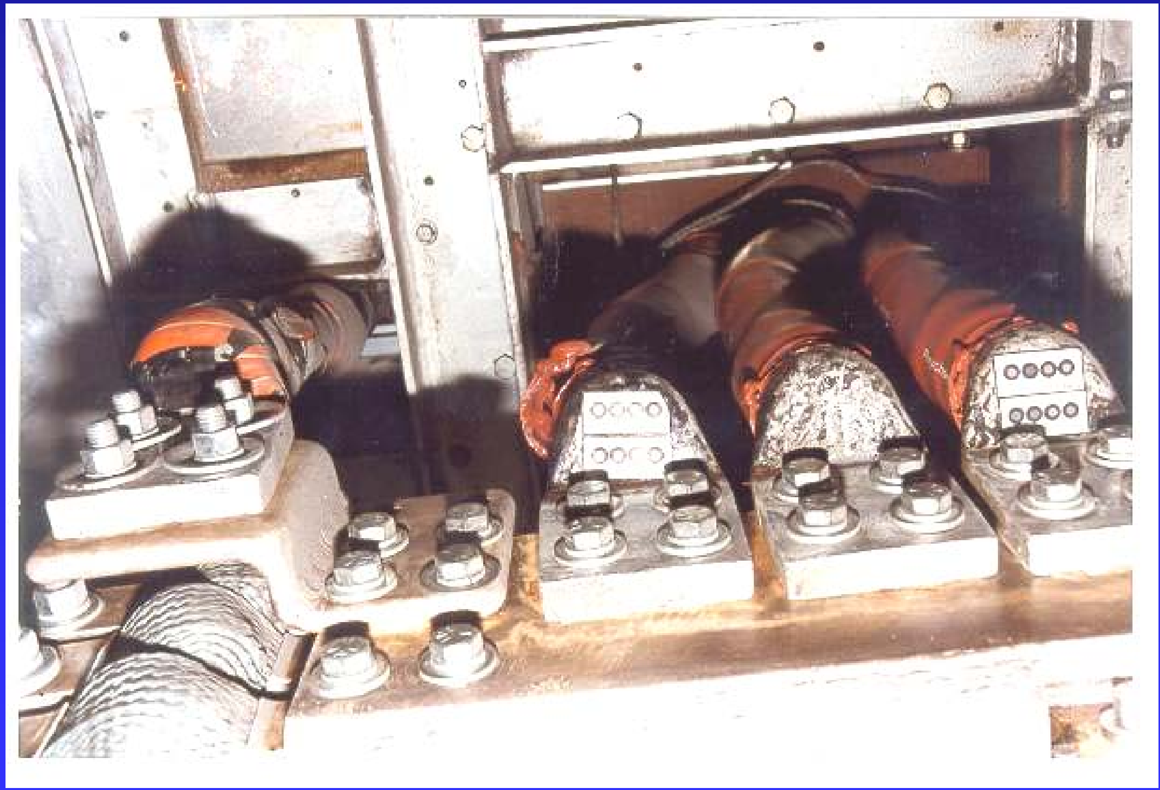


MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Example of temperature stickers (Labels)

(Courtesy of Manitoba Hydro)



MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Remote temperature sensors

PhoneDucer (www.elwoodcorp.com)

MONITORING AND DIAGNOSTIC TECHNIQES

Resistance measurements

Tinsley 5898 Portable 200A Precision Micro-Ohmmeter

Megger DLRO10X Digital Resistance Ohmmeter

MBI

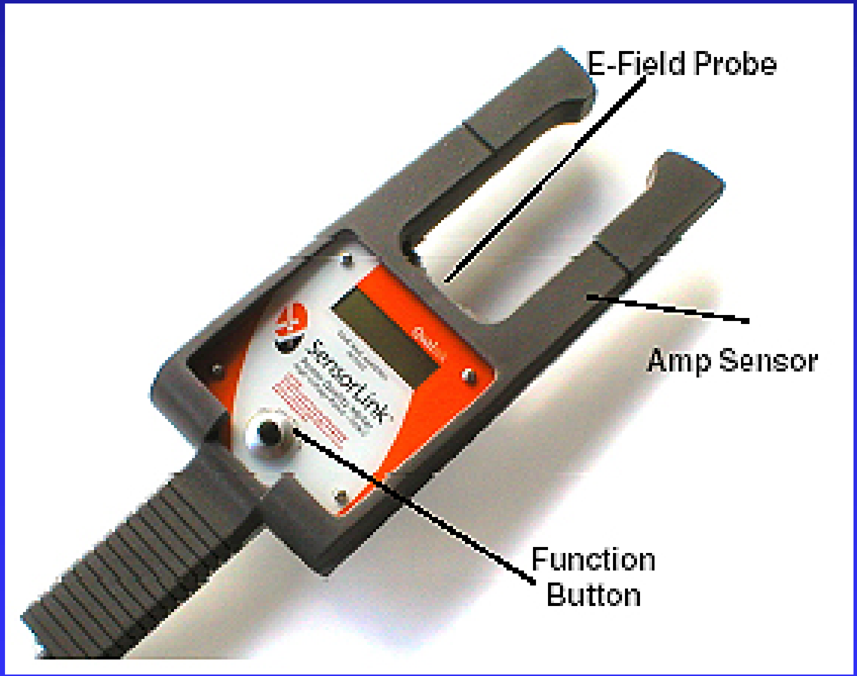
MONITORING AND DIAGNOSTIC TECHNIQES

Resistance measurements

Microohmmeter DRM-40, probe and a close-up of resistance measurement of the welded joint. (Courtesy of ndb Technologies Inc.)

MONITORING AND DIAGNOSTIC TECHNIQES

Resistance measurements

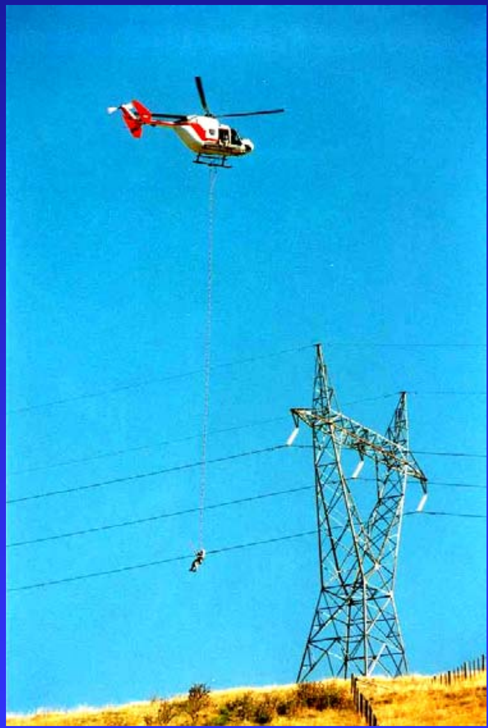


Ohmstik and Qualstik devices (Courtesy of Sensorlink)

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Resistance measurements

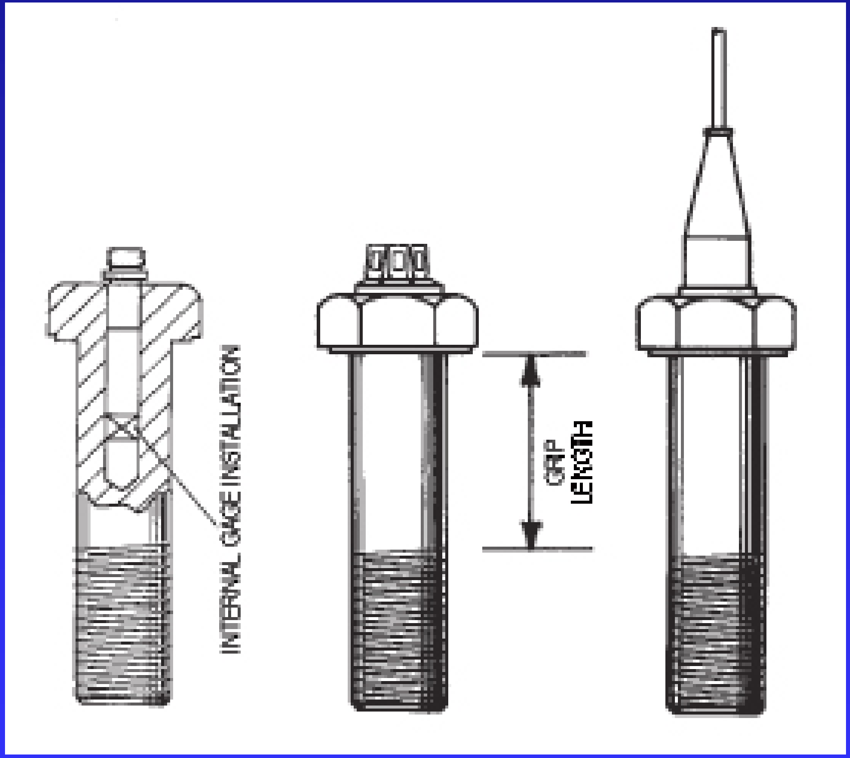



In-field measurement of joint resistance using Ohmstik (Courtesy of Transpower of New Zealand)

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Force monitoring



Schematic of Strainsert instrumented bolts

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Ultrasonic measurements

- Ultrasonic detectors provide a method of detecting sounds greater than 20 kHz.
- Loose electrical connections emit characteristic sounds that are beyond the range of the human ear.
- The ultrasonic detector provides a method of converting inaudible sounds to sounds and tones that match our hearing capabilities.
- Flashovers across an insulator make crackling sounds that are detectable even when there are no visible signs of arcing.

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Ultrasonic measurements

Ultrasonic detector Ultraprobe 10000 Digital Ultrasonic Inspection System, display panel and data views (Courtesy of UE Systems).

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Shape-Memory Alloys (SMA)

- The shape-memory effect (SME) refers to the ability of certain materials to “remember” and restore their shape upon heating, even after being initially severely deformed.
- When cooled below its transformation temperature (martensite), SMA has a very low yield strength and can be deformed quite easily into a new shape
- When heated above its transformation temperature, SMA undergoes a change in crystal structure which causes it to return spontaneously to its original shape (austenite).
- During this isotropic transformation process, as the atoms shift back to their original positions, a substantial amount of energy is released.
- A single cube of shape-memory alloy can exert enough force to move an object weighing 4650 kg!

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Schematic of Shape-Memory Effect

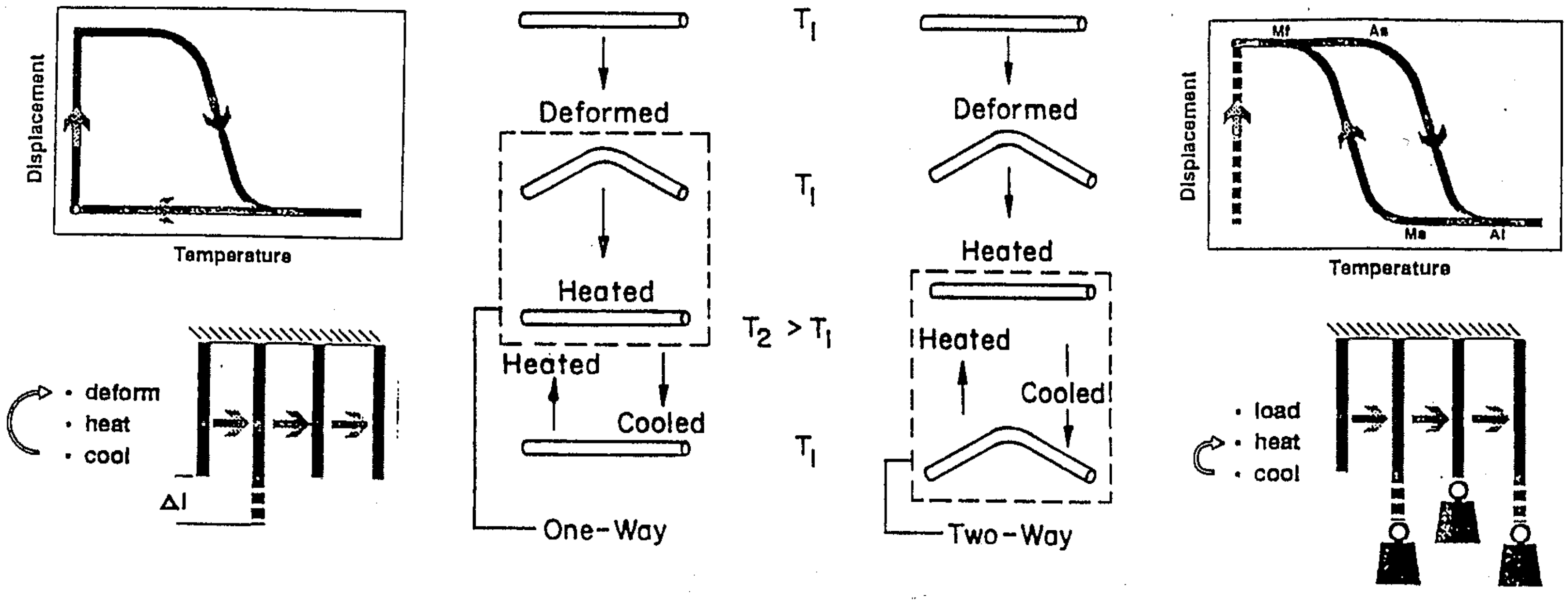
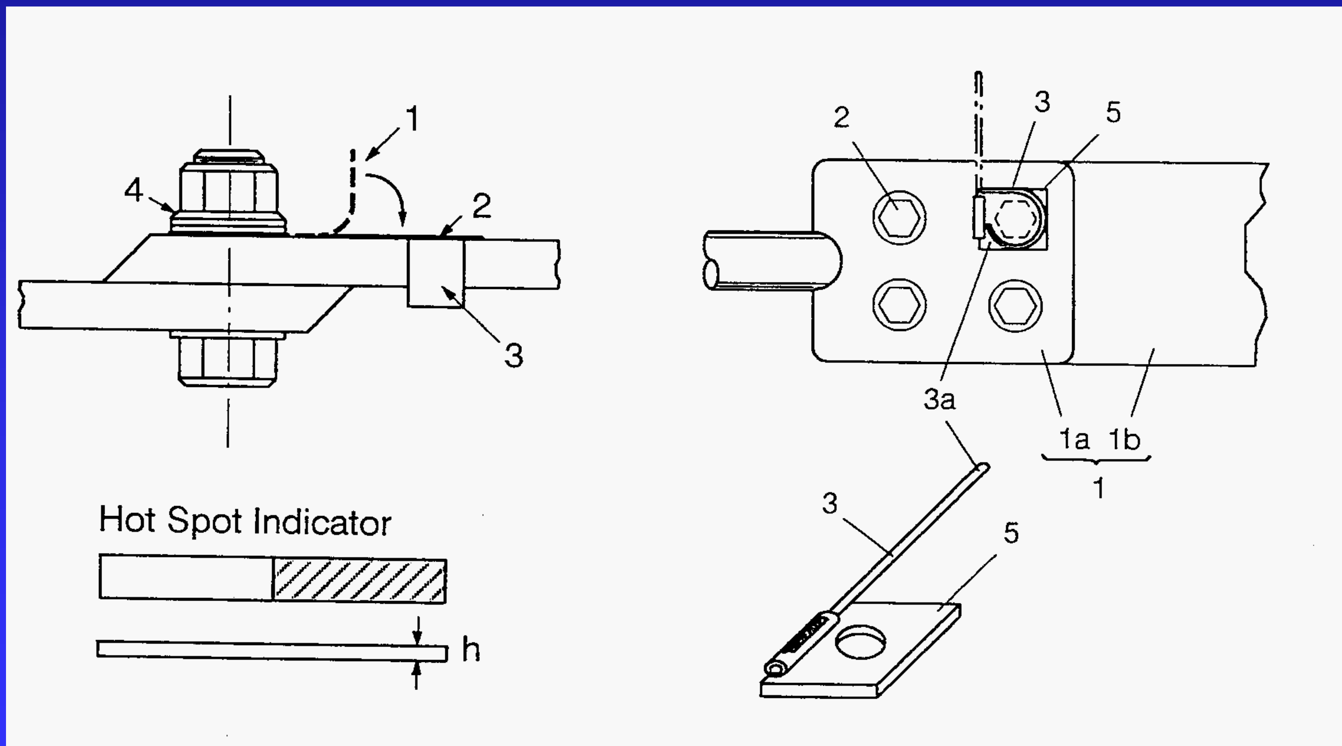


Fig.3 One-way shape-memory effect.

Fig.4 Schematic of two-way effect.

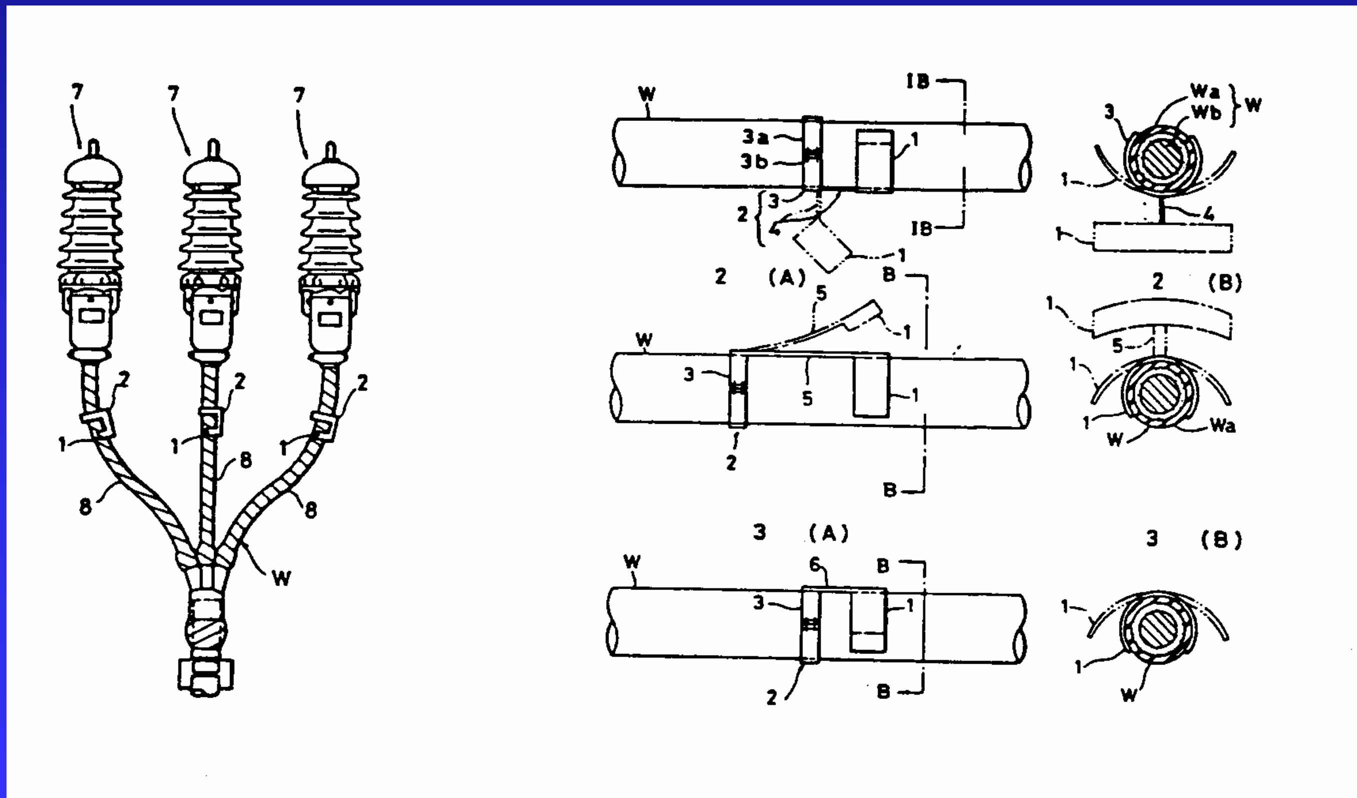
MONITORING AND DIAGNOSTIC TECHNIQES

Shape-Memory Alloy Temperature Hot-spot Indicators



MONITORING AND DIAGNOSTIC TECHNIQES

Shape-Memory Alloy Temperature Hot-spot Indicators



MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Desired Features of Wireless (Remote) Sensors

- **Low installation costs.**
- **Easy-to-use products allowing simplified maintenance and eliminating process problems.**
- **Fault-tolerant technology.**
- **Zero defects and 100% reliability from wireless products.**
- **Easy interrogation at any time without interfering with its environment.**
- **Accurate measurements and low power consumption to ensure long operating life.**

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Desired Features of Wireless (Remote) Sensors

Wireless Telemetry Solutions

- *Cellular systems*
  - **Available GSM modules.**
  - **Using existing cellular infrastructure (where available).**
  - **Range within GSM network.**
  - **Low power consumption.**
- *Dedicated wireless telemetry systems and networks*
  - **Available industrial communication modules and base stations (complying with local regulations).**
  - **Local networking and data acquisition.**
  - **Independent of other networks, no additional costs.**
  - **Possibility of long distance monitoring and/or data acquisition using existing communication infrastructure.**

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Areas of concern with wireless sensors

- **Cost.**
- **Size (Miniaturization).**
- **Power supply (Battery lifetime).**
- **Reliability.**
- **Distance of transmissions.**
- **Carrier frequency.**
- **Wireless protocol for multiple sensor nodes.**
- **Compliance with FCC regulations.**

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Wireless Temperature Monitoring Systems

SQUARE D On-Line monitoring systems for LV, MV electrical systems

- **Switchgear**
- **Circuit Breakers**
- **Capacitor Banks**
- **Transformers**
- **Motors**
- **Busways**
- **Cables**
- **HV and EHV electrical equipment**
- **Apparatus from any OEM**

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Wireless Temperature Monitoring Systems

Omega Wireless Sensor

- Operates on UHF.
- Carrier Frequency: 450 to 470 MHz
- Transmits Strain Gage, Voltage and Thermocouple Signals
- Transmitters powered by a 12V battery;
- Receivers powered by 110Vac
- Range up to 3.2 km.

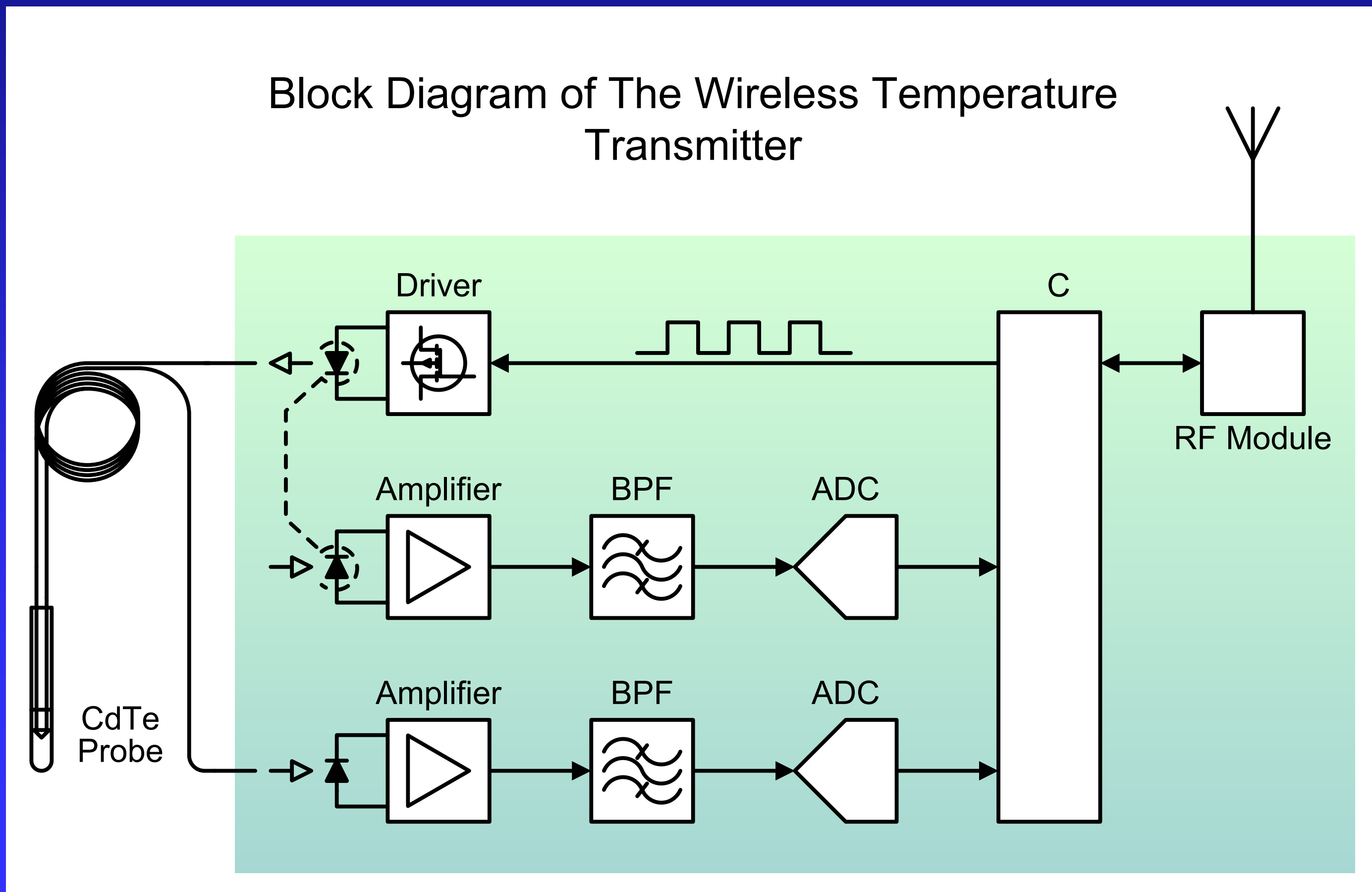
RECEIVER

TRANSMITTER

MBI

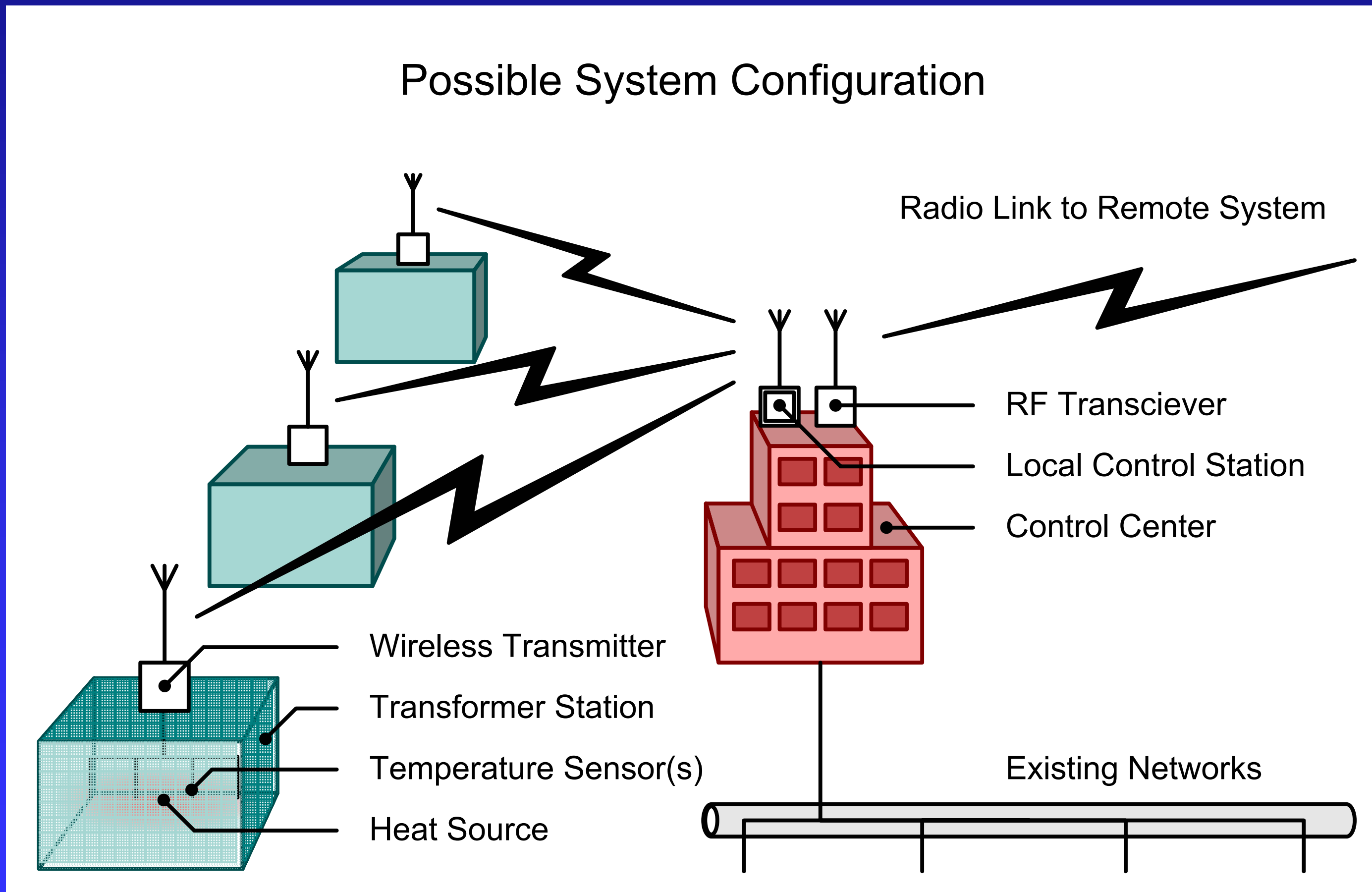
MONITORING AND DIAGNOSTIC TECHNIQES

Wireless Temperature Monitoring Systems



MONITORING AND DIAGNOSTIC TECHNIQES

Wireless Temperature Monitoring Systems



MONITORING AND DIAGNOSTIC TECHNIQES

Wireless Temperature Monitoring Systems

Power Donut2 (Courtesy USi,)

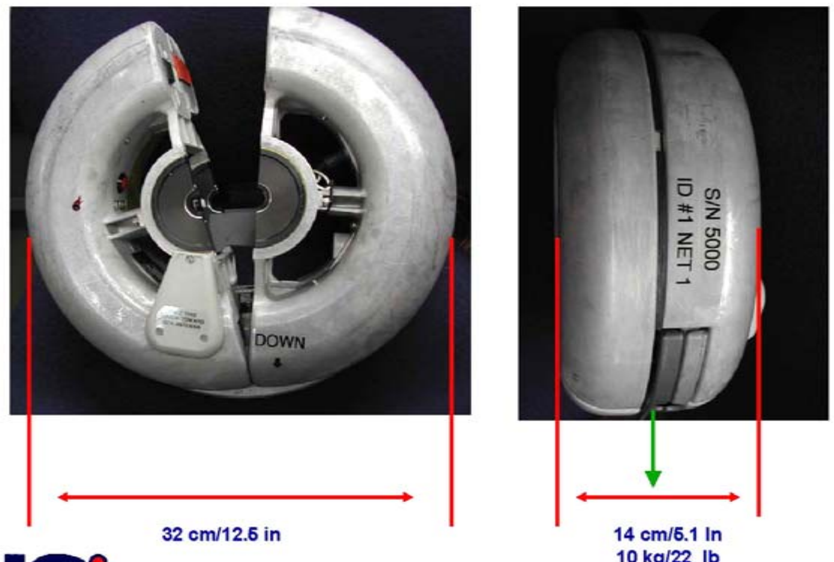
- Power Donut2 is designed for data acquisition and data logging applications on high voltage, overhead conductor systems.
- Power Donut is complete and self-contained unit powered directly from the conductor E-H field.
- Three communications options are available:
  FHSS (900 MHz / 2.4 GHz), GSM and GPRS Cell phones.
- Data output: current, voltage, conductor temperatures, conductor tension and sag, MW, MVars, MWhrs, MVarhs.
- Stores data on-board using flash RAM memory system.
- It can be installed live - from a bucket truck without taking the circuit out of service.
- Each data acquisition point can have three alarm levels: notification, early warning and alarm (reported in real time).

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Wireless Temperature Monitoring Systems

Power Donut2



USi

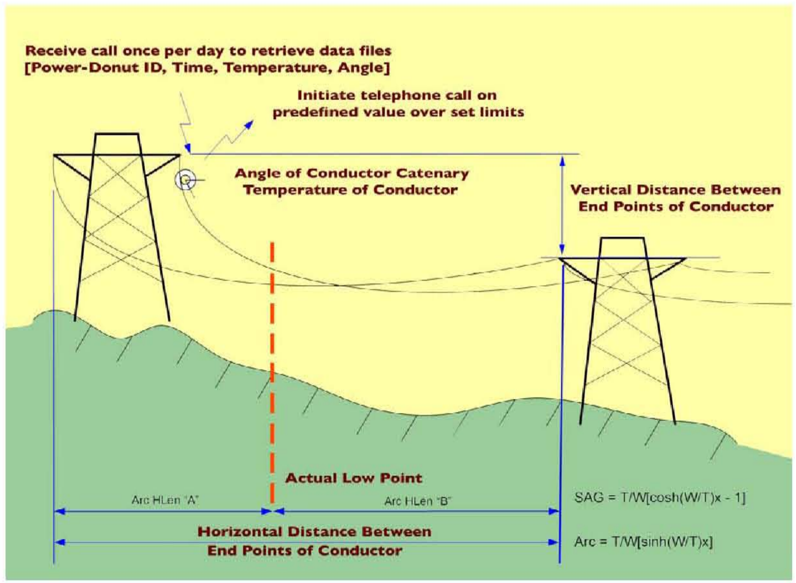
** This Information is Proprietary to USi, Armonk,NY **

MBI

MONITORING AND DIAGNOSTIC TECHNIQES

Wireless Temperature Monitoring Systems

Power Donut2 -- The Clearance Monitoring Application



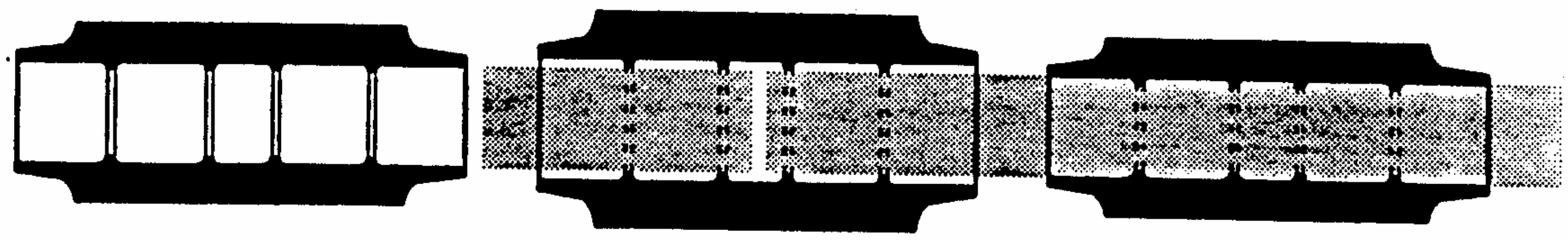
Real-Time Answers/Integrated Solutions

** This Information is Proprietary to USi, Armonk,NY **

NEW TRENDS IN CONNECTION DESIGN

Applications of Shape-Memory Alloys

Connectors

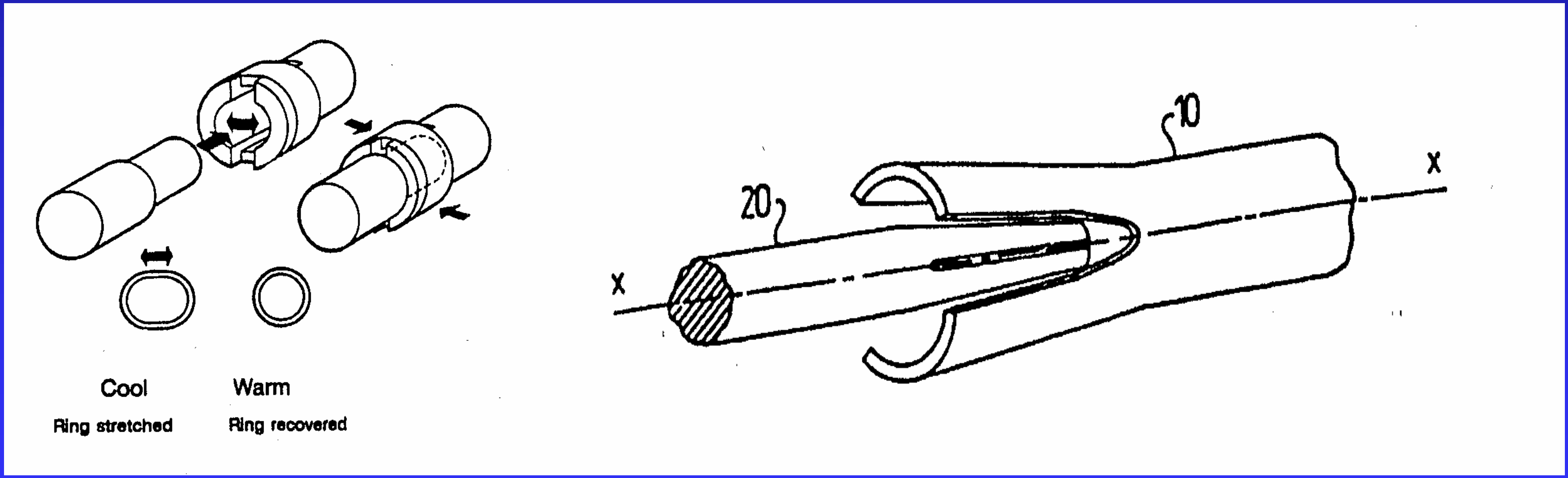


Principle of shape-memory alloy coupling (Cryofit)

NEW TRENDS IN CONNECTION DESIGN

Applications of Shape-Memory Alloys

Connectors

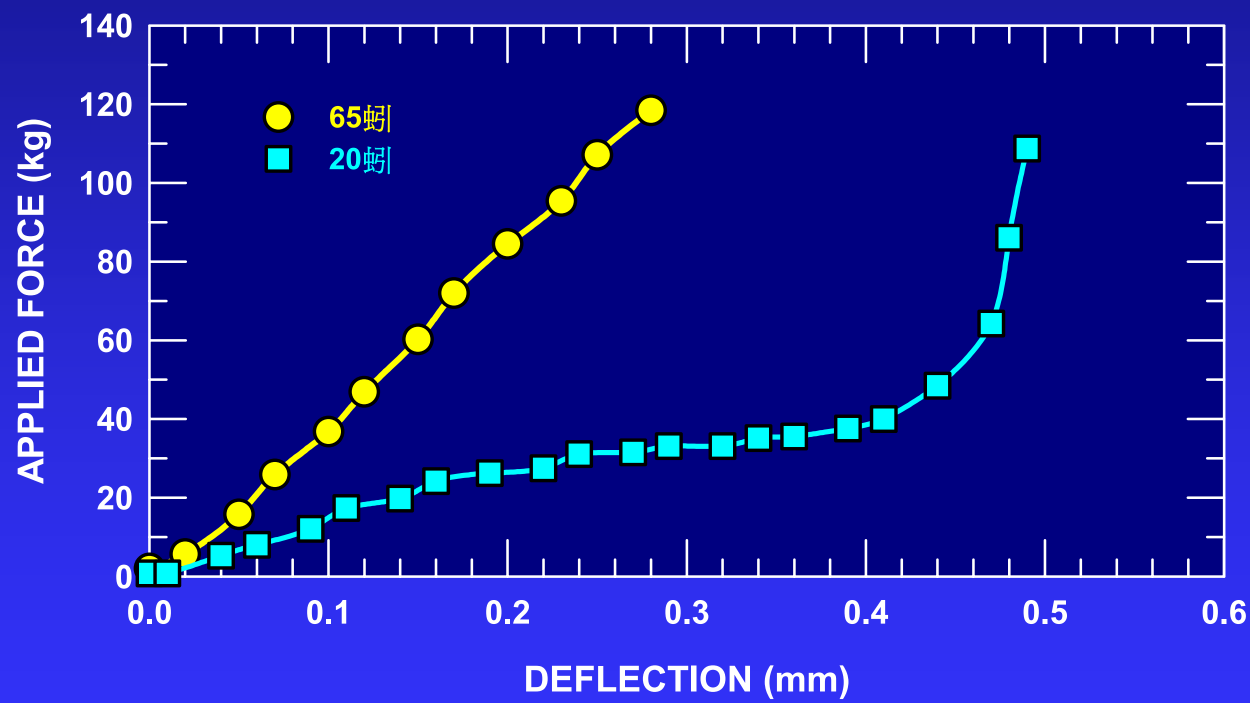


Cryocon and Souriau pin-and-socket connector

MBI

NEW TRENDS IN CONNECTION DESIGN

Applications of Shape-Memory Alloys



Shape-memory alloys disc-spring (Belleville) washer

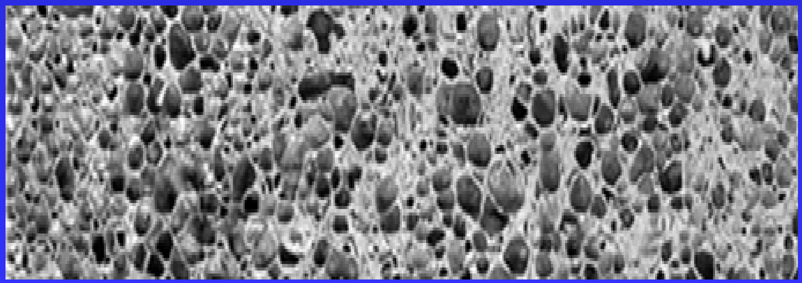
MBI

NEW TRENDS IN CONNECTION DESIGN

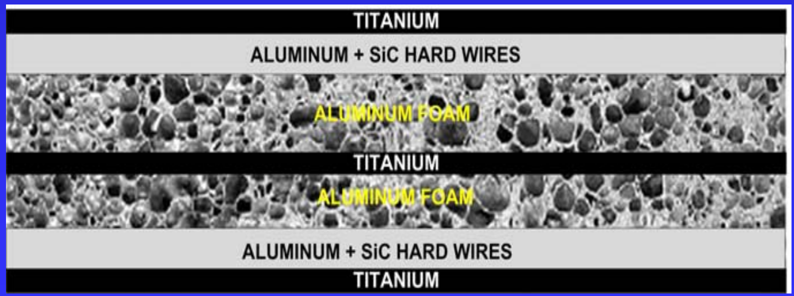
Composite materials (metallic foams)

- Metal composites can be broadly defined as a metal matrix with voids between two layers of cladding material.
- The density of void space can vary widely from less than 50% up to 90% of the material volume.
- Light weight, high volume, low cost, multiple applications

Bare foam



Reinforced foam



MBI

NEW TRENDS IN CONNECTION DESIGN

Composite materials (metallic foams)

Precursor/Dense Materials

Shaped Aluminum Composite and Sandwich Structures

MBI

NEW TRENDS IN CONNECTION DESIGN

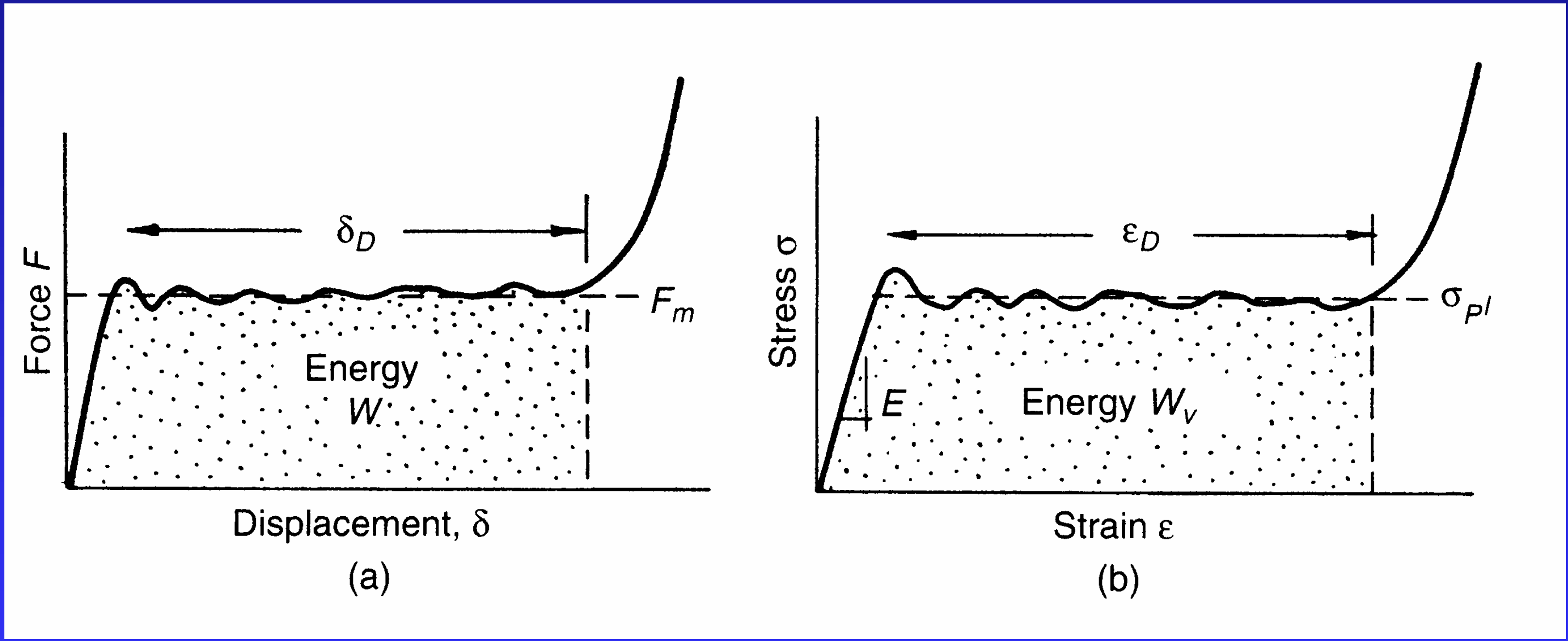
Properties of Al composite materials

- Ultra lightweight.
- High specific strength.
- High stiffness to weight ratio (up to 2 x aluminium).
- Excellent impact, vibration and energy absorption.
- Good fire retardant.
- Good sound absorption.
- Low thermal conductivity.
- Low density.
- Less hygroscopic.
- Good corrosion resistance.
- Fully recyclable.

MBI

NEW TRENDS IN CONNECTION DESIGN

Properties of Al composite materials



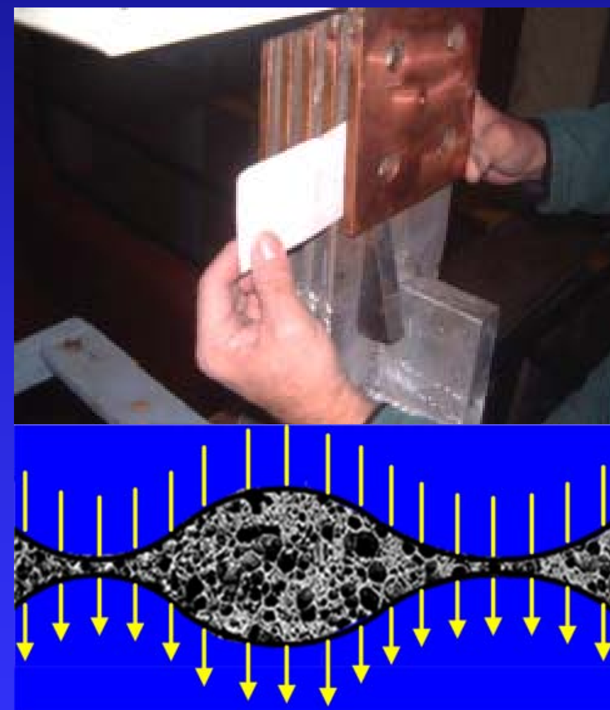
Force-displacement and stress-strain characteristics of aluminium foam composite materials

MBI

NEW TRENDS IN CONNECTION DESIGN

Applications of Al composite materials

- **Transportation**
  - *Automotive*
  - *Ships*
  - *Airplanes*
  - *Railroads*
- **Security**
  - *Military*
  - *Public / Personal*
- **Construction**
- **Acoustic applications**
- **Power**



Composite (foam) material used as A transition washer

MBI

RELIABILITY OF POWER CONNECTIONS

Workshop Summary

- Surface Roughness
  - An appropriately selected surface roughness is essential for acceptable connector performance
- Mechanical Force
  - Minimum mechanical force is essential for acceptable connector performance
- Formation of Intermetallics
  - Should be avoided
- Fretting
  - Minimize or eliminate micro-motion at electrical interfaces.
- Lubrication
  - Essential for acceptable connector performance
- Surface Preparation
  - Appropriate surface preparation of conductors and contact surfaces is essential for acceptable connector performance
- Area of True Contact
  - Generally very small
- Connector Technologies
  - Connector performance depends on connector technology and design
- Connector Degradation
  - Connector degradation may have a highly deleterious effect on the operating cost of power network.

MBI

RELIABILITY OF POWER CONNECTIONS

Imagination is more important than knowledge

A. Einstein

MBI