NETA Self-Paced Technical Seminar

Electrical Testing Basics: What You Need to Know to Succeed Part 1

Presented by:
Jim White
Shermco Industries

2010

Electrical Maintenance and Safety Conference

An **InterNational Electrical Testing Association (NETA)** Event

Hyatt Regency, Long Beach, California

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Electrical Testing Basics: What You Need to Know to Succeed Part 1

Presented by:

Jim White

Shermco Industries

February 17, 2010

Electrical power system analysis starts with a core set of instruments and analysis techniques. Understanding the fundamentals is absolutely necessary in order to assess the health of your equipment.

This seminar is offered in two parts, either or both of which can be attended. Some of the most common electrical test equipment and theory will be covered, including use of a megohmmeter, insulation power factor, dc winding resistance and microhmmeter. These tests will be related back to the ANSI/NETA MTS-2007 Standard.

Beginning with basic principles for each test, the seminar will cover specific tests for transformers, circuit breakers (air, vacuum, oil, and gas), switchgear, and switches. The seminar format will allow time for questions and interaction with attendees during the presentation.

James R. White

Jim White is the Training Director for Shermco Industries and the principal Shermco Representative on the NFPA 70B Committee. Jim is the alternate NETA Representative on the NFPA 70E Committee and serves as the NETA Representative on the IEEE/NFPA Arc-Flash Hazard Work Group (RTPC) Ad Hoc Committee. He served as the Chairman of the 2008 IEEE Electrical Safety Workshop. Jim is a NETA Certified Level IV Electrical Testing Technician and a member of the NETA Safety Committee.

POWER TEST 2010 Electrical Maintenance and Safety Conference

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Electrical Testing Basics

What You Need To Know To Succeed

Jim White
Shermco Industries, Inc

2010 Electrical Maintenance and Safety Conference

Motor Overload Relays (MORs)

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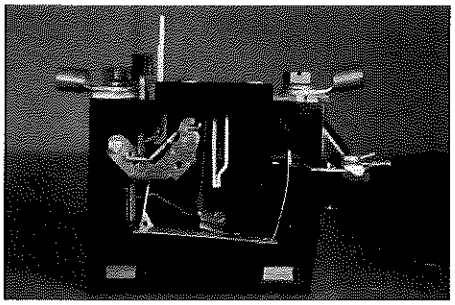
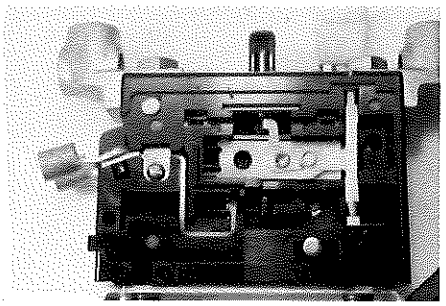
Two Types

Bimetal



Solder Pot



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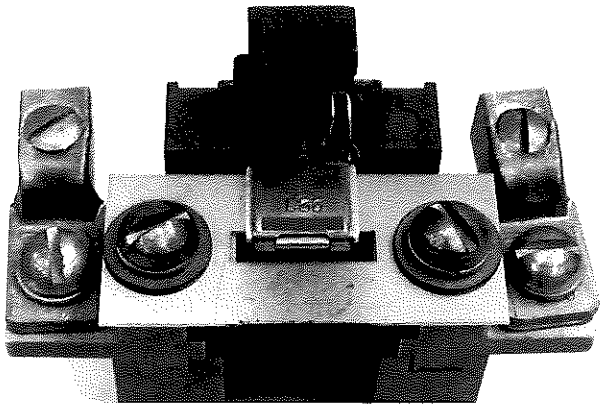

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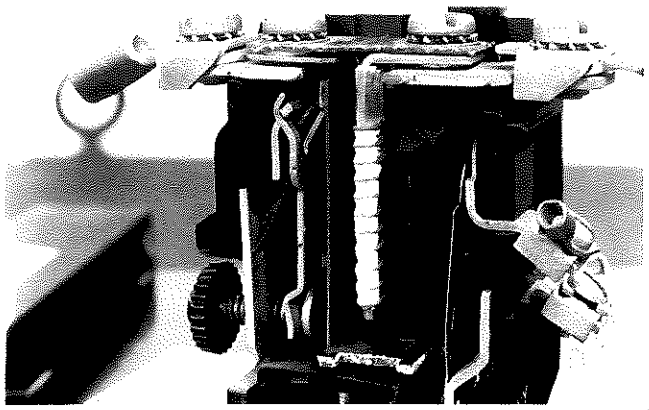

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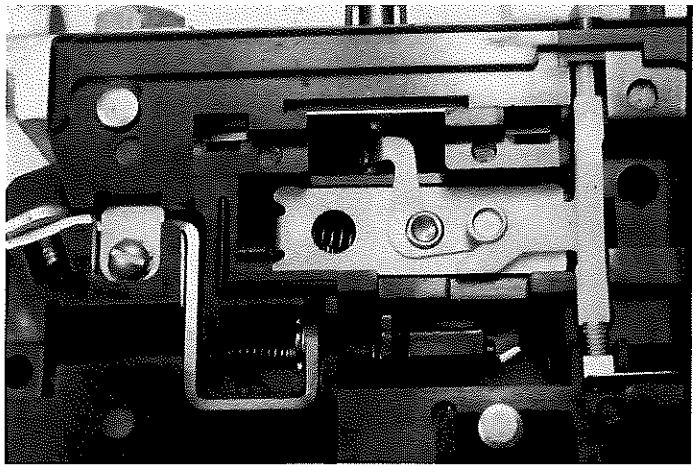

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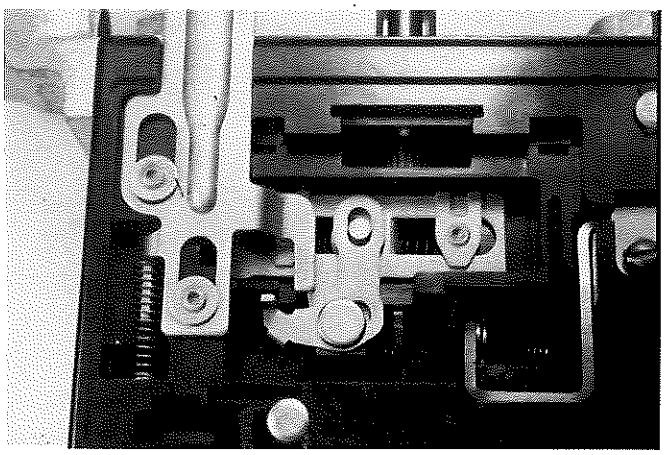

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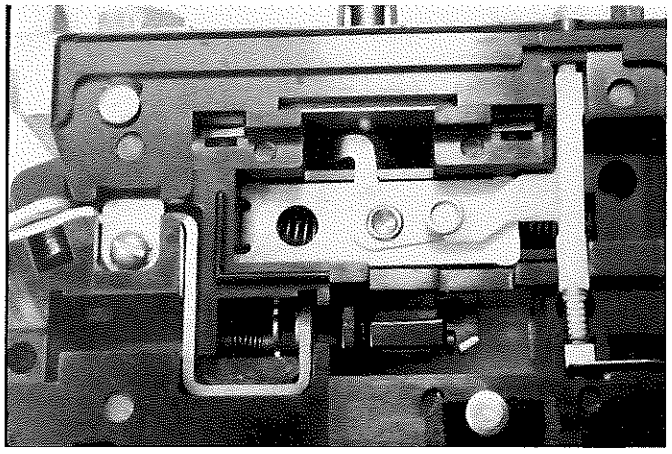
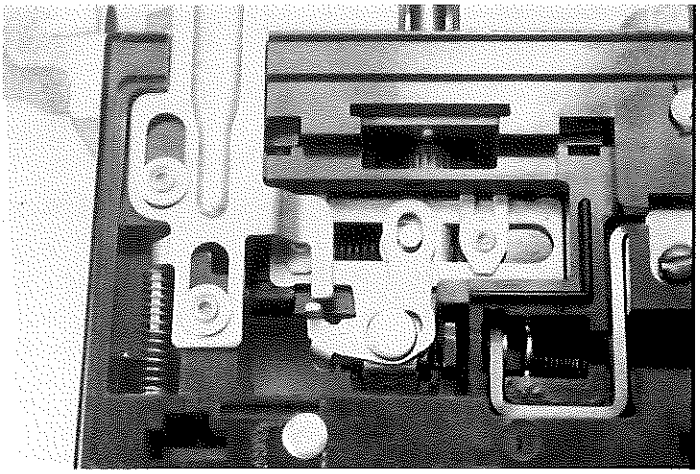


Solder Pot Open



ANSI/NETA MTS-07

7.16.1.1 Motor Control, Motor Starters, Low-Voltage

1. Visual and Mechanical Inspection

1. Inspect physical and mechanical condition.
2. Inspect anchorage, alignment, and grounding.
3. Prior to cleaning the unit, perform as-found tests, if required.
4. Clean the unit.
5. Inspect contactors.

*6. Motor-Running Protection

1. Compare overload element rating with motor full-load current rating to verify correct sizing.
2. If motor-running protection is provided by fuses, verify correct fuse rating considering motor characteristics and power-factor correction capacitors.

7. Inspect bolted electrical connections for high resistance using one of the following methods:

8. Use appropriate lubrication on moving current-carrying parts and on moving and sliding surfaces.

9. Perform as-left tests.

2. Electrical Tests

1. Perform resistance measurements through bolted connections with a low-resistance ohmmeter, if applicable, in accordance with Section 7.16.1.1.1.

2. Perform insulation-resistance tests for one minute on each pole, phase-to-phase and phase-to-ground with starter closed, and across each open pole. Test voltage shall be in accordance with manufacturer's published data or Table 100.1.

*3. Perform insulation-resistance tests on all control wiring with respect to ground. The applied potential shall be 500 volts dc for 300-volt rated cable and 1000 volts dc for 600-volt rated cable. Test duration shall be one minute. For units with solid-state components, follow manufacturer's recommendation.

4. Test motor protection devices in accordance with manufacturer's published data. In the absence of manufacturer's data, use Section 7.9.

7.9.1.11 49R Thermal Replica Relay

1. Determine time delay at 300 percent of setting.
2. Determine a second point on the operating curve.

*3. Determine pickup.

3.1 Test Values – Visual and Mechanical

1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value. (7.16.1.1.1.7.1)
2. Bolt-torque levels should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.12. (7.16.1.1.1.7.2)
3. Results of the thermographic survey shall be in accordance with Section 9. (7.16.1.1.1.7.3)

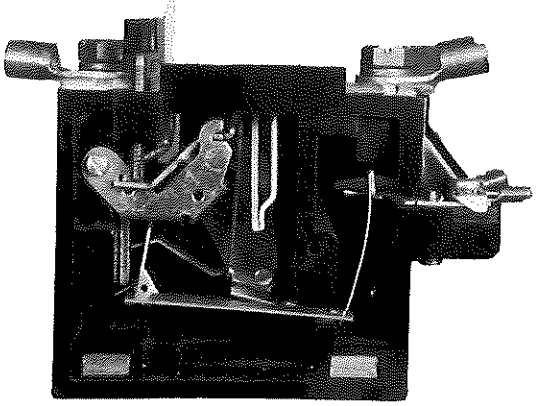
3.2 Test Values – Electrical

1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value.
2. Insulation-resistance values should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.5. Values of insulation resistance less than this table or manufacturer's recommendations should be investigated.

3. Insulation-resistance values of control wiring should be comparable to previously obtained results but not less than two megohms.
4. Motor protection parameters shall be in accordance with manufacturer's published data or Section 7.9.
5. Circuit breaker test results shall be in accordance with Section 7.6.1.1.
6. Control devices should perform in accordance with system design and/or requirements.

5. Test circuit breakers in accordance with Section 7.6.1.1.
6. Perform operational tests by initiating control devices.

Testing MORs



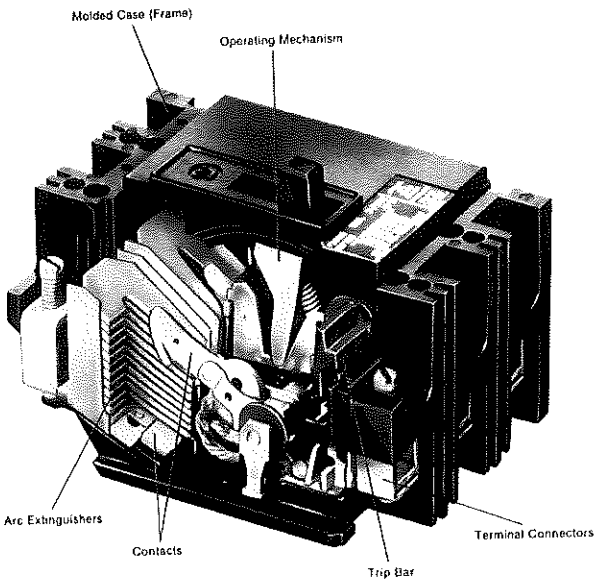
Low-Voltage Circuit Breakers

Molded and Insulated-Case Circuit Breakers

Construction and Operation

Main Components

- Frame
- Operating Mechanism & Trip Unit
- Terminal Connections
- Contact Assembly
- Arc Extinguishers



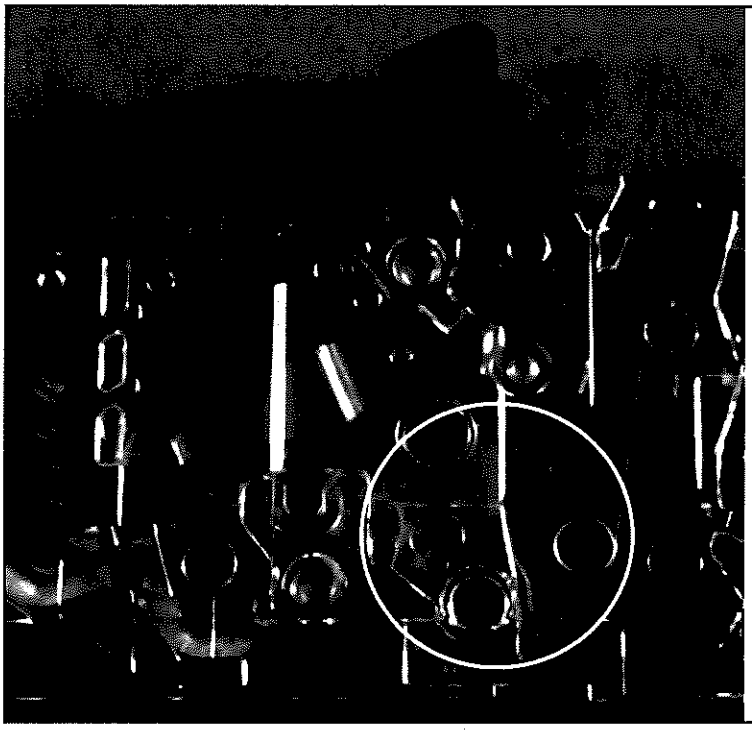
Courtesy Westinghouse Electric, "Breaker Basics"

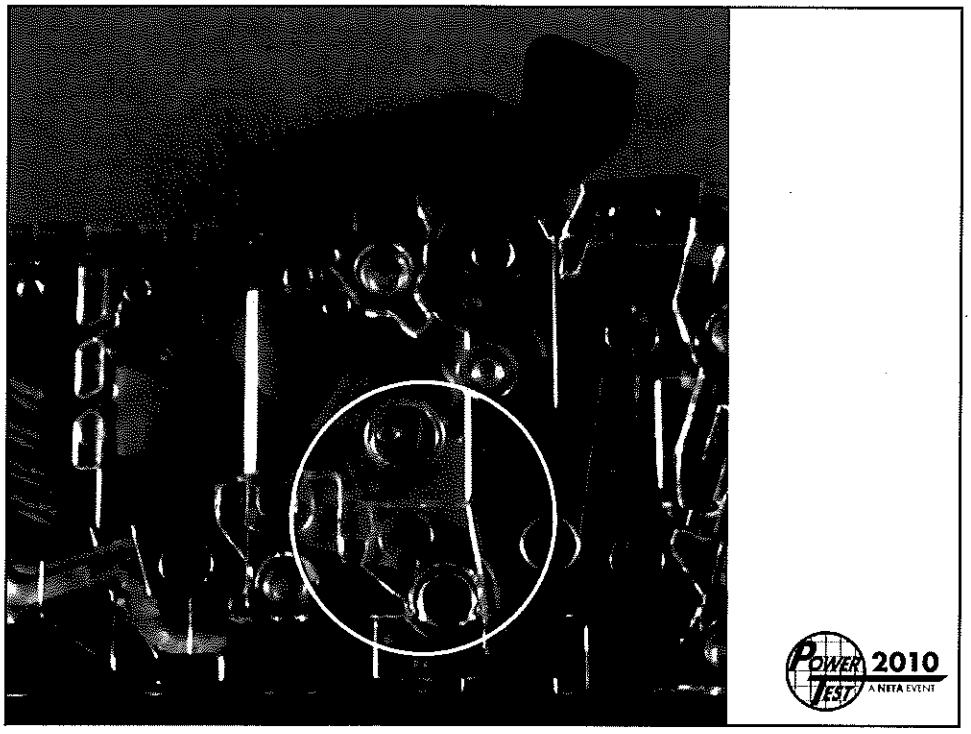
Frame

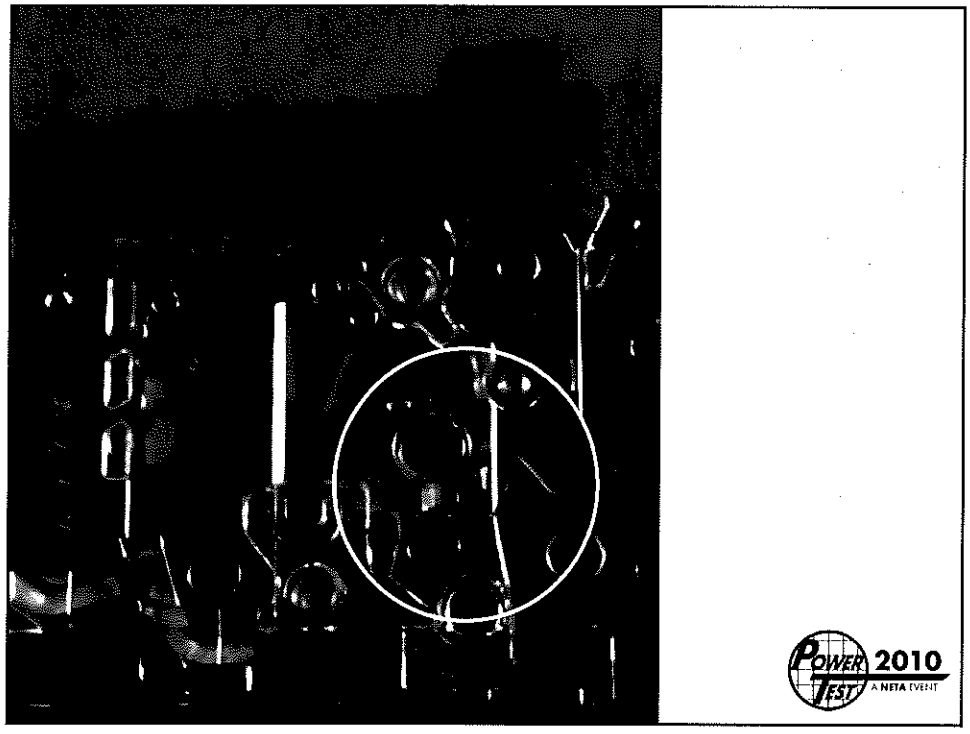
- Provides mounting for components
- Part of insulation system

Operating Mechanism

- Opens and closes the contacts
- Molded-case circuit breakers use a trip latch
  - Can bind over time
  - Must be exercised




POWER TEST 2010
A NETA EVENT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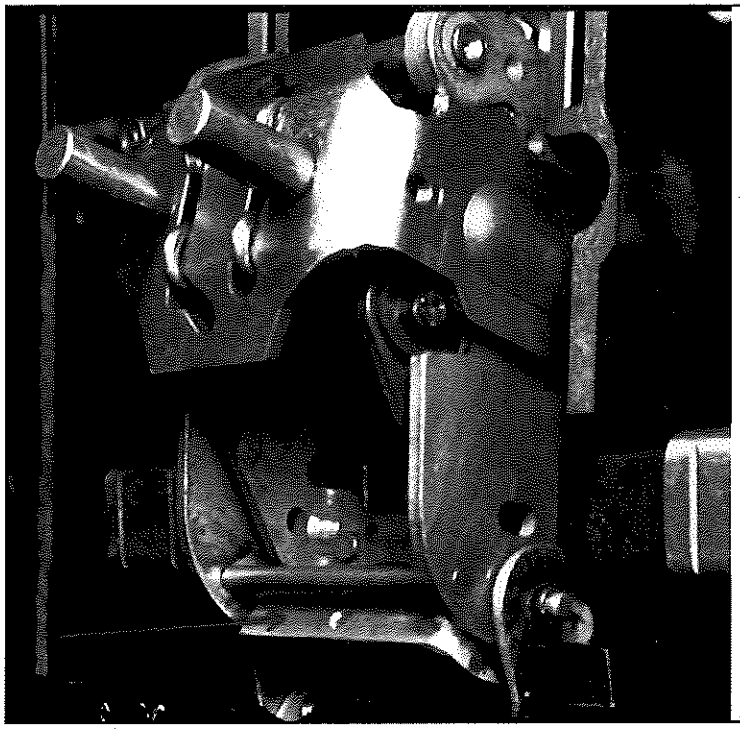
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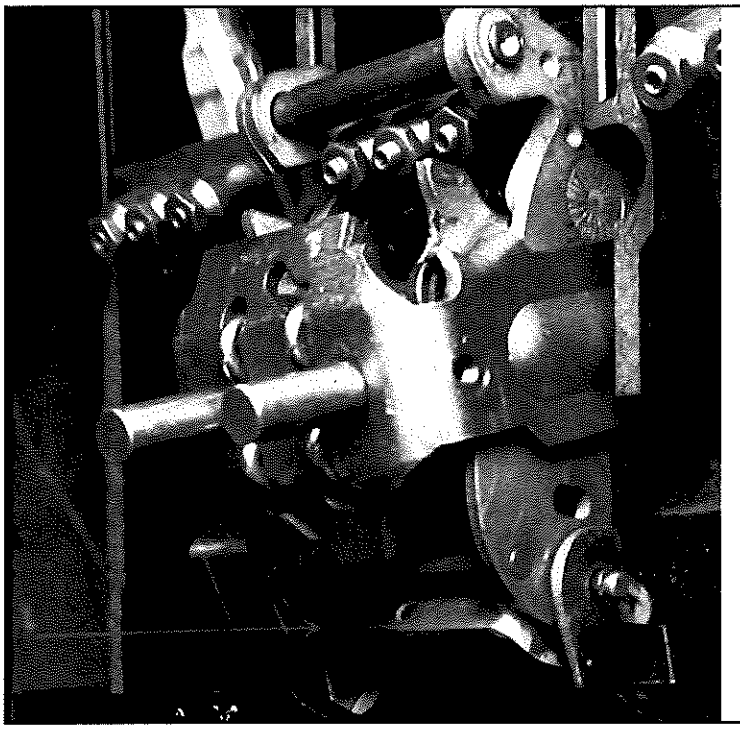
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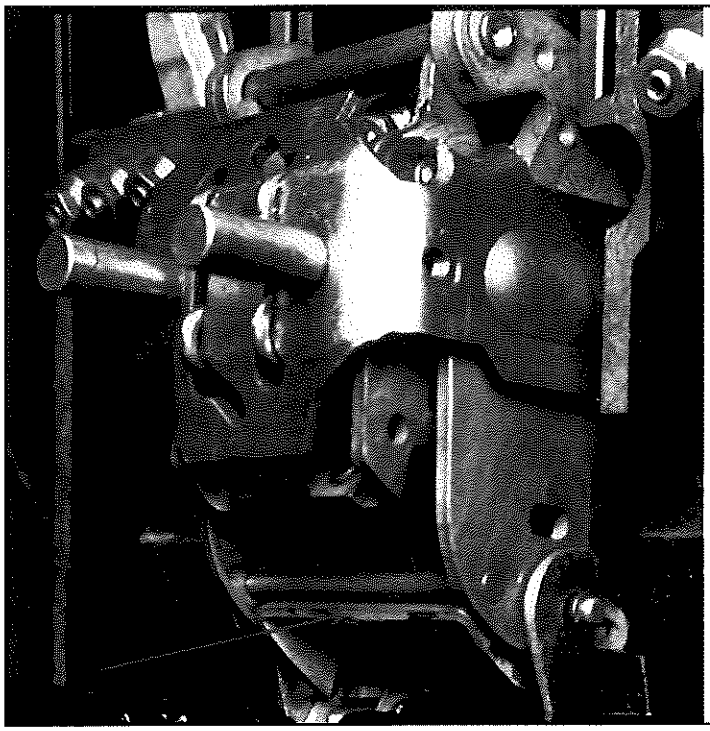
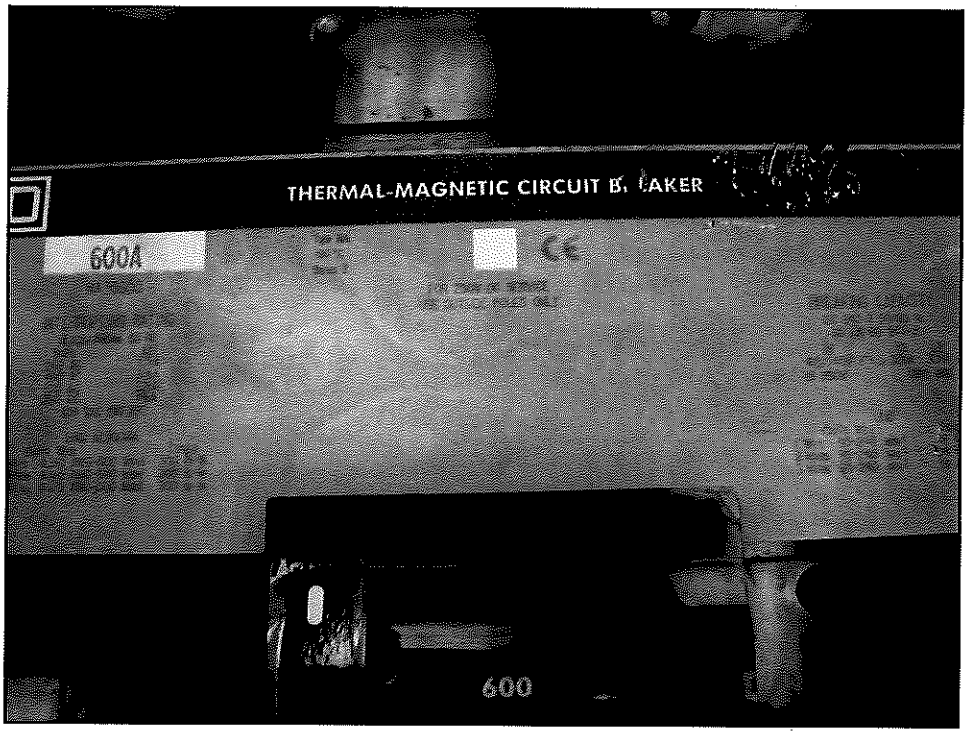


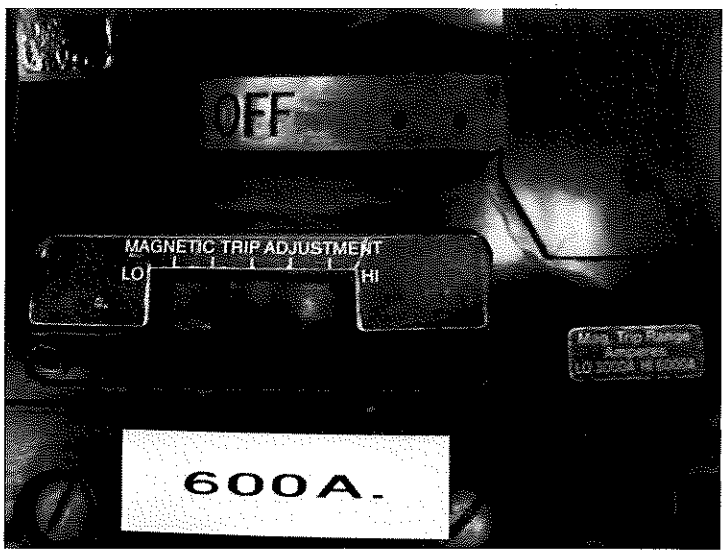
Trip Unit

- Thermal magnetic
- NEC - "general purpose circuit breaker"
- Thermal unit for overloads
  - Bi-metal
  - Long-Time Delay (LTD)
- Magnetic for short circuits
  - Instantaneous (INST)
  - No intentional time delay

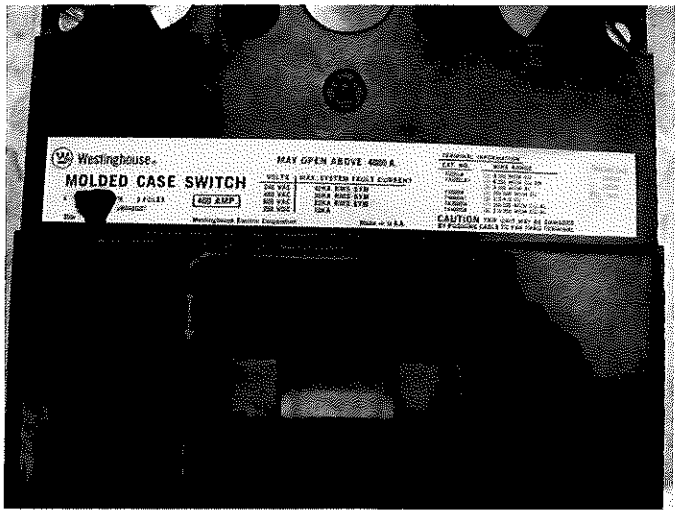
Thermal Magnetic



Adjustable Instantaneous

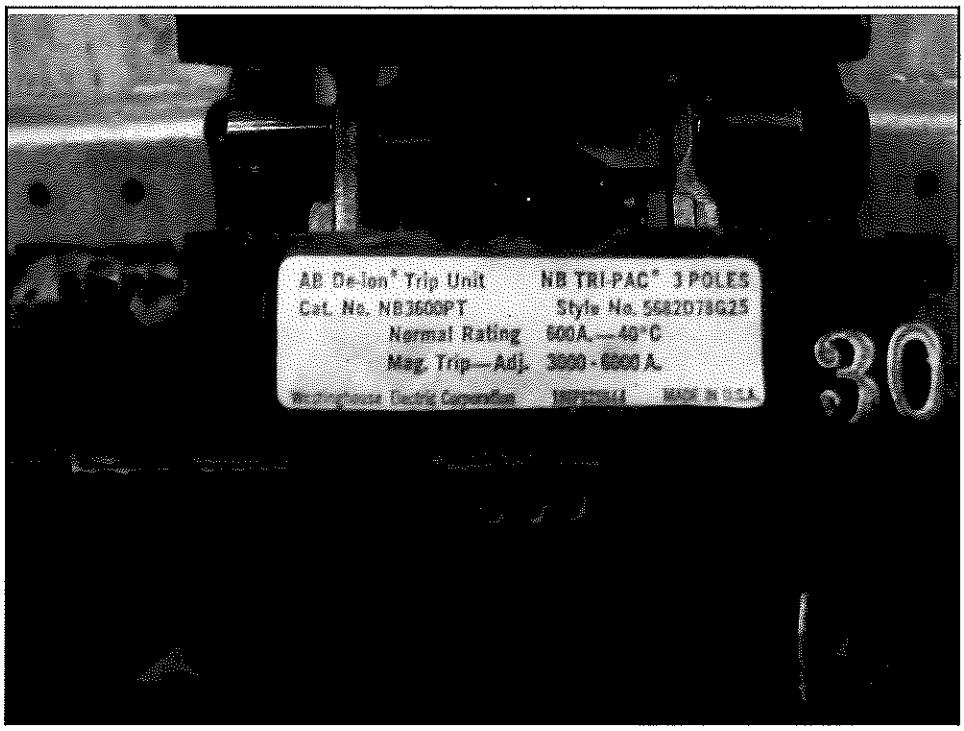


Molded-Case Switch



No OCPD

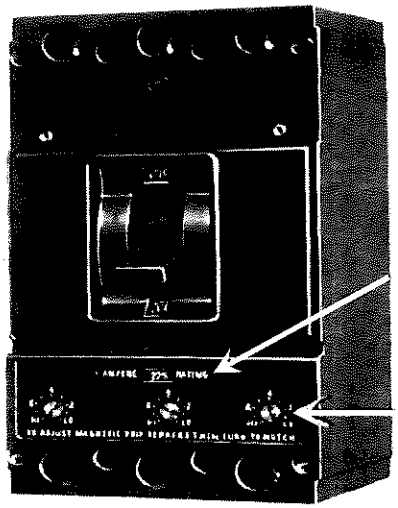
Used To Open/Close Only



Thermal Magnetic Breaker

Some Models Can Also Have Electronic Trip

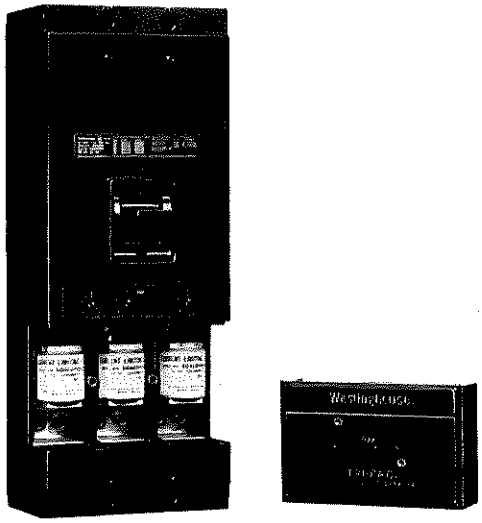
Thermal Magnetic



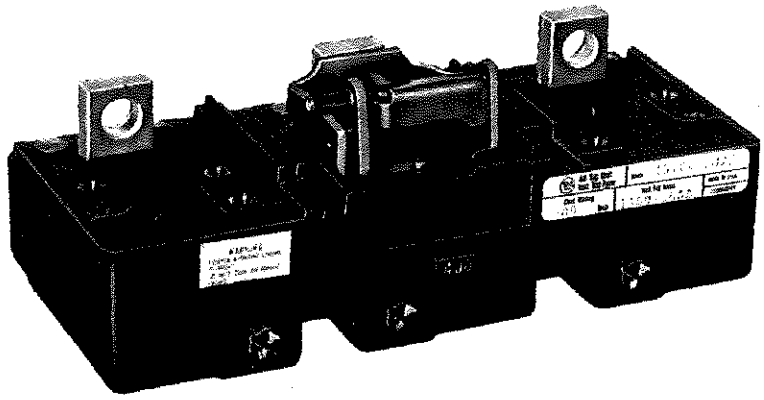
Continuous Current Rating

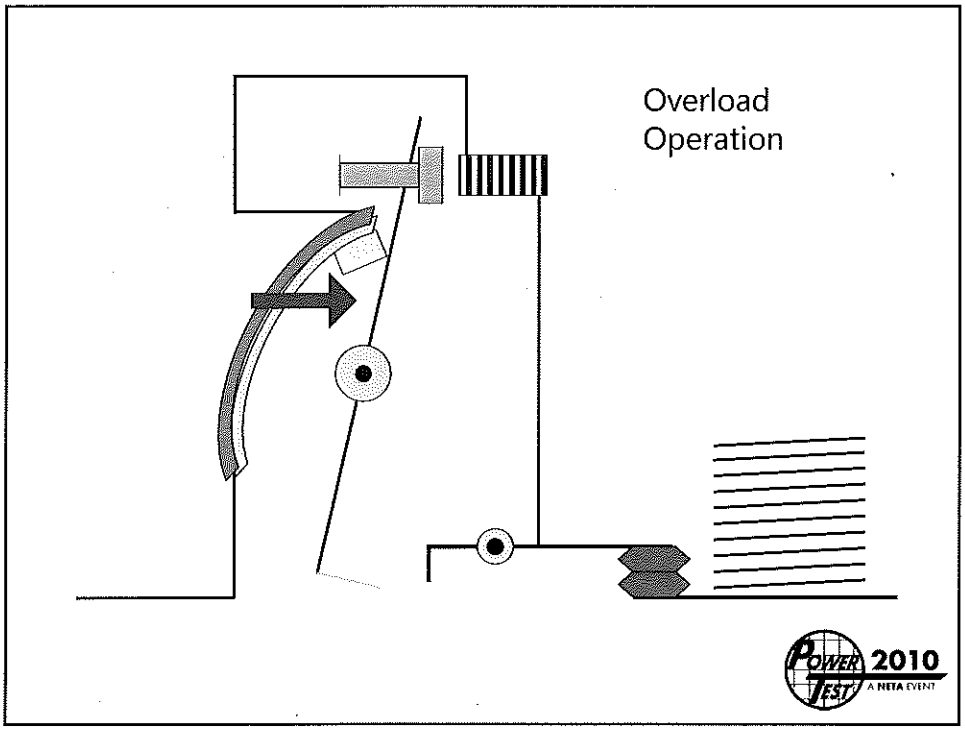
Instantaneous Trip Adjustment

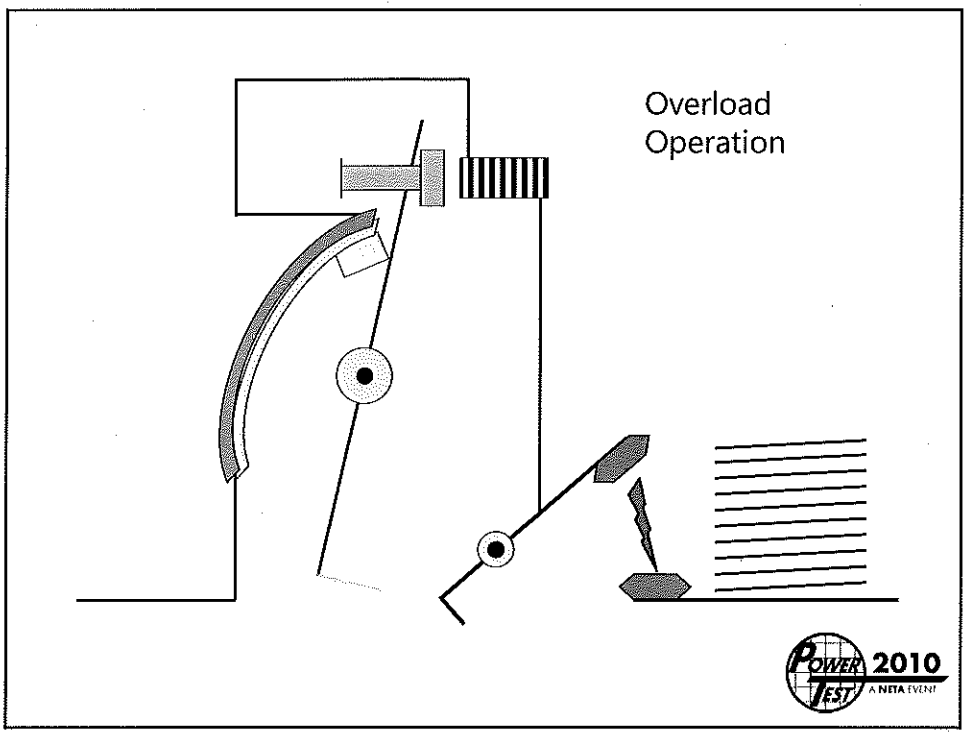
Current-Limiting Fuse Breaker



Interchangeable Trip




Overload
Operation
POWER TEST 2010
A NETA EVENT


Overload
Operation
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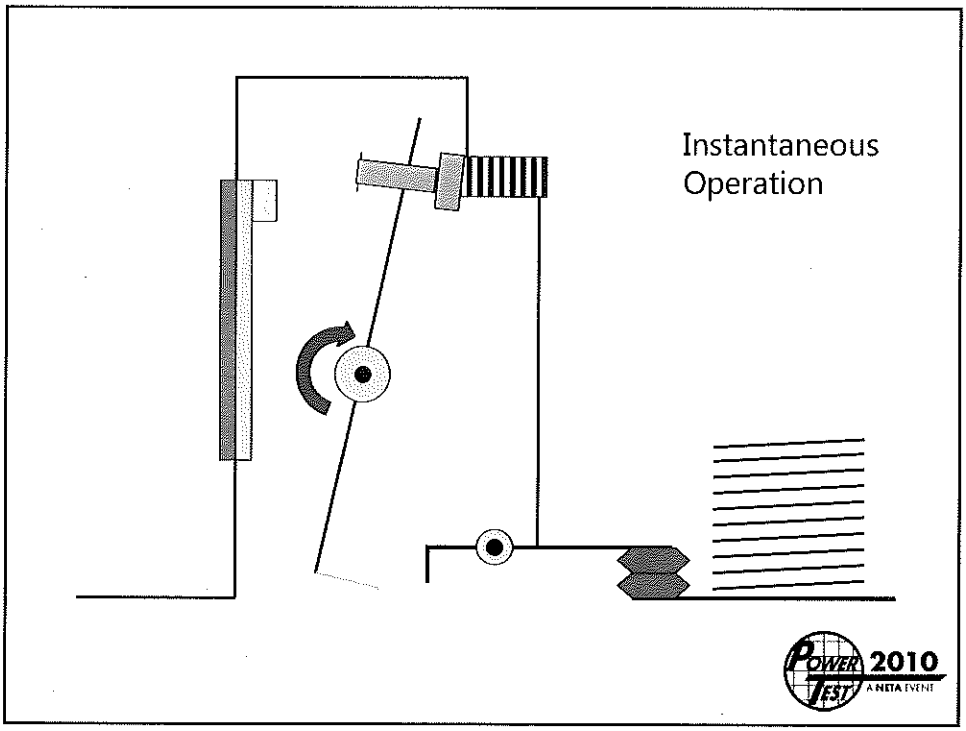
Instantaneous
Operation
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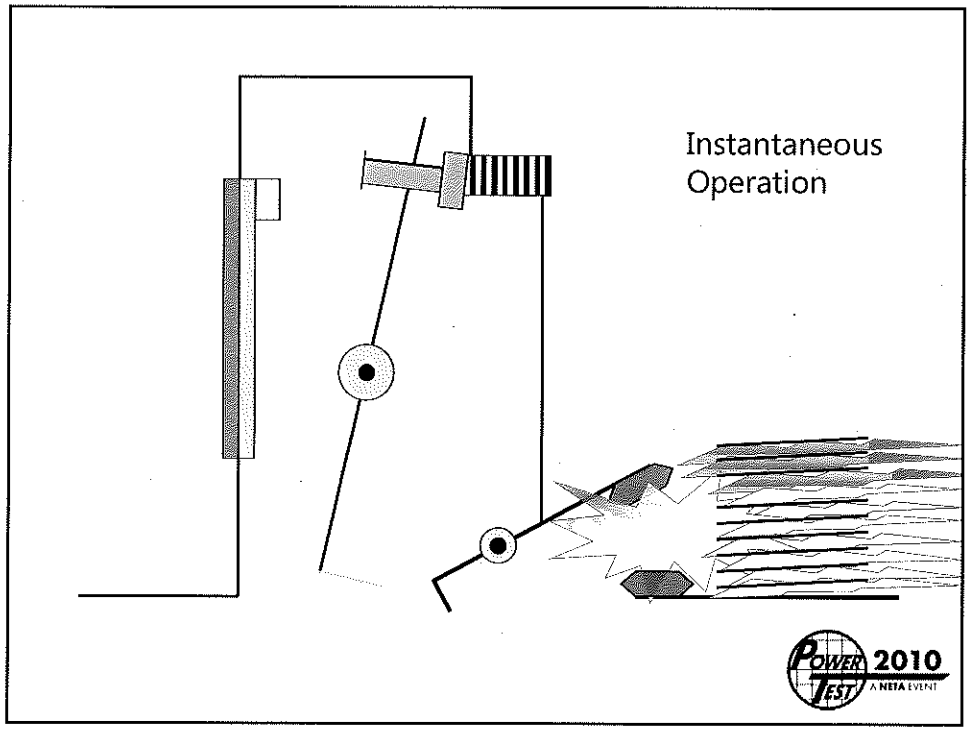
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Operation
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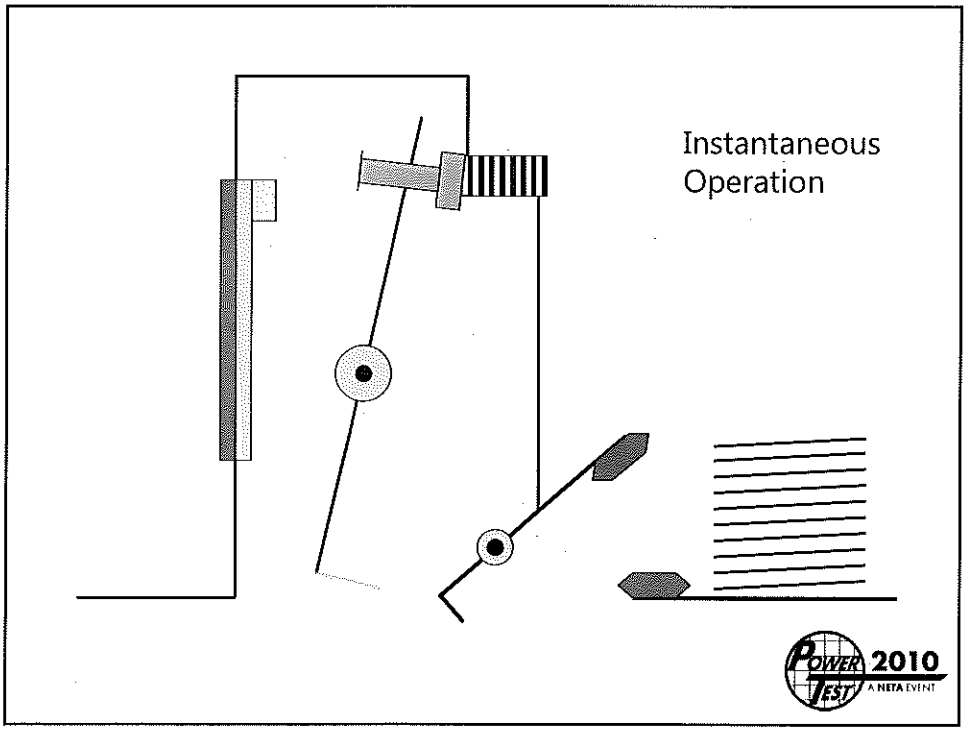
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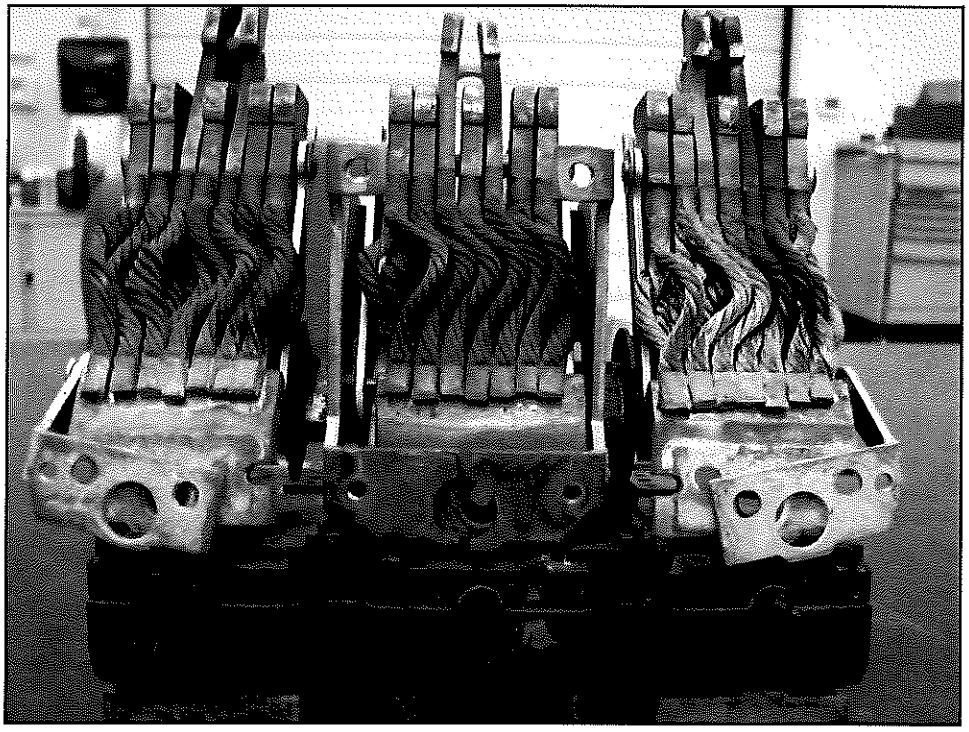
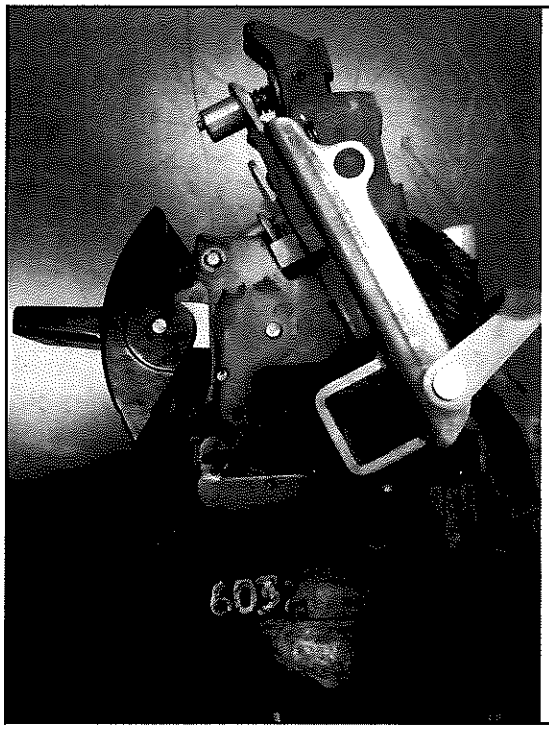
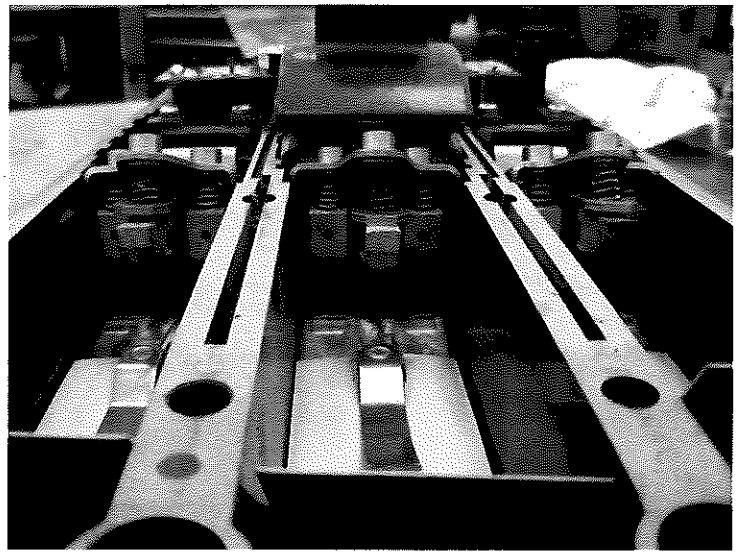


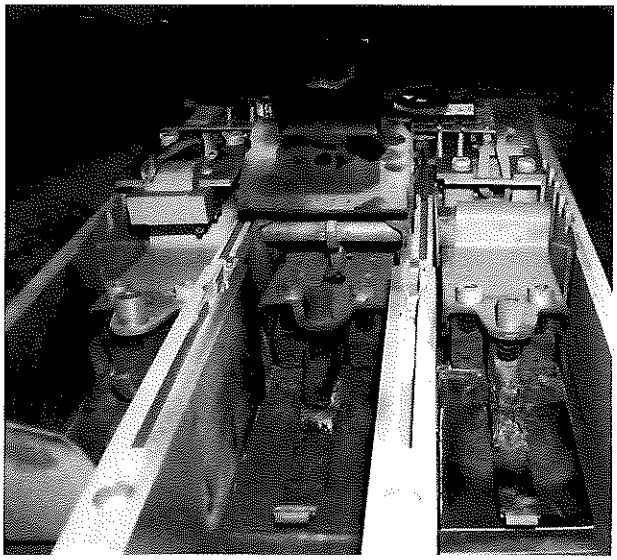


Operating Mechanism, Contact Assembly and Trip Unit

Contact Assemblies

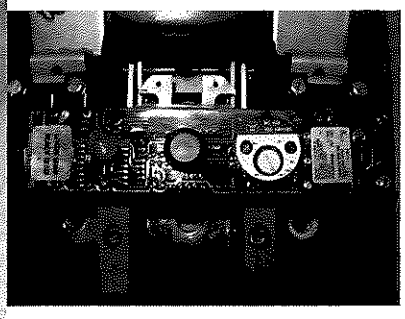


Welded Contacts

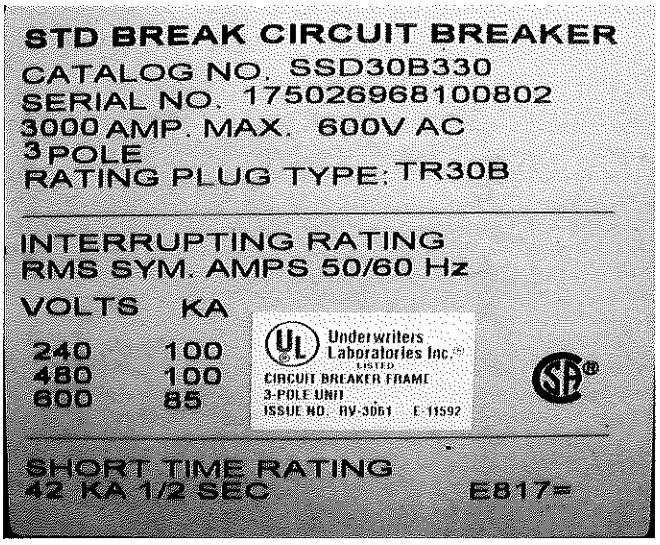


Terminal Connectors

Insulated-Case



Ratings



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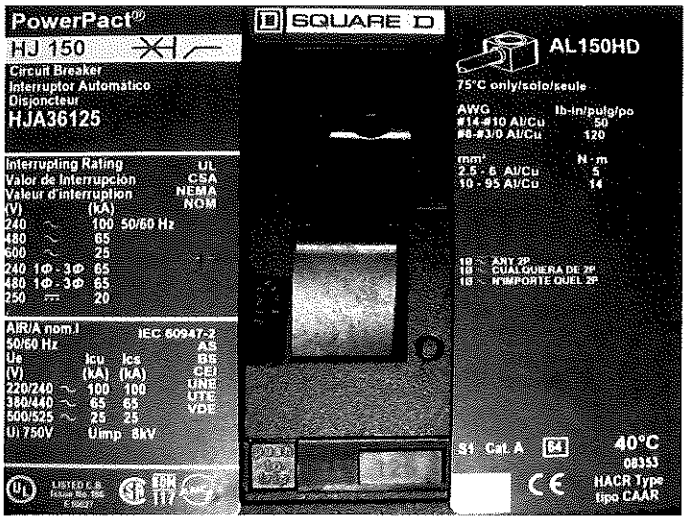
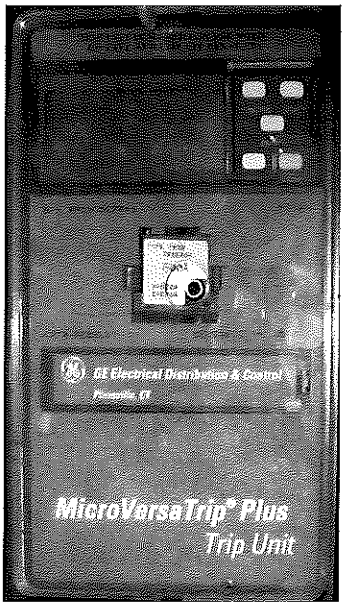
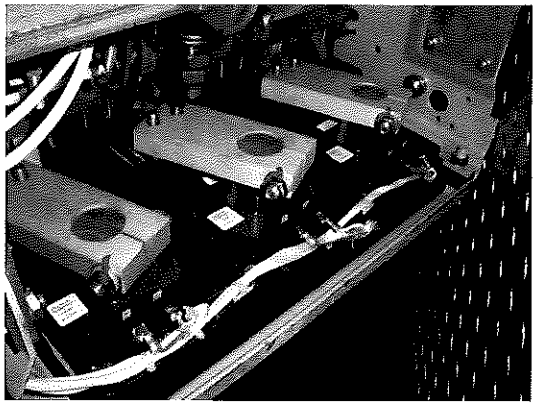
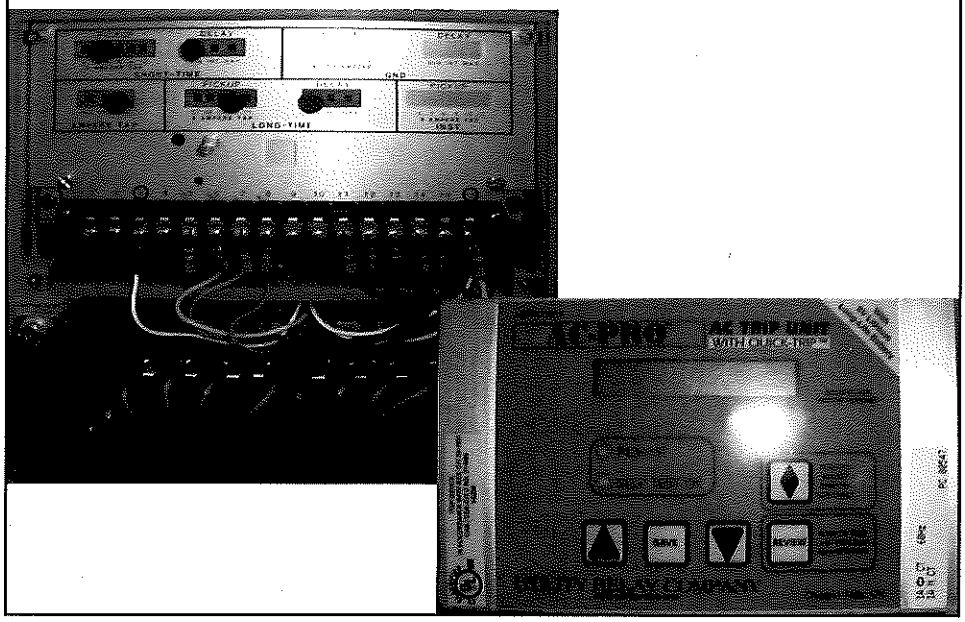


Electronic





Electronic



ANSI/NETA MTS-07

7.6.1.1 Circuit Breakers, Air, Insulated-Case/Molded-Case

1. Visual and Mechanical Inspection

1. Inspect physical and mechanical condition.
2. Inspect anchorage and alignment.
3. Prior to cleaning the unit, perform as-found tests, if required.
4. Clean the unit.
5. Operate the circuit breaker to insure smooth operation.
6. Inspect bolted electrical connections for high resistance using one of the following methods:
    1. Use of a low-resistance ohmmeter in accordance with Section 7.6.1.1.2.
    2. Verify tightness of accessible bolted electrical connections by calibrated torque-wrench method in accordance with manufacturer's published data or Table 100.12.
    3. Perform a thermographic survey in accordance with Section 9.
7. Inspect operating mechanism, contacts, and arc chutes in unsealed units.
8. Perform adjustments for final protective device settings in accordance with coordination study provided by end user.
9. Perform as-left tests.

2. Electrical Tests

1. Perform resistance measurements through bolted connections with a low-resistance ohmmeter, if applicable, in accordance with Section 7.6.1.1.1.
2. Perform insulation-resistance tests for one minute on each pole, phase-to-phase and phase-to-ground with the circuit breaker closed, and across each open pole. Apply voltage in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.1.
3. Perform a contact/pole-resistance test.

*4. Perform insulation-resistance tests on all control wiring with respect to ground. The applied potential shall be 500 volts dc for 300-volt rated cable and 1000 volts dc for 600-volt rated cable. Test duration shall be one minute. For units with solid-state components, follow manufacturer's recommendation.

5. Determine long-time pickup and delay by primary current injection.
6. Determine short-time pickup and delay by primary current injection.
7. Determine ground-fault pickup delay by primary current injection.
8. Determine instantaneous pickup current by primary injection.

*9. Test functions of the trip unit by means of secondary injection.

10. Perform minimum pickup voltage test on shunt trip and close coils in accordance with Table 100.20.
11. Verify correct operation of auxiliary features such as trip and pickup indicators, zone interlocking, electrical close and trip operation, trip-free, antipump function, and trip unit battery condition. Reset all trip logs and indicators.
12. Verify operation of charging mechanism.

3.1 Test Values - Visual and Mechanical

1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value. (7.6.1.1.1.6.1)
2. Bolt-torque levels should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.12. (7.6.1.1.1.6.2)
3. Results of the thermographic survey shall be in accordance with Section 9. (7.6.1.1.1.6.3)
4. Settings shall comply with coordination study recommendations. (7.6.1.1.1.8)

3.2 Test Values – Electrical

1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value.
2. Insulation-resistance values should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.1. Values of insulation resistance less than this table or manufacturer's recommendations should be investigated.
3. Microhm or dc millivolt drop values should not exceed the high levels of the normal range as indicated in the manufacturer's published data. If manufacturer's data is not available, investigate values that deviate from adjacent poles or similar breakers by more than 50 percent of the lowest value.
4. Insulation-resistance values of control wiring should be comparable to previously obtained results but not less than two megohms.
5. Long-time pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time-current characteristic tolerance band, including adjustment factors. If manufacturer's curves are not available, trip times should not exceed the value shown in Table 100.7. (Circuit breakers exceeding specified trip time shall be tagged defective.)

Test Values – Electrical (Cont'd)

6. Short-time pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time-current tolerance band. (Circuit breakers exceeding specified trip time shall be tagged defective.)
7. Ground fault pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time-current tolerance band. (Circuit breakers exceeding specified trip time shall be tagged defective.)
8. Instantaneous pickup values of molded-case circuit breakers should fall within manufacturer's published tolerances. In the absence of manufacturer's published tolerances, refer to Table 100.8. (Circuit breakers exceeding specified trip time shall be tagged defective.)
9. Pickup values and trip characteristics should be within manufacturer's published tolerances. (Circuit breakers exceeding specified trip time shall be tagged defective.)
10. Minimum pickup voltage on shunt trip and close coils should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, refer to Table 100.20.
11. Breaker open, close, trip, trip-free, antipump, and auxiliary features should function as designed.
12. Charging mechanism shall function as designed.

Low-Voltage Power Circuit Breakers

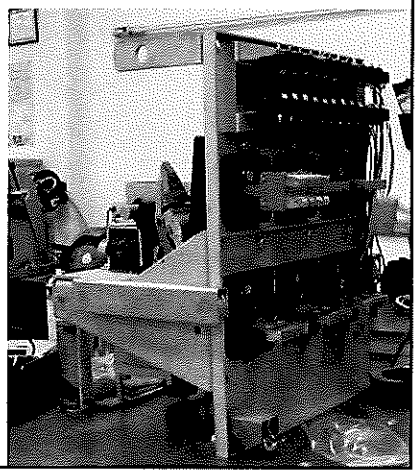
Construction and Operation

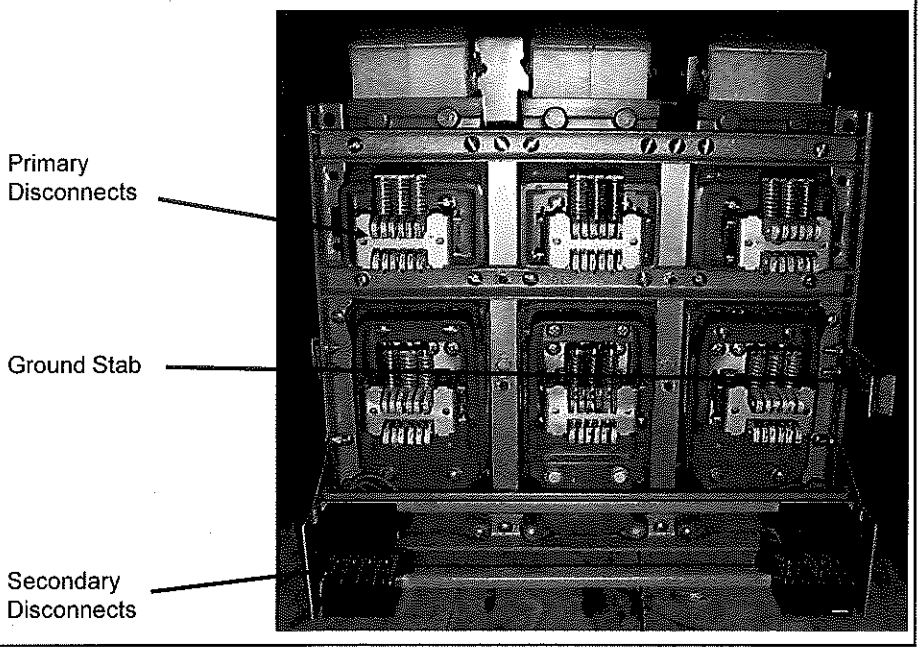
Key Components

- Frame
- Main stabs/primary disconnects
- Secondary stabs / secondary disconnects
- Contacts
- Arc extinguishers
- Operating mechanism
- Overcurrent trip device

Frame

- Supports components
- Not part of insulation system
- Open-air construction

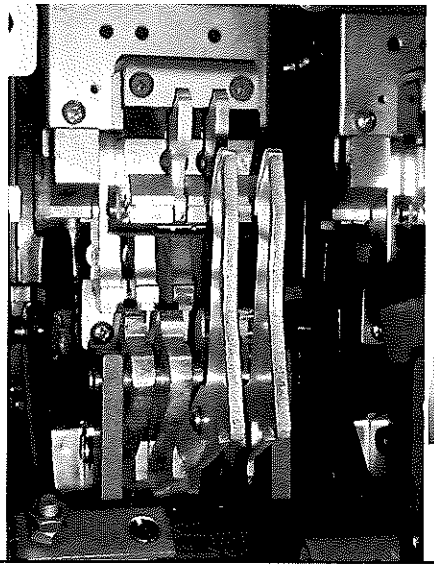


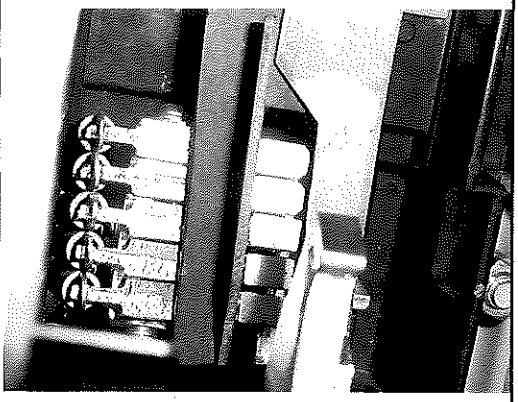


Contact Assemblies

- Arcing
  - Makes first, breaks last. Harder alloy than mains
- Main
  - Carries load current
- Intermediate
  - Same purpose as arcing
- Auxiliary
  - Control power and indicator lights

Contact Assemblies





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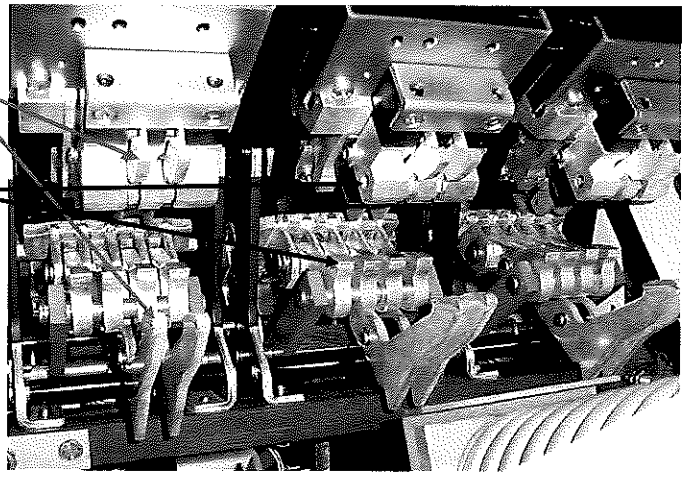
Contact Assemblies

Arcing

Main



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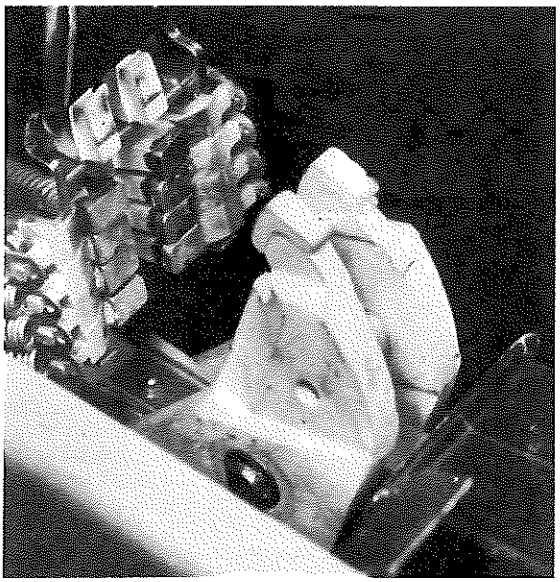
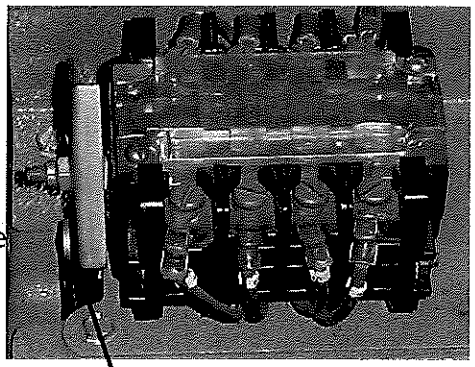
Intermediate Contact Assembly



Auxiliary Contacts

- Mechanically operated contacts
  - a or b contacts
  - a contacts NO
    - In same position as breake
  - b contacts NC
    - Opposite to breaker
  - Driven by operating mechanism



Mechanical Linkage from Operating Mechanism

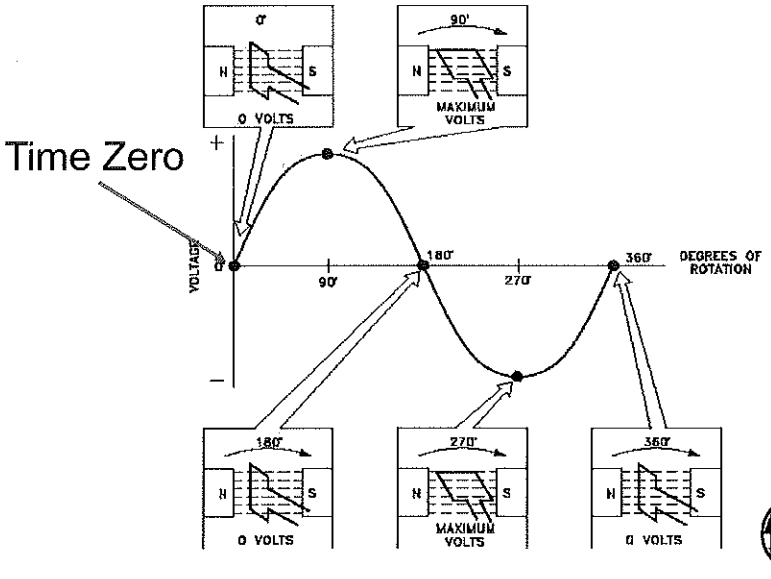
Arc Extinguishing

- Main purposes
  - Contain arc
  - Stretch arc
  - Cool arc
  - Extinguish arc
- Arc must be extinguished ASAP
- Restrike occurs when arc can re-establish itself

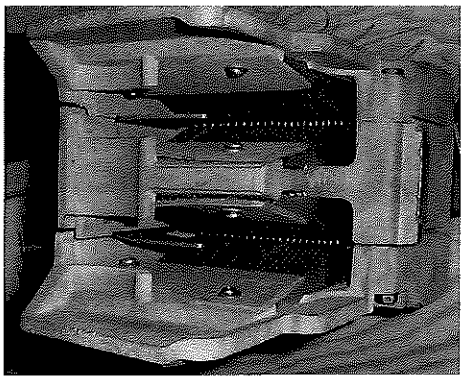
Maximum Total Clearing Time

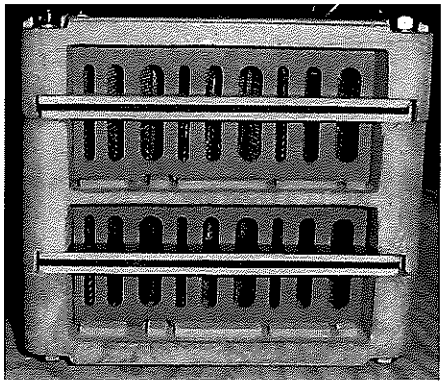
- Typical operating times
  - MCCB – 1.5 to 2 cycles
  - LVPCB – 3 to 4 cycles
  - MVACB - 5 to 7 cycles
  - MVVCB - 2 cycles
- Proper arc extinguishing is a safety issue
  - Maintenance and proper application are critical
- Arc can only be interrupted at "time zero"

Generating Power



Arc Chutes



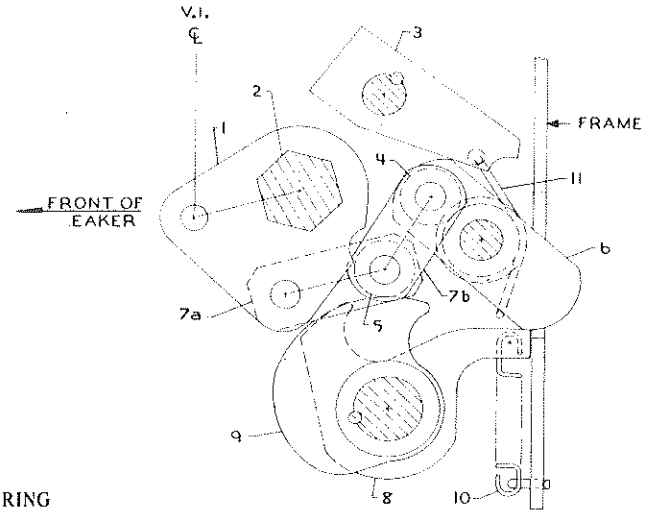


Operating Mechanism

Breaker Open

Springs Discharged

1 OUTPUT CRANK
2 JACKSHAFT
3 TRIP LATCH
4 TRIP ROLLER
5 CLOSING ROLLER
6 TRIP LINK
7a CLOSING TOGGLE
7b CLOSING TOGGLE
8 PROP
9 CLOSING CAM
10 PROP SPRING
11 LINKAGE RETURN SPRING



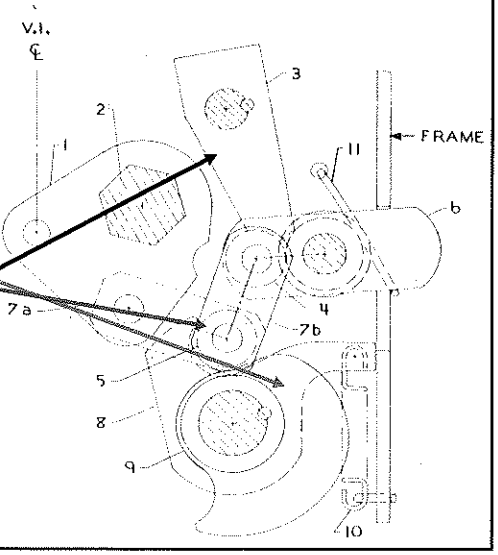
Breaker Open – Springs Charged

Closing Cam Rotated

Closing Toggles (7a & 7b) Drop

Trip Latch Repositioned

Note that it holds the Trip Roller (4) in a fixed position now



Breaker Closed – Springs Discharged

Hitting CLOSE Button

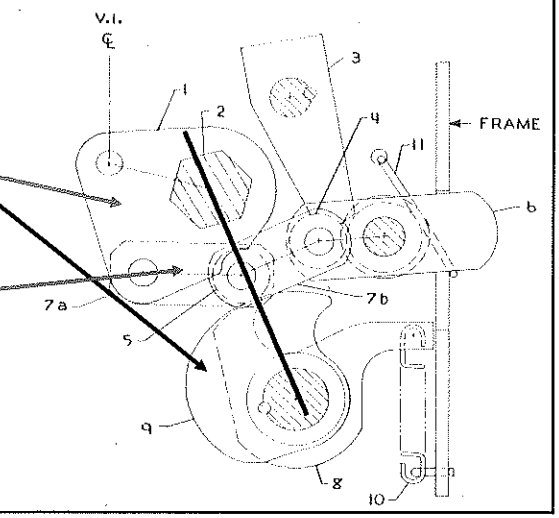
Closing Cam Rotates

Output Crank Rotates

This is driven by the springs, closing the contacts

Closing Toggles Extend

Breaker is held closed by Closing Roller (5) being held by Closing Cam (9) and Trip Roller (4) being held by Trip Latch (3)

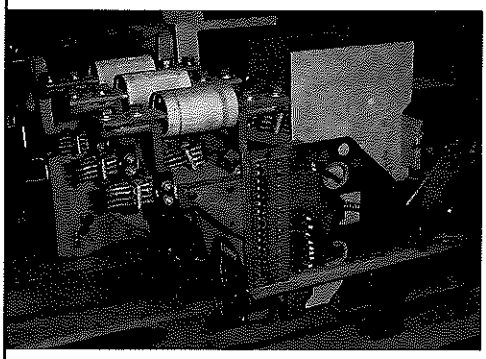


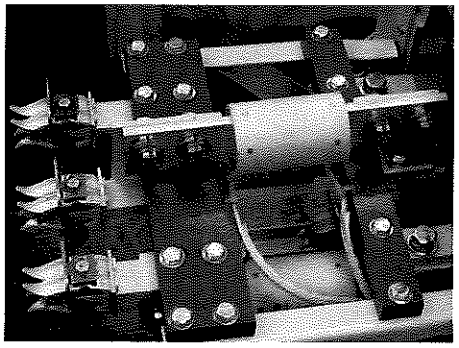
Secondary Components

- Current-Limiting Fuses
- Undervoltage Trip Device
- Bell Alarm and Lockout
- Blown Fuse Indicator

Current-Limiting Fuses

Used when available short-circuit current is higher than Interrupting Rating of breaker

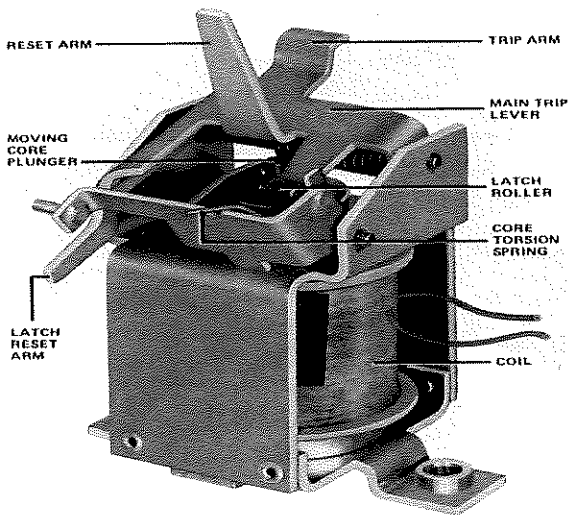




Current-Limiting Fuses

- Can blow when testing OCPD
  - Instantaneous pickup sometimes close to fuse operating current
- Use flexible straps or bus

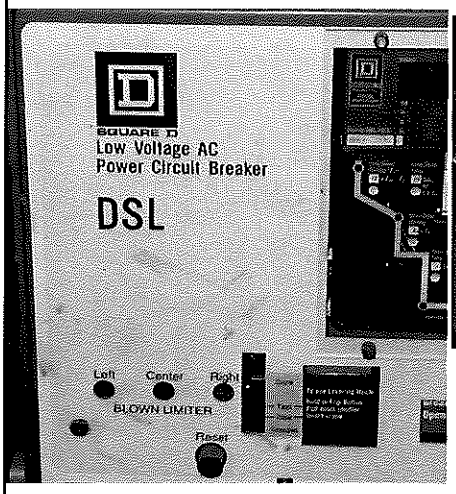
Undervoltage Trip

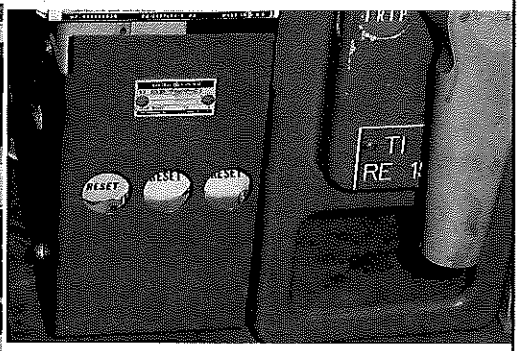


Undervoltage Trip

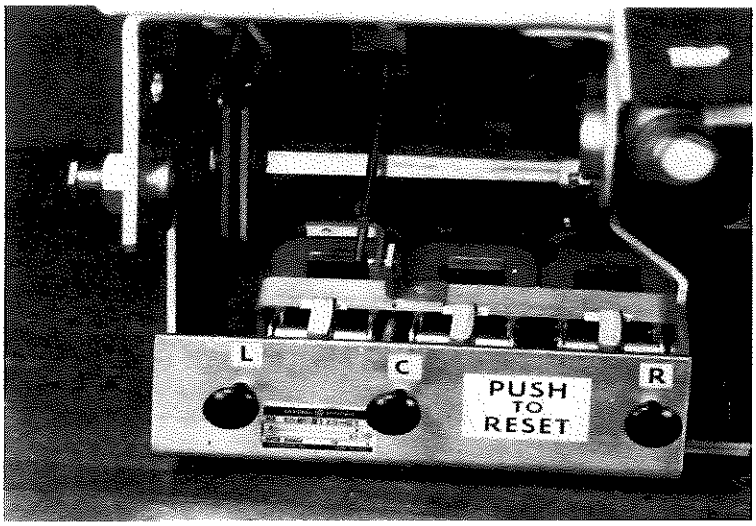
- Operates trip paddle when voltage is below dropout
- When testing breaker voltage is zero
- May need to energize with voltage above minimum dropout

Blown Fuse Indicator





Blown Fuse Indicator



Blown Fuse Indicator

- Often has lockout
- Lockout prevents breaker from closing if fuse has operated
- Must reset lockout

ANSI/NETA MTS-2007

7.6.1.2

Circuit Breakers, Air, Low-Voltage

1. Visual and Mechanical Inspection

1. Inspect physical and mechanical condition.
2. Inspect anchorage, alignment, and grounding.
3. Verify that all maintenance devices are available for servicing and operating the breaker.
4. Prior to cleaning the unit, perform as-found tests, if required.
5. Clean the unit.
6. Inspect arc chutes.

7. Inspect moving and stationary contacts for condition, wear, and alignment.
8. Verify that primary and secondary contact wipe and other dimensions vital to satisfactory operation of the breaker are correct.
9. Perform all mechanical operator and contact alignment tests on both the breaker and its operating mechanism in accordance with manufacturer's published data.

10. Inspect bolted electrical connections for high resistance using one of the following methods:
    1. Use of a low-resistance ohmmeter in accordance with Section 7.6.1.2.2.
    2. Verify tightness of accessible bolted electrical connections by calibrated torque-wrench method in accordance with manufacturer's published data or Table 100.12.
    3. Perform a thermographic survey in accordance with Section 9.

11. Verify cell fit and element alignment.
12. Verify racking mechanism operation.
13. Use appropriate lubrication on moving current-carrying parts and on moving and sliding surfaces.
14. Perform as-left tests.
15. Perform adjustments for final protective device settings in accordance with coordination study provided by end user.
16. Record as-found and as-left operation counter readings, if applicable.

2. Electrical Tests

1. Perform resistance measurements through bolted connections with a low-resistance ohmmeter, if applicable, in accordance with Section 7.6.1.2.1.
2. Perform insulation-resistance tests for one minute on each pole, phase-to-phase and phase-to-ground with the circuit breaker closed, and across each open pole. Apply voltage in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.1.

3. Perform a contact/pole-resistance test.

*4. Perform insulation-resistance tests on all control wiring with respect to ground. The applied potential shall be 500 volts dc for 300-volt rated cable and 1000 volts dc for 600-volt rated cable. Test duration shall be one minute. For units with solid-state components, follow manufacturer's recommendation.

5. Determine long-time pickup and delay by primary current injection.

6. Determine short-time pickup and delay by primary current injection.

7. Determine ground-fault pickup and delay by primary current injection.

8. Determine instantaneous pickup current by primary current injection.

*9. Test functions of the trip unit by means of secondary injection.

10. Perform minimum pickup voltage test on shunt trip and close coils in accordance with Table 100.20.

11. Verify correct operation of auxiliary features such as trip and pickup indicators, zone interlocking, electrical close and trip operation, trip-free, antipump function, and trip unit battery condition. Reset all trip logs and indicators.
12. Verify operation of charging mechanism.

3.1 Test Values – Visual and Mechanical

1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value. (7.6.1.2.1.10.1).
2. Bolt-torque levels should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.12. (7.6.1.2.1.10.2)

3. Results of the thermographic survey shall be in accordance with Section 9. (7.6.1.2.1.10.3)
4. Settings shall comply with coordination study recommendations. (7.6.1.2.1.15)

3.2 Test Values – Electrical

1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value.
2. Insulation-resistance values of breakers should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.1. Values of insulation resistance less than this table or manufacturer's recommendations should be investigated.

3. Microhm or dc millivolt drop values should not exceed the high levels of the normal range as indicated in the manufacturer's published data. If manufacturer's data is not available, investigate values that deviate from adjacent poles or similar breakers by more than 50 percent of the lowest value.
4. Insulation-resistance values of control wiring should be comparable to previously obtained results but not less than two megohms.

5. Long-time pickup values should be as specified, and the trip characteristic shall not exceed manufacturer's published time-current characteristic tolerance band, including adjustment factors. If manufacturer's curves are not available, trip times shall not exceed the value shown in Table 100.7. (Circuit breakers exceeding specified trip time shall be tagged defective.)
6. Short-time pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time-current tolerance band. (Circuit breakers exceeding specified trip time shall be tagged defective.)

7. Ground fault pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time-current tolerance band. (Circuit breakers exceeding specified trip time shall be tagged defective.)
8. Instantaneous pickup values should be within the tolerances of manufacturer's published data. In the absence of manufacturer's published data, refer to Table 100.8. (Circuit breakers exceeding specified trip time shall be tagged defective.)

9. Pickup values and trip characteristic should be as specified and within manufacturer's published tolerances. (Circuit breakers exceeding specified trip time shall be tagged defective.)
10. Minimum pickup voltage on shunt trip and close coils should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, refer to Table 100.20.

11. Auxiliary features should operate in accordance with manufacturer's published data.
12. The charging mechanism should operate in accordance with manufacturer's published data.

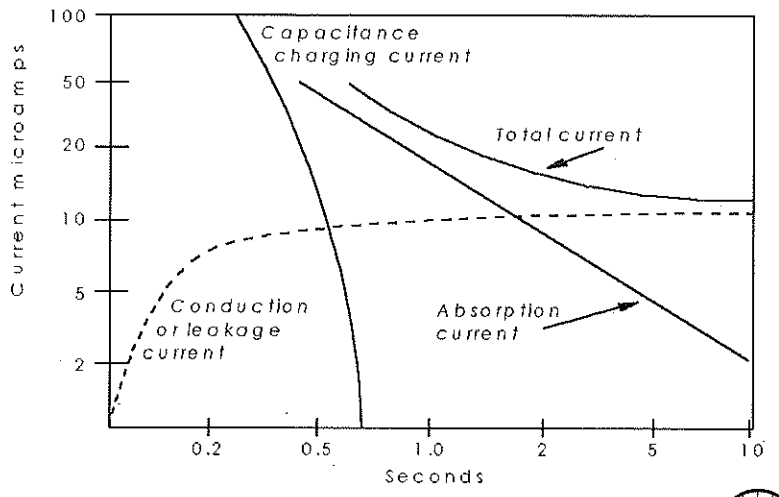
Testing Low-Voltage Circuit Breakers

Common Tests

- Insulation resistance
- DC overpotential (LVPCB)
- Contact resistance
- OCPD testing
  - Long-Time Delay (LTD)
  - Nuisance trip
  - Instantaneous
  - Short-Time Delay (STD)
  - Ground Fault (GF)
- Auxiliary devices

Insulation Resistance

DC Current Components



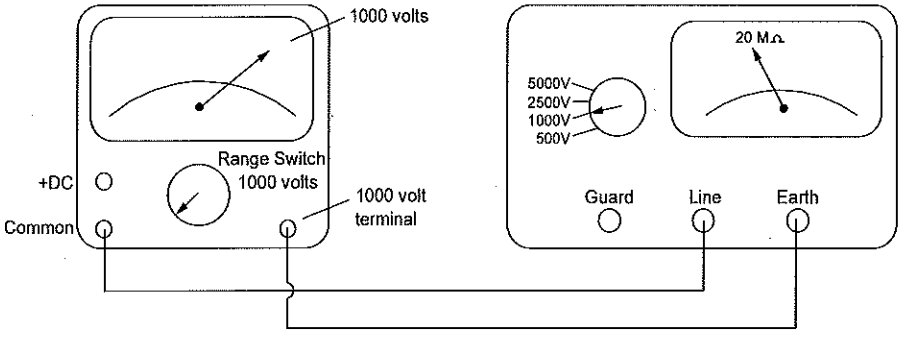
Megohmmeter or Hypot?

- Megohmmeter has limited capacity
  - As insulation weakens, voltage output decreases due to increased current
  - Won't damage insulation
- Hipots maintain their voltage output
  - As insulation weakens, Hipots can push through

Megohmmeter or Hypot?

- Megohmmeter
  - Finds gross defects only
  - Won't damage insulation
  - Lower voltage output
- Hipot
  - Stresses insulation
  - Finds tracking, weak insulation, moisture intrusion
  - Can damage insulation if misused

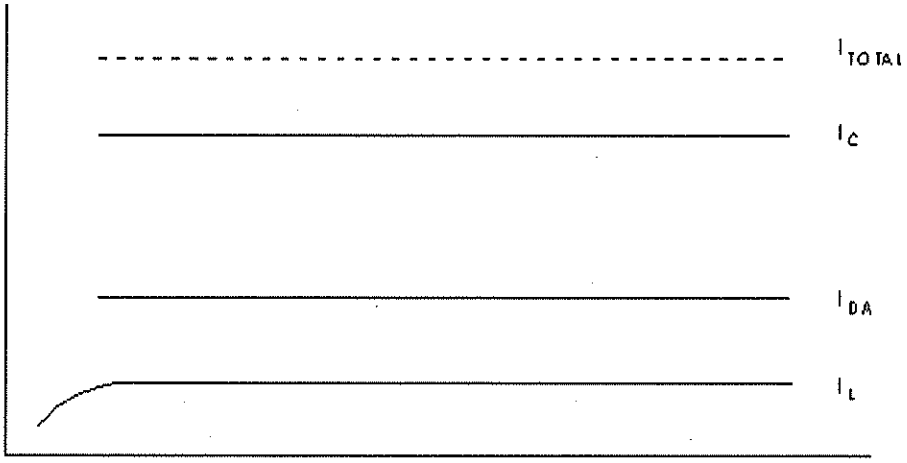
Checking Out A Megohmmeter



AC Hypots

- Much larger and heavier than dc test equipment
- Cannot measure leakage current directly
- Usually a go/no-go test
- AC overpotential testing deteriorates insulation
- Very good for vacuum bottle integrity test

AC Components



Insulation Can be Deteriorated by:

- Moisture
- Dirt and contaminants
- Heat and arcing
- Dielectric stresses
- Hostile environments
  - H_2S
  - CHLORINE
  - FLOURINE

Major Components Are Affected

- Arc chutes
- Backboard assemblies
- Phase pole units
- Megohmmeter tests only show gross defects
- DC overpotential test will stress insulation
  - Uncover more defects

Insulation Resistance Test

- Frame on molded and insulated case CB
- Control wiring on LVPCB
- Can be compared to base line and trended
- Never test solid state devices or components
- Refer to ANSI/NETA Table 100.1
- Correct to 20^0C base temperature
  - Table 100.14

DC Overpotential

DC Overpotential

- ANSI/NETA MTS-2007 Table 100.2
- LVPCB use 2,500 volts
- Vtest = 2 RATED VOLTS + 1,000 VOLTS
- Example:

635V X 2 + 1,000V

- Minimum insulation resistance reading should be:

1MΩ per kV + 1kV

2.5MΩ + 1MΩ = 3.5MΩ

ANSI/NETA MTS-2007 Table 100.2

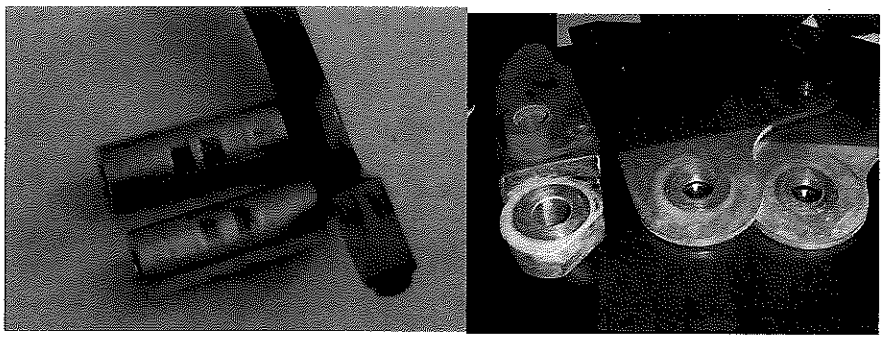
Type of Switchgear	Rated Maximum Voltage (kV) (rms)	Maximum Test Voltage (kV)	
		AC	DC
Low-Voltage Power Circuit Breaker Switchgear	.254/.508/.635	1.6	2.3
Metal-Clad Switchgear	4.76	14	20
	8.25	27	37
	15.0	27	37
	27.0	45	a
	38.0	60	a
Station-Type Cubicle Switchgear	15.5	37	a
	38.0	60	a
	72.5	120	a
Metal-Enclosed Interrupter Switchgear	4.76	14	20
	8.25	19	27
	15.0	27	37
	27	45	a
	38.0	60	a

DC Overpotential - All Voltages

Circuit Breaker Open	# Tests	Insulation Tested
Line Stab to Load Stab	3	Arc Chute or Vacuum Bottle
Circuit Breaker Closed	**# Tests**	**Insulation Tested**
Line Stab to Ground	3	Backboard – Stab to Ground
Phase to Phase	3	Backboard – Stab to Stab

Contact Resistance

Causes of Increased Resistance



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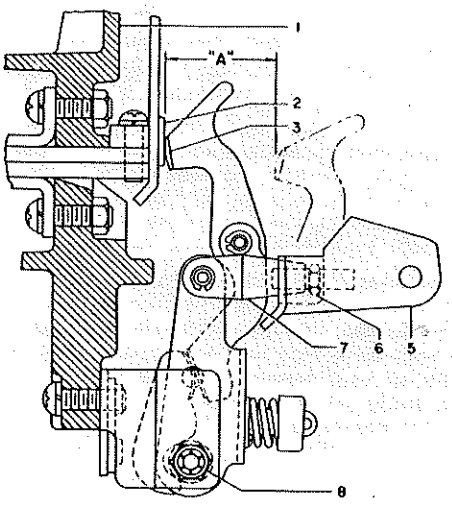
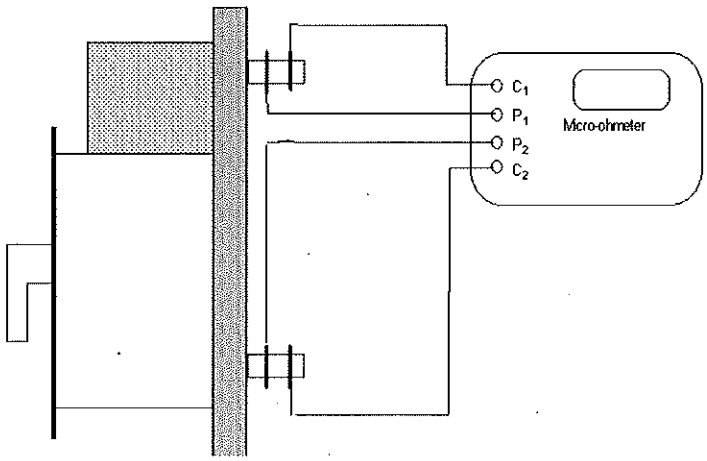
Damage Caused By Lack Of Lubrication

Current Path



1 Upper Molding
2 Stationary Contact
3 Movable Contact
5 Insulator
6 Adjusting Stud
7 Yoke
8 Nut (Self-Locking)

Contact Resistance



Results Interpretation

- ANSI/NETA MTS-2007
  - 50% Rule
- Shermco Circuit Breaker Shop
- LV Breakers
  - 0 to 100μΩ – Excellent
  - >300μΩ – Trouble
- MV Breakers
  - 0 to 80μΩ – Excellent
  - >250μΩ – Trouble

OCPD Tests

Types of Tests

- Primary Injection
- Secondary Injection

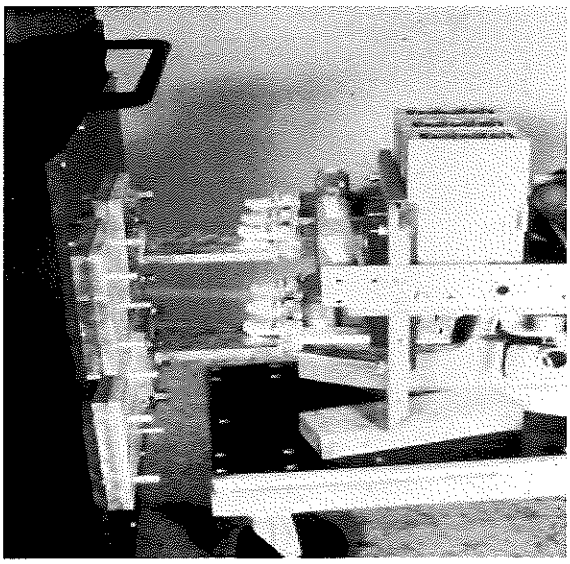
Primary Injection

- Injects load current through primary stabs
- Low-voltage / high current
- Tests all components of solid-state & microprocessor devices
  - Sensors
  - Power supply
  - Interconnecting wiring
  - Logic circuits
  - Timing circuits
  - Trip output & coil

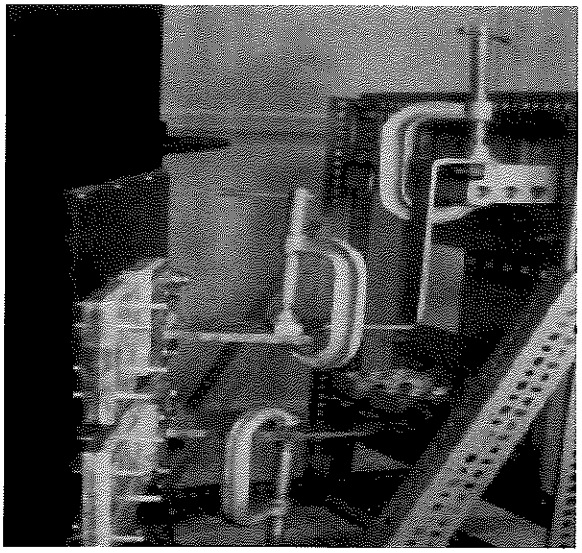
Primary Injection

- Preferred method of testing
- Drawbacks
  - Heavy, expensive equipment
  - Labor intensive
  - Extended down time
  - Expensive
- 3 methods of connection
  - Directly onto stabs
  - Onto bus bar or links
  - Using twisted cable

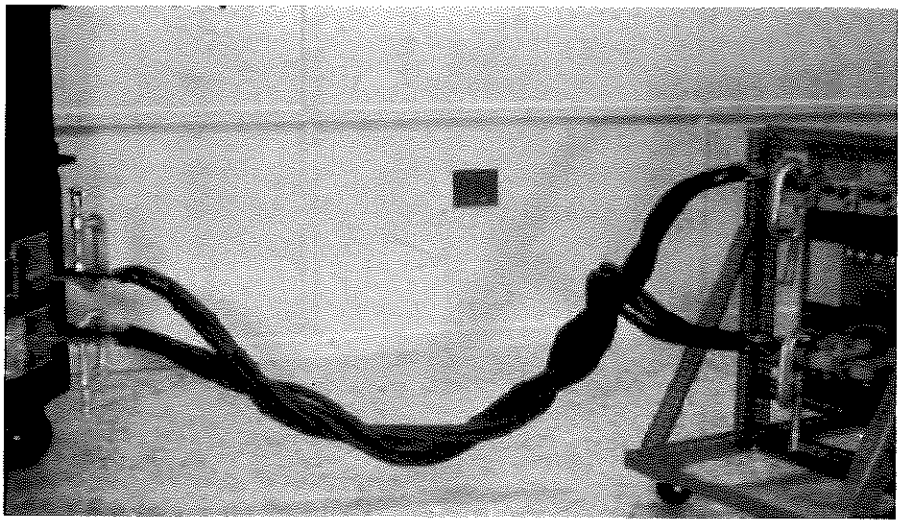
Directly Onto Stabs



Using Bus Bar



Using Cables



Secondary Injection

- Light, portable equipment
- Accurate
  - Some manufacturers only give rough numbers
- Easy to use
- Inexpensive
- Low down time
- Good to check calibration of trip unit with

Secondary Injection

- Drawbacks
  - Each manufacturer has different set
  - Some manufacturers have one set per trip unit style
  - Doesn't give complete test
  - Not tested:
    - Sensors
    - Power supply
    - Interconnecting wiring

Order of Tests (Thermal Magnetic MCCB)

- Long-Time Delay
  - Breaker is cool (ambient)
- Nuisance Trip
  - In between LTD tests
  - 100% rated for 300 seconds (5 minutes)
  - Allows breaker to cool down
- Instantaneous
  - Magnetic
  - Not affected by temperature

Order of Tests (LVPCB & ICCB)

- Long-Time Delay (LTD)
- Instantaneous (INST)
- Short-Time Delay (STD)
- Ground Fault (GF)

Overcurrent Device Functions

Functions

- Instantaneous
  - Short circuit protection
- Long-Time Delay (LTD)
  - Overcurrent protection
- Short-Time Delay (STD)
  - Short circuit protection
- Ground Fault
  - Phase-to-ground faults

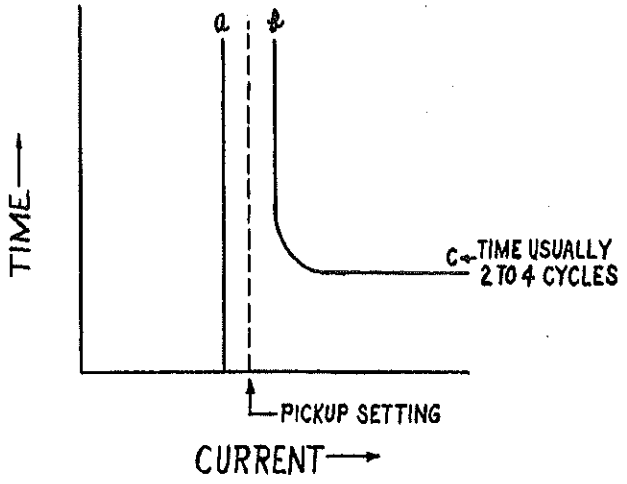
Primary Injection

- Standard test points
  - ANSI/NETA MTS-07
  - ANSI/NFPA 70B
- LTD – 3 times LTD pickup
- STD – 1.5 times STD pickup
- GF – 1.5 times GF pickup
- Instantaneous – at set point only, no timing test

Instantaneous

- Short circuit protection
- No intentional time delay
- Spring tension on armature sets minimum pickup
- Points a and b show pickup tolerance
- Point c shows Maximum Total Clearing Time

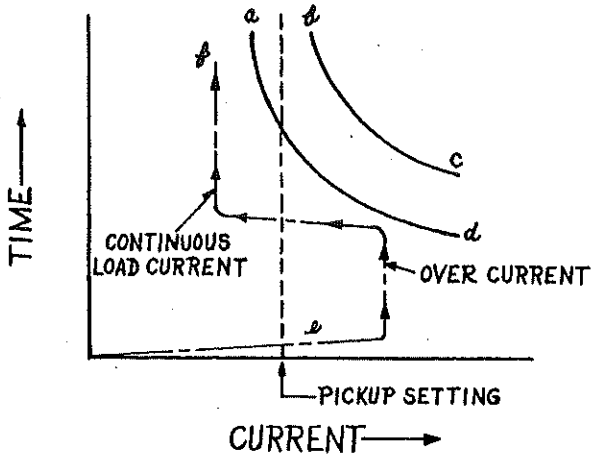
INSTANTANEOUS CHARACTERISTIC CURVE



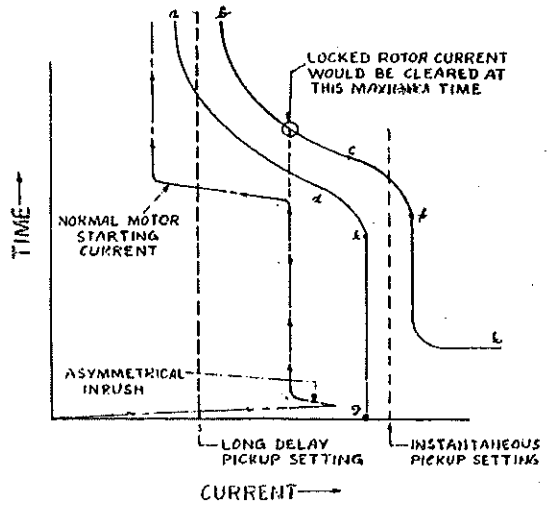
Long-Time Delay

- Overcurrent protection
- Operation in seconds
- Base units have one time band
- Upgraded units have multiple time bands
- Minimum pickup is Number 1 line on curve
- Upper limit points b & c
- Lower limit points a & d

Long -Time Delay Characteristic Curve



Long-Time and Instantaneous Curves

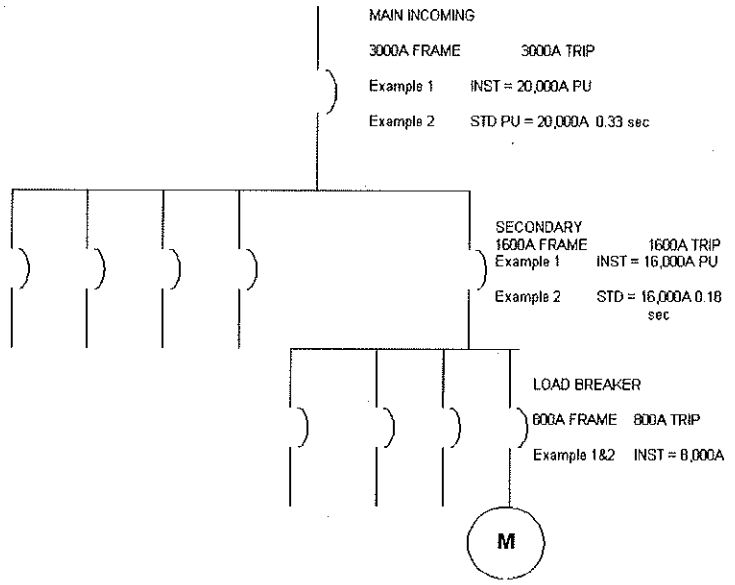


ITE/Gould OD-3

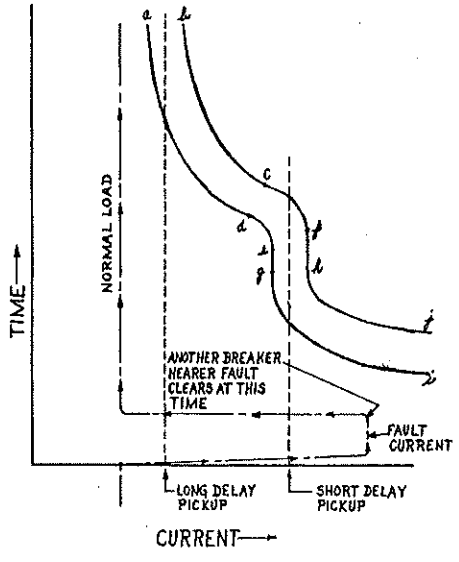
Short-Time Delay

- Short circuit protection
- Time delay to allow for proper coordination
- Up to 0.5 second

Short-Time Delay

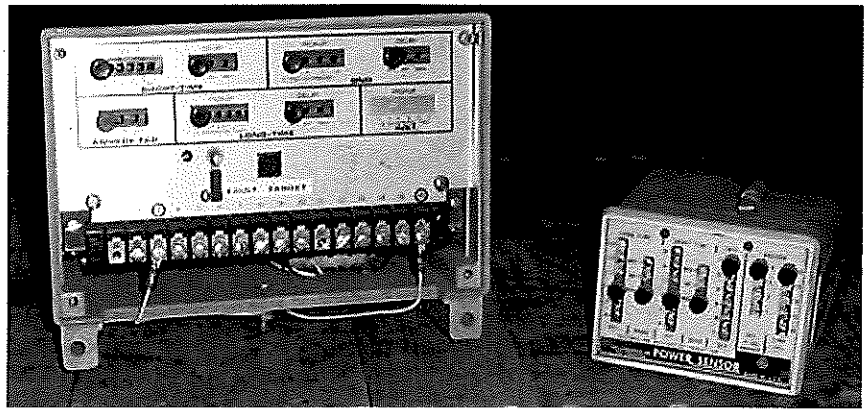


Long -Time and Short -Time



ITE/Gould OD-5

Solid State

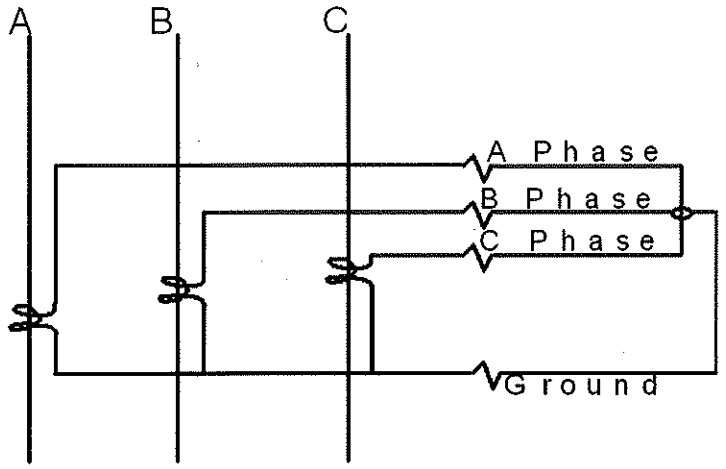


ITE SS-5

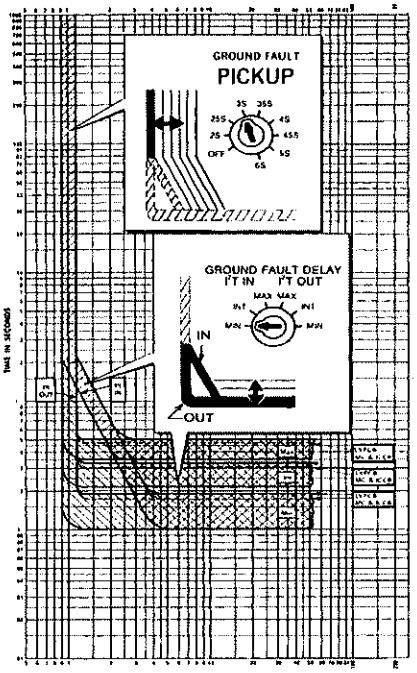
Ground Fault

- Can add Ground Fault (GF) function with electronic OCPD
  - Phase-to-ground protection
  - Senses imbalanced currents
  - Same operating times as STD
  - Generally less than 0.50 second

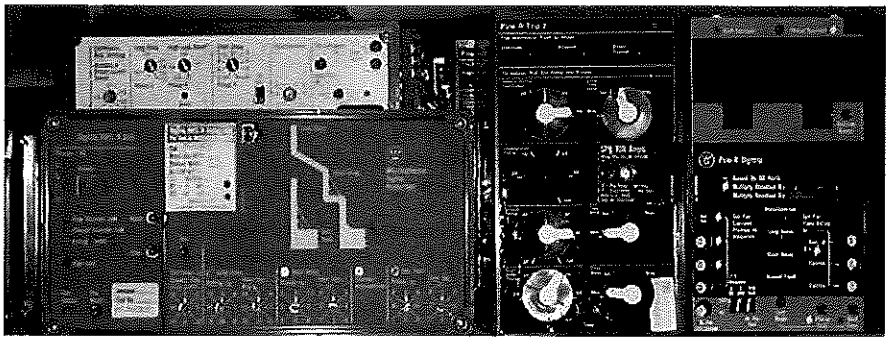
Ground Fault Sensing



Ground Fault Characteristic Curve



Micro-Processor



I^2t Function

- Used for large, transient overloads that would cause a trip
- Used instead of setting LTD above 100%
- Shifts STD curve to the right
- To calculate correct line to get timing:

STD PU x 1.5 = Test Current

Test Current = Multiple
Sensor Rating

Example

- Westinghouse/C-H DigiTrip®
- Settings w/800A sensor:
  - LTD = 0.8 LTD Band = 24
  - S_2 = 4 STD Band = MIN
  - LTD PU = 640A STD PU = 2,560A
  - INST = 9,600A

Example

2,560 x 1.5 = 3,840A test current

I^2t in:

$$\frac{3{,}840A}{800} = 4.8 \text{ Multiple}$$

- Time band would be read on the #4.8 line
- Approximately 0.55 to 0.85 seconds

Example

- I^2t out

  3,840 A test current

- STD pickup drawn on #1.5 line
- Read time from 1.5 x 1.5 = 2.25 line (straight portion of STD curve)

  Approximately 0.1 to 0.18 second

DigiTrip® Time-Current Curve

Auxiliary Devices

- Test for function
  - Minimum pickup voltage on shunt trip and close coils IAW manufacturer's published data.
    - Refer to Table 100.20.
  - Breaker open, close, trip, trip-free, antipump, and auxiliary features
  - Charging mechanism

Medium-Voltage Circuit Breakers

MV Circuit Breaker Classifications

- By interrupting medium
  - Air or air-magnetic
  - Vacuum
  - Oil
  - Air blast
  - SF_6 or gas

Medium-Voltage Air-Magnetic Circuit Breakers

Main Components

- Frame
- Barrier
- Insulators (pole units)
- Disconnects
  - Primary
  - Secondary
- Contact assemblies
- Operating mechanism
- Arc Extinguishers (chutes)

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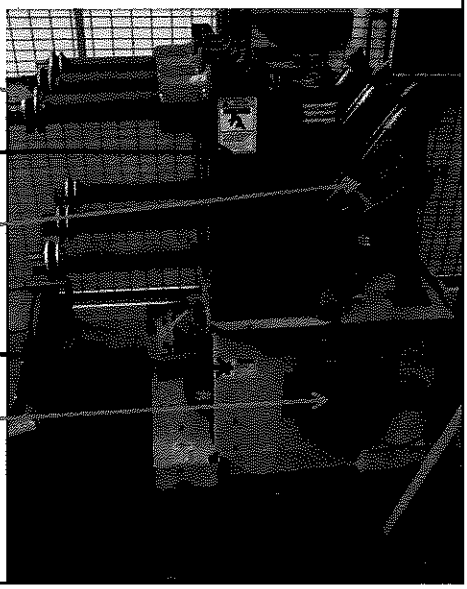
Primary Components

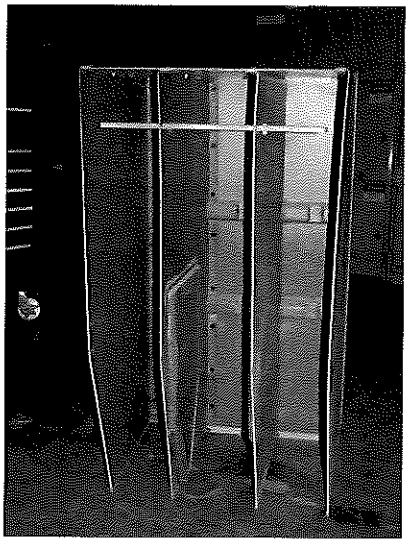
- Primary disconnects
- Pole units
- Contact assemblies
- Frame
- Secondary disconnects

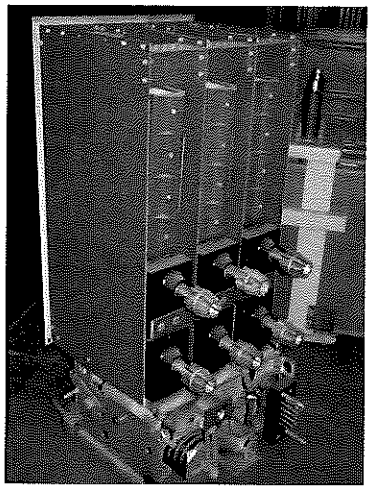


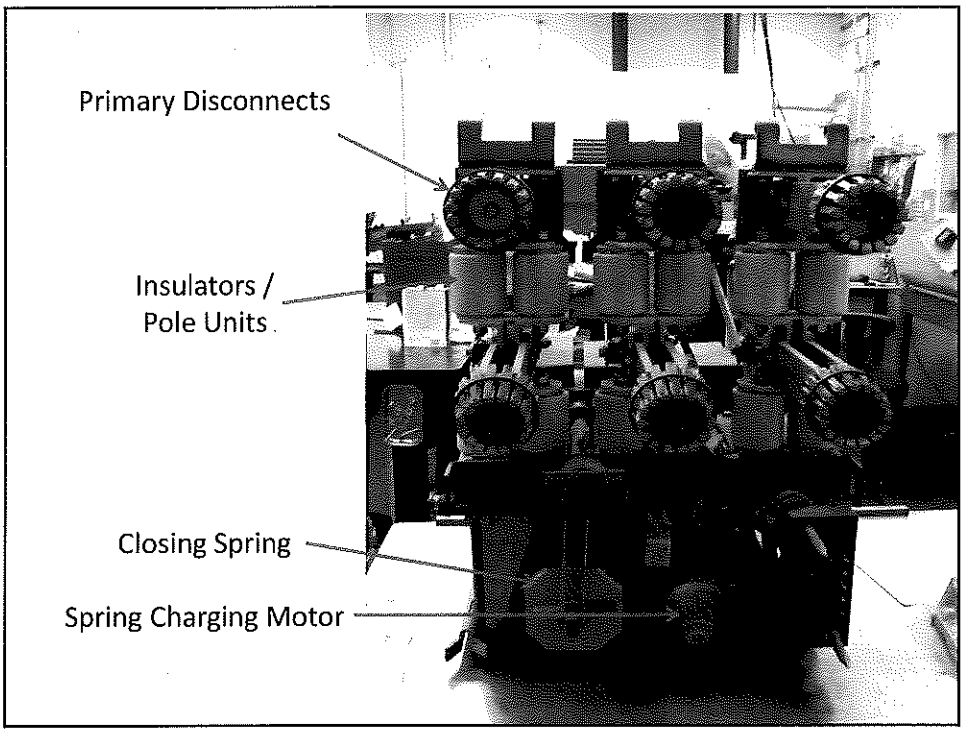
Frame

Supports components

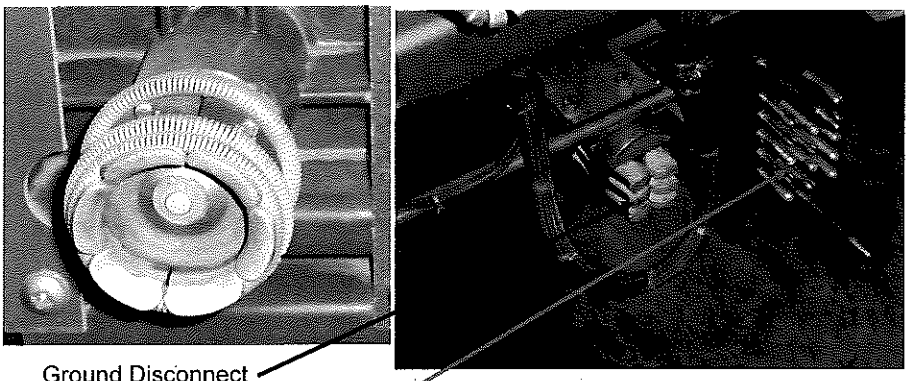
Barrier



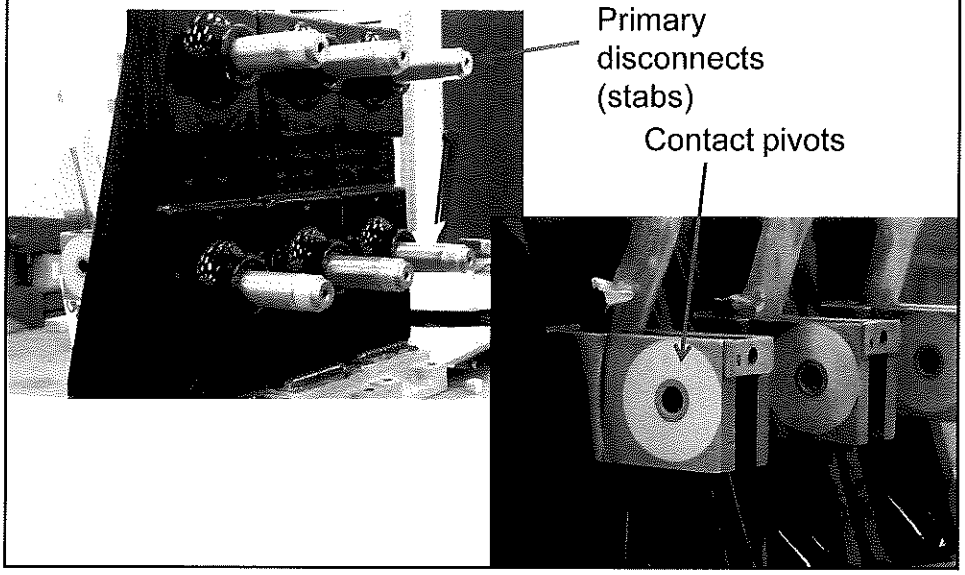




Primary, Secondary and Ground Disconnects - Medium-Voltage



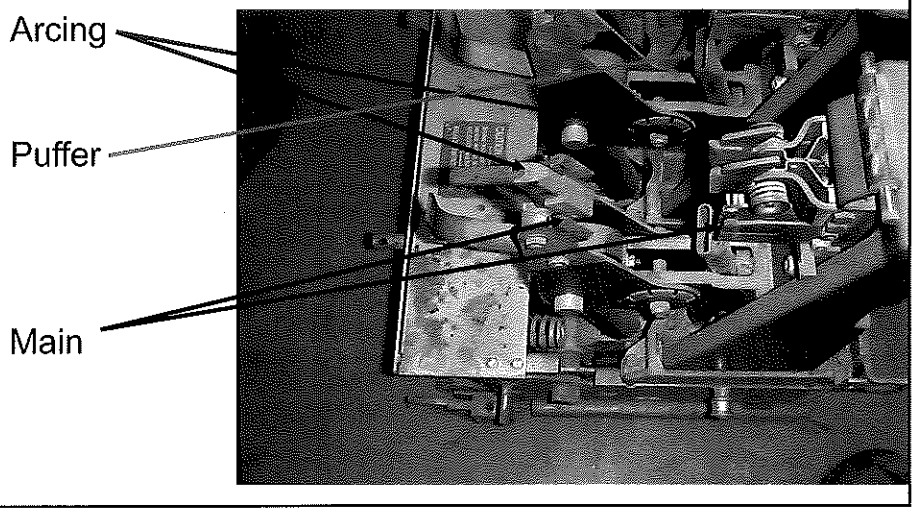
Pole Units



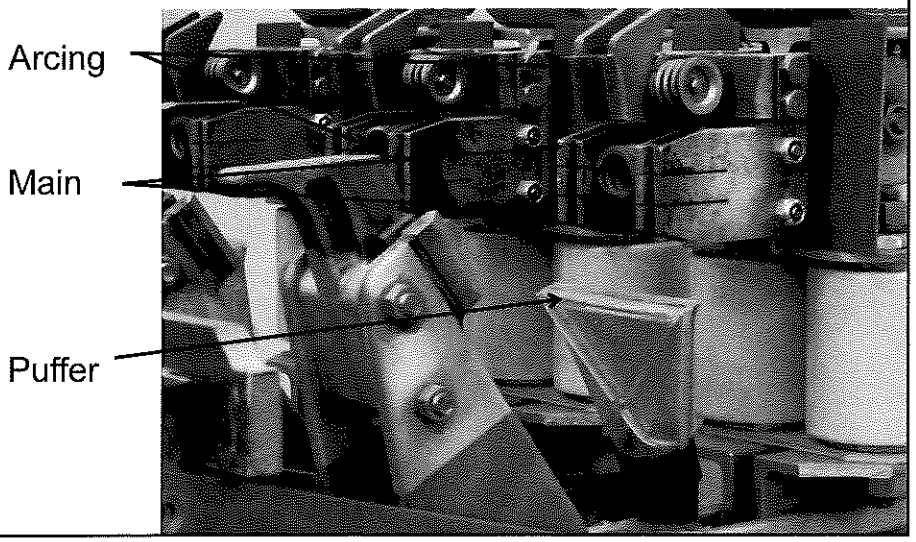
Pole Units / Bushings

Insulate
conductors
from ground

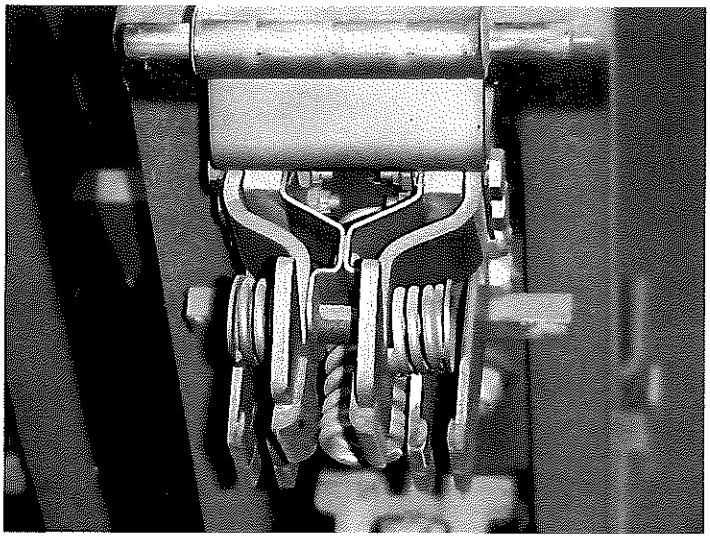
Contact Assemblies



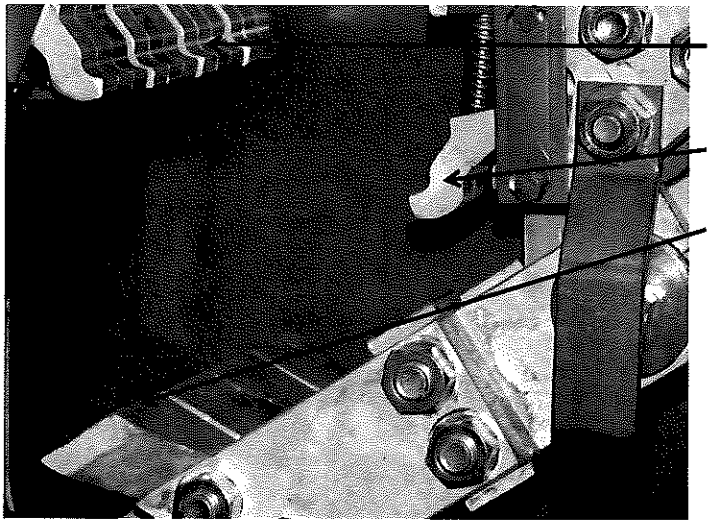
Bayonet Contacts



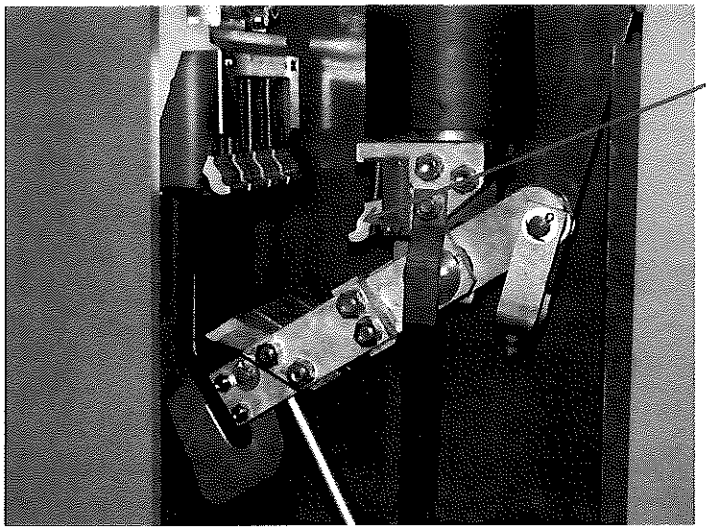
Bayonet Contacts



Butt Contacts



Main Butt/Arcing Bayonet Contacts



Note
Intermediate
Contacts

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Assembling Contacts

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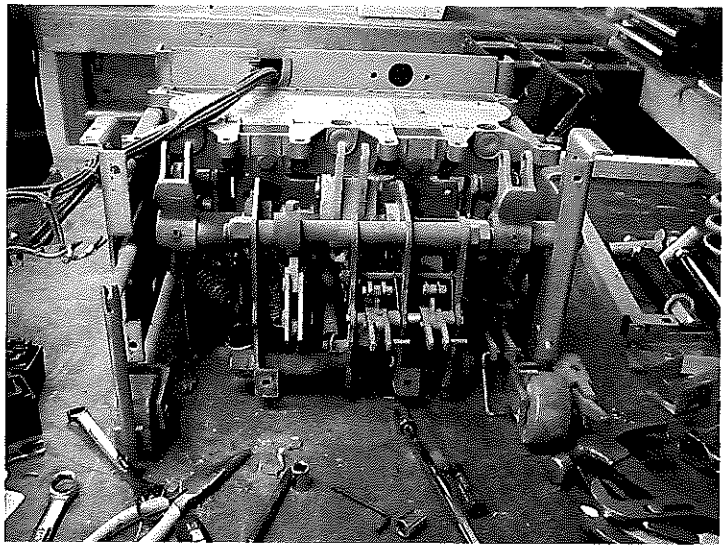
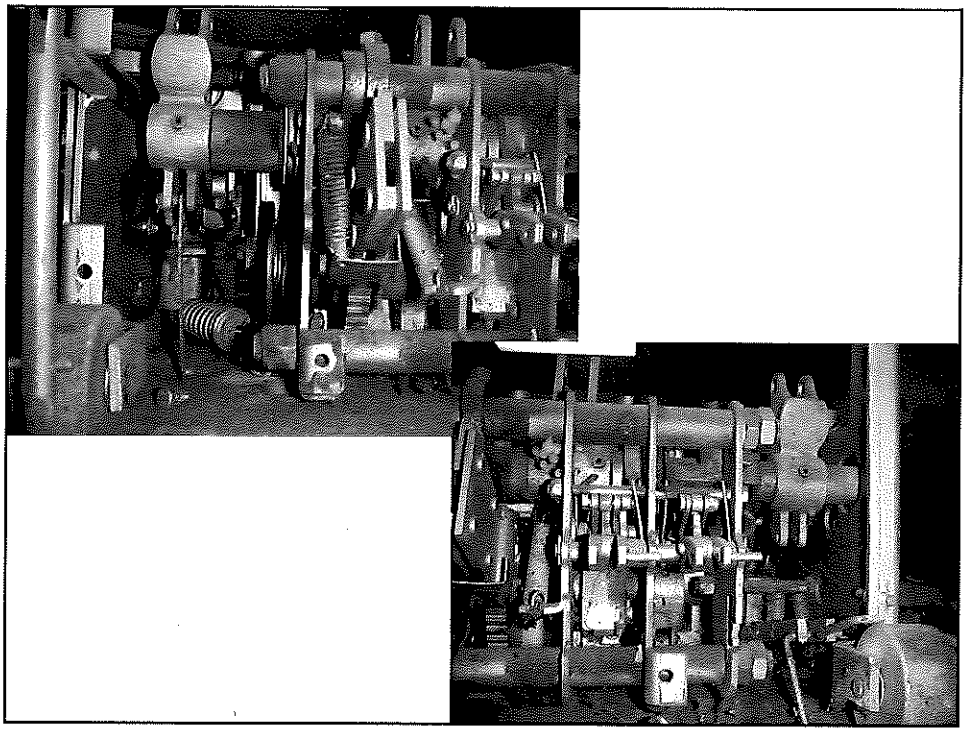
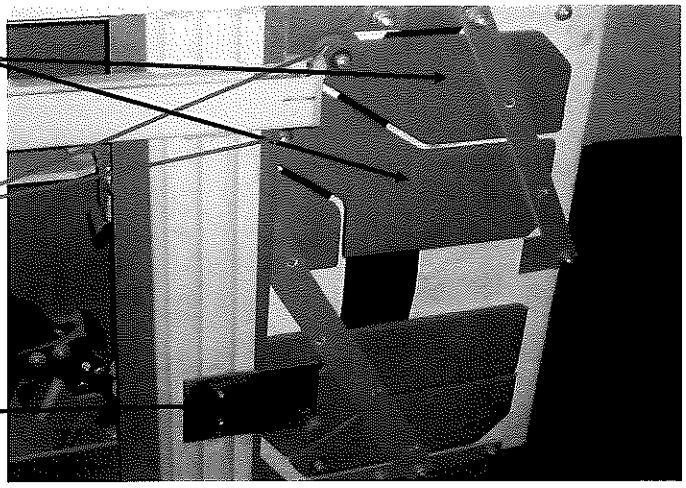
Operating Mechanism

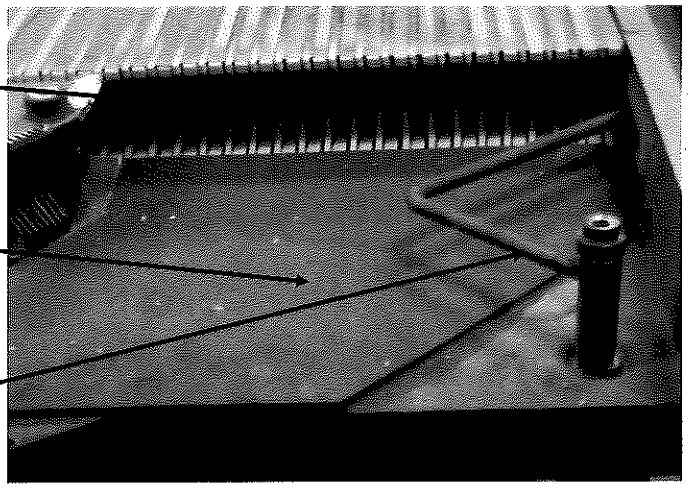




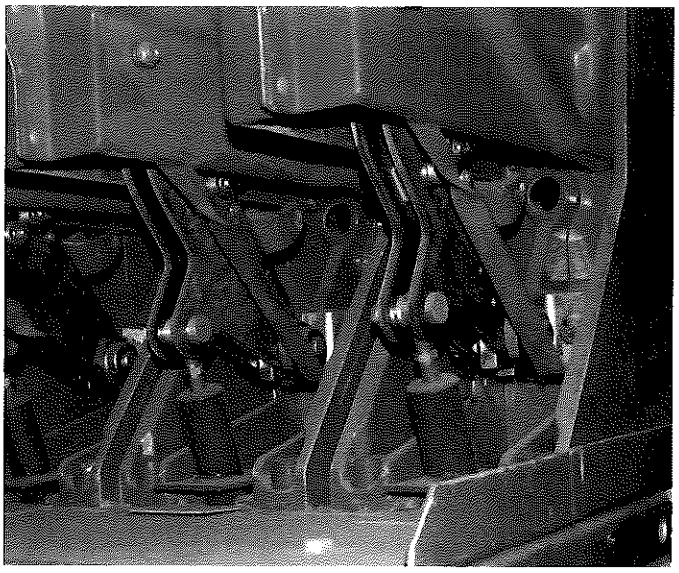
Arc Chutes



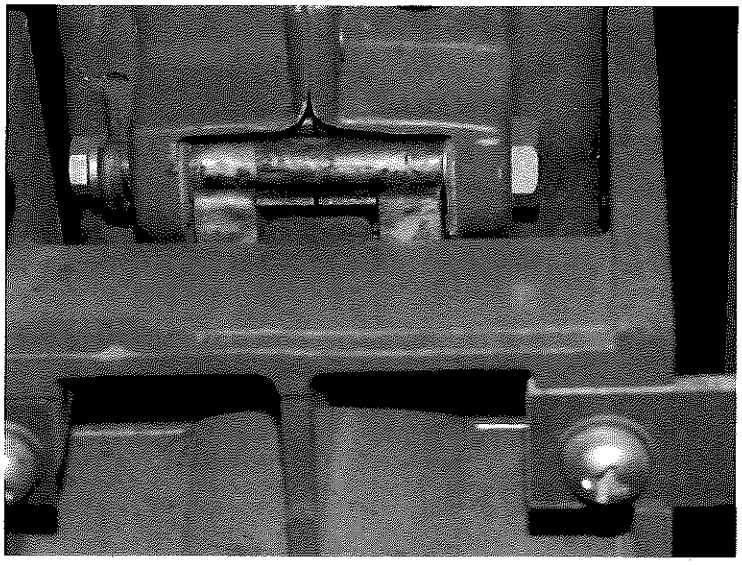
Arc Chutes



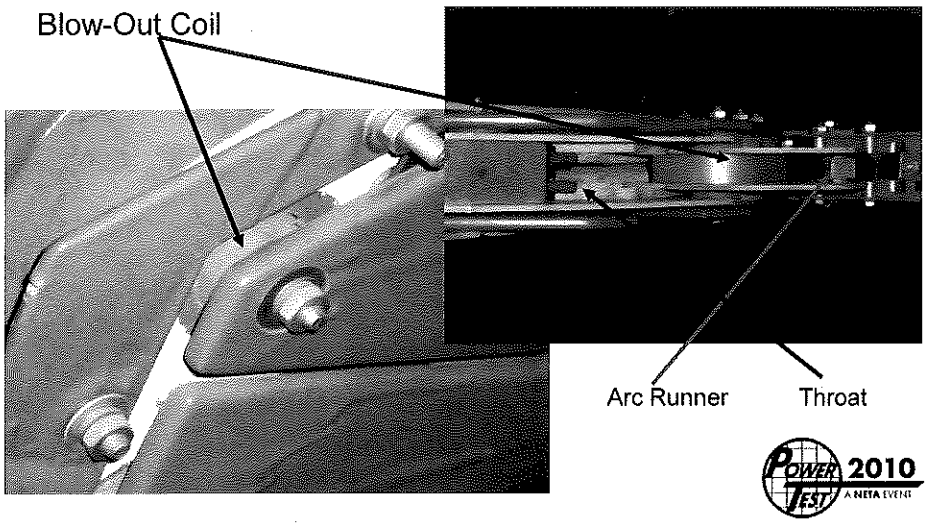
Arc Runner-to-Load-Side Disconnect



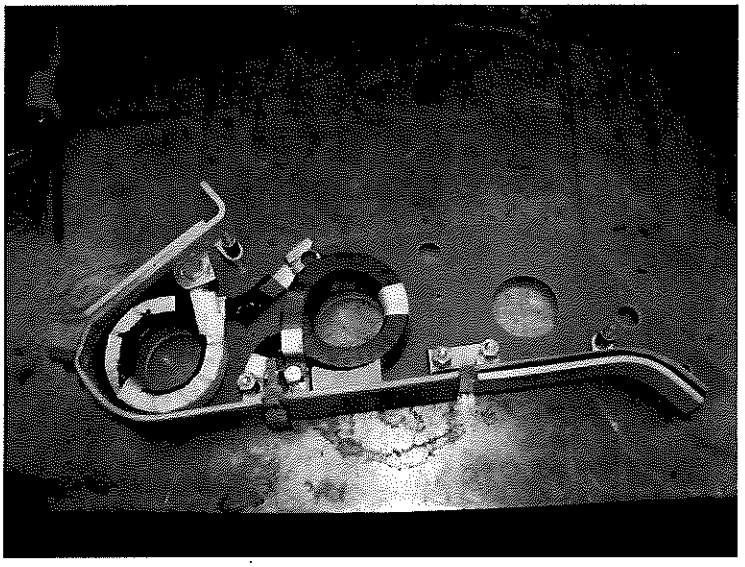
Arc Runner-To-Line-Side Disconnect

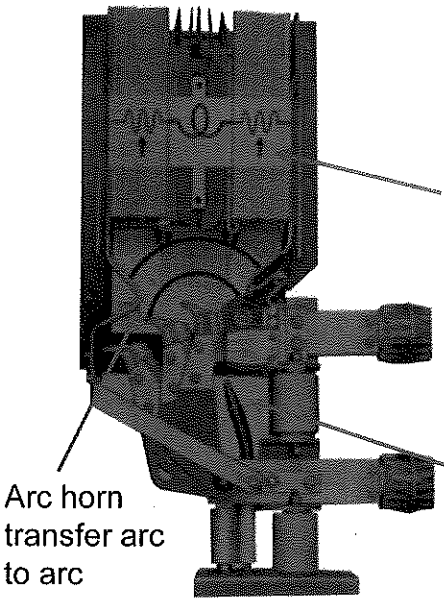


Arc Chutes



Blowout Coil Assembly





Hot arc rises

Arc cuts blowout coils

Creates magnetic field that pulls arc up

Puffer blows arc up into arc chute

Arc horn transfer arc to arc runners

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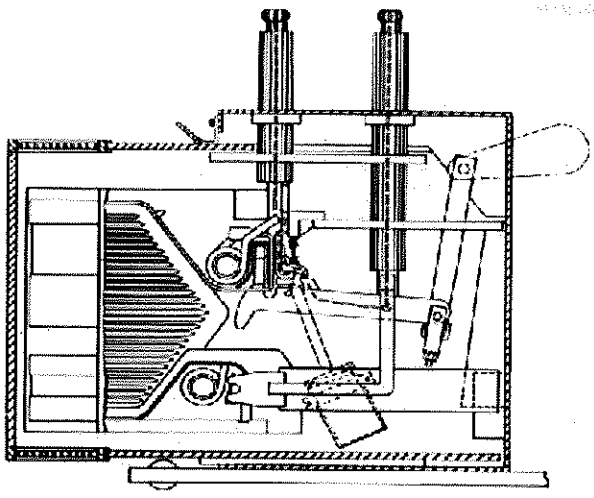
Normal Load Current



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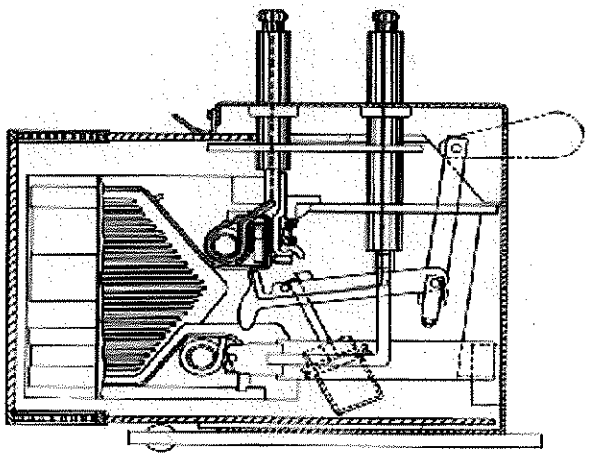
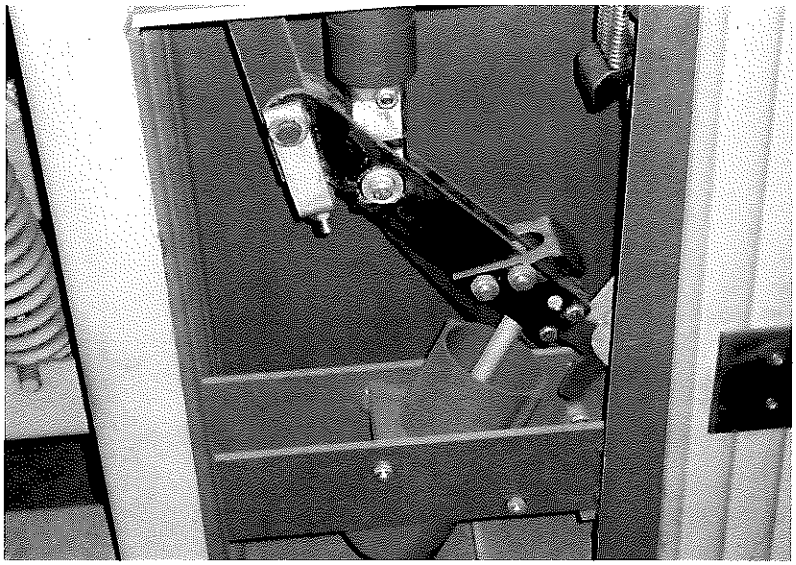
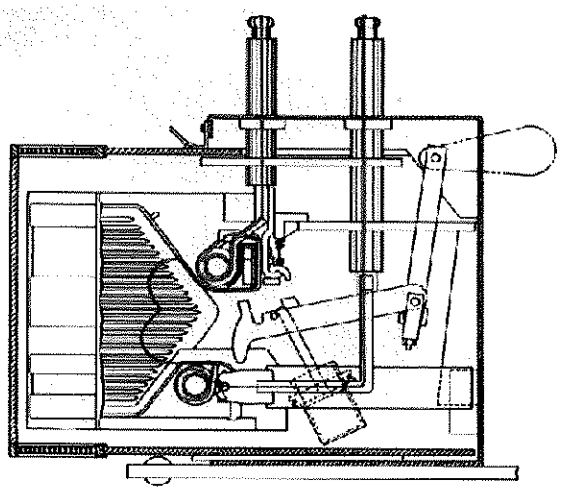
Start of Arc Interruption



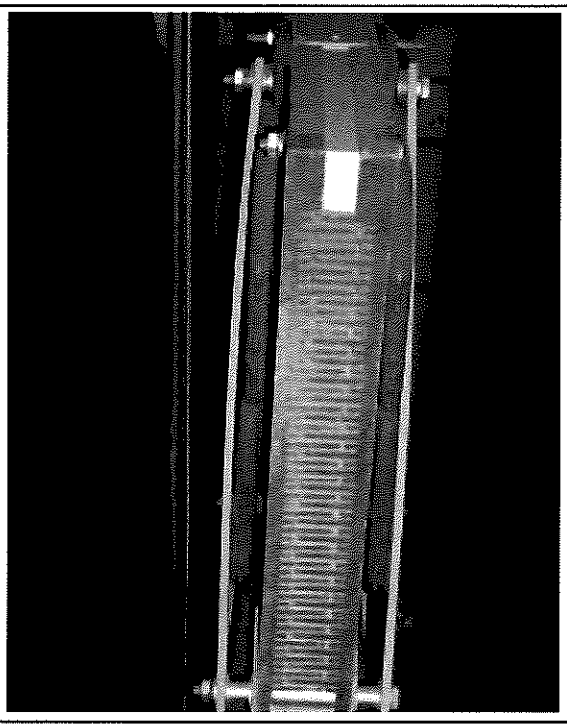
Puffer Assembly



Arc Being Stretched and Cooled



Muffler/Vent Assembly

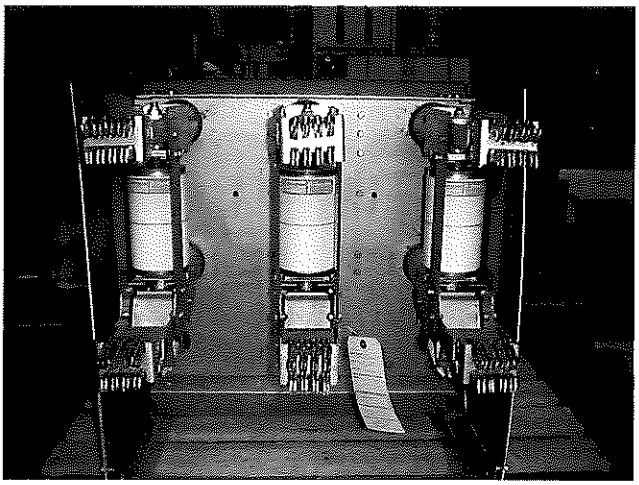


Medium-Voltage Vacuum Circuit Breakers

Main Components

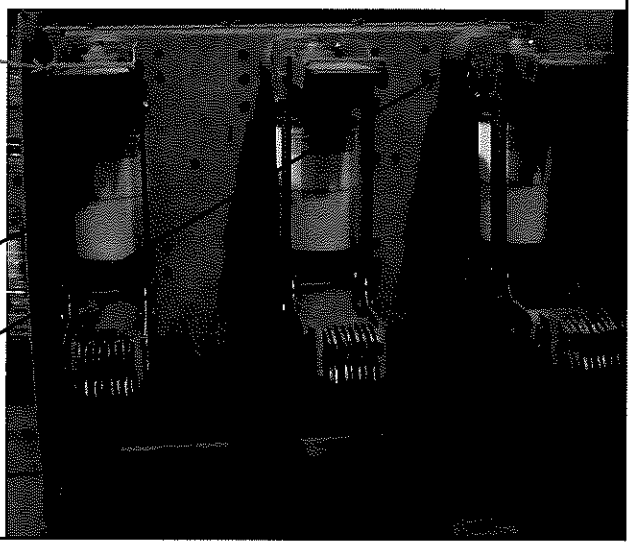
- Frame
- Barrier
- Insulators (pole units)
- Disconnects
  - Primary
  - Secondary
- Vacuum bottles
- Operating mechanism

Frame

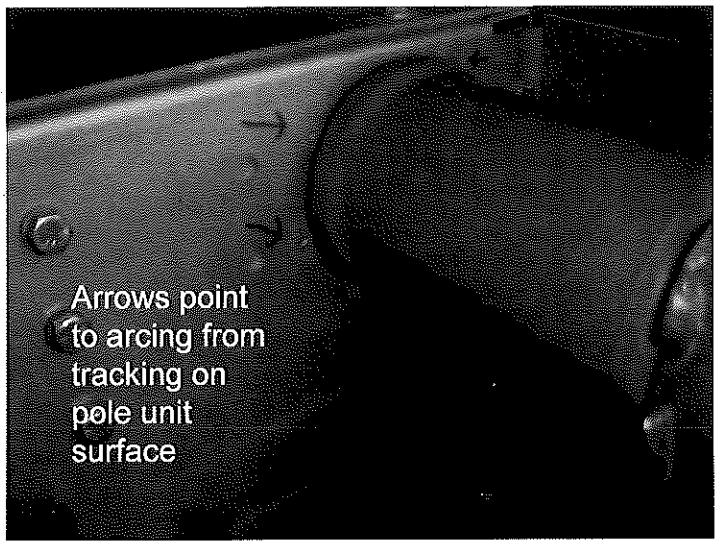


Pole Units – Vacuum Bottles – Primary Disconnects

- Primary Disconnects
- Vacuum Bottles
- Pole Units

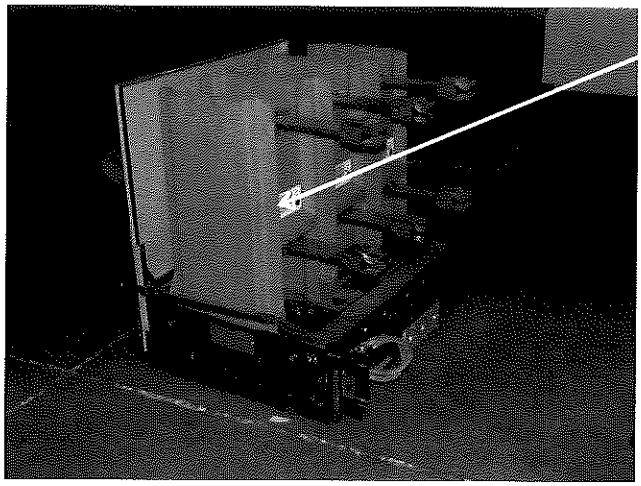


Pole Unit (Insulators)



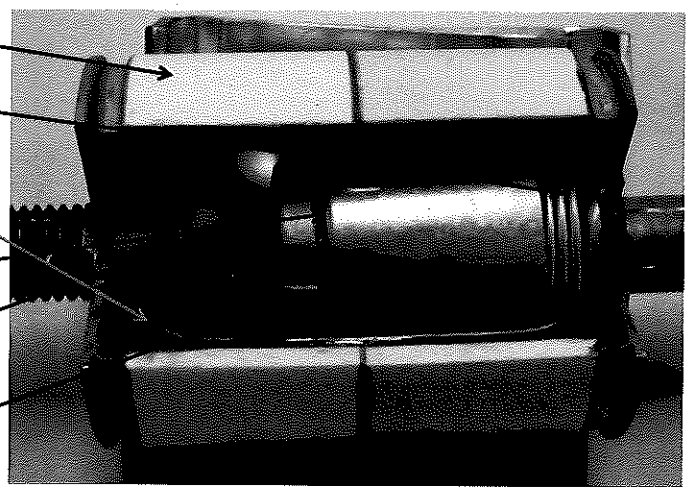
Barriers – Secondary Disconnects

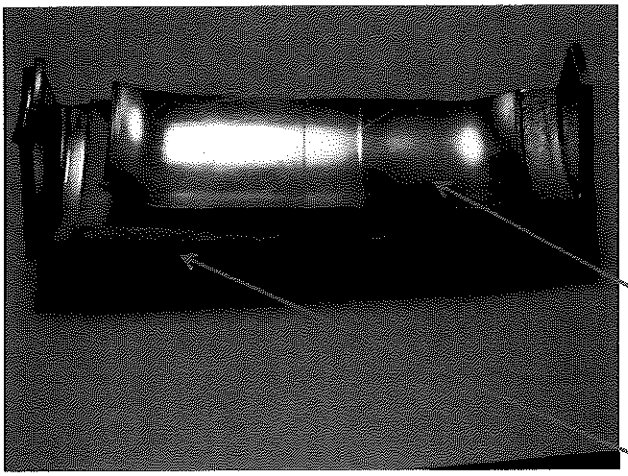
VCB Barrier



Barrier

Vacuum Bottle

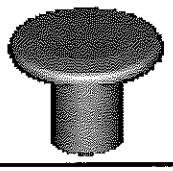
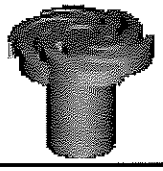
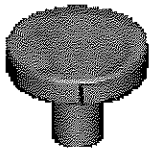




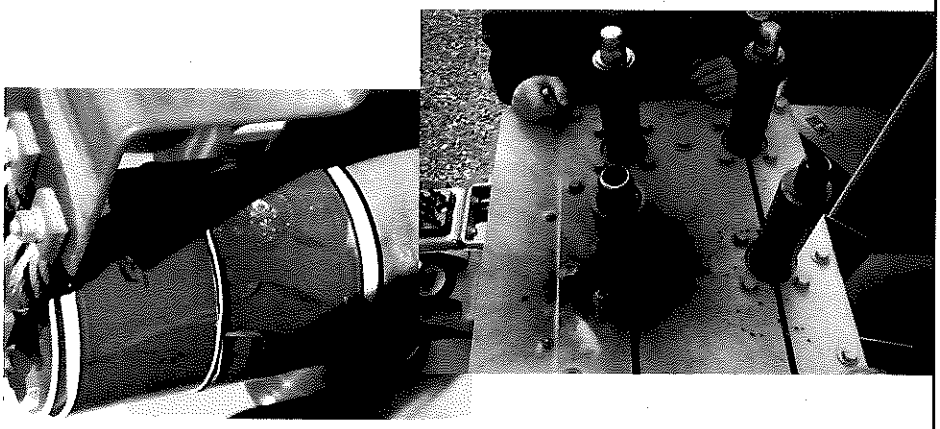
Vapor condensing shield

Hardened ceramic and stainless steel end caps

Types of Vacuum Breaker Contacts

Contact Structure	Flat Contact	Spiral Contact	Axial Magnetic Field Contact
Figure			
Application	VCB (General) EBS Contactor	VCB (Large capacity)	VCB (More interruption) VCB (Low surge)
Materials	Cu-Cr alloy Ag-WC alloy Cu-W alloy	Cu-Cr alloy	Cu-Cr alloy Ag-WC alloy

Vacuum Bottle Failure



ANSI/NETA MTS-2007

7.6.1.3 Circuit Breakers, Air, Medium-Voltage

7.6.1.4 Circuit Breakers, Vacuum, Medium-Voltage

1. Visual and Mechanical Inspection

1. Inspect physical and mechanical condition.
2. Inspect anchorage, alignment, and grounding.
3. Verify that all maintenance devices are available for servicing and operating the breaker.
4. Prior to cleaning the unit, perform as-found tests, if required.
5. Clean the unit.

6. Inspect arc chutes.
7. Inspect moving and stationary contacts for condition, wear, and alignment.
8. If recommended by manufacturer, slow close/open breaker and check for binding, friction, contact alignment, contact sequence, and penetration.
9. Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer's published data.

10. Inspect bolted electrical connections for high resistance using one of the following methods:
    1. Use of a low-resistance ohmmeter in accordance with Section 7.6.1.3.2.
    2. Verify tightness of accessible bolted electrical connections by calibrated torque-wrench method in accordance with manufacturer's published data or Table 100.12.
    3. Perform a thermographic survey in accordance with Section 9.

11. Verify cell fit and element alignment.
12. Verify racking mechanism operation.
13. Inspect puffer operation.
14. Use appropriate lubrication on moving current-carrying parts and on moving and sliding surfaces.
*15. Perform time-travel analysis.
16. Perform as-left tests.
17. Record as-found and as-left operation-counter readings

2. Electrical Tests

1. Perform resistance measurements through bolted connections with a low-resistance ohmmeter, if applicable. See Section 7.6.1.3.1.
2. Perform insulation-resistance tests for one minute on each pole, phase-to-phase and phase-to-ground with the circuit breaker closed, and across each open pole. Apply voltage in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.1.

*3. Perform insulation-resistance tests on all control wiring with respect to ground. The applied potential shall be 500 volts dc for 300-volt rated cable and 1000 volts dc for 600-volt rated cable. Test duration shall be one minute. For units with solid-state components or control devices that cannot tolerate the applied voltage, follow manufacturer's recommendation.
4. Perform a contact/pole-resistance test.

5. With the breaker in a test position, perform the following tests:

   1. Trip and close breaker with the control switch.

   2. Trip breaker by operating each of its protective relays.

   3. Verify mechanism charge, trip-free, and antipump functions.

*6. Perform minimum pickup voltage tests on trip and close coils in accordance with Table 100.20.

*7. Perform power-factor or dissipation-factor tests with breaker in both the open and closed positions.

*8. Perform power-factor or dissipation-factor test on each bushing.

*9. Perform an overpotential test on each phase with the circuit breaker closed and the poles not under test grounded. Test voltage should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.19.

10. Verify blowout coil circuit continuity.

11. Verify operation of heaters, if applicable.

*12. Test instrument transformers in accordance with Section 7.10.

3.1 Test Values – Visual & Mechanical

1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value. (7.6.1.3.1.10.1)
2. Bolt-torque levels should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.12. (7.6.1.3.1.10.2)

3. Results of the thermographic survey shall be in accordance with Section 9. (7.6.1.3.1.10.3)
4. Compare travel and velocity values to manufacturer's published data and previous test data. (7.6.1.3.1.15)

3.2 Test Values - Electrical

1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value.
2. Circuit breaker insulation resistance should be in accordance with Table 100.1.

3. Insulation-resistance values of circuit breakers should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.1. Values of insulation resistance less than this table or manufacturer's recommendations should be investigated.
4. Microhm or dc millivolt drop values shall not exceed the high levels of the normal range as indicated in the manufacturer's published data. If manufacturer's data is not available, investigate values that deviate from adjacent poles or similar breakers by more than 50 percent of the lowest value.

5. Breaker mechanism charge, close, open, trip, trip-free, and antipump features shall function as designed.
6. Minimum pickup for trip and close coils shall be in accordance with manufacturer's published data. In the absence of manufacturer's data, refer to Table 100.20.
7. Power-factor or dissipation-factor values shall be compared with previous test results of similar breakers or manufacturer's published data.

8. Power-factor or dissipation-factor and capacitance values should be within ten percent of nameplate rating for bushings. Hot collar tests are evaluated on a milliampere/milliwatt loss basis, and the results should be compared to values of similar bushings.
9. If no evidence of distress or insulation failure is observed by the end of the total time of voltage application during the overpotential test, the circuit breaker is considered to have passed the test.

10. The blowout coil circuit should exhibit continuity.
11. Heaters should be operational.
12. The results of instrument transformer tests shall be in accordance with Section 7.10.

7.6.1.3 Vacuum Circuit Breakers

2. Electrical Tests

9. Perform a vacuum bottle integrity (overpotential) test across each vacuum bottle with the breaker in the open position in strict accordance with manufacturer's published data. **Do not exceed maximum voltage stipulated for this test.** Provide adequate barriers and protection against x-radiation during this test. Do not perform this test unless the contact displacement of each interrupter is within manufacturer's tolerance. (Be aware that some dc high-potential test sets are half-wave rectified and may produce peak voltages in excess of the breaker manufacturer's recommended maximum.)

3.2 Test Values - Electrical

9. If no evidence of distress or insulation failure is observed by the end of the total time of voltage application during the vacuum bottle integrity test, the test specimen is considered to have passed the test.

Testing Medium-Voltage Air and Vacuum Circuit Breakers

Common Tests

- Insulation resistance (wiring)
- Insulation resistance (pole unit)
- Contact resistance
- DC overpotential
- Insulation power factor
  - Pole units
  - Arc chutes / vacuum bottle
- Vacuum bottle integrity
- Safety megohmmeter check

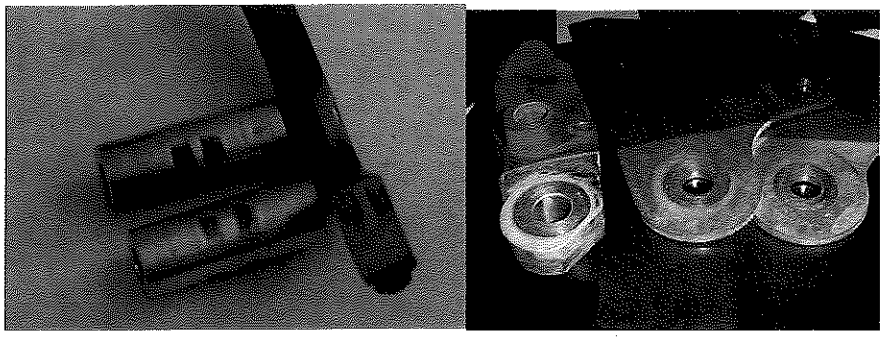
Insulation Resistance

Table 100.1

Nominal Rating of Equipment (Volts)	Minimum Test Voltage (DC)	Recommended Minimum Insulation Resistance (Megohms)
250	500	25
600	1,000	100
1,000	1,000	100
2,500	1,000	500
5,000	2,500	1,000
8,000	2,500	2,000
15,000	2,500	5,000
25,000	5,000	20,000
34,500 and above	15,000	100,000

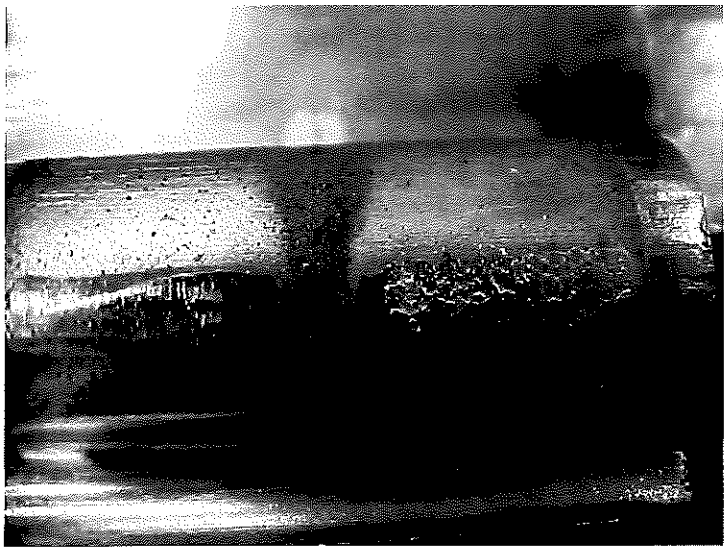
Contact Resistance

Causes of Increased Resistance

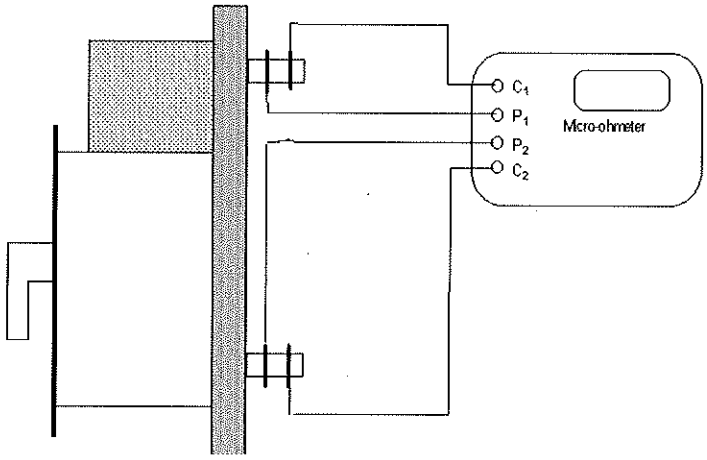


POWER TEST 2010 A NETA EVENT

Damage Caused By Lack Of Lubrication



Contact Resistance



DC Overpotential

DC Overpotential

- ANSI/NETA MTS-2007 Table 100.2
- 5kV insulation 20kV dc
- 8.25kV insulation 37kV dc
- 15kV insulation 37kV dc

ANSI/NETA MTS-2007 Table 100.2

Type of Switchgear	Rated Maximum Voltage (kV) (rms)	Maximum Test Voltage (kV)	
		AC	DC
Low-Voltage Power Circuit Breaker Switchgear	.254/.508/.635	1.6	2.3
Metal-Clad Switchgear	4.76	14	20
	8.25	27	37
	15.0	27	37
	27.0	45	a
	38.0	60	a
Station-Type Cubicle Switchgear	15.5	37	a
	38.0	60	a
	72.5	120	a
Metal-Enclosed Interrupter Switchgear	4.76	14	20
	8.25	19	27
	15.0	27	37
	27	45	a
	38.0	60	a

DC Overpotential - All Voltages

Circuit Breaker Open	# Tests	Insulation Tested
Line Stab to Load Stab	3	Arc Chute or Vacuum Bottle
Circuit Breaker Closed	**# Tests**	**Insulation Tested**
Line Stab to Ground	3	Backboard – Stab to Ground
Phase to Phase	3	Backboard – Stab to Stab

Results Interpretation

- ANSI/NETA MTS-2007
  - 50% Rule
- Shermco Circuit Breaker Shop
- MV Breakers
  - 0 to 80μΩ – Excellent
  - >250μΩ – Trouble

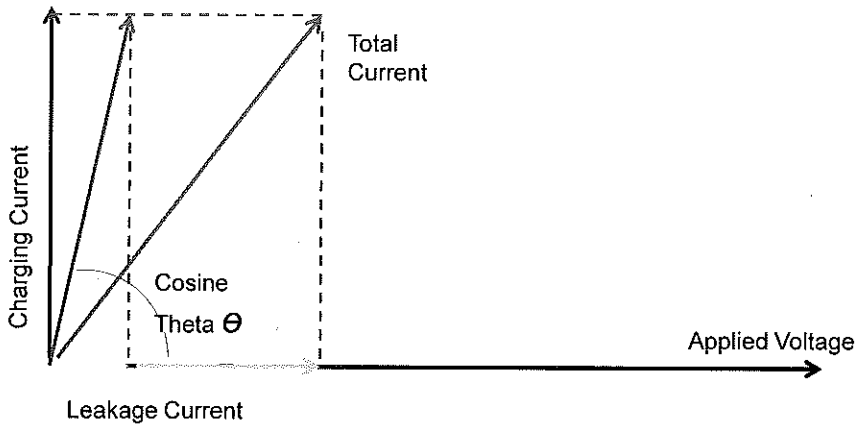
Insulation Power Factor

Air & Vacuum Medium-Voltage

Power Factor Basics

- Power factor is cosine of the dielectric watts-loss and the total current
- As leakage increases, angle between voltage and total current decreases
  - Perfect insulation = 0% pf — Cosine of 90^0
  - Short circuit = 100% pf — Cosine of 0^0
  - All insulation has some leakage
- 1% pf typical for medium-voltage oil-filled equipment — Cosine of 89.427^0

Power Factor Basics



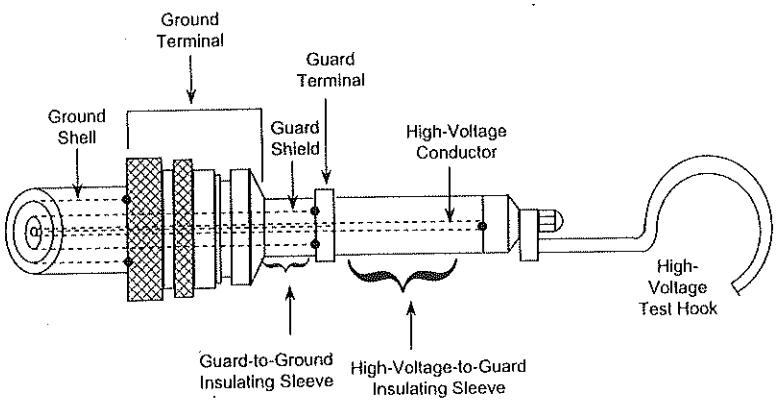
Power Factor Basics

- %pf = $\frac{\text{WATTS ABSORBED BY INSULATION}}{\text{VOLTAGE X CHARGING CURRENT}}$ X 100

10kV %pf = $\frac{\text{watts x 10}}{\text{mA}}$

- Correct test results to 20^0C
- Evaluation based on:
  - Comparison to like units
  - Factory recommendations
  - Doble Engineering™ Test Data Sheets
- Dissipation factor and power factor are essentially equal from 0% TO 10% pf

High-Voltage Hook

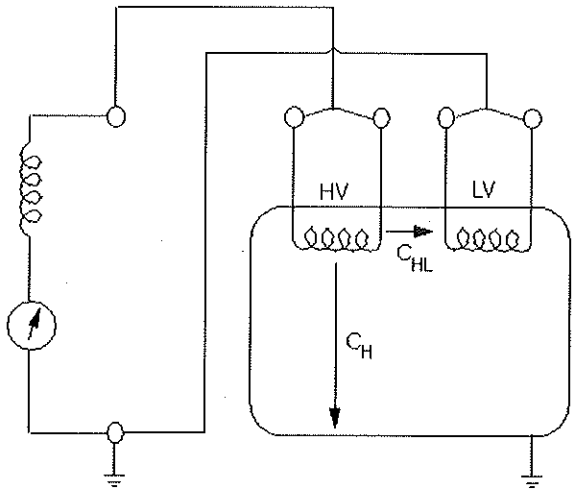


Keep hook away from ground – about 90 degrees, if possible

3 Tests

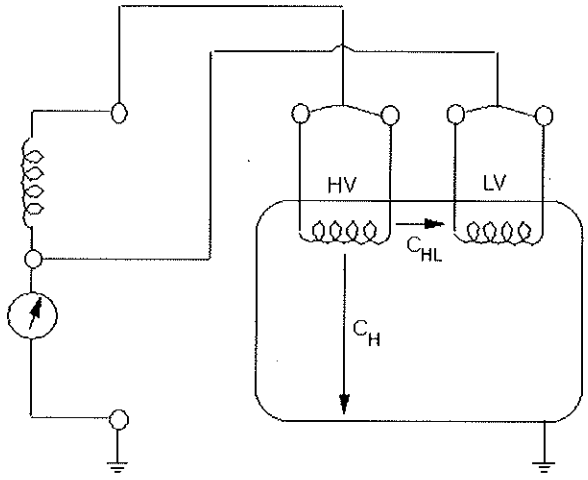
- GST-L-Ground
  - Low-voltage return lead connected to ground
- GST-L-Guard
  - Low-voltage return lead guarded
- UST
  - Ground return guarded

GST-L-Ground



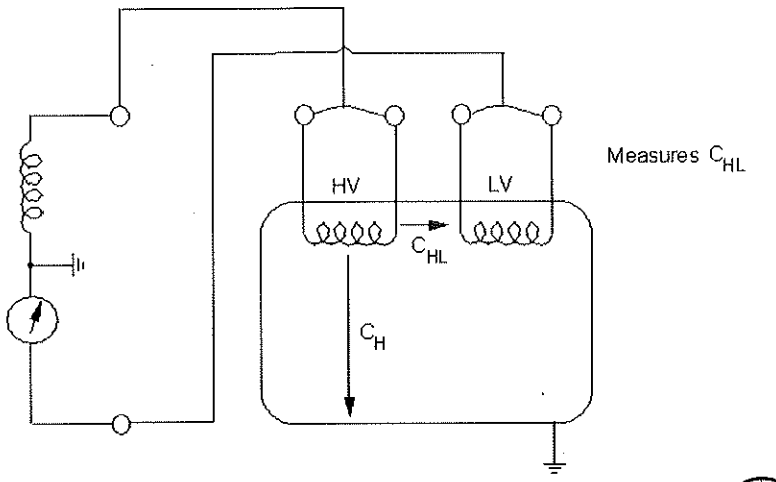
Measures $C_{HL}+C_H$

GST-L-Guard



Measures C_H

Ungrounded-Specimen (UST)



Power Factor

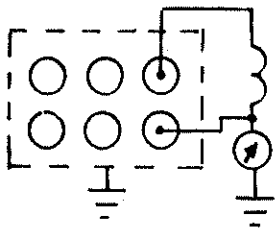
- If current is less than 200µA
  - Do not use %pf
  - Use watts loss
- % Humidity 80% or less
- Ground and short all bushings

Power Factor

- 2 connections
  - Guarded (tests 1 – 6)
  - UST (tests 7 – 9)
- Guard is done on all bushings (BKR open)
  - Mostly tests bushings
- UST is done on each phase unit (BKR open)
  - Mostly tests interrupter
- No rule-of-thumb values available

Air CB Power Factor

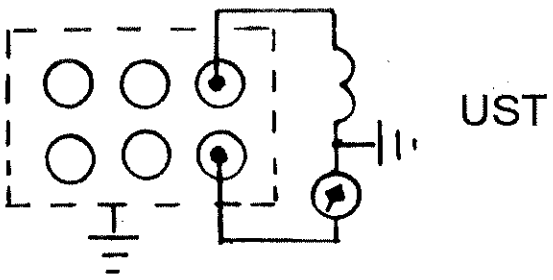
- GST-L-Guard
  - Pole unit to ground
  - Operating rod
  - Puffer unit
  - Phase barrier



GST-L-GUARD

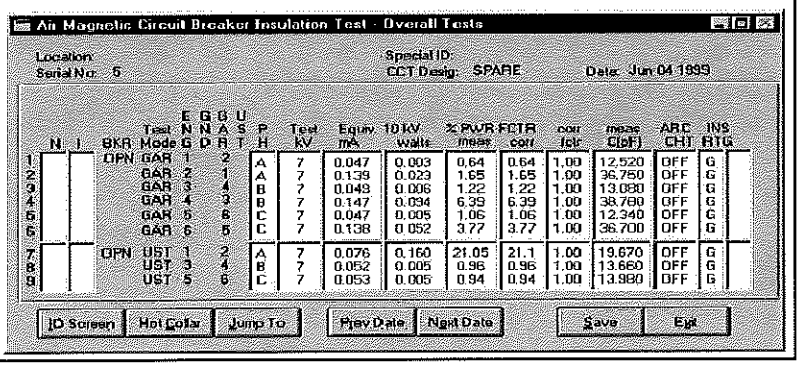
Air CB Power Factor

- UST
  - Arc chute
  - Phase barrier



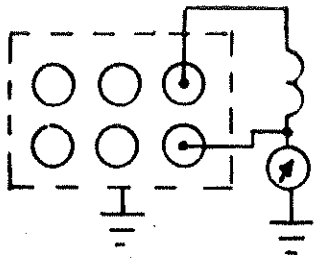
Air-Magnetic Breakers

- Evaluate watts-loss
- GE Magne-Blast SAL
  - Up to 5% pf ok
  - 10% do not energize



Vacuum CB Power Factor

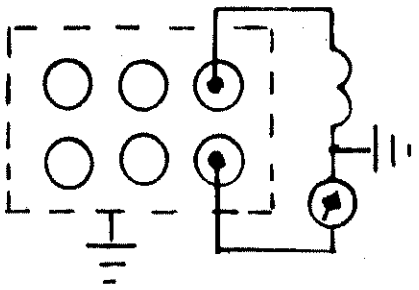
- GST-L-Guard
  - Pole unit to ground
  - Operating rod
  - Vacuum bottle



GST-L-GUARD

Vacuum CB Power Factor

- UST
  - Across bottle
  - Vacuum bottles should have 0 or near 0 losses
  - High losses indicate bad bottle or contamination



UST

Example Test Results Vacuum Breaker

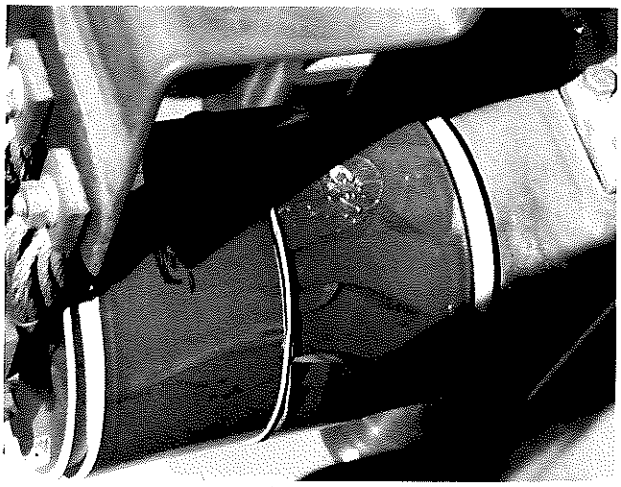
Test Mode	Test Connections	Ph	Test kV	mA	Watts
GND	ENG 1 FLT 2	A	10	0.242	0.027
GND	ENG 2 FLT 1	A	10	0.262	0.032
GND	ENG 3 FLT 4	B	10	0.241	0.032
GND	ENG 4 FLT 3	B	10	0.252	0.030
GND	ENG 5 FLT 6	C	10	0.241	0.027
GND	ENG 6 FLT 5	C	10	0.254	0.026
UST	ENG 1 UST 2	A	10	0.047	0.001
UST	ENG 3 UST 4	B	10	0.047	0
UST	ENG 5 UST 6	C	10	0.047	0

Vacuum Bottle Integrity Test

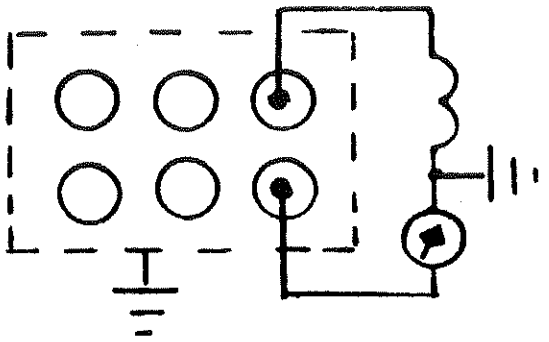
Vacuum Bottle Integrity Test

- Use ac hipot
- Can use dc hipot if it doesn't produce voltage spikes
  - HIPOTRONICS 860PL
  - HIPOTRONICS 880PL
  - HIPOTRONICS 7BT60A
  - BIDDLE 222060
  - GE 282A2610P001
- The above use full-bridge rectifiers

Damage to Vacuum Bottle



Vacuum Bottle Integrity Test



Recommended Test Voltages

• GE	15kV	36kV ac	40kV dc
• West/CH	15kV	27kV ac	40kV dc
• Siemens	15kV	37.5kV ac	53kV dc
	28kV	45kV ac	63.6kV dc

Vacuum Bottle Integrity Test

Warning:

Vacuum bottles emit x-rays if they fail. Keep the breaker between you and the bottle and stay as far away as the leads will allow.

The amount of x-radiation is low.

Safety Megohmmeter Check

Safety Megger Check

- Last test before inserting breaker
- Any time breaker is out of the cubicle
- Apply 500V DC
- Should see no reflection of the meter
- Shows any shorts inside the breaker
  - Washers, tools, parts, etc.

End Of Part 1