Evaluation Tools for Electric Motor Testing

Logic Diagrams

Technical Report

Evaluation Tools for Electric Motor Testing

Logic Diagrams

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Troubleshooting Guideline for Electric Motors: Decision Logic Trees, EPRI, Palo Alto, CA: 2001. 1004003.

REPORT SUMMARY

The Advanced Electric Motor Predictive Maintenance Group foresaw the need to develop a living document to integrate logic diagrams and appendices associated with common motor problems and failures. These logic diagrams and appendices are intended for use as a reference by engineers and technicians with a minimum of specific motor troubleshooting knowledge.

Background

Over the past several years, the power industry has experienced a measured decline in knowledge in the area of motor problem troubleshooting—largely due to industry downsizing and retirement. EPRI sponsored development of these *Evaluation Tools for Electric Motor Testing: Logic Diagrams* to ensure an appropriate level of guidance for new employees. Assisting with guideline development were the following companies: Ameren, City Public Service of San Antonio, Constellation Energy, Dynegy, Exelon, Kansas City Power & Light, Niagara Mohawk, Public Service Electric & Gas, and TXU.

Objective

To develop a system of integrated logic diagrams and appendices for troubleshooting common electric motor problems and failures.

Approach

Utilities developed these logic diagrams utilizing their experience and knowledge. They received input from their in-house predictive maintenance teams. The scope of the project was coordinated with the NMAC Large Electric Motor User Group (LEMUG).

Results

Each logic diagram in the troubleshooting guideline begins with a general observation indicating a possible problem or task, and develops solutions in the direction most likely taken by a knowledgeable and skilled expert. Following are key electric motor areas covered in the logic diagrams:

- Winding resistance to ground
- Polarization index testing
- Capacitance to ground test

- Motor current analysis for rotor bar failure
- Dissipation/power factor test
- Dissipation/power factor tip-up test
- Surge test
- Description for oil analysis
- General lubrication analysis
- Discoloration of housing or indication of heat
- Slow start (excessive acceleration time)
- Over temperature alarm
- White powder in stator

Accompanying the logic diagrams are appendices containing general information about the suggested testing along with references to specific testing procedures and technical reports. The appendices address 1) the single phase rotor test, 2) electromagnetic interference (EMI) diagnostics, 3) what to do when when a motor is full of dirt, oil, or a combination of the two; 4) the electromagnetic core imprefection detector (EL-CID)/loop test, 5) loose motor winding end turns/bracing, 6) loose stator core wedge, 7) growler testing, 8) motor winding greasing, and 9) thermography scan of electric motors.

EPRI Perspective

EPRI intends for these logic diagrams to be a living documentation of troubleshooting knowledge that can be easily updated to incorporate additional technologies and problem indications as they arise. This report complements NMAC Troubleshooting of Electric Motors, (EPRI report 1000968), which deals with operating symptoms. Related EPRI reports include the Electric Power Plant Reference Series (EL-5036-V6) and the Electric Motor Predictive Maintenance Program (TR-108773-V1-2).

Keywords

Troubleshooting
Electric motors
Predictive maintenance

Background

Over the past several years, the power industry has experienced a measured decline in knowledge in the area of motor problem troubleshooting—largely due to industry downsizing and retirement. EPRI sponsored development of these Evaluation Tools for Electric Motor Testing: Logic Diagrams to ensure an appropriate level of guidance for new employees. Assisting with guideline development were the following companies: Ameren, City Public Service of San Antonio, Constellation Energy, Dynegy, Exelon, Kansas City Power & Light, Niagara Mohawk, Public Service Electric & Gas, and TXU.

INTRODUCTION

Over the past several years, the power industry has experienced a measured decline in knowledge in the area of motor problem trouble-shooting. It is believed that the major cause for this gradual loss of experience is due to retirement and industry downsizing. The AEMPM Group has seen the need to develop a system of integrated logic diagrams associated with common motor problems and failures, in an effort to capture and organize this information for future use.

These logic diagrams were developed by the Utilities utilizing their expertise and knowledge. These logic diagrams are intended to be a general guide and quick reference for use by engineers and technicians possessing a minimum of specific motor trouble-shooting knowledge. In each case the logic diagram starts with a general observation indicating a possible problem or task, and develops in the direction most likely taken by a knowledgeable and skilled expert. The logic diagrams are accompanied with general information about the suggested testing along with locations for finding specific testing procedures and additional technical information.

These logic diagrams are intended to be a living documentation of information that can be easily updated to incorporate additional technologies and problem indications as they are developed and identified in the future.

Following the logic diagrams are appendices. Appendices are documents that did not lend themselves to the discipline of specific steps, but nevertheless could generally be helpful to those interested in the subject matter and the knowledge it contains.

ABSTRACT

The AEMPM Group foresaw the need to develop a living document to integrate logic diagrams and appendices associated with the common motor problems and failures. These logic diagrams are intended for use as a reference or for use by those with minimal motor trouble-shooting knowledge.

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PRELIMINARY TROUBLESHOOTING GUIDELINE FOR ELECTRIC MOTORS: DECISION LOGIC TREES

Logic Diagram 1-Winding Resistance to Ground

General Information

Winding insulation resistance to ground testing provides information on the integrity of the insulation system between the energized conductors and ground. This Insulation Resistance (IR) testing can provide direct information on failed insulation (short) or can indicate a condition of insulation weakness. Weakness is typically indicated by low resistance readings or by comparison from previous readings taken under similar conditions (trending data.)

Low resistance readings are most often caused by contamination. This contamination can be a result of moisture or other conductive foreign matter. It is very important to insure that the insulation system under test is above the dew point temperature during testing. This insures that moisture is not condensing on the insulation surface.

Temperature of the insulation system can also affect resistance readings. It is very important to compensate all the resistance readings for temperature. This process is explained in detail in IEEE Standard P43 Section 6.3 “Effect of Temperature”. However, as a general rule, insulation resistance readings reduce by half for every ten degrees C. This approximation can only be used when the insulation temperature is near 40C. When the insulation is significantly different from 40C the formula provided in the above standard should be used.

The IR testing is done using DC voltage. Standard tester voltage ranges vary from 500 vdc to 10,000 vdc with most testers using 500 vdc. The voltage range used for testing should never be higher than the normal peak ac operating voltage of the insulating system under test. The generally accepted absolute minimum resistance reading for energizing a motor is one megohm plus one megohm per Kv operating voltage.

Diagram Details:

Box 1-Resistance differences greater than three percent (3%) are most likely caused by loose connections (either on the supply cable or at the motor). However, this condition can also be a result of broken or disconnected windings in units that have multiple parallel windings in their stator. Loose connections can cause excessive heating to occur at the connection point. This condition will also cause an imbalance of the phase current and will result in excessive motor heating during operation.

Box 2-If the differences in resistance readings are greater than 3%, the cable and motor lead connections should be checked and tightened if required and the test run again. If the resistance difference does not drop within the 3% window, the motor should be isolated from the cables and the motor tested again. This will indicate if the motor or the cable is the problem.

Box 3-All connections should be tight and in good condition.

Box 4-This is the resistance to ground test that is used to identify if the ground insulation is in good condition and is described in detail in IEEE Standard 43.

Box 5-This box indicates that the winding has just failed the winding to ground resistance testing and the problem needs to be addressed using the Winding Resistance to Ground Logic. Once this problem is resolved, the process should be continued following the logic for a successful test (Pass) from Box 4.

Box 6-Box number six indicates that the motor leads and supply cables were not found loose and the most likely cause for the imbalance is shorted turns in the windings. Winding surge testing will need to be performed to confirm or eliminate shorted turns as the cause for the problem. Winding surge testing is very specialized and is typically not done in the field. If a field test is done and the motor is not identified as having shorted turns, the motor should be monitored for possible signs of overheating conditions.

Turn insulation shorting will cause local heating of the shorted windings. It is possible to visually inspect the stator windings and identify signs of overheated insulation. Additional information on turn insulation is described in the EPRI Power Plant Electrical Reference Series Volume 16 Section 5.3.1.1.

Box 8-This oval indicates an option for monitoring the motor and continuing to run the machine based on the successful surge test. However, at this point, it is recognized that there is a good chance the motor is developing an electrical problem and additional resources should be consulted (local motor experts) to assess the situation and risks.

Box 9-This box indicates that the motor failed the surge test. The motor will require repair before it is returned safely to service. A complete rewind of the stator is the normal solution. However, it may be possible to cut out the failed turn or coil and continue operation. This process is described in "Temporary Operation of Motors With Cut-Out Coils" EPRI-4059 Project 2330-1 Final Report June 1985 and in "Synchronous Machine Operation with Cut-Out Coils" EPRI-4983 Project 2330-1 Final Report January 1987.

Box 10-This is the final step of returning the machine to service with additional monitoring after all the testing is completed or after the winding is repaired.

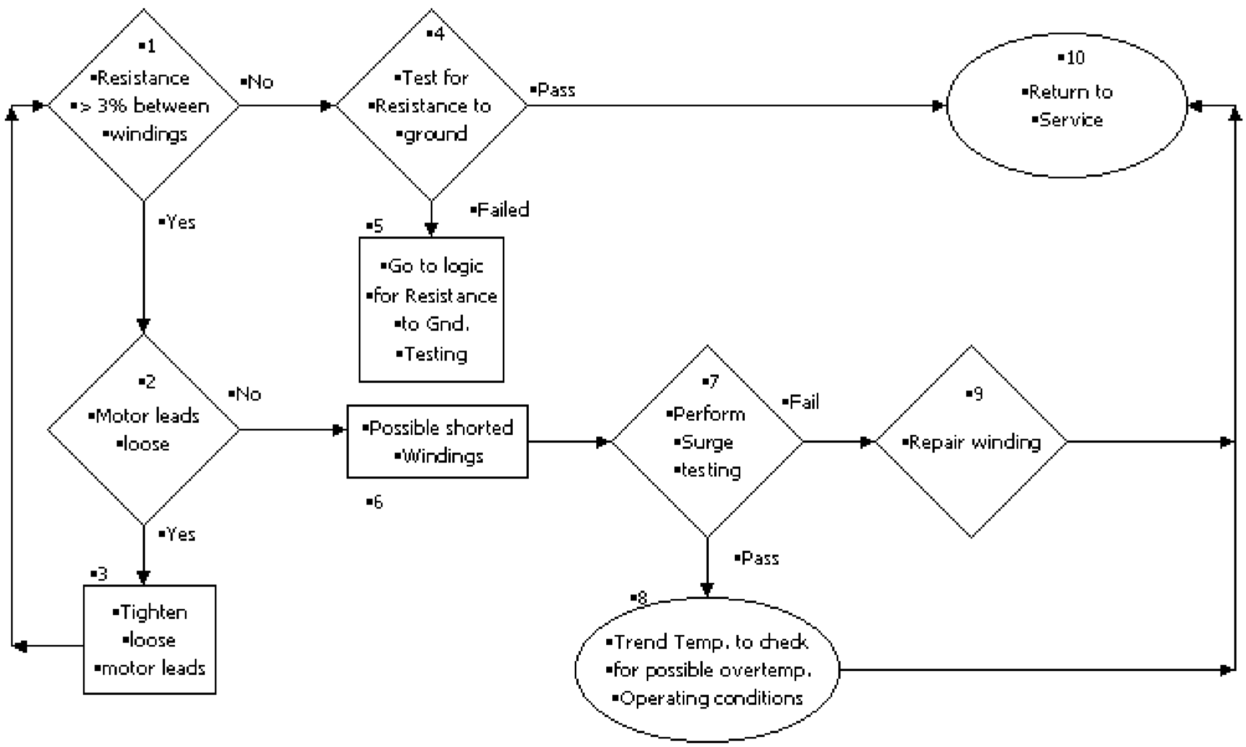

Figure 1-1
Winding Resistance to Ground

Logic Diagram 2-Polarization Index Testing

General Information

The Polarization Index (PI) test is almost always combined with the IR testing. The PI test provides additional information about the insulation system that is not available from the IR Test alone. The PI test is defined as the ratio of the ten (10) minute IR test reading divided by the one (1) minute IR reading. Ratios of 2 or more are generally considered being acceptable. Since the PI test is a ratio of readings, temperature compensation is not necessary. However, testing should still be done with the insulation system above the dew point temperature.

It should be noted that some of the new epoxy insulation systems could provide one (1) minute IR readings that are extremely high, making it difficult to obtain a ratio of 2. If the IR test measurements are in excess of 5,000 megohms, the PI test can be disregarded.

A comprehensive presentation of the procedure and theory of this testing is covered in IEEE Standard P43, “IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery” and ASTM D 257-93, “Standard Test Methods of DC Resistance or Conductance of Insulating Materials”.

Diagram Details:

Box 1-Insulation Resistance testing of motors are typically done from the supply breaker location with the breaker racked out of service. This method includes the motor and the supply cable in the tested circuit. If the testing is being done at the motor leads, go to block number 2 after reading the remainder of the following block I information.

Since most motors are wye connected, only one phase lead needs to be checked. It should be also noted that most motors have the neutral connection internal to the motor and it is not grounded. If a ground is indicated check to see that the motor neutral is not wired to ground.

When the motor neutral is not accessible and all three phases are measured together, the resistance reading indicated will normally be approximately three times less than if each phase were tested individually. However, since all three phases are in parallel, it is possible to have one phase much lower than the other two phases. Under this situation, the reading could not be considered to be three times greater than its single-phase equivalent.

The IR testing provides a good one (1) minute reading, go directly to the PI testing (Box 5) taking and recording resistance readings every minute up to the ten (10) minutes required. If the one (1) minute IR reading is low or zero, there is a problem and it will be necessary to isolate the motor from the supply cables (Box 2).

Box 2-The IR test indicated a bad reading from the supply breaker. The next logical step is to isolate the supply cables from the motor circuit and test the motor again.

Box 3-If the motor was successfully operated in the past 12 to 24 hours, it is likely that its insulation has not suffered any substantial degrading from the time it was last operated. It is also likely that it is still warm and above the dew point temperature.

Box 4-If the motor has not been operated recently and the motor heaters are not keeping the motor temperature above the dew point, it is a good chance that the winding insulation is wet and needs to be dread out before the test can be completed.

Box 5-If the motor successfully passes the one (1) minute IR testing, one should continue taking IR readings each minute for the next nine (9) minutes. If the ratio of the ten (10) minute reading divided by the one (1) minute reading is greater than two (2), the motor has successfully passed the IR and PI test indicating a high probability of good ground insulation condition.

A PI ratio of less than two (2) may not be an indication of bad insulation. If the insulation is of the modern epoxy and has a very high one (1) minute IR reading (greater than 5,000 megohms), the insulation can be considered to be in good condition. Older motors made with hydroscopic insulation systems, will provide good PI ratios when the windings are warm but will pick up moisture from the air very quickly one the motor is taken out of service resulting in low PI ratios. Additional cleaning and drying of the motor may be necessary before testing again.

Box 6-Failing the IR test with the supply cables in the circuit often is a result of one or more bad supply cable. Many times supply cables are routed through manholes where they can become contaminated with water. The supply cables should be disconnected at the motor and the motor tested again at the motor leads.

Box 7-A failed IR test under these conditions most likely is a result of direct exposure to moisture or some other contaminant or a result of damage due to some outside force that occurred since the motor was last operated. Check to see if anyone had been working in the area where damage or exposure to contaminants may have occurred.

Box 8-Is the IR reading at or near zero resistance? If it is, there is a good chance that the motor leads are shorted at the lead box. This condition should be visually check and corrective action taken if necessary. If the IR reading is greater than 1% of the minimum, it is likely that the motor has been contaminated with moisture and should be dried.

Box 9-Since the motor has passed the IR testing after the cables were disconnected, it indicates that there is one or more bad supply cables. If the cables are run through any manholes, these manholes may be full of water. It is possible to improve cable IR readings by removing the water from manholes and using heat to dry the weak cables. The heat is normally applied using a welder to pass DC current (less than cable rated AC current) down the conductor and back on one of the remaining conductors. This should only be done on a temporary basis and the weak cable should be replaced as soon as practical.

Box 10-There are several methods presently in use to dry motor stator windings. In many cases the contamination is only a result of surface moisture. Using only the existing motor heaters can sometimes drive off this moisture. In cases where motor heaters were not originally installed, it is possible to place a small space heater or drop lights under open motors to provide heat. It is also necessary to maintain a circulation of air around the motor during drying. These methods will normally require 24 to 36 hours to show signs of improvement in readings.

If the windings have more than surface moisture or if schedule is a major concern, direct heat or baking will be required. It is possible to accelerate the drying time of an AC motor by passing a DC current through its stator windings. Care should be taken to insure that the temperature of the motor insulation does not exceed $85^{o}C$. Motors that have high moisture contamination will require removal and oven baking drying.

Box 11-There have been occasions where contamination has been found in the motor lead box or that the motor lead has shorted to ground. This should be check and if a problem is found, determination if local repair can be made.

Box 12-Once a corrective action has been taken by drying, cleaning, or repairing the motor; the motor should be subjected to a second IR test. If the motor passes the test the PI test can be started. In the event the motor fails the IR testing again, additional corrective action may be necessary.

Box 13-The decision to make a local repair will depend on several factors that are beyond the scope of this analysis. This decision can vary widely depending on the experience of the local workers, the value of the machine and the cost of the repairs.

Box 14-Once the motor has passed the IR and PI testing it should be considered ready for service. There may also be times where the decision is made to return the motor to service even though it did not pass the PI testing. This can occur due to extremely high one (1) minute resistance readings from new epoxy insulating systems or in cases where the IR testing indicates that the resistance is above minimum and management determines that the risk of a motor failure upon energization is off set by other circumstances.

If the measured resistance is greater than one hundred times the minimum acceptable limit, there is a minimum risk associated with insulation failure upon energization of the motor. This risk increases significantly as the measured resistance approaches the minimum acceptable limit value.

Box 15-After the motor is cleaned or a local drying process has taken place and the IR or PI testing is performed again, a determination needs to be made to address if the process is having the desired effect. In many cases it is necessary to complete several cycles of drying/cleaning before acceptable reads are reached on older equipment or the decision is to send the motor out for repair or baking.

Box 16-Once it is determined that the repair cannot be made at the plant or that the attempts to clean or dry the windings are unsuccessful it becomes time to send the motor out to a qualified repair shop.

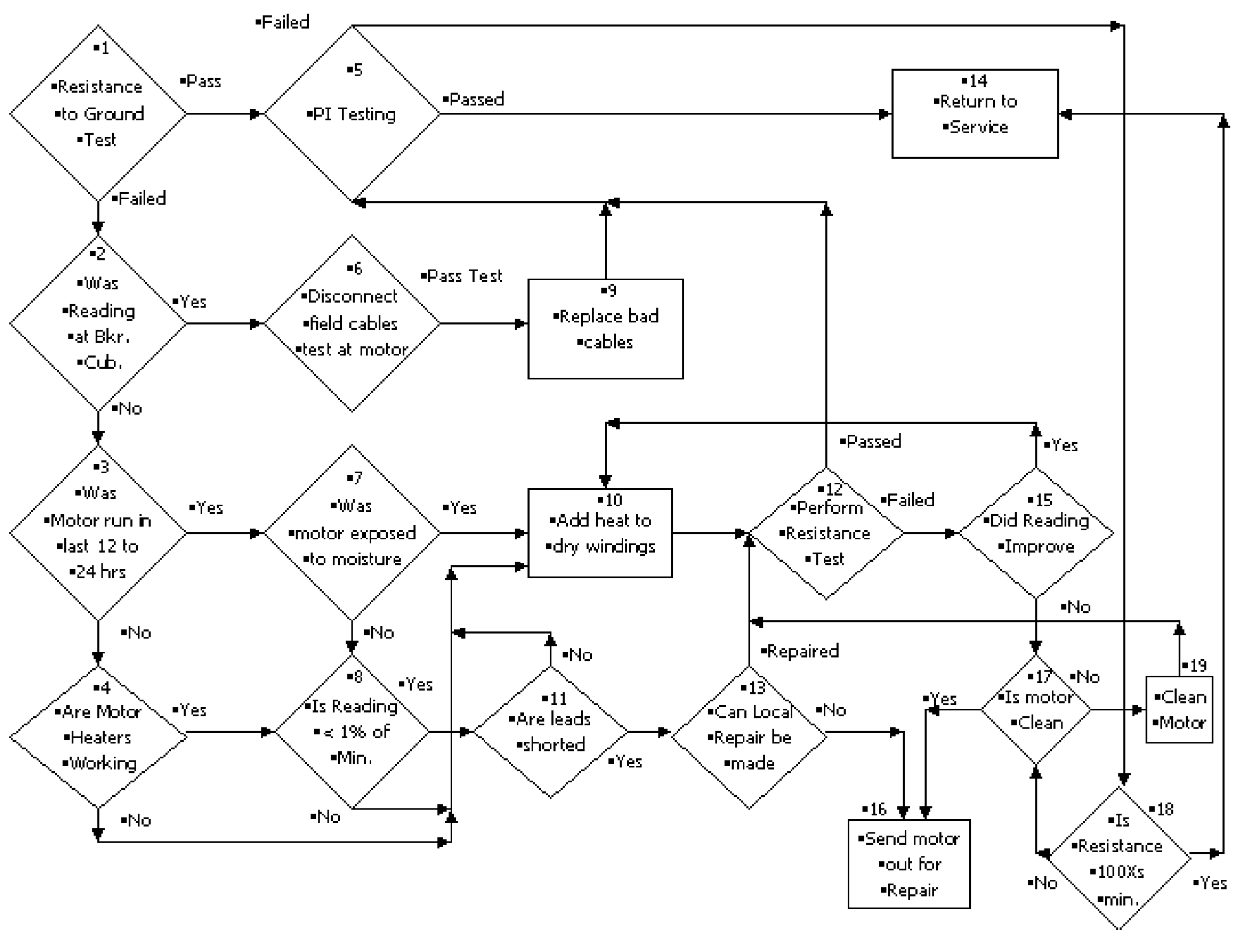

Figure 1-2
Polarization Index Test

Logic Diagram 3-Capacitance to Ground Test

General Information

Capacitance indicates the amount of material buildup on the windings in AC & DC motors. Capacitance levels are influenced by various factors so a single reading is not feasible. Trending a motor's reading over time or comparing the readings of similar motors in the same environment provides the most reliable information.

Box 1-Reason to take trending data on AC/DC motors is to determine the cleanliness of the motor.

Box 2-The first thing that needs to be done is to take baseline data of the motor.

Box 3-The next test after a period of time will determine the cleanliness of the motor. Has the capacitance to ground increased since the last test-YES or NO?

Box 4-NO-Less than 10% change from baseline and reading is low compared to similar motors.

Box 5-Result of the test is motor is OK for service and should be monitored on a normal schedule.

Box 6-YES-The motor has an upward trend showing a 10%-100% change from baseline and the reading is low compared to similar motors.

Box 7-YES-Result of the test is to monitor more often.

Box 8-NO-The motor has an upward trend showing a 100%-200% change from the baseline or is in midrange compared to similar motors.

Box 9-YES-Result of the test is to schedule cleaning; monitor more often to better define trends.

Box 10-NO-The motor has an upward or unstable trend or reading of greater than 200% change from baseline or is high compared to other similar motors.

Box 11-Result of the test is to correlate with the resistance to ground; perform insulation system physical inspection.

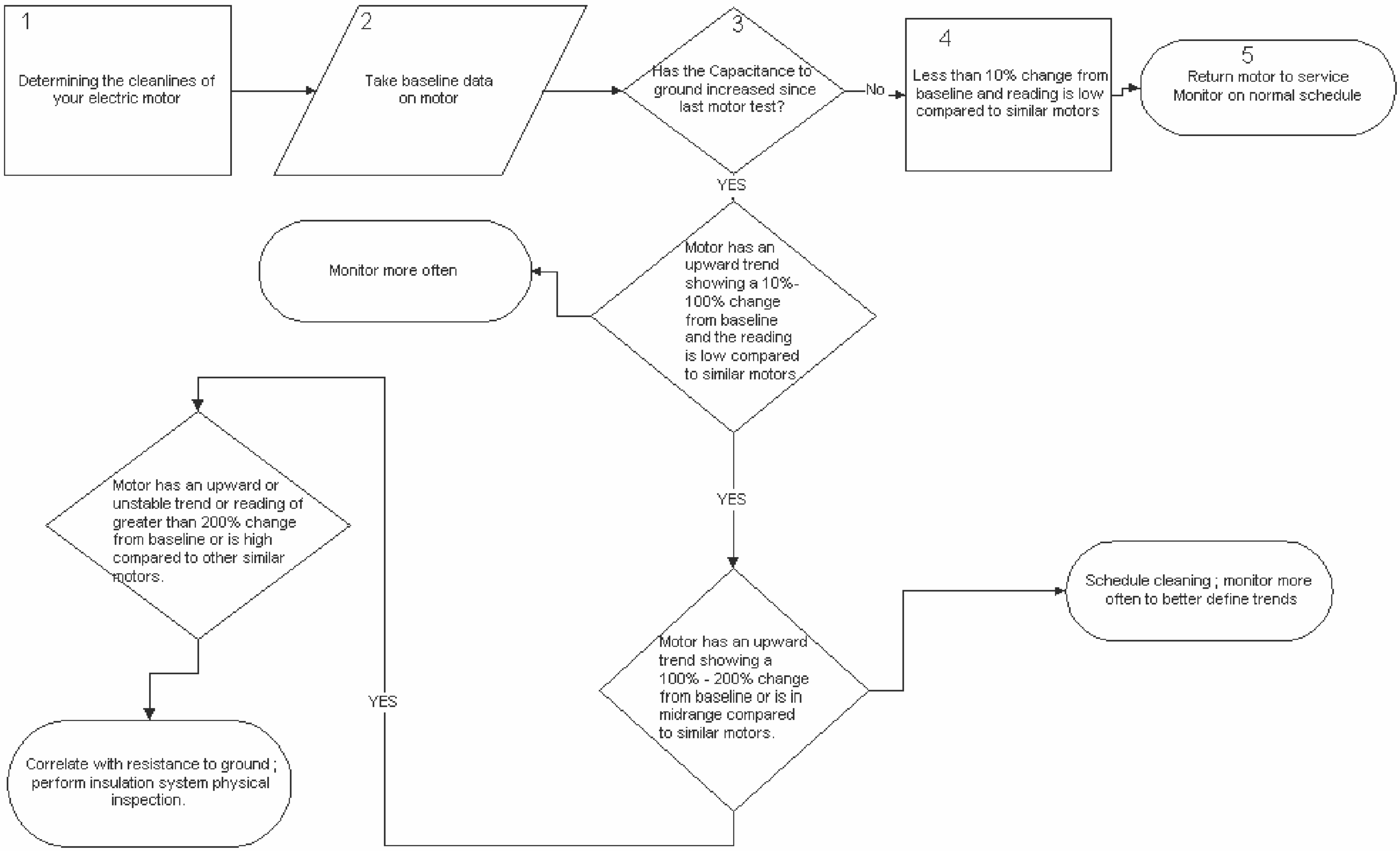

Figure 1-3
Capacitance to Ground Test

Logic Diagram 4-Motor Current Analysis for Rotor Bar Failure

General Information

Current analysis utilizes current measurements to perform high frequency spectrum analysis to detect broken rotor bars and rotor eccentricity. Most test devices also have provisions to detect problems with power quality such as voltage or current imbalance. See phase current/voltage imbalance for more information.

A three (3) phase induction rotor is made of rotor bars connected to two shorting rings on either end, with metal laminations between the rings. The assembly resembles a squirrel cage, hence the name. The stator induces a voltage in the rotor causing circulating currents in the rotor bars. These currents in turn cause another magnetic field pattern around the rotor called revolving rotor fields, which cause the rotor to turn.

Rotor bar defects cause high motor temperatures, increased vibration and loss of torque. If the condition is not detected and repaired it can cause stator failure if the broken rotor bar contacts the stator/windings. The vibration will reduce bearing life and the circulating currents set up in the rotor laminations will cause core damage.

Eccentricity between the stator and rotor will cause increase vibration and potential rotor/stator rubbing.

References: PdMA Product support manual; EPRI References Series, Volume 6, Motors; EPRI References Series Volume 16 Handbook to Assess the insulation Condition of Large Rotating Machines.

Diagram Details:

Box 1-Repeat the test to ensure the results are consistent. The motor should be loaded to 70% of the rated load. Load or current fluctuations could affect test results.

Box 2-Test a similar motor for comparison. Some motors exhibit abnormalities at high frequencies which will cause questionable results for current analysis and vibration analysis.

Box 3-Perform vibration analysis on the motor. Each time a broken rotor bar passes a motor pole there will be a perturbation in the magnetic field which should be evident at line frequency.

Box 4-Check motor speed. Broken rotor bars can increase the motor slip which would be evident from the rotor RPM. See speed fluctuation.

Box 5-Check the current and temperature of the motor. Broken rotor bars will reduce the efficiency of the motor and will increase the current and stator temperature.

Box 6-Disassemble motor, inspect for rotor bar cracking. Check bearings for wear.

Box 7-Perform Growler test or pass high current/low voltage through the rotor and check for cold rotor bars.

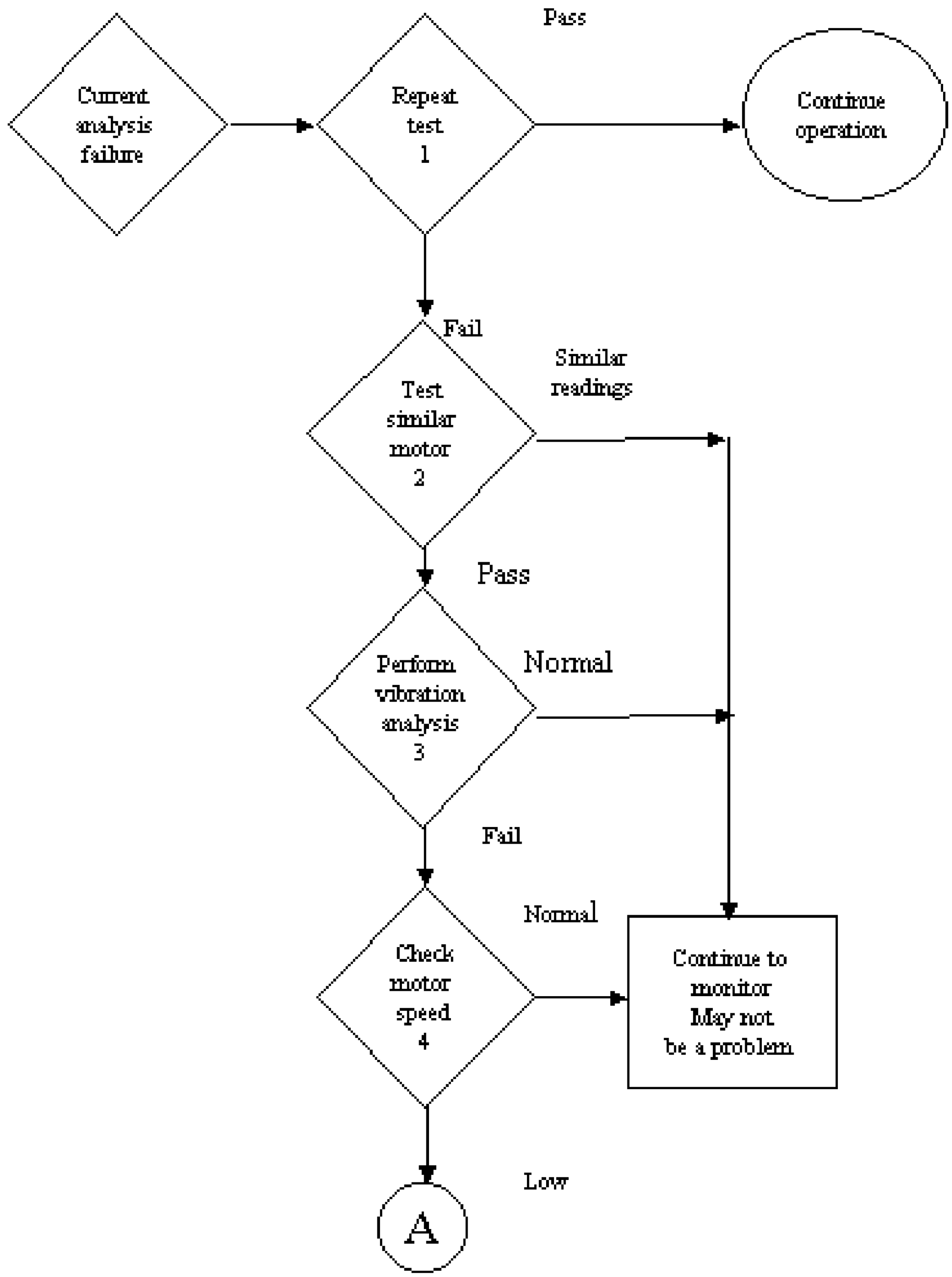

Figure 1-4
Motor Current Analysis for Rotor Bar Failure

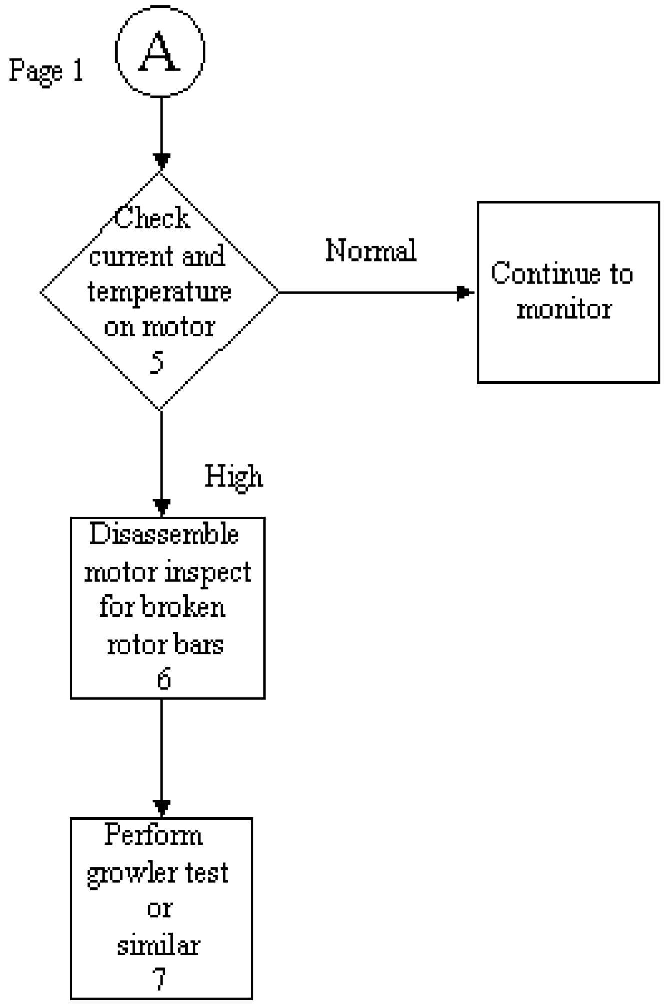

Figure 1-5
Motor Current Analysis for Rotor Bar Failure

Logic Diagram 5-Dissipation/Power Factor Test

General Information

The Dissipation/Power Factor test is used to provide information concerning the possibility of a change in insulation condition. The test setup primarily includes placing an AC voltage between the insulation conductor and ground and measuring the phase angle of the resistive current and reactive current in relation to each other. The maximum test voltage level should be limited to below normal line to neutral voltage of the machine

The theory is that changes in the ratios of these two currents will signal a change in the insulation condition. References indicate that good Epoxy-mica insulation will register dissipation factors of 0.5% or less and good asphaltic insulation will be found to be less than 3%.

This test is typically only used as a monitoring guide to identify if additional testing needs to be performed. Indications of bad test results will trigger a need for cleaning and drying of the insulation to determine if the problem is contamination. If the insulation is clean and dry, the question then becomes how bad is the insulation and how long will it be before it becomes unserviceable. This information can only be obtained from additional test and experience with similar conditions.

It is preferred to isolate each winding, when possible, to improve the sensitivity of the test. It should also be noted that grading paint as normally found on 6.6Kv and higher voltage motors will normally dominate the tip-up effect and void the test results. Additional information covering the Dissipation Power Factor testing can be found in the following references:

1. "*Handbook to Assess the Insulation Condition of Large Rotating Machines*", EPRI Volume 16, Section 5.1.2.3

2. "*Recommended Practice for Measurement of Power Factor Tip-Up of Stator Coil Insulation:, New York: Institute of Electrical Engineers*", 1975. IEEE Std. 286-1975

3. "*Critical Examination of the Dissipation Factor Tip-Up as a Measure of Partial Discharge Intensity*", In IEEE Transactions (EI), vol. 13, no. 1. New York: Institute of Electrical and Electronics Engineers, February 1978, pp. 14-24

4. Generator Instructions, Drying Hydroelectric Generator Windings, Canadian General Electric Company

5. Generator Instructions, Drying Turbine-Generator Windings, General Electric Company, GEI-69534D

6. IEEE Standard 43-1974, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery, Institute of Electrical and Electronics Engineers, Inc.

7. IEEE Standard 56-1977, IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10,000 kVA and Larger), Institute of Electrical and Electronics Engineers, Inc.

8. IEEE Standard 67-1990, IEEE Guide for Operation and Maintenance of Turbine Generators, Institute of Electrical and Electronics Engineers, Inc.

9. IEEE Standard 492-1974, IEEE Guide for Operation and Maintenance of Hydro-Generators, Institute of Electrical and Electronics Engineers, Inc.

10. NEMA MG5.2 Installation of Vertical-Turbine-Driven Generators and Reversible Generator/Motors for Pumped Storage Installations.

11. Power Factor Tests on Water-Cooled Generators, E. H. Povey, 1973 DCCM, Page Sec. 7-601, Doble Engineering Company

Box 1-If the dissipation/power factor reading is less than .5% for epoxy insulation and less than 3% for asphaltic insulation it is normally considered in good condition as stated in the EPRI "Handbook to Assess the Insulation Condition of Large Rotating Machines" as identified in the references above.

Box 2-If this is the first time a power factor test is done and it is within the acceptable ranges, the data should be recorded along with the test conditions (i.e. ambient and winding temperatures along with relative humidity, etc.) for future trending use. If existing test data is available, it should be compared to the new data for indications of significant changes.

Box 3-As stated above, the recorded data should include the test conditions along with the actual test data.

Box 4-Does the motor have grading paint? A motor with grading paint will often provide indications of high losses and provide false indications of bad insulation condition.

Box 5-If there are no significant changes from the previous testing the insulation should be considered to be in the same condition as previously tested in relation to contamination. However, a Dissipation/Power Factor Tip-Up test should be done along with a standard ground resistance and polarization index testing to provide the additional data to determine the service condition of the insulation.

Box 6-The primary cause for bad dissipation/power readings is contamination. If the indications are bad, the first step is to insure that the insulation under test is clean and dry. If it is clean and dry, additional testing is required to determine the overall insulation condition.

Box 7-Ground Resistance and PI testing need to be performed to assist in making a determination of the condition of the insulation.

Box 8-Care should be used in cleaning insulation. Only clean with approved cleaning materials. Care should be taken not to overheat insulation anytime it is being dried. References included above cover procedures and practices for proper cleaning and drying insulation in rotating machines.

Box 9-If all indications are good and data is recorded the machine should be returned to service.

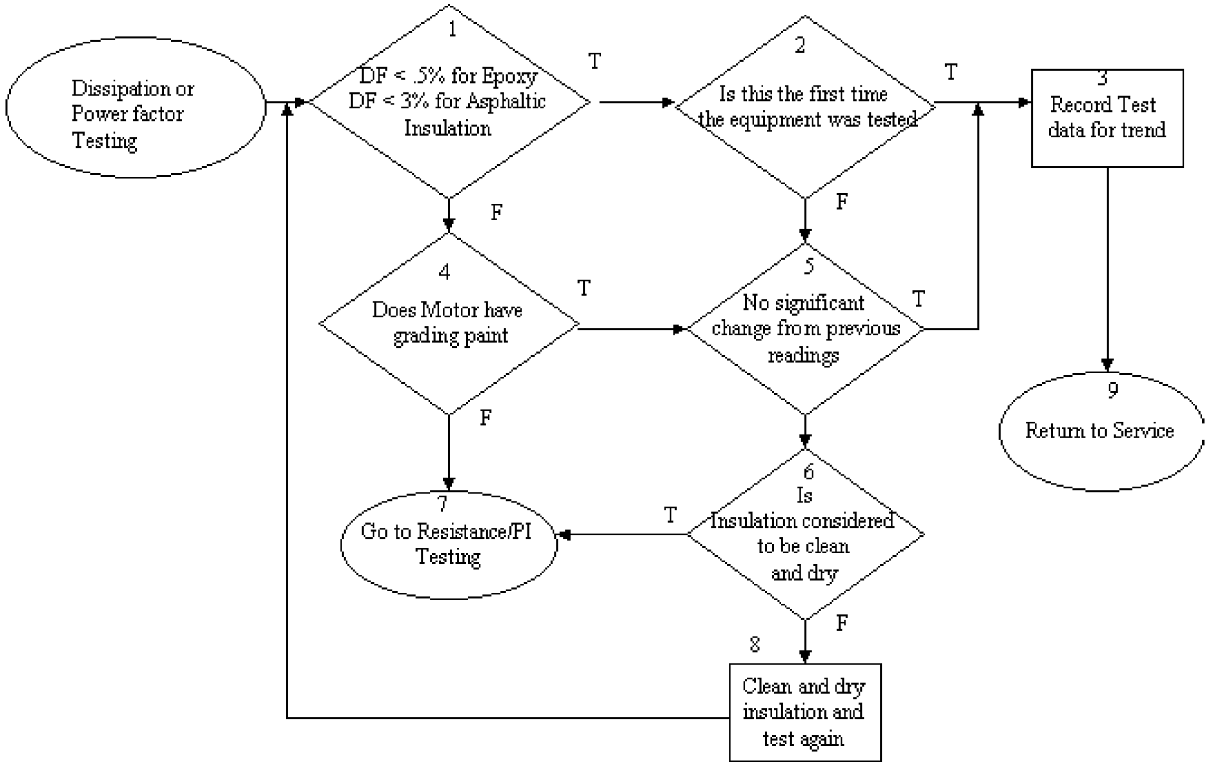

Figure 1-6
Dissipation/Power Factor Test

Logic Diagram 6-Dissipation/Power Factor Tip-Up Test

General Information

The Dissipation/Power Factor Tip-Up test is very similar to the Dissipation/Power Factor Test as described in a separate section of this program. The test setup and equipment is basically the same in both tests. However, the tip-up testing is done using two different voltage levels. The levels normally used are 100% and 25% of normal line to neutral voltage.

The theory is that as the voltage increases, the partial discharge activity will increase in proportion to the number of voids in the insulation. The “tip-up value” is defined as the ratio of dissipation/power factor at the 100% voltage divided by the level found at the 25% voltage level. Therefore, a higher tip-up indicates a higher insulation void content and thus, is an indication of insulation deterioration.

This test is typically only used as a monitoring guide to identify if additional testing needs to be performed. Indications of bad test results will trigger a need for cleaning and drying of the insulation to determine if the problem is contamination. If the insulation is clean and dry, the question becomes how bad has the insulation become and how long will it be before it becomes unserviceable. This information can only be obtained from additional tests and experience with similar conditions.

It is preferred to isolate each winding for test when possible to improve the sensitivity of the test. It should also be noted that grading paint as normally found 6.6Kv and higher voltage motors will normally dominate the tip-up effect and void the test results. Additional information covering the Dissipation/Power Factor and Tip-Up testing can be found in the following references: EPRI "Handbook to Assess the Insulation Condition of Large Rotating Machines", Volume 16, Section 5.1.2.3: "Recommended Practice for Measurement of Power Factor Tip-Up of Stator Coil Insulation, New York: Institute of Electrical and Electronics Engineers, 1975. IEEE Std. 286-1975; and "Critical Examination of the Dissipation Factor Tip-Up as a Measure of Partial Discharge Intensity", In IEEE Transactions (E1), vol. 13, no. 1. New York: Institute of Electrical and Electronics Engineers, February 1978, pp. 14-24.

Box 1-If this is the first time the equipment has been tested for Dissipation/Power Factor Tip-Up the data needs to be recorded along with the test conditions (i.e. temperature, humidity, etc.) for future trending analysis. As a general guide, the tip-up on an epoxy-mica insulation should be below 1% as stated in EPRI "Handbook to Assess the Insulation Condition of Large Rotating Machines".

Box 2-There is a good possibility that the insulation has deteriorated if the tip-up value has increased significantly. Epoxy insulation in good condition should have a tip-up value of less than 1%. If the testing indicates that the tip-up is acceptable or only slightly different, the data should be recorded and the trend checked.

Box 3-If the tip-up measurements are excessive, it could be a result of contamination. The insulation should be cleaned and dried and tested again. If the windings are clean and dry and the tip-up test is still excessive, the data should be recorded and additional testing perform to determine the extent of deterioration that has occurred. A Power Factor test should be done along with a standard ground resistance and polarization index testing to provide the additional data to determine the service condition of the insulation.

Box 4-The recorded data should include the measurements of the dissipation/power factor along with the test voltage levels. Ambient and winding insulation temperature should be recorded along with relative humidity. Records should be kept for all tests up until the winding insulation is replaced.

Box 5-Care should be used in cleaning insulation. Only clean with approved cleaning materials. Care should be taken not to overheat insulation anytime it is being dried. The following are several good references for drying insulation in rotating machines:

1. Generator Instructions, Drying Hydroelectric Generator Windings, Canadian General Electric Company

2. Generator Instructions, Drying Turbine-Generator Windings, General Electric Company, GEI-69534D

3. IEEE Standard 43-1974, EIII Recommended Practice for Testing Insulation Resistance of Rotating Machinery, Institute of Electrical and Electronics Engineers, Inc.

4. IEEE Standard 56-1977, IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10,000 kVA and Larger), Institute of Electrical and Electronics Engineers, Inc.

5. IEEE Standard 67-1990, IEEE Guide for Operation and Maintenance of Turbine Generator, Institute of Electrical and Electronics Engineers, Inc.

6. IEEE Standard 492-1974, IEEE Guide for Operation and Maintenance of Hydro-Generators, Institute of Electrical and Electronics Engineers, Inc.

7. NEMA MG5.2 Installation of Vertical-Turbine-Driven Generators and Reversible Generator/Motors for Pumped Storage Installations.

8. Power Factor Tests on Water-Cooled Generators, E. H. Povey, 1973 DCCM, Page Sec. 7-601, Doble Engineering Company.

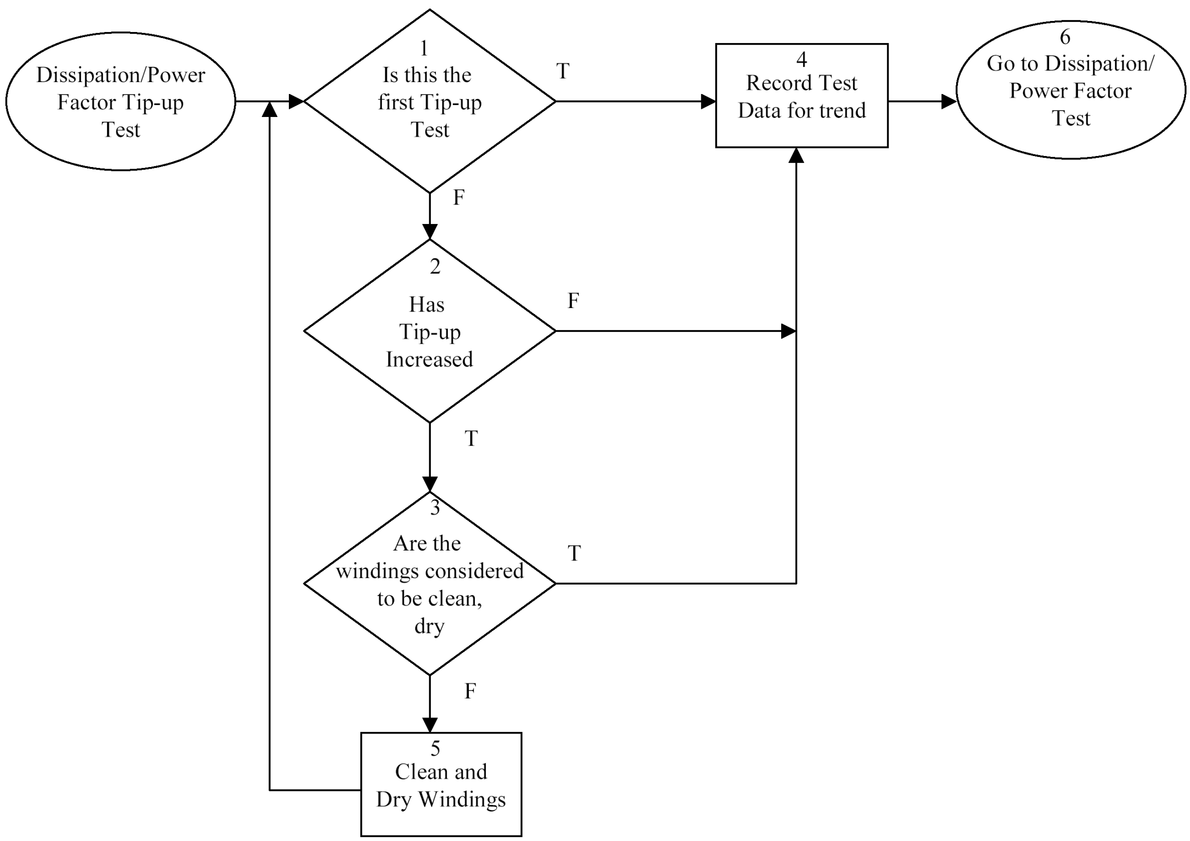

Figure 1-7
Dissipation Power Factor Tip-Up Testing

Logic Diagram 7-Surge Test

General Information

The Surge Comparison test is primarily used to test the condition of turn insulation, however, it can also detect weak groundwall insulation or windings that were improperly connected. The surge test is based on the premise that all phases of a motor are identical. The test involves applying simultaneous voltage pulses to two sections (coils, parallels, or phases) of a winding and displaying the reflected waveform on an oscilloscope screen. The pulse is created by discharging a capacitor into the motor winding. Because motor windings behave as inductors, the reflected pulse should oscillate between the motor and test set. If the motor is in good condition, the inductance of each phase will be equal and the reflected waveform from all three phases should be identical. Any variation between the phases would be evident by separation between the waveform of the phases. A turn to turn short lowers the inductance of a winding since it effectively reduces the number of turns in the winding. The lower inductance of the winding will result in the displayed waveform shifting left compared to a winding in good condition. The test technician must interpret the displayed waveforms to determine if the motor passes or fails. The surge test is typically a pass/fail test. It provides limited information about the relative condition of the motor.

Normally surge testing is conducted at a motor repair facility to test new coils as a motor is being rewound. When surge testing is used on a motor that has been completely wound, the test set is usually connected directly to the motor leads. All power factor capacitors and surge protection devices must be removed from the circuit. The test is considerably more sensitive if the rotor is removed, but it is possible to test a motor with the rotor in place. IEEE standard 522 describes an alternative test method using an exciter coil to induce a surge in the motor. This alternative method allows coils to be test individually.

EPRI “Power Plant Electrical Reference Series” Volume 6 (EL-5036-V6) Section 6.8 and Volume 16 (EL-5036-V16) Section 5.1.2.7 provide additional information on surge testing and provide recommendations on test voltage. IEEE standard 522 also provides additional information on recommended test voltages.

Logic Tree

Boxes 1 to 2-The surge test typically provides little warning before insulation failure. To prevent unexpected failures of the groundwall insulation, winding resistance to ground a polarization index should be tested before conducting a surge test. If the peak test voltage to be applied during the surge test is greater than the voltage applied for resistance to ground test, a DC Hipot test should be conducted at the surge test voltage. Most surge test sets have DC hipot capabilities also.

Boxes 4 to 6-A waveform that slopes downward instead of oscillating is caused by an open or high resistance circuit. The capacitor in the surge test set is being slowly discharged by the test set. An open winding is very unusual. The test setup should be thoroughly inspected. Check all connections between the test set and the motor. If no problems with the test setup can be found, stop the surge test and proceed to the winding resistance balance test.

Boxes 7 to 9-A single low amplitude pulse is caused by a sold short to ground. The Resistance to Ground or Hipot tests should have detected a short to ground. However the winding may have failed to ground during the surge test. A follow-up DC Hipot or Winding Resistance to Ground test will be necessary to confirm the insulation condition. If the winding has failed to ground it will be necessary to repair the motor before it can be returned to service.

Boxes 10 to 13-Instability or sudden shifts in the waveform can indicate a developing turn to turn short. Instability in the waveform is usually caused by an intermittent breakdown in the winding insulation (arcing). A sudden shift to the left (often accompanied by a drop in amplitude) indicates a breakdown in turn-to-turn insulation as voltage is increased. An unstable waveform can also be caused by motor that is too large for the motor test set. Some surge test set manufacturers advocate surge testing at the breaker. Capacitance for the feeder cable loads down the tester and cause instability in the displayed waveform. Typically testing should be conducted at the motor.

If surge testing is being used as a predictive maintenance test, watching for an unstable waveform is the best indication of a turn-to-turn short. If a solid short is present, the waveform will be stable but shifted from the other phases. If the test is being preformed after a motor trip or to confirm a winding resistance imbalance or winding inductance imbalance, the technician should watch for separation between waveforms also.

Boxes 14 to 20-Separation between waveforms can indicate shorted windings. However, if the rotor was not removed from the motor, mutual inductance between the rotor and stator can also cause the waveforms to be shifted. Rotating the rotor 120^{o} between testing each phase may help to cancel the effects of rotor coupling. If the rotor cannot be removed or rotated to cancel the effects of rotor coupling, the test technician must watch for sudden changes in the waveform as the voltage is increased. If a solid turn-to-turn short is detected, motor circuit analysis may be able to confirm an inductive imbalance. Unlike the surge test, motor circuit analysis cannot detect insulation weaknesses that allow arcing at operating voltage.

Box 21-If it is determined that the motor failed the surge test, the motor must be repaired before it is safely returned to service. Normally a motor would be completely rewound. However it may be possible to cut out the failed turn or coil and continue operation. Refer to “Temporary Operation of Motors with Cut-Out Coils” EPRI EL4095 Project 2330-1 Final Report June 1995 and “Synchronous Machine Operation with Cut-Out Coils” EPRI EL-4983 Project 2330-1.

Boxes 22 to 23-The motor turn insulation can be assumed to be in good condition if the waveforms are stable and overlap. The motor can be safely returned to service.

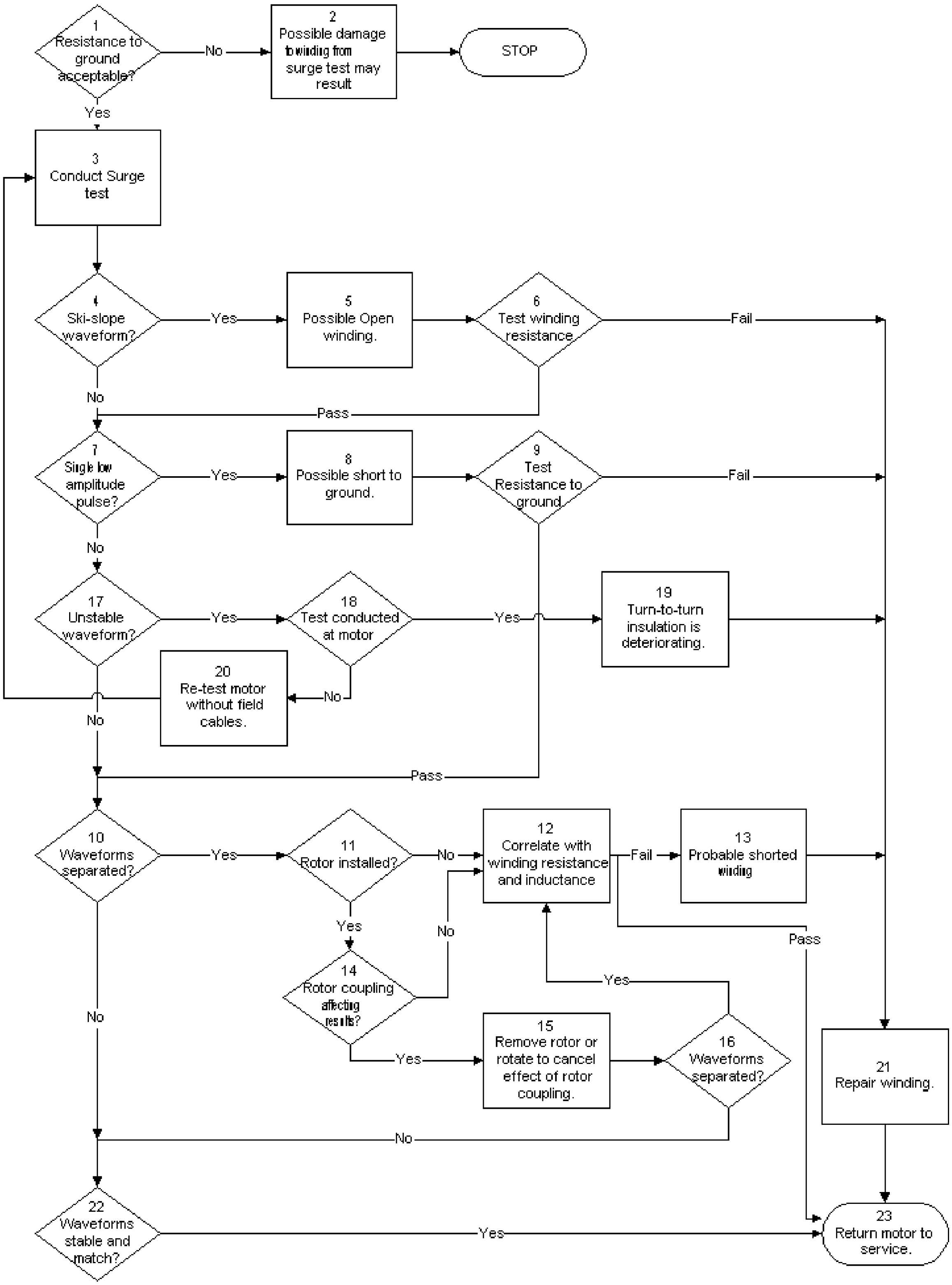

Figure 1-8
Surge Test

Logic Diagram 8- Description for Oil Analysis

General Information

Oil analysis has changed many times in recent years. Today with the rapidly changing computer technology, oil analysis continues to evolve into a predictive maintenance tool that we cannot do without. As with most predictive maintenance tools, the goal of oil analysis is to increase the reliability and availability of our machines, while at the same time we want to minimize our maintenance costs. This flowchart was developed to give the user a basic idea of how oil analysis should be approached. Oil analysis is a technique, not just a test. There is no one (1) correct way. Learning a technique will take time, training and patience, however the results can be very significant.

There are two (2) main parts to the testing phase of oil analysis. The first part is in field testing, consisting of visual, olfactory and blotter tests. These test can be preformed just about anywhere by anyone with just a little training. An unsatisfactory result from these tests doesn't always tell you what the problem is, but will lead you to look for other symptoms. Also, in severe cases, it will allow you to start taking immediate action to save a machine. The second part is lab testing. There are many qualified labs that can perform a wide array of tests. Which lab you choose is not as important as the ability to trend the data from the lab. Without the ability to trend data, oil analysis becomes more reactive maintenance rather than predictive maintenance.

The second phase of oil analysis is analyzing the data. In most cases if you have a severe problem you will notice it during the in-field tests. However these tests will not always tell you exactly what the problem is. All oil samples should be sent out to a lab for complete analysis. The lab test will narrow down, and in most cases, pinpoint the exact problem. Lab test data can also be used to trend small changes in the oil's composition so that oil changes can be scheduled well in advance, saving time and money.

Logic Tree (Figures 1-10 through 1-13)

Box 1: Obtaining an oil sample is very critical. Without a properly obtained, representative, oil sample, the most advanced testing machines are just expensive toys. All personnel taking oil samples should be trained to insure consistency and accuracy of the samples.

Boxes 2-4: The field tests are your first line of defense. They can be preformed in any order. They are easy test but unsatisfactory results can save valuable time when a machine has a severe problem. Look for water or contamination in the oil, smell the oil for a burnt odor, also you may want to perform a blotter test. Rings or deposits could be signs of a problem.

Boxes 5-13: When the field tests are complete, send the sample off for the lab tests and when you receive the results, look for trends or abnormalities. Your oil lab should have a reference sample to compare with your oil sample. Your lab should also be able to tell you what the instrument error is for the tests performed.

Box 14: In most cases all tests will be satisfactory and no action will be required. Continue performing routine sampling and testing at predetermined intervals. If a problem does exist or a trend seems to be developing, the interval should be adjusted appropriately.

Boxes 18-29: Normal oil should be clean, free from dirt, water or metal. It should also look like fresh oil of the same grade. If the result of the visual tests is unsatisfactory, you should be able to describe the results as one of these boxes. This will point you in a direction of further testing and possible corrective action.

Box 30-31: When oil begins to smell like rotten eggs or burnt, it is possible that it could be overheating and oxidizing. See the table for further tests and possible solutions.

Boxes 32-41: A field blotter test is not usually performed on an oil sample unless the oil is suspected of having a problem. If an oil sample appears to be dark or contain water a blotter test may be used in conjunction with the visual test to narrow the list of possible problems. Special blotter paper may be purchased, but ordinary business card stock will provide results in most cases. Don't set the card on a flat surface. Place two drops of oil on the card and allow it to sit for about 1-2 hours. You should be able to describe the results as one of these boxes. This will point you in a direction of further testing and possible corrective action.

Table (Logic Diagram)

The table lists 12 of the most common problems associated with lube oil. It then lists the symptoms, causes, verification tests, and solutions for each problem. Since there are several test performed on each oil sample and each unsatisfactory result can point to several problems, the flowchart is designed to lead you to the possible problems associated with each result. Once a possible problem has been identified, check the list of symptoms against the other test results to confirm or reject the problem. If all the symptoms have been check and you are still unsure of the exact problem, request the verification tests to confirm or reject the problem. Once the exact problem has been determined, check the list of possible causes and solutions.

Note: It is a good practice to request a second sample to confirm a problem and eliminate sampling error prior to performing extensive work on a system.

Logic Diagram 9-General Lubrication Analysis

Problem	Symptoms	Causes	Verification	Solutions
Oxidation	Dark Center Blotter (B) Dark Color (V) Burnt Odor (V) Increased Acid (Tan) Increased Viscosity (Vis) Additive Depletion (SC)	Time Elevated Temperature Metallic Contamination Air Contamination Metallic Wear Additive Depletion	RBOT-Short Lifetime FTIR-Spectrum	Change Oil Investigate Temp Investigate Wear Add Defoamant Investigate Metallic Contamination Investigate General Contamination
Sheer Breakdown	Blotter? Decreased Viscosity (Vis)	High Stress Application Time	FTIR-from New Oil	Use Multigrade Oil Change Oil
Wrong Oil/Wrong Addition	Off Color (V) Viscosity Additive Package Acid (Tan)	Human Error Manufacturer Error Manufacturer Change	FTIR-Spectrum Question Personnel Investigate Maintenance Records Question Vendor	Change Oil Train Personnel Evaluate Use
Water Contamination	Milky (V) Standing Water (V) Water Blotter (B) Viscosity (Vis)-Depends on Lab Positive Crackle Increased Na (SC)	Leaking Seals Contaminated Source Breather Intrusion Component Washing Weather Leaking Oil Cooler	Karl Fisher->New Oil FTIR-Spectrum Investigate Component Washing Check Seals Verify SW System Check Fill Source	Inspect/Repair Seals Inspect/Repair Breathers Stop Dousing Component Storage Ensure Proper Source Inspect/Repair Coolers

Problem	Symptoms	Causes	Verification	Solutions
Dirt Contamination	Visual-Severe Cases (V) Blotter-Severe Cases (B) High Silicon (SC) High Aluminum (SC) High Particle Count (PC) High TDS (TS)	Faulty Breather No Breather Bad Shaft/Motor Seals Contaminated Source Poor FME During Repair	FTIR-Spectrum Question Personnel Sample Source Oil	Inspect/Repair Seals Inspect/Repair Breather Change Oil/Flush Reservoir Improve Housekeeping Ensure Proper Source Storage
Fuel Contamination	Fuel Smell (O) Big Spread/Concentric Rings (B) Decreased Viscosity (Vis) Base-(TBN)	Ring Blowby Scorched Cylinders Source Contamination	FTIR-Spectrum	Change Oil Replace Rings/Cylinder Linings Check Source
Glycol Contamination	Globules (V) Green/Blue Color (V) Black & Pasty Center (B) Viscosity-(Vis) Depends on Lab High Sodium (SC) High Potassium (SC) High Boron (SC) Positive Crackle (K)	Cracked Engine Part Contamination Source Blown Head Gasket Leaking Oil Cooler	FTIR-Spectrum Karl Fisher-High Water	Change Oil Inspect/Repair Engine Check Source Inspect/Repair Oil Cooler

Problem	Symptoms	Causes	Verification	Solutions
Metal Contamination	Blackish Color (V) Rust Particles/Sludge (V) Concentrated Center (B) High Iron High Cr, Ni, Sn, Al, Pb, Cu, Agiti, Ti	Faulty/Missing Breather Faulty Seals Cutting, Welding, Grinding in Area Contaminated Source Poor FME	Magnet Test - + FTIR-Spectrum Ferrogram-Visual Evidence	Inspect/Repair Breather Seals Change Oil Check Source
Wear	Shimmering (V) Particles on Bottom (V) Concentrated Center (B) High Fc, Cr, Ni, Al, Pb, Cu, Sn, Agiti (SC) MolyB High Particle Count Visual Metalic Particles (PT) TAN + See Oxidation	Faulty Component Excell/Shock Loads Wrong Oil Dirt Contamination Excessive Vibes Sheer Breakdown Oxidation Wrong Oil Additive Depletion Oil Contamination Foam Reduced Dispersancy	FTIR-Spectrum Ferrogram-Visual Evidence	See Solution for Other Causes Change/Filter Oil Investigate Vibe Levels Investigate Loading

Problem	**Symptoms**	**Causes**	**Verification**	**Solutions**
Air Etrainment	Foam in Oil (V)	Machine Design Rduced Additive Package Source Contamination Wrong Oil/Package	FTIR-Spectrum	Change/Flush Oil Check Source
Reduced Dispersancy	See Sheer Breakdown See Addiive Depletion		FTIR-Spectrum	
Additive Depletion	Dense Deposit Zone (B) Reduce K, MolyB, Ph, Zi, Ca, Ba, Mg (SC) Increased Particles Positive Crackle TAN +	Normal Depletion Increased Contaminants Wrong Oil	FTIR-Spectrum See Various Contaminants	Change Oil Investigate Contamination

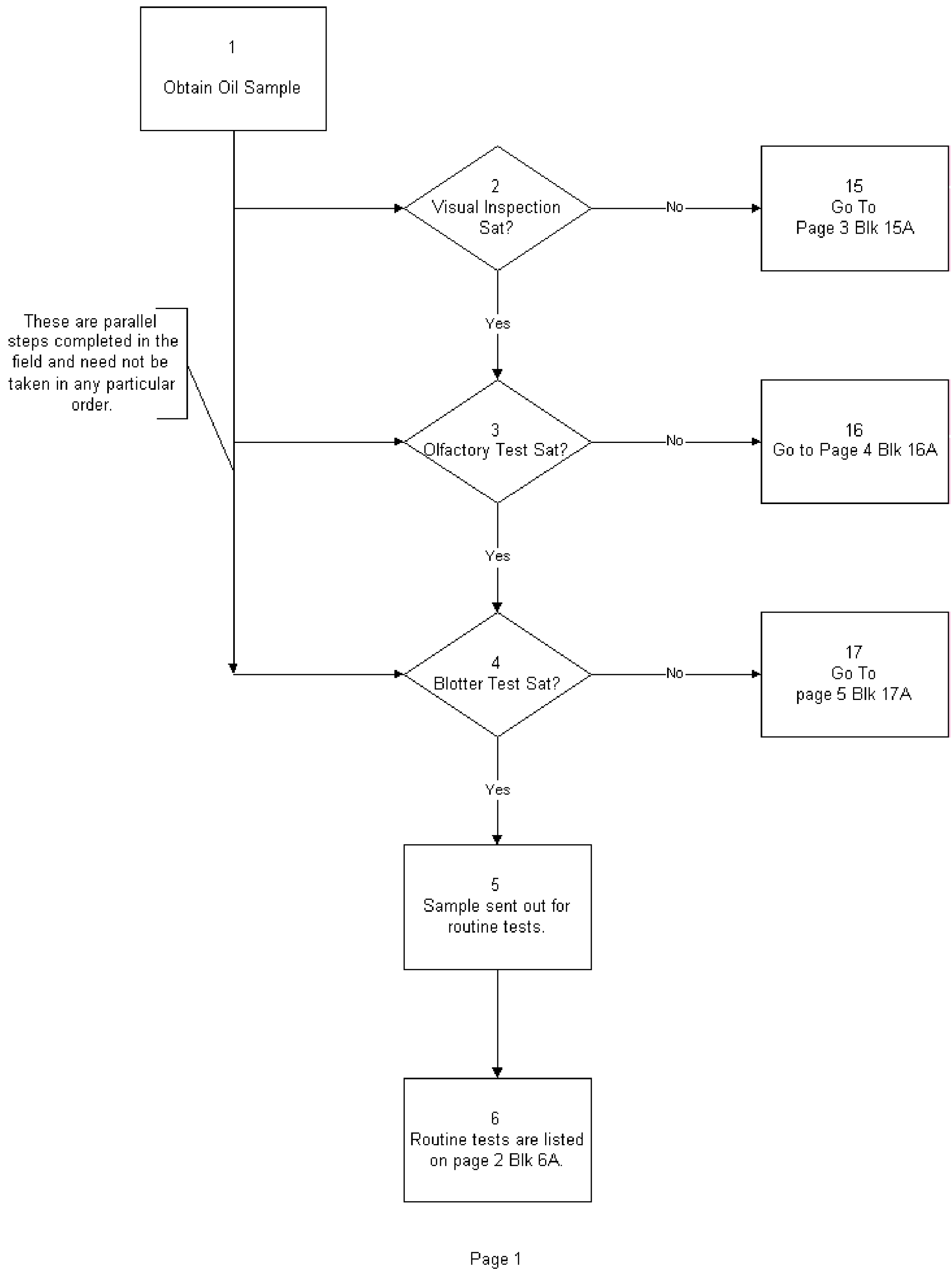

Figure 1-9
Oil Analysis

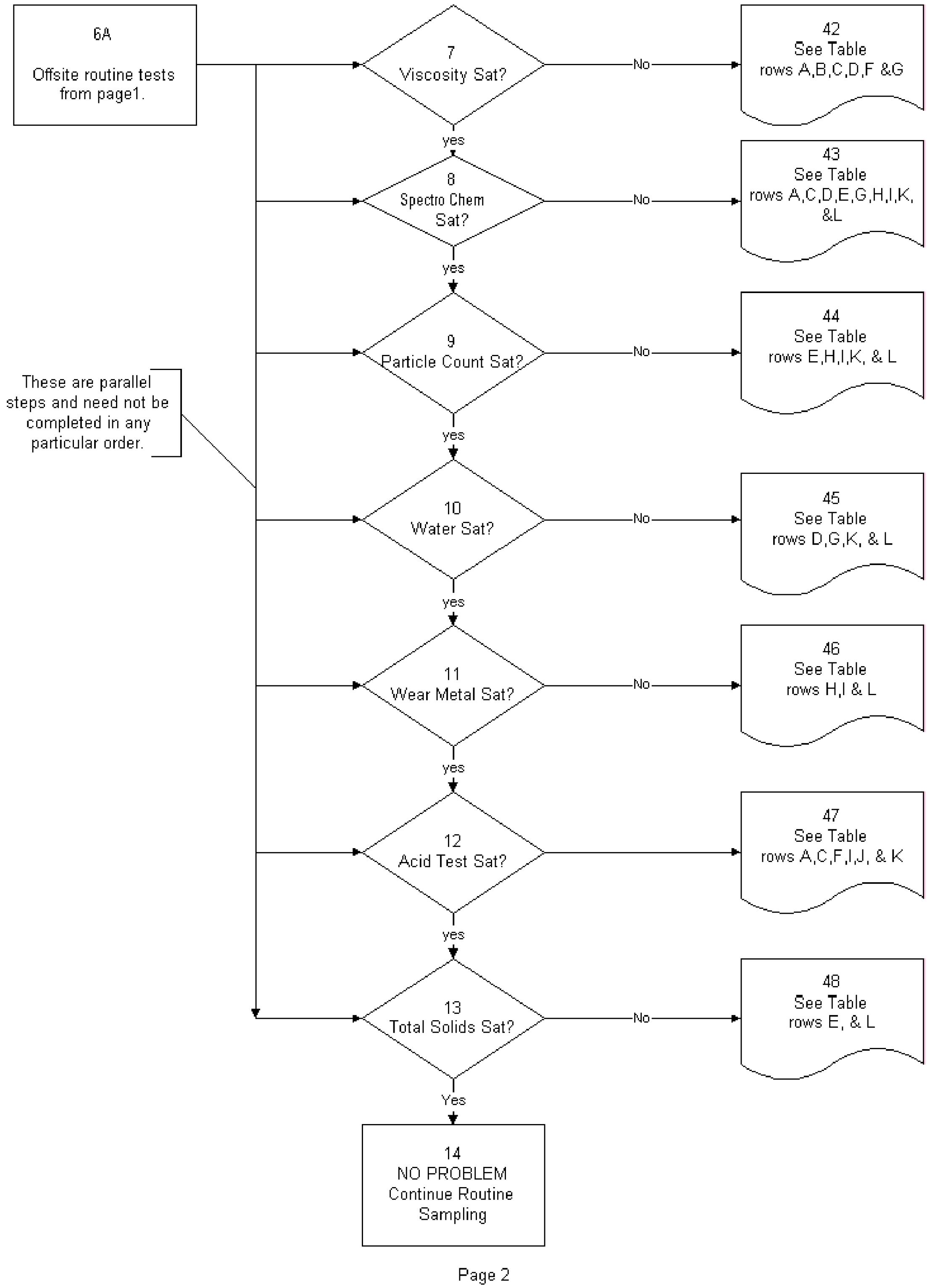

Figure 1-10
Oil Analysis

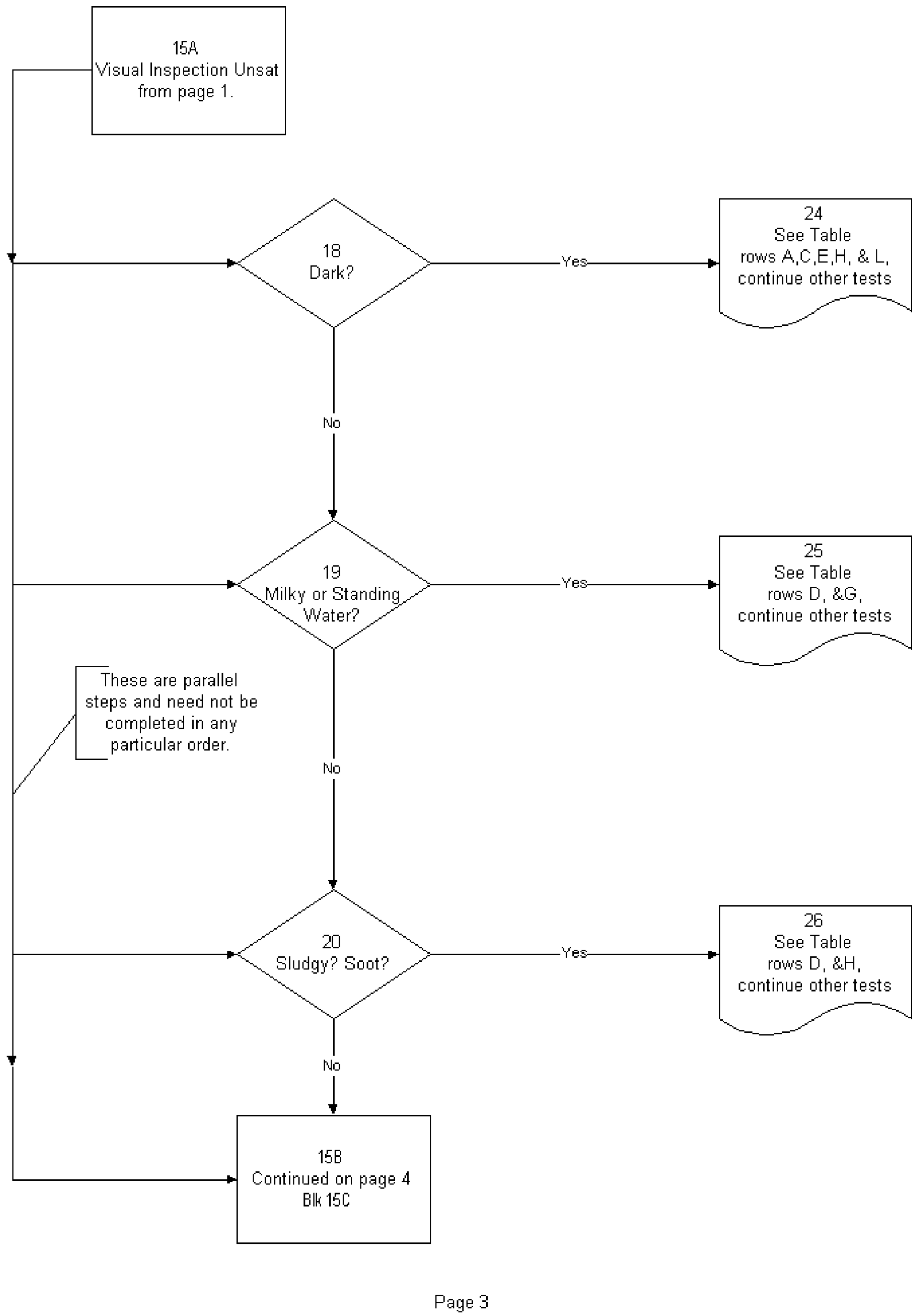

Figure 1-11
Oil Analysis

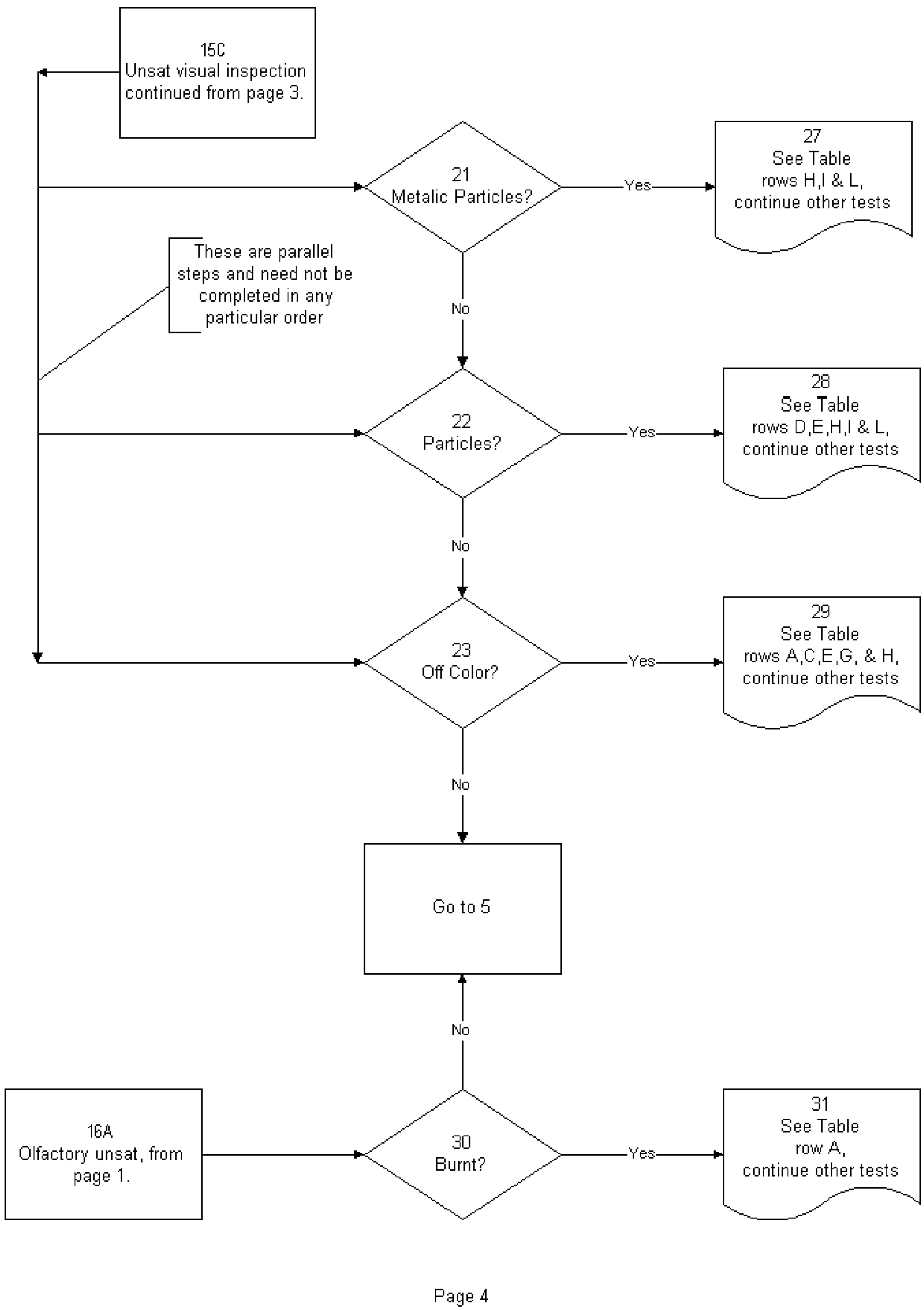

Figure 1-12
Oil Analysis

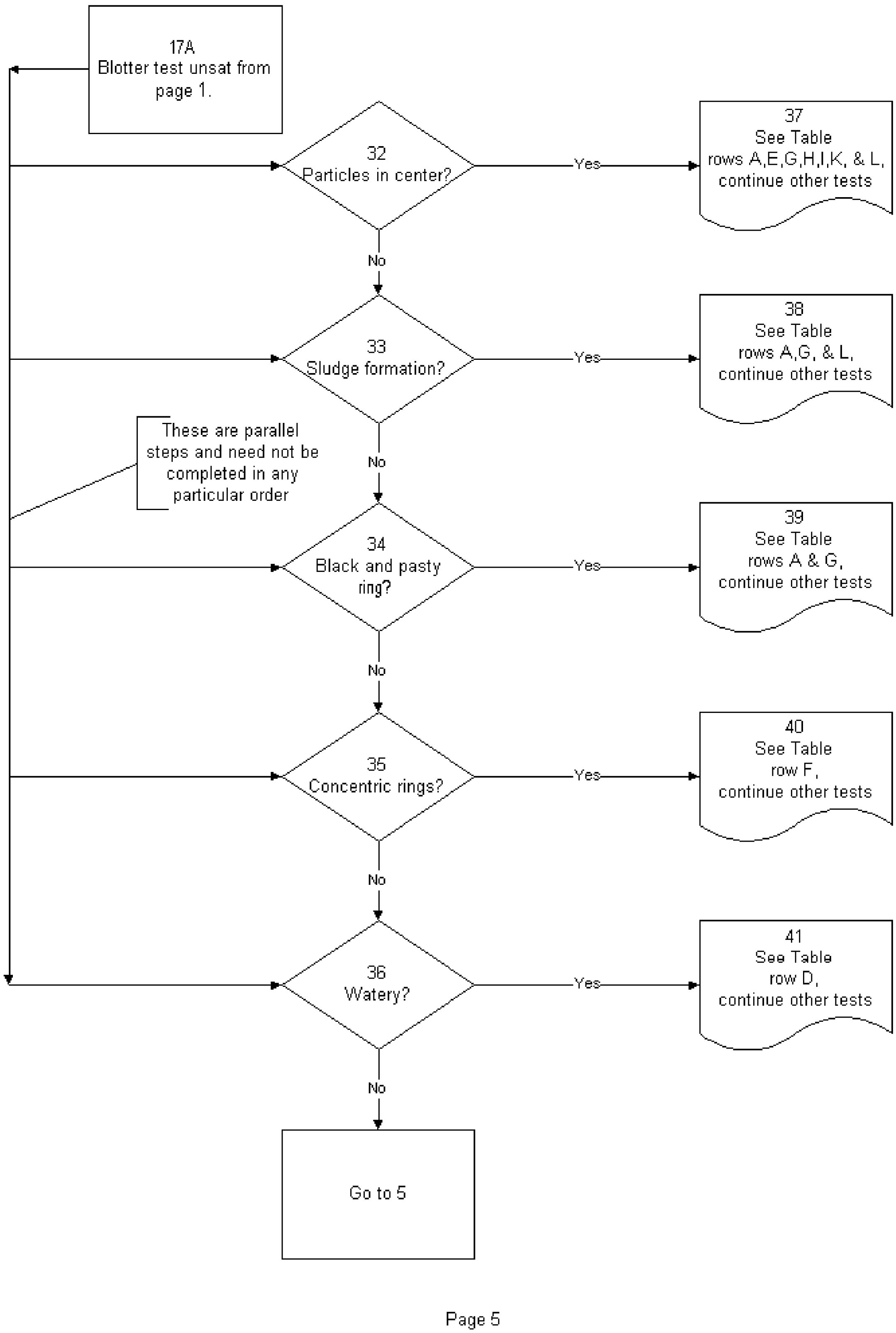

Figure 1-13
Oil Analysis

Logic Diagram 10-Discoloration of Housing or Indication of Heat

Box 1-Check the surface temperature of the motor using thermography or pyrometer. Compare the temperature to previous readings or compare them to similar motors. Check for unusual smells.

Box 2-If there is high temperature noted in the bearing area. Check the Bearing.

Box 3-If there is high temperature noted in the stator area, see the logic for general over temperature alarm.

Box 4-If there are no indications of over temperature, check other parameters to see if they are normal. Check the current readings to see if they are normal or compare them to other similar motors. Check the voltage readings to see if they are normal or unbalance. See logic for over temperature alarm.

Box 5-Check vibrations as secondary check for other problems.

Box 6-If no problems are found continue running the motor and check the equipment history.

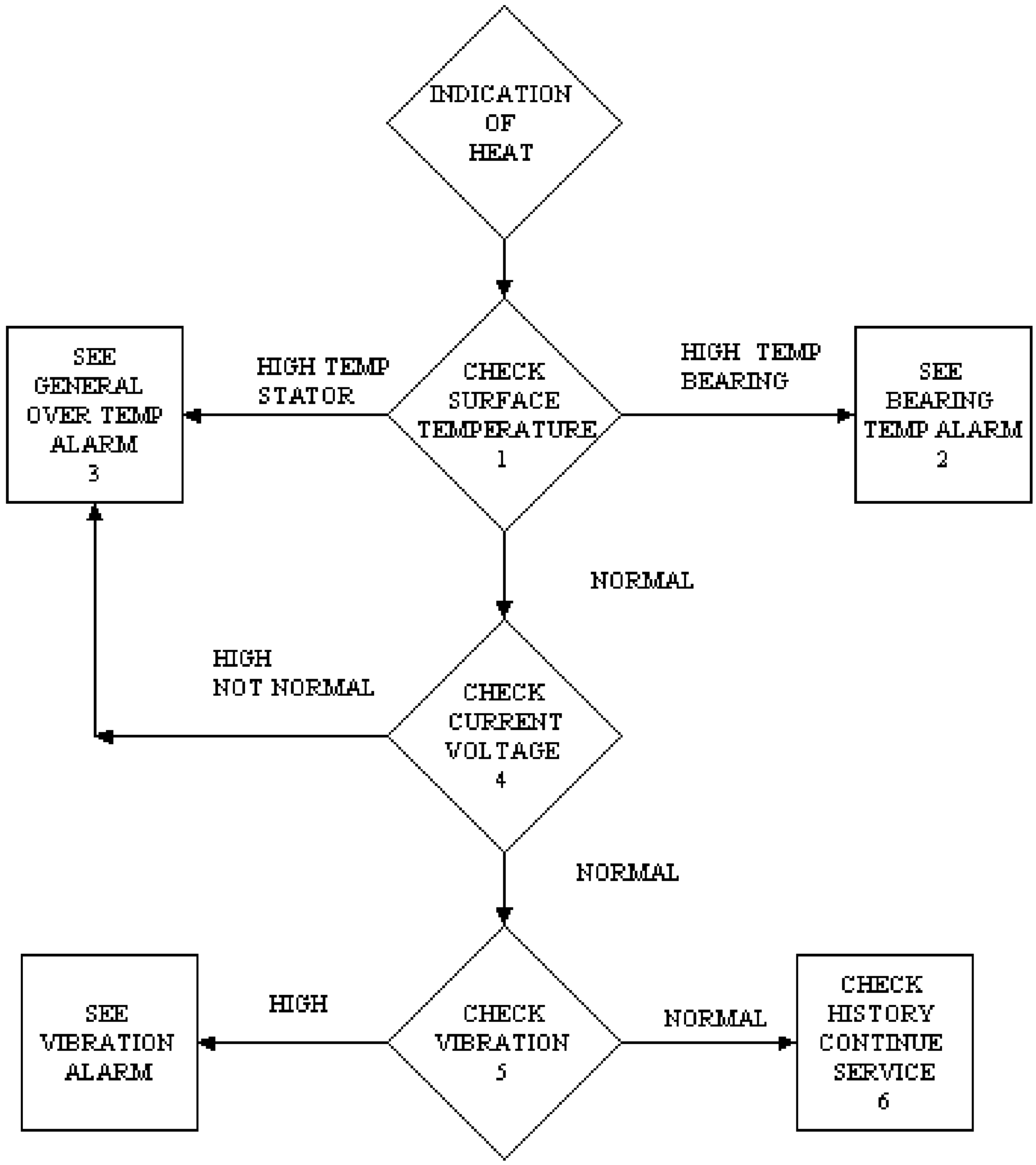

Figure 1-14
Discoloration of Housing or Indication of Heat

Logic Diagram 11-Slow Start (Excessive Acceleration Time)

General Information

Increased acceleration time is usually caused by either low voltage or increased load during startup. This logic diagram is written for squirrel cage induction motors which are started using full voltage starting.

Box 2-If the motor did not reach full speed refer to the logic diagram for slow speed (future). The full-load speed for an induction motor is typically 1-3% less than the synchronous speed. NEMA MG 1-12.46 states that the slip speed of a motor cannot vary more than 20% from nameplate.

> Example:
>
> For a nameplate full-load speed of 1750
>
> (1800-1750)*0.2=10
>
> Therefore, the allowed speed variation is 1740-1760.

Box 4-Is the torque requirements of the load too large for the motor to accelerate? If this is a new system, verify that the correct NEMA design type motor was used. Loads, such as crushers or pulverizer, which encounter material at startup or reciprocating compressors which start loaded may require a motor with higher starting torque. If this is an exiting system, has the load increased? Verify the load was started properly. Many centrifugal pumps and compressors are designed to be started with the discharge closed. The motor may not be able to accelerate the load with the discharge open.

Box 6-Monitor the supply voltage during motor starting and running. NEMA MG 1-12.44 states that a motor should operate successfully under running conditions with ± 10% rated voltage. Locked rotor (starting) and breakdown torques vary with the square of the applied voltage. Even if voltage is within the NEMA specified ± 10% rated voltage, it is possible that the motor will not have sufficient torque to accelerate the load.

> Example:
>
> If a motor has a starting torque equal to 125% full load torque at rated voltage. Assume voltage is reduced to 80% of rated. The resulting starting torque will be:

$$\frac{80^2}{100^2} * 125\% = 80\%$$

Box 9-Unbalanced phase voltages will decrease locked-rotor and breakdown torques. If the voltage unbalance is severe, the torque available may not be able to accelerate the load. NEMA MG 1-14-35 does not recommend running a motor with greater than 1% voltage unbalance due to overheating concerns. If the motor is operated with voltage unbalance greater than 1%, it must be derated according to NEMA standards.

Box 10-Rotor cage defects can cause increased acceleration times. Listen for noise at start up due to broken rotor bars. Vibration analysis, current signature analysis, or power signature analysis can be used to test for broken rotor bars.

Reference-NEMA MG-1

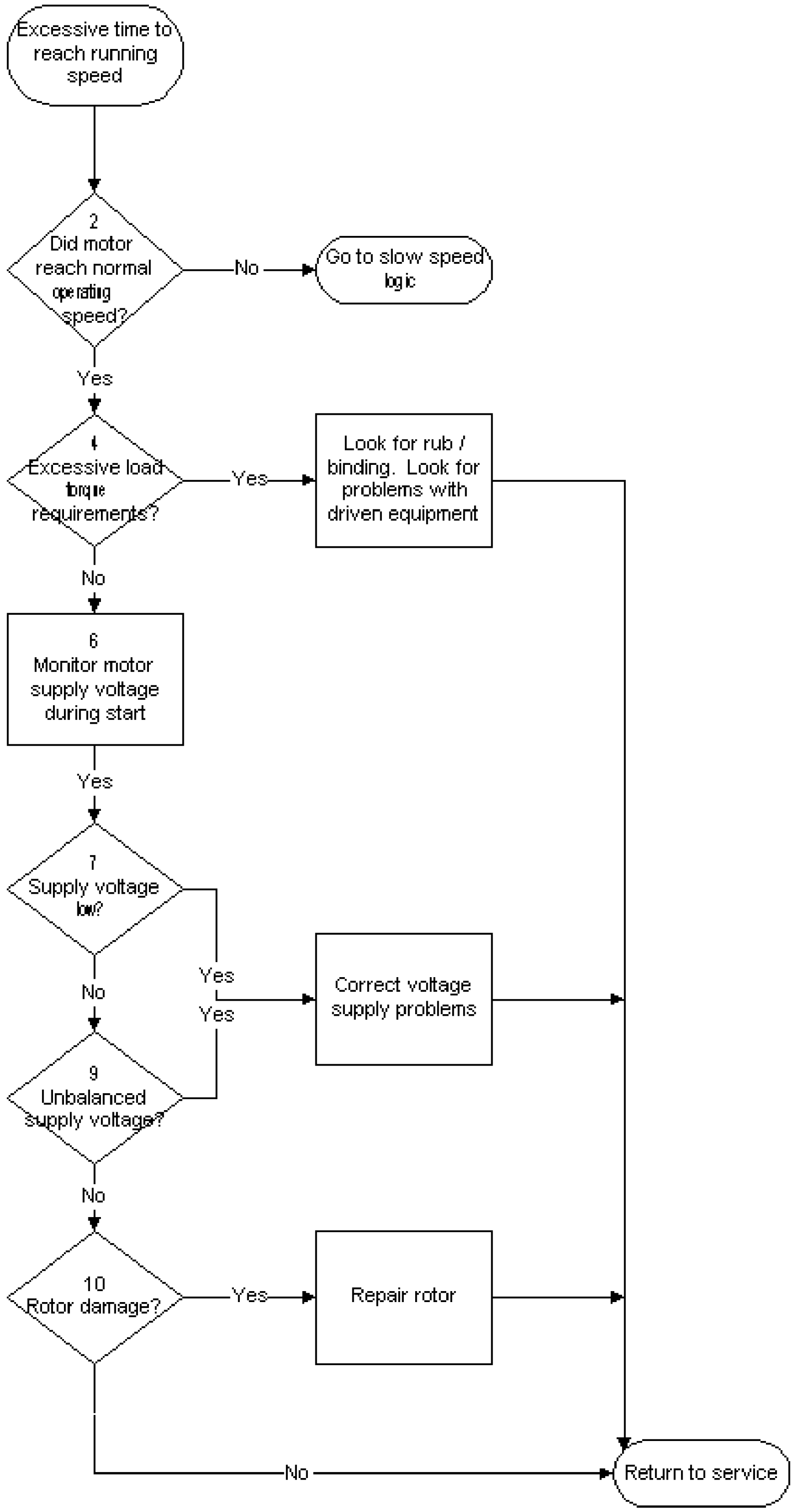

Figure 1-15
Slow Start (Excessive Acceleration Time)

Logic Diagram 12-Over Temperature Alarm

General Information

A motors operating temperature is rated according to ANSI/NEMA standard MG 1-1978. The insulation system is rated for temperature rise. The table below shows the insulation classes plus the rated temperatures with no service factor taken into consideration:

Class A-60^{o}C

Class B-80^{o}C

Class F-105^{o}C

Class H-125^{o}C

Several thermocouples or RTD's are installed in a motor's stator, usually in the slot, which detect the operating temperature of the motor. The over temperature alarm is usually set just below the insulation rating. Stator insulation degrades over time due to heat generated by the motor. If the temperature of the motor is kept within the insulation rating the motor could be expected to last 40 years or more. If the motor is operated at 10^{o}C over the insulation rating continuously the motor life would be cut in half.

Box 1-If a motor is started and stopped too frequently the stator temperature will rise rapidly and an over temperature alarm is likely. The motor's vendor manual will usually give the maximum starting frequency.

Box 2-Summer heat or steam leak can cause the ambient air temperature to increase to a point where the motor high temperature alarm comes in.

Box 3-Check the motors inlet and outlet air vents for dirt or blockage. If the motor is water cooled check for adequate water flow through the valves and heat exchanger. Check the water temperature to see if it is normal.

Box 4-Perform thermography on the motor. Check motor air inlet and discharge temperatures. Check for hot spots on motor casing. Check motor leads for loose connections. If the motor is water cooled check water inlet and discharge temperature.

Box 5-Check the TE's or RTD's at the motor for proper operation. Check the wiring from the motor's junction box for opens or shorts. A large AC electric motor is usually equipped with several spare stator TE's if needed.

Box 6-Check the current reading of the motor to see if it is normal, or compare the current readings to similar motors. Check to see if the discharge rate of the pump is also high. Reduce load on the motor if possible. Question what has changed with the system. Has the pump been rebuilt? Is the flow control valve working correctly?

Box 7-Check the line voltage to see if it is normal. Check for voltage imbalance between the three (3) phases. A voltage imbalance causes negative sequence currents/fields in the motor. The motor temperature will rise exponentially with the percent unbalance. A 3% imbalance will cause a 10% reduction in horse power. EPRI EL-5036 Vol 6 discusses problems with negative sequence corrects as well as ANSI/NEMA MG 1-1978. Two options are available for this problem, reduce load or balance the line voltage, which may not be practical or possible.

Box 8-Check the insulation rating of your motor. Compare it to the high temperature alarm point. The alarm should be at or below the temperature rating of the motor. Adjust the alarm set point if wrong.

Box 9-A 10C temperature rise over the insulation rating will reduce the motor life by 50% per EPRI EL-5036 Vol 6, 16.

Box 10-Perform a polarization index test (PI) to determine if the motor is dirty. See logic for PI testing.

Box 11-Disassemble motor and inspect for clogged cooling passages or broken welds. Inspect core for discoloration, burn spots, broken teeth, fused metal or core insulation dusting. Check for tape separation and girth cracking just outside the slot. Check for wedge looseness and/or signs of axial movement outside of the slot.

Box 12-See logic for core loss testing.

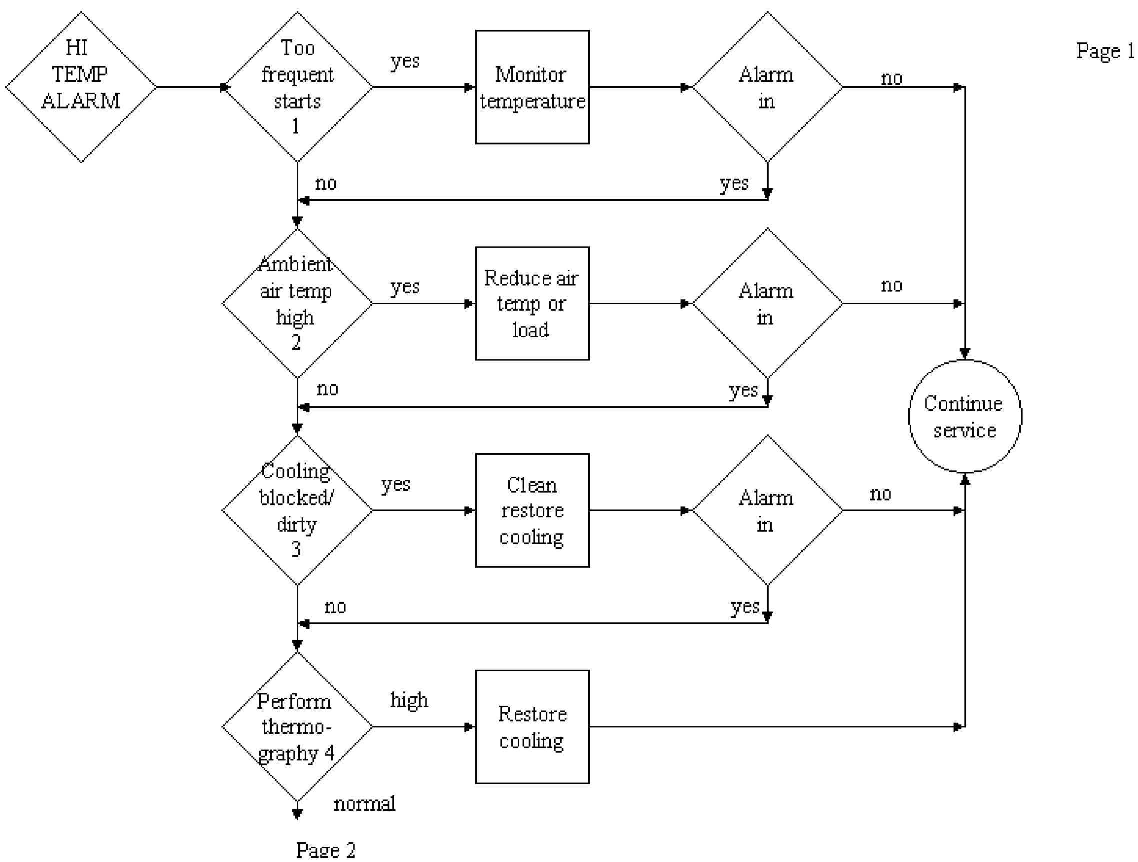

Figure 1-16
Over Temperature Alarm

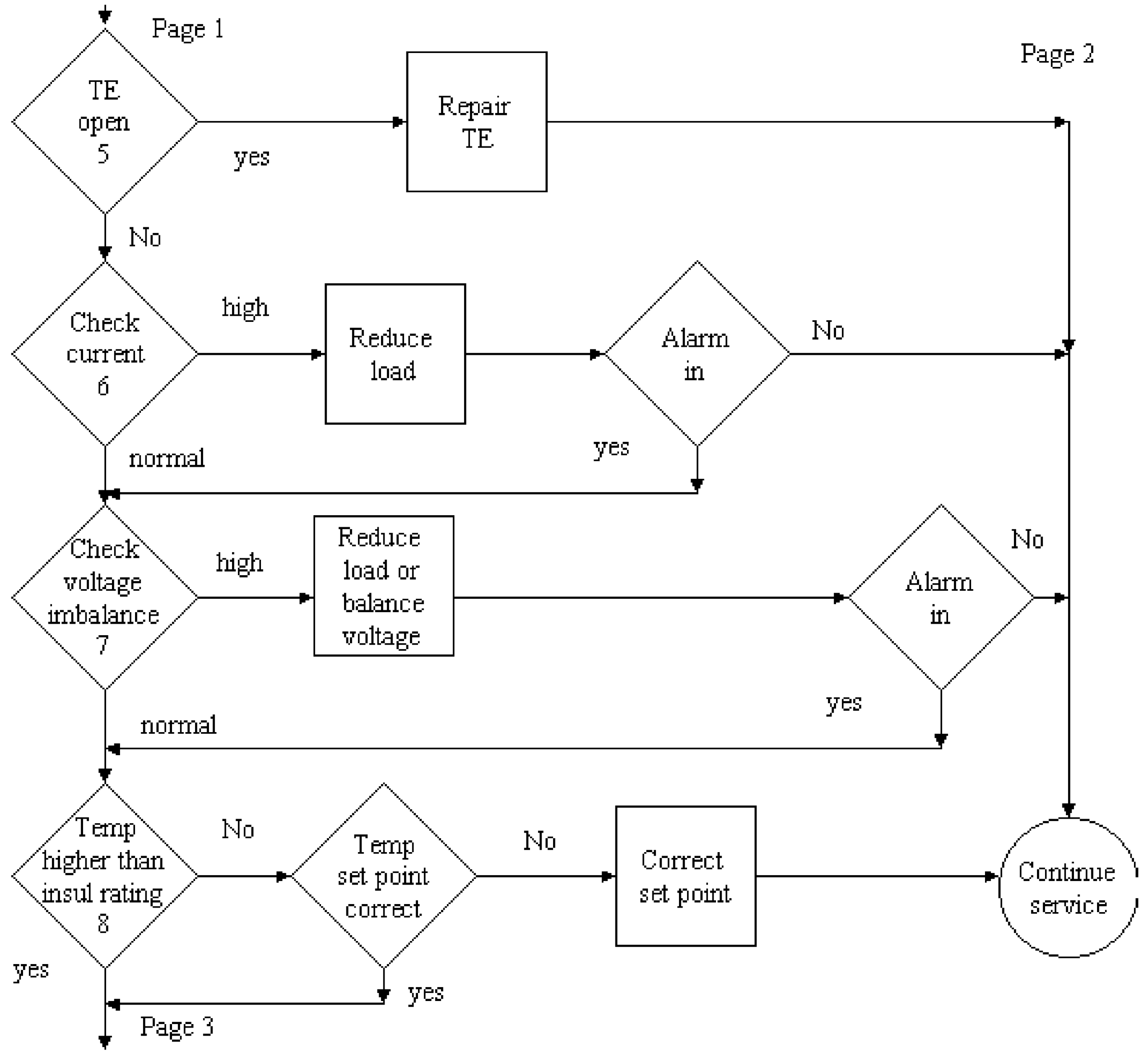

Figure 1-17
Over Temperature Alarm

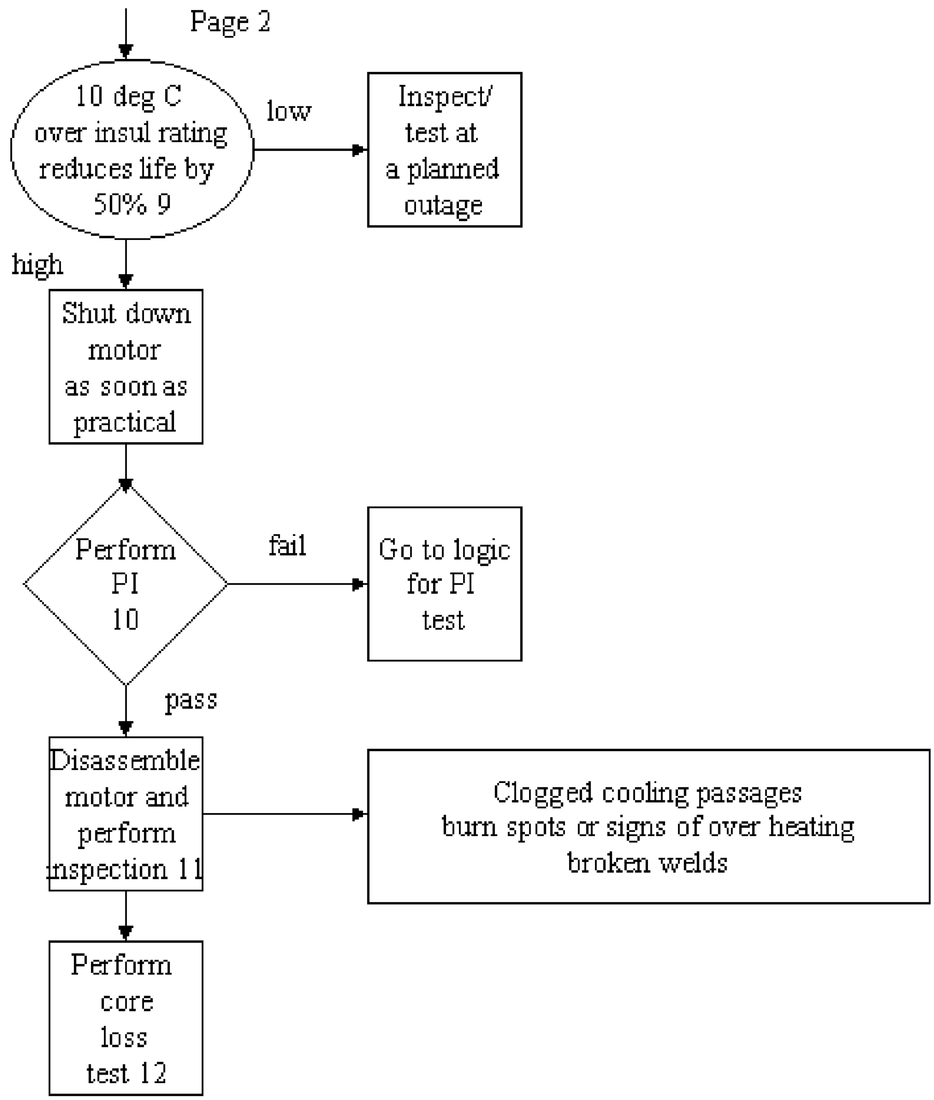

Figure 1-18
Over Temperature Alarm

Logic Diagram 13-White Powder in Stator

General Information

White or brown powder found in a motor can be caused by two different means. The movement of supports caused by vibration can cause the insulation to abrade or appear to be sanded. White powder between the end arms of windings or in the slot of the stator is caused by corona or partial discharge. Partial discharge can be found in motors 6KV and higher. Partial discharge is a gas breakdown phenomenon where the air ionizes and there is a small spark. Partial discharge can occur in the end arms of two adjacent coils with different potentials that are too close. The white powder is the result of the sparks eroding the insulation as if it were sand blasted. Partial discharge can occur in the slot where there are voids in the insulation or looseness of the coil. The air ionizes in the void causing insulation breakdown. The damage caused by the corona will appear white, but in more advanced stages, brown due to the heat generated. Areas affected in the end arms can be revarnished to give a sacrificial finish for the corona to work on. This will extend the life of your motor. Note that corona ozone to be created, this gas will attack rubber goods and is very corrosive. If you have a motor known to have partial discharge activity, a frequency for visual inspection should be implemented, partial discharge testing should also be considered.

Box 1-If powder is found on a support or blocking check for looseness. Check the windings for cracks due to movement.

Box 2-If powder is on the end arms next to the core check to see if you grading tape or grading paint. Semi conducting paint can be painted on to repair the surface.

Box 3-If powder is on the end arms, the end arms can be revarnished. Ensure the powder is wiped off and the surface is free of oil.

Box 4-Check wedges for signs of looseness. See stator core wedge loose for more information.

Box 5-If powder is in the motor leads, ensure the leads are not touching each other or the junction box. Separate the leads to ensure they have adequate air space. Inspect the leads to ensure the ozone created has not cracked the insulation.

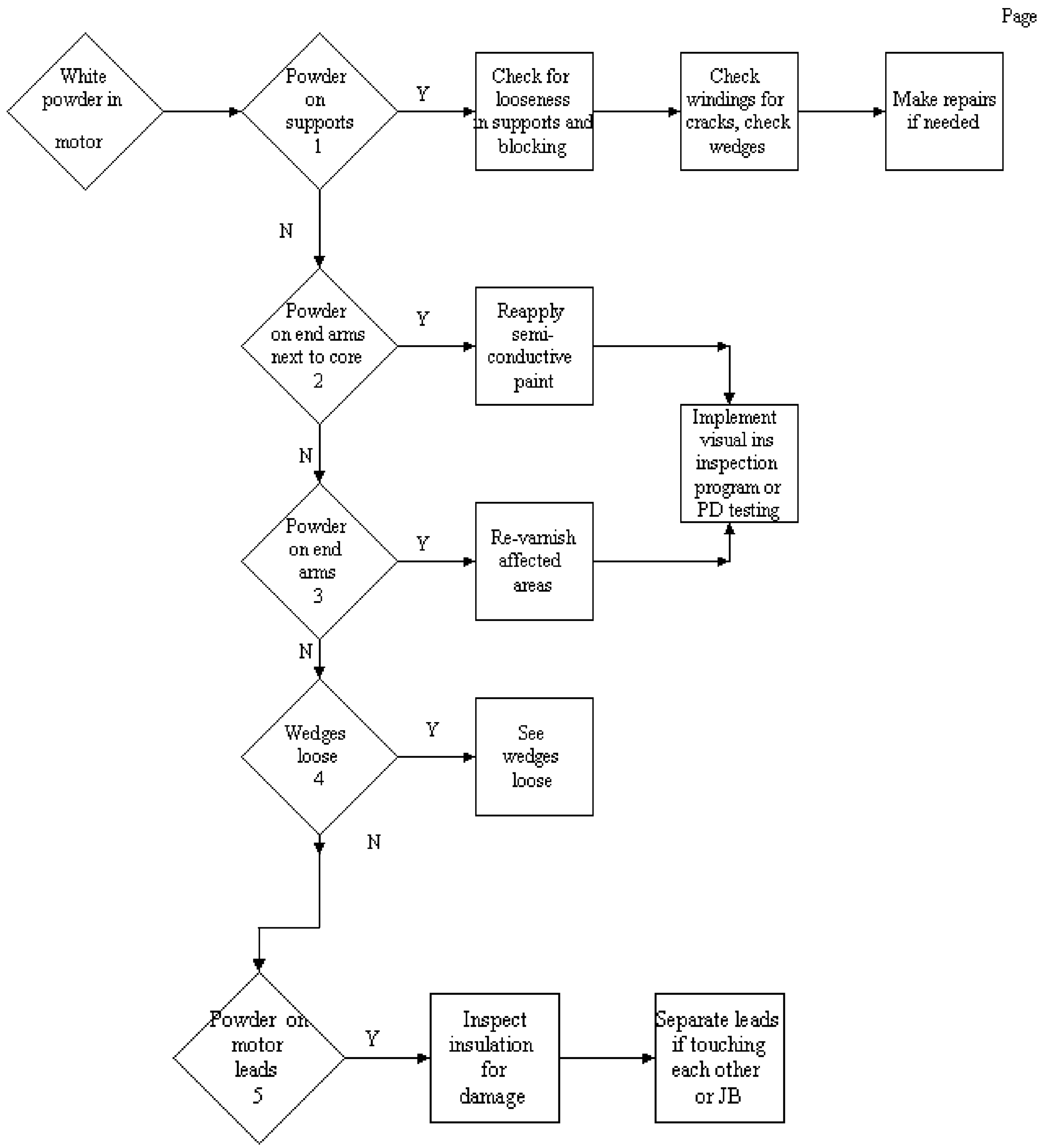

Figure 1-19
White Powder Stator

APPENDICES

A

SINGLE PHASE ROTOR TEST

The test procedure is simple and only requires use of power supplies and metering equipment commonly found at most electrical facilities. The test concept is based on the ability to reflect the rotor cage impedance back into any of the stator windings using transformer action.

The test is done be establishing a low-level AC voltage (10% of rated) across any two (2) or the three (3) phase motor leads. This causes a small portion of rated current (about 8% of rated) to flow through these two (2) windings. The rotor bars become part of the inductive circuit due to transformer action. As the rotor is turned slowly by hand, any significant change in rotor circuit impedance (broken bar) is reflected back into the stator circuit as a change in AC current. This change is typically an indication of either broken bars or bar to connection ring breaks.

The test connection procedure requires the connection of a stable AC supply voltage (50 or 60 Hz) across two (2) of the three (3) phase windings. A current meter is placed in series with the voltage supply. The connection circuit can include the motor supply cables since they should not change. However, if the cable runs are long, they can become a major part of the total impedance circuit and minimize the effect on current due to rotor problems. The motor need not be uncoupled if it can be turned easily.

With the power applied across two (2) of the windings, the motor circuit should draw approximately 8% of rated current. The amp meter reading should be monitored and the motor rotor should be slowly rotated at an even rate (1/8 to ¼ rpm). The current should remain stable during rotor rotation. A significant dip in current (10% or more) is a good indication of a broken bar or bar to ring connection.

Although the test current is significantly less than normal running current, the windings are still subject to resistance heating. Care should be taken to minimize the time of machine energization.

Motor winding temperature can be monitored by using the motor winding RTD’s (if equipped) or by using the Resistance Method as described in IEEE Standard 112-1991 Sec.8.3.3. Winding temperature should not be allowed to exceed 75^{o}C.

Motors have been known to run successfully for some time with cracked or broken bars. However, once a bar breaks, it is likely to become loose in the slot and start arcing. Eventually, the bar will be thrown from the rotor and damage both the rotor and the stator. This will typically result in a stator rewind, rotor re-bar and rotor iron re-stack along with significant re-work of the stator core surface.

Starting current places the most stress on rotor cages. To maximize the remaining life of a motor with suspected broken rotor bars; the number of starts should be minimized. To reduce the possibility of developing broken rotor bars, the motor should not exceed the manufacturers recommendations covering starting.

B
EMI DIAGNOSTICS

EMI and RFI are acronyms for various types of electrical emissions, interference or noise, also referred to as electromagnetic interference and radio frequency interference.

EMI diagnostics involves the broadband acquisition and analysis of frequencies typically in the range of 10 kilohertz to 1 gigahertz using high frequency current transformers and special radio receivers/spectrum analyzers.

EMI may be caused by random electrical noise, corona, partial discharges, and arcing, and may be of a synchronized or unsynchronized nature. Utility sources of EMI include transmission lines, transformers, switches, static exciters, electrostatic precipitators and motors and generators. Other commonly encountered sources of EMI include computers, TV sets, radios and cell phone.

EMI problems and possible causes encountered within the Utility environment can be divided into five (5) basic identifying groups:

1. Arcing-broken rotor bars, loose connectors, broken conductors (including within the stator).
2. Corona-dirty or contaminated windings, some internal insulation voids.
3. Gap Discharges-partial discharges
4. Microsparking-possible sign of dirt contamination, chemical residue, oil or rust.
5. Random Noise-insulation contamination, wet stator bars.

When pursuing EMI diagnostics it is imperative that the Analyst be fully equipped and trained. As James Timperley, of AEP, states at the EPRI Electromagnetic Interference Conference in Annapolis, Maryland in 1999:

“Separating the defect related EMI from the ambient RF signals and the usual broadband electronic pollution in an industrial environment requires experience, sophisticated test equipment and a skilled technique. Those who attempt to accomplish this task must be familiar with high frequency propagation as well as the operation of power frequency systems and their failure modes.”

C
MOTOR FULL OF DIRT/OIL/DUST

General Information

Motors are subjected to different environmental conditions and operational environments. The ideal motor environment would be a moderate temperature (68^{o}-72^{o} Farenheit), humidity controlled (50% relative humidity), filtrated air room. The motor winding would never be contaminated by dirt, oil would not be present to mix with the dust that is not there and winding temperatures would never exceed the manufacturer's design rating. Not many plants have an ideal environment. The problem with a less than ideal environment is that airborne contaminants are pulled into open motor frames by the normal cooling air flow. The contaminants will mix with oil and/or moisture and build up in low velocity locations around the winding end turns and stator air passages. The chief concerns to the motor are increased operating temperatures due to loss of heat transfer and/or blocked air ducts, abrasion/breakdown of the winding insulation due to chemical attack, reduced dielectric strength of insulation due to moisture intrusion.

In lieu of the ideal environment, the following actions can be taken to determine if a degrading condition or "internal contamination" exist that needs to be addressed to ensure the design life of your motors:

1. Monitor and trend winding temperatures. The single most important data for determining if a winding is dirty is winding temperature. An increase in winding temperature is the primary indication of a degradation in heat transfer capability and/or blockage of air passages in the motor. Motor winding insulation class (A, B, F, H) are thermal classifications that when not exceeded will statistically provide a finite design life. Exceeding a motor's thermal limit will result in a reduction in thermal life (a rule of thumb is that a 10 degree centigrade rise in temperature above design will halve the winding life). The EPRI's "Power Plant Electrical Reference Series, Vol 6,Section 6.8, provides the calculation for design life of a class B motor and how to calculate winding life lost due to operating above thermal design temperatures of a motor: Design Life=$90{,}000e^{-0.07t}$. Dirt, dust, grease, oil all will reduce heat transfer in a motor and drive up operating temperatures. Therefore, an increase in winding temperatures as read by winding RTD's, an external temperature monitor, or thermography trend of inlet/outlet air temperatures provide a means on identifying changes that may correlate to a dirty winding.

2. A marked decrease in polarization index/insulation resistance can be an indication of surface contamination. PdMA's MCE tester identifies contaminated insulation by a series of downward spikes over a polarization index test.

3. A change in winding capacitance can be caused by a change in the coil surface condition/geometry as a result of dirt/grease.

4. Visual inspection of the motor can provide indications of motor contamination. Air inlet screens/filters blocked by dirt, dust, oil or grease are good indication of what the motor internals may be. Discharge screens/filters that show signs of blockage may indicate internal contamination. If oil, dust or grease can be seen on the back of the motor laminations, or on the winding end turns (if visible) it is likely that the motor is internally contaminated.

Repairs

Cleaning of some degree is required for a motor that is believed to have internal cleanliness concerns. The required cleaning in order of cost/severity are as follows:

1. Rewind due to damaged insulation

2. Steam clean, dip and bake (recondition)

3. Steam clean and bake

4. On-site disassembly, hand clean using CO_2 cleaning or; solvent dampened, lint free cloths manual cleaning

5. Partial disassembly to clean end turns using manual cleaning

The degree of repair will vary based on the contaminant, it’s compatibility with the insulation system, etc.

D
EL-CID/LOOP TEST

General Information

The EL-CID and the Loop tests are used for detecting shorted laminations in motor and generator cores. Both of these test work by exciting the core iron using an externally supplied current induction (supply loop) to establish a flux field in the core iron. The loop test utilizes a high core flux density and thermography to locate resulting “Hot Spots” and the EL-CID test utilizes a low flux density and detects shorted laminations using an amplified magnetic pick-up search coil.

As the motor or generator core size increases, the supply loop circuit impedance increases. This in turn requires that the supply test voltage be increased to obtain the required current for testing. There is a point where the EL-CID test may be preferred due to its lower supply current and flux density requirements. The decision between the loop and EL-CID testing is typically made based on the availability of supply voltage necessary and convenience of using the available test equipment. Most motor shops have test equipment that can easily loop test motors up to 5,000 Hp.

Motor and generator cores are made up of thousands of individual sections of core iron. Each of these sections are designed to be insulated from the adjacent sections to minimize or eliminate circulating currents in the core. These circulating currents can cause localized hot spots. These hot spots will accelerate the aging of the adjacent insulation and can result in core iron melting and motor failure. The Loop test is a high flux core test used to detect shorted laminations or localized imperfections, and the short circuit currents that result in ‘hot spots’.

The Loop test involves inducing flux into the core using a calculated number of turns as determined by IEEE-56, then comparing to a reference loop to ensure the intended amount of flux, and using an IR camera to locate areas of higher temperature-‘hot spots’. As a note, before the use of IR cameras, the hand or later, a spot radiometer was used to detect temperature differences. Typically, ‘hot spots’ are defined as those areas that are $5^{o}C$ to $10^{o}C$ above the coolest core temperature.

The EL-CID test uses a signal processing unit to graph sensed current (mA) indications as a current sensor is passed over the core. The higher current readings are an indication of shorted laminations, with an increasingly higher current reading an indication of severity. As a general rule of thumb, if the reading indication is 100 mA or greater, then consider performing a Loop Test with its higher magnitude of flux.

Possible consequences of lamination faults include having a ‘hot spot’ that may darken the local iron, overheat the windings and lead to premature aging, or in an extreme case lead to melted iron and rotor damage.

Typical Repairs:
In order of ease and in cases of less severity, the repairs include:

- Core Cracking-flexing the core iron to break connections and inhibit current flow
- Spreading the laminations and inserting ‘insulating paint’
- Inserting Mica splitting into the laminations
- Removal of a deteriorated section of iron and filling with epoxy
- Re-stacking of the core

References:

“*Handbook to Assess the Insulating Condition of Large Rotating Machines*”. EPRI Electric Power Plant Reference Series, Volume 16,

IEEE-56

E
MOTOR WINDING END TURNS/BRACING LOOSE

Motors with form wound coils generally have some form of end turn bracing. The end turns are severely stressed during motor starts. Current inrush, starting torque, windage all change rapidly. The forces are strong enough to physically move the stator end turn. Motor manufacturers have com up with numerous ways to support/restrain the stator end turns so that the starting forces will not result in a breakdown of the ground wall insulation, the turn-to-turn insulation or the phase/line connections. Surge rings, spacer wedges, glass roving, coil spacers are all mechanical supports that either limit coil movement, or lessen the damaging effect of coil movement. Checking the integrity of these physical restrain systems in necessary to understand the overall health of a motor. Highest area of stress is the line coil.

Failure to identify a breakdown of the end turn supports will ultimately result in either failure of groundwall insulation due to rubbing between coils, or between a coil and the slot iron; or a failure of turn-to-turn insulation due to cyclic stress fatigue of the mechanical connections in the line or phase connections. Another potential failure mode of a loss of end turn bracing is contact between a stator coil with the rotor.

Some methods of identifying loose end turn bracing are as follows:

1. Visual inspection is the most common method of detection. Visual inspection can be performed using a flexible boriscope through vent screens, or inspection plates. Partial/full disassembly that allows visual access to the end turns (normally requires removal of an end bell) and a hands-on inspection. Signs of loose end turns are:

   Broken surge bracket connections (clips, welds, loose bolts, etc.)

   Missing/loose end turn spacers

   Broken roving/ties for coil to surge bracket

   Powdering of winding insulation, end turn spacer material, roving/ties

   Greasing on end turns between coil to spacer interface

2. DC Step voltage will stress the winding insulation to the DC equivalent of full line voltage, which may result in excessive leakage current, or breakdown of insulation weakened by loose end turn induced stresses.

3. Surge testing may also be useful in identifying turn-to-turn insulation degradation of insulation weakened by loose end turn induced stresses.

4. Partial discharge activity……on-line/off-line.

Repairs

Repairs will very depending on the extent of looseness. In an extreme case, a rewind may be required. Often times a permanent repair is possible, even in field repairs can be made, depending on the size/amount of room a particular design has in its end turn area. Many form wound motors do have sufficient room to allow an experience electrician/winder to replace missing spacer wedges with felt pads soaked in an air curing, expanding epoxy that expands as it dries to tighten itself between coils. Loose or missing roving/tie cord soaked in an air/heat curing epoxy/resin can be replaced without need for a rewind. If space allows, spacers or additional ties can be added the motor end turn area using the same methods above to improve th end turn bracing of a motor. In addition, damaged insulation can be reinsulated, once again if space permits by an experienced electrician/winder.

F
STATOR CORE WEDGE LOOSE

General Information

A condition where the stator wedges offer no support for the stator bars. Also a stator core wedge is said to be loose when the wedges can physically move out of the slots.

Partial or complete looseness of individual wedges can be caused by the following:

1. Manufacturing defects/design materials: Excessive use of resilient materials during manufacture may contribute to relaxation during service. Core pressure, the applied and retained core pressure should be sufficiently high to ensure even distribution of the clapping force throughout the punching and to avoid slackness and distortion.

2. Vibration of the stator core and frame due to inadequate support of the core in the stator frame, unbalanced phase loading, insufficient endwinding support, and vibrations due to the 120-HZ ovalizing force caused by the magnetic field.

3. Transient event/slow start, which exert high electromagnetic forces on the end windings and can cause loosening of inadequate endwinding bracing.

4. Normal wear due to thermal cycling: the likelihood of this occurring is a function of the machine axial core length and machine duty (the rate at which the machine is started and stopped).

5. Overloading: prolong overloading the machine could have the same effects as numbers 3 and 4 above.

Common Symptoms

1. There will be a dust or grease generated by fretting actions and these deposits will be easily seen.

2. Missing wedges

3. Punching and spacer movements

Testing Procedures

1. Partial or complete looseness of individual wedges can be detected by tapping either manually with small hamer or by mechanized means.

2. Partial Discharge detectors (machines rated 4kV and above).

3. Physical inspection: There will be a dust or grease generated by fretting actions and these deposits will be easily seen. Where dust and/or grease is present, it is important to distinguish between simple wedge vibration, which may not be a serious concern, and a bar vibration that is always a major concern. Loose wedges may simply cause a small amount of vibration and generate significant amounts of dust without causing severe damage to the wedge. But if prolonged, it could cause bar vibration, may wear into the core iron, and allow filler migration. Observing the amount of dust or grease can not easily assess the degree of deterioration, but if deposits are widespread and heavy, it is certain that bar vibration is occurring.

4. If looseness is suspected, the degree of looseness can be evaluated by carefully inserting knife blade between punchings.

Possible Consequences

1. Loose wedges could results in loose coil, abrasion of ground wall insulation which could lead to ground fault.

2. Coils may loosen and contact the rotor; the loose wedges may chew up and fall into the air gap. Metallic materials in the air gap, particularly those that are larger and magnetic, can cause damage sufficient to require re-stocking the core and replace the stator winding.

3. Loose wedges could cause bar vibration, may wear into the core iron and may allow filler migration.

Repairs

1. Replace the filler materials and/or rewedge.

2. Local looseness can be corrected by adding tapered shims to the affected tooth areas. (core looseness)

3. General looseness can be corrected by re-tightening the core clamping bolts (core looseness).

G
GROWLER TESTING

Growler Testing can be used to check for broken rotor bars and shorted turns in stator windings on induction motors. Growler testing uses the principal that a closed loop of varying flux around any conductor will induce a varying voltage across it. If this conductor (such as a rotor cage or stator coil) forms a closed path, current will flow through it. Growler testing will always require removal of the rotor from the motor.

A growler is a devise made primarily from laminated steel similar to that used to make motor cores. It is typically formed with each punching in the shape of a “U” or a “H”. These punching are then stacked together and an insulated 120 Vac coil is wrapped around its center. This coil is used to establish a magnetization flux field in the growler, which is applied to the areas of the motor to be tested.

Growlers are typically divided into two (2) general classes known as “internal” or “external”. The internal growler is primarily used for testing stator coils. Placing it inside the stator, it is usually “U” shaped and much smaller than the external type.

The external growler is used most often for testing the motor rotor and is “H” shaped. This test is done by placing the rotor just above the open end of the “H” of the growler. The growler open end should span several rotor slots (1/3 to ½ of the total slots) and the inner surface of the top half of the growler should be shaped to provide a surface that is somewhat tangent to the radius of the rotor.

Stator Coil Testing

Testing of motor stator coils for shorted turns can be accomplished by placing the growler inside the stator across the slot of the coil to be tested. A thin piece of metal similar to a hack saw blade is then placed just above the slot containing the other side of the coil. The hack saw blade should be arrange so that it is lengthwise over the slot aligned with the slot wedge.

The motor coil under test must be disconnected at both ends. When the growler is energized, it will form a 60 Hz flux loop around one side of the coil in the slot just beneath it. If there are any shorted turns in the coil, current will be induced in the shorted windings. This current in the shorted turns will then establish a varying flux field in the slot on the other side of the coil under test and cause the hack saw blade to vibrate. Each motor coil can be tested on at a time by moving the Growler and the hack saw blade progressively around the motor stator slots. If any shorted windings are found, the coil should be replaced if possible or the stator rewound. Continued operation with a shorted stator winding will eventually result in a failed winding.

Rotor Bar Testing

Testing of the motor rotor for broken bars is done by placing the rotor in supports just above the open ends of the external growler as described above. The motor rotor is normally positioned with its shaft on supports straddling the growler so that the rotor can be rotated while maintaining a minimum clearance from the growler. Once again the growler is energized and a thin piece of metal is held just above each of the rotor slots at the top of the rotor. The metal indicator should vibrate at every slot indicating current flow down the bar just beneath it. If the metal blade does not vibrate, it is a good sign that the bar is broken and not conducing current. All the top slots should be checked and then the rotor turned to expose the remaining slots for testing.

H

MOTOR WINDING GREASING GUIDELINE

Motor winding greasing develops when a bond breaks between two (2) insulating surfaces and allows movement within the motor stator winding. The insulating surfaces rub together (called fretting), producing a white powder that combines with an oil mist atmosphere created by the cooling action within a motor. The combination deposits a light gray powder on the stator surface (winding greasing).

The primary method of detection is visual. There are no known electrical tests that will detect a breakdown in the integrity of the winding blocking structure within the motor stator. There are monitoring systems available that detect motor end winding movement and vibration using fiber optic sensors.

When greasing is evident, there are two (2) methods of repair commonly used to extend the life of the motor. They are the following:

1. Remove all loose motor stator blocking, clean stator, replace blocking and coat blocking and windings with epoxy resins. (Long term repair)

2. Clean motor stator blocking and windings, coat with Red Eye resins. (Short term repair)

Failure to address a motor winding greasing will continue to allow fretting of the winding insulation. The most common failures associated with winding movement are the failure in the series connection between windings, shorted end windings and failure of torque applications are the most prone to develop motor winding greasing.

I
THERMOGRAPHY SCAN OF ELECTRIC MOTORS

General Information

Thermography is the technique for measuring localized surface temperatures using a camera capable of detecting light in the infrared bandwidth.

Comparative Versus Trending

Thermography can be used to scan equipment for the detection of temperature abnormalitites by using the two (2) most commonly applied methods of fault detection-temperature comparison and the temperature trending. The comparison method detects anomalies by comparing measurements among a population of similar equipment to reveal abnormal readings. The trending method graphs temperature readings for historical comparisons, usually in conjunction with ambient readings.

Electric motors may be trended on a periodic basis with particular attention being given to those times with increased ambient temperatures.

There are four (4) basic areas of concentration when scanning electric motors:

1. Stator-As indicated by skin temperatures with consideration to the cooling medium flow, usually air. General rule of thumb-the life of a winding can be shortened by half with every 10^{o}C rise above nameplate specifications. Possible causes for elevated stator temperatures could be dirty air intakes, dirty discharges or windings, clogged air passages, and motor overloading.

2. Bearings-As indicated by the bearing surface temperature with special emphasis to the loaded area of the bearing. Overheating will degrade the seal and allow foreign material to enter the bearing and/or cause the loss of lubrication. The following are general notes regarding different bearing types:
   - Anti-Friction Bearings-Temperature of most anti-friction bearings can run 130 degrees above ambient. However, the seal, depending on the type may have a lower acceptable operating temperature, and thus may fail before the bearing material.
   - Sleeve Bearings-Surface temperatures o sleeve bearing present difficulties due to the dissipation of heat caused by the depth of material between the loading area and the outside surface, and the cooling medium. It may be possible to compare thermography readings to the thermocouple indication of similar bearings under

similar load to determine condition. Note that the babbitt material has a melting point of approximately 200^{o}F.

– Thrust Bearing-The thrust bearing may be located in a position as to not lend itself to surface temperature readings. In this case, compare and trend the thermocouple readings.

3. Connections-Surface temperature of the lead box should indicate a near ambient reading with normal distribution of heat. If this is not the case, then the lead box may need to be opened for a closer examination of the individual leads. Using the comparative method among the leads, determine if all are normal, keeping in mind that the amount of insulating material may only allow for a small difference in surface temperature (1-3^{o}F) between leads.

4. Coupling-Although rare, some cases of elevated coupling temperatures exist and are usually attributable to severe misalignment and/or lubrication problems.

Reference-TR-108773-V2 *Electric Motor Predictive Maintenance Program*, Final Report, August 1999

Target:
Steam Turbines, Generators, and Balance-of-Plant

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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