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MOTOR CIRCUIT EVALUATION SURVEY

for the

MILL MOTORS

at
XYZ COMPANY

by:

Douglas K. Smithman, P.E.

April 29, 2007

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MOTOR CIRCUIT EVALUATION SURVEY

April 29, 2007

This is a report on the findings of a Motor Condition Evaluation (MCE) survey of the Mill Motors at XYZ Company. The table below summarizes the individual machines tested, their condition and any recommendations as a result of this survey. Those with exceptions are color coded to denote the severity of the exception.

high priority	medium priority	low priority

MACHINE	CONCERN	RECOMMENDATION
BSL-710 Bottom Steckel Mill Motor	Low Polarization Indices on the interpole and A1 circuit. Partial discharging on armature should be monitored. Shape of PI profile is disturbing but not unusual in steel mill equipment. Insulation resistance should increase with time and polarization but this armature goes down.	Wipe all ceramic buss insulators with non-residue solvent. Re-test in dryer conditions.
BSL-711 Top Steckel Mill Motor	Low Polarization Indices on the interpole and A1 circuit. Partial discharging on armature should be monitored. Shape of PI profile is disturbing but not unusual in steel mill equipment.	Wipe all ceramic buss insulators with non-residue solvent. Re-test in dryer conditions.

After the standard tests the motor brushes were removed in order to test the armature and the interpoles individually. This type of testing is beyond the capabilities of the MCE, which is designed for periodic testing and trending, so a hand megger was used. Data is including in the tables below.

Temperature corrections for 15°C are shown adjacent to the raw data. This chart is used to determine appropriate correction factors according to IEEE-43.

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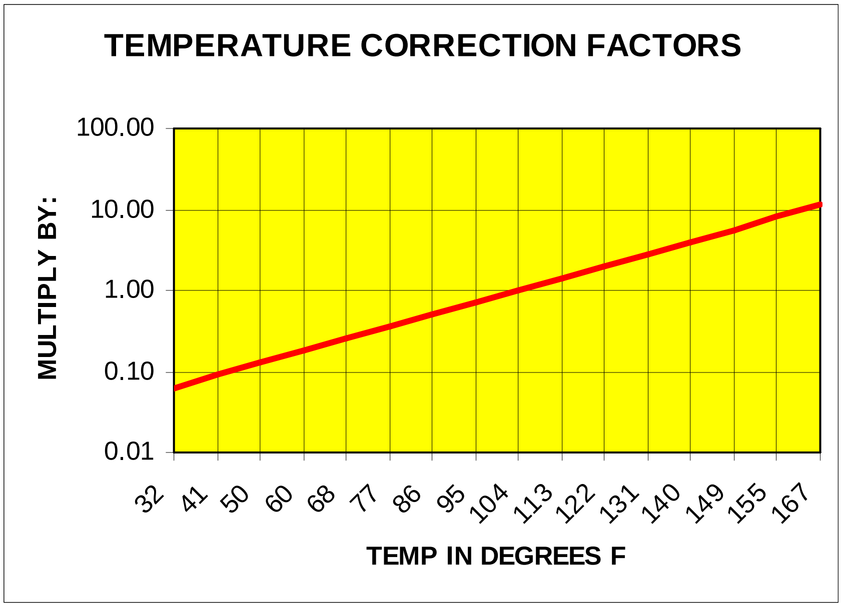

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Top Motor

	Armature		A1/Interpoles		A2	
	Raw	Corrected	Raw	Corrected	Raw	Corrected
15 sec	600	108	68	12	600	108
30 sec	720	130	73	13	620	112
45 sec	980	176	74	13	630	113
60 sec	1270	229	73	13	630	113
90 sec	1740	313	72	13	630	113
2 min	1950	351	59	11	630	113
3 min	2000	360	58	10	630	113
4 min	2000	360	57	10	630	113
5 min	2000	360	56	10	620	112
6 min	2000	360	56	10	600	108
7 min	2000	360	55	10	580	104
8 min	2000	360	56	10	600	108
9 min	2000	360	55	10	590	106
10 min	2000	360	55	10	590	106

DA		1.76		1.00		1.02
PI		1.57		0.75		0.94

Bottom Motor

	Armature		A2/Interpoles		A1	
	Raw	Corrected	Raw	Corrected	Raw	Corrected
15 sec	300	54	160	32	226	41
30 sec	490	88	170	31	228	41
45 sec	700	126	180	32	227	41
60 sec	800	144	180	32	223	40
90 sec	1100	198	180	32	216	39
2 min	1300	234	183	33	214	39
3 min	1600	288	186	33	213	38
4 min	1900	342	190	34	212	38
5 min	2000	360	192	35	212	38
6 min	2000	360	195	35	212	38
7 min	2000	360	199	36	213	38
8 min	2000	360	202	36	214	39
9 min	2000	360	105	19	215	39
10 min	2000	360	205	37	214	39

DA		1.63		1.06		0.98
PI		2.50		1.14		0.96

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The megger readings on both armatures and on the A2 side of the Top Motor were very erratic. This indicates partial discharging in the insulation system. Partial discharging is a destructive condition that should be monitored. Damage may take weeks, months or years to become a problem but damage to the insulation system is taking place every time a discharge occurs.

Also, there was a significant rain fall less than 48 hours prior to these tests.

Please find the following reports attached.

1. MCE MOTOR CONDITION SUMMARY – ‘OVR(MCE)’ in the insulation resistance category means that the measurement exceeds the upper limit of the MCE tester; 2,000MΩ - uncorrected.
2. MCE POLARIZATION INDEX AND DIELECTRIC ABSORPTION SUMMARY – If a field in blank or ’N/C’, this indicates that the PI or DA ratio could not be calculated. This occurs when one or both of the values exceed the measurable scale of the MCE tester, 3,500 MΩ.
3. PI RAW DATA.

MCE Summary Report

Submitted By: D. K. Smithman, P.E. **Description:** Steckel Mill Drive Motors **Date:** 04/29/2007

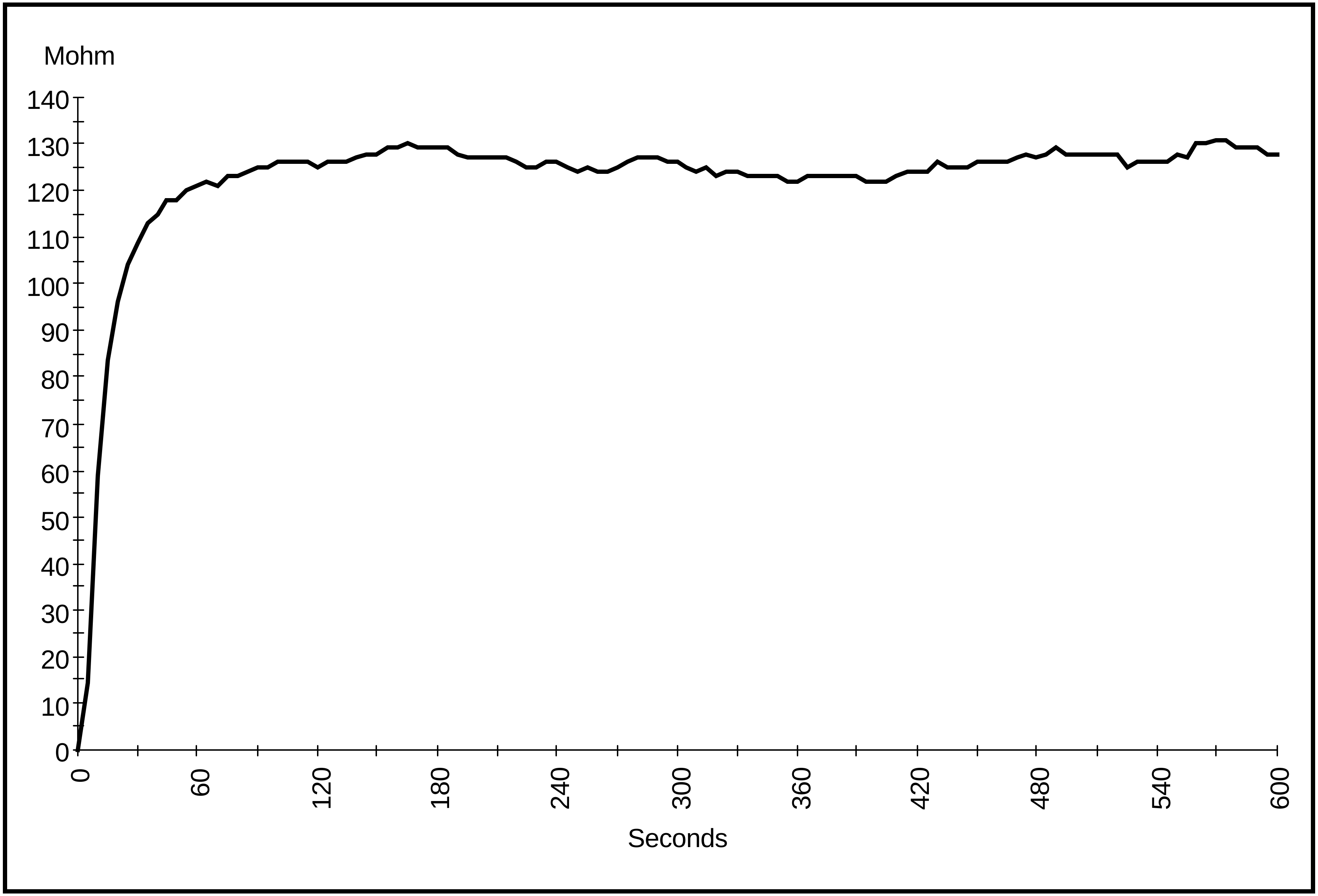
Test Date	Resistance to Ground	Capacitance to Ground	Resistance or Resistive Imbalance	Inductance or Inductive Imbalance	Motor Condition
Motor ID 710 Lower Steckel Mill Motor					
Motor Section DC Armature					
4/29/2007 8:13:44 AM	46.2 Mohm	870750 pF	0.00505 Ohms	3.835 mH	Observe
Motor Section DC Field					
4/29/2007 9:31:09 AM	OVR (MCE) Mohm	82000 pF	0.2685 Ohms	31.72 mH	Observe
Motor ID 711 Upper Steckel Mill Drive					
Motor Section DC Armature					
4/29/2007 7:55:59 AM	13.3 Mohm	973750 pF	0.00386 Ohms	3.605 mH	Caution
Motor Section DC Field					
4/29/2007 8:58:52 AM	OVR (MCE) Mohm	73250 pF	0.2665 Ohms	23.44 mH	Caution

MCE Polarization Index and Dielectric Absorption Summary Report

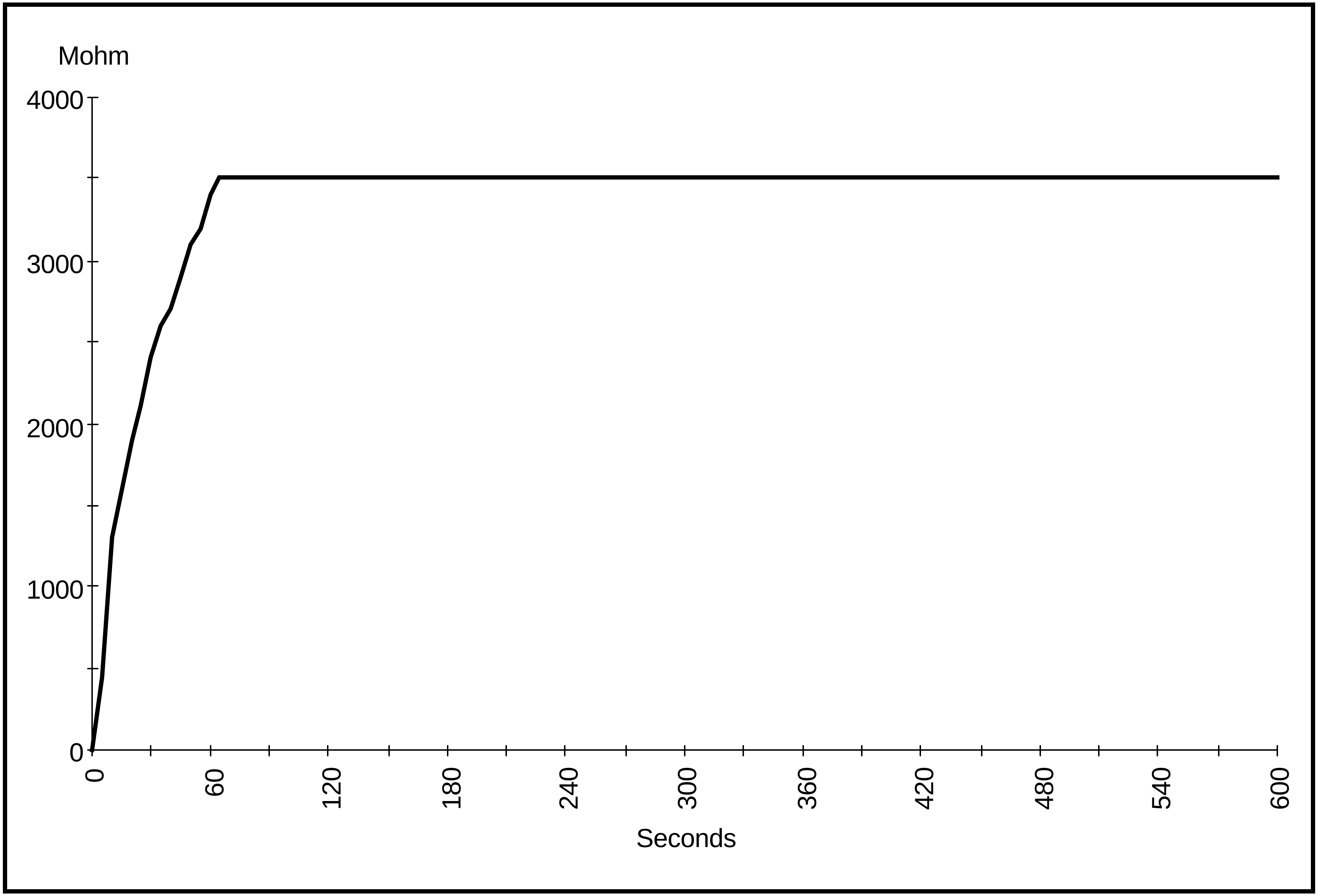
Submitted By: D. K. Smithman, P.E. **Description:** Steckel Mill Drive Motors **Date:** 04/29/2007

Motor Section / PI Baseline Date	Baseline Voltage	Last Test Date	Last Test Type	Result	Test Voltage	User
Location Name MCE\MS-Conshohocken\Edger Motors						
Motor ID 710 Lower Steckel Mill Motor						
DC Armature						
4/29/2007 8:31:52 AM	500	4/29/2007 8:31:52 AM	PI	1.06	500	
DC Field						
4/29/2007 9:25:59 AM	500	4/29/2007 9:25:59 AM	PI	1.03	500	
Motor ID 711 Upper Steckel Mill Drive						
DC Armature						
4/29/2007 8:07:12 AM	1000	4/29/2007 8:07:12 AM	PI	0.93	1000	
DC Field						
4/29/2007 9:10:29 AM	1000	4/29/2007 9:10:29 AM	PI	1.4	1000	

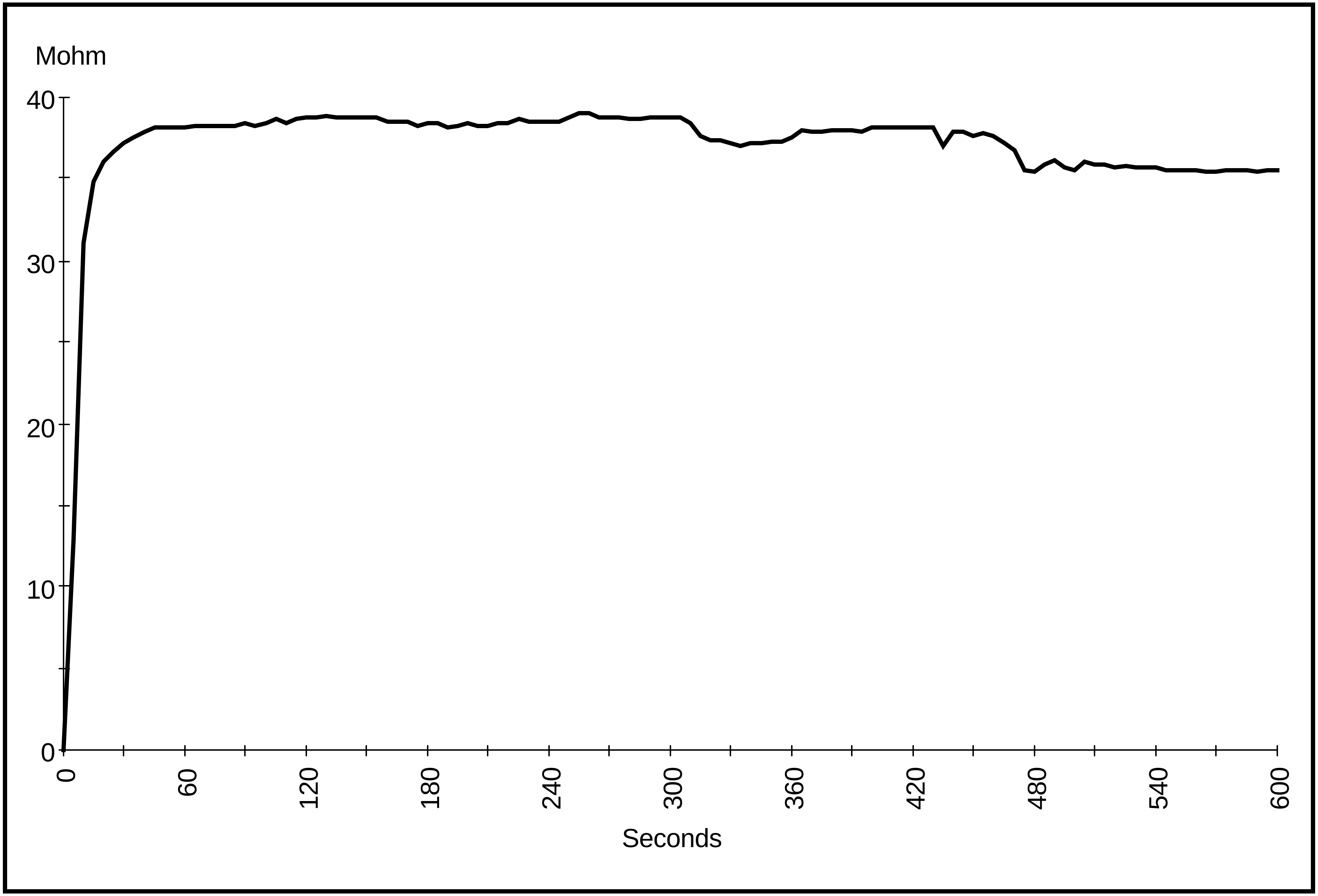
PI Test (710 Lower Steckel Mill Motor - DC Armature) 04/29/2007 08:31:52 AM



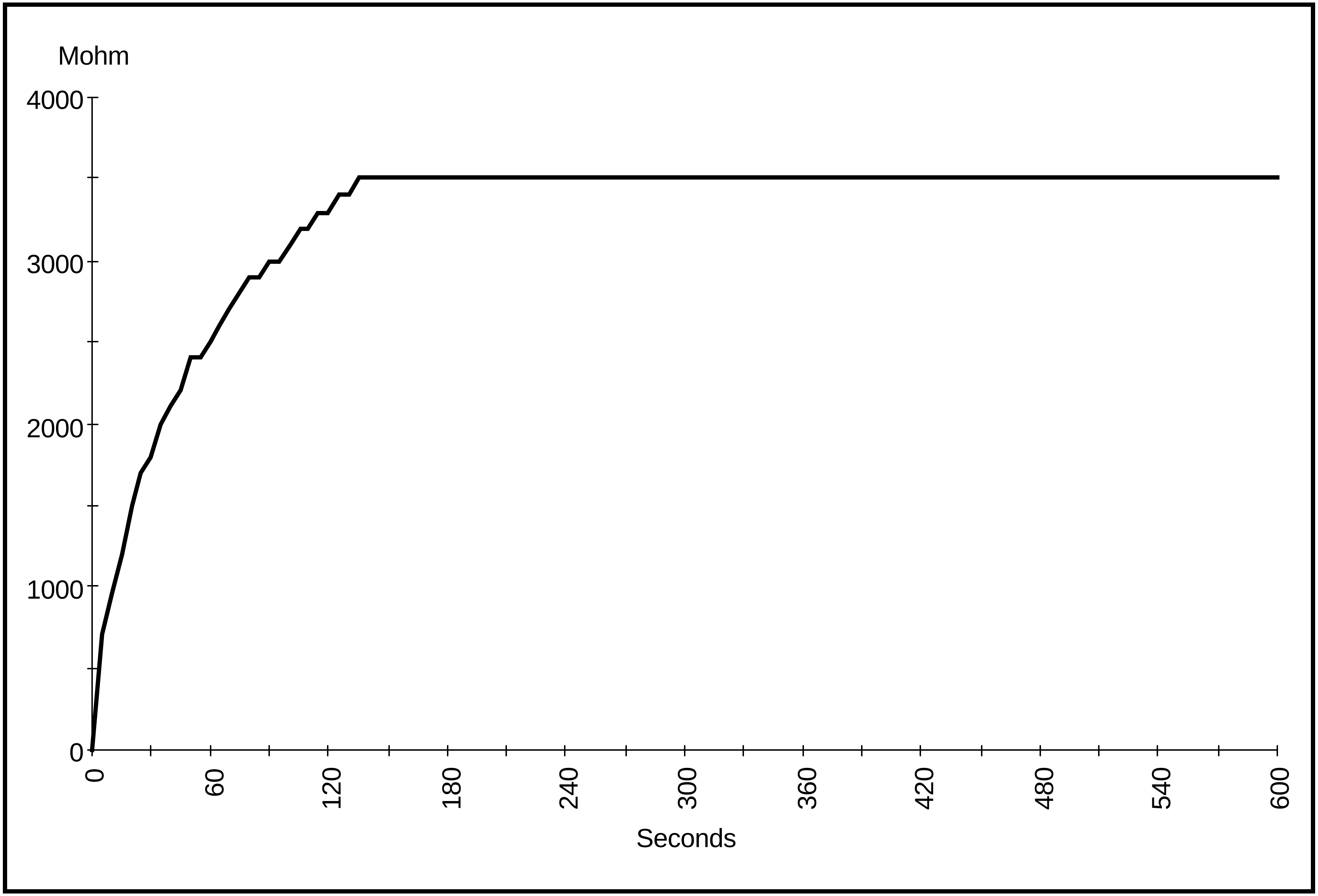
PI Test (710 Lower Steckel Mill Motor - DC Field) 04/29/2007 09:25:59 AM



PI Test (711 Upper Steckel Mill Drive - DC Armature) 04/29/2007 08:07:12 AM



PI Test (711 Upper Steckel Mill Drive - DC Field) 04/29/2007 09:10:29 AM



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MOTOR CIRCUIT EVALUATION SURVEYS

This report documents the findings of a Motor Circuit Evaluation (MCE) survey. This survey was conducted using an MCE tester. MCE testers measure several physical parameters of electrical circuits in a highly accurate and repeatable fashion. This results in a quantum increase in measurement quality over conventional 'megger' testing. The quality of the data makes it possible to trend each of the measured parameters over time to spot deteriorating conditions long before they interfere with circuit operation.

Parameters measured in the standard test are:
1. Resistance to ground (temperature corrected)
2. Capacitance to ground
3. Circuit resistance (temperature corrected) or resistive imbalance
4. Circuit inductance or inductive imbalance

In addition to the standard test, the customer may choose to include Polarization Index testing and/or Rotor Influence Coefficient testing. Polarization Index testing provides a valuable second opinion to insulation health. IEEE 43-2000 notes:

> **9.4 Machines rated at 10 000 kVA and less, to be considered in suitable condition for operation or for over potential tests, should have either a value of the polarization index or a value of the insulation resistance (at 40 ^{o}C) at least as large as the recommended values.**
>
> **9.5 Machines rated above 10 000 kVA should have both the polarization index and insulation resistance above the minimum values.**

Rotor Influence Coefficient testing is not an IEEE specified test, however it does provide valuable insight into the condition of induction, synchronous and wound-rotor motors.

MEASUREMENT METHOD

The circuit temperature is measured and entered into the MCE to be used for temperature correction. Temperature correction removes the 'apples and oranges' comparisons common in insulation measurement programs. The relationship between insulation resistance and temperature is approximately two-to-one for every 10^{o}C change in temperature. This makes trending of uncorrected data virtually meaningless. It also precludes comparison with IEEE and other published minimum levels.

The attention to quality measurements continues with the connections to the circuit being tested. Each measurement clip actually contains to legs of a circuit, one attached to each side of the clip. When testing is initiated, resistance through the entire circuit on each measurement lead is measured. If the resistance is greater than 1 Ω, the test is terminated until the connection is corrected. This ensures that rust, surface dirt or other connection errors do not contaminate the values being measured.

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Upon completion of the test, the lead resistances are re-checked to ensure that they haven't come loose during the test. If they have, the test is automatically aborted.

The test results are compared against alarm values during the test. This allows the operator to make an immediate assessment of anomalous conditions and to re-test or perform further investigations as needed. The alarm levels are either absolutes or historical averages or both.

Upon completion of a test, the values are archived for reporting and future reference.

RESISTANCE-TO-GROUND TESTS

Resistance-to-ground tests, commonly known as 'Megger' tests, are done to evaluate the condition of insulation systems. MCE resistance-to-ground testing is a temperature compensated megger test. Insulation resistance values are extremely sensitive to winding temperature. As noted earlier, this sensitivity results in approximately a two-to-one error for every 10 ^{o}C in temperature change. By mathematically compensating for winding temperature, MCE eliminates this error automatically. IEEE43-2000 recommendations for test voltage and minimum insulation resistance are shown below.

Guidelines For Test Voltages

Winding Rated Voltage	Insulation Resistance Test Direct Voltage
<1,000	500
1,000-2,500	500-1,000
2,501-5,000	1,000-2,500
5,001-12,000	2,500-5,000
>12,000	5,000-10,000

Minimum Insulation Resistance Values, Corrected to 40°C

Resistance values are in MΩ	
$IR_{1\ min}$ = kV+1	For most windings made before about 1970, all field windings, and others not described below.
$IR_{1\ min}$ = 100	For most DC armature and AC windings built after 1970 (form wound coils).
$IR_{1\ min}$ = 5	For most machines with random wound stator coils and form wound coils rated below 1kV.

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CAPACITANCE-TO-GROUND TESTS

Resistance-to-ground testing and PI measurement are time proven methods of determining insulation health and quality. However, changes in capacitance-to-ground provide another good indicator of contaminant build-up. This measurement provides a 'second opinion' of sorts and improves the level of confidence in decision-making based on these tests. Standard practice is to increase monitoring frequency for changes of more than 10% from a statistical baseline and schedule a cleaning for changes greater than 100%. Also, a very high (>999,999 pF) value combined with a 0.00 value of resistance-to-ground, is an indication of a 'hard' ground, as opposed to carbon tracking or generally deteriorated insulation. This is important in floating systems such as DC power circuits and is a strong indicator that immediate action is required.

A point of confusion sometimes arises when we state that a high capacitance indicates poor insulation. This is easily explained by the mathematical definition of capacitance in an alternating circuit;

$$C = \frac{i}{de/dt}.$$

This shows that capacitance equals the charging current divided by the rate of potential change. It also shows that for a given potential change, de/dt, capacitance and current are proportional. Since the highest current exists in a grounded situation, this also produces the greatest capacitance. Please keep in mind that this explanation neglects inductive and resistive affects in alternating circuits.

RESISTANCE AND INDUCTANCE TESTS

Insulation to ground failures are certainly a major cause of motor failures; however they are not the only cause. Coils and circuits can also fail when the insulation between the windings fails or when conductors themselves fail. Magnetic circuit components such as laminations, air gap and amortisseur windings can also fail. Measuring and trending resistance and inductance can often provide early warnings of pending problems before they result in overheating and catastrophic failure. Used together, these parameters reinforce conclusions and provide a higher level of confidence in results than either measurement would by itself. Standard practice is to increase monitoring frequency for resistance changes of more than 3% from a statistical baseline and to inspect for defects for changes greater than 5%. For inductance measurements, the limits are 8% and 15%, respectively.

POLARIZATION INDEX TESTS

An additional property of insulation that has a significant effect on its quality is how it builds up a charge. In a good, clean insulation system, the resistance-to-ground value will continue to rise while voltage is applied and the insulation polarizes. However, if significant amounts of water, dirt, or oil are present, the resistance-to-ground will hold steady or even drop over time. The polarization index (PI) is a good method of measuring the cleanliness of an insulation system. It is the ratio of the ten-minute resistance-to-ground measurement to the one-minute measurement. IEEE 43-2000, paragraph 9.2 recommends a PI of 2.0 or better for Class B or Class F insulation systems, which covers most modern motors. Paragraph 4.3.5 notes that temperature

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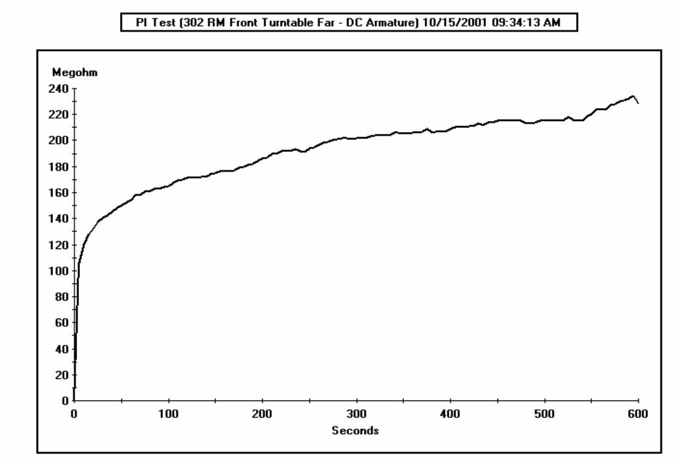
correction is not required for PI calculation. This is because PI is a ratio and the temperature corrections cancel out mathematically.
IEEE43-2000 minimums for PI are shown below.

Recommended Minimum PI Values

Note: If the one-minute insulation resistance value is above 5,000 MΩ the calculated PI may not be meaningful

Thermal Class Rating	Minimum PI
Class A	1.5
Class B	2.0
Class F	2.0
Class H	2.0

Plots of the data recorded during a PI test, called PI profiles, are also insightful. An ideal profile will rise quickly at first and then at a slower rate through the entire test. Leveling off or dropping values often indicate marginal insulation or contamination build-up. Also, a jittery profile indicates partial discharging is taking place, that is, the voltage builds to a high enough potential to partially discharge, does so and builds up again. This cyclical discharging may take place at the same potential or at increasing potentials as the insulation gradually polarizes.



ROTOR INFLUENCE COEFFICIENT TESTS

The Rotor Influence Coefficient (RIC) test is designed to find faults in the rotor and air gap in induction motors. It will also identify loose connections. Phase-to-phase inductance is measured every five electrical degrees as the rotor is manually rotated through 90 degrees. For a perfect rotor, this data will produce three offset sine waves. Faults will be shown by spikes, skewing and baseline offsets of the data.