A NEW APPROACH TO PERFORM ACCELERATED RELIABILITY TESTING OF LOW TENSION MOTORS

Shaik Hussain Basha & Sudhangshu Chakravorty

Reliability Centre, Global R&D, Crompton Greaves Limited, Mumbai, India

E-mail: hussain.shaik@cgglobal.com; sudhangshu.chakravorty@cgglobal.com

ABSTRACT

Most of the engineers finds it very tedious to do accelerated reliability test of any motor product if it has to be mechanically loaded as it involves lot of difficulties in motor's loading capabilities and its size, which also directly impacts the development time and cost. This is why all the sequences in accelerated reliability test are done on no-load condition which gives results but are not accurate since in field motors are always under loading condition. To overcome all these difficulties, the paper proposes a new approach to perform accelerated reliability testing of low tension 3 phase motors under full load without actually coupling mechanical load to the motor shaft. The approach is simple and easy to implement. In this approach, instead of mechanical loading motor is equivalently loaded just by giving a supply voltage approximately 20-25% greater than the rated voltage to get same load current similar to fully loaded motor across all the three phases. Therefore, the application of proposed approach to perform accelerated reliability testing is experimented on low tension motor and results were discussed in detailed in the paper. From our practical work, the proposed approach has proven more accurate results compared to the results of previously conducted Reliability analysis done on no-load condition. Hence, the approach will definitely leads to get faster and better results in a simple and cost effective way.

Keywords: Accelerated testing, HALT, motor loading schemes, motor test set ups

1. INTRODUCTION

Reliability has continued to be prime concern of the motor designers and manufacturers since induction motor is the workhorse for modern manufacturing and process plants. It has been clearly seen that some form of "accelerated reliability testing" is required to detect latent failures modes in the laboratory which can pose reliability problems during field, since large scale manufacturers cannot wait for the field results to establish the reliability of their products. An accelerated Reliability test like HALT (Highly accelerated life testing) is an advance testing technique used to identify the design weaknesses, failure modes and product design margins (operating limits). In such test an aging/invoked deterioration of an item will induce to produce normal failures in a very short time by operating at stress levels much higher than would be expected in normal use. But conducting "accelerated testing" on motors would be a challenging task for the engineers as it involves many difficulties in motor loading capabilities and motor sizes. Also, to do so one should have large reliability test facilities this requires high development cost and time. To avoid these difficulties, in general, most of the engineers perform these accelerated tests at no-load conditions. However, it would be inadequate as we aren't simulating field conditions so that test results may not be as same as field results.

From literature survey it is observed that a number of loading schemes have been developed without actually loading the motor such as dual frequency method, phantom loading method, synthetic loading method, variable inertia test [1]–[4] but these methods have their corresponding pros and cons. Recently Metwally [5] proposed the concept of "Loadless full load method" for equivalent loading of 3-phase induction which is simple and cost effective. The method is simply to connect the motor under test while it is unloaded to a supply of voltage higher than the rated voltage of the motor by about 20-25%. It has been found that a voltage of 120% of the rated voltage of the motor under test is a suitable value for motors of different sizes and speeds. This value of voltage circulates a current which exceeds the full load current for small size motors and stays less than the full load current for large size motors. This method does not require any mechanical load to be coupled to the motor shaft. The motor draws only the full load losses from the electrical supply. Hence, there is no need for some arrangement to either dump an electrical power equal to the rated power of the motor under test or to return it to the supply. To validate Loadless full load method, an experimental study has been carried out and the results have provided confidence to use this method.

Therefore, in this work, the concept of "Loadless full load method" is adopted for equivalent loading of 3 phase motor and conducting accelerated reliability testing on them. This approach helps us to simulate the field conditions i.e., full load condition instead of no-load condition, and also avoids motor loading setup with high development cost and time.

2. PROPOSED ACCELERETED RELIABILITY TEST SET-UP FOR 3-PHASE MOTORS

Figure 1 represents a schematic diagram of proposed laboratory layout of Accelerated Reliability test set up. The proposed test setup is very simple, cost effective and easy to implement. This is because as the setup completely avoids mechanical load set up. The set up includes a test motor; 3-phase power source to run motor; auto transformer to get required over voltages; power instrumentation with data acquisition system to monitor and store line to line voltages and line currents at motor terminal during the entire test; thermocouples and a data logger to monitor temperature rise in and around test motors; and a environmental chamber to create temperature and humidity stresses on motor at much elevated stress levels.

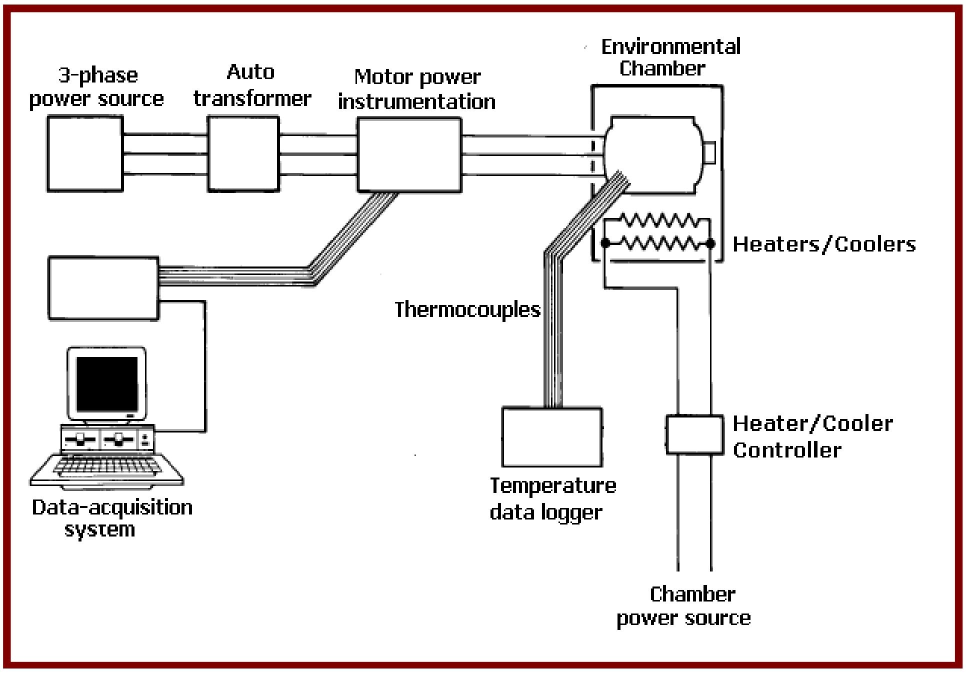

Figure1: Schematic diagram of proposed laboratory layout of Accelerated Reliability test setup

3. EXPERIMENTAL WORK TO VALIDATE "LOADLESS FULL-LOAD METHOD"

Tests have been conducted on Crompton Greaves make 7.5 hp 4P TEFC SCR Motor to validate the method i.e., achieving full load current by increasing input voltage by approx. 20-25% without actually loading the motor. Both the full load tests at rated voltage (415V) and no-load test at 23% above the rated voltage (510V) were performed with the help of motor testing equipment i.e., RDS®, M.E.A. Testing System for a duration of three hours each. Using motor test system performance test data has been captured for every 5 min of operation in both tests as shown in Appendix-I, Table 1-2. Table 1 present the motor performance test data conducted at rated voltage and Table 2 present the motor performance test conducted at above 23% above the rated voltage. Respectively the temperature rise graphs for both the cases are also captured as shown in Appendix-II, Figure 2.

These experimental results were compared each other and the results confirmed that the full load current is same in both the cases. Hence this method is used for equivalent loading of motor during accelerated reliability testing of motors.

4. PROPOSED APPROACH TO EXECUTE ACCELERATED RELIABILITY TESTING – A CASE STUDY ON 20HP MOTORS

An accelerated Reliability test like HALT is conducted on Crompton Greaves make 15 kW 4P TEFC SCR Motor (ND160L) to determine its operating limits and to identify design weaknesses/weak components. A step-by-step approach to execute HALT is explained as below:

Step1: Conducting design verification test to confirm product specifications

Before doing HALT, it is necessary that the motors to be tested should pass design verification tests which performed within the specified limits. This is because, in general HALT stress levels will start above specified stress levels.

Step2: Development of HALT test plan

To develop a HALT test plan one should have good understanding of product like its functionality, specifications, applications, applicable field stresses, critical parameters to reliability (CTR), failure criterion etc. Since motor is not a new product, it is known that in the field motors experienced gradual/rapid deterioration is due to combined effect of electrical (like voltage fluctuations), mechanical (like vibrations) and environmental stresses (like temperature, humidity. Therefore all these stresses are considered in HALT test cycle as shown in Table 3 and the test cycle repeats in a stepped manner.

Cycle	Voltage (V)	Current (amps)	Duration	Load / No load	Combined Stresses		
					Temperature	Humidity	Switching (On/ Off)
1	510	27.5	3 hrs	Full load	50ºC	95% RH	50 min On & 10 min Off
Total duration per Cycle = **3 hrs** No. of Switching per cycle = **3** No. of samples to be tested = **3**							

Table 3: Test cycle plan

In general, HALT is a series of tests. The following typical tests were performed during HALT on motors and corresponding stress profiles are shown in Fig. 3-6.

1. Vibration step stress test
2. Low temperature step stress test

3. High temperature step stress test with humidity
4. Thermal Cycling test

Step3: Design and development of HALT test up

Proposed Accelerated Reliability test setup (explained in section 3) was designed and developed to execute the above series of tests

Step4: Execution of HALT

Motor to be tested is kept inside the environmental chamber to create control environment and connected to a power source which supplies input voltage of 23% greater than rated voltage to get full load current on motor winding. To measure/monitor temperature rise of the motor, thermocouples were positioned at different locations of motor body and stator windings. Before starting the test, major motor parameters are measured at room temperature under operation condition and recorded. After that the following tests are performed in a series until the operating limits were found or it reaches to fundamental limit of the technology.

1. Vibration step stress test

   The parameters for random and sinusoidal Vibration test are the frequency limits, the 'g' or 'Grms' level and the duration of exposure. Uniformly for each vibration step rise level, 3 hours of exposure is applied in both sinusoidal and random vibration tests. The frequency band is chosen as 10 Hz to 250 Hz. The test has been carried out as shown in Fig. 3 until an operating limit has been found.

2. Low temperature step stress test

   The low temperature test steps started from -10°C. Depending on the failure yield at each step, the advancing steps are decided. The test has been carried out as shown in Fig. 4 until an operating limit has been found

3. High temperature step stress test with humidity

   The high temperature & humidity steps were started from 60°C & 95 %RH. Depending on the failure yield at each step, the advancing steps are decided. The test has been carried out as shown in Fig. 5 until an operating limit has been found.

4. Thermal cycling test

   The thermal cycling is carried out within the observed thermal operating limits as shown in Fig. 6. The dwell time in each of the temperature extremes (high and low) is chosen as 3hrs. The transition time from high to low & low high is taken as approx. 30mins and total test duration for one cycle is 7hrs. Uniformly, 7 numbers of thermal cycles are successfully carried out.

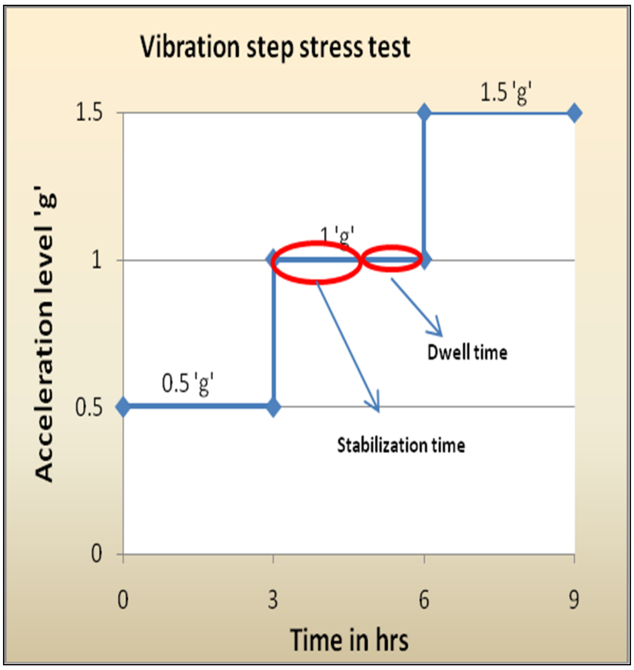

Fig. 3: Vibration step stress test profile

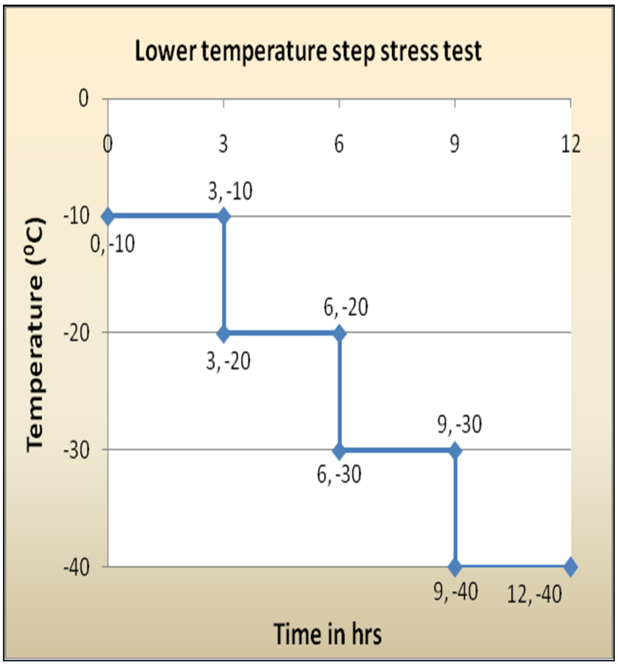

Fig. 4: Low temperature step stress test profile

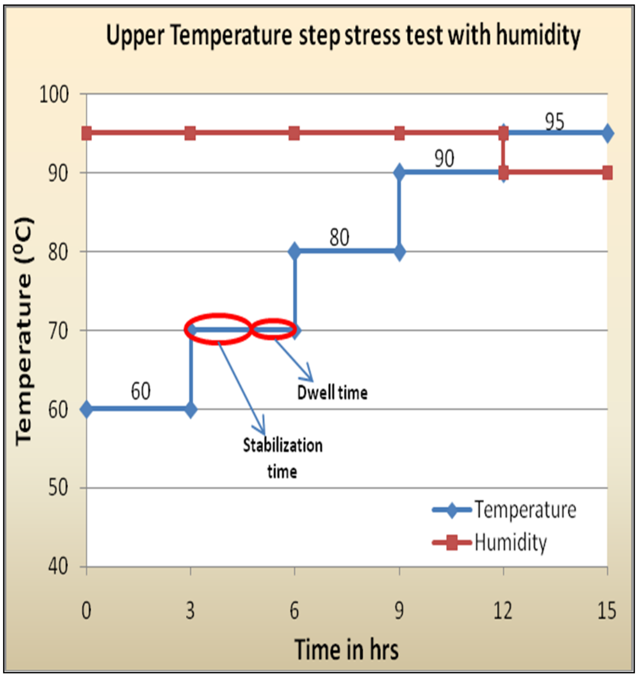

Fig. 5: High temperature step stress test profile

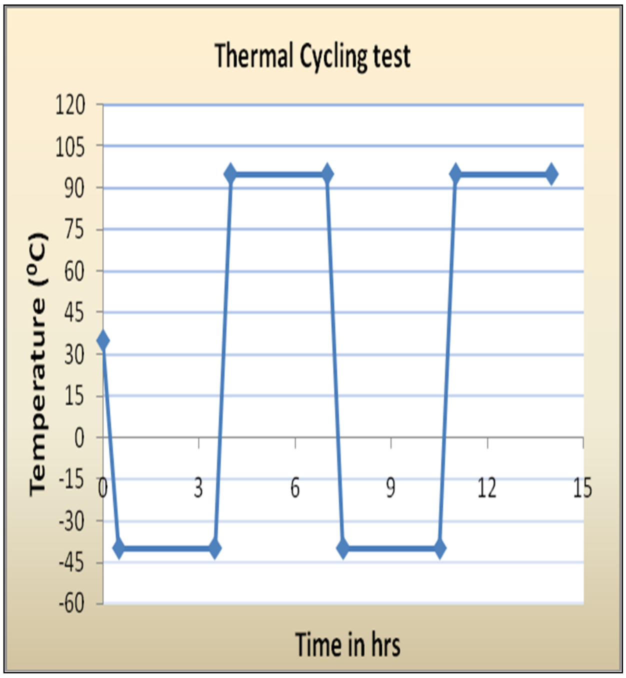

Fig. 6: Thermal cycling test profile

Step5: HALT test results

Series of tests conducted	HALT Test Findings		
	Sample 1	**Sample 2**	**Sample 3**
1. Vibration step stress test	No abnormality is observed	No abnormality is observed	At the end of 4th step rise, heavy noise is observed and the reason was found to be as **rotor touch failure (soft failure)**. The problem was corrected and test continued.
2. Low temperature step stress test	No abnormality is observed at the end of test	No abnormality is observed at the end of test	No abnormality is observed at the end of test
3. High temperature step stress test with humidity	At the start of 5th step rise, sudden rise in temperature is observed. No failure is observed at the end of 7th step rise.	**FAILED** at 7th step rise **(hard failure)** It is observed that sample drew more current before it fails. It is concluded as **winding failure** due to **inter-turn short**.	No abnormality is observed at the end of 7th step rise.
4. Thermal cycling test	No failure is observed at the end of 7 thermal cycles	Test stopped as motor failed	Sudden rise in temperature was observed at the end of 4th cycle. No failure was observed at the end of 7 no. of thermal cycles.
5. High temperature step stress test with humidity	**FAILED** at the start of 11th step rise **(hard failure).** It is concluded as **winding failure** due to **inter-turn short**.	Test stopped as motor failed	**FAILED** at the end of 9th step rise **(hard failure).** Additional sudden rise in winding temperature was observed before it fails. It is concluded as **winding failure** due to **phase to phase short**

Step6: HALT conclusion

The observed failure modes and their failure mechanisms, operating limits etc. from HALT results are compared with the previously conducted motor reliability analyses. From the results it is found that an average of 25% of deviation in thermal limits and 40% of deviation in vibration limits are observed. It means that the operating limits are much lower compare to previous results. In addition, the analysis also identified CTR (Critical to Reliability) components/parameters like insulation paper, location of failure zone etc for reliability improvement to further motor life extension.

5. CONCLUSION

This paper presented an approach to perform accelerated reliability testing on 3- phase motors using the proposed test set up. The approach is very simple, cost effective and easy to implement. This is because; the proposed test set up completely avoids mechanical load setup since motor is equivalently loaded just by giving a supply voltage approximately 20-25% greater than the rated voltage to get same load current similar to fully loaded motor. This in turn helps to eliminate the complexities involved with motor loading capabilities, motor sizes, and requirement of large reliability test facilities. Therefore, the proposed setup directly saves development cost and lots of time. Therefore, using the proposed approach a practical work of HALT on 20hp three phase motor is conducted and results of work is explain in-detailed in the paper. The results of the proposed work provided good results when compared with previous history of reliability test results conducted at no-load conditions in terms of its operating limits determined for the same failure modes. In addition, the analysis provided information on critical to reliability parameters to further motor life extension. Hence, this approach will lead any engineer to get faster and better results in a simple and cost effective way.

6. ACKNOWLEDGMENT

The authors would like to express their gratitude to the management of Crompton Greaves Ltd., for providing the necessary authorization and opportunity to publish this paper.

7. REFERENCES

[1] Ytterberg A. "A new method for fully loading induction machines not having a driving motor or a load machine, the so-called Jolting test", Teknesk Tidsykvijt,1921.

[2] Fong W. "New temperature test for poly-phase induction motors by phantom loading". Proc IEEE 1972;1A(7):883±7.

[3] Ghoneem G. "Temperature tests for three phase induction motors by a new synthetic loading system", Port Said Sci Engng Bull 1995; 7: ±75.

[4] Garvey SD, Colak I, Wright MT. "Variable inertia test for full load temperature rise testing of induction machines". Proc IEE Electric Power Appl 1995; 142 (3).

[5] H.M.B. Metwally. "Loadless full load temperature rise test for three phase induction motors". Energy Conversion and Management 42 (2001), 519-528.

APPENDIX-I Motor performance test data

Motor Test Results – Full load test @ 415V										
Model.		s1				Test No.		1		
Serial No.		1832J				Date		12/5/2011		
Speed [rpm]	Torque [Nm]	Current_L1 [A]	Current_L2 [A]	Current_L3 [A]	Voltage_URS [V]	Voltage_UST [V]	Power In [W]	Power_Out [W]	Efficiency [%]	Power Factor
1455	35.48	10.61	10.38	10.54	417.4	415	6366	5406	84.9	0.84
1453	35.48	10.65	10.42	10.56	417	414.7	6387	5399	84.5	0.84
1452	35.6	10.65	10.41	10.56	417.2	414.7	6408	5412	84.5	0.84
1450	35.6	10.62	10.38	10.53	417.1	414.6	6397	5405	84.5	0.85
1449	35.48	10.58	10.35	10.49	416.9	414.3	6379	5384	84.4	0.85
1448	35.48	10.65	10.41	10.55	417.1	414.8	6432	5380	83.7	0.85
1447	35.6	10.68	10.45	10.58	416.5	414.4	6454	5394	83.6	0.85
1447	35.6	10.66	10.43	10.56	417	414.3	6462	5394	83.5	0.85
1446	35.6	10.67	10.43	10.57	417.1	414.7	6465	5390	83.4	0.85
1445	35.48	10.63	10.39	10.52	417.1	414.5	6440	5369	83.4	0.85
1445	35.48	10.65	10.41	10.54	417.1	414.5	6457	5369	83.1	0.85
1444	35.48	10.64	10.41	10.54	417.1	414.3	6460	5365	83.1	0.85
1444	35.6	10.66	10.42	10.55	417.1	414.6	6472	5383	83.2	0.85
1443	35.6	10.67	10.43	10.56	416.9	414.3	6480	5379	83	0.85
1443	35.48	10.69	10.45	10.58	417	414.5	6499	5362	82.5	0.85
1443	35.6	10.66	10.43	10.55	416.9	414.3	6476	5379	83.1	0.85
1443	35.48	10.66	10.42	10.55	416.9	414.6	6476	5362	82.8	0.85
1443	35.48	10.67	10.44	10.56	416.9	414.3	6492	5362	82.6	0.85
1442	35.48	10.85	10.62	10.75	416.7	414.4	6623	5358	80.9	0.86
1442	35.6	10.67	10.44	10.57	416.9	414.5	6496	5375	82.7	0.85
1442	35.6	10.63	10.41	10.53	417.2	414.4	6472	5375	83.1	0.85
1442	35.6	10.66	10.44	10.56	416.8	414.2	6489	5375	82.8	0.85
1442	35.6	10.65	10.43	10.55	416.7	414.1	6484	5375	82.9	0.86
1442	35.48	10.7	10.48	10.6	416.8	414.1	6518	5358	82.2	0.86
1441	35.48	10.65	10.42	10.55	417	414.2	6479	5354	82.6	0.85
1441	35.48	10.65	10.43	10.55	416.8	414.3	6477	5354	82.7	0.85
1441	35.48	10.65	10.43	10.54	416.7	414.2	6492	5354	82.5	0.86
1441	35.48	10.68	10.45	10.57	416.9	414.4	6495	5354	82.4	0.85
1441	35.6	10.67	10.45	10.57	416.7	414.3	6491	5371	82.8	0.85
1441	35.6	10.66	10.44	10.56	416.9	414.3	6495	5371	82.7	0.86
1441	35.48	10.65	10.42	10.54	416.9	414.4	6482	5354	82.6	0.86
1441	35.48	10.7	10.47	10.59	417	414.6	6507	5354	82.3	0.85
1441	35.48	10.68	10.45	10.57	416.8	414.3	6502	5354	82.3	0.86
1441	35.48	10.67	10.44	10.56	416.7	414.2	6494	5354	82.5	0.86
1441	35.48	10.7	10.47	10.59	416.8	414.2	6511	5354	82.2	0.85
1441	35.48	10.67	10.44	10.56	416.7	414.1	6492	5354	82.5	0.86
Generated by RDS®, M.E.A. Testing Systems Ltd. http://www.meatesting.com										

Table 1: Full load motor performance test data conducted at rated voltage (415V)

Motor Test Results – No load test @ 510V										
Model.		S1				Test No.		2		
Serial No.		1832J				Date		12/6/2011		
Speed [rpm]	Torque [Nm]	Current_L1 [A]	Current_L2 [A]	Current_L3 [A]	Voltage_URS [V]	Voltage_UST [V]	Power_In [W]	Power_Out [W]	Efficiency [%]	Power Factor
1495	0.68	10.65	10.37	10.48	510.6	507.4	1216	106	8.7	0.13
1495	0.68	10.66	10.37	10.47	510.4	507.3	1239	106	8.6	0.13
1495	0.68	10.64	10.35	10.46	510.4	507.6	1227	106	8.6	0.13
1495	0.57	10.59	10.31	10.41	510.2	507	1222	88.5	7.2	0.13
1495	0.68	10.57	10.29	10.38	510	506.7	1218	106	8.7	0.13
1495	0.68	10.58	10.31	10.41	510.4	507.2	1240	106	8.6	0.14
1495	0.68	10.57	10.3	10.39	509.9	507.1	1244	106	8.5	0.14
1495	0.57	10.58	10.31	10.4	510.4	507.3	1253	88.5	7.1	0.14
1495	0.68	10.55	10.28	10.37	510.3	506.8	1224	106	8.7	0.13
1495	0.57	10.51	10.24	10.33	510	506.8	1242	88.5	7.1	0.14
1495	0.68	10.61	10.33	10.42	510.3	507.5	1249	106	8.5	0.14
1495	0.57	10.54	10.25	10.35	510.3	507	1244	88.5	7.1	0.14
1494	0.79	10.59	10.31	10.38	510.4	507.3	1244	124	10	0.14
1495	0.79	10.57	10.29	10.36	510	507	1241	124	10	0.14
1495	0.79	10.56	10.28	10.35	510.3	506.8	1235	124	10	0.14
1495	0.68	10.58	10.3	10.37	510.5	507.6	1253	106	8.5	0.14
1495	0.68	10.56	10.28	10.35	510.3	507.2	1255	106	8.5	0.14
1495	0.68	10.51	10.23	10.34	509.9	506.9	1240	106	8.6	0.14
1495	0.79	10.51	10.23	10.33	509.6	506.5	1232	124	10	0.14
1495	0.68	10.55	10.27	10.38	510.4	507.5	1252	106	8.5	0.14
1495	0.79	10.51	10.24	10.35	510.2	507.1	1236	124	10	0.14
1495	0.79	10.54	10.26	10.36	510.2	507.3	1228	124	10.1	0.13
1495	0.79	10.51	10.23	10.34	509.8	506.6	1228	124	10.1	0.14
1495	0.79	10.58	10.3	10.42	510.6	507.9	1278	124	9.7	0.14
1495	0.79	10.49	10.23	10.33	509.9	506.7	1226	124	10.1	0.14
1495	0.79	10.53	10.28	10.37	510.1	506.9	1259	124	9.8	0.14
1495	0.79	10.56	10.29	10.41	510.6	507.4	1273	124	9.7	0.14
1495	0.79	10.57	10.31	10.42	510.4	507.6	1248	124	9.9	0.14
Generated by RDS®, M.E.A. Testing Systems Ltd. http://www.meatesting.com										

Table 2: No-load motor performance test data conducted at 23% above rated voltage (510V)

APPENDIX-II Motor temperature rise graphs

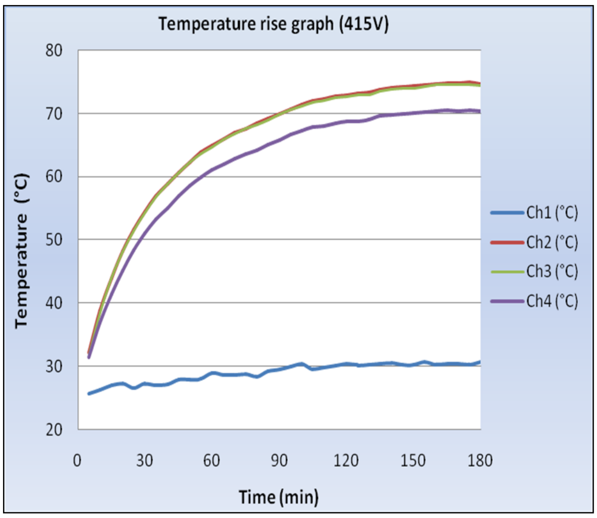

Fig. 2(a): Temperature rise graph @ 415V

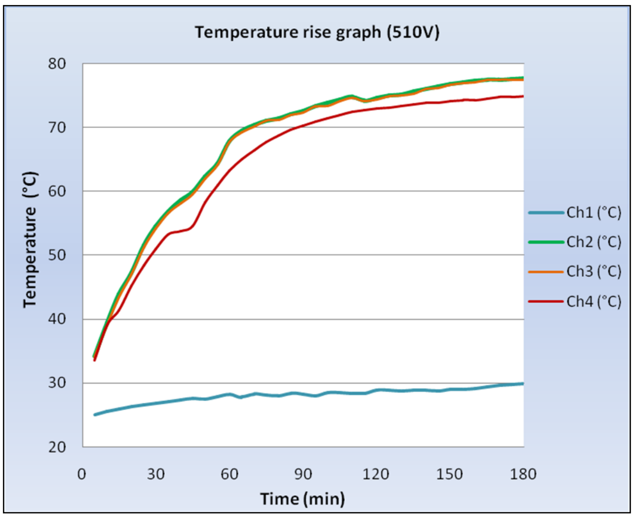

Fig. 2(b): Temperature rise graph @ 510V