Advanced Machines and Energy Systems (AMES) Group

ENERGY EFFICIENCY PROJECTS AT UCT

Department of Electrical Engineering

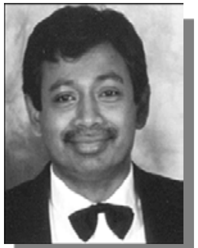
Overview

- Vision
- Key Group Members
- Collaboration
- Research Outputs & HR Development
- Laboratory Facility
- Research Areas
- Details of Current Research

Vision

- To provide feasible technical solutions to relevant industrial problems, whilst maintaining a high scholarly research content
- This is achieved by engaging highly skilled personnel and by applying a methodical approach to problem solving
- To disseminate research findings through technical reports and peer-reviewed publications
- To develop human resource capacity in electrical machines, drives and energy systems, which will eventually contribute towards innovation and poverty alleviation

Key Group Members



Prof. Pragasen Pillay
PhD, CEng, FIEEE, FIET
Professor UCT, Clarkson
Electrical Machines, Drives and Renewable Energy

Dr. Azeem Khan
PhD, MIEEE
Senior Lecturer, UCT
PM Machines & Drives, Wind Energy

Dr. Ben Sebitosi
PhD, CEng, MIEEE
Snr Research Officer, UCT
Rural Electrification, Renewables, Energy Policy

Dr. Paul Barendse
PhD, MIEEE
Lecturer, UCT
Electric Drives, Fault Diagnosis

Mr. Marubini Manyage
MSc, MIEEE
Research Officer, UCT
Machine Design, Energy Efficiency

Mr. Chris Wozniak
BSc
Technical Officer, UCT
Electrical Machines & Energy Systems

Post Graduate Students

- **PhD Students: (5)**
  - Mr F. Endrejat, Mr M. Manyage , Mr R. Naidoo, Mr D. Singh, Mr R. Okou
- **MSc Students: (8)**
  - Miss P. Ijumba, Miss K. Masemola, Mr R. Solomon, Mr G. Mwaba, Mr T. Madangombe, Mr H. Mzungu, Mr S. Sager, Mr P. Kiryowa
- **BSc(Eng) Final-year Thesis Students: (15)**
  - About 15 students supervised per year for final-year thesis project

Collaboration – South Africa

- **Academic Institutions:**
  - **DUT** - Deepak Singh, Senior Lecturer – Physics
  - **DUT** - Dr. Poobie Govender, Prof Krishnan Kanny
  - **University of Pretoria** – Mr Raj Naidoo, Senior Lecturer – EE
  - **University of Stellenbosch** – Prof W. van Niekerk, Prof M.J. Kamper, Dr D. Johnson

- **Government / Parastatals:**
  - **NRF**
  - **THRIP**
  - **DST** – Mr L. Simpsom, Ms T. Mailula, Dr Boni Mehlomakulu
  - **SANERI** – Mr K. Nassiep, Dr M. Bipath, Dr T. Mali

- **Industry:**
  - **ESKOM** – Mr L. Pillay, Mr S. Bisnath, Mr J. Gosling, Dr S. Higgins, Mr R. Koch, Mr Y. Brijmohan, Dr T.L. Mthombeni,
  - **SASOL** – Mr F. Endrejat, Mr T. Perumal, Mr D. Willemse
  - **LHM** – Mr R. Melaia

Collaboration – International

- **Clarkson University, Potsdam, NY, USA**
  - **SMMA** - The Motor and Motion Association
  - **EMERF Consortium** - Electrical Motors Educational and Research Foundation
  - **NYSERDA** - New York State Energy Research and Development Authority
- **Aalborg University, Denmark** (wind energy)
- **University of Picardie, France** (condition monitoring)
- **Politecnico di Torino, Torino, Italy** (motor lamination losses)
- **Graduate school of Telecom. and IT**, **Addis Ababa, Ethiopia** (Cellphone Keyboard Customization for Rural Applications)
- **GTZ**, German Aid Agency (environment and rural electrification)
- **Centre for Research in Energy and Energy Conservation** of Makerere University, **Uganda** (white LEDs dissemination)

Research Outputs & HR Development

	2007	2006	2005	2004
Human Resource Development	3xPhD 1xMSc 12xBSc	2xPhD 0xMSc 6xBSc	1xPhD 1xMSc 5XBSc	1xPhD 0xMSc 6XBSc
Journals papers (Peer-reviewed, international)	6	5	6	11
Conference papers (Refereed international mainly and some local)	16	12	14	7
Contract Research - Eskom	3	3	1	1
Contract Research - Other Industries	1	1	1	0

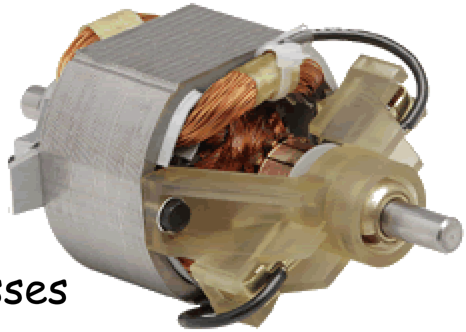
Laboratory Facility

- Flexible distribution system with the capability of various DC and AC supplies
- Two, 250kW DC machines and 4-quadrant drives
  - Fed directly from the UCT 11kV ring mains through 11kV/500V transformers
- 6.6kV, 520kW Alternator (driven by afore-mentioned DC machines)
- 75kW induction motor with a 75kW drive
- Several small and medium DC, AC machines and drives including test benches and testing equipment
- These unique capabilities, allows lab testing of machines that is not capable at some international institutions

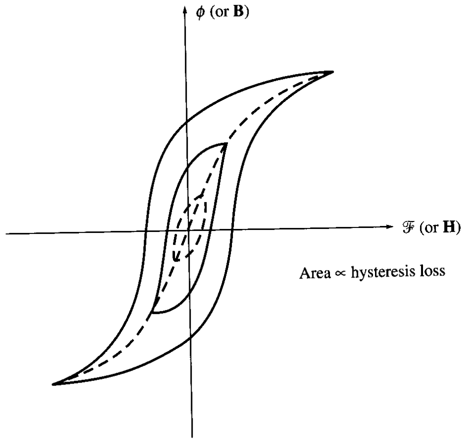
Current Research Areas

- **Energy Efficiency - Machines**
  - Core loss study
  - Electric motors for demand side management
  - MV petrochemical drives
- **Machine Design Projects**
  - Small wind generator design
  - Low voltage High Current Traction motor design
- **Condition Monitoring**
  - Fault studies and condition monitoring of induction motors, PM motors and wind generators
- **Rural Electrification and Alternate Energy Sources**
  - Applications of white LEDs
  - Optimization of solar water pumping systems
  - Solar water heaters
  - Flywheels for energy storage
  - Biomass
- **Power Systems Applications**
  - Power quality
  - Dip classification using wavelets
  - Impacts of renewable energy sources on power systems

Motor Lamination Core Losses



- **Background:**
  - Motorized applications are major electricity consumers, in SA and USA, 64 % and 60 % of total electricity, respectively
  - Core losses can be 25 % ~ 30 % of the total losses, even higher with newer designs, such as SRMs and BDCMs
  - Variable speed drives produce harmonics that increase core losses

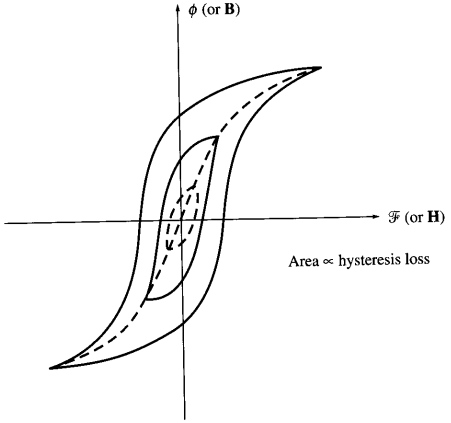


- **Research Focus:**
  - Develop a scientific understanding of lamination core losses
  - Develop core loss design equations suitable for motor designs applications especially in software design packages
- **Goals:**
  - Improving motor efficiency by reducing core losses
  - Aid motor designers with better models
  - Realize energy and dollar savings
  - Reducing peak demand levels and delaying the need for new stations

- **Environmental benefits:**
  - Reduce C02 emissions by efficient use of electricity

Core Loss Predictions

- **Classical core loss predictions use: Steinmetz formulae for predicting area under BH-Loop**
- **Several improvements suggested over the years**
- **However current disagreements in literature on:**
  - Computing coefficients for formulae
  - Structure of coefficients
  - Dependence on the operational parameters, such as frequency and flux density
- **Current work in this areas has led to reliable analytical expressions for predicting core losses in lamination strips**
- **Formulae validated on Epstein test bench**
- **Plan to integrate formulae into Finite Element Analysis software - Magsoft**



$$P = P_h + P_e$$

$$P = k_h f B_p^{1.6} + k_e (f B_p)^2$$

$$P = k_h f B_p^{a+bB} + k_e (f B_p)^2$$

$$P = k_h f B_p^{\alpha} + k_e (f B_p)^2 + k_{ex} (f B_p)^{1.5}$$

$$P = k_h f^{\beta} B_p^{\alpha} + k_e (f B_p)^2 + k_{ex} (f B_p)^{1.5}$$

$$P = k_h f B_p^{a+bB_p+cB_p^2} + k_e (f B_p)^2 + k_{ex} (f B_p)^{1.5}$$

$$P = \frac{f}{\dfrac{k_{h1}}{B_p^{\alpha}} + \dfrac{k_{h2}}{B_p^{\beta}} + \dfrac{k_{h3}}{B_p^{\lambda}}} + k_e (f B_p)^2$$

New Commercial Test Bench System

- Fully customized
  - Streamlined for high f tests
  - The only unit in the US!
- Uses a 352-turn frame
- Up to 4.0 kHz
- Fully automated
  - Can run tests faster
- Temperature monitoring

Traction Motor Design

Mr. Marbini Manyage

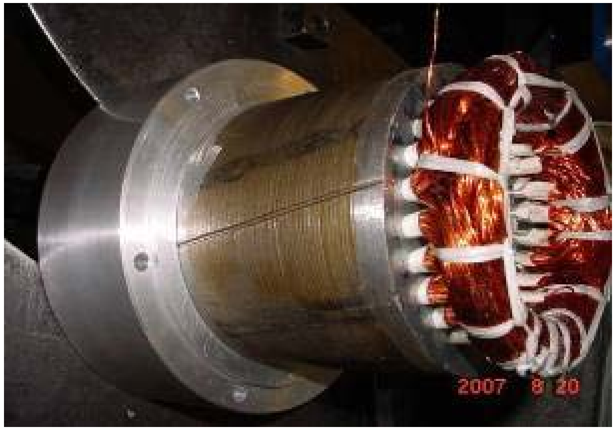
Funding: ESKOM Senior Fellowship, US DOE and NYSERDA

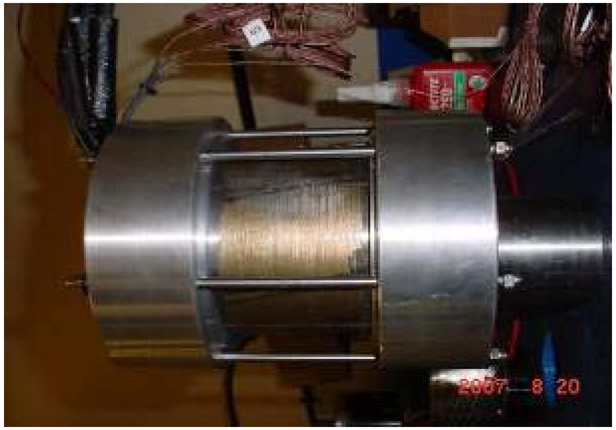
- **Description and Use**
  - Design a high efficiency Low Voltage High Current Permanent Magnet Synchronous Motor for traction applications
  - Motor will be used in a 24V battery-operated pallet truck
  - Compete with DC and AC induction motors
  - Benefits: Long battery lifespan and extended operating cycles

- **Design Challenges**
  - Low voltage inverter limit (14.5 VLL AC)
  - Cogging and Ripple torque
  - No cooling, Maximum temperature (180degC)
  - Stator outer diameter < 120mm

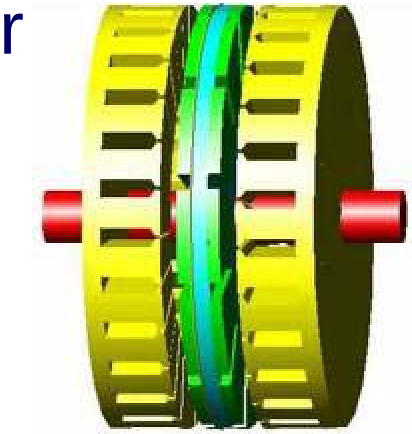
- **Efficiency improvement**
  - Better core loss prediction using improved core loss formula and new test bench
  - Choice of laminations
  - Reduce winding resistance

Traction Motor Prototyping





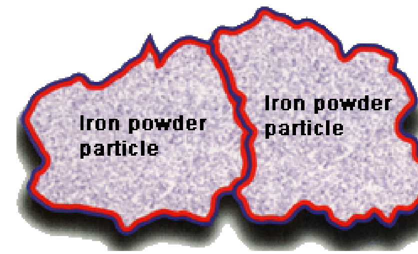
SMC Axial-flux PM Generator



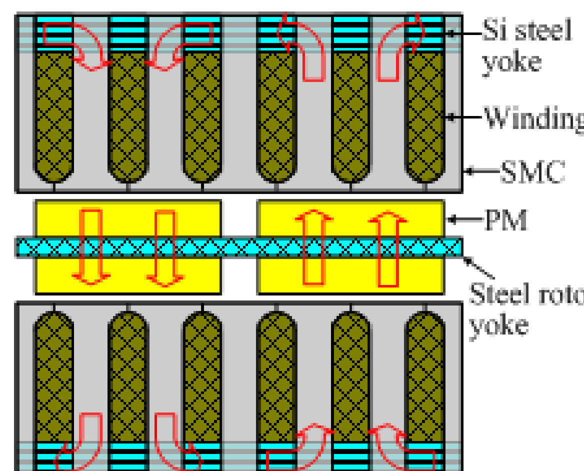
Dr. Azeem Khan

Funding: 2004 – present NRF Thuthuka; April 2005 – December 2006 ESKOM, US DOE, NYSERDA, Warner Energy

- **Background:**
  - Axial-flux PM generator design has highest torque density
  - However, slotting of AFPM stator core is problematic:
    - ☒ Difficult to machine tape-wound stator core
    - ☒ Magnetic properties of core affect by machining process

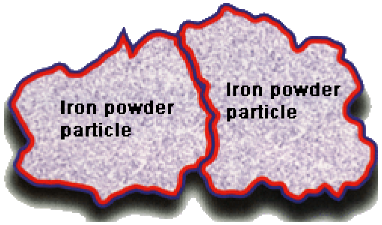


- **SMC Axial-flux PM generator with single rotor, double stator:**
  - Uses Soft Magnetic Composite (SMC) material
  - Easy to manufacture - Slotted cores are pressed
  - Shorter flux paths, high torque density, high efficiency
- **Previous work showed need for composite (SMC + steel) stator core structure:**
  - Steel in magnetic circuit increases effective permeance of circuit, thus reducing effect of lower SMC permeability
  - Steel in circuit also reduces SMC required, thus reducing effect of higher SMC core loss

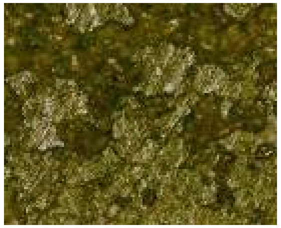


Construction of the prototype

- **SMC teeth:- Machining of SMC cores by end-mill:**
  - Cost effective, easily accessible process
  - Avoids high cost of pressing SMC parts for prototyping
  - Good dimensional tolerances
- **Pre-machined SMC core:**
  - Core in pressed and heat-treated state
  - Good insulation between iron regions through bulk of material
  - Microscopic image of SMC surface shows this clearly:
- **Machined SMC core:**
  - Machining action results in elongation / smear of iron regions on machined surfaces
  - Degradation of insulation between iron regions
  - Increased conductivity and hence eddy current losses on / near machined surfaces
- **Acid treatment process introduced to eliminate smeared iron on machined surfaces**
  - Phosphoric acid solution used to etch smeared iron
  - Acid reacts with iron only and not with insulation epoxy
  - Etched parts ultrasonically cleaned in methanol to prevent corrosion
  - Lower surface conductivity




Pre-machined


Machined


Acid treated

Stator cores tested

- **Two identical machined SMC cores prototyped:**
  - 1st case : machined SMC core with untreated teeth
  - 2nd case: machined SMC core with acid treated teeth

Untreated core

Acid treated core

Effect of Armature Rewinding on Induction Motor Efficiency

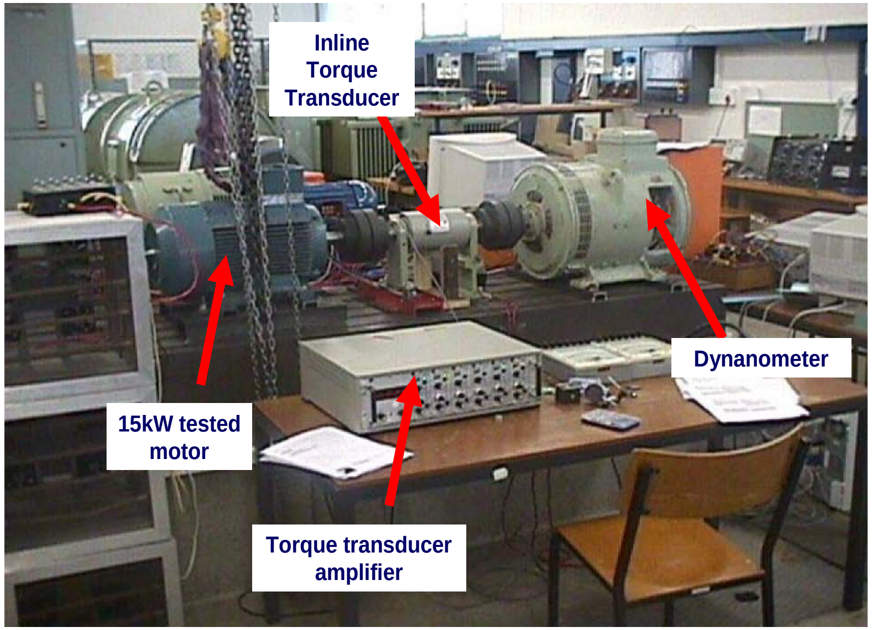
Mr. Heskin Mzungu

Funding: 2007 – ESKOM

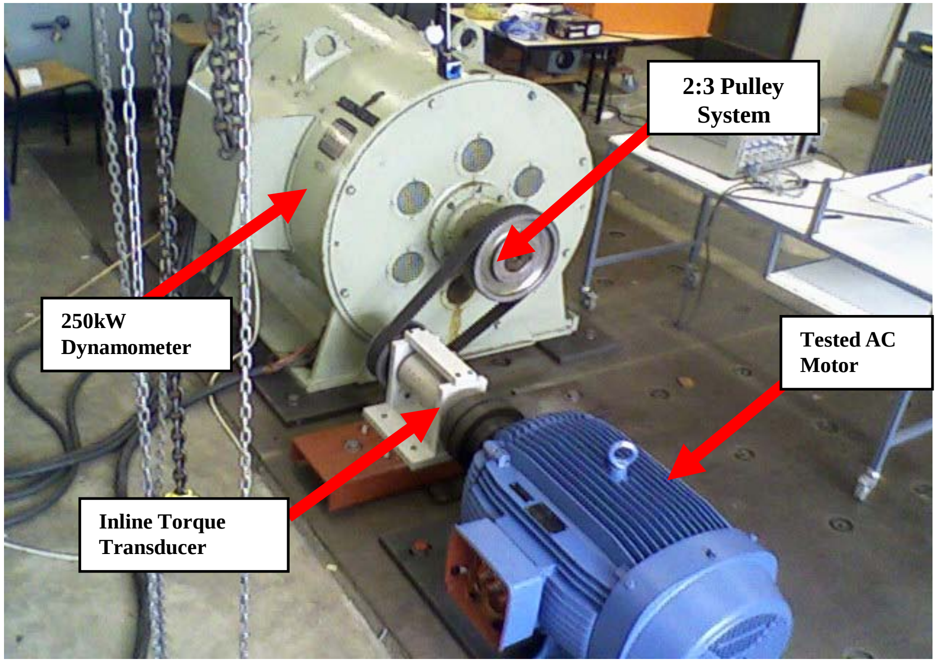
- **Background**
  - Motorized loads such as induction motors account for 60% the load in industry.
  - With more than 5 billion Rands spent on over 2 years on motor repair, the impact of motor repair on efficiency in South Africa is unknown.
- **Research Focus**
  - The comparison of the different procedures followed in international standards such as the IEEE 112, IEC 60034, JEC 37 and others
  - The impact of the process of armature rewind on induction motor efficiency
- **Objectives**
  - Construction of state of the art test rigs to produce very accurate efficiency values for the different motors
  - Rigorous testing of motors before and after rewinding

Test Rigs

- Two test rigs commissioned in Electric Machines lab at UCT
- Range of motors to be tested and rewound: 3kW, 7.5kW, 11kW, 15kW, 22 kW, 37.5kW, 45kW, 55kW



15kW test rig to test from 3-15kW

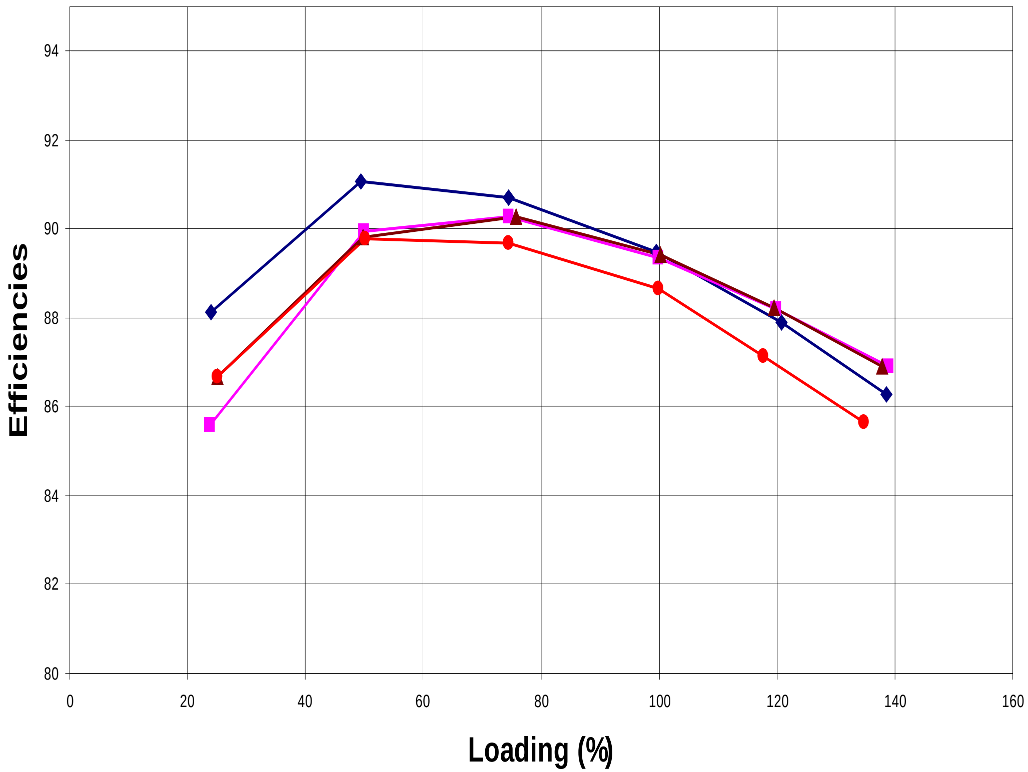


55kW test rig to test from 22-55kW

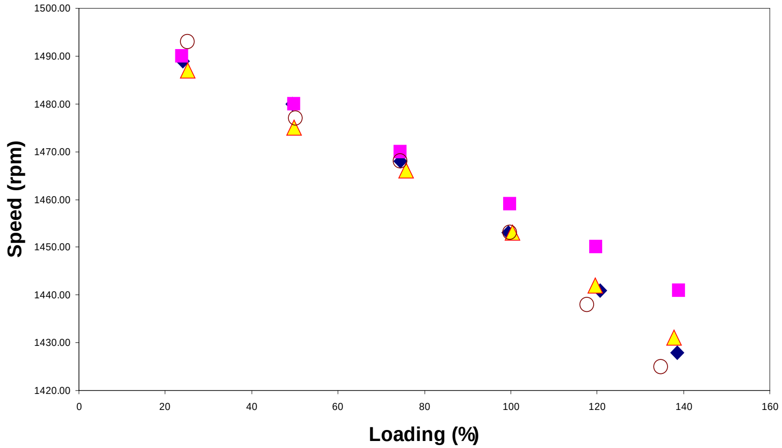
Test Rigs

- **Accuracy and repeatability of tests are very important. A 15kW motor is used to validate this.**

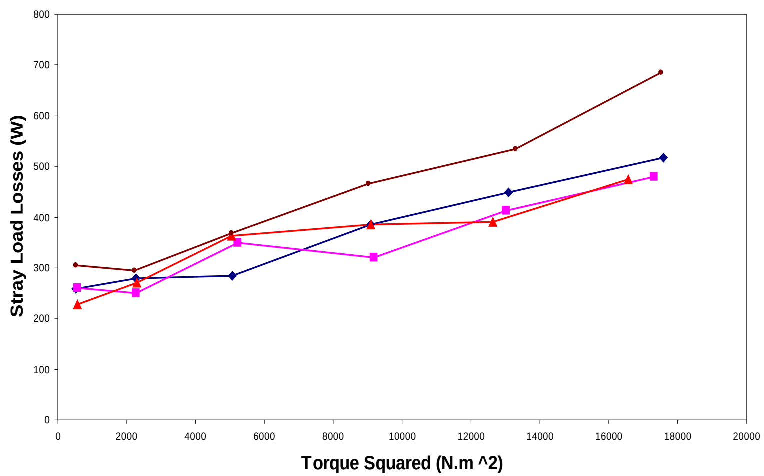
Efficiency vs Load for 15kW motor



Speed vs Load



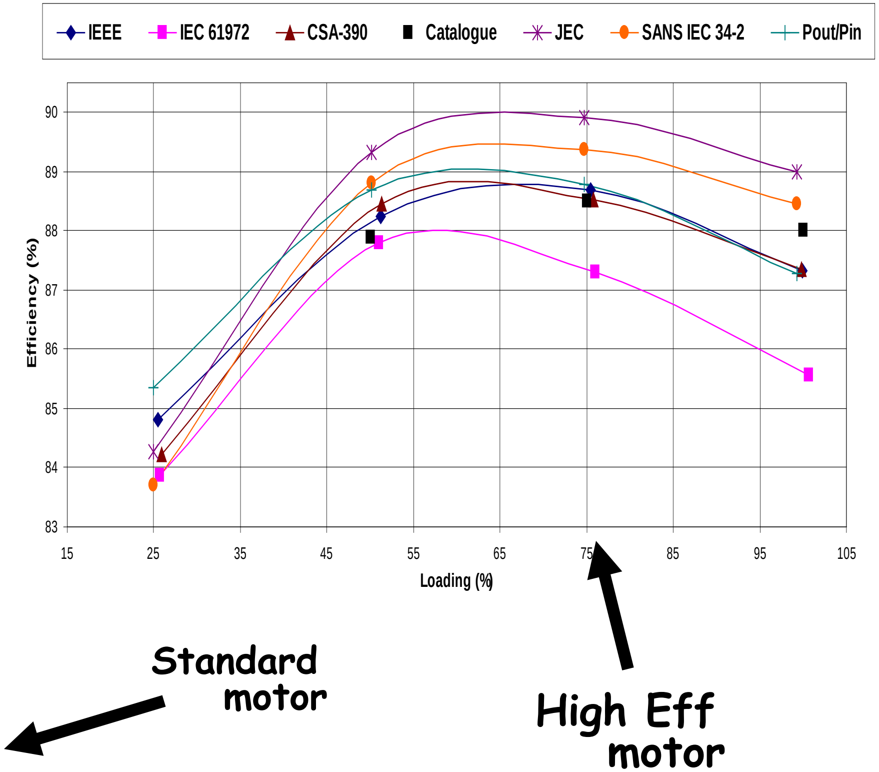
Losses vs Torque^2

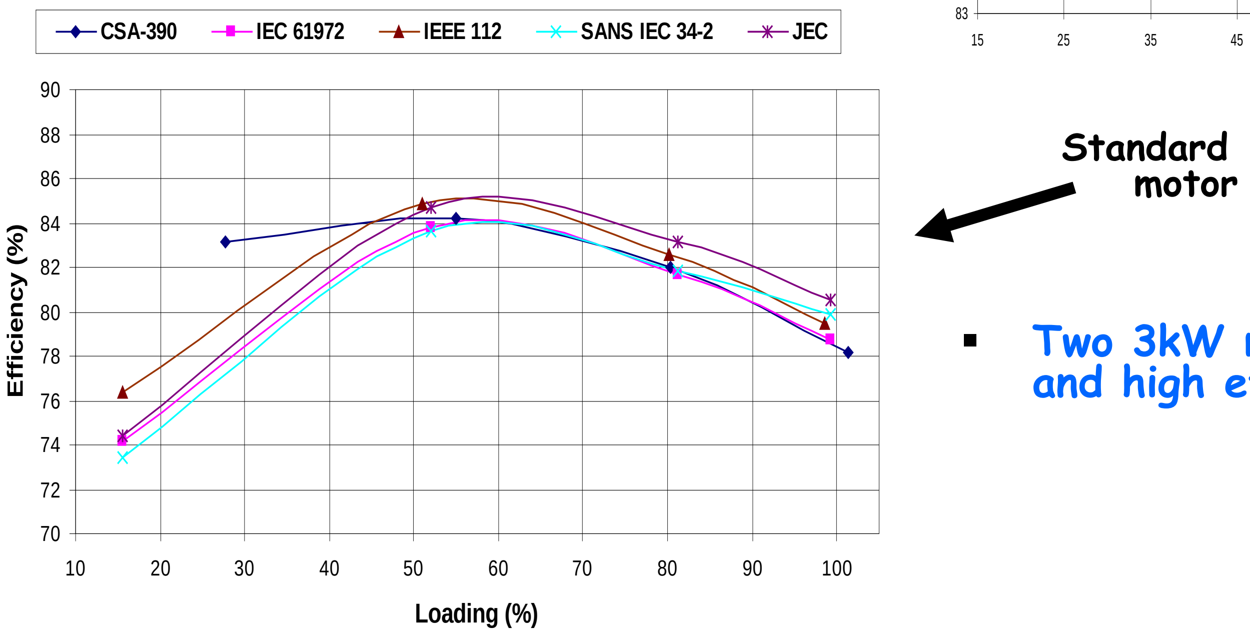


Comparison of Efficiency Standards

- Efficiency tests performed as per SANS IEC 34-2, JEC 2137, IEEE 112 and CSA 390 standards and compared with Pout/Pin and catalogue

- Discrepancy between the efficiencies are due to the treatment of stray losses, temperature (Pout/Pin) and manufacturers quoting calculated catalogue efficiencies rather than tested values





- Two 3kW motors tested (standard and high efficiency motors)

Comparison of Efficiency Standards

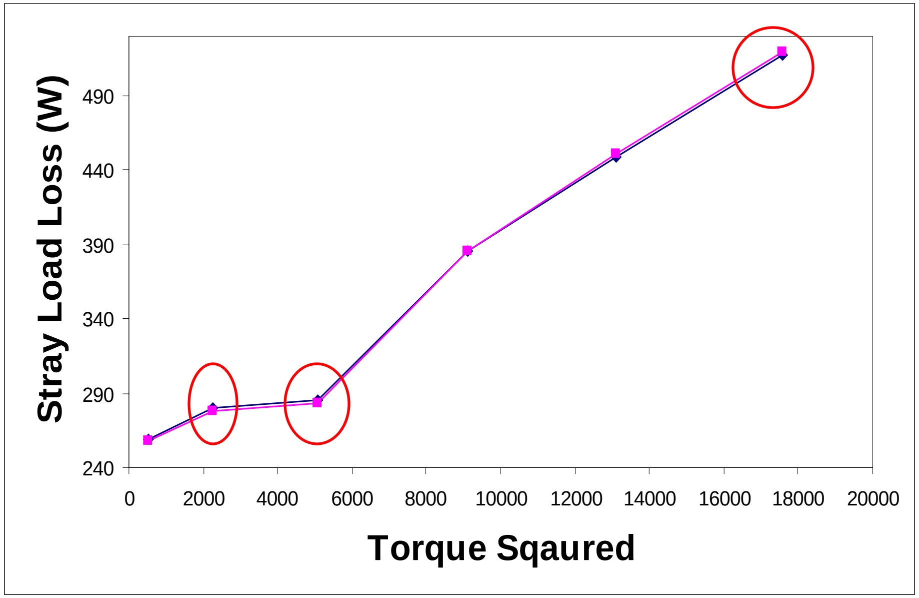
Standard	Method of SLL
IEEE 112	Indirect Method*
SANS IEC 60034-2	Assumed Values
JEC 2137	Ignore SLL
CSA 390	Indirect Method

- Stray Load losses are losses that are the most difficult to measure. This is due to there non-linearity and numerous causes.
- The different standards employ different ways of calculating them. This is where the biggest difference is in the standards

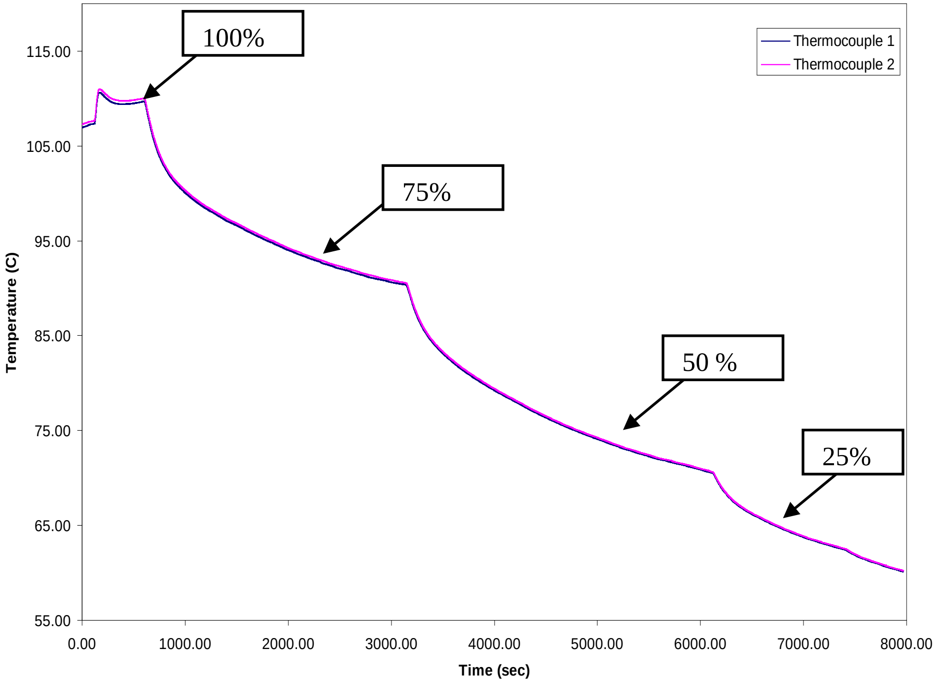
$$P_{stray} = (P_{elec} - P_{mech}) - (P_{Fr,W} + P_{Fe} + P_{rotor} + P_{stator})^{*}$$

Effects of Temperature

- Investigation on the effects of temperature on efficiency during testing
- Losses increase with an increase in temperature. Efficiency therefore is affected

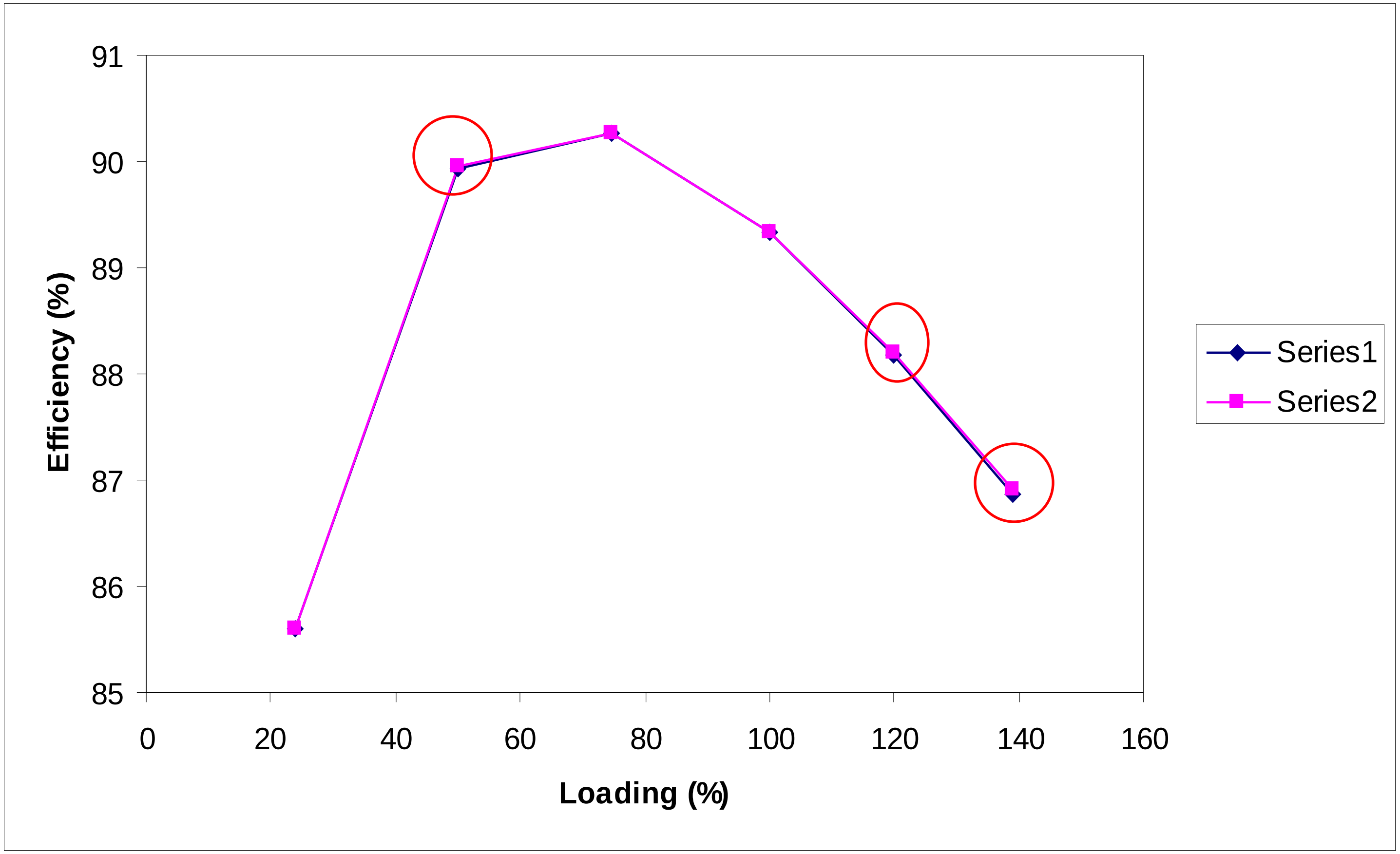


- SLL variation of up to 1%



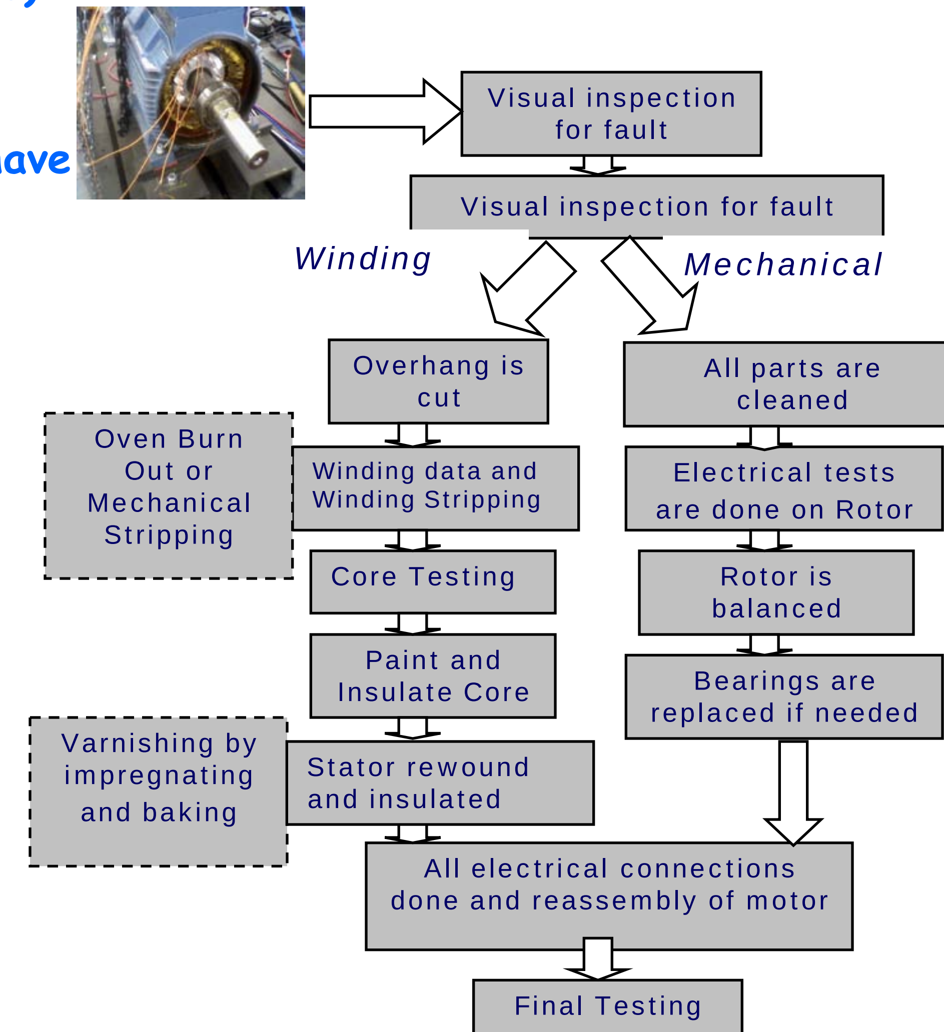
Effects of Temperature

- Efficiency maximum variation of up to 0.5%
- This is significant when trying to investigate the effects of rewinding
- It has been reported in literature that motor can loss or gain up a 1% in efficiency



Armature rewinding

- Impact on motor efficiency (and/or losses) can occur at any point during the rewind process
- South African Rewind and Refurbishment standards such SANS 1804 and 10242 have a standard procedure



Motor loss	Affected by
Stator core losses	• Overheating core steel during stripping •Damaging core insulation during winding removal •Excessive abrasion and grinding during core cleaning
Friction and Windage losses	•Bearings and cooling fan not replaced to original conditions •Incorrect bearing fits •Incorrect bearing preload
Stator Winding Losses (I^2R losses)	•Reducing conductor cross-sectional area •Changing number of turns •Using wrong winding configuration •Machining rotor
Rotor losses (I^2R losses)	•Altering rotor bars and end rings •Changing cage design
Stray load losses	•Change in air gap symmetry and air gap unconventional behavior •Bent motor shaft or damaged end shields

Comparison of 3kW Std and HE Motor

- **Two induction motors were compared:**
  - Standard motor: 3kW, 4-pole
  - High efficiency: 3kW, 4-pole

- **Objectives:**
  - Efficiency differences between motors assessed
  - Operating performance differences between motors, when subjected to the same load assessed
  - To assess effectiveness of retrofitting standard motors with high efficiency motors

3kW HE Motor with Dynamometer

Methodology

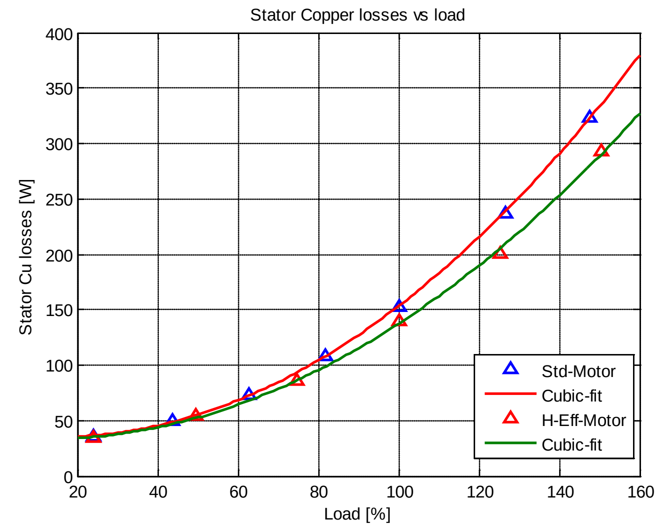
- **IEC 60034-2-1 standard used to assess efficiency both motors**

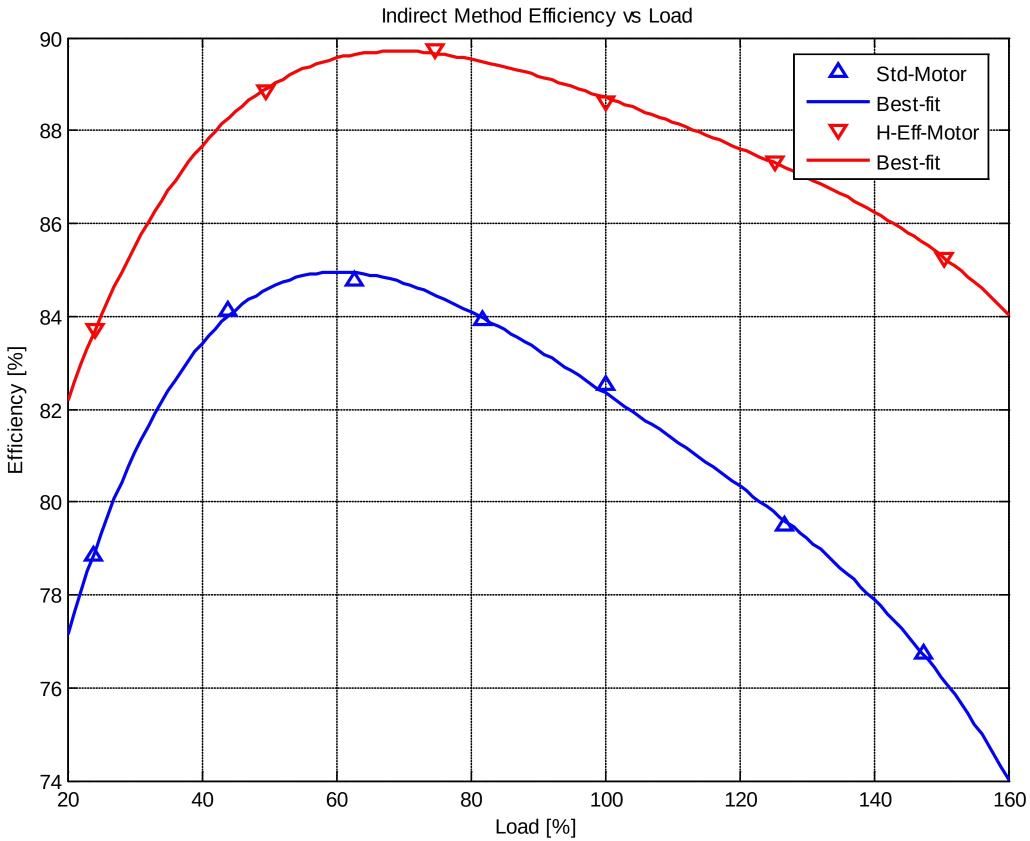
- **Equivalent circuit parameters determined for both motors:**
  - No-load test
  - Locked Rotor test

- **Operating performance differences assessed using equivalent circuits and superimposing pump load curve**

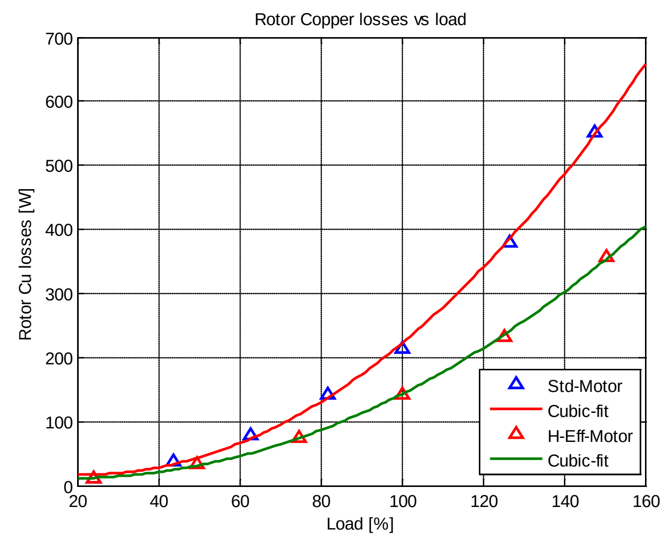
IEC60034 Test Results

- **IEC 60034-2-1 standard used to assess efficiency both motors:**
  - 3kW Standard and High Efficiency motors tested
  - Full temperature compensation for losses as per standard



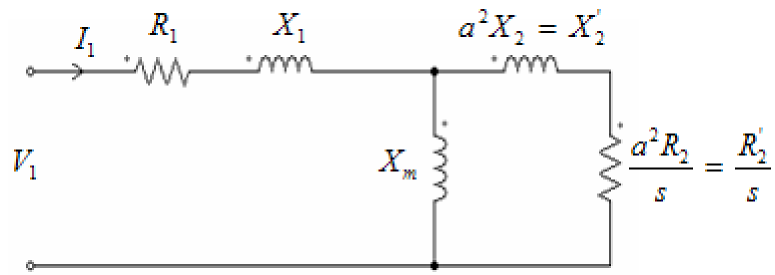


Efficiency vs Load comparison



Equivalent Circuit Parameters

- **Equivalent circuit parameters determined for both motors:**
  - No-load test
  - Locked Rotor test
  - IEEE recommended equivalent circuit used:



IEEE recommended equivalent circuit

- **Equivalent circuit parameters:**
  - Standard motor

R_1	2.08667Ω
X_1	4.273668Ω
X_m	66.560161Ω
X_2'	4.273668Ω
R_2'	2.122202Ω
P_{rot}	$134.668566W$

High Efficiency motor

R_1	1.5Ω
X_1	3.642159Ω
X_m	72.252463Ω
X_2'	3.642159Ω
R_2'	1.99416Ω
P_{rot}	$88.924099W$

Operating Performance

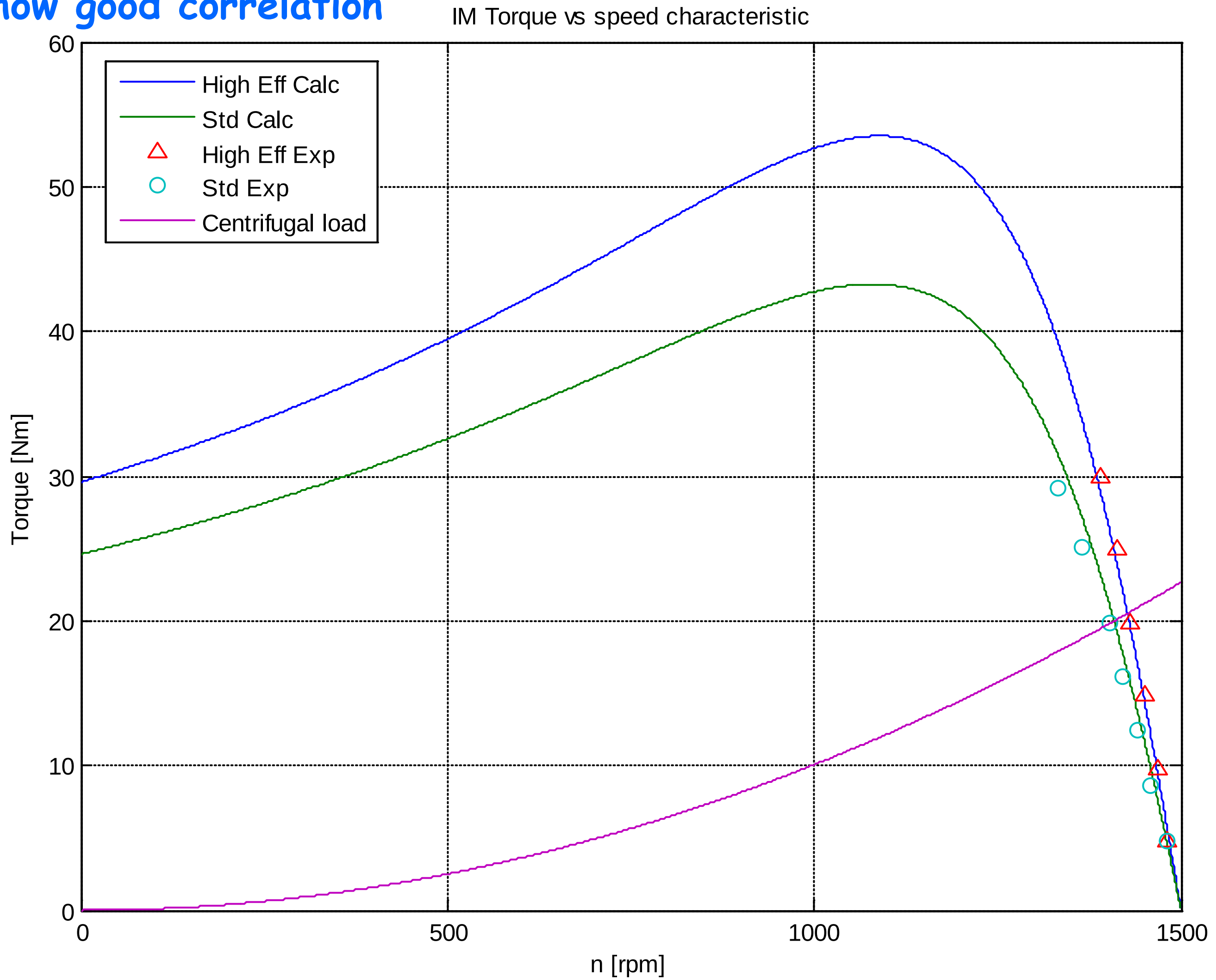
- Equivalent circuits used with Matlab program to predict performance of motors
- Centrifugal pump load curve superimposed on characteristics of both motors
- Comparison with experimental results

Operating Performance: Torque vs Speed

- Torque vs speed curves of both motors with centrifugal pump load curve superimposed
- Experimental results show good correlation

- Standard motor:
  - Slip=6.1%
  - Speed=1408.5rpm

- High Efficiency motor:
  - Slip=4.85%
  - Speed=1427.3rpm

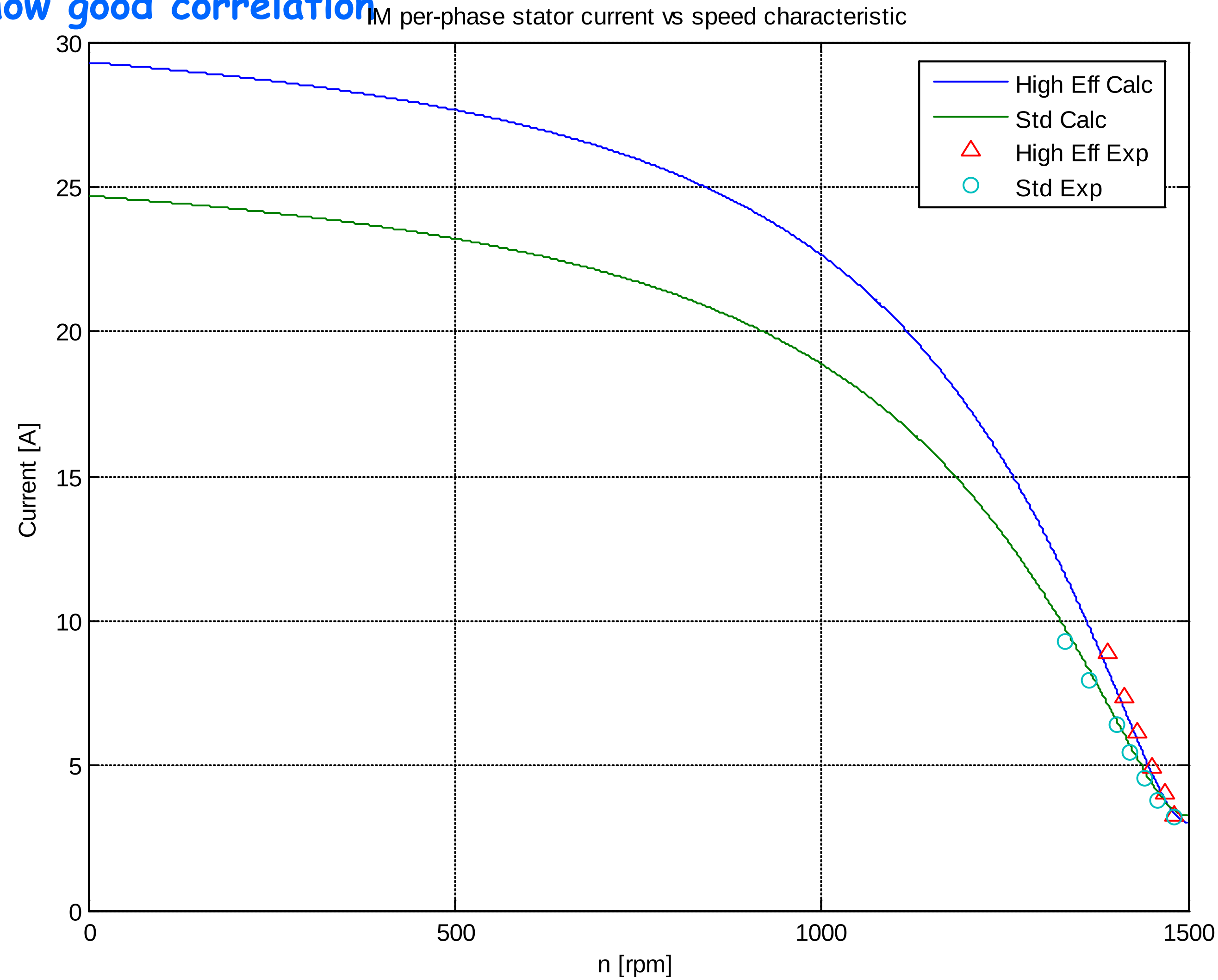


Operating Performance: Current vs Speed

- Current vs speed curves of both motors
- Experimental results show good correlation

- Standard motor:
  - Slip=6.1%
  - Speed=1408.5rpm
  - I1_load=6.28A
  - pf=0.78 lagging

- High Efficiency motor:
  - Slip=4.85%
  - Speed=1427.3rpm
  - Current=6.1A
  - pf=0.8 lagging

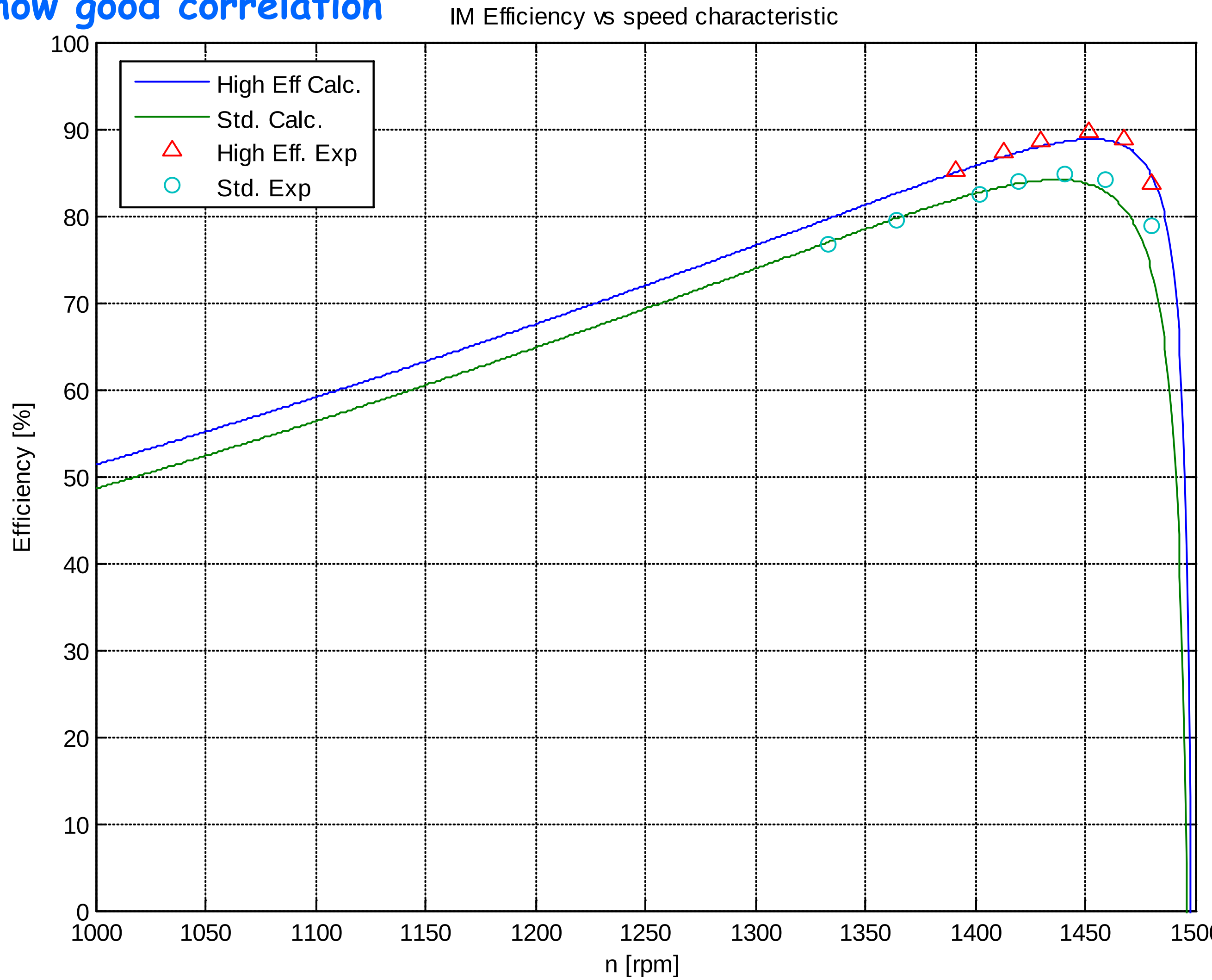


Operating Performance: Efficiency

- Efficiency vs speed curves of both motors
- Experimental results show good correlation

- Standard motor:
  - Slip=6.1%
  - Speed=1408.5rpm
  - Eff_load=83.1%

- High Efficiency motor:
  - Slip=1%
  - Speed=1427.3rpm
  - Efficiency=87.8%



Operating Performance: Energy

- **Energy saving based on reduction in input power drawn by High Eff motor:**
  - Same centrifugal pump load
  - 3kW Std motor replaced with 3kW High Eff
- **Standard motor input power:**
  - Pin = 3.39kW
- **High Efficiency motor input power:**
  - Pin = 3.38kW
- **Reduction in input power drawn by High Eff motor:**
  - ΔPin = 10.64W !!!
  - ΔPin = 0.3% !!!

For further enquiries, please contact:

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