Eolyc's Wind Generator

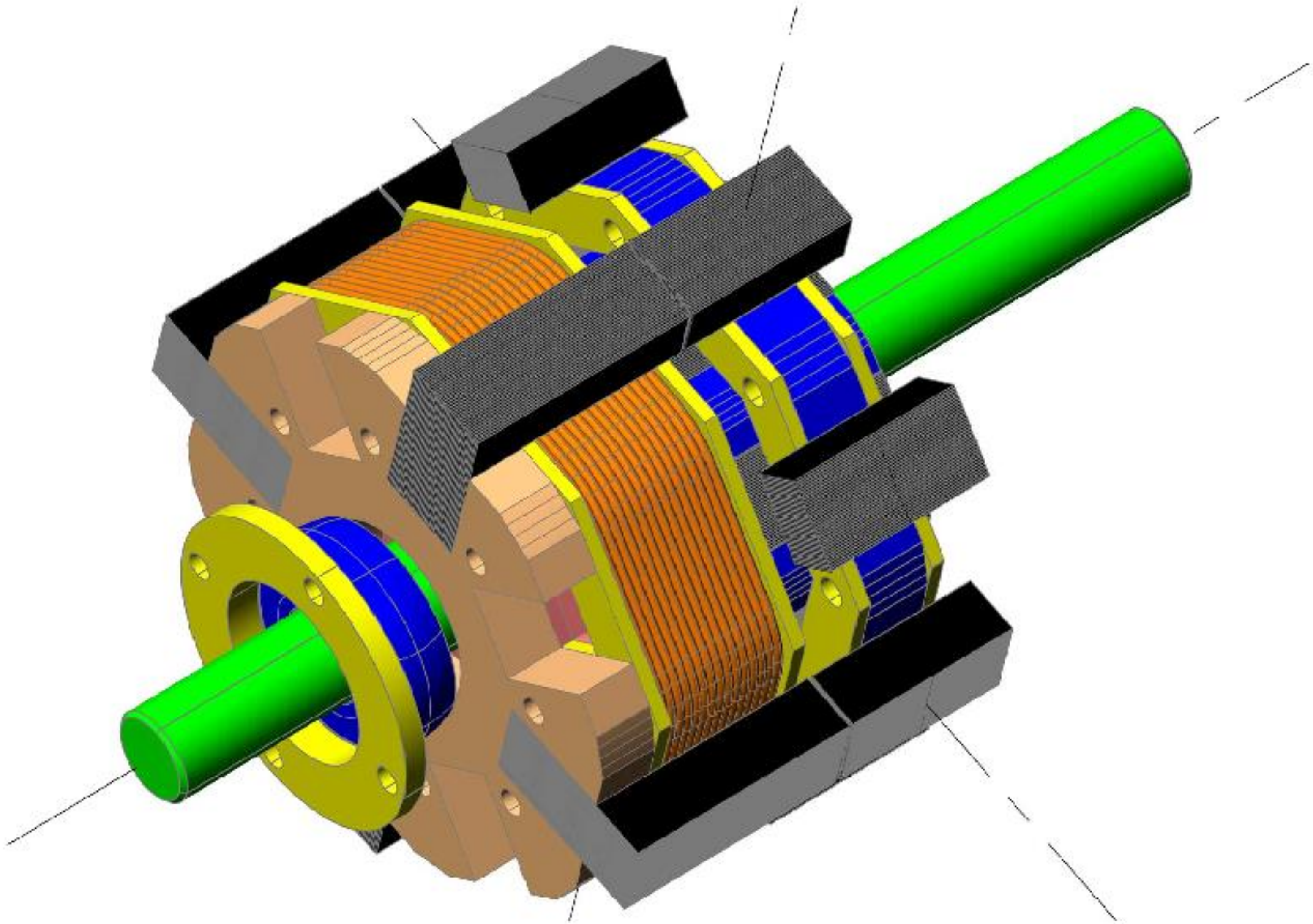
3 phase Axial Flux Ironless Generator

with NdFeB Permanent Magnets

R&D Process and Chronology

Startup with advanced ideas

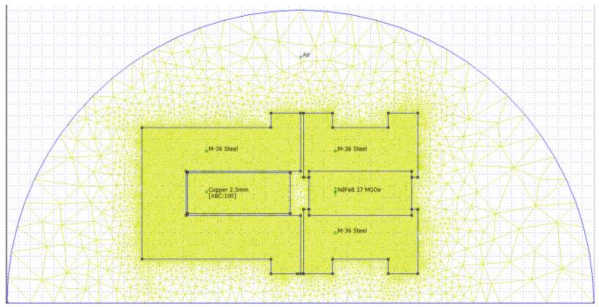
- Concentrating multiphase transverse flux topology with permanent magnet excitation



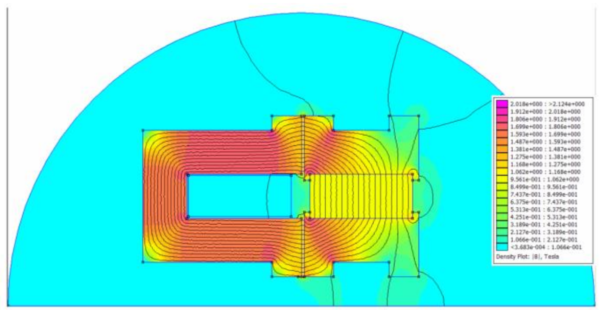
Concentrating transverse flux topology

- Simulation results for elementary generator

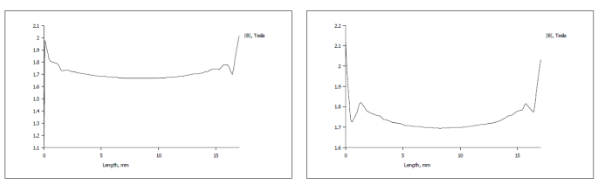
PM Axial Flux Concentrating Direct Drive Wind Generator



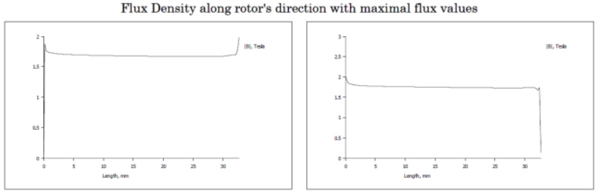
Planar model prepared in FEMM with geometry imported from AutoCAD .dxf file



2D Magneto-static analysis result solved by Finite Element Method Magnetic package

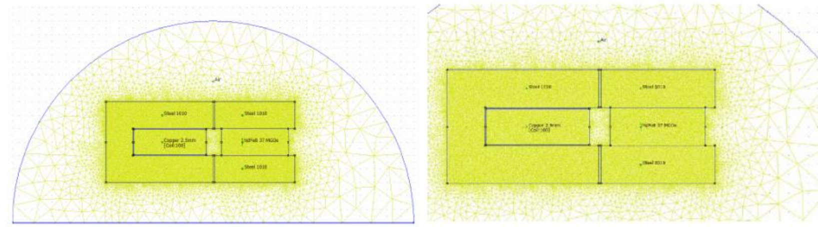


Flux Density along rotor's direction with maximal flux values

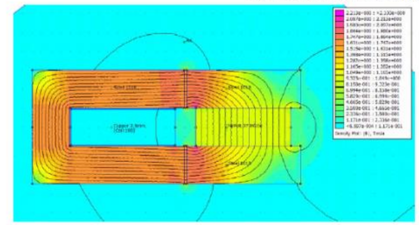


Flux Density along stator's direction with maximal flux values

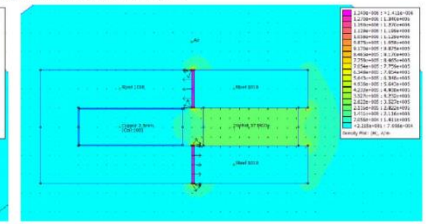
PM Axial Flux Concentrating Direct Drive Wind Generator



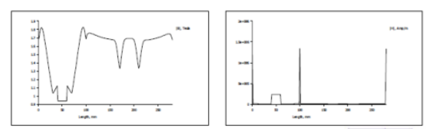
Planar model prepared in FEMM with geometry imported from AutoCAD .dxf file



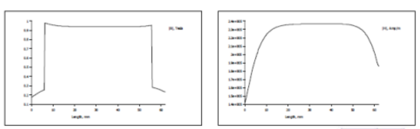
2D Magneto-static analysis result solved by FEMM package (Flux Density)



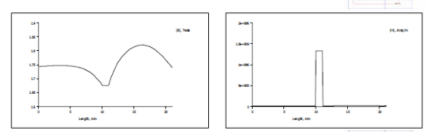
2D Magneto-static analysis result solved by FEMM package (Field Intensity)



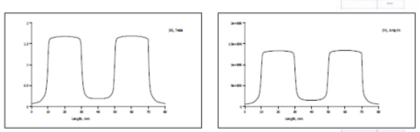
Density along the middle of cores and gaps



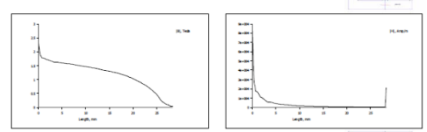
Density along the PM's axial direction



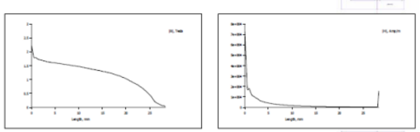
Density along the air gap's axial direction



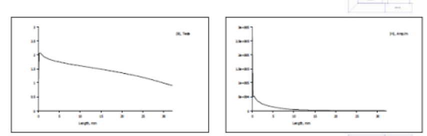
Density along the air gap's radial direction



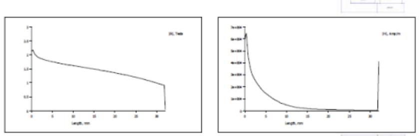
Density along bottom stator's direction with maximal flux values



Density along top stator's direction with maximal flux values



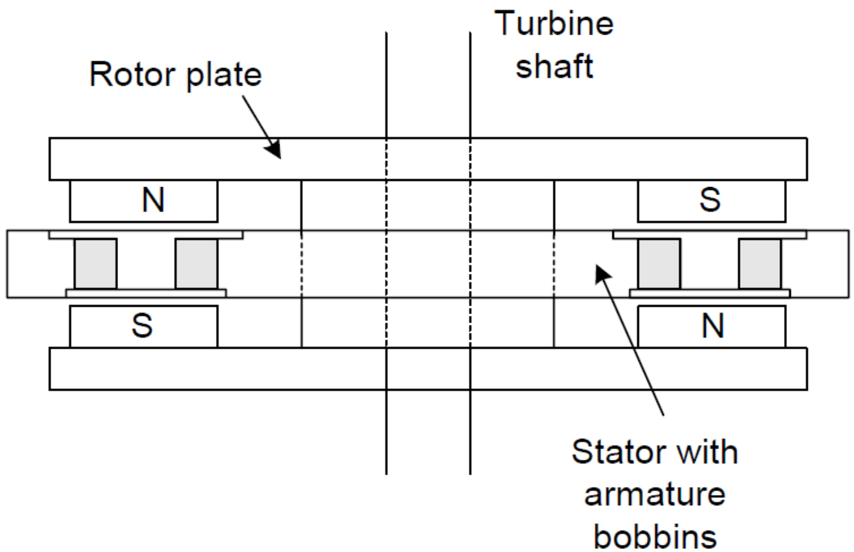
Density along bottom rotor's direction with maximal flux values

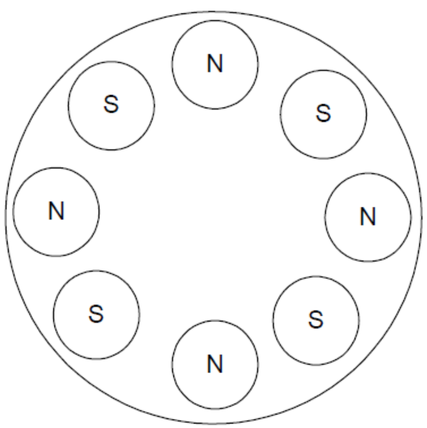


Density along top rotor's direction with maximal flux values

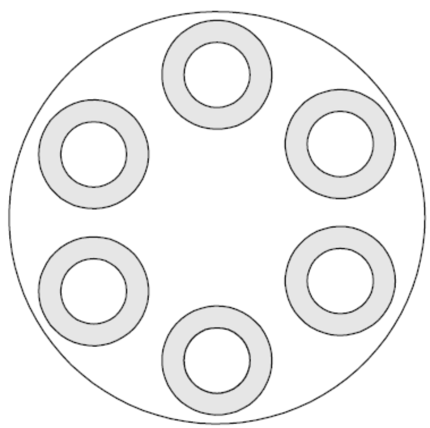
Following traditional ideas

- Multiphase Axial Flux Ironless Generator with permanent magnet excitation





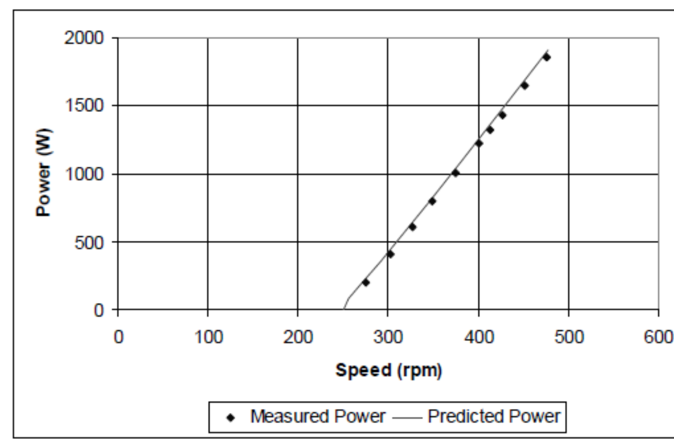
Rotor disc



Stator disc

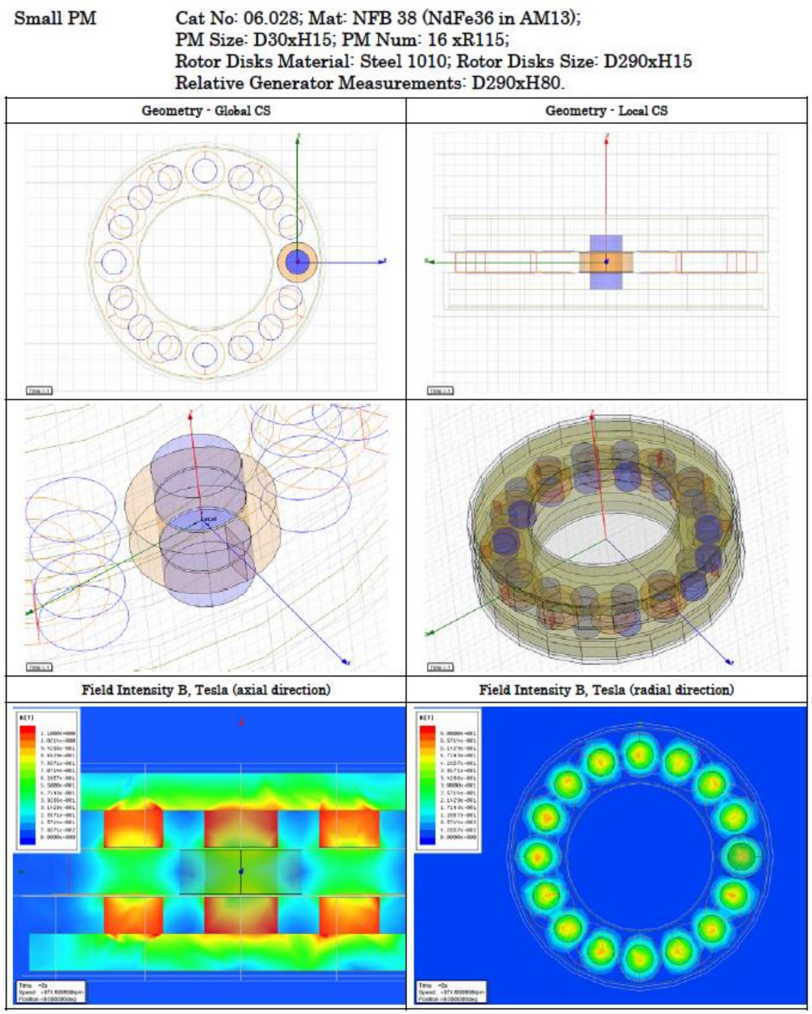
		1kW	2.5kW
Rated power	W	1000	2500
Rated speed	rpm	300	250
Rated frequency	Hz	40	33.3
Rated EMF (per coil)	V	33.6	205
Number of phases		3	3
Number of pole pairs		8	8
Number of armature coils		12	12
Generator diameter	mm	462	590
Generator length	mm	55	60

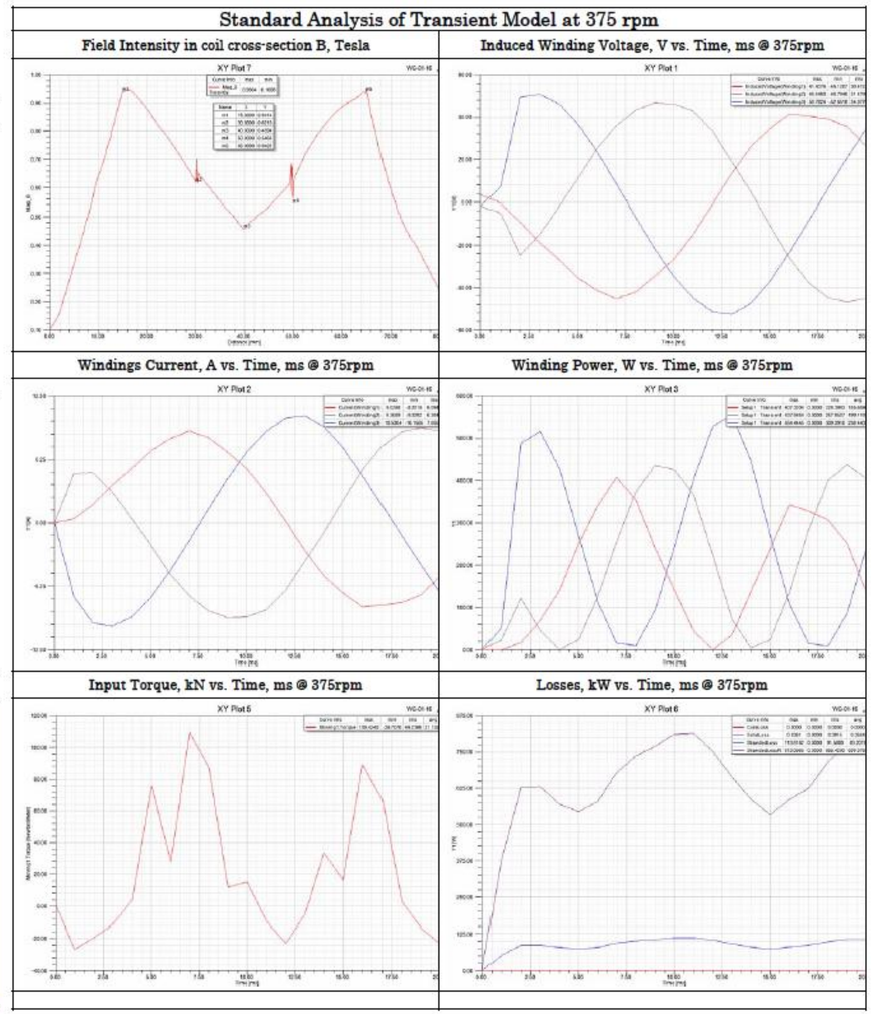
	1 kW		2.5 kW	
	Measured	Predicted	Measured	Predicted
Coil inductance (mH)	4.67	4.59	67	81
Coil resistance (ohms)	1.02	0.97	12.9	11.1
V/100rpm/coil	11.03	11.2	86.0	82.1



Axial Flux Ironless Generator

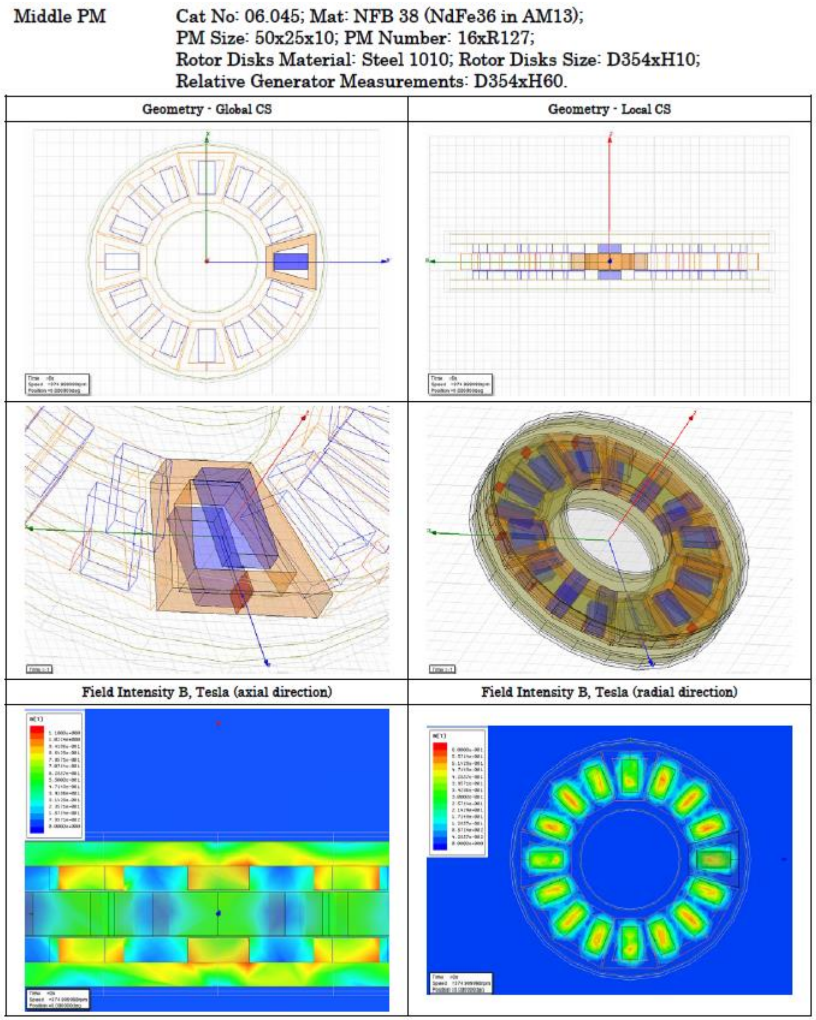
- 3D Simulation results – small cylinder magnets poles

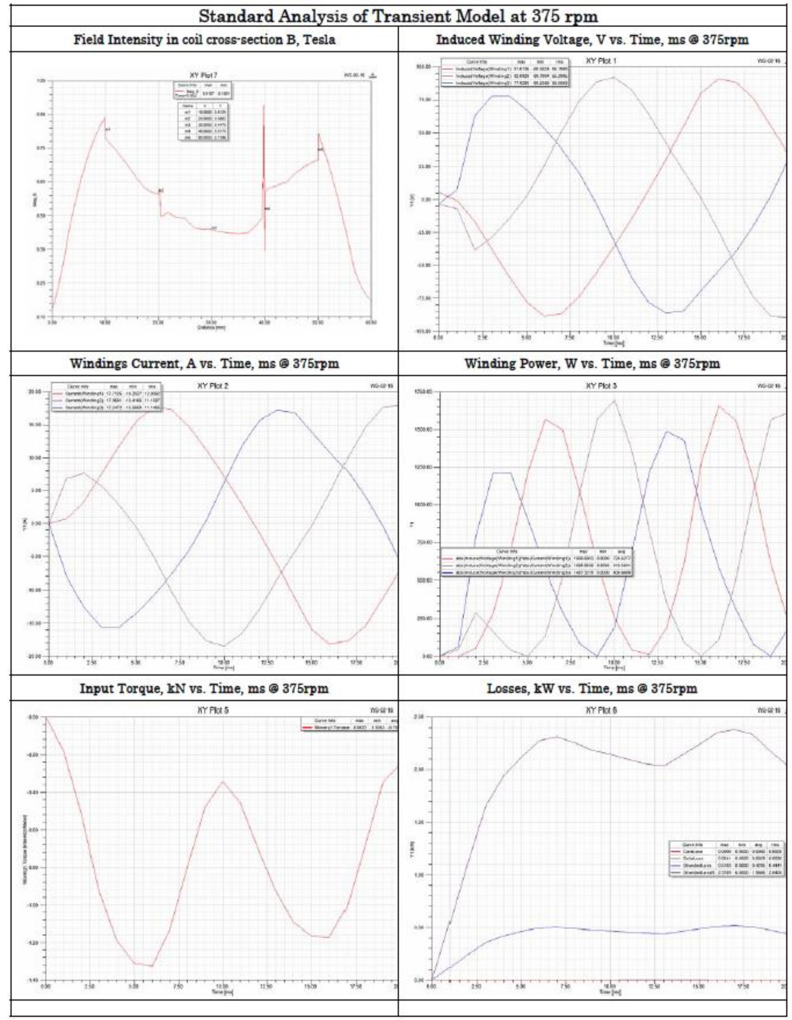




Axial Flux Ironless Generator

- 3D Simulation results – medium parallelepiped magnet poles



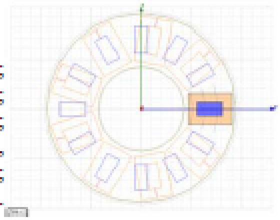


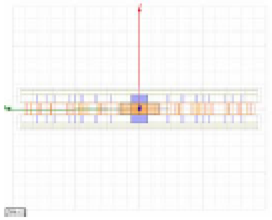
Axial Flux Ironless Generator

- 3D Simulation results – big parallelepiped magnet poles

Simulation case Model-06/Project-01-02-12-sq

Axial Flux Ironless Generator with 12 Poles and 9 Coils connected in 3 Phase Scheme;
NdFeB PM Cat. No 06.013: 24 x Size A2 x B1 x C0.5 in, Mat. NFB 38;
Rotor Disk: 2 x Size D374 x d170 x H6.35 mm, Mat. Steel 1010;
Coils: 9 pcs., Internal Size as PM, Rectangular Shape,
Cross-section 18x18mm, 72 turns, D2.0 mm;
Almost all dimensions are the same or close to once in article from Garrison F. Price at all.





M0-06_P-01-02-12-sq

PM Price: 403.20

T [Nm]

	T [Nm] @ 2 Ohm Load	T [Nm] @ 4 Ohm Load	T [Nm] @ 6 Ohm Load
200	13.46	7.39	5.53
500	30.57	16.49	11.42
800	44.60	25.18	17.49

Pin [W]

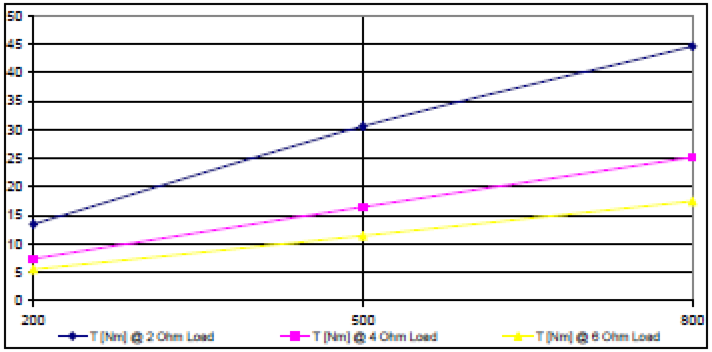
	Pin [W] @ 2 Ohm Load	Pin [W] @ 4 Ohm Load	Pin [W] @ 6 Ohm Load
200	281.9	154.8	115.8
500	1,600.7	863.3	597.9
800	3,736.2	2,109.8	1,465.0

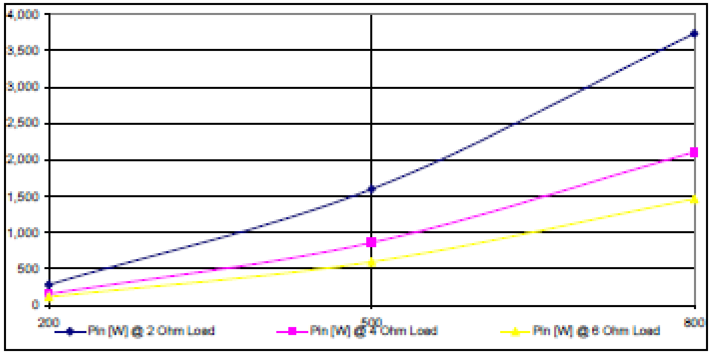
Pout [V]

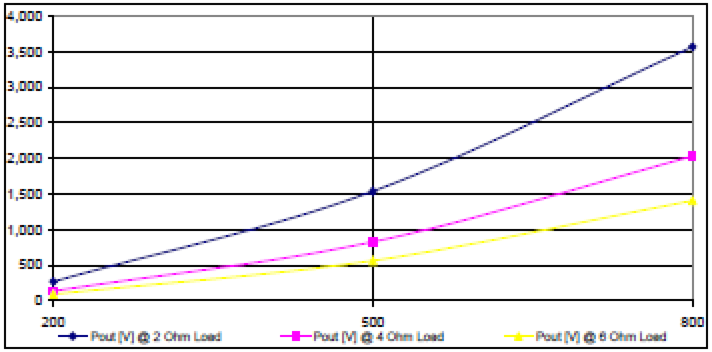
	Pout [V] @ 2 Ohm Load	Pout [V] @ 4 Ohm Load	Pout [V] @ 6 Ohm Load
200	267.99	137.27	92.20
500	1,537.92	826.69	562.99
800	3,564.64	2,029.17	1,404.63

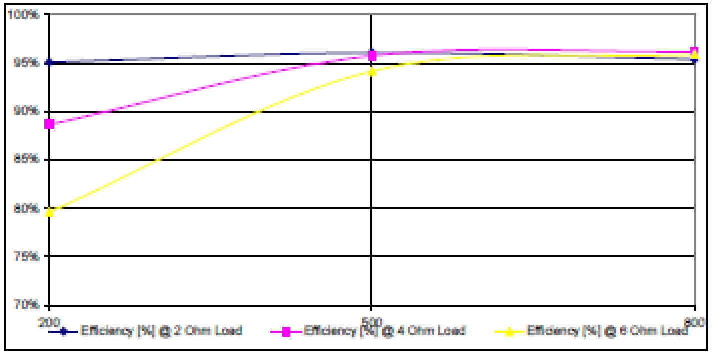
Efficiency [%]

	Efficiency [%] @ 2 Ohm L	Efficiency [%] @ 4 Ohm L	Efficiency [%] @ 6 Ohm Load
200	95.1%	88.7%	79.6%
500	96.1%	95.8%	94.2%
800	95.4%	96.2%	95.9%







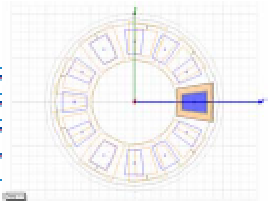


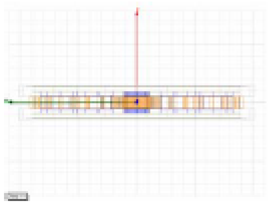
Axial Flux Ironless Generator

- 3D Simulation results – medium wedge magnet poles

Simulation case Model-07/Project-01-01-12

Axial Flux Ironless Generator with 12 Poles and 9 Coils connected in 3 Phase Scheme;
NdFeB PM: 24 x Wedge N42 55*44*30*8 (http://www.solbergavind.se/);
Rotor Disk: 2 x Size D357 x d191 x H8 mm, Mat. Steel 1010;
Coils: 9 pcs., Internal Size as PM, Trapezoidal Shape,
Cross-section 12x18mm, 72 turns, D2.0 mm.





M0-07_P-01-01-12

PM Price: 288.00

T [Nm]

	T [Nm] @ 4 Ohm Load	T [Nm] @ 7 Ohm Load	T [Nm] @ 10 Ohm Load
50	6.46	5.33	4.94
200	23.63	11.60	8.95
500	144.64	56.47	28.52

Pin [W]

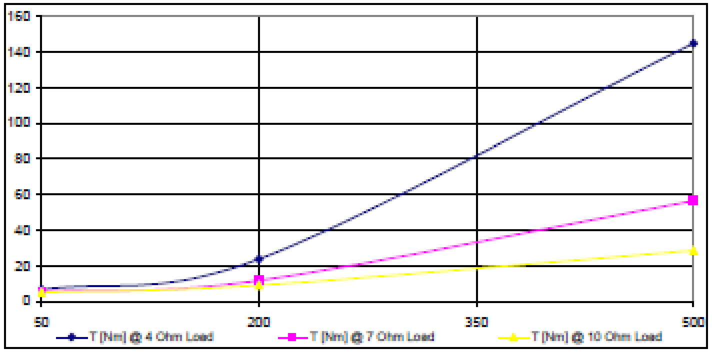
	Pin [W] @ 4 Ohm Load	Pin [W] @ 7 Ohm Load	Pin [W] @ 10 Ohm Load
50	33.8	27.9	25.9
200	495.0	242.9	187.4
500	7,573.3	2,956.7	1,493.4

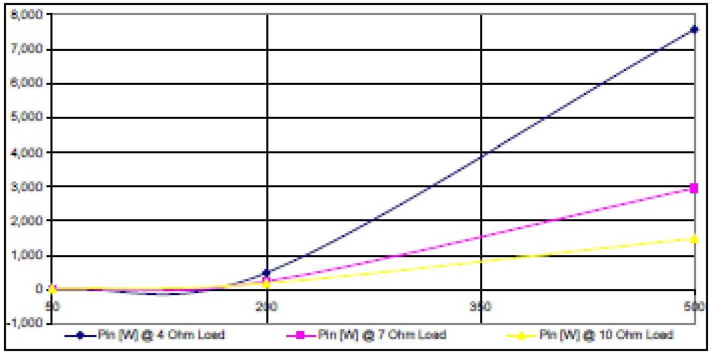
Pout [W]

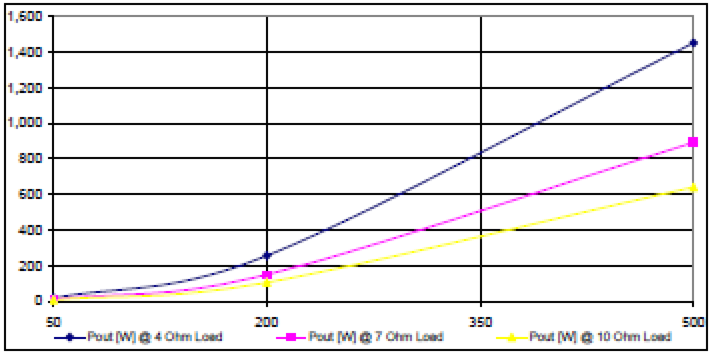
	Pout [W] @ 4 Ohm Load	Pout [W] @ 7 Ohm Load	Pout [W] @ 10 Ohm Load
50	16.65	9.56	6.71
200	256.03	149.82	105.80
500	1450.52	891.12	640.14

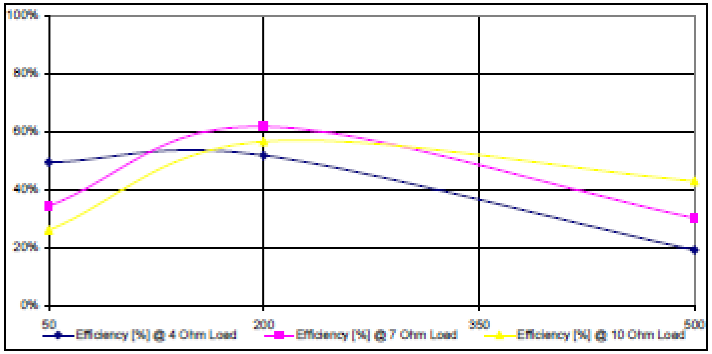
Efficiency [%]

	Efficiency [%] @ 4 Ohm L	Efficiency [%] @ 7 Ohm L	Efficiency [%] @ 10 Ohm Load
50	49.3%	34.3%	25.9%
200	51.7%	61.7%	56.5%
500	19.2%	30.1%	42.9%









Axial Flux Ironless Generator

- After simulation design summary – based on medium wedge magnet poles

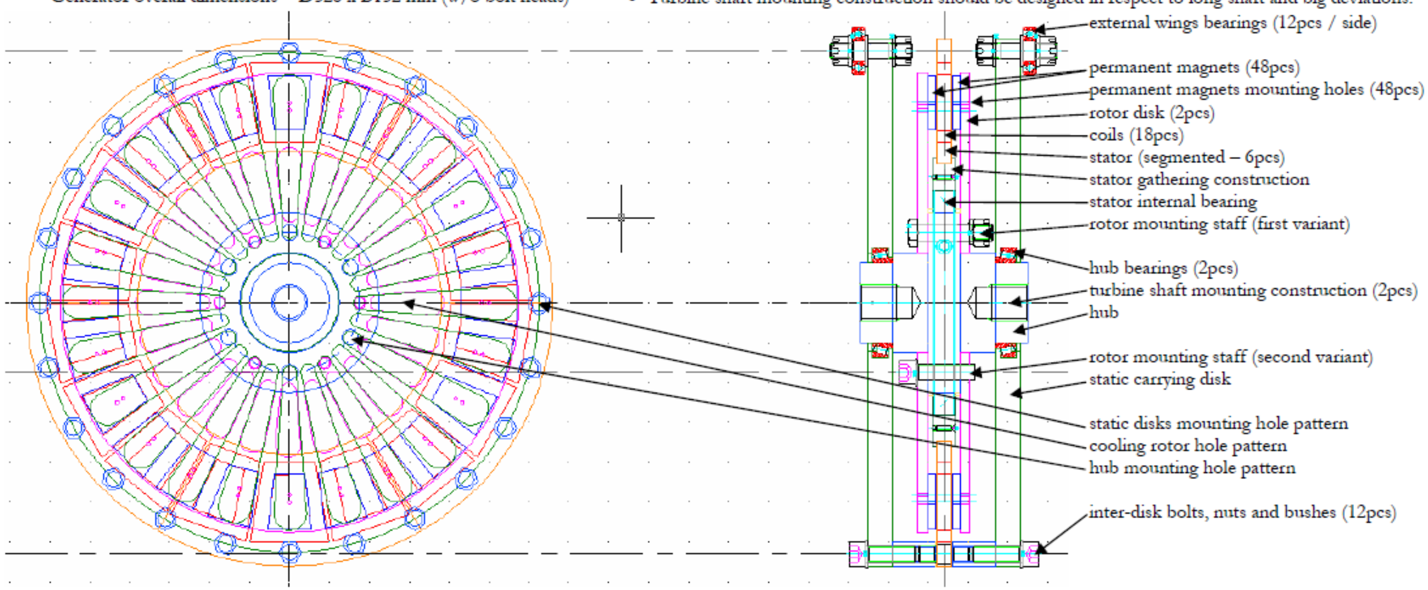
Axial Flux Ironless (AFIL) Generator parameters and construction

PM kind	Wedge 55x44x30x8 hole d3.4 mm
PM pieces / Poles / Pole pairs	48 / 24 / 12
Radial PM repetition ratio	0.70766
Radial Inter PM space	15.36
PM placement pattern	24 x R200 x d3.4 mm
Air gap total	16 mm
Steel Rotor Disk height	10 mm
Steel Rotor Disk External Diameter	D460 mm
Steel Rotor Disk Internal Diameter	D100 mm
Steel Rotor Disk Hole Patterns	24 x R200 x d3.4 mm (PM fixture) 6 x R140 x d16 mm (Hub fixture) 6 x R140 x d10.2 mm (Mount Tool)
Static Carrying Disk Diameter	528 mm
Static Carrying Disk Hole Patterns	12 x R252 d16 mm (inter-disk bolts) 12 x R252 d16 mm (external wings)
Hub Bearings	2 x Roller D110xd80xB20 mm
Stator Internal Bearing	Roller D180xd225xB22 (sx011836)
External wings bearings	Roller D47xd20xB12 (DIN 615)
Generator overall dimensions	D528 x B152 mm (w/o bolt heads)

Geometry	Poles 24 / Coils 18
Coils / Phases / Coils per Phase	18 / 3 / 6
Radial Coil repetition ratio	0.87718
Radial Inter PM space	8.31 @ 12 mm coil width
Coil placement pattern	3 x 6 x R200 mm
Air gap	2 x 1 mm
Coil height	14 mm
Coil cross-section	12 x 14 mm
Coil turns	42 x d2.0 mm
Plastic Stator Disk	D528 x d304 x H14 mm (in mounted state)
Plastic Stator Disk Segments	6
Coils/Phases per Segment	3

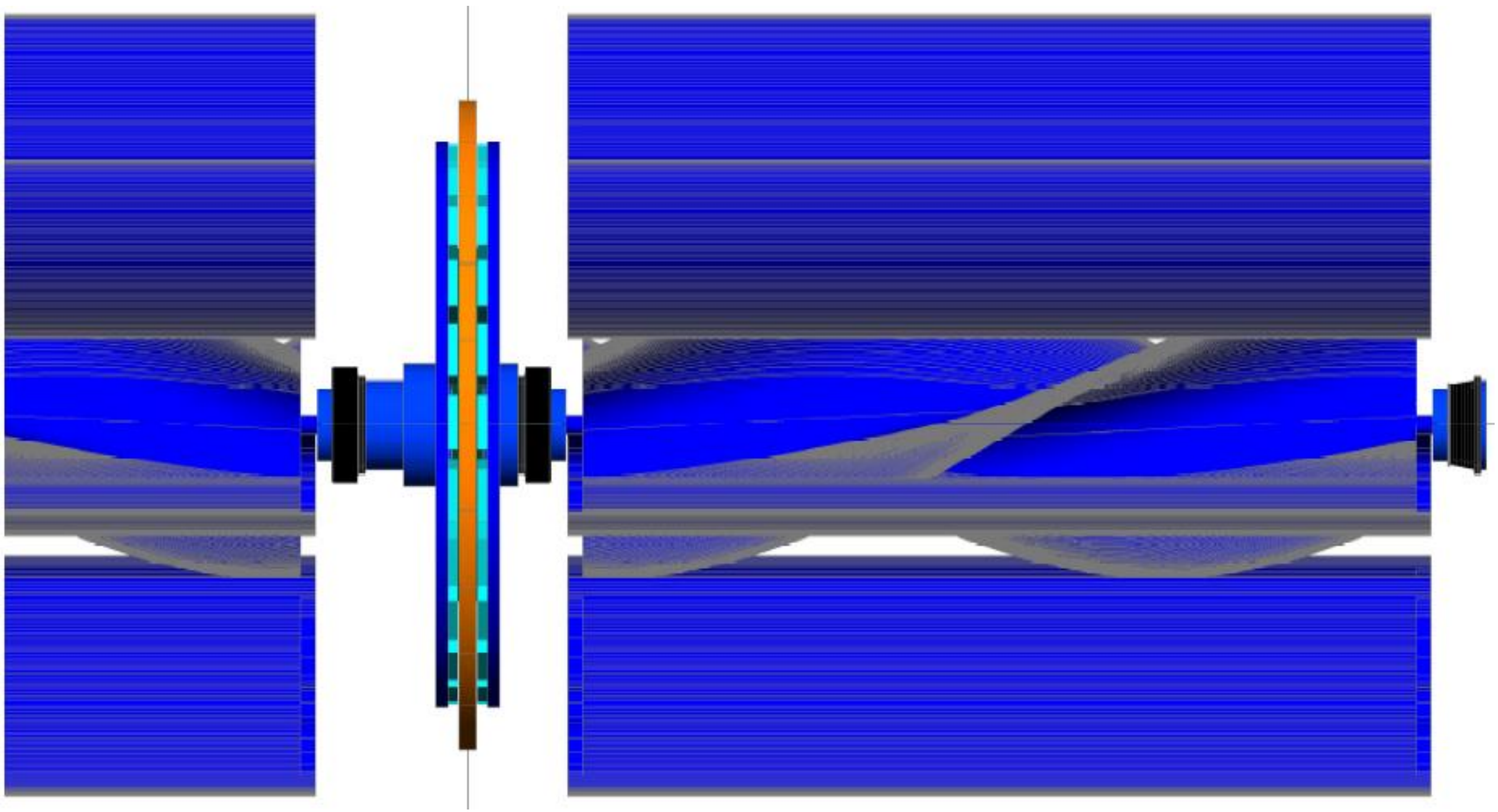
Notes:

- Construction is designed to fit both wedge 55x44x30x8 and 70x46x28x10 PMs;
- Both rotor and carrying disks should be made with maximal cooling efficiency;
- Stator gathering construction should be tuned to fit all incl. 24 and 16 poles 140/6 rotor disks;
- Construction has to be made in respect to turbine mounting and carrying;
- Construction should to be designed to be tolerant to external environment;
- Turbine shaft mounting construction should be designed in respect to long shaft and big deviations.



Generator Construction

- 3D model of wind turbine, generator rotor and stator – first revision



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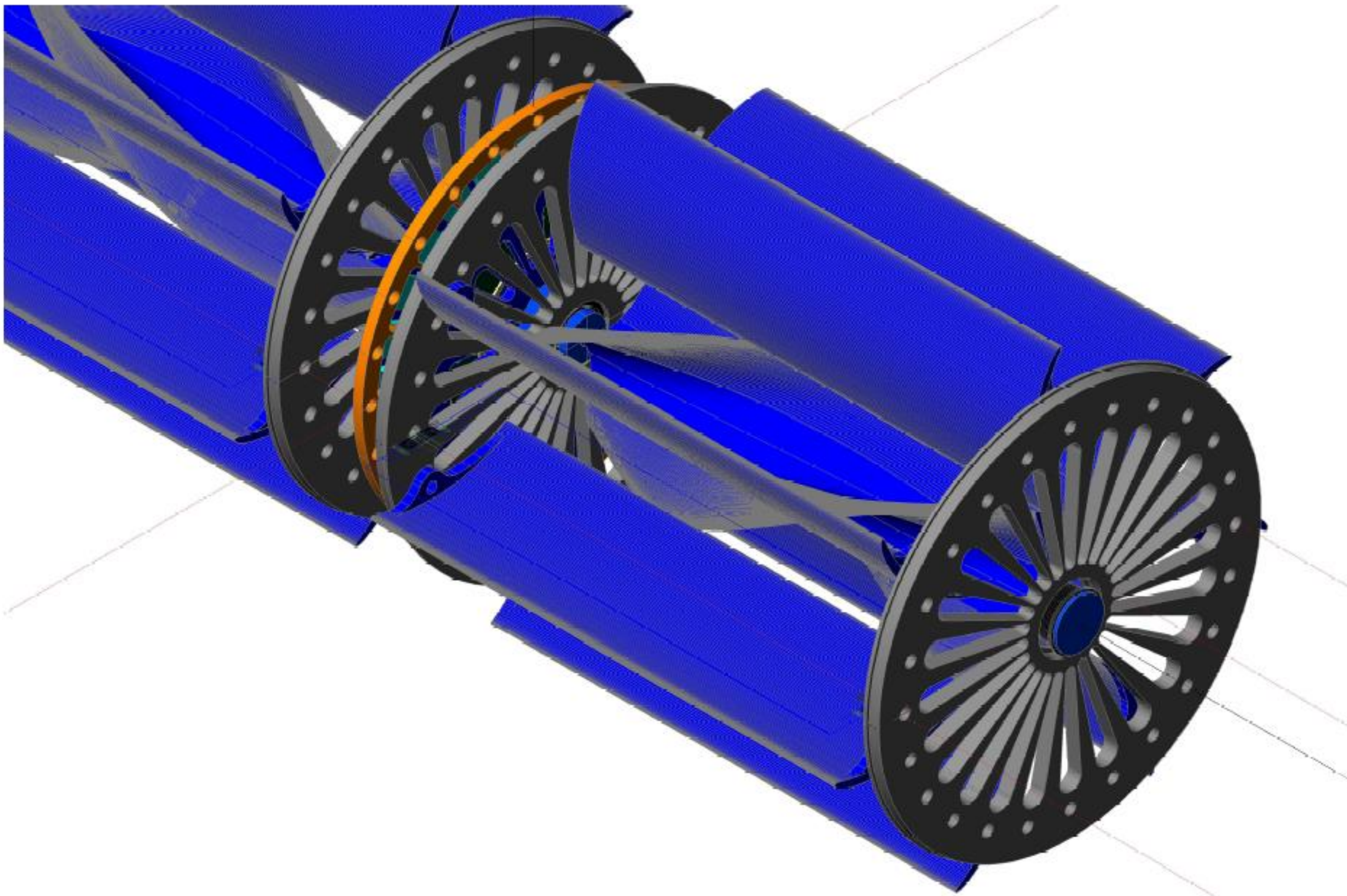

Generator Construction

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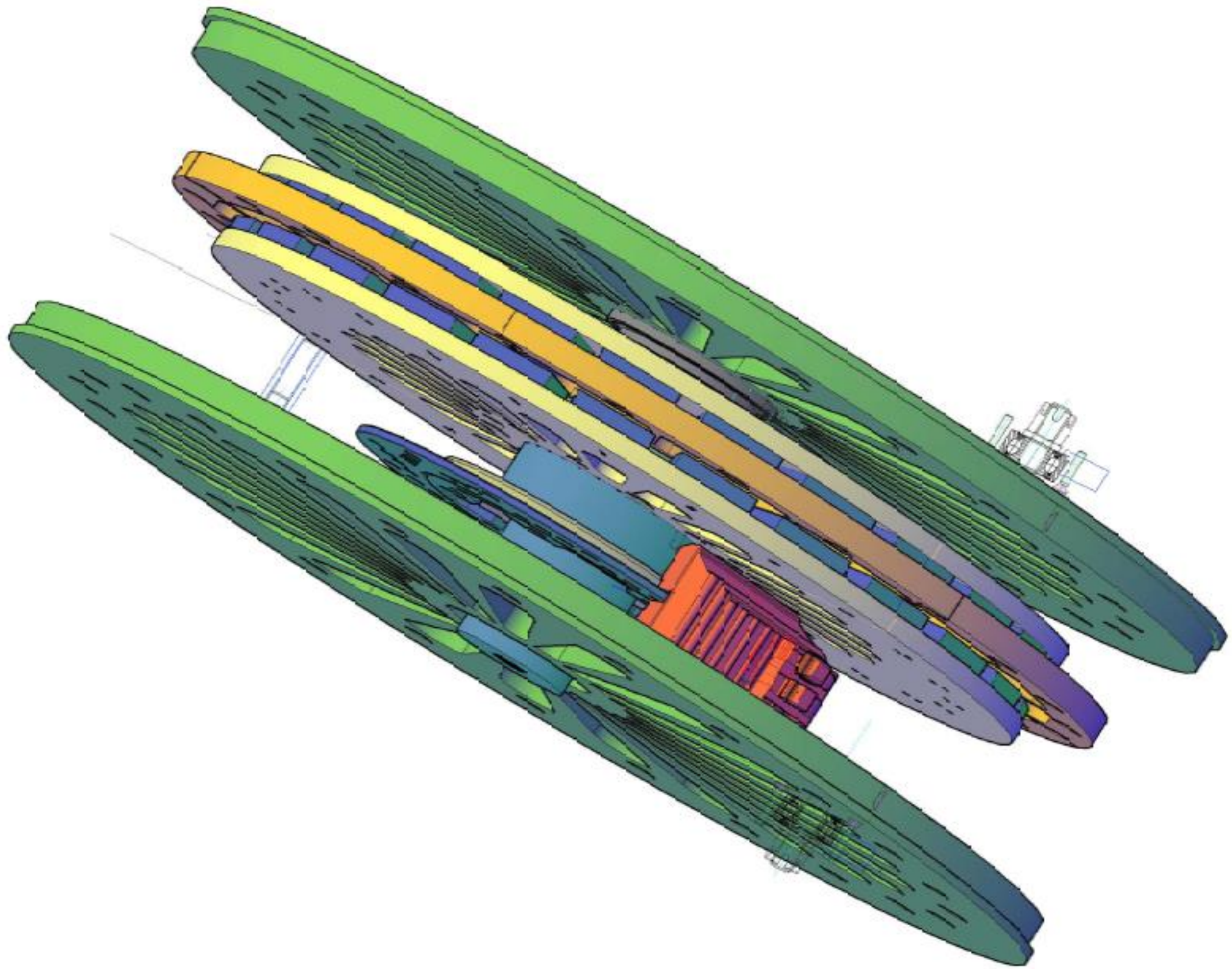
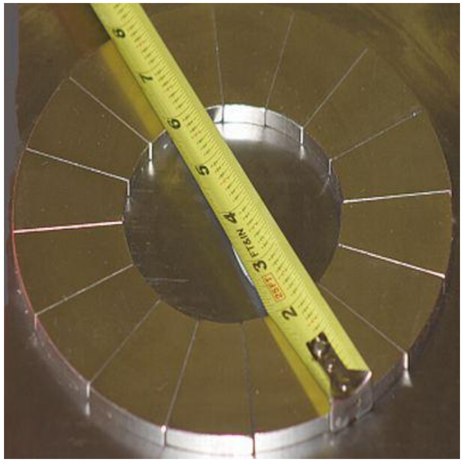


Generator Construction

- NdFeB Permanent Magnets – supplier selection and delivery

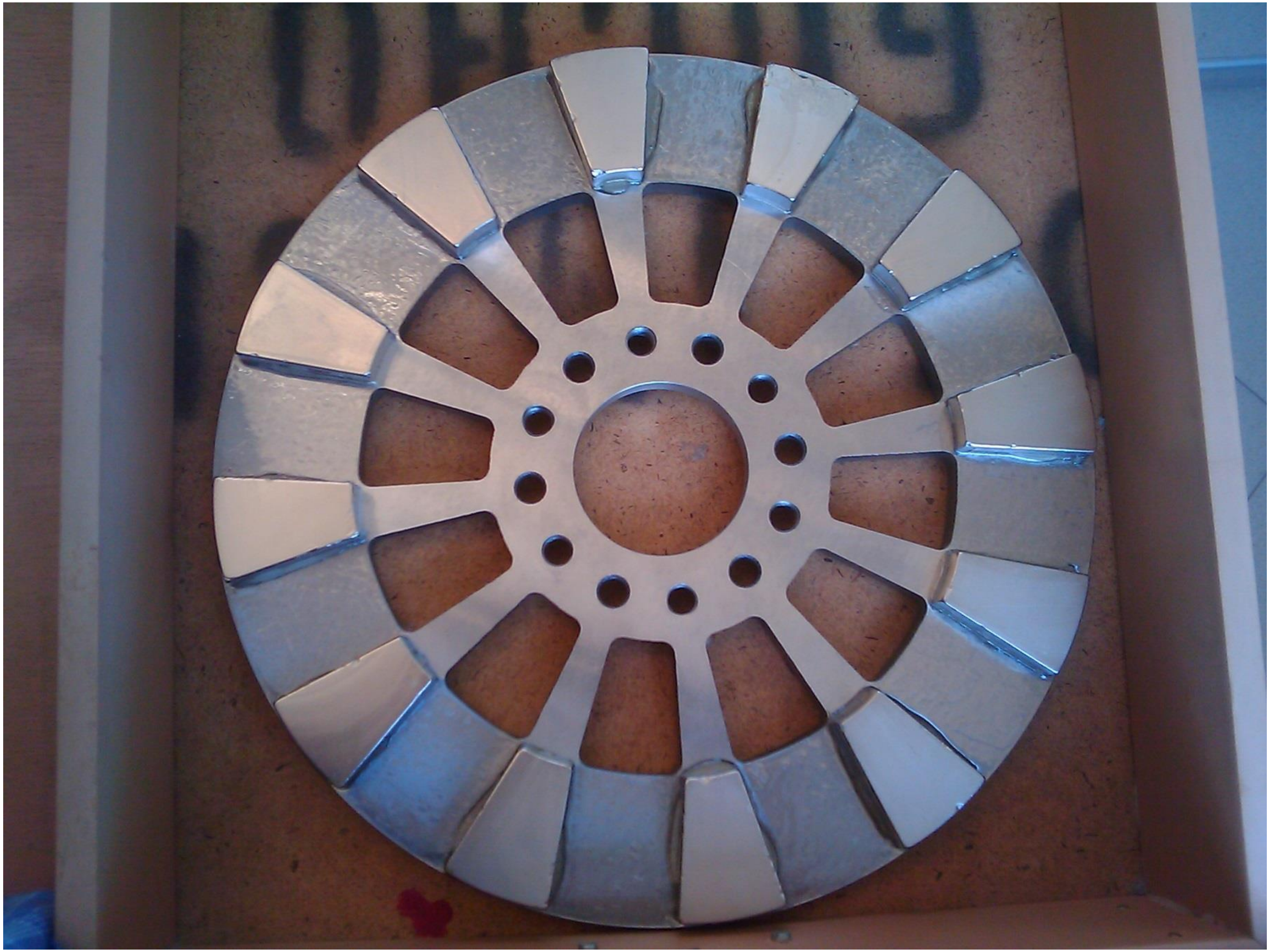
Dailymag Magnetic Technology (Ningbo) Limited is a Chinese leading manufacturer and exporter of permanent magnets etc.

Wind Generator NdFeB Magnets 22.5 degree
8 inch OD x 4 inch ID x 0.5 inch thick
Wedge Segment Shape, Grade N35~N52
Nickel-Copper-Nickel triple layer coated



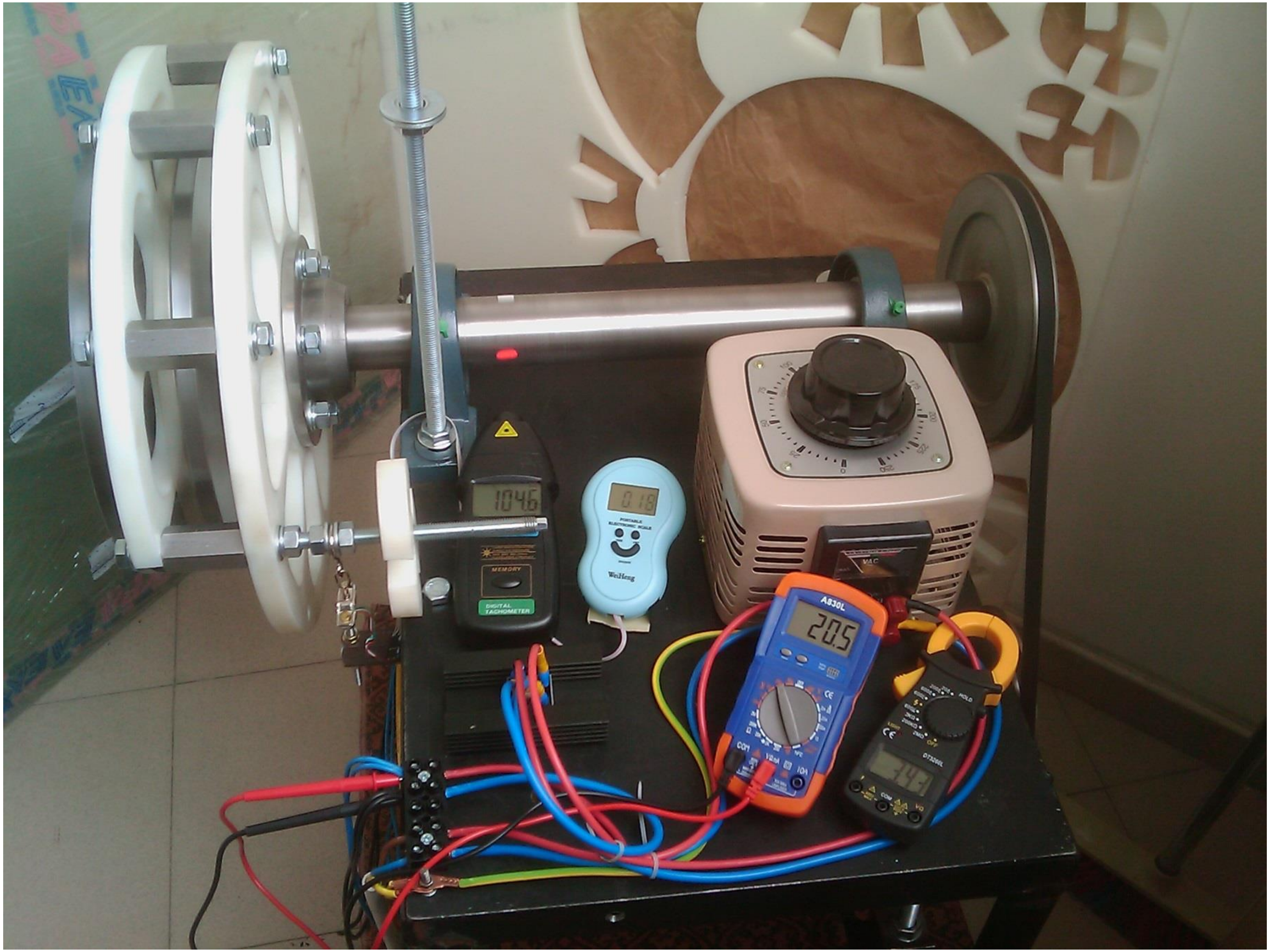
Generator Implementation

- The rotor disk



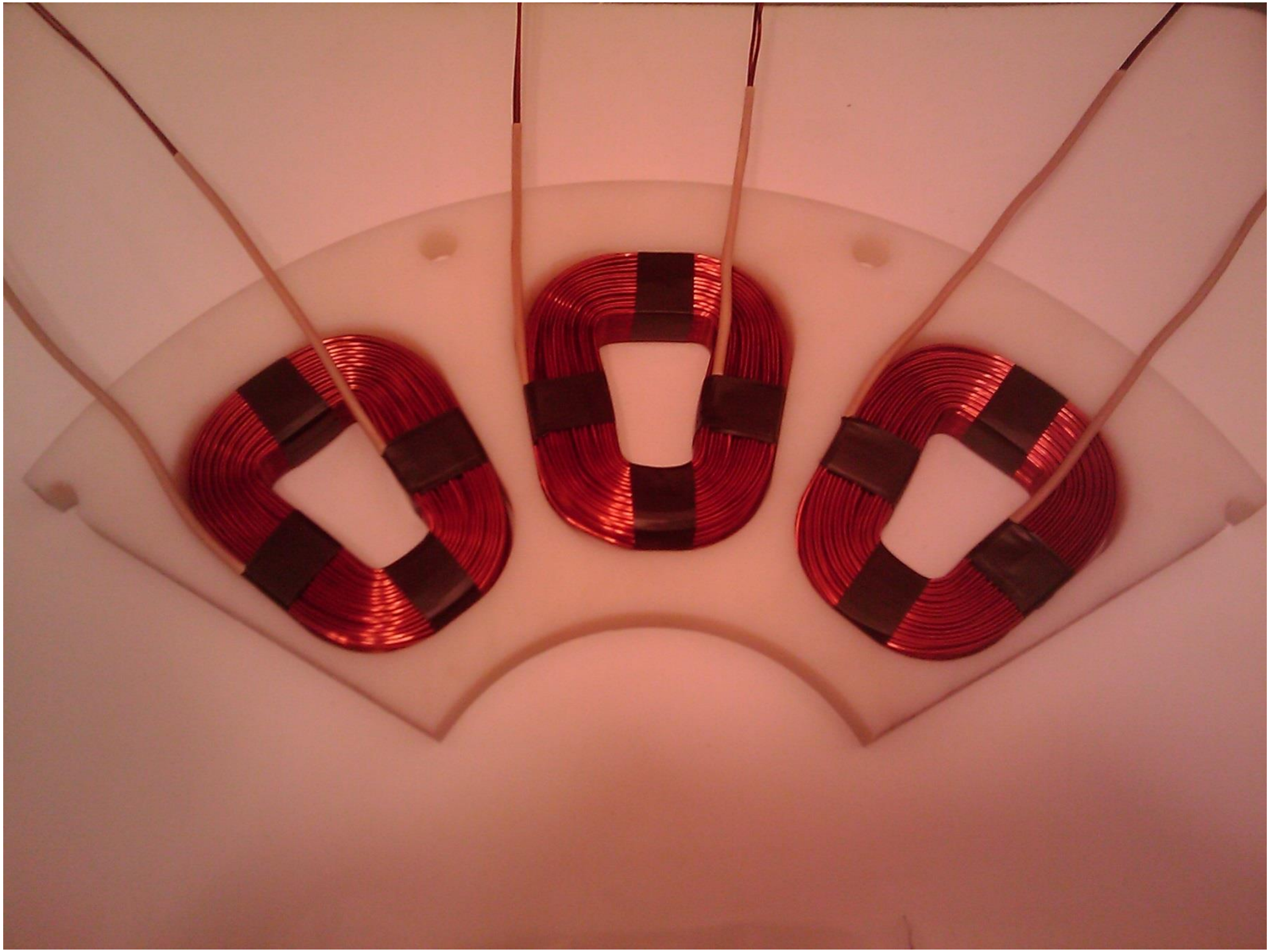
Generator Implementation

- The startup staff



Generator Implementation

- The stator segment

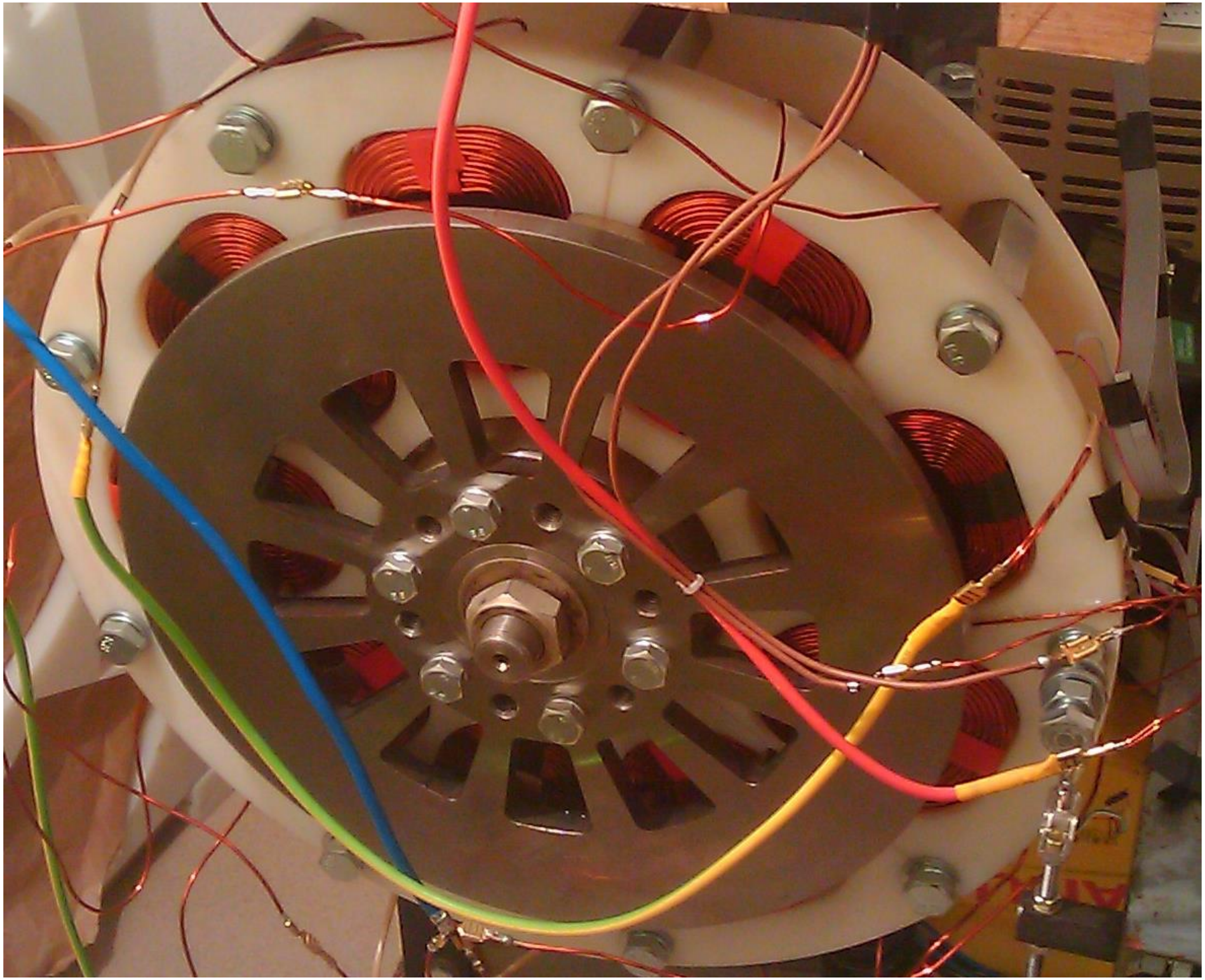


Generator Implementation

- The first assembling together

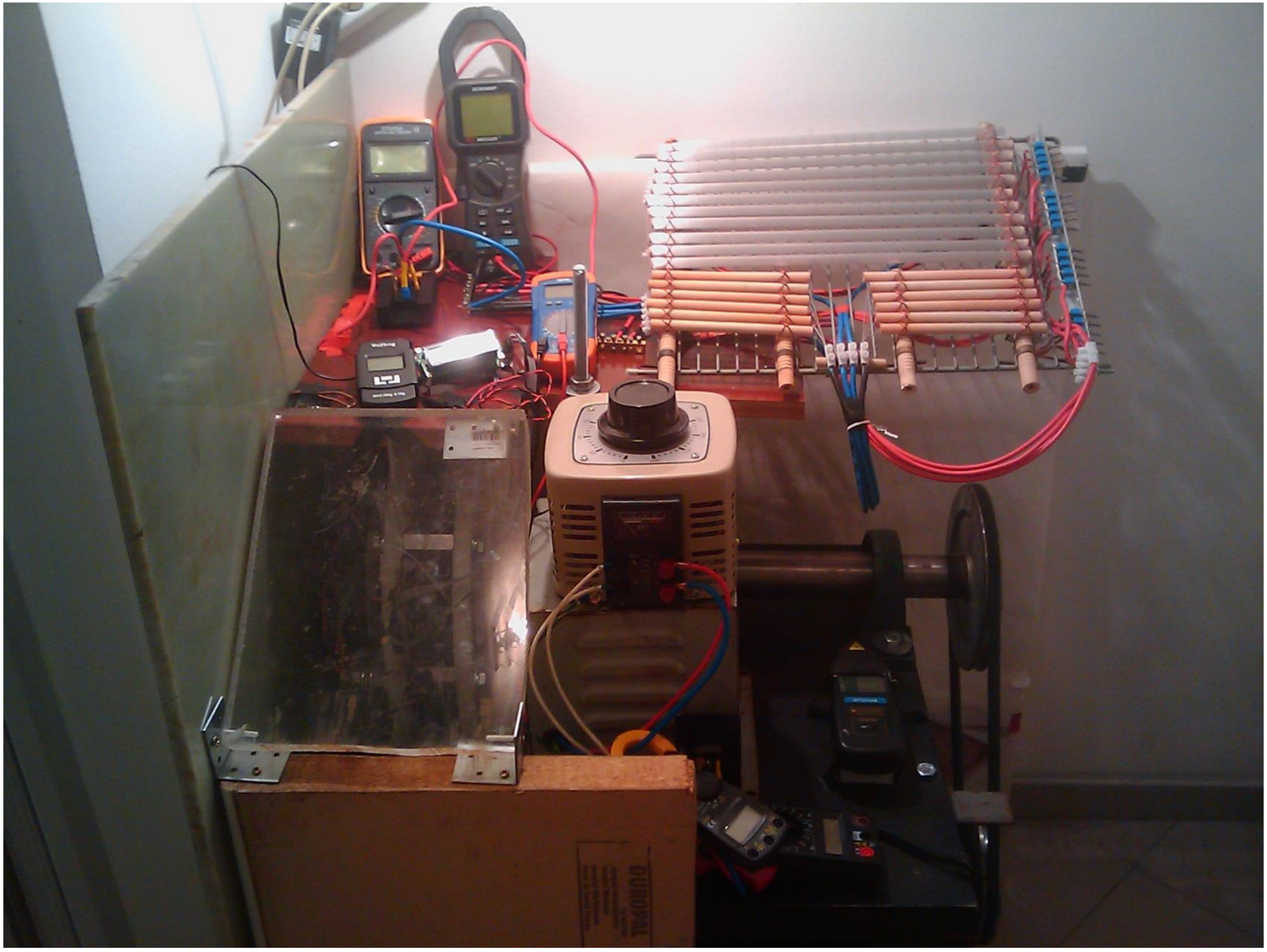
Generator Implementation

- Generator mounted on the test bed – (both first revision)



Test Bed Implementation

- Test bed – first revision

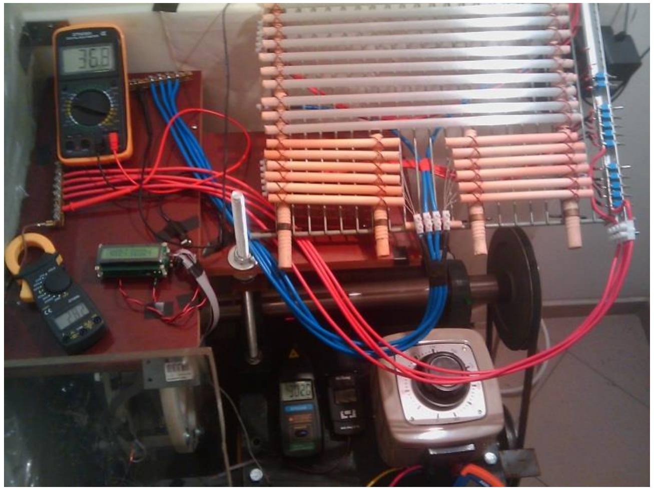


Generator Testing

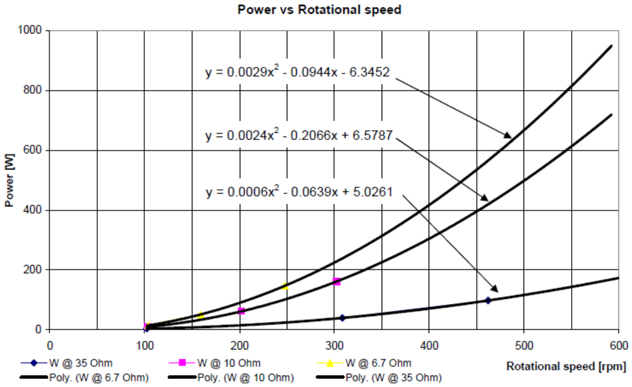
- Generator mounted on the test bed – energy production

First Light

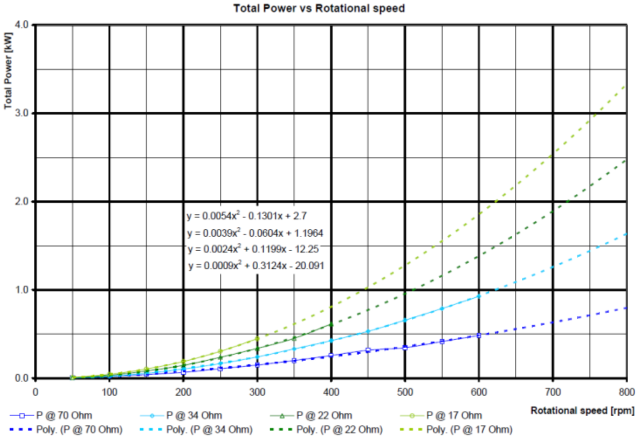
First Watts



First measured 100ths of Watts

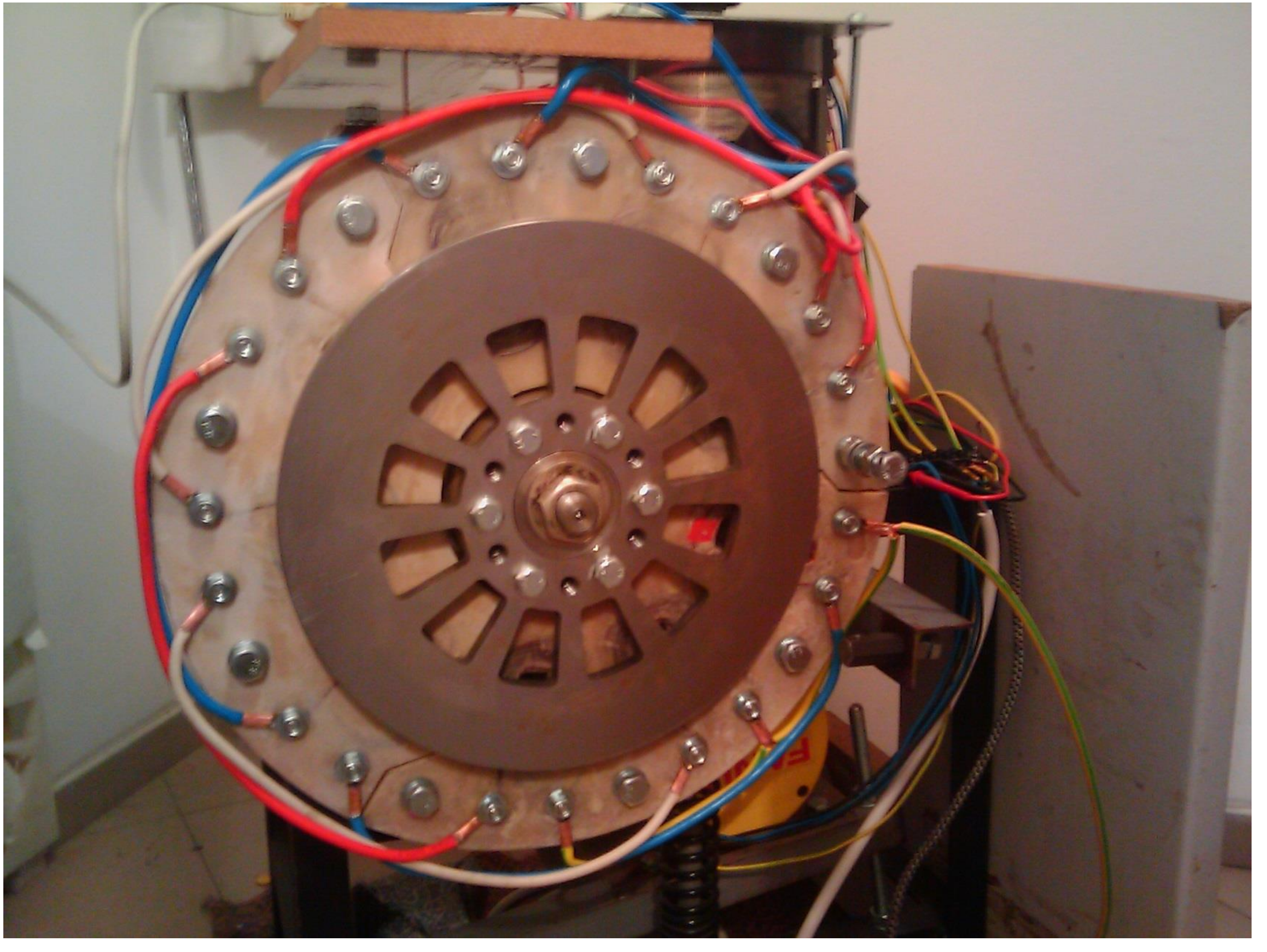


First measured 1000 Watts



Generator Improvements

- Wind Generator – first revision with modified stator (molding technology)



Generator and Turbine

- First assembling of the generator and the turbine

Generator and Turbine

- Rotational test of the generator and the turbine

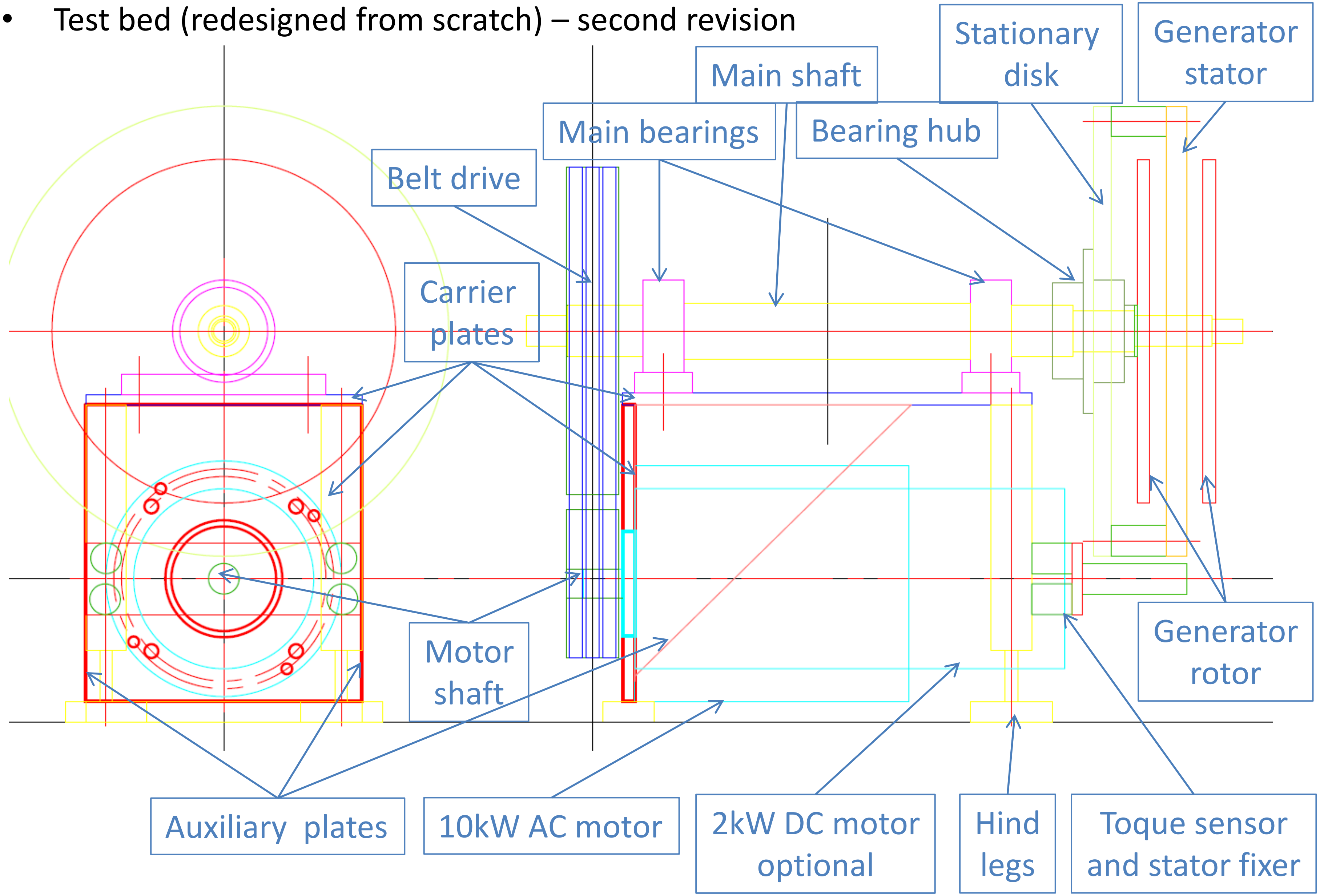
Generator, Turbine and Wings

- The generator, the turbine and the wings

The field test suite (Belmeken)

Test Bed Improvements

- Test bed (redesigned from scratch) – second revision



Mechanical System Improvement

- Test bed – belt drive is using V-Belts pulleys for taper bushes by Bea Ing. S.P.A.

PULEGGE A GOLE TRAPEZOIDALI PER BUSSOLA CONICA
V-BELTS PULLEYS FOR TAPER BUSHES

Descrizione e caratteristiche - Description and features

Le pulegge per cinghie trapezoidali sono costruite secondo le specifiche ISO 4183 / DIN 2211
Our V-belt pulleys are manufactured according to International Standard ISO 4183 / DIN 2211

Materiale - Material

Ghisa EN-GJL-200 (G20 - UNI 5007)
Cast iron EN-GJL-200(G20 - UNI 5007)

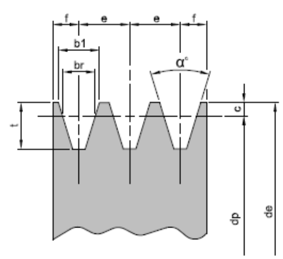
Trattamento e Bilanciatura
Protective treatment and Balancing

Tutte le pulegge standard sono protette con un trattamento superficiale di FOSFATAZIONE e BILANCIATE STATICAMENTE per essere idonee ad un funzionamento fino alla velocità periferica di 35 m/sec.
The surface of all our standard pulleys is protected by phosphated treatment. All the pulleys are Statically Balanced and can be used for peripheric speed up to 35 m/sec

Calcolo della velocità periferica (Vp)
Periferic speed table (Vp)

$$Vp = \frac{\pi \cdot dp \cdot n}{60 \cdot 1000} = \frac{dp \cdot n}{19100} = m/sec$$

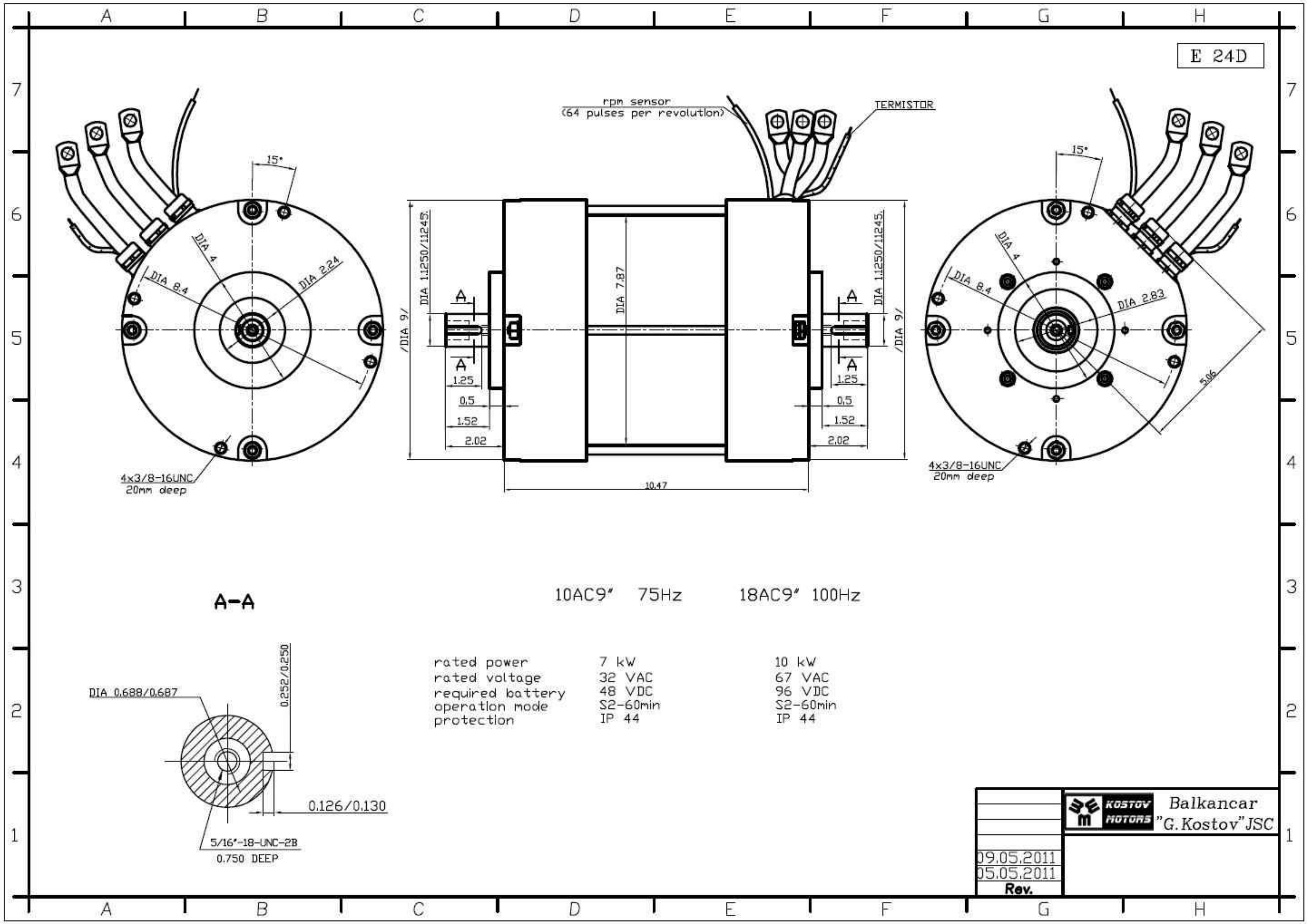
dp = **diametro in mm** - diameter/mm
n = **giri al minuto** - revolutions per minute
Vp = **velocità in m/sec** - speed



Dimensioni puleggia Dimension of Pulleys								
codice	dp mm	α gradi	b1 mm	br mm	e mm	f mm	c mm	t mm
SPZ (mm)	< 80 > 80	34° 38°	9,7	8,5	12	8	2	11
SPA (mm)	< 118 > 118	34° 38°	12,7	11	15	10	2,8	13,8
SPB (mm)	< 190 > 190	34° 38°	16,3	14	19	12,5	3,5	17,5
SPC (mm)	< 315 > 315	34° 38°	22,0	19	25,5	17	4,8	23,8

Electrical System Improvement

- Test bed with Kostov's AC Motor and Curtis' Controller



Electrical System Improvement

- Test bed with Kostov's AC Motor and Curtis' Controller

ON-ROAD AC INDUCTION MOTOR CONTROLLER

MODEL 1238R

CURTIS

DESCRIPTION

The Curtis Model 1238R provides energy efficient control of AC induction motors performing on-vehicle traction drive duties. It offers vehicle developers a highly cost-effective combination of power, performance and functionality.

APPLICATION

Designed for use as a traction controller for on-road electric and hybrid passenger vehicles using 72–96V system voltages, and other similar applications with low or medium duty cycles.

Patents Pending

Only Curtis AC can offer:

- **Curtis VCL—Vehicle Control Language** is an easy to use programming language that allows vehicle developers to write powerful logic functions and create a 'virtual system controller'. Curtis offers customers VCL development tools and training. Curtis also provides a VCL service where Curtis engineers will work with the OEM to create any custom VCL code required.
- **Indirect Field Orientation (IFO) vector control** algorithm generates the maximum possible torque and efficiency across the entire speed range. Advanced Curtis IFO vector control provides superb drive 'feel', improved speed regulation and increased gradeability.
- **Curtis Auto-Tune** function enables quick and easy characterization of the AC motor without having to remove it from the vehicle. Curtis AC controllers are fully compatible with any brand of AC motor.
- **Dual-Drive functionality** is standard, allowing correct control of applications featuring twin traction motors. This function ensures smooth and safe operation, minimal tire wear and correct load sharing between the traction motors at all times.
- **Configurable CANbus** connection allows communication with other CANbus enabled devices. Model 1238R is CANopen compatible and can be further customized and configured using VCL.
- **Integrated System Controller** - More than just a motor controller, it is also powerful system controller. It features a comprehensive allocation of multi-function I/O pins for use as analog inputs, digital inputs, contactor coil drivers and proportional valve drivers. In addition to this local I/O, this controller can use VCL to map and configure the remote I/O available on other CANbus devices, send messages to CAN displays and thus control and monitor the entire system.

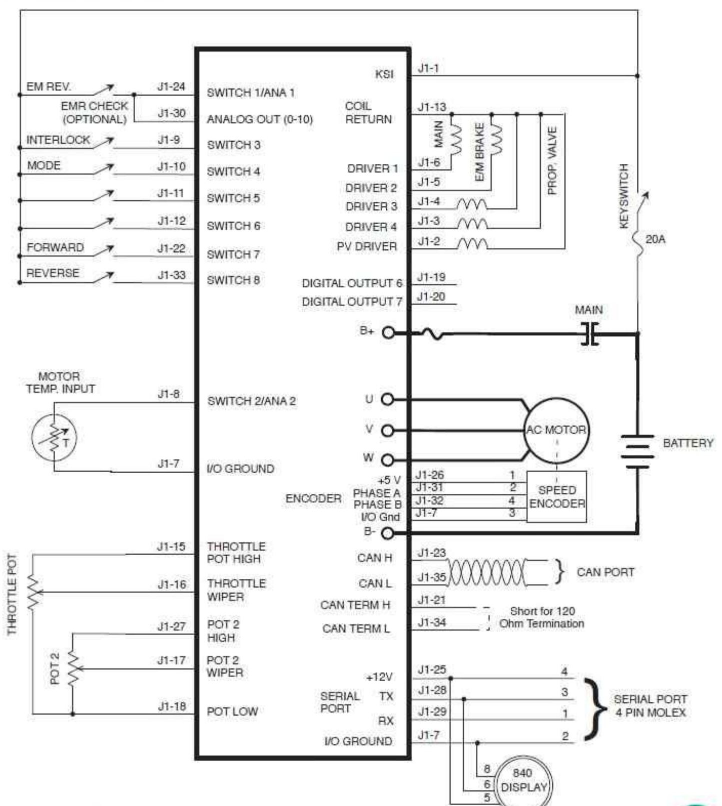
FEATURES

Advanced functionality, compact power

- High frequency, silent operation across the 0–300Hz stator frequency range.
- Two models of 1238R are available, offering outputs of 550A or 650A for a 72–96V nominal system voltage. This is a 72–96V nominal system voltage. This is a true 2 minute RMS rating, not a short duration 'boost' rating.

MODEL 1238R

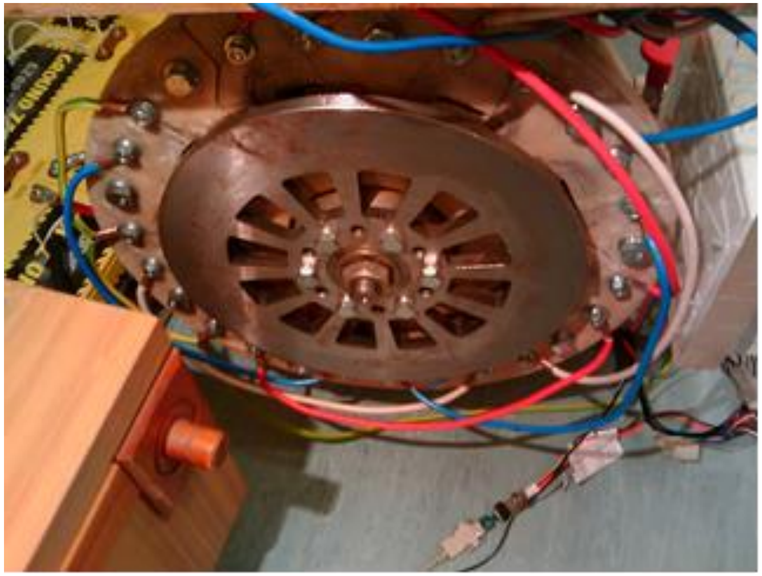
TYPICAL WIRING

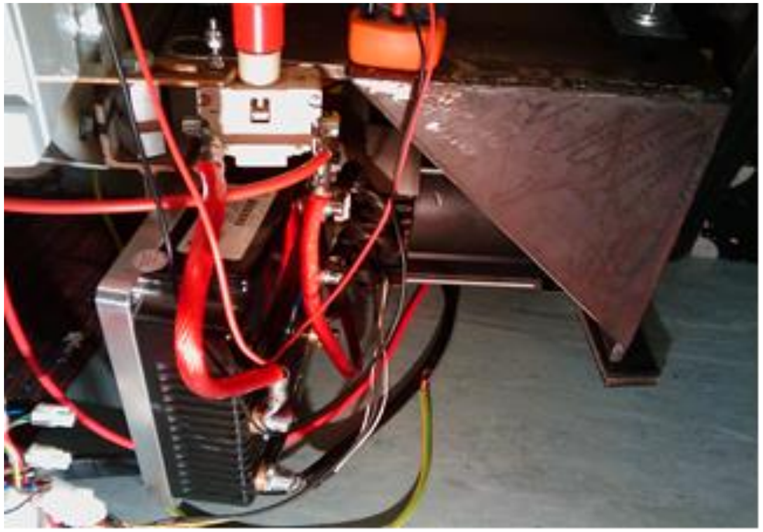


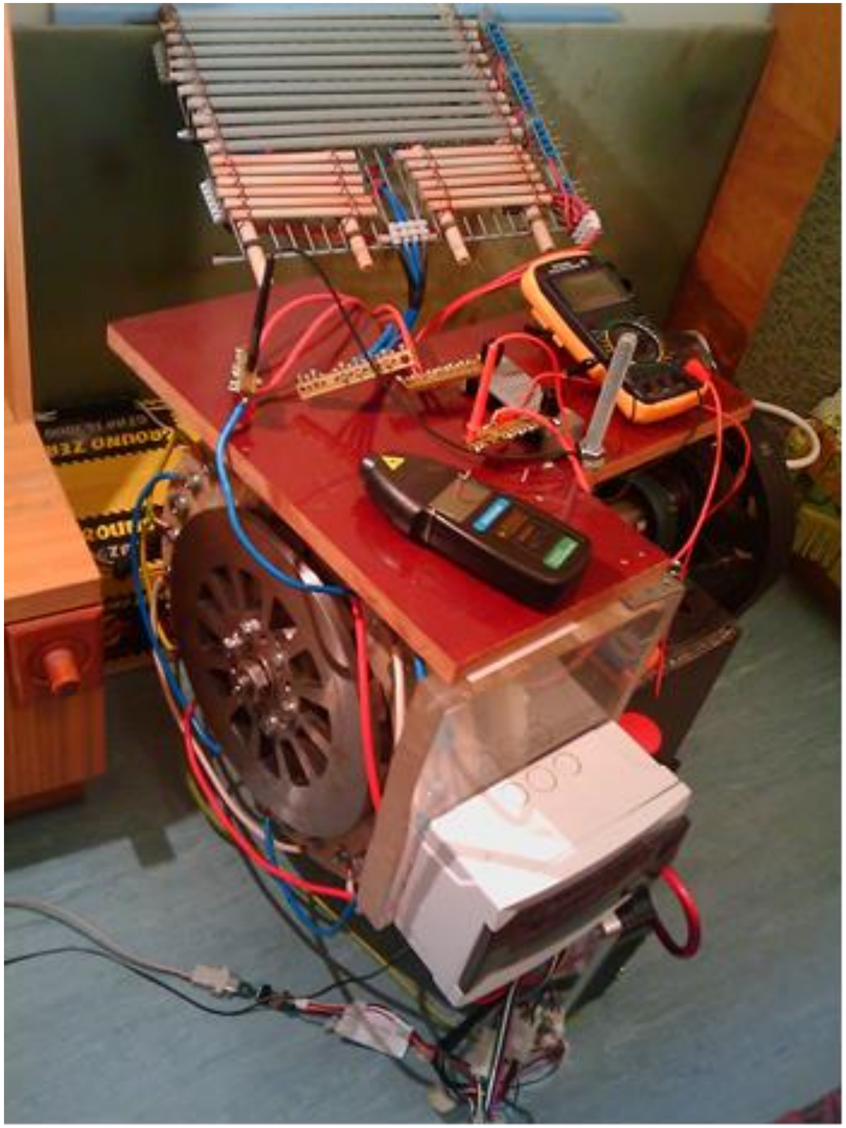
WARRANTY Two year limited warranty from time of delivery.

Test Bed Improvements

- Test bed (redesigned from scratch) – second revision

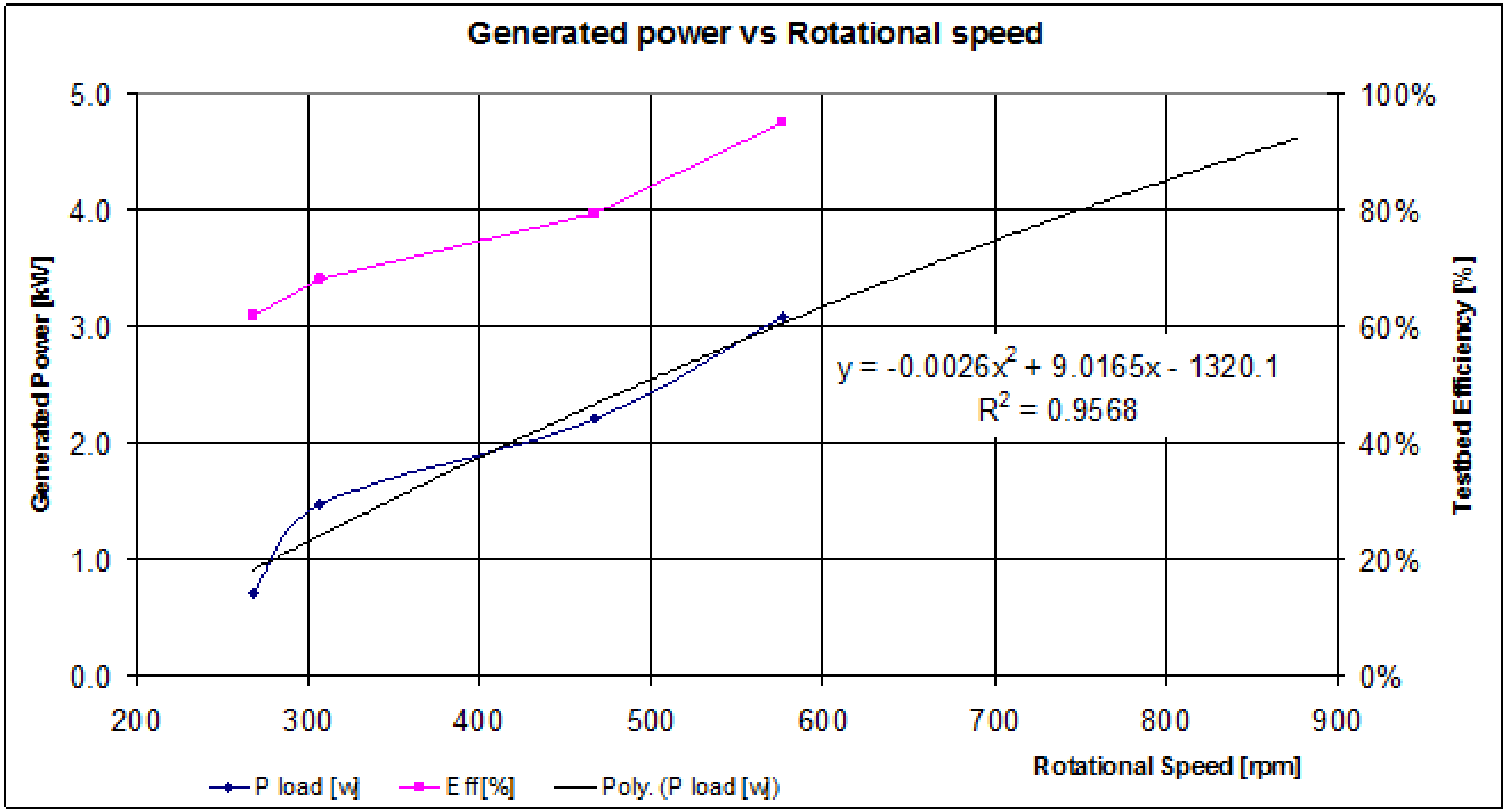






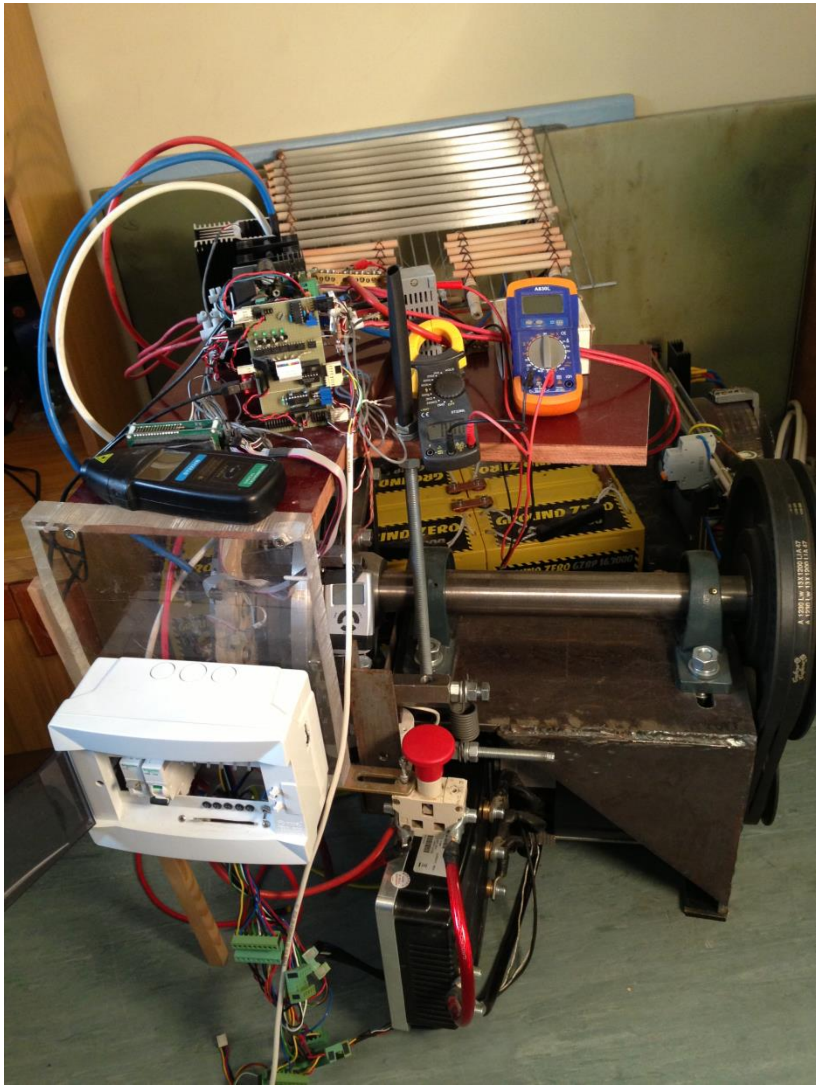
Generator Testing

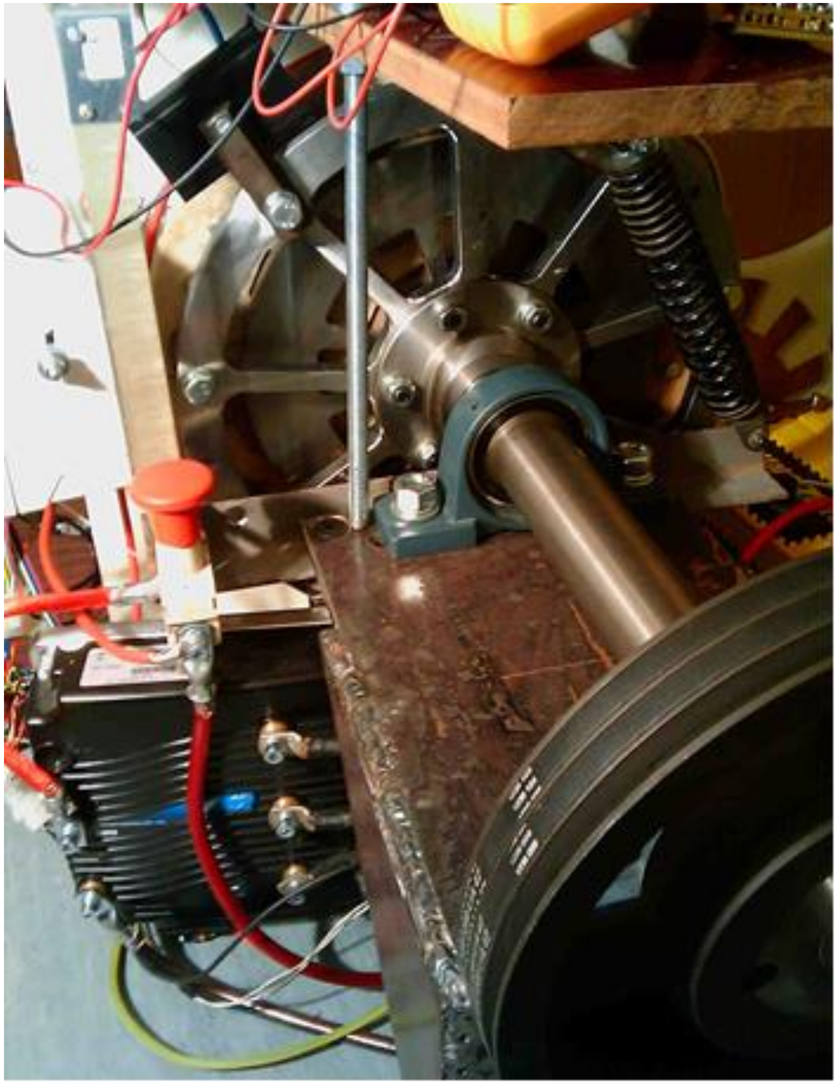
- Generator mounted on the second revision test bed – energy production



Test Bed Improvements

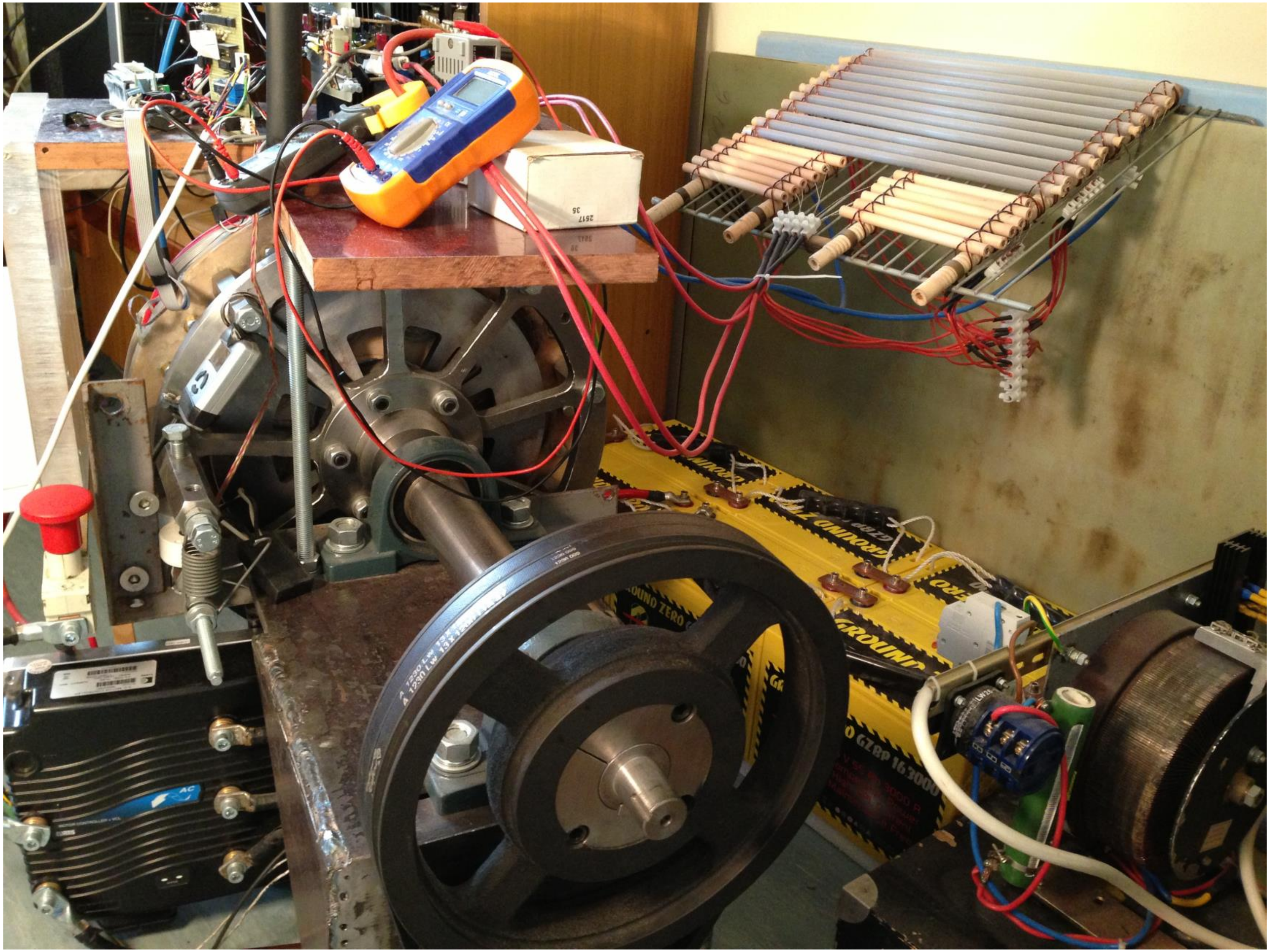
- Test bed – modified second revision





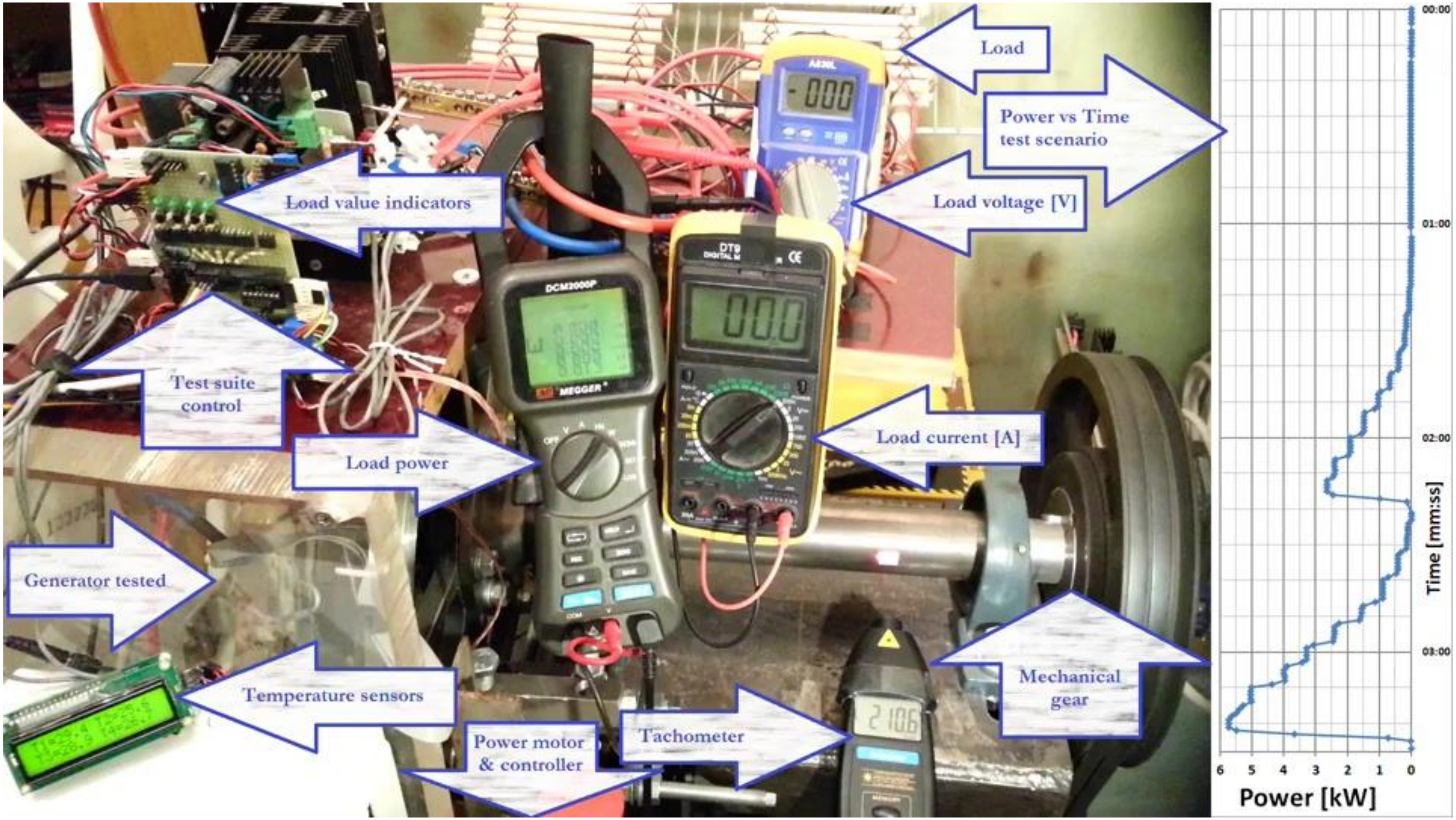
Test Bed Improvements

- Test bed – modified second revision



Test Bed Improvements

- Test bed – modified second revision (complete staff)

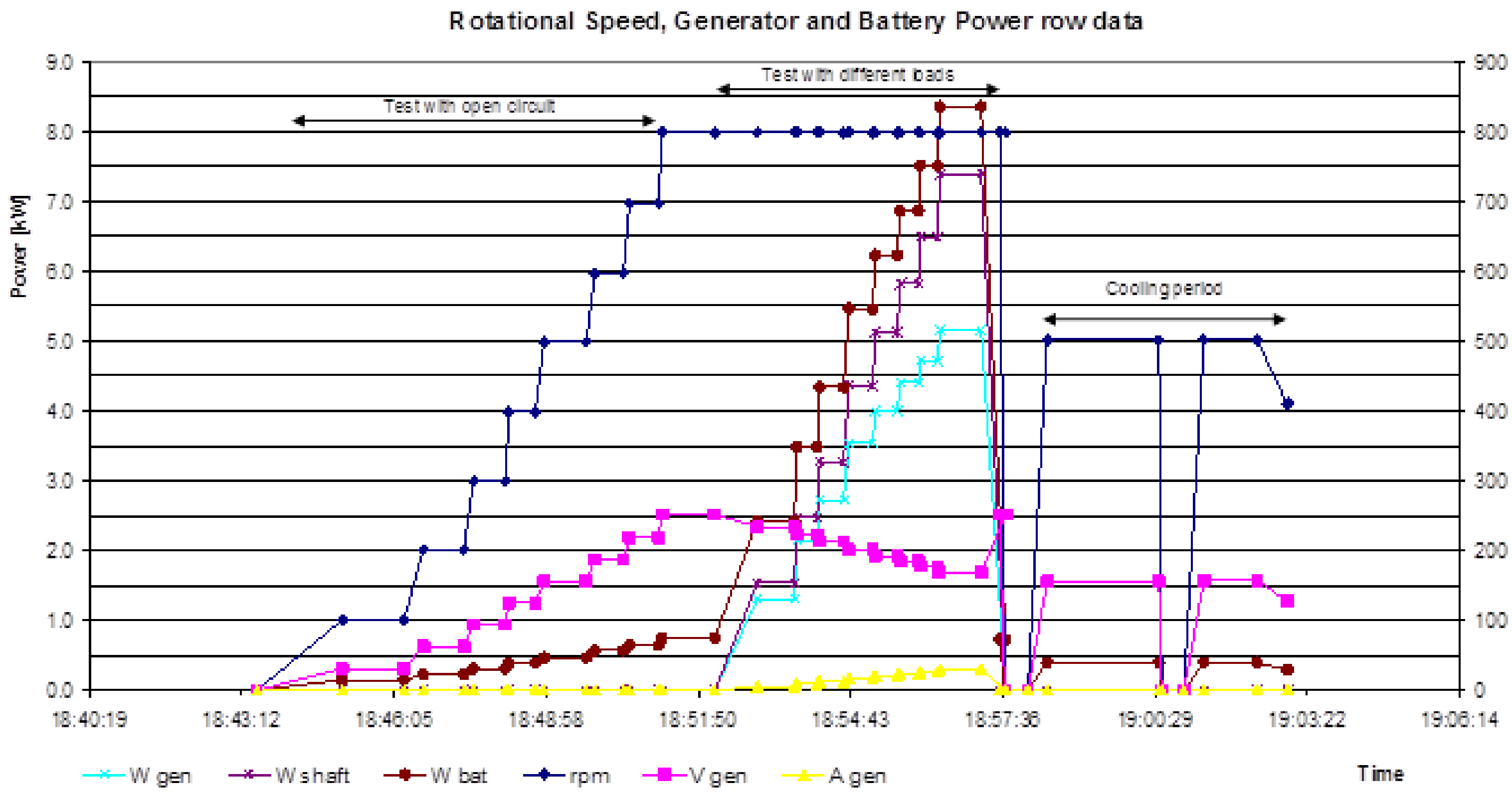


Generator Testing

- Generator mounted on the second revision test bed – energy production

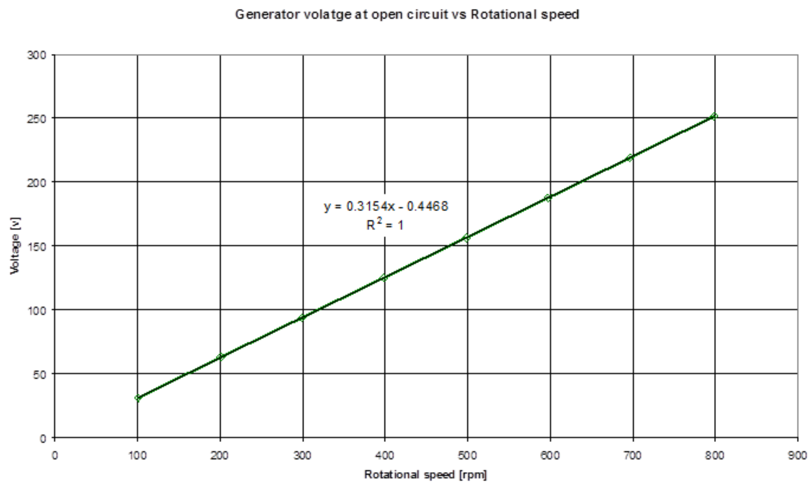
Tests after mounting torque and temperature sensors

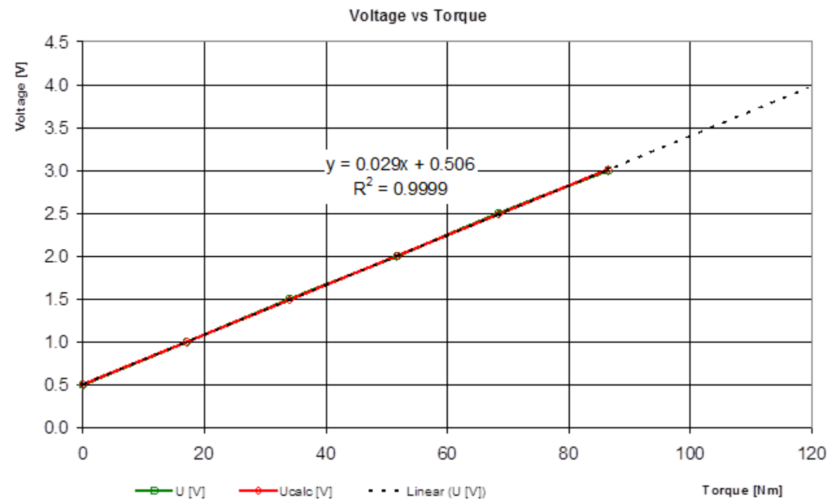
- Short time max power measured on 18 March – 5150 W (30.5A x 169V) @ 798 rpm and 5.5 Ohm load;
- Long time max power measured on 17 March – 4860 W (28.5A x 171.1V) @ 806 rpm and 6.2 Ohm load;
- Short time max power measured on 14 March – 4200 W (26.1A x 161.4V) @ 725 rpm and 6.2 Ohm load;
- Long term max power measured on 12 March – 3300 W (21.6A x 152.5V) @ 650 rpm and 7.1 Ohm load;
- More power output at rpm above 800 and load current above 30 A can be reached with better mechanical balancing and stator cooling.

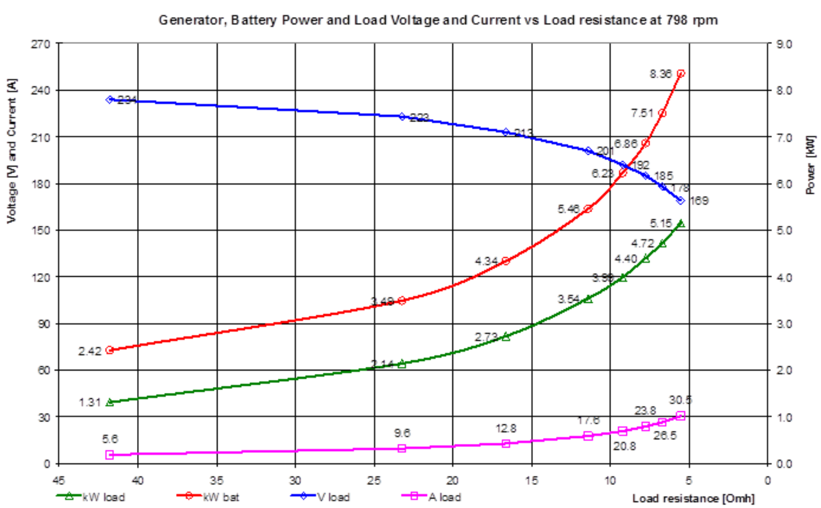


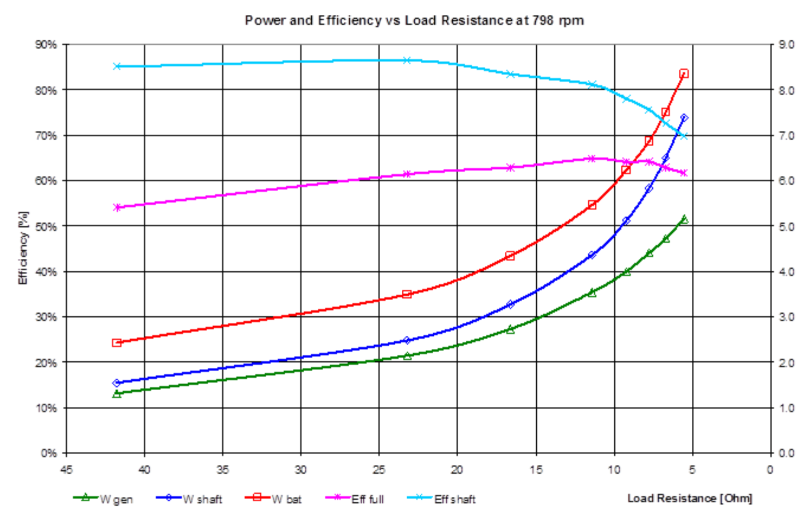
Generator Testing

- Generator mounted on the second revision test bed – measured power up to 5 kW



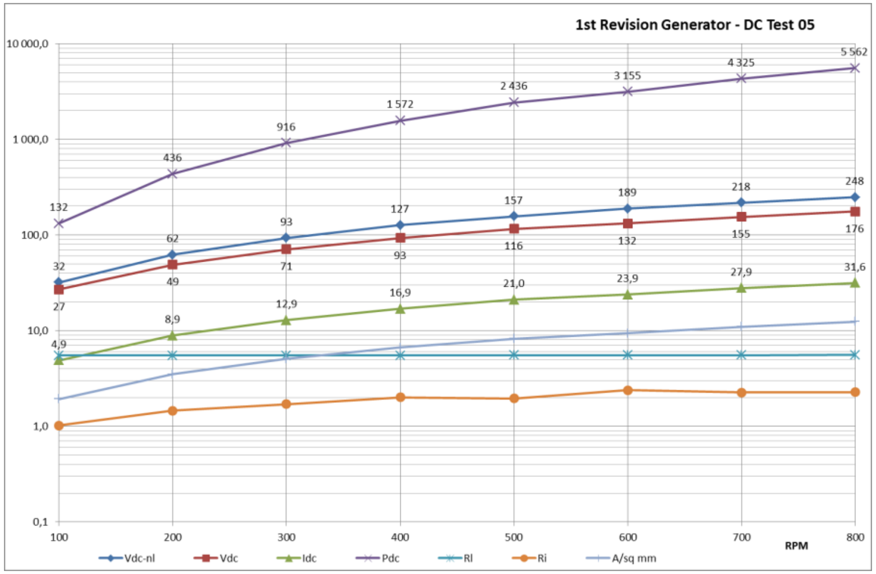


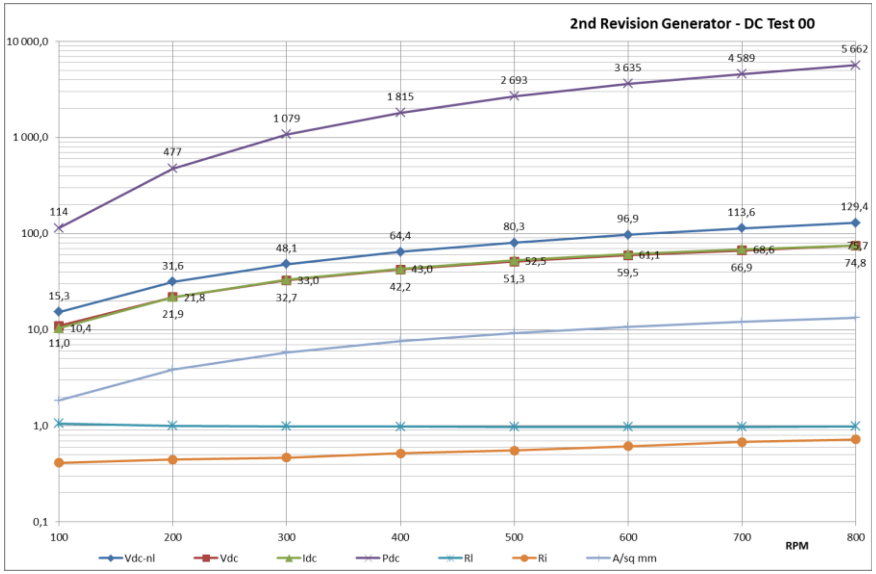


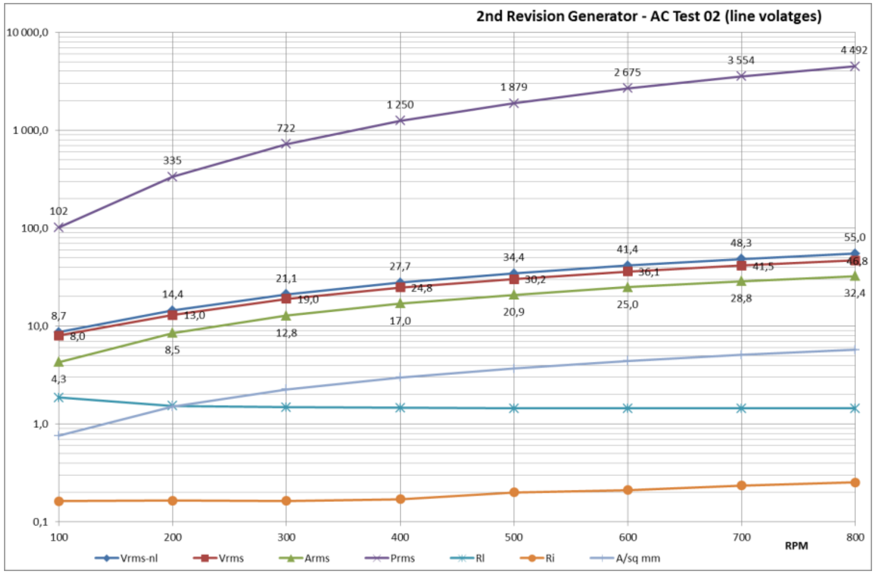


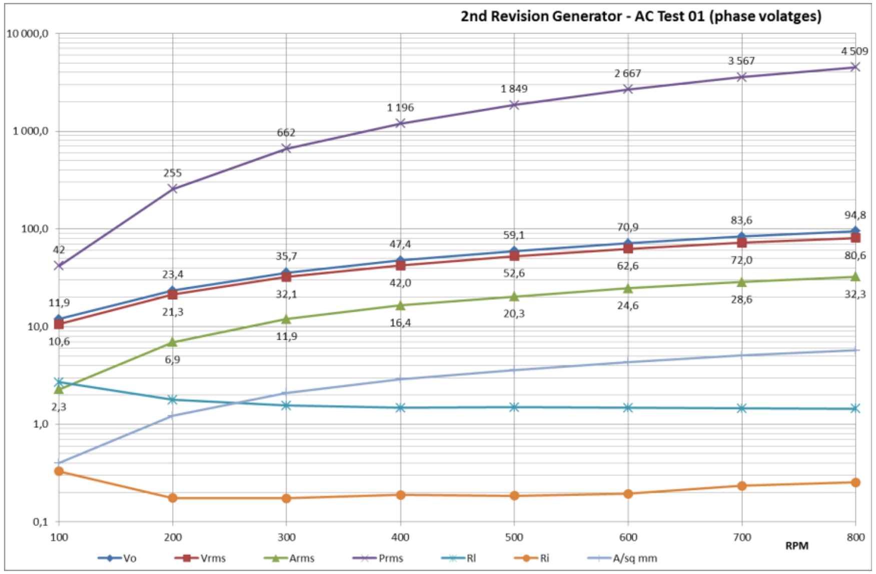
Generator Testing

- Generator mounted on the second revision test bed (AC/DC Load comparison)



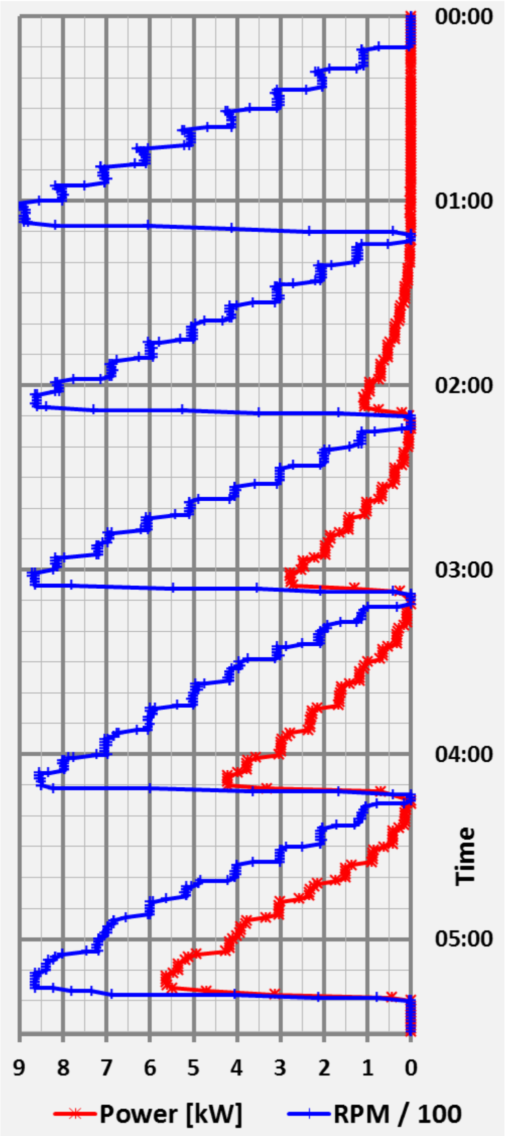


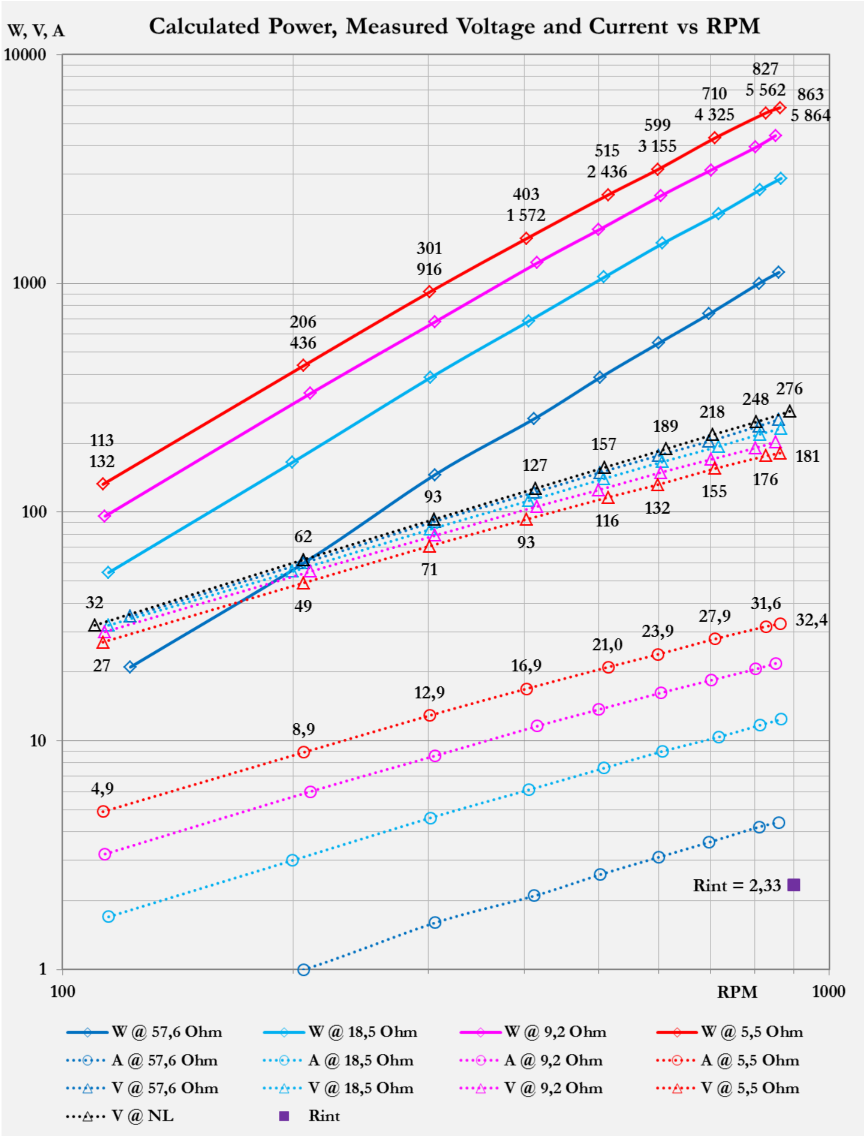




Generator Testing

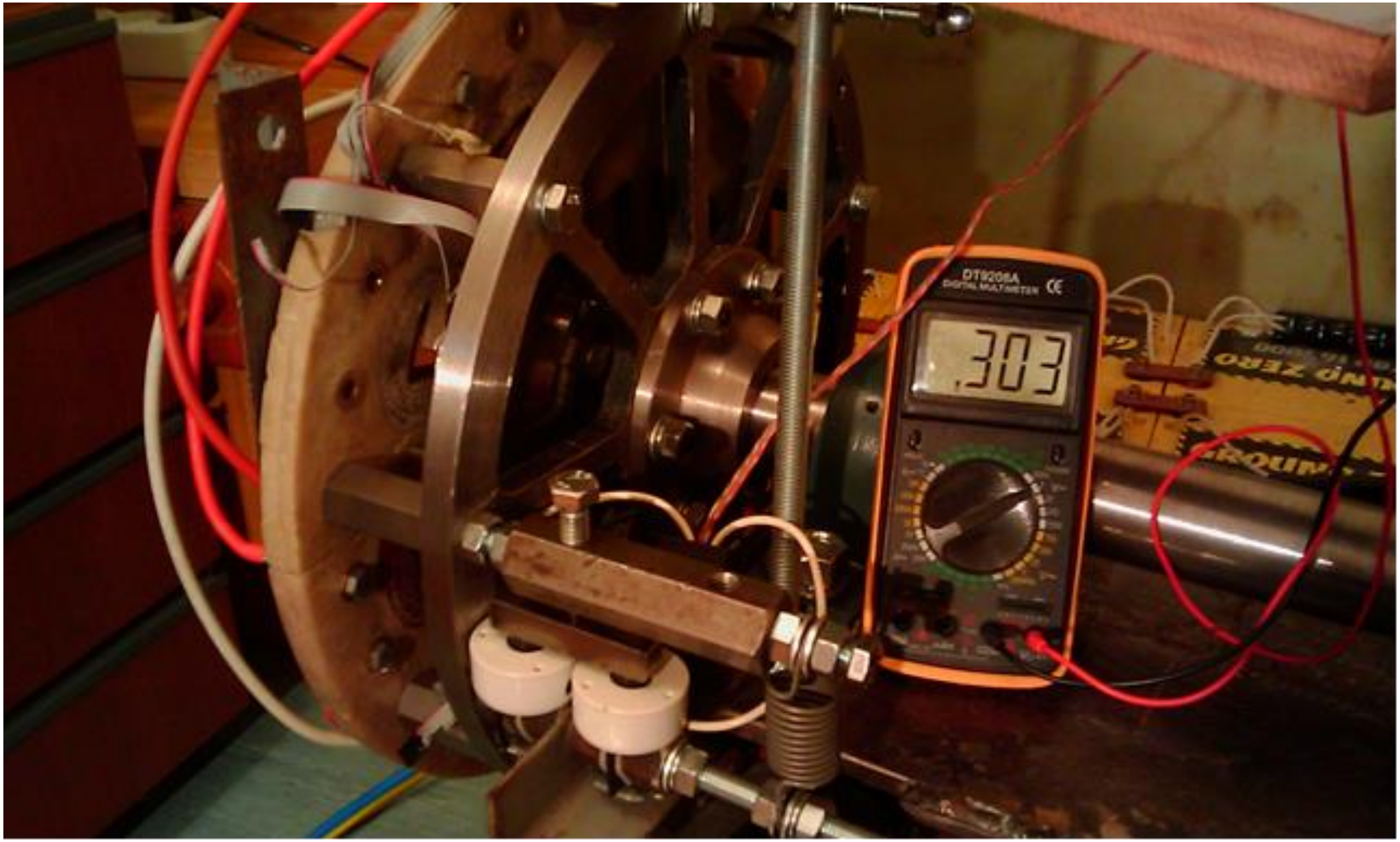
- Generator mounted on the second revision test bed (long test)





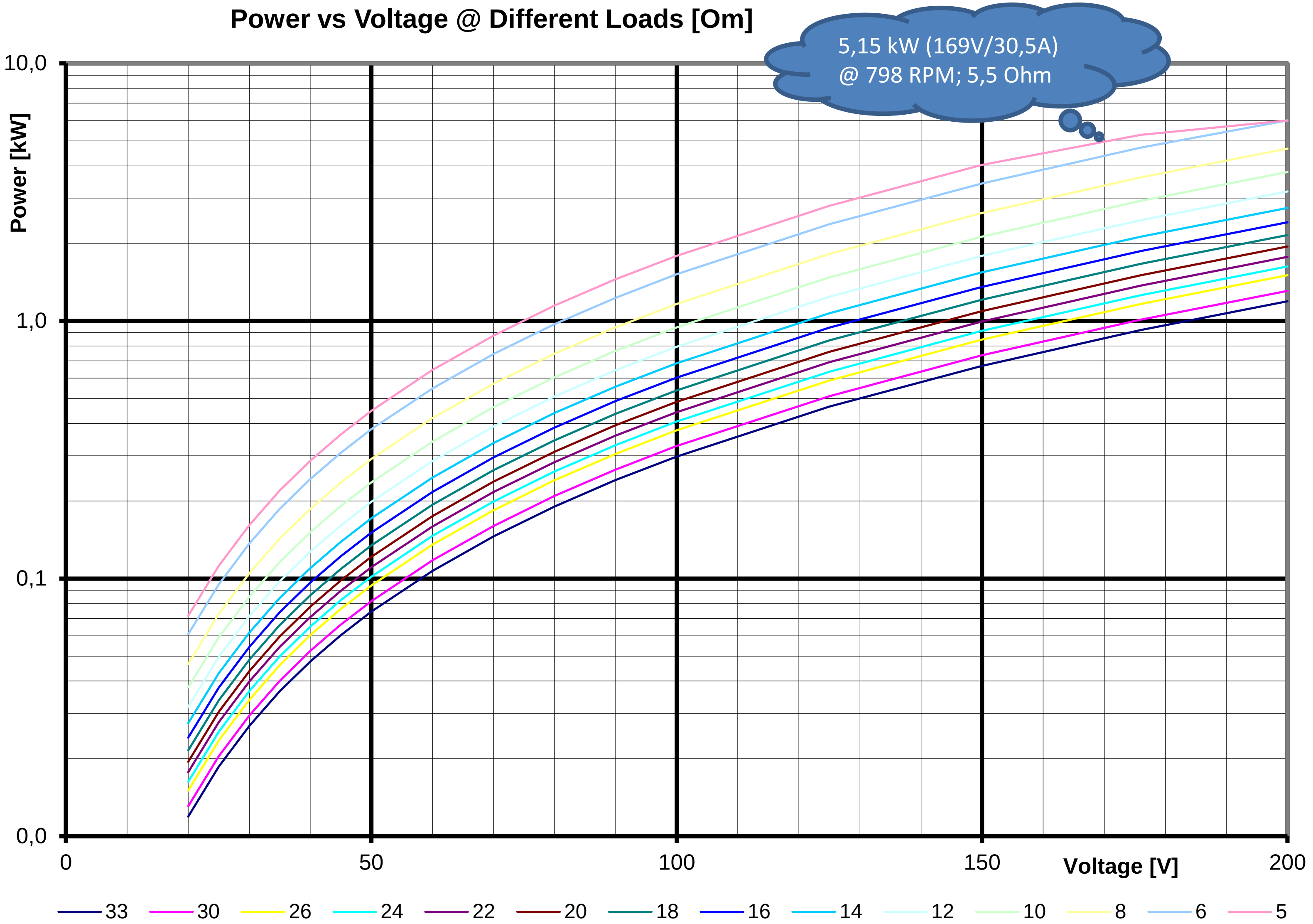
Test Bed Improvements

- Test bed – modified second revision with torque and temperature sensors



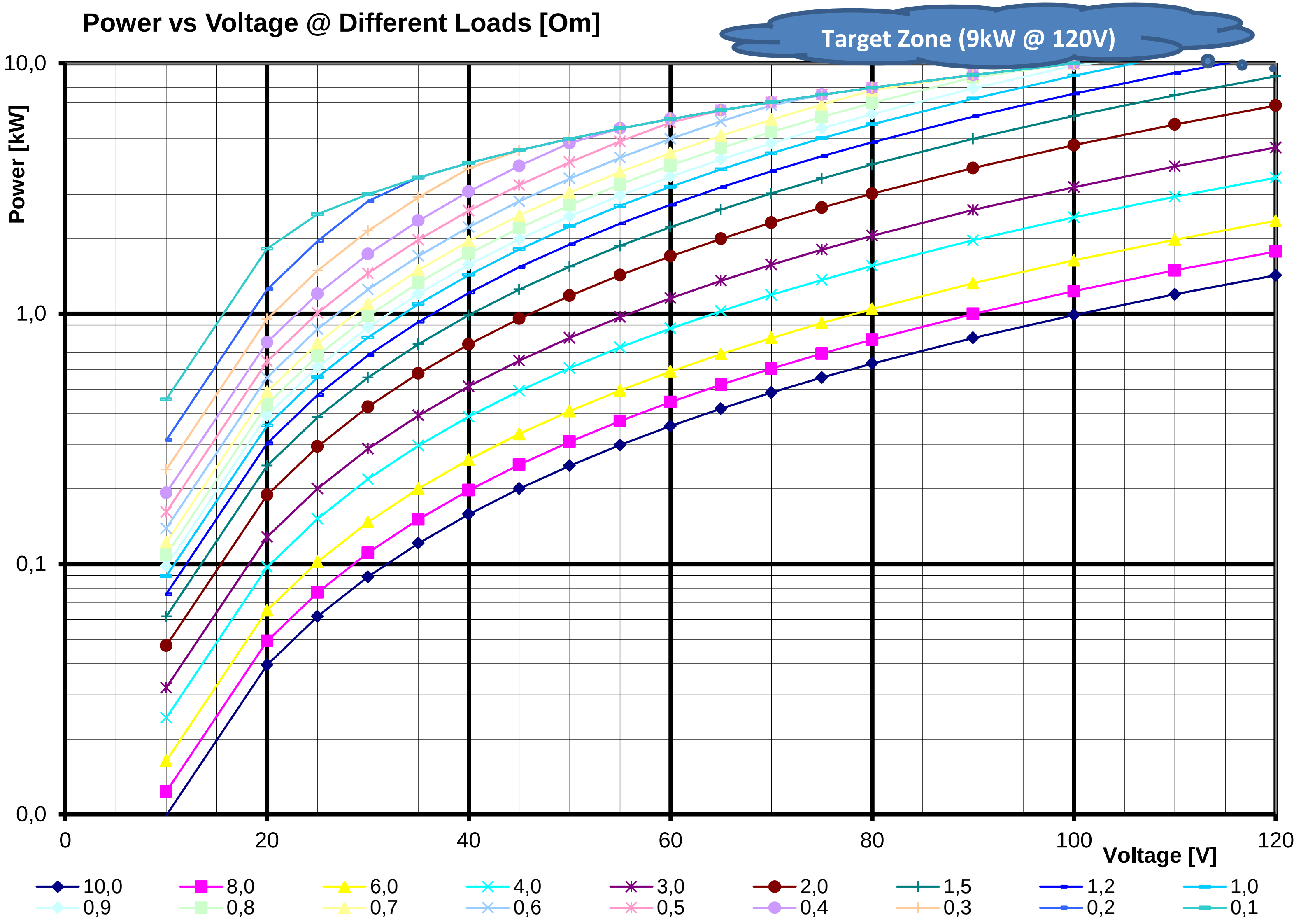
Next Generator Improvements

- ***Current Stator Base – wire size: D1.8 mm, 2.54 mm²; coil: 120 windings***



Stator Redesign (Coil)

- ***Next Stator Base – wire size: 1.8 x 3.15 mm, 5.67 mm²; coil: 60 windings***

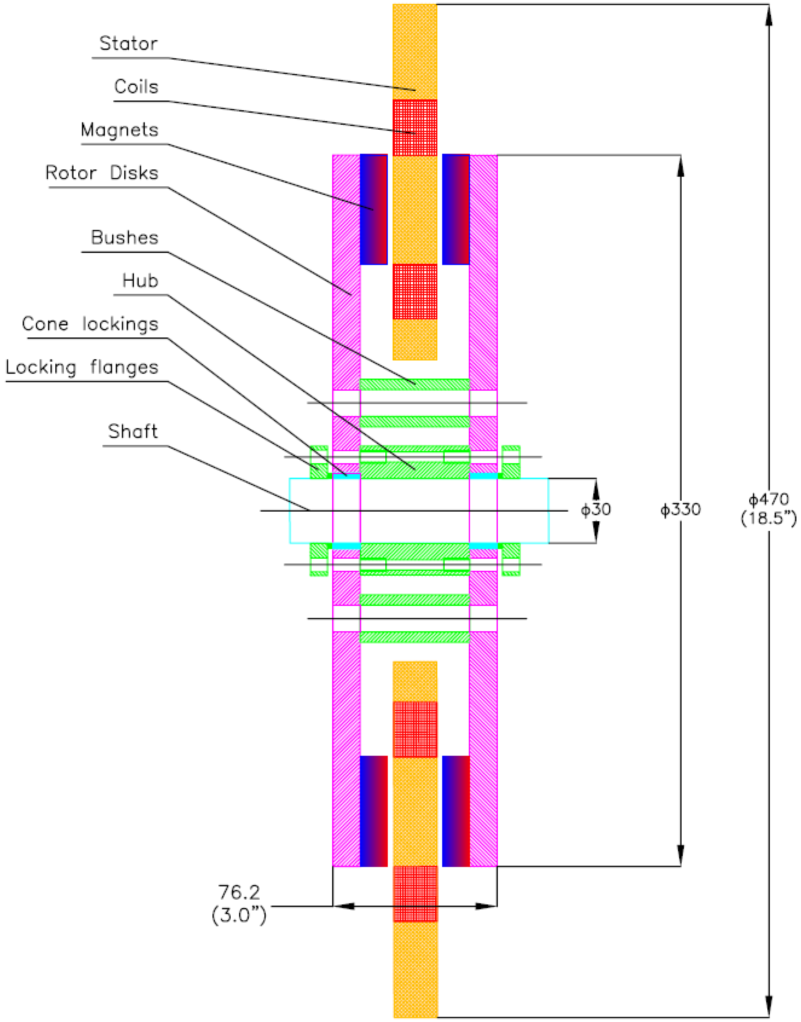


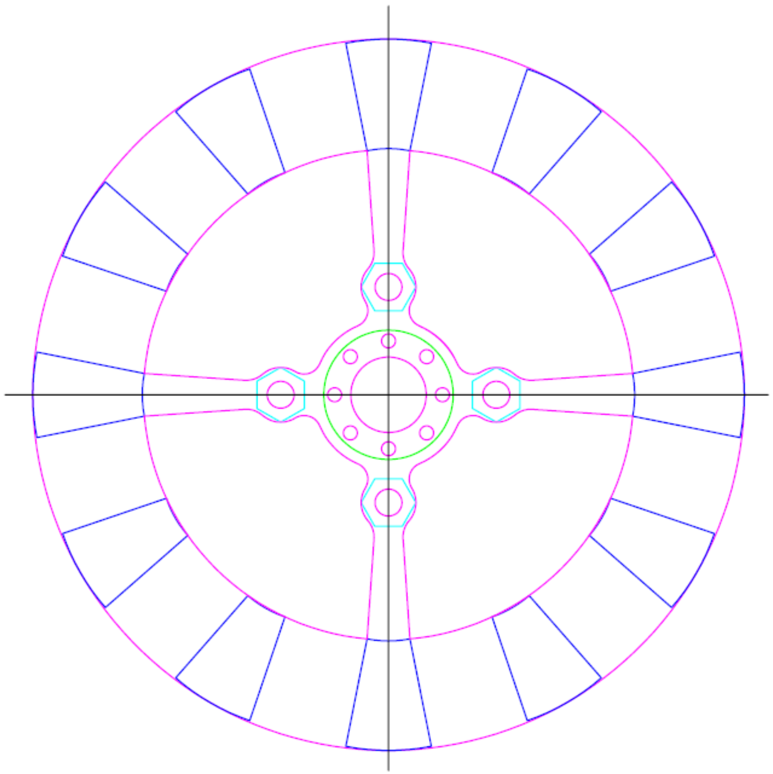
Stator Redesign (Coil)

- ***Production of the new coils***

Generator Redesign

- ***Rotor design with light hub and centered cone bushes and plotted stator***





Generator Redesign

- ***Modified to use centered cone bushes by Bea Ing. S.P.A. for mounting to the shaft***

CALETTATORI - DATI TECNICI
LOCKING ASSEMBLIES - THECNICAL DATA

Calcolo del minimo diametro esterno mozzo (DM)
Calculation of the minimum outside diameter of hub (DM)

$$DM \geq D \cdot K$$

D = **diametro esterno calettatore (mm)**
outside diameter of locking assemble (mm)
K = **coefficiente (vedi tabella)**
coefficient (see table)

Per il calcolo del valore K, non riportato in tabella applicare la seguente formula:
To calculate the "K" value not shown in the table, use the following formula:

$$K = \sqrt{\frac{\sigma\, 0{,}2 + (C \cdot PN)}{\sigma\, 0{,}2 - (C \cdot PN)}} \; (mm)$$

σ 0,2 = **carico di snervamento del materiale (N/mm²)**
yield strength of the material (N/mm²)
C = **fattore in funzione del tipo di applicazione**
factor depending on the type of the application
PN = **pressione superficiale del mozzo**
surface pressure of the hub

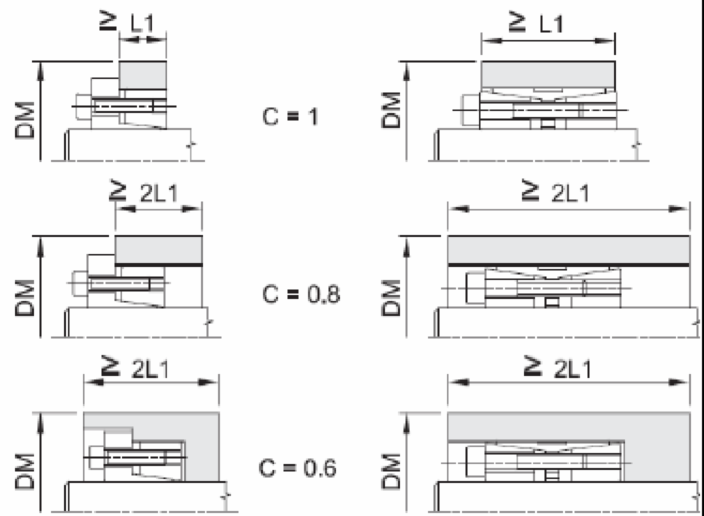


TABELLA DEL COEFFICIENTE "K" - COEFFICIENT "K" TABLE

	GG-20			GG-30 GTS-35 ALSi1MgMn			GGG-38 GS-400 St.42-3			GGG-50 GS-500 C-40		
valori indicativi per il carico di snervamento σ 0,2 in N/mm²	150			200			250			300		
pn N/mm²	0,6	0,8	1	0,6	0,8	1	0,6	0,8	1	0,6	0,8	1
80	1.39	1.58	1.81	1.28	1.39	1.53	1.21	1.30	1.39	1.18	1.24	1.31
85	1.42	4.63	1.90	1.30	1.42	1.57	1.23	1.32	1.42	1.19	1.26	1.34
90	1.46	1.69	2.00	1.32	1.46	1.62	1.25	1.34	1.46	1.20	1.28	1.36
95	1.49	1.75	2.11	1.34	1.49	1.68	1.26	1.37	1.49	1.21	1.30	1.39
100	1.53	1.81	2.24	1.36	1.53	1.73	1.28	1.39	1.53	1.22	1.31	1.41

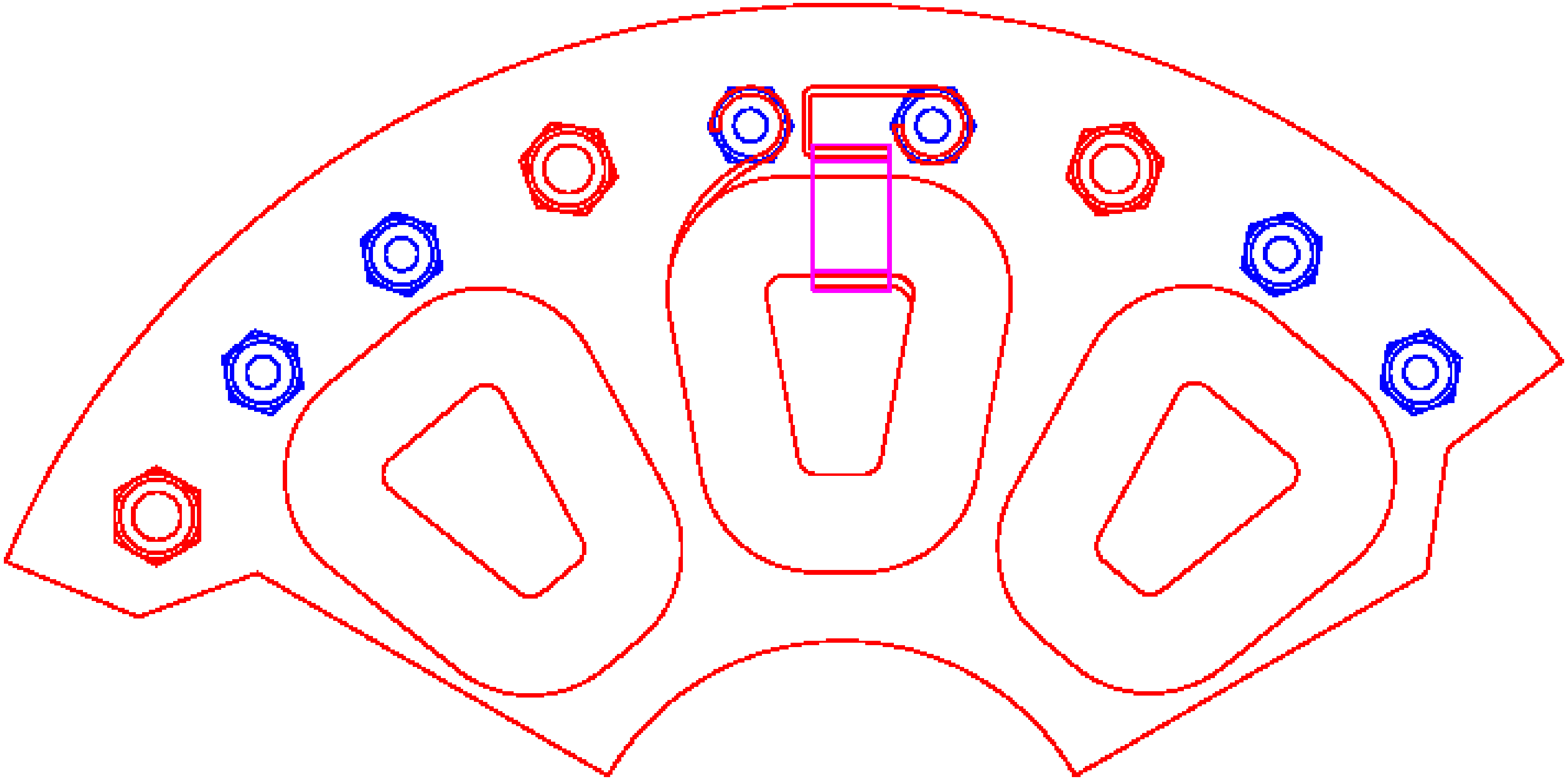
	GGG-60 GS-600 C-45			GGG-70 GS-70 C-60								
valori indicativi per il carico di snervamento σ 0,2 in N/mm²	350			400			450			600		
pn N/mm²	0,6	0,8	1	0,6	0,8	1	0,6	0,8	1	0,6	0,8	1
80	1.15	1.20	1.26	1.13	1.18	1.22	1.11	1.15	1.20	1.08	1.11	1.14
85	1.16	1.22	1.28	1.14	1.19	1.24	1.12	1.16	1.21	1.09	1.12	1.15
90	1.17	1.23	1.30	1.15	1.20	1.26	1.13	1.18	1.22	1.09	1.13	1.16
95	1.18	1.25	1.32	1.15	1.21	1.27	1.14	1.19	1.24	1.10	1.14	1.17
100	1.19	1.26	1.34	1.16	1.22	1.29	1.14	1.20	1.25	1.11	1.14	1.18

Stator Redesign (Segment)

- ***Stator template for molding technology***

Stator Redesign (Segment)

- ***New stator geometry for plotting technology***



Stator Redesign (All segments)

- ***New stator after plotting and ready for coil mounting***

Stator Redesign (Complete staff)

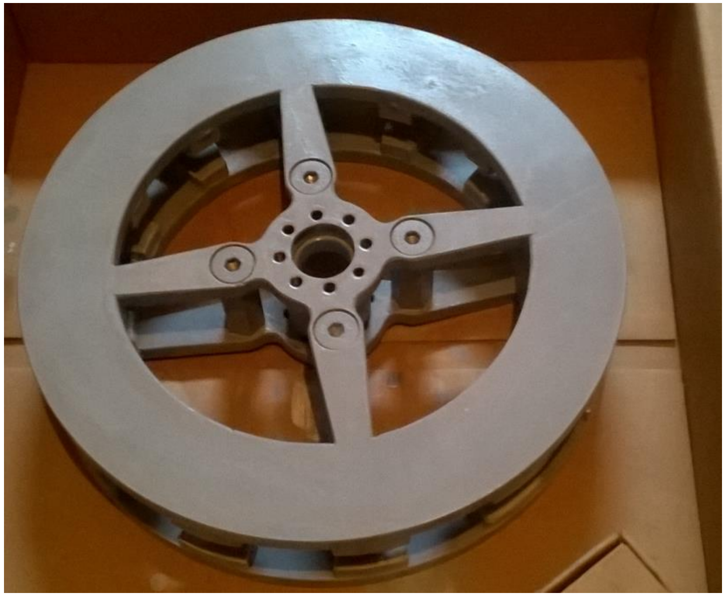
- ***New stator produced by plotting technology and Cu plate wires***

Rotor Redesign (Assembled)

- ***Assembled rotor with light hub, spacers and centered cone bushes***

Rotor Redesign (Painted)

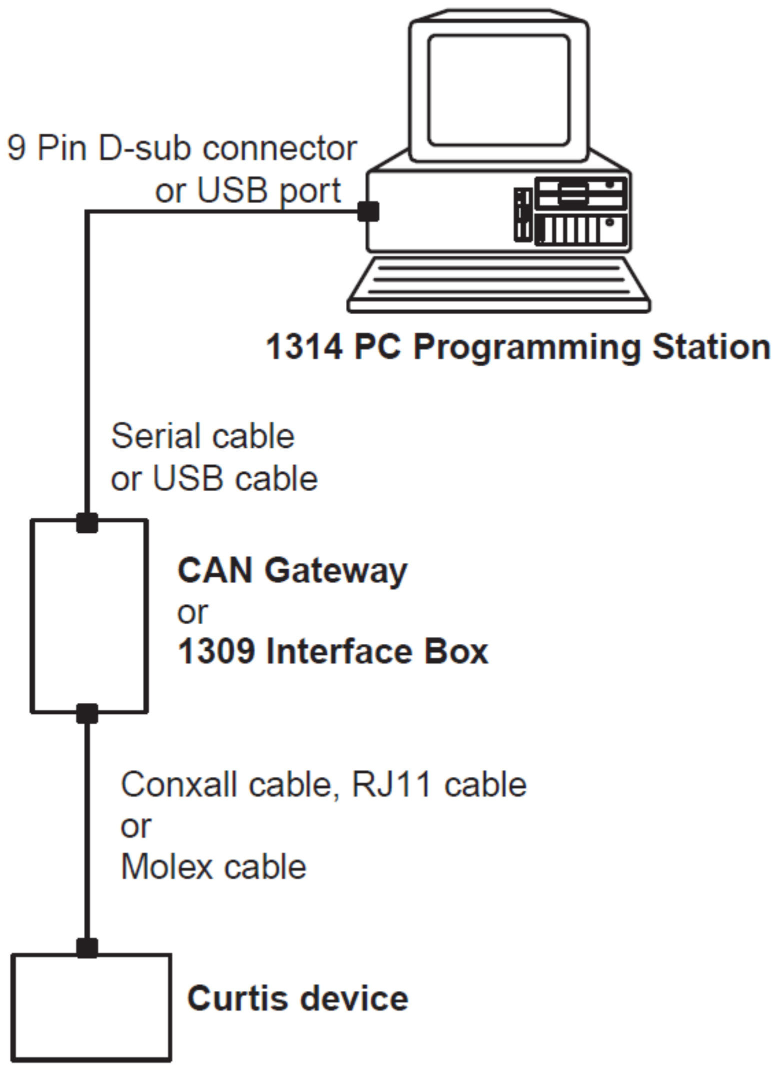
- ***Assembled and painted rotor, stator carrier disk both mounted on the field***

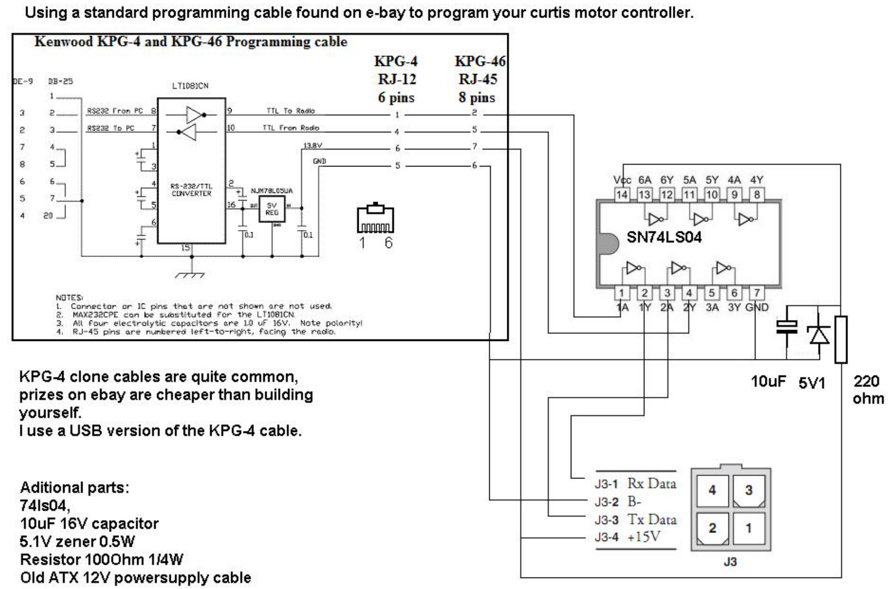



The field test suite (Shabla)

Electrical System Improvement

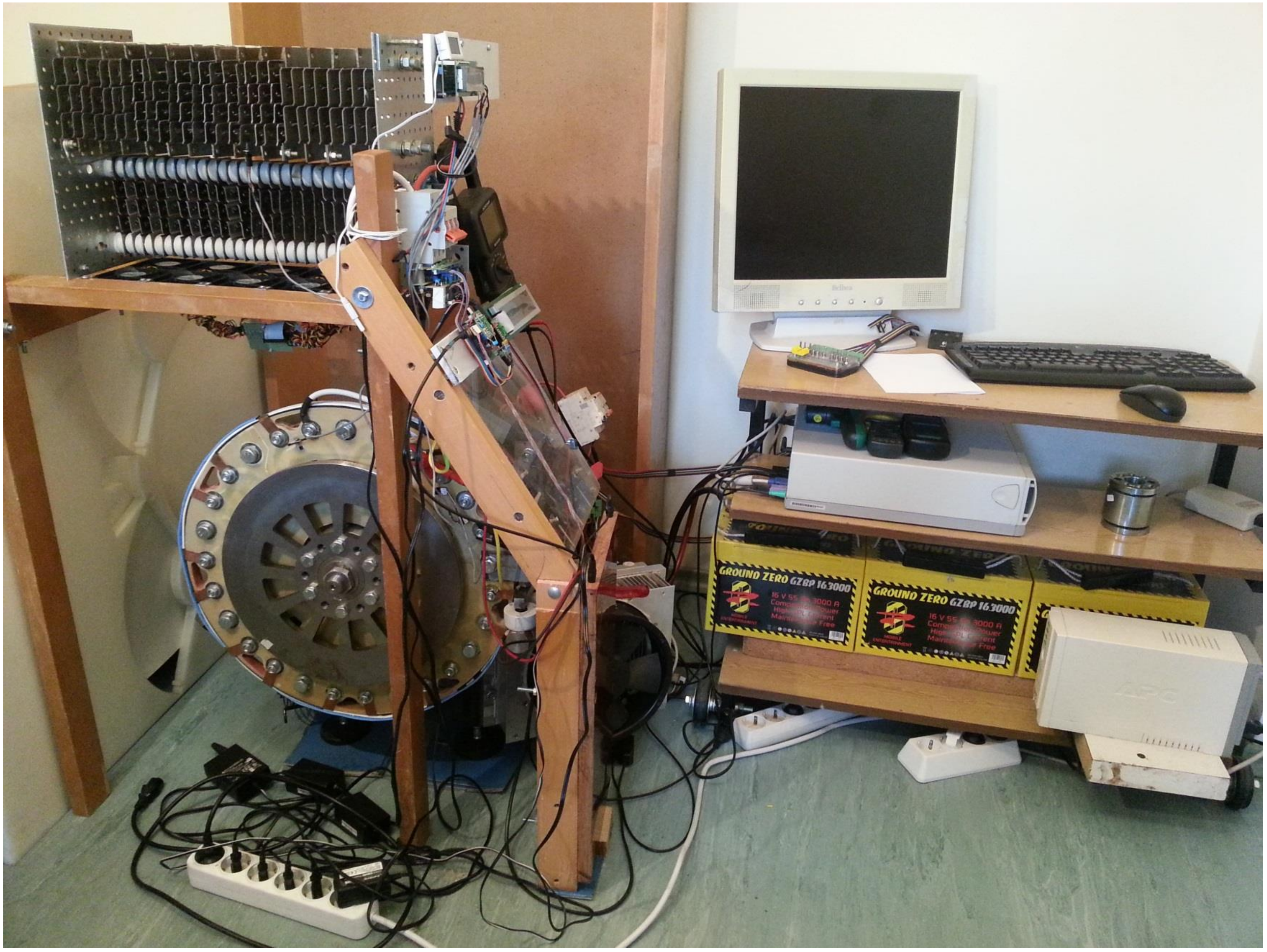
- Test bed – rev. 3 with PC Station interconnection and Cooler for Curtis’ Controller





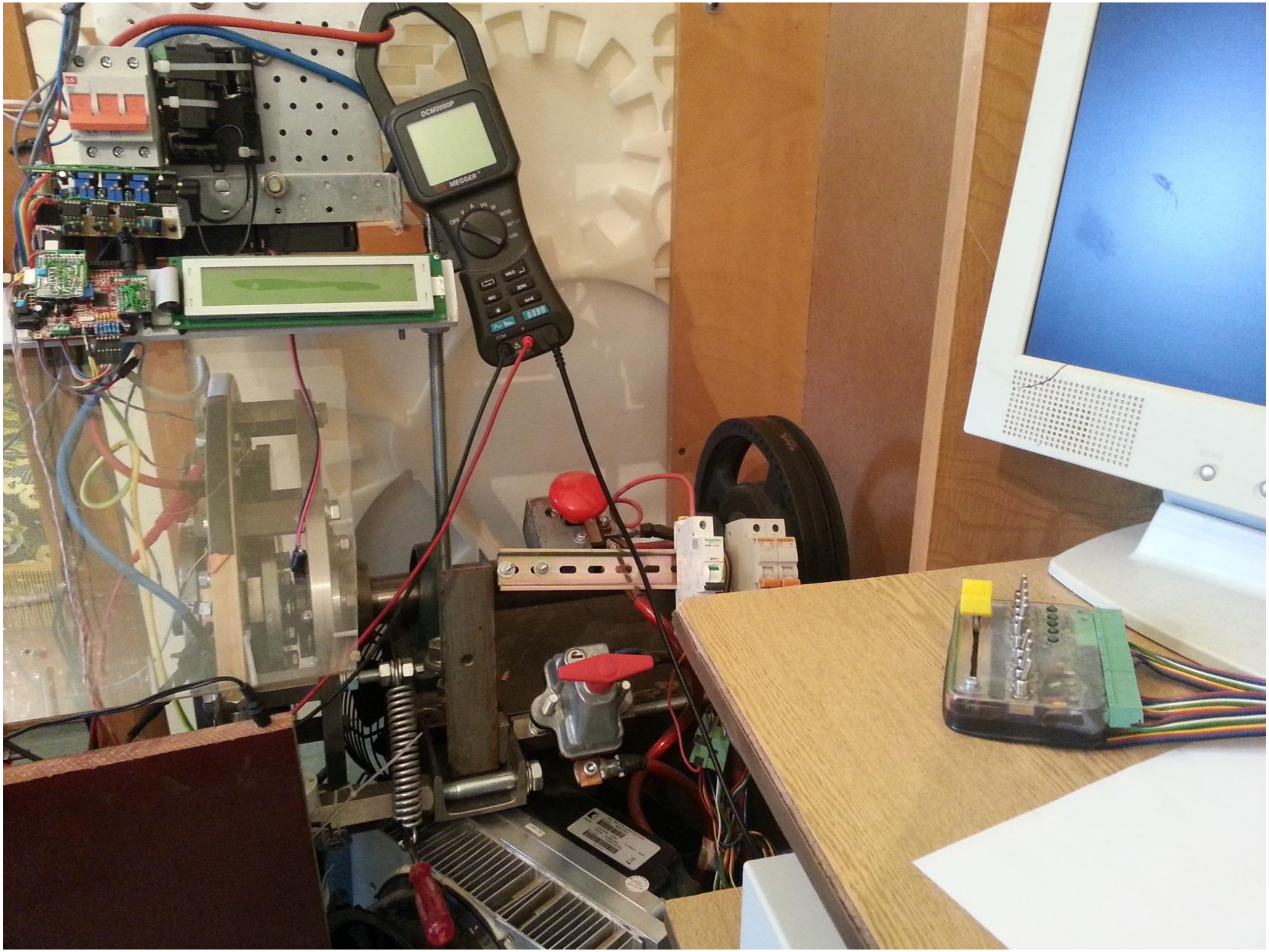
Electrical System Improvement

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 1-st rev.



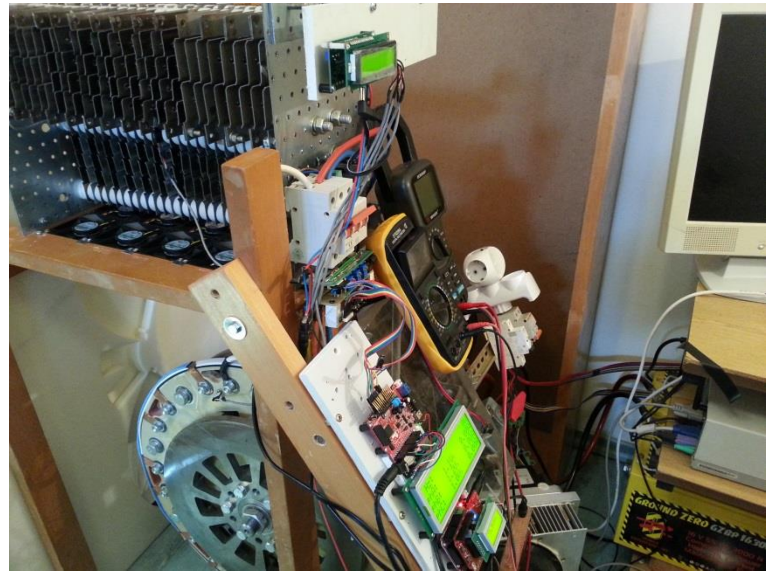
Electrical System Improvement

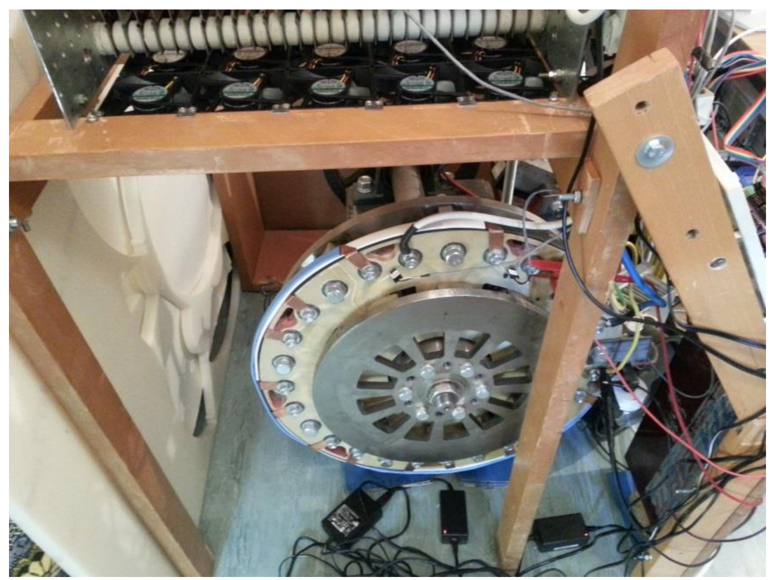
- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 1-st rev.



Electrical System Improvement

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.





Electrical System Improvement

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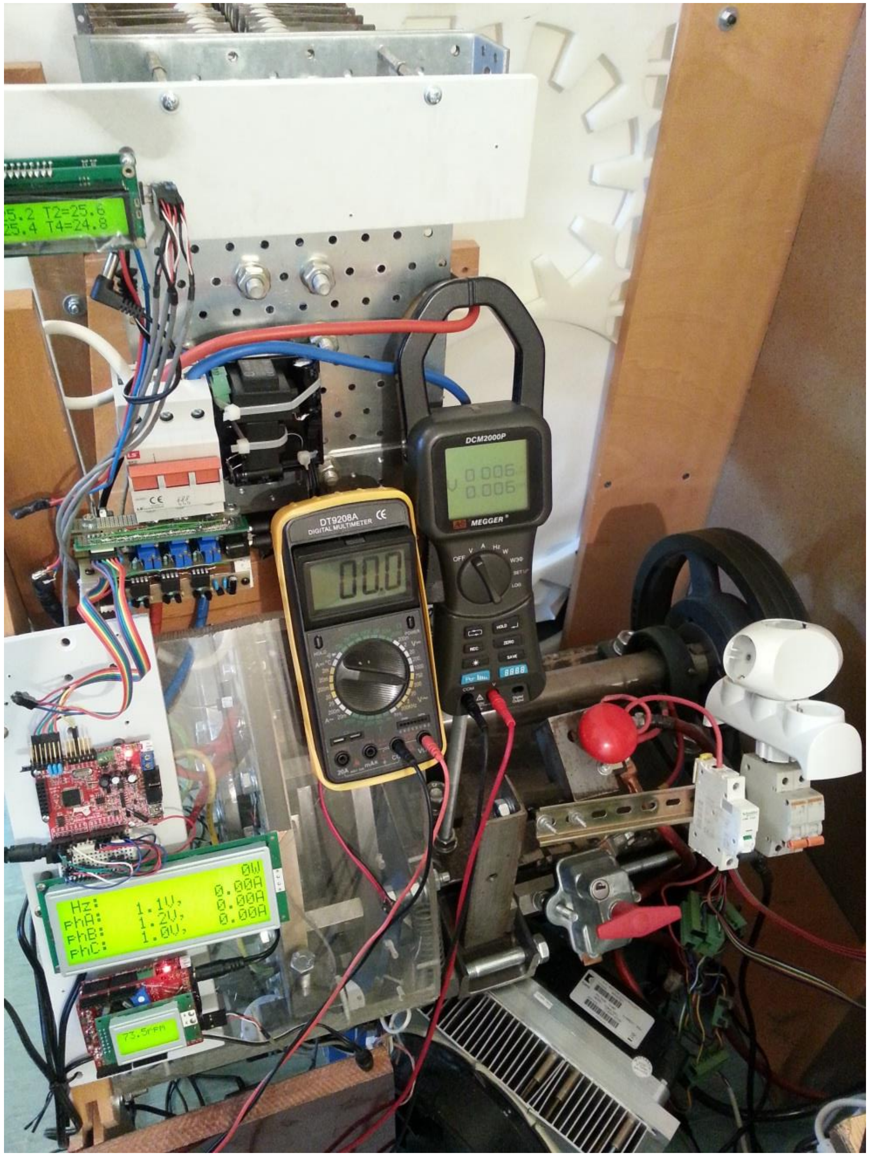
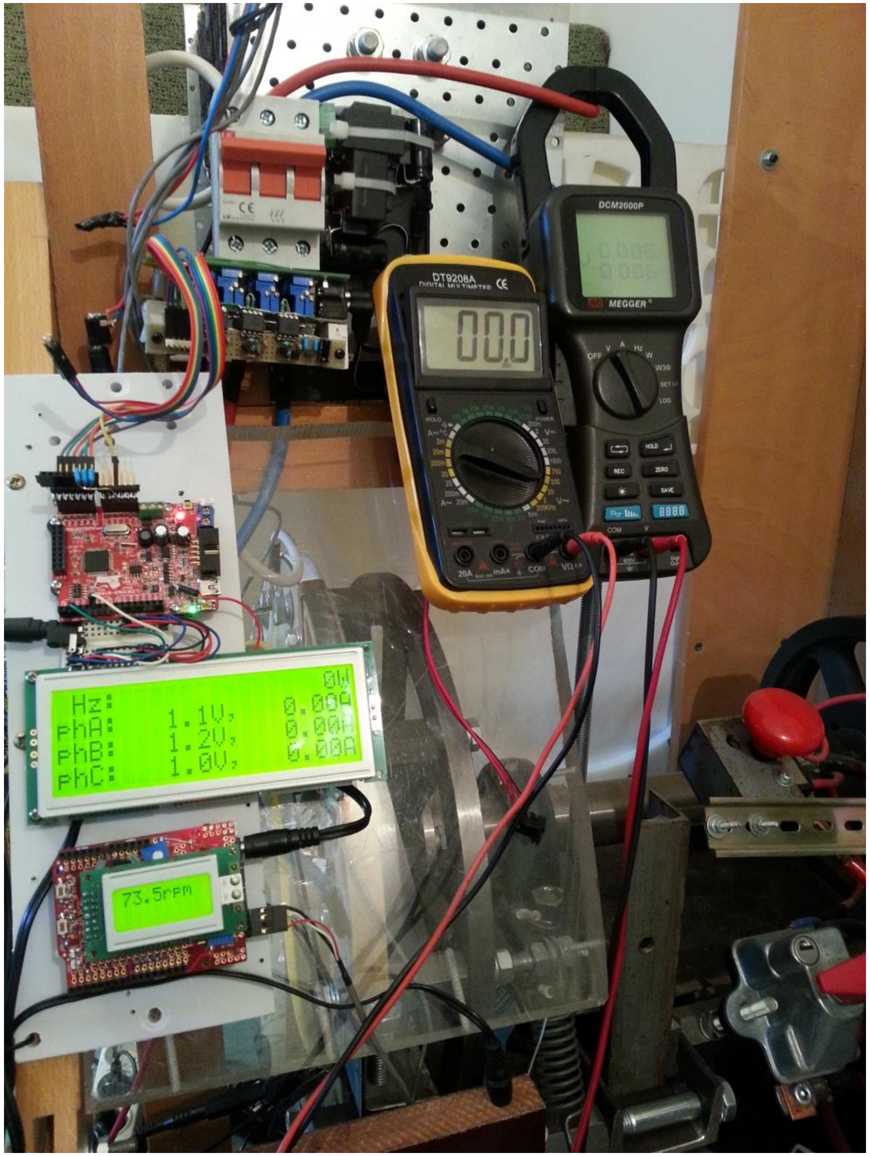
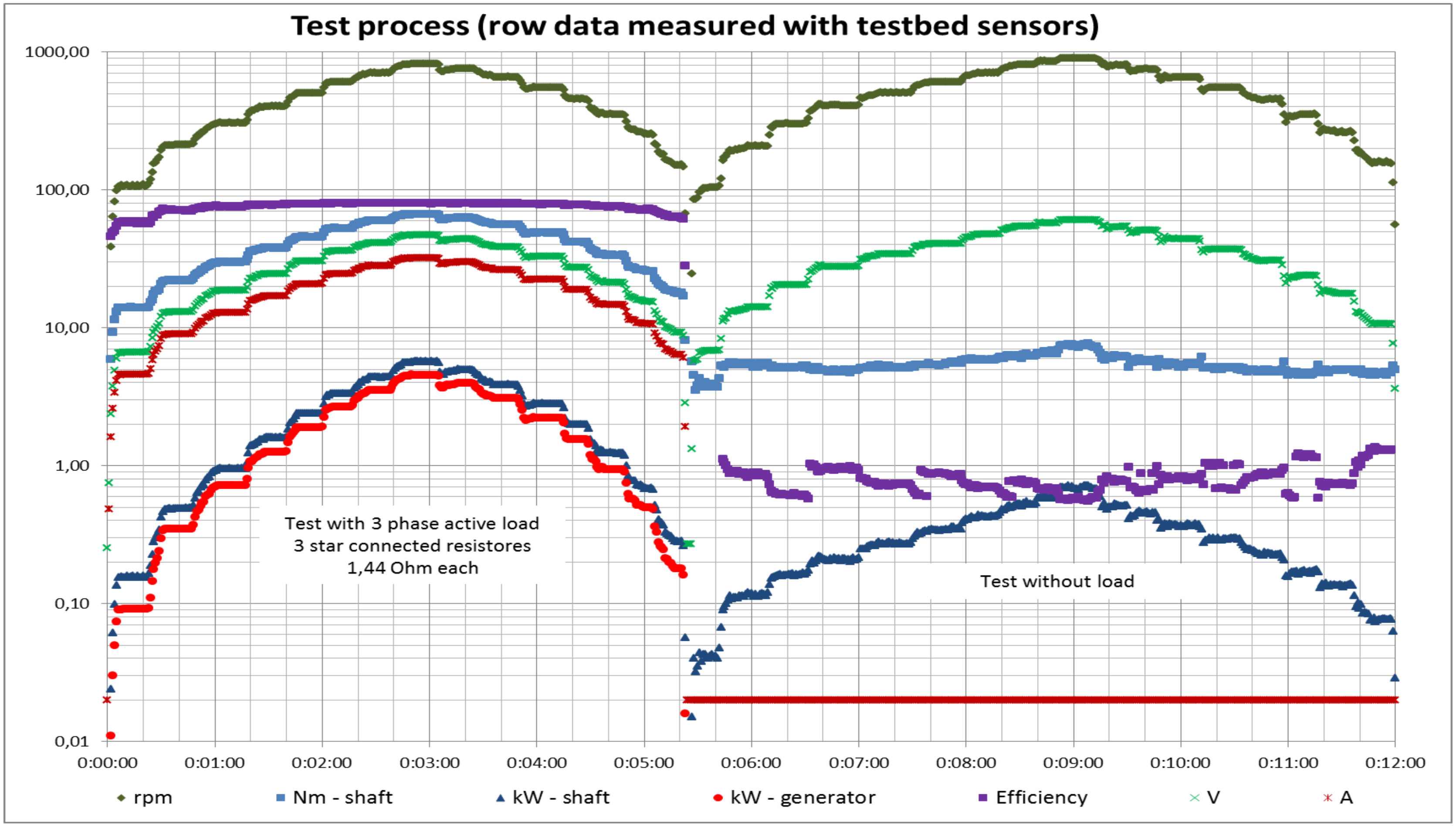




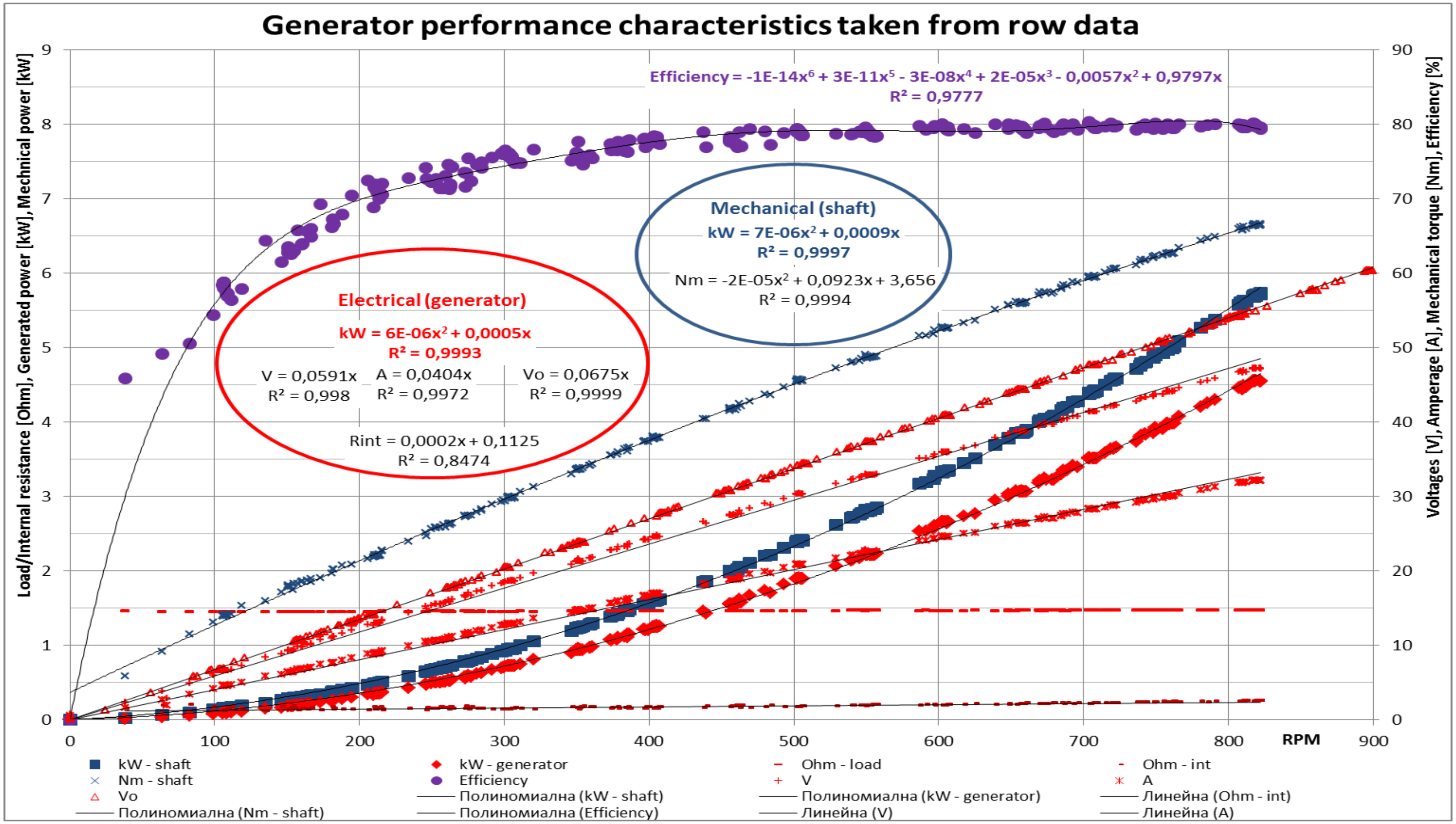
Measurement Results

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.



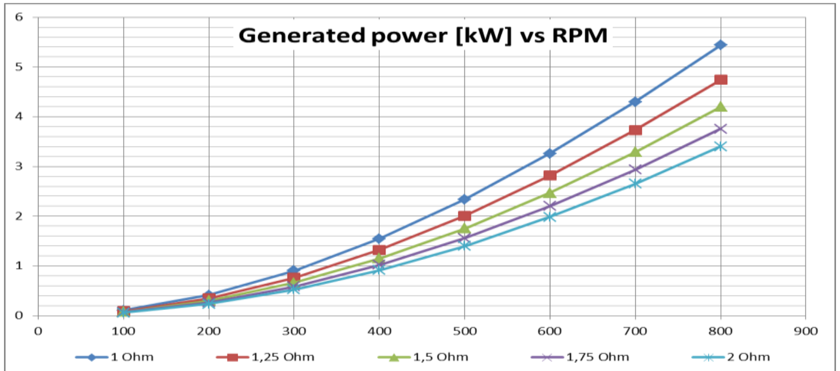
Measurement Results

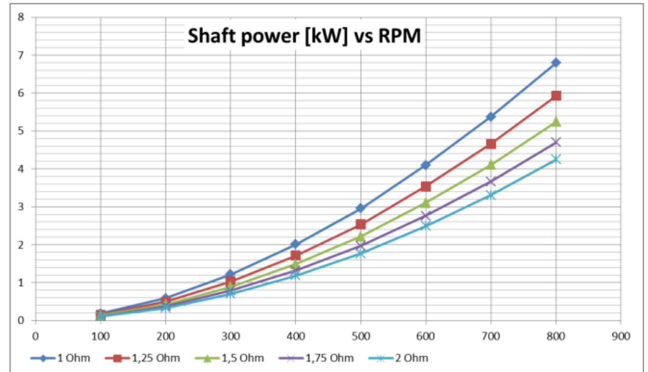
- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.

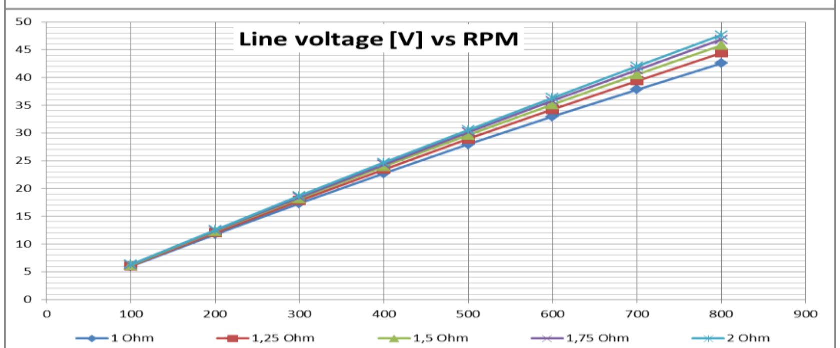


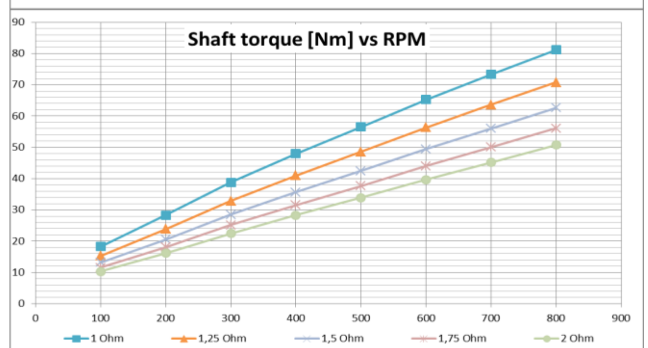
Measurement Results

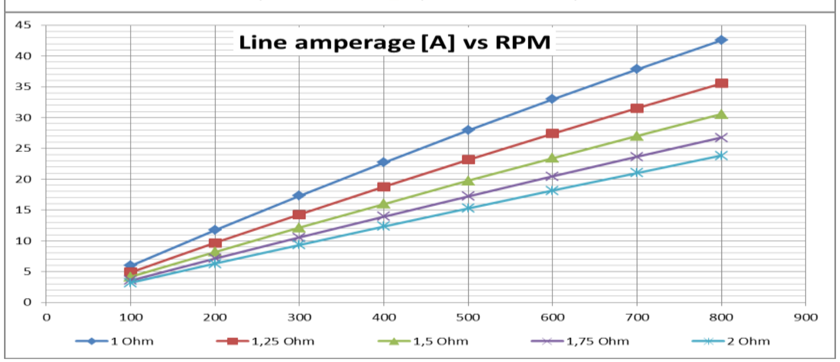
- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.

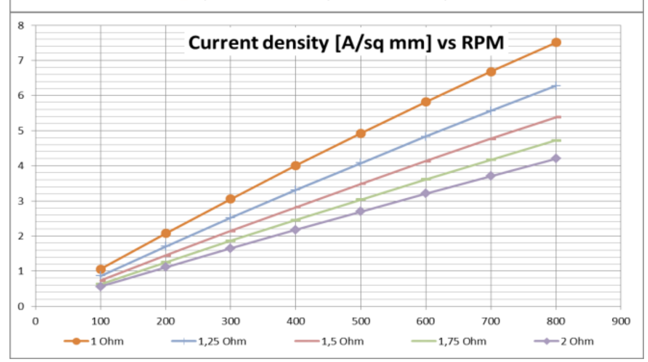












Measurement Results

- Generator 2-nd rev., Test bed 3-rd rev., 3-phase load and data acquisition 2-nd rev.