SUMMER SCHOOL 2023, HIPO, ELECTRIC DRIVES TECHNOLOGY LABORATORY

AXIALLY LAMINATED SYNCHRONOUS RELUCTANCE MACHINE (ALASYNRM)

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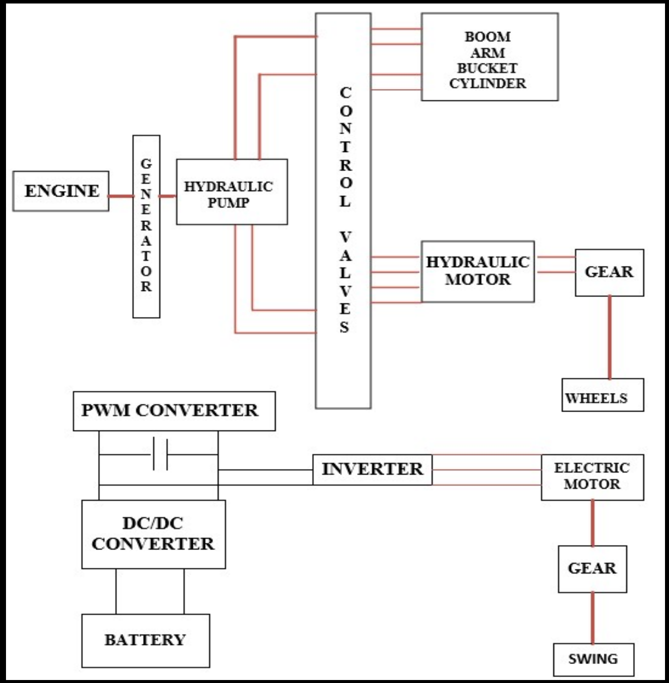
BACKGROUND

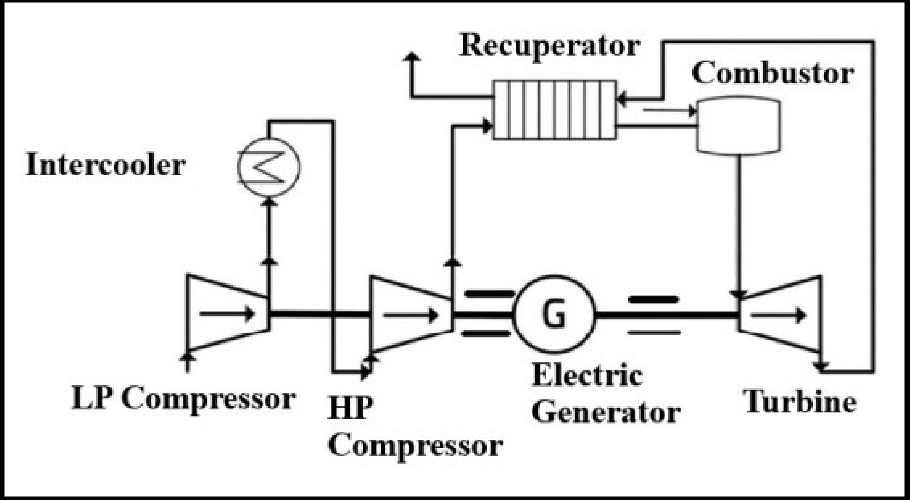
- Climate crisis leading to the increased demand of electrification of non-road mobile machineries (NRMM).
- Primary application is the NRMM's which do not operate constantly at full power but have high peak power and low average power- a hybrid excavator.



Internal structure of hybrid structure

MICRO GAS TURBINE AS AN APU

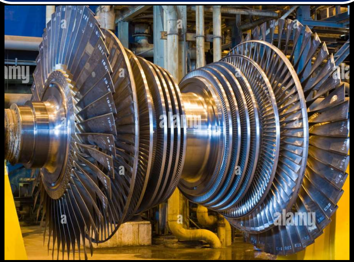
- LUT, Finland has designed IRG2 (Intercooled, recuperated double compressor single turbine) micro gas turbine which can provide an electrical output efficiency of 35%.
- The novelty in this approach is a double compressor, a single shaft and hydrogen as fuel resulting in no emissions.
- The turbine is used to run the electrical generator at 100,000 rpm .



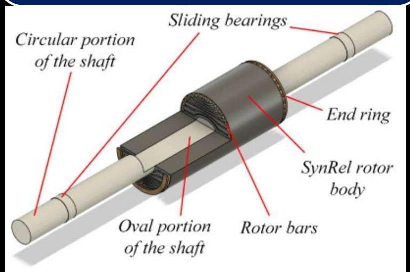
Internal structure of single shaft double compressor intercooled recuperated APU

Component of an electrical generator for a micro-gas turbine

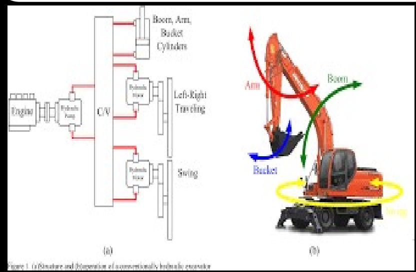
IRG2.1 Single shaft turbine and compressor



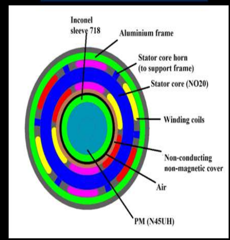
Shaft rotor dynamics and bearings analysis

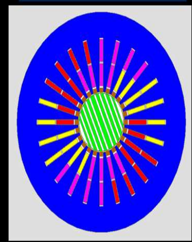


Control of hybrid excavator utilizing MGT



Electrical generator for 27 kW MGT



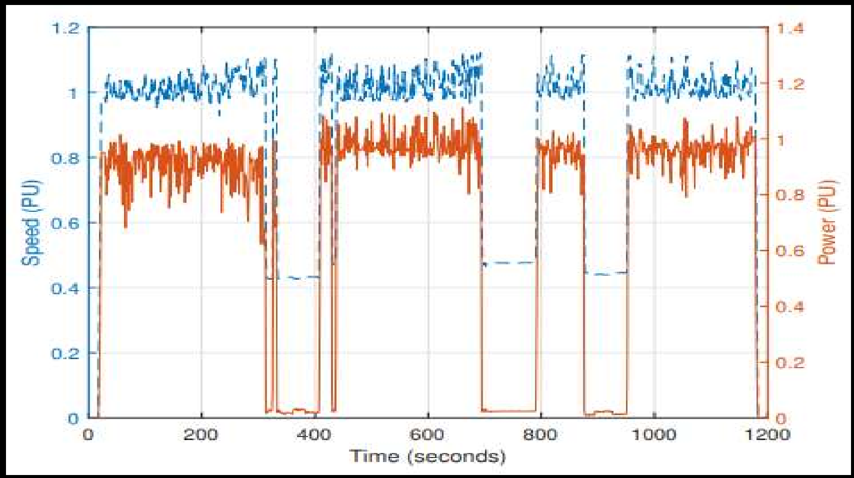


Power converter for 27 kW MGT generator

Selection of the Generator (Estimation of Power Needed)

- When the ICE is supplying 75% of the time and the state of charge of the battery is taken from start to end, the average output power generated by ICE is 50%.

- As a starting point, if APU can deliver 27 kW constant power, it should be capable of supplying an ICE powered excavator equipped with about 50 kW ICE.



Normalized load cycle of an excavator

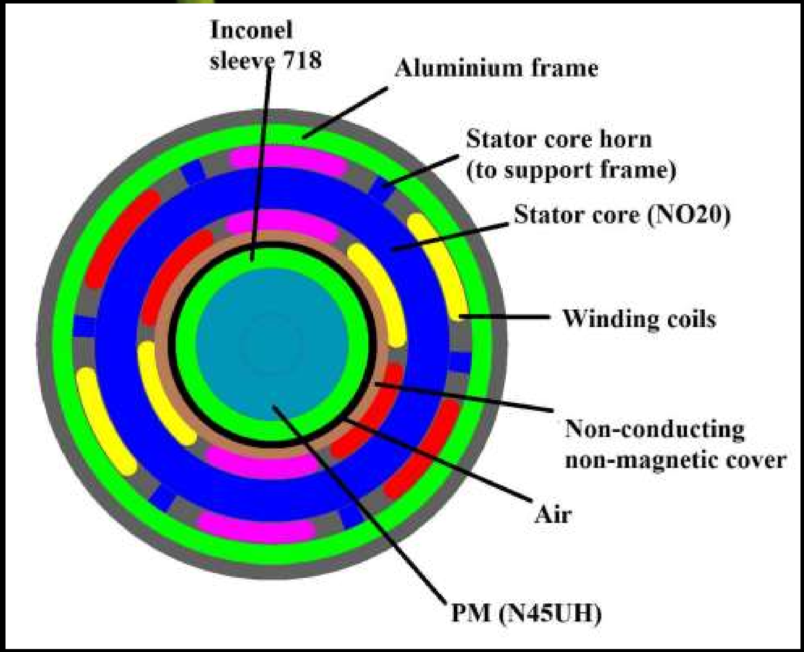
MACHINES FOR MGT

Induction machine (IM)

- strong resistance to high temperatures
- reduced manufacturing costs
- easy control
- endure severe mechanical stresses if a solid rotor is utilized.

PMSM (Permanent magnet synchronous machine)

- high efficiency, high-power density
- mature enough production technology
- small size
- low acoustic noise



PMSM APU generator 27 kW designed for MGT

Singh, S., Petrov, I., Pyrhönen, J., & Sergeant, P. (2022, September). Conceptual Design of High-Speed Permanent-Magnet Generator for a Micro Gas Turbine. In *2022 International Conference on Electrical Machines (ICEM)* (pp. 1696-1702). IEEE.

COMPARISON OF DIFFERENT MACHINES

Induction machine (IM)
- strong resistance to high temperatures
- reduced manufacturing costs
- easy control
- endure severe mechanical stresses if a solid rotor is utilized.

PMSM (Permanent magnet synchronous machine)
- high efficiency, high-power density
- mature enough production technology
- small size
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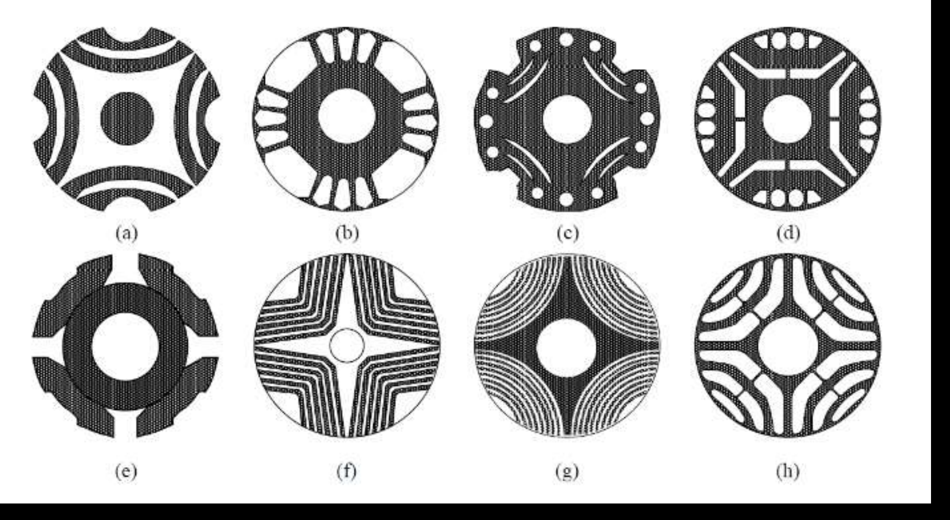
Synchronous reluctance machine
- **Inherent simplicity**
- **Inexpensive cost**
- **Mechanically strong for 100 krpm**

ABB

SYNCHRONOUS RELUCTANCE MACHINE

- Machine produces torque using magnetic reluctance.
- The difference between the d-axis inductance and q-axis inductance is responsible for producing torque. The rotor in this motor does not include any field winding but the stator includes 3- phase symmetrical winding.



SYNCHRONOUS RELUCTANCE MACHINE

$$P = \frac{3U_s}{2\omega_s}\left(\frac{1-\frac{L_d}{L_q}}{L_q}\right)\sin 2\delta$$

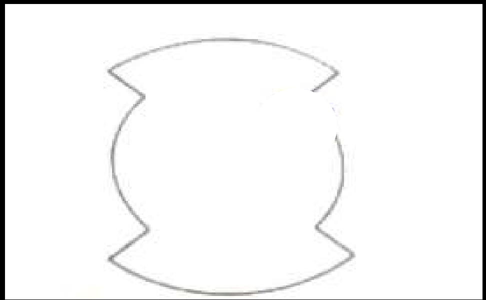
$$T_{em} = \psi_{md} i_q - \psi_{mq} i_d = L_{md} i_d i_q - L_{mq} i_q i_d =$$
$$= i_q i_d \left(L_{md} - L_{mq}\right) = i_s^2 \left(L_{md} - L_{mq}\right)\sin(2\kappa).$$

$$\kappa = \arctan\sqrt{\frac{L_d}{L_q}}.$$

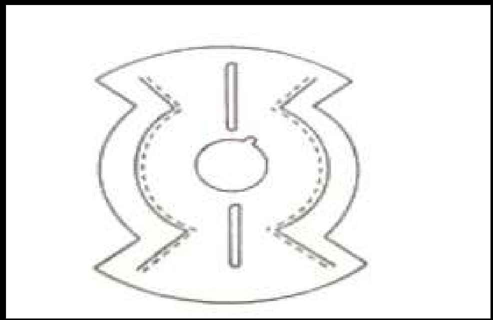
SYNCHRONOUS RELUCTANCE MACHINE

They can be classified as:

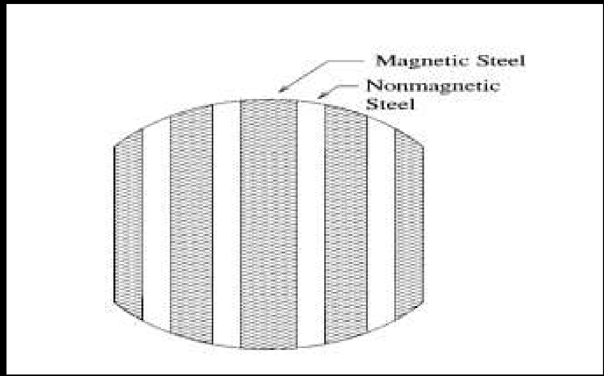
- Axially laminated
- Radially laminated



Salient rotor low Ld/Lq



Radially laminated rotor (Flux barriers punched into steel)

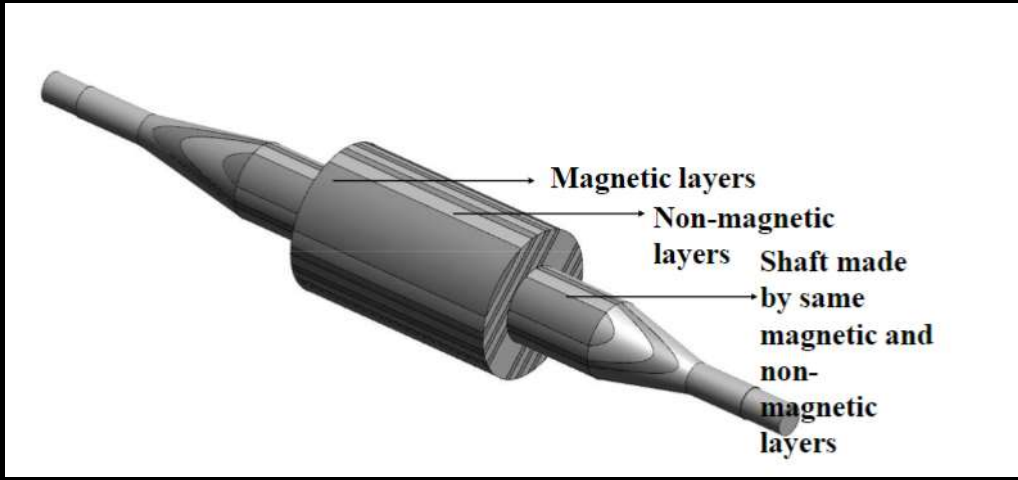


Axially laminated rotor (High Ld/Lq)

ALASYNRM

Rotor layers are joined by either:

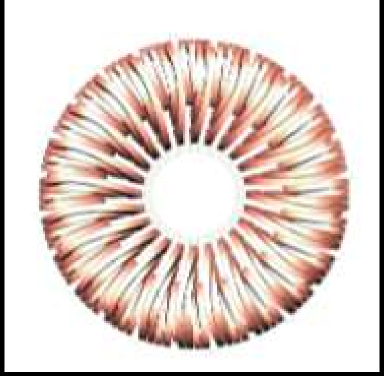
- Hot-isostatic pressing
- Vacuum brazing
- Explosion welding

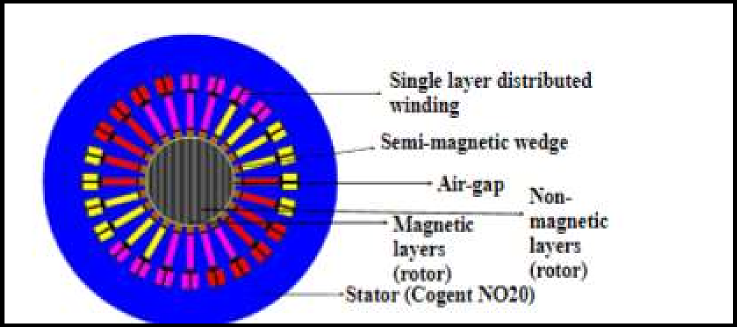


DESIGN OF 27 KW 100 KRPM ALASYNRM

Major factors before designing:

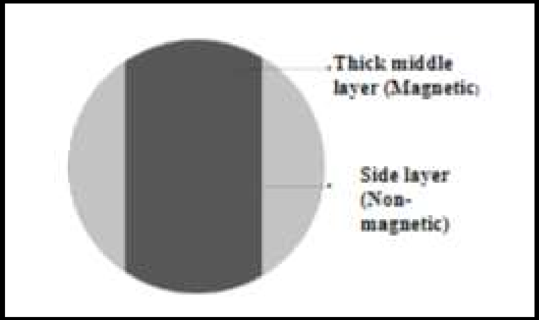
- Optimsation of rotor.
- Optimsation of stator design.

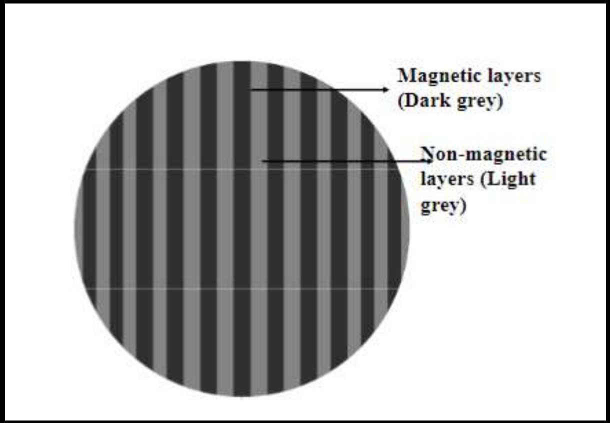


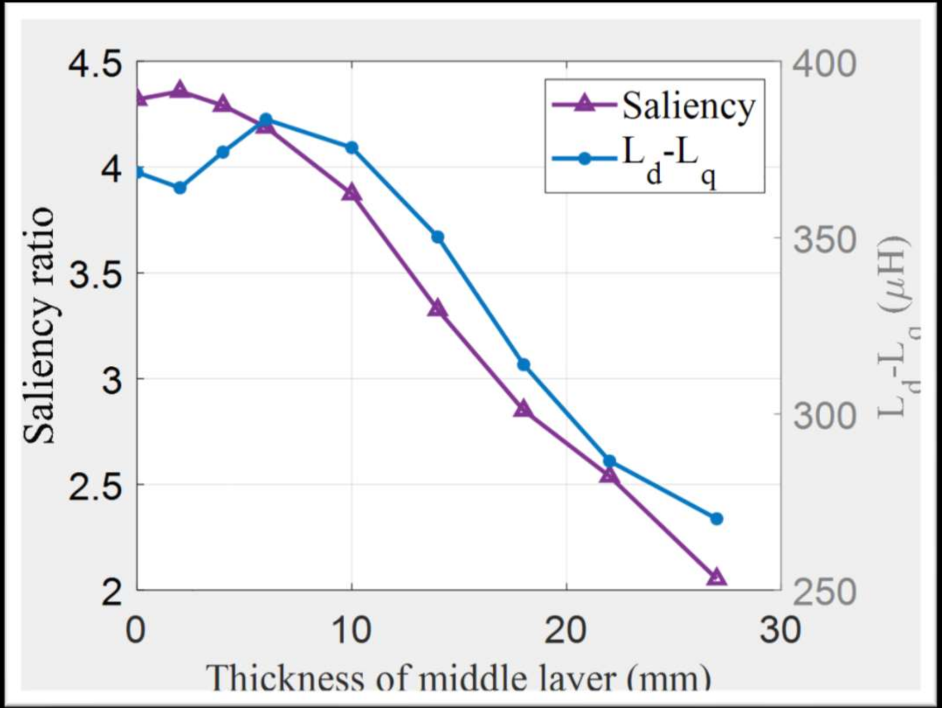


Stator with distributed drum windings

ROTOR OF 27 KW 100 KRPM ALASYNRM

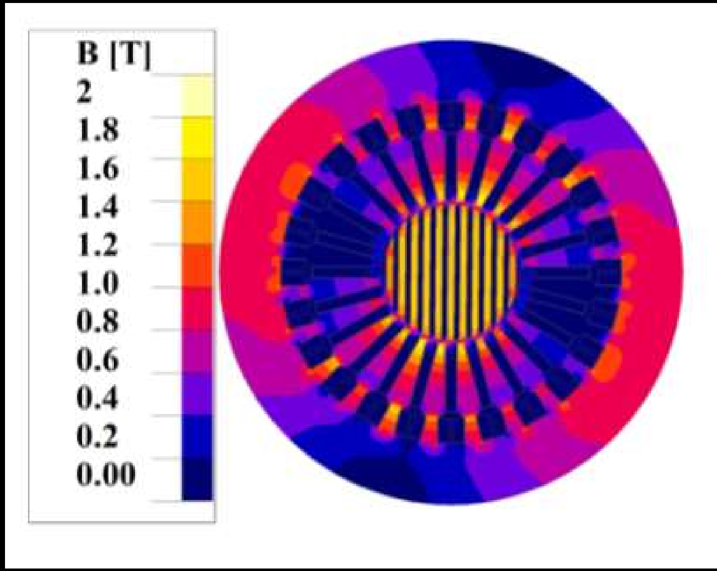






27 KW 100 KRPM ALASYNRM

A 27 kW 100 krpm is developed for the application of Micro-Gas Turbine.



COMPARISON OF PMSM ROTOR VS ALASYNRM FOR 27 KW 100 KRPM

Parameters	PMSM	ALASynRM
Torque (Nm)	2.61	2.69
Phase Voltage (RMS)	**164.3**	239.76
Winding loss (W)	292.80	292.80
Rotor loss (W)	7.496	103
Iron loss (W)	478.28	1097.93
Power (W)	27126	28070
Friction and Windage loss (W)	135	135
Total loss (W)	913.576	1628.73
Efficiency (%)	96.74	94.51
Power factor	**0.99**	**0.60**
Rated current (RMS) A	55.15	65
Current Density (A/mm2)	9	10

LIMITATIONS WITH ALASYNRM

- Saliency is low (4), which affects the power factor of the machine.
- Open slot winding is considered.
- Magnetic slot wedge affects the rotor losses (41% reduction).
- Overall flux density in the system is high causing higher iron losses (1.2 T in yoke and 0.8 T in air gap).
- Shaft construction can have different alternatives.
- Manufacturing and mechanical issues are dominating the design.

Thank you for attention

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