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TREBALL FI DE GRAU

**Grau en Enginyeria Elèctrica**

# DISSENY D'UN GENERADOR D'IMANTS PERMANENTS PER A UNA MINI-TURBINA EÒLICA D'EIX VERTICAL AÏLLADA DE XARXA

## Annexos

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**Convocatòria:** Addicional. Quadrimestre de primavera 2019-2020

# ÍNDEX ANNEXOS

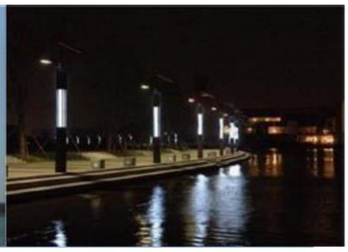
# Annex I. Aerogenerador *"Etneo 300DS"*

etneo

## Small Vertical Wind Turbines DS300


Etneo introduces the small wind turbines with vertical axis made with its partners in Taiwan , nicknamed the land of typhoons. Tests conducted in test fields, the wind tunnel laboratories such as TUV NEL ( UK) NREL (USA), Windtest KAISER ( Germany), MIRDC (TAIWAN institute for testing of micro wind turbines) the active installations for some years up to today provide excellent production capacity, solving all the problems of the horizontal ones, noise from vibration or all the power losses due to the need to orientate the rotor to the wind.

Our turbines are working on two principles: **Savonius** or inside blades with nozzles oriented on the 4 cardinal points, always ready to capture the wind, very useful at the start of rotation of the wind generator with low winds. **Darrieus** or outer blades that allows the turbine to work very well with turbulence or strong winds. Our products are ideal for grid connection with ABB inverter and energy storage systems with photovoltaic modules to ensure a larger capacity of the whole storage solution.



Etneo Italia srl – via Giovanni Bovio n°6 28100 Novara – Tel +39 0321.697200 Fax: +39 0321.688515

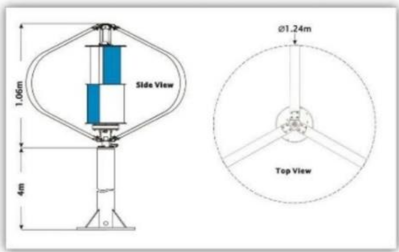
# Small Vertical Wind Turbines DS300


## HiVAWT Vertical Axis Wind Turbine Power System
## Model number: DS300

### ***PRODUCT SPECIFICATIONS***

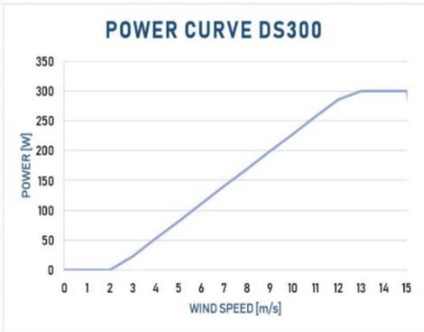
| General Specifications | | | |
|---|---|---|---|
| **Rated Power** | 300W | **Wind Speed max. power** | 15 m/s |
| **Rated wind speed** | 12.5 m/s | **Cut in Wind Speed** | <3 m/s |
| **Cut out Wind Speed** | 15.5 m/s | **Survival Wind Speed** | 60 m/s |

| Dimensions/Weight | |
|---|---|
| **Rotor Diameter** | 1.24 m |
| **Rotor Height** | 1.06 m |
| **Tower Height** | 4.00 m (minimum) |
| **Total Height** | 5.06 m (minimum) |
| **Turbine Weight** | 25.5 kg w/o tower |
| **Rotor Specifications** | |
| **External Darrieus** | 3 blades |
| **Internal Savonius** | 2 layers |
| **Blades Material** | Anodized aluminum |
| **Axis Material** | Galvanized steel SS400 |




| Generator Specifications | |
|---|---|
| **Generator Type** | AC, 3phase, Synchronism PMG |
| **Rated Output** | 300W |
| **Braking System** | |
| **Automatic** | 3-phase short circuit braking system |
| **Manual** | Optional |
| **Operation Conditions** | |
| **Ambient Temperature** | -10~40℃ |
| **Ambient Humidity** | 95% max. |

**Power Curve**

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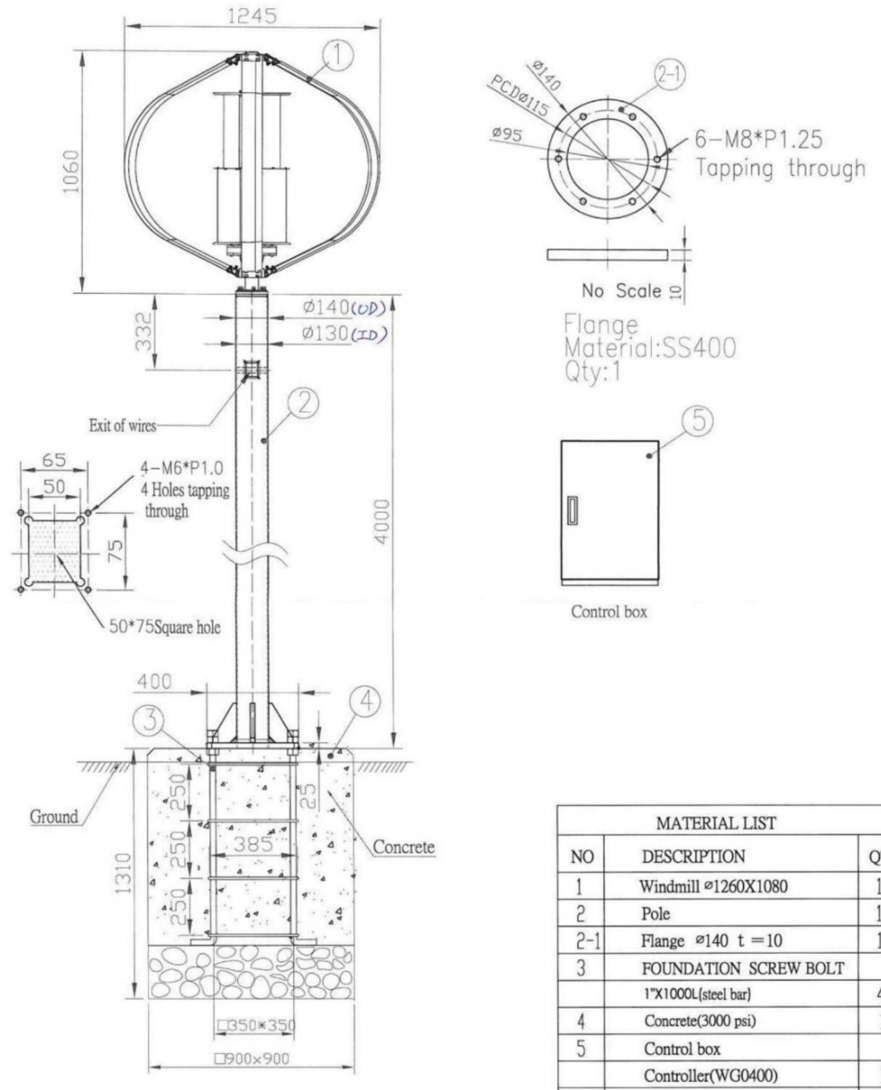
## Small Vertical Wind Turbines DS300




MATERIAL LIST

| NO | DESCRIPTION | QTY |
|---|---|---|
| 1 | Windmill ⌀1260X1080 | 1 |
| 2 | Pole | 1 |
| 2-1 | Flange ⌀140 t =10 | 1 |
| 3 | FOUNDATION SCREW BOLT | |
| | 1"X1000L(steel bar) | 4 |
| 4 | Concrete(3000 psi) | 1 |
| 5 | Control box | |
| | Controller(WG0400) | 1 |
| | Battery 12V 100AH | 2 |

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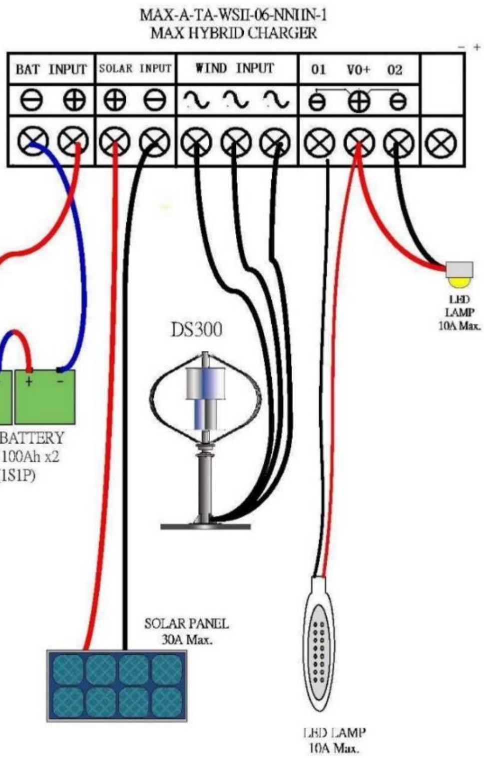
## Small Vertical Wind Turbines DS300






The hybrid Standard controller is able to manage in total autonomy the two different sources, solar and wind, togheter with the storage in the battery pack.

The advanced technology allows accurate control of all the generated values, the turbine speed, the output power, the capacity of stored energy. The product is also water proof and equipped with all protections for short circuit, over-current or voltage etc.

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# Annex II. Taula de conductors normalitzats

| **Mesura nominal del conductor** | | Resistència a 20°C ($\Omega$/m) | | Diàmetre total pels conductors esmaltats de Cu y Al (mm) | | | Diàmetre total pels conductors de coure(mm) aïllats con: | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Paper | | Cotó | | | | Fibra de vidre | |
| | | IS: 4800(I) | | IS: 4800 (II) | | | IS: 3454 | | IS: 450 | | | | IS: 4685 | |
| | | | | | | | | | Simple | | Doble | | | |
| dc (mm) | Àrea (mm$^2$) | Cu | Al | Fino | Medi | Gruixut | Ordi-nari | Fi | Ordi-nari | Fi | Ordi-nari | Fi | Simple Capa | Doble capa |
| 0,020 | 0,0003142 | 54,88000 | - | 0,025 | 0,027 | - | - | - | - | - | - | - | - | - |
| 0,025 | 0,0004909 | 35,12000 | - | 0,031 | 0,034 | - | - | - | - | - | - | - | - | - |
| 0,032 | 0,0008043 | 21,44000 | - | 0,040 | 0,043 | - | - | - | - | - | - | - | - | - |
| 0,040 | 0,0012570 | 13,72000 | - | 0,050 | 0,054 | - | - | - | - | - | - | - | - | - |
| 0,050 | 0,001964 | 8,781000 | - | 0,062 | 0,068 | - | - | - | - | - | - | - | - | - |
| 0,063 | 0,003118 | 5,531000 | - | 0,078 | 0,085 | - | - | - | - | - | - | - | - | - |
| 0,071 | 0,003960 | 4,355000 | - | 0,088 | 0,095 | - | - | - | - | - | - | - | - | - |
| 0,080 | 0,005027 | 3,430000 | - | 0,098 | 0,105 | 0,116 | - | - | - | - | - | - | - | - |
| 0,090 | 0,006363 | 2,710000 | - | 0,110 | 0,117 | 0,128 | - | - | - | - | - | - | - | - |
| 0,100 | 0,007855 | 2,915000 | - | 0,121 | 0,129 | 0,141 | - | - | - | - | - | - | - | - |
| 0,112 | 0,009853 | 1,750000 | - | 0,134 | 0,143 | 0,155 | - | - | - | - | - | - | - | - |
| 0,125 | 0,012270 | 1,405000 | - | 0,149 | 0,159 | 0,171 | - | - | - | - | - | - | - | - |
| 0,140 | 0,01540 | 1,120000 | - | 0,166 | 0,176 | 0,189 | - | - | 0,244 | 0,229 | 0,371 | 0,295 | - | - |
| 0,160 | 0,02011 | 0,857500 | - | 0,187 | 0,199 | 0,213 | - | - | 0,264 | 0,249 | 0,391 | 0,315 | - | - |
| 0,180 | 0,02545 | 0,677500 | - | 0,209 | 0,222 | 0,237 | - | - | 0,284 | 0,269 | 0,411 | 0,335 | - | - |
| 0,200 | 0,03142 | 0,548800 | 0,89130 | 0,230 | 0,245 | 0,261 | - | - | 0,304 | 0,289 | 0,431 | 0,355 | - | - |
| 0,224 | 0,03941 | 0,437500 | 0,71050 | 0,256 | 0,272 | 0,290 | - | - | 0,354 | 0,326 | 0,481 | 0,404 | - | - |
| 0,250 | 0,04909 | 0,351200 | 0,57040 | 0,284 | 0,301 | 0,320 | 0,500 | 0,425 | 0,380 | 0,352 | 0,507 | 0,430 | 0,380 | 0,456 |
| 0,280 | 0,06158 | 0,280000 | 0,45470 | 0,315 | 0,334 | 0,353 | 0,530 | 0,455 | 0,410 | 0,382 | 0,537 | 0,461 | 0,410 | 0,486 |
| 0,315 | 0,07794 | 0,221200 | 0,35930 | 0,352 | 0,371 | 0,391 | 0,565 | 0,490 | 0,445 | 0,417 | 0,572 | 0,496 | 0,445 | 0,521 |
| 0,355 | 0,09899 | 0,17420 | 0,28290 | 0,395 | 0,414 | 0,435 | 0,605 | 0,530 | 0,486 | 0,458 | 0,613 | 0,531 | 0,486 | 0,562 |
| 0,400 | 0,12570 | 0,13720 | 0,22280 | 0,442 | 0,462 | 0,483 | 0,650 | 0,575 | 0,531 | 0,503 | 0,658 | 0,582 | 0,531 | 0,607 |
| 0,450 | 0,15910 | 0,10840 | 0,17610 | 0,495 | 0,516 | 0,538 | 0,700 | 0,625 | 0,582 | 0,554 | 0,709 | 0,632 | 0,582 | 0,658 |
| 0,500 | 0,19640 | 0,08781 | 0,14260 | 0,548 | 0,569 | 0,591 | 0,750 | 0,675 | 0,632 | 0,604 | 0,759 | 0,683 | 0,632 | 0,708 |
| 0,560 | 0,24630 | 0,07000 | 0,11370 | 0,611 | 0,632 | 0,658 | 0,810 | 0,735 | 0,693 | 0,665 | 0,820 | 0,744 | 0,693 | 0,769 |
| 0,630 | 0,3118 | 0,05531 | 0,08982 | 0,684 | 0,706 | 0,730 | 0,880 | 0,805 | 0,763 | 0,736 | 0,891 | 0,814 | 0,763 | 0,839 |
| 0,710 | 0,3960 | 0,04355 | 0,07072 | 0,757 | 0,790 | 0,815 | 0,985 | 0,885 | 0,869 | 0,842 | 0,997 | 0,895 | 0,844 | 0,920 |
| 0,750 | 0,4418 | 0,03903 | 0,06338 | 0,809 | 0,832 | 0,858 | 1,025 | 0,925 | 0,910 | 0,882 | 1,037 | 0,935 | 0,885 | 0,961 |
| 0,800 | 0,5027 | 0,03430 | 0,05570 | 0,861 | 0,885 | 0,911 | 1,075 | 0,975 | 0,960 | 0,933 | 1,087 | 0,986 | 0,935 | 1,011 |
| 0,850 | 0,5675 | 0,03038 | 0,04934 | 0,918 | 0,937 | 0,964 | 1,125 | 1,025 | 1,011 | 0,983 | 1,138 | 1,036 | 0,986 | 1,062 |
| 0,900 | 0,6363 | 0,02710 | 0,04401 | 0,965 | 0,990 | 1,017 | 1,175 | 1,075 | 1,081 | 1,034 | 1,188 | 1,087 | 1,036 | 1,112 |
| 0,950 | 0,7089 | 0,02432 | 0,03950 | 1,017 | 1,041 | 1,070 | 1,225 | 1,125 | 1,112 | 1,084 | 1,239 | 1,137 | 1,087 | 1,163 |
| 1,000 | 0,7855 | 0,02195 | 0,03565 | 1,068 | 1,093 | 1,123 | 1,275 | 1,200 | 1,162 | 1,135 | 1,290 | 1,215 | 1,135 | 1,215 |
| 1,060 | 0,8826 | 0,01954 | 0,03173 | 1,130 | 1,155 | 1,184 | 1,335 | 1,260 | 1,225 | 1,195 | 1,350 | 1,275 | 1,200 | 1,275 |
| 1,120 | 0,9853 | 0,01750 | 0,02842 | 1,192 | 1,217 | 1,246 | 1,395 | 1,320 | 1,285 | 1,255 | 1,310 | 1,335 | 1,260 | 1,335 |
| 1,180 | 1,0937 | 0,015770 | 0,025600 | 1,254 | 1,279 | 1,308 | 1,455 | 1,380 | 1,345 | 1,315 | 1,470 | 1,395 | 1,320 | 1,395 |
| 1,250 | 1,2273 | 0,014050 | 0,022820 | 1,325 | 1,351 | 1,381 | 1,525 | 1,450 | 1,415 | 1,385 | 1,540 | 1,465 | 1,390 | 1,465 |
| 1,320 | 1,3687 | 0,012600 | 0,020460 | 1,397 | 1,423 | 1,453 | 1,595 | 1,520 | 1,485 | 1,460 | 1,615 | 1,535 | 1,460 | 1,535 |
| 1,400 | 1,5396 | 0,011200 | 0,018190 | 1,479 | 1,506 | 1,535 | 1,700 | 1,575 | 1,590 | 1,565 | 1,720 | 1,645 | 1,540 | 1,615 |
| 1,500 | 1,7674 | 0,009757 | 0,015840 | 1,581 | 1,608 | 1,638 | 1,800 | 1,675 | 1,695 | 1,665 | 1,820 | 1,745 | 1,640 | 1,720 |
| 1,600 | 2,0109 | 0,008575 | 0,013930 | 1,683 | 1,711 | 1,741 | 1,900 | 1,775 | 1,795 | 1,765 | 1,920 | 1,845 | 1,745 | 1,820 |
| 1,700 | 2,2701 | 0,007596 | 0,012340 | 1,785 | 1,813 | 1,844 | 2,000 | 1,875 | 1,895 | 1,865 | 2,020 | 1,945 | 1,845 | 1,920 |
| 1,800 | 2,5450 | 0,006775 | 0,011000 | 1,888 | 1,916 | 1,947 | 2,100 | 1,975 | 1,995 | 1,970 | 2,125 | 2,045 | 1,945 | 2,020 |
| 1,900 | 2,8357 | 0,006081 | 0,009876 | 1,990 | 2,018 | 2,049 | 2,200 | 2,075 | 2,095 | 2,070 | 2,225 | 2,150 | 2,045 | 2,120 |
| 2,000 | 3,1420 | 0,005488 | 0,008913 | 2,092 | 2,120 | 2,152 | 2,350 | 2,250 | 2,225 | 2,195 | 2,375 | 2,275 | 2,145 | 2,225 |
| 2,120 | 3,5304 | 0,004884 | 0,007932 | 2,214 | 2,243 | 2,275 | 2,470 | 2,370 | 2,345 | 2,315 | 2,495 | 2,395 | - | 2,395 |
| 2,240 | 3,9413 | 0,004375 | 0,007105 | 2,336 | 2,366 | 2,398 | 2,590 | 2,490 | 2,465 | 2,440 | 2,620 | 2,515 | - | 2,515 |
| 2,360 | 4,3749 | 0,003941 | 0,006401 | 2,459 | 2,488 | 2,522 | 2,710 | 2,610 | 2,585 | 2,560 | 2,740 | 2,635 | - | 2,640 |
| 2,500 | 4,9093 | 0,003512 | 0,005704 | 2,601 | 2,631 | 2,665 | 2,850 | 2,725 | 2,730 | 2,700 | 2,880 | 2,780 | - | 2,780 |
| 2,650 | 5,5162 | 0,003126 | 0,005077 | 2,754 | 2,784 | 2,819 | 3,000 | 2,875 | 2,830 | 2,850 | 3,035 | 2,930 | - | 2,930 |
| 2,800 | 6,1583 | 0,002800 | 0,004547 | 2,907 | 2,938 | 2,972 | 3,150 | 3,025 | 3,030 | 3,005 | 3,185 | 3,080 | - | 3,080 |
| 3,000 | 7,0695 | 0,002439 | 0,003961 | 3,110 | 3,142 | 3,176 | 3,350 | 3,225 | 3,235 | 3,205 | 3,385 | 3,285 | - | 3,285 |
| 3,150 | 7,7941 | 0,002212 | 0,003593 | 3,263 | 3,284 | 3,330 | 3,500 | 3,375 | 3,385 | 3,355 | 3,540 | 3,435 | - | 3,435 |
| 3,350 | 8,8153 | 0,001956 | 0,003177 | 3,466 | 3,498 | 3,534 | 3,700 | 3,575 | 3,585 | 3,560 | 3,740 | 3,635 | - | 3,690 |
| 3,550 | 9,8993 | 0,001742 | 0,002829 | 3,670 | 3,702 | 3,738 | 3,900 | 3,775 | 3,790 | 3,760 | 3,940 | 3,840 | - | 3,890 |
| 3,750 | 11,0461 | 0,001561 | 0,002535 | 3,873 | 3,905 | 3,942 | 4,100 | 3,975 | 3,990 | 3,965 | 4,145 | 4,040 | - | 4,095 |
| 4,000 | 12,5680 | 0,001372 | 0,002228 | 4,127 | 4,160 | 4,196 | 4,350 | 4,300 | 4,245 | 4,125 | 4,395 | 4,295 | - | 4,345 |
| 4,250 | 14,1881 | 0,001215 | 0,001974 | 4,380 | 4,414 | 4,451 | 4,600 | 4,550 | 4,495 | 4,470 | 4,650 | 4,545 | - | - |
| 4,500 | 15,9064 | 0,001084 | 0,001761 | 4,634 | 4,668 | 4,705 | 4,850 | 4,800 | 4,750 | 4,720 | 4,900 | 4,800 | - | - |
| 4,750 | 17,7209 | 0,000973 | 0,001580 | 4,889 | 4,923 | 4,961 | 5,100 | 5,050 | 5,000 | 4,975 | 5,155 | 5,050 | - | - |
| 5,000 | 19,6370 | 0,0008781 | 0,001426 | 5,142 | 5,177 | 5,215 | 5,350 | 5,300 | 5,225 | 5,225 | 5,405 | 5,305 | - | - |

**Taula 1.** Conductors normalitzats (Font: (33))

# Annex III. Pauta de càlcul. Mathcad

# DIMENSIONAMENT I CÀLCUL ANALÍTIC

## 1. Especificacions inicials del generador

- **Potència elèctrica nominal [$P_n$]** $Pn := 300$ W

El generador que es pretén dissenyar ha de proporcionar una potència útil de 300W, per tant, s'ha de conèixer que potència ha de ser transmesa a aquest a través de la turbina eòlica. Per conèixer aquest valor és farà us del rendiment del generador [$\eta_{generador}$].

*"Reglament (UE) 2019/1781 de la comissió de l'1 de octubre de 2019"*

> *"La eficiència energètica dels motors trifàsics amb una potència nominal igual o superior a 0,12 kW i inferior a 0,75 kW, amb 2, 4, 6 o més de 8 polos, que no siguin motors de seguretat aumentada «Ex eb», correspondrà* ***com a mínim al nivell d'eficiència IE2".***

:=

| | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | 0 | "2 pols" | "4 pols" | "6 pols" | "8 pols" |
| 1 | "High IE2" | "67.064%" | "70.474%" | "68.886%" | "53.156%" |
| 2 | "Premium IE3" | "71.614%" | "75.299%" | "71.034%" | "66.694%" |
| 3 | 'S. Premium IE4" | "76.116%" | "79.499%" | "76.043%" | "72.507%" |

S'ha detenir en compte que aquest reglament s'aplica a motors trifàsics de 50Hz i per tant els reglaments obtinguts són referenciats a aquesta freqüència. Per aquest motiu, la taula mostrada només serà una representació dels valors aproximats de rendiment que han de tenir els motors d'aquest caire. Finalment, pel cas d'estudi s'ha decidit utilitzar un valor de:

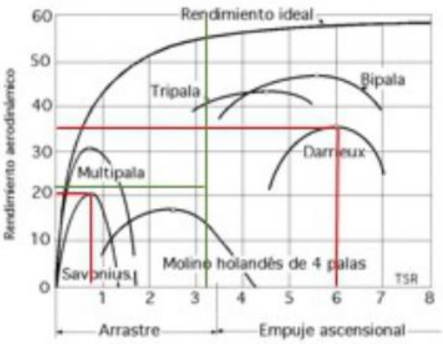
- **Eficiència del generador [ ηgenerador ]** $\eta generador := 0.95$

| | Totally enclosed asynchronous machines | Sailent-pole synchronous machines or PMSMs | Nonsalient-pole synchronous machines: Indirect cooling, Air | Nonsalient-pole synchronous machines: Indirect cooling, Hydrogen | Nonsalient-pole synchronous machines: Direct water cooling | DC machines |
|---|---|---|---|---|---|---|
| A/kA/m, RMS | 30–65 | 35–65 | 30–80 | 90–110 | 150–200 | 25–65 |
| Air-gap flux density $\hat{B}_{\delta 1}$/T | 0.7–0.9 | 0.85–1.05 | 0.8–1.05 | 0.8–1.05 | 0.8–1.05 | 0.6–1.1 |
| Tangential stress $\sigma_{Ftan}$/Pa | | | | | | |
| minimum | 12 000* | 21 000* | 17 000* | 51 000* | 85 000* | 12 000* |
| average | 21 500* | 33 500* | 36 000* | 65 500* | 1,14 500* | 29 000* |
| maximum | 33 000* | 48 000* | 59 500* | 81 500* | 1,48 500* | 47 500* |
| | *cos φ = 0.8 | *cos φ = 1 | *cos φ = 1 | *cos φ = 1 | *cos φ = 1 | *$\alpha_{DC}$ = 2/3 |

- **Factor de potència nominal [cos ϕ]** $\cos\varphi := 1$

- **Freqüència [f]** $fs := 20$ Hz
- **Velocitat nominal [Nn]** $Nn := 100$ rpm
- **Parell de pols** $p := \frac{60 \cdot fs}{Nn}$ $p = 12$
- **Número de fases [m]** $m := 3$
- **Potència de la turbina [Ptur]** $Ptur := \frac{Pn}{\eta generador \cdot \cos\varphi}$ $Ptur = 315.789$ W

Tenint en compte que l'aerogenerador escollit porta incorporades 4 pales de tipus Savonius i 3 pales Darrieus i que el φ rotor de la turbina es de 1,24m:




$Drturbina := 1.24$ m

$\rho aire := 1.225 \frac{kg}{m^3}$

$TSR := 0.57 \cdot 0.9 + 0.43 \cdot 6$ $TSR = 3.093$

En la gràfica:

Com $TSR = 3.093 \rightarrow \eta aero := 0.218$

$Pvent := \frac{Ptur}{\eta aero}$ $Pvent = 1.449 \times 10^3$

$$v := \sqrt[3]{\frac{2 \cdot Pvent}{\pi \cdot \left(\frac{Drturbina}{2}\right)^2 \rho aire}} \qquad v = 12.511 \frac{m}{s}$$

## 2. Dimensionament del generador eòlic PMSG

Suposarem una **Capa de corrent [A]** d'entre 35000-65000 A/m:

$$A := 35000 \ \frac{A}{m}$$

| | Asynchronous machines | Sailent-pole synchronous machines or PMSMs | Nonsalient-pole synchronous machines: Indirect cooling, Air | Nonsalient-pole synchronous machines: Indirect cooling, Hydrogen | Nonsalient-pole synchronous machines: Direct water cooling |
|---|---|---|---|---|---|
| $A$/kA/m | 30–65 | 35–65 | 35–80 | 90–110 | 150–200 |
| | Stator winding | Armature winding | | Armature winding | |
| $J$/A/m$^2$ | $3–8 \times 10^6$ | $4–6.5 \times 10^6$ | $3–5 \times 10^6$ | $4–6 \times 10^6$ | $7–10 \times 10^6$ |
| $AJ$/A$^2$/m$^3$ | $9 \times 10^{10}$ to $52 \times 10^{10}$ | $14 \times 10^{10}$ to $42.25 \times 10^{10}$ | $10.5 \times 10^{10}$ to $40 \times 10^{10}$ | $36 \times 10^{10}$ to $66 \times 10^{10}$ | $105 \times 10^{10}$ to $200 \times 10^{10}$ |

Suposarem una **TRV** (Torque per rotor volume) d'entre 14-42 kNm/m$^3$:

$$TRV := 15000 \ \frac{N}{m^3}$$

| Class of machine | TRV kNm/m$^3$ |
|---|---|
| Small totally-enclosed motors (Ferrite magnets) | 7 - 14 |
| Totally-enclosed motors (sintered Rare Earth or NdFeB magnets) | 14 - 42 |
| Totally-enclosed motors (Bonded NdFeB magnets) | 20 |
| Integral-hp industrial motors | 7 - 30 |
| High-performance servomotors | 15 - 50 |
| Aerospace machines | 30 - 75 |
| Large liquid-cooled machines (e.g. turbine-generators) | 100 - 250 |

Imant NdFeB 35H (N35H):

| | Characteristic | Units | min. | nominal | max. |
|---|---|---|---|---|---|
| Magnetic Properties | **Br**, Residual Induction | Gauss | 11,700 | 12,100 | 12,500 |
| | | mT | 1170 | 1210 | 1250 |
| | **H$_{cB}$**, Coercivity | Oersteds | 10,900 | 11,450 | 12,000 |
| | | kA/m | 868 | 911 | 955 |
| | **H$_{cJ}$**, Intrinsic Coercivity | Oersteds | 17,000 | | |
| | | kA/m | 1,353 | | |
| | **BHmax**, Maximum Energy Product | MGOe | 33 | 36 | 38 |
| | | kJ/m$^3$ | 263 | 283 | 302 |

- **Densitat de flux remanent [Br]:** $Brm := 1.17 \ T$
- **Coercitivitat [Hc] a 120ºC:** $Hc := 868000 \ \frac{A}{m}$
- **Permeabilitat buit [μo]** $\mu o := 4 \cdot \pi \cdot 10^{-7} \ \frac{H}{m}$
- **Permeabilitat relativa [μr]** $\mu r := \frac{Brm}{\mu o \cdot Hc} \qquad \mu r = 1.073$

Es planteja un pitjor escenari, treballar al màxim d'aïllament F (155ºC). La coercitivitat resulta:

- **Coeficient de TºC reversible per a la coercitivitat [α(Hcj)]:** $\alpha(Hc) := 0.605 \quad \frac{\%}{ºC}$

$\Delta T := 155 - 120 = 35 \quad ºC$

$Hc155 := Hc - Hc \cdot \Delta T \cdot \frac{\alpha(Hc)}{100} \qquad Hc155 = 6.842 \times 10^{5} \quad \frac{A}{m}$

## Dimensionament $D^2 \cdot L$:

$$TRV = \frac{M}{\frac{\pi}{4} \cdot D^2 \cdot L} \rightarrow D^2 \cdot L = \frac{M}{\frac{\pi}{4} \cdot TRV}$$

***Parell*** : $\omega tur := \frac{2\pi\, Nn}{60} \quad \rightarrow \quad M := \frac{Ptur}{\omega tur} = 30.156 \quad Nm$

$D2L := \frac{M}{\frac{\pi TRV}{4}} = 2.56 \times 10^{-3} \quad m^3$

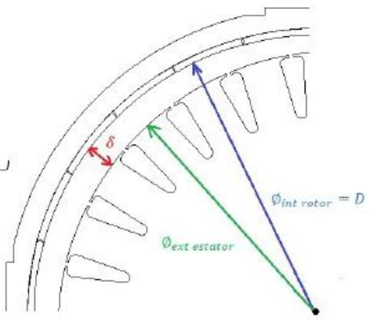
S'estima : $Lemp := 40 \quad mm$ Per tant, el diàmetre interior del rotor serà:

$\rightarrow \quad D := \sqrt{\frac{D2L}{\frac{Lemp}{1000}}} = 0.253 \qquad \rightarrow \quad D := 0.250 \quad m$

***Entreferro*** : $\delta := 0.0002 + 0.003 \cdot \sqrt{\frac{D \cdot \frac{Lemp}{1000}}{2}} = 4.121 \times 10^{-} \, m \qquad \rightarrow \quad \delta := 0.5 \quad mm$

El diàmetre exterior del estator serà:

$\phi ext\_est := D - \frac{2 \cdot \delta}{1000} = 0.249 \quad m$



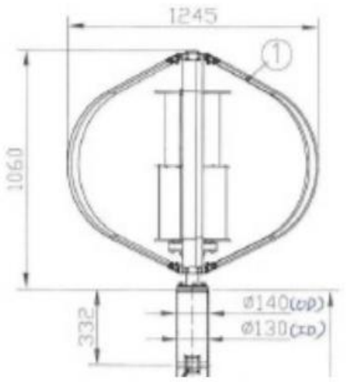

**Diàmetre interior del rotor:** $D = 0.25 \quad m$

**Diàmetre exterior del estator:** $\phi ext\_est = 0.249 \quad m$

**Entreferro** : $\delta = 0.5 \quad mm$

## 3. Determinació de l'eix

Per determinar les dimensions de l'eix s'ha de tenir en compte el diàmetre del màstil del l'aerogenerador. Per poder escollir els 130-140 mm que proposa la fitxa tècnica s'haurà de comprovar que el càlcul no superi el diàmetre mínim:



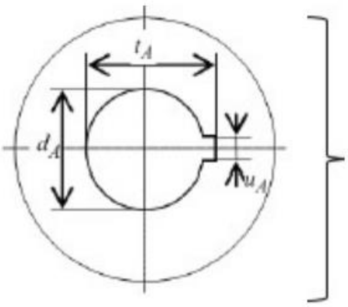

$$\tau_{eix} := 3.5 \cdot 10^{7} \quad \frac{N}{m^2}$$

$$W_{t\_min} := \frac{M}{\tau_{eix}} = 8.616 \times 10^{-7}$$

El diàmetre mínim de l'eix serà:

$$d_{A\_min} := \sqrt[3]{W_{t\_min} \cdot \frac{16}{\pi}} = 0.016$$

→ Aquest diàmetre s'ha de normalitzar per catàleg i es farà ús del KIENLE:




$d_A := 17$ mm

$t_A := 19$ mm

$u_A := 5$ mm

Tot i així, com s'ha comprovat que el diàmetre del màstil és superior al diàmetre mínim, s'utilitzaran **130 mm** com a obertura interior del generador.

## 4. Debanat ESTATÓRIC

$Q := 27$ ranures

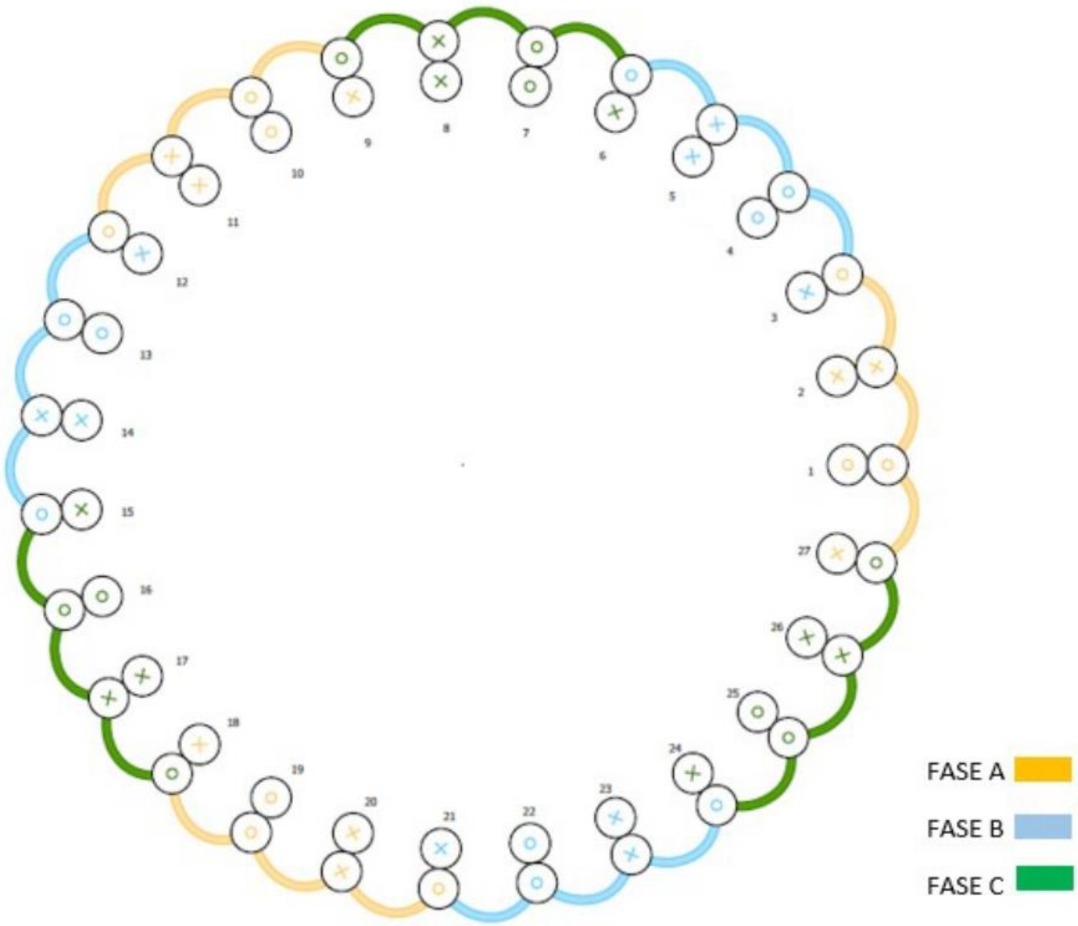
$p = 12$ parell de pols

$m = 3$ fases

$$q := \frac{Q}{2 \cdot p \cdot m} = 0.375$$ ranures per pol i fase → DEBANAT DISTRIBUIT $q > 1$

$$Y_p := \frac{Q}{2 \cdot p} = 1.125$$ → Pas polar expressat en ranures

$$Y_f := \frac{Q}{2 \cdot m} = 4.5$$




El debanat proposat és de **doble capa.** Com q (número de ranures per pol i fase) no es un número sencer, no es poden aplicar les formules teòriques del factor de debanat. Per poder calcular aquest valor es farà ús dels fasors d'una de les fases del generador, aquest mètode s'anomena *"Voltage Vector Graph"*.

Primerament es construirà l'star slot del bobinat i els vectors que formaran la fase A. Finalment, es farà el càlcul dels vectors de voltatge de dita fase.

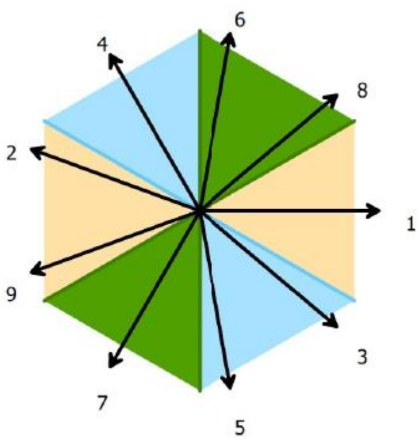
t = MCD (Q, p) = MCD (27, 12)= 3 → $t := 3$

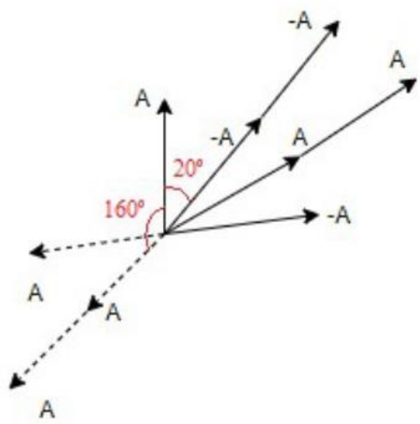
$$Q_1 := \frac{Q}{t} = 9$$

$$p_1 := \frac{p}{t} = 4$$

$angle1 := \frac{2 \cdot \pi}{Q} \cdot t = 0.698\,rad$  $angle2 := 40$ graus → Angle entre radis

$angle_u := \frac{p}{t} \cdot angle1 = 2.793$ graus → Angle de ranura a ranura

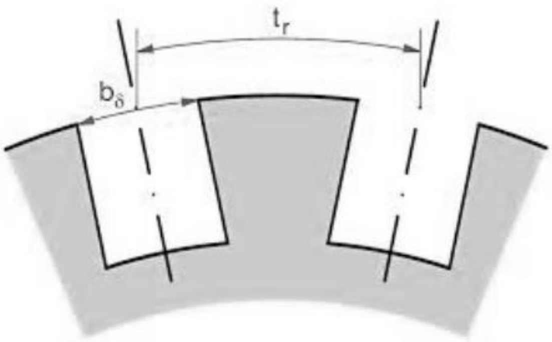



$$\xi_\omega = \frac{1\lfloor 0° - 1\lfloor 160° - 1\lfloor 160° + 1\lfloor 320° + 1\lfloor 320° - 1\lfloor 120°}{6}$$  $\xi_\omega := 0.9452$

## 4. Aplicació del FACTOR DE CARTER

La disminució de la valor de la inducció en una màquina amb ranures a diferència d'un altre amb entreferro uniforme, es pot obtenir incrementant el valor de la longitud de l'entreferro mitjançant el **FACTOR DE CARTER**.




$b_\delta := 2$ mm

$t_r := \frac{\pi \cdot \phi ext\_est \cdot 1000}{Q} = 28.972$ mm

$k := \frac{\frac{b_\delta}{\delta}}{5 + \frac{b_\delta}{\delta}} = 0.444 \rightarrow$ $be := k \cdot b_\delta = 0.889$

$k_{cs} := \frac{t_r}{t_r - be} = 1.032$

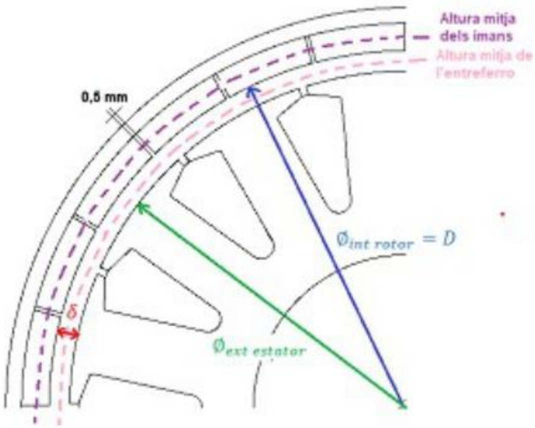
$\delta_{cs} := k_{cs} \cdot \delta = 0.516$ mm $\rightarrow$ L'entreferro equivalent serà doncs: $\delta_{cs} = 0.516$ mm

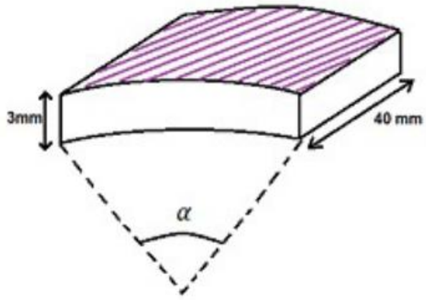
## 5. IMANTS DE NdFeB

Es realitzarà una primera estimació del valor de la inducció en els imants:

- Factor de recobriment: $\frac{Sm}{sg}$

Per calcular el factor de recobriment polar, s'utilitzarà l'alçada mitja dels imants i de l'entreferro tal i com es mostra a la figura següent:




$\alpha := 14.77$

Tenint en comte el valor de l'entreferro calculat: $D := 250$ mm

a) Imants: $D + 1.5 + 1.5 = 253$ mm

$$Sm := \alpha \cdot \frac{D}{2} \cdot Lemp \cdot \frac{\pi}{180} = 1.289 \times 10^3$$

b) Entreferro: $$Sg := 2 \cdot Lemp \cdot \pi \cdot \frac{\phi ext\_est \cdot 1000}{2} = 3.129 \times 10^4$$

$$\frac{Sm \cdot 24}{Sg} = 0.989$$

$\sigma := 0.989$

- Factor de saturació: $k_1 := 1$
- Altura imposada dels imants: $l_m := 3$ mm

$$B_\delta := Brm \cdot \frac{1}{1 + k_1 \cdot \mu r \cdot \sigma \cdot \frac{\delta_{cs}}{l_m}} = 0.9895 \quad T$$

## 6. DEBANAT ESTATÒRIC

Simulat un principal debanat al SWAT-EM, aquest ens mostra la possibilitat de tenir un debanat amb 3 fils connectats en paral·lel (aa=3) o la possibilitat de la connexió total en sèrie (aa=1)

$$\xi_\omega = 0.945$$

$$Q = 27$$

$$fs = 20 \quad Hz$$

$$p = 12$$

$$\phi ext\_est = 0.249 \quad m$$

$$\tau_p := \frac{\pi \cdot \phi ext\_est}{2 \cdot p} = 0.033 \quad m$$

$$\phi_\delta := \frac{2}{\pi} \cdot B_\delta \cdot \frac{Lemp}{1000} \cdot \tau_p = 8.213 \times 10^{-4} \quad Wb$$

Es procedirà al càlcul del número de espires per pol i fase per a cadascuna de les possibilitats de connexió:

### *A) Connexió total en sèrie aa=1*

$$E_{aa1} := 90 \quad V$$

$$n_{s\_aa1} := \frac{E_{aa1}}{\frac{2 \cdot \pi}{\sqrt{2}} \cdot \xi_\omega \cdot p \cdot \phi_\delta \cdot fs} = 108.729 \rightarrow n_{s\_aa1} := 109 \quad \text{ranures per pol i fase}$$

$$aa := 1 \quad \begin{cases} N_{s\_aa1} := n_{s\_aa1} \cdot p = 1308 & \text{espires per fase} \\ Z_{t\_aa1} := N_{s\_aa1} \cdot 2 \cdot m = 7848 & \text{condutors} \\ Z_{r\_aa1} := \frac{Z_{t\_aa1}}{Q} = 290.667 \quad Z_{r\_aa1} := 291 & \text{conductors per ranura} \\ N_{t\_aa1} := \frac{Z_{t\_aa1}}{2} = 3924 & \text{espires} \end{cases}$$

***B) Connexió en paral·lel aa=3***

$E_{aa3} := \frac{90}{3}$ V

$n_{s\_aa3} := \frac{E_{aa3}}{\frac{2 \cdot \pi}{\sqrt{2}} \cdot \xi_{\omega} \cdot p \cdot \phi_{\delta} \cdot fs} = 36.243 \rightarrow n_{s\_aa3} := 37$ ranures per pol i fase

$aa := 3$

$N_{s\_aa3} := n_{s\_aa3} \cdot p = 444$ espires per fase

$Z_{t\_aa3} := N_{s\_aa3} \cdot 2 \cdot m = 2664$ condutors

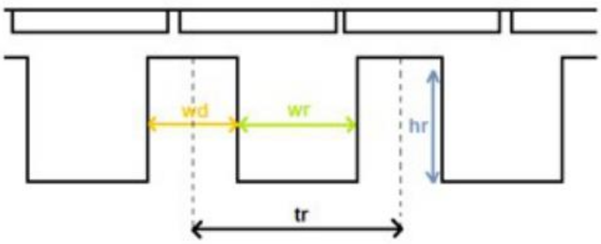
$Z_{r\_aa3} := \frac{Z_{t\_aa1}}{Q} = 290.667$ $Z_{r\_aa3} := 99$ conductors per ranura

$N_{t\_aa3} := \frac{Z_{t\_aa3}}{2} = 1332$ espires

## 6.1 Dimensionament del debanat estatòric

Per al dimensionament de l'estator es necessitarà la suposició d'alguns valors d'induccions màximes. En la taula següent es mostrarà quins valors seran d'utilitat pel càlcul de les dimensions físiques de la màquina.

| | | |
|---|---|---|
| Inducció màxima a l'entreferro | $\hat{B}_{\delta}$ | $\hat{B}_{\delta} \leq 1{,}1\,T$ |
| Inducció màxima a les dents | $\hat{B}_{ts}$ | $\hat{B}_{ts} \leq 1{,}6\,T$ |
| Inducció màxima a la corona estatòrica | $\hat{B}_{sy}$ | $\hat{B}_{sy} \leq 1{,}4\,T$ |
| Inducció màxima a la corona rotòrica | $\hat{B}_{ry}$ | $\hat{B}_{\delta} \leq 1{,}4\,T$ |




$\tau_p = 0.0326$ m

$\tau_r := \frac{\tau_p}{\frac{Q}{2 \cdot p}} = 0.029$ m

$B_{max\_dent} := 1.6$ T

Teorema de Gauss: $\phi_\delta := \phi_{dent}$ → $w_d := \dfrac{B_\delta \cdot \tau_p}{B_{max\_dent} \cdot \dfrac{Q}{2 \cdot p}} = 0.018$ m

$$w_r := \tau_r - w_d = 0.01105 \quad \text{m}$$

## 6.2 Conductors

Pel càlcul del diàmetre dels conductors s'escollirà un valor de densitat de corrent [**Δ**] de **4 A/mm²**

$$\Delta := 4 \ \frac{A}{mm^2}$$

| | Asynchronous machines | Sailent-pole synchronous machines or PMSMs | Nonsalient-pole synchronous machines: Indirect cooling, Air | Indirect cooling, Hydrogen | Direct water cooling | DC machines |
|---|---|---|---|---|---|---|
| A/kA/m | 30–65 | 35–65 | 30–80 | 90–110 | 150–200 | 25–65 |
| J/A/mm² | Stator winding 3–8 | Armature winding 4–6.5 | 3–5 | Armature winding 4–6 | 7–10 | Armature winding 4–9 |
| J/A/mm² | Copper rotor winding 3–8 | Field winding: 2–3.5 Multi-layer | | | | Pole winding 2–5.5 |
| J/A/mm² | Aluminium rotor winding 3–6.5 | 2–4 Single-layer | 3–5 | Field winding 3–5 | 6–12 | Compensating winding 3–4 |
| | | | With direct water cooling, in field windings 13–18 A/mm² and 250–300 kA/m can be reached | | | |

### *A) Connexió en paral·lel aa=1*

$I_{n\_aa1} := 1.4$ A $\quad FO := 0.4$

$S_{c\_aa1} := \dfrac{I_{n\_aa1}}{\Delta} = 0.35 \ mm^2$ → $d_{c\_aa1} := \sqrt{4 \cdot \dfrac{S_{c\_aa1}}{\pi}} = 0.668$ mm

Catàleg => $d_{c\_aa1} := 0.71$ mm

$$S_{c\_aa1} := \pi \cdot \frac{d_{c\_aa1}^2}{4} = 0.396 \quad mm^2$$

$$\Delta_{aa1} := \frac{I_{n\_aa1}}{S_{c\_aa1}} = 3.536$$

$$S_{ranura\_aa1} := \frac{Z_{r\_aa1} \cdot S_{c\_aa1}}{FO} = 288.031 \quad mm^2$$

$$h_{ranura\_aa1} := \frac{S_{ranura\_aa1}}{w_r \cdot 1000} = 26.055 \quad mm$$

***B) Connexió en paral·lel aa=3***   $I_{n\_aa3} := 3.5$ A   $FO := 0.4$

$$S_{c\_aa3} := \frac{I_{n\_aa3}}{\Delta} = 0.875 \quad mm^2 \rightarrow \quad d_{c\_aa3} := \sqrt{4 \cdot \frac{S_{c\_aa3}}{\pi}} = 1.056 \quad mm$$

Catàleg => $d_{c\_aa3} := 1.060$ mm

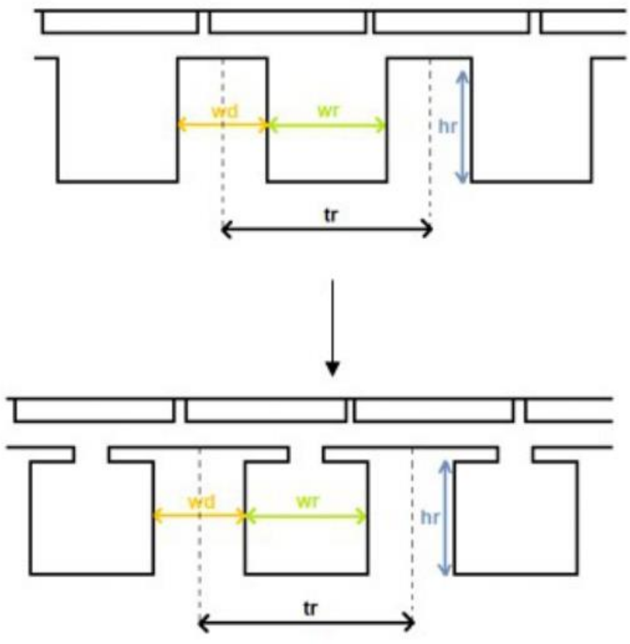
$$S_{c\_aa3} := \pi \cdot \frac{d_{c\_aa3}^{\,2}}{4} = 0.882 \quad mm^2$$

$$\Delta_{aa3} := \frac{I_{n\_aa3}}{S_{c\_aa3}} = 3.966$$

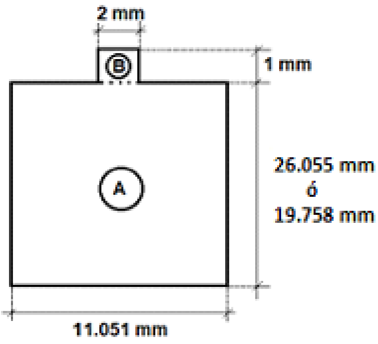
$$S_{ranura\_aa3} := \frac{Z_{r\_aa3} \cdot S_{c\_aa3}}{FO} = 218.412 \quad mm^2$$

$$h_{ranura\_aa3} := \frac{S_{ranura\_aa3}}{w_r \cdot 1000} = 19.758 \quad mm$$

La ranura calculada és totalment rectangular i l'obertura és massa gran i pot ocasionar grans pèrdues i una elevada saturació en el generador, per aquest motiu, una vegada aconseguides les dimensions aproximades de la ranura, s'ha optat per escollir-ne una de mateixes dimensions però amb algunes alteracions com indica la figura següent.



## Àrea A:




$A_{Aranura\_aa1} := w_r \cdot 1000 \cdot (h_{ranura\_aa1} - 0.001) = 288.02$ $mm^2$

$A_{Aranura\_aa3} := w_r \cdot 1000 \cdot (h_{ranura\_aa3} - 0.001) = 218.401$ $mm^2$

## Àrea B:

$A_{Branura\_aa1} := 2$ $mm^2$

$A_{Branura\_aa3} := 2$ $mm^2$

$$FO_{aa1} := \frac{Z_{r\_aa1} \cdot S_{c\_aa1} \cdot 100}{A_{Aranura\_aa1} + A_{Branura\_aa1}} = 39.726 \quad \% \quad \text{OK}$$

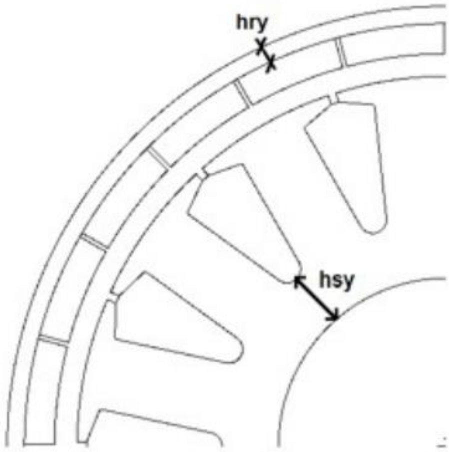
$$FO_{aa3} := \frac{Z_{r\_aa3} \cdot S_{c\_aa3} \cdot 100}{A_{Aranura\_aa3} + A_{Branura\_aa3}} = 39.639 \quad \% \quad \text{OK}$$

*Culata estatòrica:* $B_{sy} := 1.4$ T

Teorema de Gauss: $\phi_\delta := \phi_{sy}$ $\rightarrow$ $h_{sy} := \frac{B_\delta \cdot \tau_p}{B_{sy} \cdot 2} = 0.0115$ m

*Culata rotòrica* $B_{ry} := 1.4$ T

Teorema de Gauss: $\phi_\delta := \phi_{ry}$ $\rightarrow$ $h_{ry} := \frac{B_\delta \cdot \frac{\pi \cdot 0.256}{2 \cdot 12}}{B_{ry} \cdot 2} = 0.0118$ m



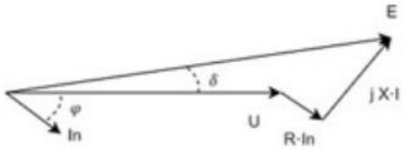
## 7. DIMENSIONAMENT REAL DELS IMANTS

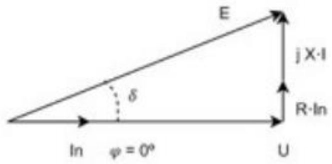
- **Factor de dispersió [$\sigma_o$]:** $\sigma_o := 1.2$
- **Corrent màxim en pu [$I_{pu}$]:** $I_{max\_aa1} := I_{n\_aa1} \cdot \sqrt{2}$ $\quad I_{max\_aa3} := I_{n\_aa3} \cdot \sqrt{2}$

$$I_{pu\_aa1} := \frac{I_{max\_aa1}}{I_{n\_aa1}} = 1.414 \qquad k_{m\_aa1} := I_{pu\_aa1}$$

$$I_{pu\_aa3} := \frac{I_{max\_aa3}}{I_{n\_aa3}} = 1.414 \qquad k_{m\_aa3} := I_{pu\_aa3}$$

- **Factor d'utilització de l'imant [$\zeta_m$]:** $\zeta_m := 0.6$
- **Factor de recobriment polar [$\alpha_p$]:** $\alpha_p := \sigma = 0.989$
- **Angle entre el fasor In i Eo [$\delta_{In\,i\,Eo}$]:** En el cas d'estudi, com cos ϕ=1 l'angle entre In i Eo serà el mateix que E i U, per tant δ




$\delta_{In\_Eo\_aa1} := 9.31$ º

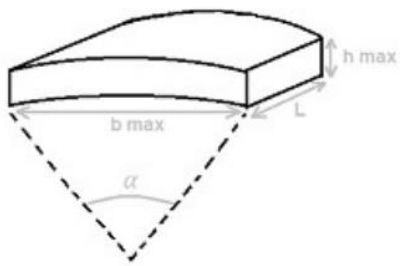
$\delta_{In\_Eo\_aa3} := 0.284$ º

### 7.1 Mida màxima dels imants

- **Amplada màxima imants:** $b_{max} := \alpha_p \cdot \tau_p = 0.032$ m
- **Altura màxima imants:** $Df := \phi ext\ est + 2 \frac{\delta_{cs}}{}$

$$h_{max} := \frac{Df + \frac{2 \cdot l_m}{1000} - \phi ext\_est}{2} = 3.516 \times 10^{-3}$$

- **Longitud màxima imants:** $L_{max\ imans} := Lemp = 40$ mm



## 7.1. Criteri de volum mínim

### *A) Connexió total en sèrie aa=1*

$$k_{ad} := \frac{\left(\alpha_p \cdot \pi + \sin\left(\alpha_p \cdot \pi\right)\right)}{4 \cdot \sin\left(\alpha_p \cdot \frac{\pi}{2}\right)} = 0.786$$

$$C_{v\_aa1} := \frac{0.2 \cdot \sigma_o \cdot k_{m\_aa1} \cdot k_{ad} \cdot \tan\left(\delta_{In\_Eo\_aa1} \cdot \frac{\pi}{180}\right)}{\zeta_m} = 0.073$$

- **Volum mínim:** $P_{abs} := \frac{Pn}{\eta generador \cdot \cos\varphi} = 315.789$ W

  $V_{min\_aa1} := C_{v\_aa1} \cdot \frac{P_{abs}}{fs \cdot Brm \cdot Hc155} = 1.437 \times 10^{-6}$ $m^3$

- **Altura mínima:** $h_{v\_min\_aa1} := \frac{V_{min\_aa1}}{b_{max} \cdot \frac{Lemp}{1000}} = 1.114 \times 10^{-3}$ m

### *B) Connexió en paral·lel aa=3*

$$k_{ad} := \frac{\left(\alpha_p \cdot \pi + \sin\left(\alpha_p \cdot \pi\right)\right)}{4 \cdot \sin\left(\alpha_p \cdot \frac{\pi}{2}\right)} = 0.786$$

$$C_{v\_aa3} := \frac{0.2 \cdot \sigma_o \cdot k_{m\_aa3} \cdot k_{ad} \cdot \tan\left(\delta_{In\_Eo\_aa3} \cdot \frac{\pi}{180}\right)}{\zeta_m} = 2.203 \times 10^{-3}$$

- **Volum mínim:** $P_{abs} := \frac{Pn}{\eta generador \cdot \cos\varphi} = 315.789$ W

  $V_{min\_aa3} := C_{v\_aa3} \cdot \frac{P_{abs}}{fs \cdot Brm \cdot Hc155} = 4.344 \times 10^{-8}$ $m^3$

- **Altura mínima:** $h_{v\_min\_aa3} := \frac{V_{min\_aa3}}{b_{max} \cdot \frac{Lemp}{1000}} = 3.369 \times 10^{-5}$ m

## 7.2. Criteri de desmagnetització

---------------------------------- 1r MÈTODE --------------------------------

### *A) Connexió total en sèrie aa=1*

$I_{Max\_aa1} := I_{n\_aa1} \cdot \sqrt{2} \cdot k_{m\_aa1} = 2.8$ A

$A_{Max\_aa1} := Z_{t\_aa1} \cdot \frac{I_{Max\_aa1}}{\pi \cdot \phi ext\_est} = 2.809 \times 10^{4}$ $\frac{A}{m}$

$FMM_{desmag\_aa1} := A_{Max\_aa1} \cdot \frac{\tau_p}{2} = 457.8$ A

- **Altura mínima:** $h_{V\_min\_aa1} := \frac{FMM_{desmag\_aa1}}{Hc155} = 6.691 \times 10^{-4}$ m

### *B) Connexió en paral·lel aa=3*

$I_{Max\_aa3} := I_{n\_aa3} \cdot \sqrt{2} \cdot k_{m\_aa3} = 7$ A

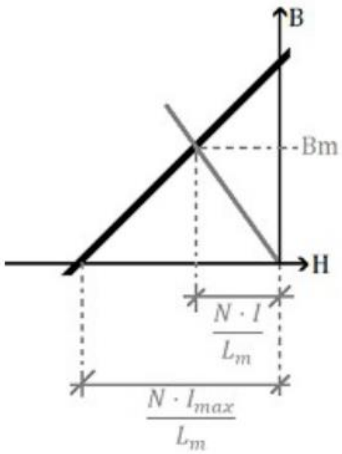
$A_{Max\_aa3} := Z_{t\_aa3} \cdot \frac{I_{Max\_aa3}}{\pi \cdot \phi ext\_est} = 2.384 \times 10^{4}$ $\frac{A}{m}$

$FMM_{desmag\_aa3} := A_{Max\_aa3} \cdot \frac{\tau_p}{2} = 388.5$ A

- **Altura mínima:** $h_{V\_min\_aa3} := \frac{FMM_{desmag\_aa3}}{Hc155} = 5.678 \times 10^{-4}$ m

---------------------------------- 2n MÈTODE ----------------------------------

### A) Connexió total en sèrie aa=1




$$B_m = \frac{1}{1 + \mu_m \cdot \frac{k_1}{k_2} \cdot \frac{l_\delta}{l_m} \cdot \frac{S_m}{S_\delta}} \cdot \left[ B_r + \mu_o \cdot \mu_m \cdot \frac{N \cdot I_n}{L_m} \right]$$

Terme que desplaça la recta cap a la dreta o cap a l'esquerre

$$L_{max\_imants\_aa1} := \frac{N_{s\_aa1} \cdot I_{Max\_aa1}}{Hc155} = 5.353 \times 10^{-3} \quad m$$

$$FMM_{Desmag\_aa1} := 1.35 \cdot \frac{N_{s\_aa1}}{p} \cdot \xi_\omega \cdot \left(I_{n\_aa1} \cdot 3\right) = 584.162 \; A$$

$$\frac{FMM_{Desmag\_aa1}}{L_{max\_imants\_aa1}} = 1.091 \times 10^{5} \quad \frac{A}{m}$$

### B) Connexió en paral·lel aa=3

$$L_{max\_imants\_aa3} := \frac{N_{s\_aa3} \cdot I_{Max\_aa3}}{Hc155} = 4.543 \times 10^{-3} \quad m$$

$$FMM_{Desmag\_aa3} := 1.35 \cdot \frac{N_{s\_aa3}}{p} \cdot \xi_\omega \cdot \left(I_{n\_aa3} \cdot 3\right) = 495.734 \; A$$

$$\frac{FMM_{Desmag\_aa3}}{L_{max\_imants\_aa3}} = 1.091 \times 10^{5} \quad \frac{A}{m}$$

--------------------------------- 3r MÈTODE ---------------------------------

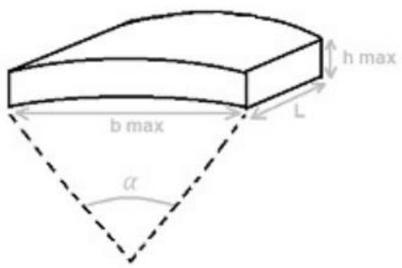
Condició de desmagnetització: $$\Delta B = \mu_o \cdot \frac{FMM}{\delta'} \leq \frac{B_r}{3} = \Delta B_{màx}$$

$$\Delta B_{max} := \frac{Brm}{3} = 0.39$$

**aa=1** $$\Delta B_{max\_aa1} := \mu o \cdot \frac{FMM_{Desmag\_aa1}}{\frac{(\delta_{cs}+l_m)}{1000}} = 0.209 \quad T \quad < \Delta Bmax \quad OK$$

**aa=3** $$\Delta B_{max\_aa3} := \mu o \cdot \frac{FMM_{Desmag\_aa3}}{\frac{(\delta_{cs}+l_m)}{1000}} = 0.177 \quad T \quad < \Delta Bmax \quad OK$$

Finalment s'ha escollit a configuració de tots els conductors connectats en sèrie **aa=1.** Per tant, les dimensions dels imants seràn les proposades a continuació:




$$b_{final} := 32.22 \quad mm$$

$$L_{final} := 40 \quad mm$$

$$h_{final} := 3 \quad mm$$

$$V_{final} := b_{final} \cdot L_{final} \cdot h_{final} = 3.866 \times 10^3 \quad mm^3$$

$$V_{Final} := \frac{V_{final}}{1000^3} = 3.866 \times 10^{-6} \quad m^3$$

$$V_{Final} = 3.866 \times 10^{-6} \quad > \quad V_{min\_aa1} = 1.437 \times 10^{-6} \quad OK$$

## 8. INDUCTÀNCIES

### 8.1 Inductància principal

$k_{sat} := 1$ $\qquad g_{eq} := k_{sat} \cdot k_{cs} \cdot \left[ \frac{(\delta + l_m)}{1000} \right] = 3.611 \times 10^{-3}$ m

**aa=1** $\qquad L_{m\_aa1} := \frac{\mu o}{\pi} \cdot m \cdot \frac{\phi ext\_est \cdot \frac{Lemp}{1000}}{g_{eq}} \cdot \left( \frac{N_{s\_aa1} \cdot \xi_\omega}{p} \right)^2 = 0.035$ H

**aa=3** $\qquad L_{m\_aa3} := \frac{\mu o}{\pi} \cdot m \cdot \frac{\phi ext\_est \cdot \frac{Lemp}{1000}}{g_{eq}} \cdot \left( \frac{N_{s\_aa3} \cdot \xi_\omega}{p} \right)^2 = 4.048 \times 10^{-3}$ H

### 8.2 Inductàcies de dispersió

- Inductància de dispersió diferencial o d'entreferro ( $L_\delta$ )

--------------------------------- 1r MÈTODE ---------------------------------

$\alpha_{us} := \frac{p \cdot 2 \cdot \pi}{Q} = 2.793$ $\qquad \xi_\omega = 0.945$

$$k_{\delta 1} := \sum_{k=1}^{300} \left[ \frac{\sin\left[(1 + 2 \cdot k m) \cdot \frac{\pi}{2}\right] \cdot \frac{\sin\left[(1 + 2 \cdot k \cdot m) \cdot q \cdot \frac{\alpha_{us}}{2}\right]}{q \sin\left[(1 + 2 \cdot k \cdot m) \cdot \frac{\alpha_{us}}{2}\right]}}{(1 + 2 \cdot k \cdot m) \cdot \xi_\omega} \right]^2 = 0.451$$

$$k_{\delta 2} := \sum_{k=-1}^{-300} \left[ \frac{\sin\left[(1 + 2 \cdot k m) \cdot \frac{\pi}{2}\right] \cdot \frac{\sin\left[(1 + 2 \cdot k \cdot m) \cdot q \cdot \frac{\alpha_{us}}{2}\right]}{q \sin\left[(1 + 2 \cdot k \cdot m) \cdot \frac{\alpha_{us}}{2}\right]}}{(1 + 2 \cdot k \cdot m) \cdot \xi_\omega} \right]^2 = 0.406$$

$\sigma_{\delta s} := k_{\delta 1} + k_{\delta 2} = 0.856$

**aa=1** $\quad L_{\delta s\_aa1} := \sigma_{\delta s} \cdot L_{m\_aa1} = 0.03$ H

**aa=3** $\quad L_{\delta s\_aa3} := \sigma_{\delta s} \cdot L_{m\_aa3} = 3.467 \times 10^{-3}$ H

------------------------------------ 2n MÈTODE ------------------------------------

$h := 3, 6 .. 100$

$h =$

| |
|---|
| 3 |
| ... |

$\xi_h :=$

| |
|---|
| 0.0606617 |
| 0.13985 |
| 0.57735 |
| 0.945214 |
| 0.945214 |
| 0.57735 |
| 0.13985 |
| 0.0606617 |
| 0 |
| 0.0606617 |
| 0.13985 |
| 0.57735 |
| 0.945214 |
| 0.945214 |
| 0.57735 |
| 0.13985 |
| 0.0606617 |
| 0 |
| 0.0606617 |
| 0.13985 |
| 0.57735 |
| 0.945214 |
| 0.945214 |
| 0.57735 |
| 0.13985 |
| 0.0606617 |
| 0 |
| 0.606617 |
| 0.13985 |
| 0.57735 |
| 0.945214 |
| 0.945214 |
| 0.57735 |

$$\Sigma := \sum_h \left(\frac{\xi_h}{h}\right)^2 = 0.019$$

**aa=1** $L_{\delta\_aa1} := L_{m\_aa1} \cdot \left(\frac{1}{{\xi_\omega}^2}\right) \cdot \Sigma = 7.374 \times 10^{-4}$ H

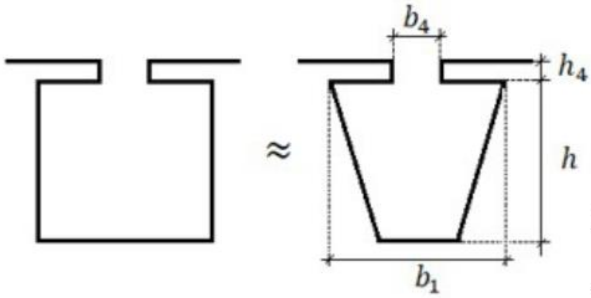
**aa=3** $L_{\delta\_aa3} := L_{m\_aa3} \cdot \left(\frac{1}{{\xi_\omega}^2}\right) \cdot \Sigma = 8.497 \times 10^{-5}$ H

- Inductància de dispersió de ranura ( $L_r$ )

$$n_{aa1} := \frac{2 \cdot m \cdot N_{s\_aa1}}{Q} = 290.667 \qquad n_{aa3} := \frac{2 \cdot m \cdot N_{s\_aa3}}{Q} = 98.667$$

-------------------------------- 1a tipologia de ranura ---------------------------

① Per : $w_d = 0.018$ m




$b_{1\_1} := w_r = 0.011$ m

$b_{4\_1} := 2 \cdot 10^{-3} = 2 \times 10^{-3}$ m

$h_{4\_1} := 1 \cdot 10^{-3} = 1 \times 10^{-3}$ m

$h_{aa1\_1} := \left(h_{ranura\_aa1} - 1\right) \cdot 10^{-3} = 0.025$ m

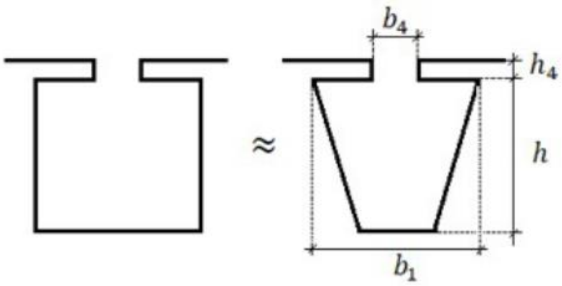
$h_{aa3\_1} := \left(h_{ranura\_aa3} - 1\right) \cdot 10^{-3} = 0.019$ m

**aa=1** $$L_{1r\_aa1} := \mu o \cdot \left(n_{aa1}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(0.6 + \frac{h_{aa1\_1}}{b_{1\_1}} + \frac{h_{4\_1}}{b_{4\_1}}\right) = 0.014 \text{ H}$$

**aa=3** $$L_{1r\_aa3} := \mu o \cdot \left(n_{aa3}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(0.6 + \frac{h_{aa3\_1}}{b_{1\_1}} + \frac{h_{4\_1}}{b_{4\_1}}\right) = 1.369 \times 10^{-3} \text{ H}$$

------------------

② Per : $w_{dn} := 0.0055$ m




$b_{1\_2} := 0.02347$ m

$b_{4\_2} := 2 \cdot 10^{-3} = 2 \times 10^{-3}$ m

$h_{4\_2} := 1 \cdot 10^{-3} = 1 \times 10^{-3}$ m

$h_{aa1\_2} := \left(h_{ranura\_aa1} - 1\right) \cdot 10^{-3} = 0.025$ m

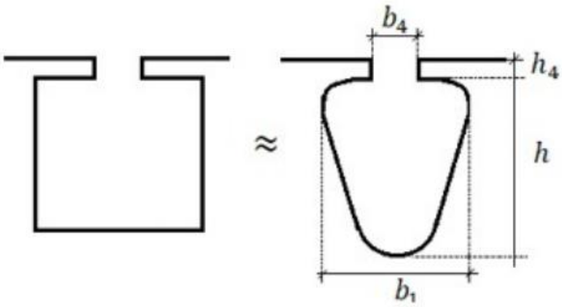
$h_{aa3\_2} := \left(h_{ranura\_aa3} - 1\right) \cdot 10^{-3} = 0.019$ m

**aa=1** $$L_{2r\_aa1} := \mu o \cdot \left(n_{aa1}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(0.6 + \frac{h_{aa1\_2}}{b_{1\_2}} + \frac{h_{4\_2}}{b_{4\_2}}\right) = 9.205 \times 10^{-3} \text{ H}$$

**aa=3** $$L_{2r\_aa3} := \mu o \cdot \left(n_{aa3}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(0.6 + \frac{h_{aa3\_2}}{b_{1\_2}} + \frac{h_{4\_2}}{b_{4\_2}}\right) = 9.294 \times 10^{-4} \text{ H}$$

---------------------------------- 2a tipologia de ranura ----------------------------------

**③** Per: $w_d = 0.018$ m




$b_{1\_3} := w_r = 0.011$ m

$b_{4\_3} := 2 \cdot 10^{-3} = 2 \times 10^{-3}$ m

$h_{4\_3} := 1 \cdot 10^{-3} = 1 \times 10^{-3}$ m

$h_{aa1\_3} := \left(h_{ranura\_aa1} - 1\right) \cdot 10^{-3} = 0.025$ m

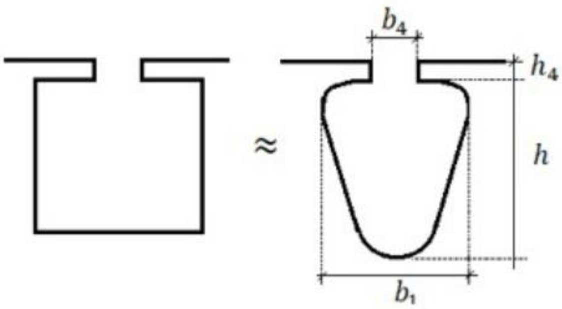
$h_{aa3\_3} := \left(h_{ranura\_aa3} - 1\right) \cdot 10^{-3} = 0.019$ m

**aa=1** $L_{3r\_aa1} := \mu o \cdot \left(n_{aa1}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(0.6 + \frac{h_{aa1\_3}}{b_{1\_3}} + \frac{h_{4\_3}}{b_{4\_3}}\right) = 0.014$ H

**aa=3** $L_{3r\_aa3} := \mu o \cdot \left(n_{aa3}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(0.6 + \frac{h_{aa3\_3}}{b_{1\_3}} + \frac{h_{4\_3}}{b_{4\_3}}\right) = 1.369 \times 10^{-3}$ H

------------------

**④** Per: $w_{dm} := 0.0055$ m




$b_{1\_4} := 0.02347$ m

$b_{4\_4} := 2 \cdot 10^{-3} = 2 \times 10^{-3}$ m

$h_{4\_4} := 1 \cdot 10^{-3} = 1 \times 10^{-3}$ m

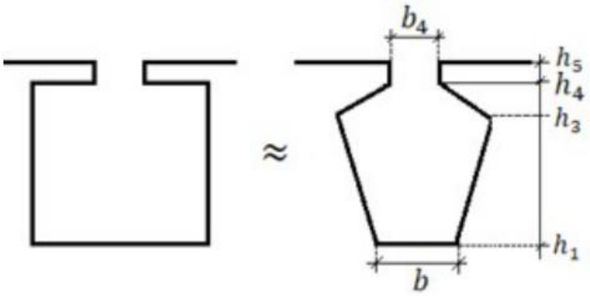
$h_{aa1\_4} := \left(h_{ranura\_aa1} - 1\right) \cdot 10^{-3} = 0.025$ m

$h_{aa3\_4} := \left(h_{ranura\_aa3} - 1\right) \cdot 10^{-3} = 0.019$ m

**aa=1** $L_{4r\_aa1} := \mu o \cdot \left(n_{aa1}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(0.6 + \frac{h_{aa1\_4}}{b_{1\_4}} + \frac{h_{4\_4}}{b_{4\_4}}\right) = 9.205 \times 10^{-3}$ H

**aa=3** $L_{4r\_aa3} := \mu o \cdot \left(n_{aa3}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(0.6 + \frac{h_{aa3\_2}}{b_{1\_2}} + \frac{h_{4\_4}}{b_{4\_4}}\right) = 9.294 \times 10^{-4}$ H

⑤ Per : $w_d = 0.018$ m




$b := 4.3137 \cdot 10^{-?}$ m

$b_{4\_5} := 2 \cdot 10^{-3} = 2 \times 10^{-3}$

$h_{1\_5} := 0$

$h_{2\_5} := 0$

$h_{aa1\_3\_5} := (h_{ranura\_aa1} - 4) \cdot 10^{-3} = 0.022$ m

$h_{aa3\_3\_5} := (h_{ranura\_aa3} - 4) \cdot 10^{-3} = 0.016$ m

$h_{aa1\_4\_5} := (h_{ranura\_aa1} - 1) \cdot 10^{-3} = 0.025$ m

$h_{aa3\_4\_5} := (h_{ranura\_aa3} - 1) \cdot 10^{-3} = 0.019$ m

$h_{aa1\_5\_5} := h_{ranura\_aa1} \cdot 10^{-3} = 0.026$ m

$h_{aa3\_5\_5} := h_{ranura\_aa3} \cdot 10^{-3} = 0.02$ m

$a1 := h_{aa1\_3\_5} = 0.022$ $b1 := h_{aa3\_3\_5} = 0.016$

$a2 := h_{aa1\_4\_5} = 0.025$ $b2 := h_{aa3\_4\_5} = 0.019$

$a3 := h_{aa1\_5\_5} = 0.026$ $b3 := h_{aa3\_5\_5} = 0.02$

**aa=1**

$$L_{5r\_aa1} := \mu o \cdot (n_{aa1})^2 \cdot \frac{Lemp}{1000} \cdot \left( \frac{h_{2\_5} - h_{1\_5}}{3 \cdot b} + \frac{a1 - h_{2\_5}}{b} + \frac{a2 - a1}{b - b_{4\_5}} \cdot \ln\left(\frac{b}{b_{4\_5}}\right) + \frac{a3 - a2}{6} \right)$$

$L_{5r\_aa1} = 0.026$ H

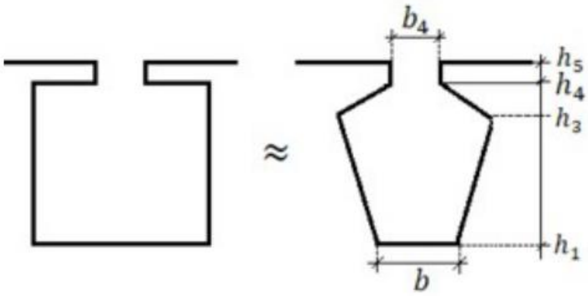
**aa=3**

$$L_{5r\_aa3} := \mu o \cdot (n_{aa3})^2 \cdot \frac{Lemp}{1000} \cdot \left( \frac{h_{2\_5} - h_{1\_5}}{3 \cdot b} + \frac{b1 - h_{2\_5}}{b} + \frac{b2 - b1}{b - b_{4\_5}} \cdot \ln\left(\frac{b}{b_{4\_5}}\right) + \frac{b3 - b2}{6} \right)$$

$L_{5r\_aa3} = 2.275 \times 10^{-3}$ H

---

⑥ Per: $w_{dm} := 0.0055$ m




$b := 9.128 \cdot 10^{-3}$ m

$b_{4\_6} := 2 \cdot 10^{-3} = 2 \times 10^{-3}$

$h_{1\_6} := 0$

$h_{2\_6} := 0$

$h_{aa1\_3\_6} := \left(h_{ranura\_aa1} - 4\right) \cdot 10^{-3} = 0.022$ m

$h_{aa3\_3\_6} := \left(h_{ranura\_aa3} - 4\right) \cdot 10^{-3} = 0.016$ m

$h_{aa1\_4\_6} := \left(h_{ranura\_aa1} - 1\right) \cdot 10^{-3} = 0.025$ m

$h_{aa3\_4\_6} := \left(h_{ranura\_aa3} - 1\right) \cdot 10^{-3} = 0.019$ m

$h_{aa1\_5\_6} := h_{ranura\_aa1} \cdot 10^{-3} = 0.026$ m

$h_{aa3\_5\_6} := h_{ranura\_aa3} \cdot 10^{-3} = 0.02$ m

$c1 := h_{aa1\_3\_6} = 0.022$

$c2 := h_{aa1\_4\_6} = 0.025$

$c3 := h_{aa1\_5\_6} = 0.026$

$d1 := h_{aa3\_3\_6} = 0.016$

$d2 := h_{aa3\_4\_6} = 0.019$

$d3 := h_{aa3\_5\_6} = 0.02$

**aa=1**

$$L_{6r\_aa1} := \mu o \cdot \left(n_{aa1}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(\frac{h_{2\_6} - h_{1\_6}}{3 \cdot b} + \frac{c1 - h_{2\_5}}{b} + \frac{c2 - c1}{b - b_{4\_6}} \cdot \ln\left(\frac{b}{b_{4\_6}}\right) + \frac{c3 - c2}{6}\right)$$

$L_{6r\_aa1} = 0.013$ H

**aa=3**

$$L_{6r\_aa3} := \mu o \cdot \left(n_{aa3}\right)^2 \cdot \frac{Lemp}{1000} \cdot \left(\frac{h_{2\_6} - h_{1\_6}}{3 \cdot b} + \frac{d1 - h_{2\_6}}{b} + \frac{d2 - d1}{b - b_{4\_6}} \cdot \ln\left(\frac{b}{b_{4\_6}}\right) + \frac{d3 - d2}{6}\right)$$

$L_{6r\_aa3} = 1.157 \times 10^{-3}$ H

- Inductància de dispersió de cap de dent ( $L_z$ )

**aa=1** $$L_{z\_aa1} := \mu o \cdot (n_{aa1})^2 \cdot \frac{Lemp}{1000} \cdot \left[ \frac{\left( \frac{t_r}{1000} - b_{4\_1} \right)^2}{8 \cdot g_{eq} \cdot \frac{t_r}{1000}} \right] = 3.692 \times 10^{-3}$$ H

**aa=3** $$L_{z\_aa3} := \mu o \cdot (n_{aa3})^2 \cdot \frac{Lemp}{1000} \cdot \left[ \frac{\left( \frac{t_r}{1000} - b_{4\_1} \right)^2}{8 \cdot g_{eq} \cdot \frac{t_r}{1000}} \right] = 4.254 \times 10^{-4}$$ H

- Inductància de dispersió de cap de bobina ( $L_{cap}$ )

$$l_{av} := 2 \cdot \frac{Lemp}{1000} + 2.3 \cdot \tau_p = 0.155$$

$$l_w := \frac{l_{av} - 2 \cdot \frac{Lemp}{1000}}{2} = 0.037$$

$$l_{ew} := 0.01 \qquad W_{ew} := l_w - 2 \cdot l_{ew} = 0.017$$

Valors tabulats: $\lambda_{lew} := 0.605$ $\quad \lambda_w := 0.028$

$$\lambda_{ws} := \frac{2 \cdot l_{ew} \cdot \lambda_{lew} + W_{ew} \cdot \lambda_w}{l_w} = 0.336$$

**aa=1** $$L_{cap\_aa1} := \mu o \cdot \frac{4 \cdot m \cdot q \cdot N_{s\_aa1}^{\ 2} \cdot l_w \cdot \lambda_{ws}}{Q} = 4.511 \times 10^{-3}$$ H

**aa=3** $$L_{cap\_aa3} := \mu o \cdot \frac{4 \cdot m \cdot q \cdot N_{s\_aa3}^{\ 2} \cdot l_w \cdot \lambda_{ws}}{Q} = 5.198 \times 10^{-4}$$ H

- ***INDUCTÀNCIA TOTAL***

**aa=1**

R1 $L_{total\_aa1R1} := L_{m\_aa1} + L_{\delta\_aa1} + L_{1r\_aa1} + L_{z\_aa1} + L_{cap\_aa1} = 0.05837$ H

R2 $L_{total\_aa1R2} := L_{m\_aa1} + L_{\delta\_aa1} + L_{2r\_aa1} + L_{z\_aa1} + L_{cap\_aa1} = 0.05328$ H

R3 $L_{total\_aa1R3} := L_{m\_aa1} + L_{\delta\_aa1} + L_{3r\_aa1} + L_{z\_aa1} + L_{cap\_aa1} = 0.05837$ H

R4 $L_{total\_aa1R4} := L_{m\_aa1} + L_{\delta\_aa1} + L_{4r\_aa1} + L_{z\_aa1} + L_{cap\_aa1} = 0.05328$ H

R5 $L_{total\_aa1R5} := L_{m\_aa1} + L_{\delta\_aa1} + L_{5r\_aa1} + L_{z\_aa1} + L_{cap\_aa1} = 0.07002$ H

R6 $L_{total\_aa1R6} := L_{m\_aa1} + L_{\delta\_aa1} + L_{6r\_aa1} + L_{z\_aa1} + L_{cap\_aa1} = 0.05705$ H

**aa=3**

R1 $L_{total\_aa3R1} := L_{m\_aa3} + L_{\delta\_aa3} + L_{1r\_aa3} + L_{z\_aa3} + L_{cap\_aa3} = 6.4472 \times 10^{-3}$ H

$$\frac{L_{total\_aa3R1}}{3^3} = 2.388 \times 10^{-4}$$

R2 $L_{total\_aa3R2} := L_{m\_aa3} + L_{\delta\_aa3} + L_{2r\_aa3} + L_{z\_aa3} + L_{cap\_aa3} = 6.00797 \times 10^{-3}$ H

$$\frac{L_{total\_aa3R2}}{3^3} = 2.225 \times 10^{-4}$$

R3 $L_{total\_aa3R3} := L_{m\_aa3} + L_{\delta\_aa3} + L_{3r\_aa3} + L_{z\_aa3} + L_{cap\_aa3} = 6.4472 \times 10^{-3}$ H

$$\frac{L_{total\_aa3R3}}{3^3} = 2.388 \times 10^{-4}$$

R4 $L_{total\_aa3R4} := L_{m\_aa3} + L_{\delta\_aa3} + L_{4r\_aa3} + L_{z\_aa3} + L_{cap\_aa3} = 6.00797 \times 10^{-3}$ H

$$\frac{L_{total\_aa3R4}}{3^3} = 2.225 \times 10^{-4}$$

R5 $L_{total\_aa3R5} := L_{m\_aa3} + L_{\delta\_aa3} + L_{5r\_aa3} + L_{z\_aa3} + L_{cap\_aa3} = 7.35391 \times 10^{-3}$ H

$$\frac{L_{total\_aa3R5}}{3^3} = 2.724 \times 10^{-4}$$

R6 $L_{total\_aa3R6} := L_{m\_aa3} + L_{\delta\_aa3} + L_{6r\_aa3} + L_{z\_aa3} + L_{cap\_aa3} = 6.23611 \times 10^{-3}$ H

$$\frac{L_{total\_aa3R6}}{3^3} = 2.31 \times 10^{-4}$$

# DIMENSIONAMENT TÈRMIC ANALÍTIC

## 1. Especificacions inicials tèrmiques del generador

- **Resistivitat del coure a 20°C:** $\rho_{cu\_20°C} := 0.0171 \ \frac{\Omega \cdot mm^2}{m}$
- **Conductivitat del coure a 20°C:** $\sigma_{cu\_20°C} := 58.5 \ \frac{S\,m}{mm^2}$
- **Coeficicient de resistència tèrmica del coure a 20°C:** $\alpha_{cu\_20°C} := 3.8 \cdot 10^{-3}$

Resistivitat del coure a 100°C: $T := 100 \ °C$

$$\rho_{cu\_100°C} := \rho_{cu\_20°C} \cdot \left[1 + \alpha_{cu\_20°C} \cdot (T - 20)\right] = 0.022 \ \frac{\Omega \cdot mm^2}{m}$$

Conductivitat del coure a 100°C:

$$\sigma_{cu\_100°C} := \frac{1}{\rho_{cu\_100°C}} = 44.846 \ \frac{S\,m}{mm^2}$$

$$\sigma_{Cu\_100°} := \sigma_{cu\_100°C} \cdot 1000^2 = 4.485 \times 10^7 \ \frac{S}{m}$$

**Resistència de fase aa1:**

**aa=1**

$$R_{f\_aa1} := \frac{N_{s\_aa1} \cdot l_{av}}{\sigma_{Cu\_100°} \cdot \pi \cdot \frac{\left(\frac{d_{c\_aa1}}{1000}\right)^2}{4}} = 11.416 \ \Omega$$

Resistència per espira: $R_{espira\_aa1} := \frac{R_{f\_aa1}}{N_{s\_aa1}} = 8.728 \times 10^{-3} \ \Omega$

Resistència FEMM: $R_{FEMM\_aa1} := \frac{R_{espira\_aa1}}{2} = 4.364 \times 10^{-3} \ \Omega$

Conductivitat FEMM:

$$\sigma_{Cu\_FEMM1} := \frac{\frac{Lemp}{1000}}{R_{FEMM\_aa1} \cdot \left[\pi \cdot \frac{\left(\frac{d_{c\_aa1}}{1000}\right)^2}{4}\right]} = 2.315 \times 10^7 \ \frac{S}{m}$$

$$\sigma_{Cu\_femm1} := \frac{\sigma_{Cu\_FEMM1}}{10^6} = 23.152 \ \frac{MS}{m}$$

**Resistència de fase aa3:**

**aa=3** $$R_{f\_aa3} := \frac{N_{s\_aa3} \cdot l_{av}}{\sigma_{Cu\_100°} \cdot \pi \cdot \frac{\left(\frac{d_{c\_aa3}}{1000}\right)^2}{4}} = 1.739 \quad \Omega \qquad R_{f\_real\_aa3} := \frac{R_{f\_aa3}}{3^2} = 0.193$$

Resistència per espira: $$R_{espira\_aa3} := \frac{R_{f\_real\_aa3}}{N_{s\_aa3}} = 4.351 \times 10^{-4} \quad \Omega$$

Resistència FEMM: $$R_{FEMM\_aa3} := \frac{R_{espira\_aa3}}{2} = 2.175 \times 10^{-4} \quad \Omega$$

Conductivitat FEMM: $$\sigma_{Cu\_FEMM3} := \frac{\frac{Lemp}{1000}}{R_{FEMM\_aa3} \cdot \left[\pi \cdot \frac{\left(\frac{d_{c\_aa3}}{1000}\right)^2}{4}\right]} = 2.084 \times 10^8 \quad \frac{S}{m}$$

$$\sigma_{Cu\_femm3} := \frac{\sigma_{Cu\_FEMM3}}{10^6} = 208.364 \quad \frac{MS}{m}$$

2. Determinació de les pèrdues del generados

**aa=1** $$P_{j\_aa1} := 3 \cdot R_{f\_aa1} \cdot I_{n\_aa1}^2 = 67.126 \quad W$$

+

$$P_{fe\_aa1} := \frac{1}{5} \cdot P_{j\_aa1} = 13.425 \quad W$$

-------------------------------

$$P_{totals\_aa1} := P_{j\_aa1} + P_{fe\_aa1} = 80.551 \quad W$$

**aa=3** $$P_{j\_aa3} := 3 \cdot R_{f\_real\_aa3} \cdot I_{n\_aa3}^2 = 7.099 \quad W$$

$$P_{fe\_aa3} := \frac{1}{5} \cdot P_{j\_aa3} = 1.42 \quad W$$

+

-------------------------------

$$P_{totals\_aa3} := P_{j\_aa3} + P_{fe\_aa3} = 8.519 \quad W$$

## 3. Escalfament

Superfície de ventilació aproximada: $Dext := 0.275$

$g_{carcassa} := 0.003$ m

$L_{carcassa} := \frac{Lemp}{1000} + 2 \cdot l_{ew} = 0.06$ m

$D_{ext\_carcassa} := Dext + 2 \cdot g_{carcassa} = 0.281$

$S_{ventilació} := \pi \cdot D_{ext\_carcassa} \cdot L_{carcassa} + 2 \cdot \frac{\pi}{4} \cdot Dext^2 = 0.172$ $m^2$

**aa=1** *VENTILACIÓ NATURAL:*

$\Delta T := 100$ °C

$k_{v1} := 1.32 \cdot \sqrt[4]{\frac{\Delta T}{\phi ext\_est}} = 5.909$ $\frac{W}{m^2 °C}$

$\Delta\Theta_{aa11} := \frac{P_{totals\_aa1}}{k_{v1} \cdot S_{ventilació}} = 79.365$ °C

*VENTILACIÓ FORÇADA:*

$v_{vent} := 12$ $\frac{m}{s}$

$k_{v2} := 3.89 \cdot \sqrt{\frac{v_{vent}}{L_{carcassa}}} = 55.013$ $\frac{W}{m^2 °C}$

$\Delta\Theta_{aa12} := \frac{P_{totals\_aa1}}{k_{v2} \cdot S_{ventilació}} = 8.525$ °C

**aa=3** *VENTILACIÓ NATURAL:*

$\Delta\Theta_{aa31} := \frac{P_{totals\_aa3}}{k_{v1} \cdot S_{ventilació}} = 8.394$ °C

*VENTILACIÓ FORÇADA:*

$\Delta\Theta_{aa32} := \frac{P_{totals\_aa3}}{k_{v2} \cdot S_{ventilació}} = 0.902$ °C

Una vegada dimensionat el generador eòlic és presentarà gràficament el seu comportament.
D'aquesta manera es podrà veure de forma analítica el seu funcionament.
Finalment, es realitzarà la característica de la màquina.

## Característica Potència-Intensitat P(I) aa=1

*Dades principals*

$N := Nn = 100$

$E := E_{aa1} = 90$

$L := L_{total\_aa1R1} = 0.058$

$cofi := 1$

$p := 12 \quad \rightarrow \quad f := p \cdot \frac{N}{60} = 20 \qquad sefi := \sqrt{1 - cofi^2}$

$a := 0$

$X := 2 \cdot \pi \cdot fs \cdot L = 7.335 \qquad R := R_{f\_aa1} = 11.416$

$$I_{max} := \frac{E}{\sqrt{R^2 + X^2}} = 6.633$$

*Voltatge de fase*

$$si(cofi) := \begin{cases} (-1) & \text{if } cofi < 0 \\ 1 & \text{if } cofi > 0 \\ 0 & \text{if } cofi = 1 \end{cases}$$

$$U_f(I, cofi) := root\left[E^2 - \left[(U \cdot |cofi| + R \cdot I)^2 + \left(si(cofi) U \cdot \sqrt{1 - cofi^2} + X \cdot I\right)^2\right], U, 0, 2 \cdot E\right]$$

$I := 0, 0.01 .. I_{max}$

$I_n := I_{n\_aa1} = 1.4$

$cof := 1$

$P(I, cofi) := 3 \cdot U_f(I, cofi) \cdot I \cdot cofi$

$P(I_n, cof) = 308.405$

$U_f(I_n, cof) = 73.43$

$$R_f := \frac{U_f(I_n, cof)}{I_n} = 52.45$$

$$P_{der}(x, cofi) := \frac{d}{dx} P(x, cofi)$$

Given $x := 1$

$cofi := 0.0001, 0.01 .. 1.0$

$$P_{der}(x, cofi) = 0$$

$I_{Pmax}(cofi) := Find(x)$ $\qquad I_{Pmax}(1) = 3.456$

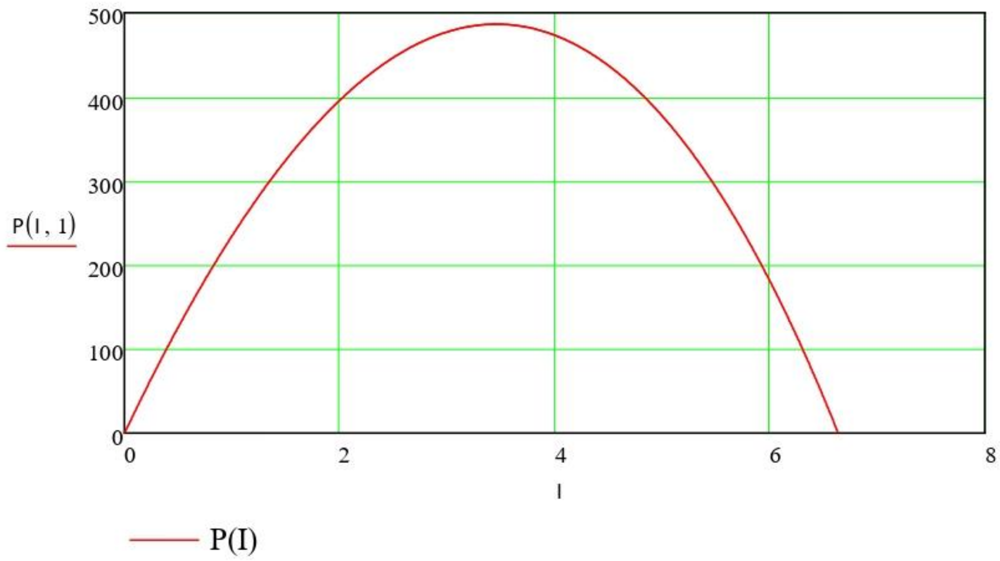
$P_{max}(cofi) := P(I_{Pmax}(cofi), cofi)$ $\qquad P_{max}(1) = 486.284$

$$R_{eq} := \frac{U_f(I_{Pmax}(1), 1)}{I_{Pmax}(1)} = 13.569$$

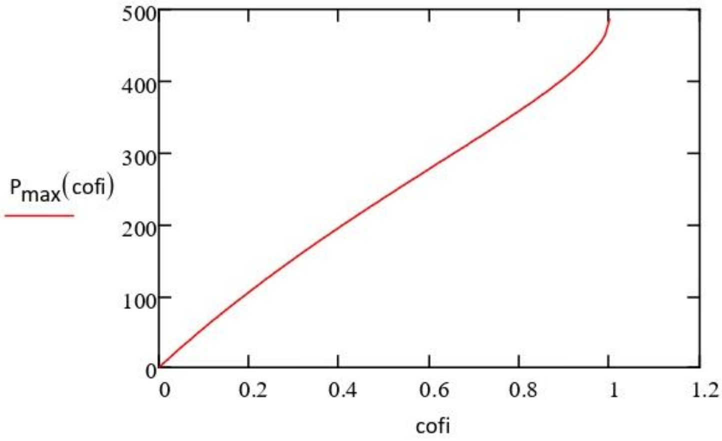
$U_f(I_{Pmax}(1), 1) = 46.899$

$$P_{interna} := P_{max}(1) + 3 \cdot R \cdot I_{Pmax}(1)^2 = 895.394$$

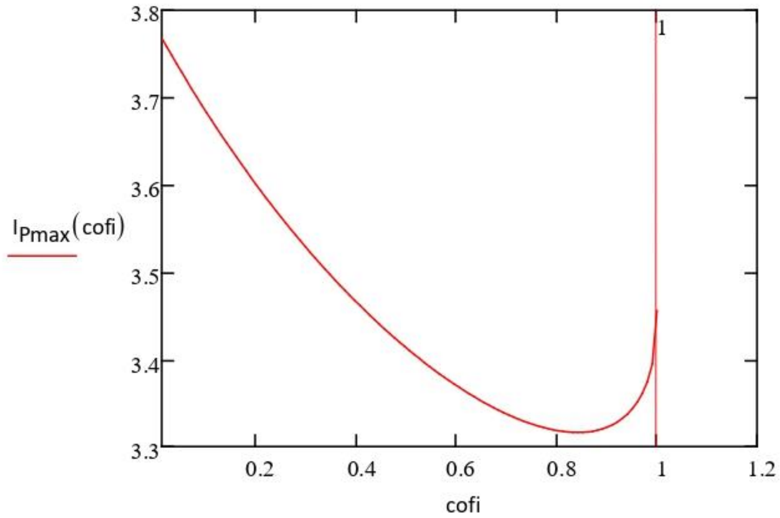
Potència elèctrica en funció de la intensitat



Potència elèctrica en funció del cofi




Intensitat (Pmax) en funció del cofi



## Característica Potència-Intensitat P(I)    aa=3

*Dades principals*

$N := Nn = 100$

$E := E_{aa3} = 30$

$L := \frac{L_{total\_aa3R3}}{3^3} = 2.388 \times 10^{-4}$    H

$cofi := 1$

$p := 12$    $\rightarrow$    $f := p \cdot \frac{N}{60} = 20$    $sefi := \sqrt{1 - cofi^2}$

$a := 0$

$X := 2 \cdot \pi \cdot fs \cdot L = 0.03$    $R := R_{f\_real\_aa3} = 0.193$

$$I_{max} := \frac{E}{\sqrt{R^2 + X^2}} = 153.46$$

*Voltatge de fase*

$$si(cofi) := \begin{cases} (-1) & \text{if } cofi < 0 \\ 1 & \text{if } cofi > 0 \\ 0 & \text{if } cofi = 1 \end{cases}$$

$$U_f(I, cofi) := root\left[E^2 - \left[(U \cdot |cofi| + R \cdot I)^2 + \left(si(cofi) U \cdot \sqrt{1 - cofi^2} + X \cdot I\right)^2\right], U, 0, 2 \cdot E\right]$$

$I := 0, 0.01 .. I_{max}$

$I_n := I_{n\_aa3} = 3.5$

$cof := 1$

$P(I, cofi) := 3 \cdot U_f(I, cofi) \cdot I \cdot cofi$

$P(I_n, cof) = 307.899$

$U_f(I_n, cof) = 29.324$

$$R_f := \frac{U_f(I_n, cof)}{I_n} = 8.378$$

$P_{der}(x, cofi) := \frac{d}{dx} P(x, cofi)$

Given $x := 1$

$cofi := 0.0001, 0.01 .. 1.0$

$P_{der}(x, cofi) = 0$

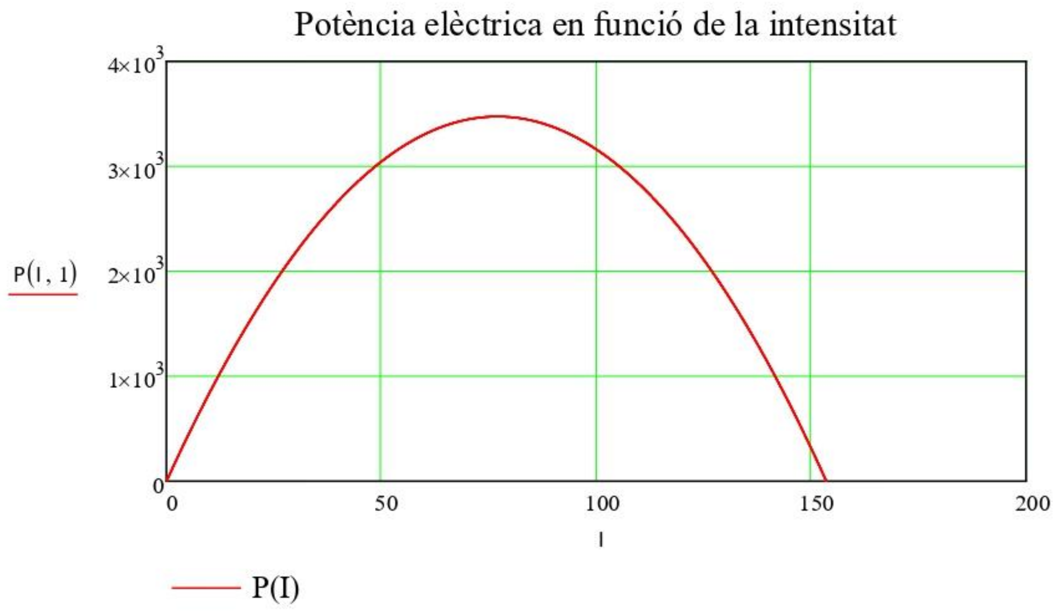
$I_{Pmax}(cofi) := Find(x)$ $I_{Pmax}(1) = 76.958$

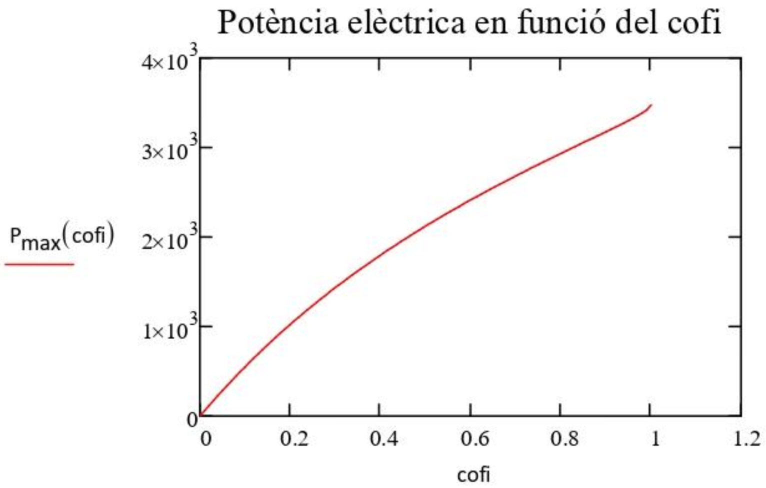
$P_{max}(cofi) := P(I_{Pmax}(cofi), cofi)$ $P_{max}(1) = 3.473 \times 10^3$

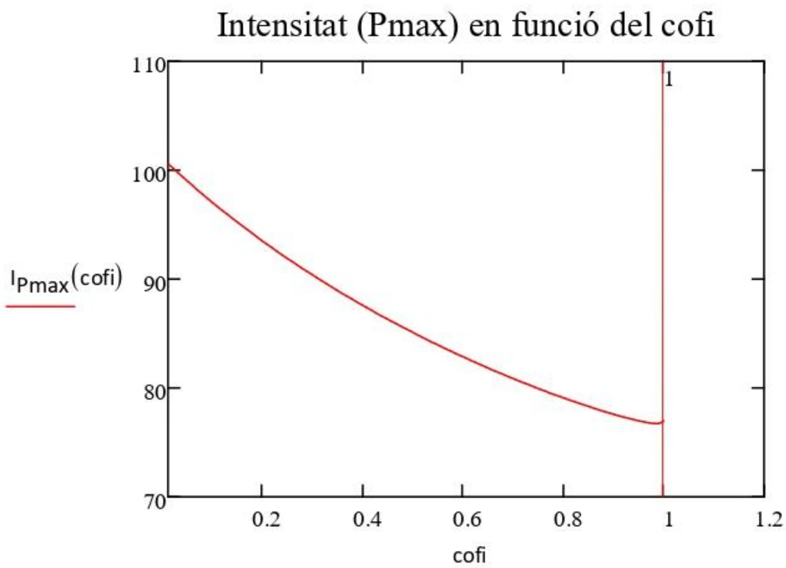
$$R_{eq} := \frac{U_f(I_{Pmax}(1), 1)}{I_{Pmax}(1)} = 0.195$$

$U_f(I_{Pmax}(1), 1) = 15.045$

$P_{interna} := P_{max}(1) + 3 \cdot R \cdot I_{Pmax}(1)^2 = 6.906 \times 10^3$




Potència elèctrica en funció del cofi
$P_{max}(cofi)$
4×10^3
3×10^3
2×10^3
1×10^3
0
0
0.2
0.4
0.6
0.8
1
1.2
cofi


Intensitat (Pmax) en funció del cofi
$I_{Pmax}(cofi)$
110
100
90
80
70
1
0.2
0.4
0.6
0.8
1
1.2
cofi

# Annex IV. Fitxa tècnica de l'imant NdFeB 35H

**ARNOLD**
MAGNETIC TECHNOLOGIES

## N35H

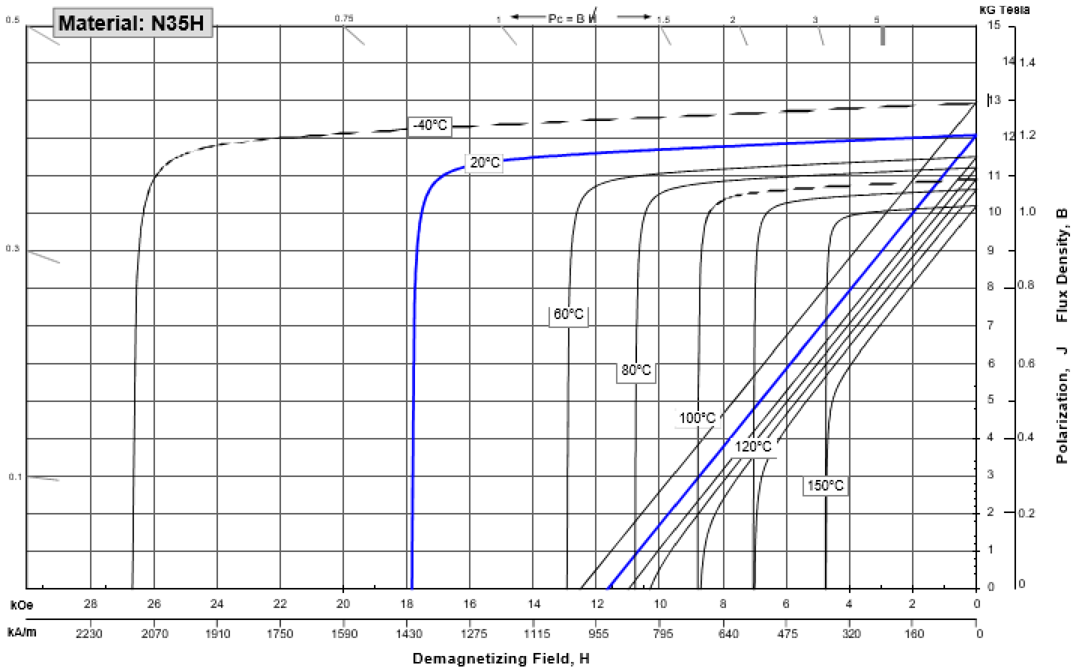
### Sintered Neodymium-Iron-Boron Magnets

These are also referred to as "Neo" or NdFeB magnets. They offer a combination of high magnetic output at moderate cost. Please contact Arnold for additional grade information and recommendations for protective coating. Assemblies using these magnets can also be provided.

| | Characteristic | Units | min. | nominal | max. |
|---|---|---|---|---|---|
| Magnetic Properties | Br, Residual Induction | Gauss | 11,700 | 12,100 | 12,500 |
| | | mT | 1170 | 1210 | 1250 |
| | $H_{cB}$, Coercivity | Oersteds | 10,900 | 11,450 | 12,000 |
| | | kA/m | 868 | 911 | 955 |
| | $H_{cJ}$, Intrinsic Coercivity | Oersteds | 17,000 | | |
| | | kA/m | 1,353 | | |
| | BHmax, Maximum Energy Product | MGOe | 33 | 36 | 38 |
| | | kJ/m³ | 263 | 283 | 302 |

| | Characteristic | Units | C // | C ⊥ |
|---|---|---|---|---|
| Thermal Properties | Reversible Temperature Coefficients [(1)] | | | |
| | of Induction, α(Br) | %/°C | -0.120 | |
| | of Coercivity, α(Hcj) | %/°C | -0.605 | |
| | Coefficient of Thermal Expansion [(2)] | ΔL/L per °Cx10⁻⁶ | 7.5 | -0.1 |
| | Thermal Conductivity | W / (m • K) | 7.6 | |
| | Specific Heat [(3)] | J / (kg • K) | 460 | |
| | Curie Temperature, Tc | °C | 310 | |
| Other Properties | Flexural Strength | psi | 41,300 | |
| | | MPa | 285 | |
| | Density | g/cm³ | 7.5 | |
| | Hardness, Vickers | Hv | 620 | |
| | Electrical Resistivity, ρ | μΩ • cm | 180 | |

Notes: (1) Coefficients measured between 20 and 120 °C
(2) Between 20 and 200 °C
(3) Between 20 and 140 °C




1 kA/m = 12.566 Oe 1 kOe = 79.577 kA/m

**Notes** The material data and demagnetization curves shown above represent typical properties that may vary due to product shape and size.
Magnets can be supplied thermally stabilized or magnetically calibrated to customer specifications.
Additional grades are available. Please contact the factory forinformation.

# Annex V. Pauta de càlcul iterativa. Maple

```
> restart
> restart, with(DynamicSystems) : with(plots, rootlocus) : with(PolynomialTools) : Digits := 10 :
> with(Physics) : with(inttrans) :
> Setup(mathematicalnotation = true) :
```

## # Disseny i dimensionament del generador eòlic (PMSG)_**aa = 1**

# En aquest full de càlcul és realitzarà una pauta d'elecció de la millor configuració del generador. Es posaràn en valor alguns paràmetres constructius i segons la potència final obtinguda i diversos valors tants dimensionals com elèctrics, s'escollirà la millor configuració del generador. En aquest full de càlcul s'aplicarà connexió en sèrie en tots els conductors (aa=1).

#Primerament, s'han exposat totes les fòrmules que el generador ha de complir i s'han anat iterant, per diferents valors de E i In, totes les configuracions possibles. Finalment, s'ha plantejat un petit programa tenint en compte diferents valors d'E i In. Mitjançant la construcció de diferentes gràfiques on s'exposen tant els valors constuctius com elèctrics, s'ha escolit la configuració més adient tenint en compte diverses variables. Principalment, aconseguir una potència que donés suficient energia com per encedre la lluminària fent un ús mínim de l'emmagatzematge, que la FEMM no sigues superior al valor de la velocitat, i escollit un dimensionament de la ranura estórica que fes viable la cabuda dels conductors.

> #Dades

> $\phi := 8.2834\cdot 10^{-4}$ :

> $\xi := 0.945$ :

> $\sigma := 44.86\cdot 10^{6}$ :

> $lav := 0.1549$ :

> $\Delta := 4\cdot 1000^{2}$ :

> $aa := 1$ :

> $hm := 3\cdot 10^{-3}$ :

> $\mu := 4\cdot \pi\cdot 10^{-7}$ :

> $\phi := 8.20057\cdot 10^{-4}$ :

> $m := 3$ :

> $Q := 27$ :

> $q := \frac{Q}{2\cdot p\cdot m}$ :

> $De := 0.249$ :

> $Lmaq := 0.04$ :

> $g := 0.5\cdot 10^{-3}$ :

> $kcs := 1.03165$ :

> $\xi := 0.945$ :

> $h4 := 1.45\cdot 10^{-3}$ :

> $b4 := 2\cdot 10^{-3}$ :

> $td := 28.972\cdot 10^{-3}$ :

> $lw := 0.03748$ :

> $\lambda w := 0.3358$ :

> $Ample := 11.082\cdot 10^{-3}$ :

> #Programa iteratiu per escollir el disseny elèctric i constructiu

> with(plots) :

> $n := 0 : i := 0$ :

> $E := 50 : In := 1$ :

> **for** $E$ **from** 50 **by** 10 **to** 90 **do**

$In := 1$ :

**for** $In$ **from** 1 **by** 0.1 **to** 2 **do**

U := 'U': P := 'P':
Sc := 'Sc': Dc := 'Dc': n_s := 'n_s':
Zt := 'Zt': Zr := 'Zr': Sr := 'Sr': Altura := 'Altura':
L := 'L': Lm := 'Lm': Lr := 'Lr': Lz := 'Lz': Lc := 'Lc': Ldif := 'Ldif': Ldisp := 'Ldisp':

$n\_s := \text{round}\left(\frac{E\cdot\sqrt{2}}{2\cdot\pi\cdot f\cdot p\cdot\phi\cdot\xi}\right) : Sc := \frac{In}{aa\cdot\Delta} : Dc := evalf\left(2\cdot\sqrt{\frac{Sc}{\pi}}\right)$ :

$ns[i] := n\_s$ :

**if** 0.00090 < *Dc* ≤ 0.00095 **then**
*Dc* := 0.00095 :
**elif** 0.00085 < *Dc* ≤ 0.00090 **then**
*Dc* := 0.00090 :
**elif** 0.00080 < *Dc* ≤ 0.00085 **then**
*Dc* := 0.00085 :
**elif** 0.00075 < *Dc* ≤ 0.00080 **then**
*Dc* := 0.00080 :
**elif** 0.00071 < *Dc* ≤ 0.00075 **then**
*Dc* := 0.00075 :
**elif** 0.00063 < *Dc* ≤ 0.00071 **then**
*Dc* := 0.00071 :
**else**
*Dc* := 0.00063 :
**end if**:

$$Sc := \frac{\pi \cdot aa \cdot Dc^2}{4} : R := \frac{n\_s \cdot p \cdot lav}{\sigma \cdot Sc} :$$

*Res*[*i*] := *R* :
*Dcond*[*i*] := *Dc* :

$$Lm := \frac{\mu}{\pi} \cdot m \cdot \frac{De \cdot Lmaq}{kcs \cdot (g + hm)} \cdot \left( \frac{n\_s \cdot p \cdot \xi}{p} \right)^2 : L\_m[i] := Lm :$$

$$Zt := n\_s \cdot p \cdot m \cdot 2 : Zr := \frac{Zt}{Q} : Sr := \frac{aa \cdot Zr \cdot \pi \cdot \left( \frac{Dc^2}{4} \right)}{FO} : Altura := \frac{Sr}{Ample} : Lr := \mu \cdot \left( \frac{2 \cdot m \cdot n\_s \cdot p}{Q} \right)^2 \cdot Lmaq \cdot \left( 0.6 + \frac{Altura - 0.001}{Ample} + \frac{h4}{b4} \right) :$$

*Z_r*[*i*] := round(*Zr*) : *hr*[*i*] := *Altura* : *L_r*[*i*] := *Lr* :

*Z_r*[*i*] := round(*Zr*) : *hr*[*i*] := *Altura* : *L_r*[*i*] := *Lr* :

$$Lz := \mu \cdot Lmaq \cdot \left( \frac{2 \cdot m \cdot n\_s \cdot p}{Q} \right)^2 \cdot \frac{(td - b4)^2}{8 \cdot kcs \cdot (g + hm) \cdot td} : Lc := \mu \cdot \frac{4 \cdot m \cdot q \cdot (n\_s \cdot p)^2 \cdot lw \cdot \lambda w}{Q} : Ldif := Lm \cdot \frac{1}{\xi^2} \cdot 0.019 :$$

*L_z*[*i*] := *Lz* : *L_c*[*i*] := *Lc* : *L_dif*[*i*] := *Ldif*:

*Ldisp* := *Lr* + *Lz* + *Lc* + *Ldif*: *Ltotal* := *Ldisp* + *Lm* :

*L_disp*[*i*] := *Ldisp* : *Ltot*[*i*] := *Ltotal* :

$$EQ0 := E = \sqrt{(U \cdot \cos(\varphi) + R \cdot In)^2 + (U \cdot \sin(\varphi) + 40 \cdot \pi \cdot Ltotal \cdot In)^2} :$$
$$EQ1 := P = 3 \cdot U \cdot In \cdot \cos(\varphi) :$$

*U* := *fsolve*(*EQ0*, *U*) : *Uf*[*i*] := *U*:
*P* := *solve*(*EQ1*, *P*) : *Pot*[*i*] := *P* :
*Inom*[*i*] := *In* :

*i* := *i* + 1 :

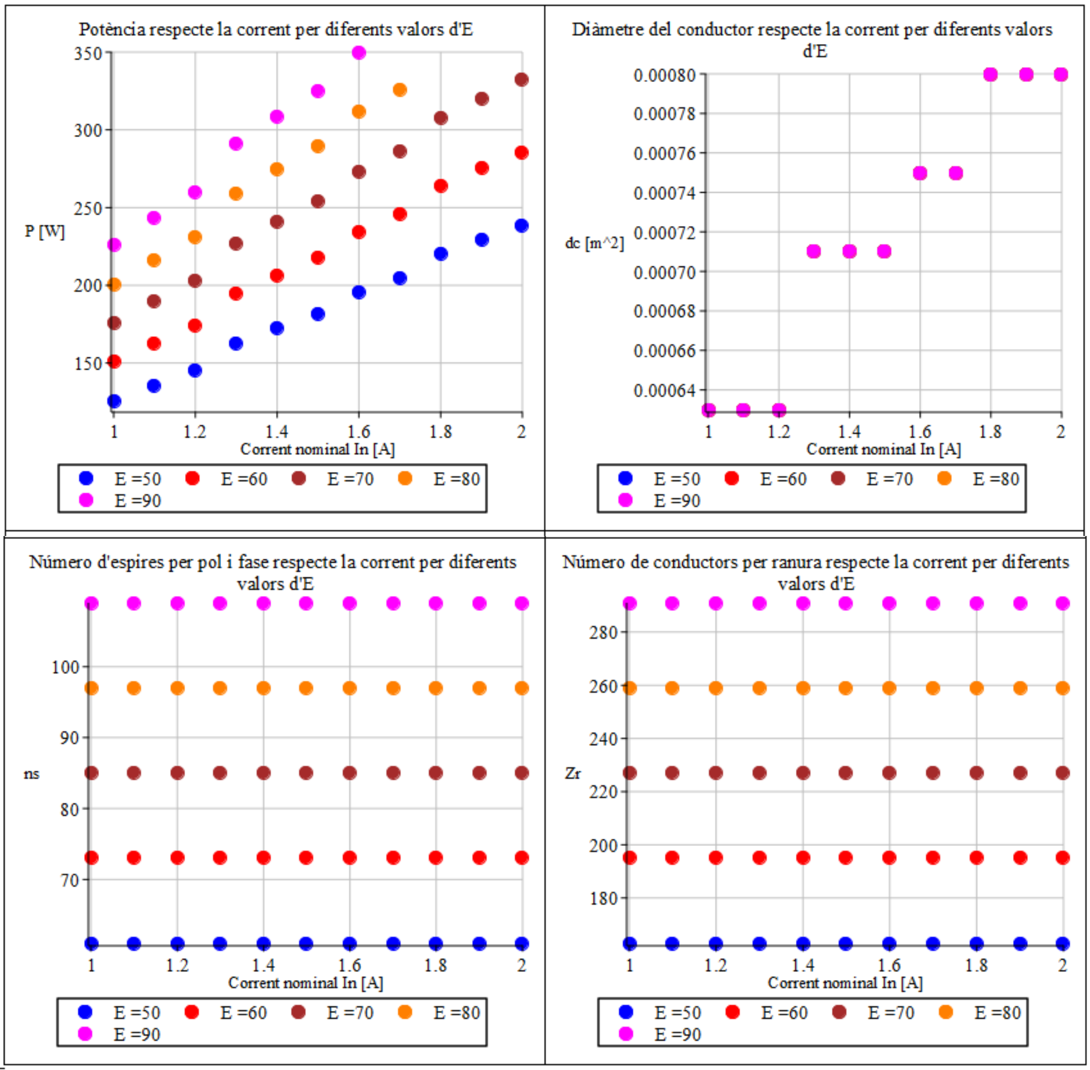
**end do**:

**if** *n* = 0 **then**
*g0*[*n*] := *pointplot*([[*Inom*[0], *Pot*[0]], [*Inom*[1], *Pot*[1]], [*Inom*[2], *Pot*[2]], [*Inom*[3], *Pot*[3]], [*Inom*[4], *Pot*[4]], [*Inom*[5], *Pot*[5]], [*Inom*[6], *Pot*[6]], [*Inom*[7], *Pot*[7]], [*Inom*[8], *Pot*[8]], [*Inom*[9], *Pot*[9]], [*Inom*[10], *Pot*[10]]], *color* = *blue*, *symbol* = *solidcircle*, *symbolsize* = 20, *legend* = "E =50") :
*g1*[*n*] := *pointplot*([[*Inom*[0], *Dcond*[0]], [*Inom*[1], *Dcond*[1]], [*Inom*[2], *Dcond*[2]], [*Inom*[3], *Dcond*[3]], [*Inom*[4], *Dcond*[4]], [*Inom*[5], *Dcond*[5]], [*Inom*[6], *Dcond*[6]], [*Inom*[7], *Dcond*[7]], [*Inom*[8], *Dcond*[8]], [*Inom*[9], *Dcond*[9]], [*Inom*[10], *Dcond*[10]]], *color* = *blue*, *symbol* = *solidcircle*, *symbolsize* = 20, *legend* = "E =50") :
*g2*[*n*] := *pointplot*([[*Inom*[0], *ns*[0]], [*Inom*[1], *ns*[1]], [*Inom*[2], *ns*[2]], [*Inom*[3], *ns*[3]], [*Inom*[4], *ns*[4]], [*Inom*[5], *ns*[5]], [*Inom*[6], *ns*[6]], [*Inom*[7], *ns*[7]], [*Inom*[8], *ns*[8]], [*Inom*[9], *ns*[9]], [*Inom*[10], *ns*[10]]], *color* = *blue*, *symbol* = *solidcircle*, *symbolsize* = 20, *legend* = "E =50") :
*g3*[*n*] := *pointplot*([[*Inom*[0], *Z_r*[0]], [*Inom*[1], *Z_r*[1]], [*Inom*[2], *Z_r*[2]], [*Inom*[3], *Z_r*[3]], [*Inom*[4], *Z_r*[4]], [*Inom*[5], *Z_r*[5]], [*Inom*[6], *Z_r*[6]], [*Inom*[7], *Z_r*[7]], [*Inom*[8], *Z_r*[8]], [*Inom*[9], *Z_r*[9]], [*Inom*[10], *Z_r*[10]]], *color* = *blue*, *symbol* = *solidcircle*, *symbolsize* = 20, *legend* = "E =50") :
*g4*[*n*] := *pointplot*([[*Inom*[0], *hr*[0]], [*Inom*[1], *hr*[1]], [*Inom*[2], *hr*[2]], [*Inom*[3], *hr*[3]], [*Inom*[4], *hr*[4]], [*Inom*[5], *hr*[5]], [*Inom*[6], *hr*[6]], [*Inom*[7], *hr*[7]], [*Inom*[8], *hr*[8]], [*Inom*[9], *hr*[9]], [*Inom*[10], *hr*[10]]], *color* = *blue*, *symbol* = *solidcircle*, *symbolsize* = 20, *legend* = "E =50") :
*g5*[*n*] := *pointplot*([[*Inom*[0], *Ltot*[0]], [*Inom*[1], *Ltot*[1]], [*Inom*[2], *Ltot*[2]], [*Inom*[3], *Ltot*[3]], [*Inom*[4], *Ltot*[4]], [*Inom*[5], *Ltot*[5]], [*Inom*[6], *Ltot*[6]], [*Inom*[7], *Ltot*[7]], [*Inom*[8], *Ltot*[8]], [*Inom*[9], *Ltot*[9]], [*Inom*[10], *Ltot*[10]]], *color* = *blue*, *symbol* = *solidcircle*, *symbolsize* = 20, *legend* = "E =50") :

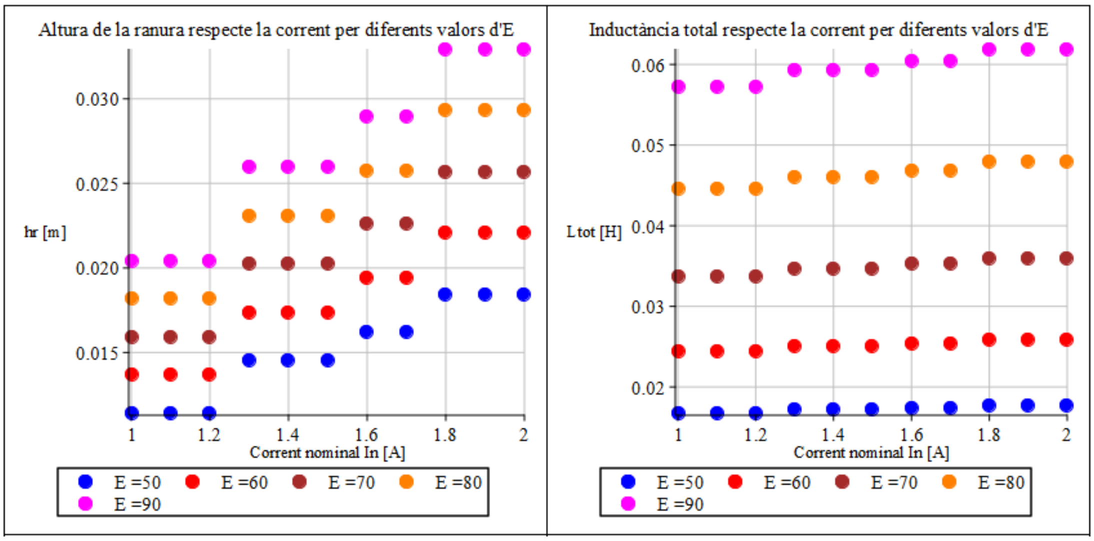
```
elif n = 1 then
g0[n] := pointplot([[Inom[11], Pot[11]], [Inom[12], Pot[12]], [Inom[13], Pot[13]], [Inom[14], Pot[14]], [Inom[15], Pot[15]],
  [Inom[16], Pot[16]], [Inom[17], Pot[17]], [Inom[18], Pot[18]], [Inom[19], Pot[19]], [Inom[20], Pot[20]], [Inom[21], Pot[21]]],
  color = red, symbol = solidcircle, symbolsize = 20, legend = "E =60") :
g1[n] := pointplot([[Inom[11], Dcond[11]], [Inom[12], Dcond[12]], [Inom[13], Dcond[13]], [Inom[14], Dcond[14]], [Inom[15],
  Dcond[15]], [Inom[16], Dcond[16]], [Inom[17], Dcond[17]], [Inom[18], Dcond[18]], [Inom[19], Dcond[19]], [Inom[20],
  Dcond[20]], [Inom[21], Dcond[21]]], color = red, symbol = solidcircle, symbolsize = 20, legend = "E =60") :
g2[n] := pointplot([[Inom[11], ns[11]], [Inom[12], ns[12]], [Inom[13], ns[13]], [Inom[14], ns[14]], [Inom[15], ns[15]], [Inom[16],
  ns[16]], [Inom[17], ns[17]], [Inom[18], ns[18]], [Inom[19], ns[19]], [Inom[20], ns[20]], [Inom[21], ns[21]]], color = red, symbol
  = solidcircle, symbolsize = 20, legend = "E =60") :
g3[n] := pointplot([[Inom[11], Z_r[11]], [Inom[12], Z_r[12]], [Inom[13], Z_r[13]], [Inom[14], Z_r[14]], [Inom[15], Z_r[15]],
  [Inom[16], Z_r[16]], [Inom[17], Z_r[17]], [Inom[18], Z_r[18]], [Inom[19], Z_r[19]], [Inom[20], Z_r[20]], [Inom[21], Z_r[21]]],
  color = red, symbol = solidcircle, symbolsize = 20, legend = "E =60") :
g4[n] := pointplot([[Inom[11], hr[11]], [Inom[12], hr[12]], [Inom[13], hr[13]], [Inom[14], hr[14]], [Inom[15], hr[15]], [Inom[16],
  hr[16]], [Inom[17], hr[17]], [Inom[18], hr[18]], [Inom[19], hr[19]], [Inom[20], hr[20]], [Inom[21], hr[21]]], color = red, symbol
  = solidcircle, symbolsize = 20, legend = "E =60") :
g5[n] := pointplot([[Inom[11], Ltot[11]], [Inom[12], Ltot[12]], [Inom[13], Ltot[13]], [Inom[14], Ltot[14]], [Inom[15], Ltot[15]],
  [Inom[16], Ltot[16]], [Inom[17], Ltot[17]], [Inom[18], Ltot[18]], [Inom[19], Ltot[19]], [Inom[20], Ltot[20]], [Inom[21],
  Ltot[21]]], color = red, symbol = solidcircle, symbolsize = 20, legend = "E =60") :

elif n = 2 then
g0[n] := pointplot([[Inom[22], Pot[22]], [Inom[23], Pot[23]], [Inom[24], Pot[24]], [Inom[25], Pot[25]], [Inom[26], Pot[26]],
  [Inom[27], Pot[27]], [Inom[28], Pot[28]], [Inom[29], Pot[29]], [Inom[30], Pot[30]], [Inom[31], Pot[31]], [Inom[32], Pot[32]]],
  color = brown, symbol = solidcircle, symbolsize = 20, legend = "E =70") :
g1[n] := pointplot([[Inom[22], Dcond[22]], [Inom[23], Dcond[23]], [Inom[24], Dcond[24]], [Inom[25], Dcond[25]], [Inom[26],
  Dcond[26]], [Inom[27], Dcond[27]], [Inom[28], Dcond[28]], [Inom[29], Dcond[29]], [Inom[30], Dcond[30]], [Inom[31],
  Dcond[31]], [Inom[32], Dcond[32]]], color = brown, symbol = solidcircle, symbolsize = 20, legend = "E =70") :
g2[n] := pointplot([[Inom[22], ns[22]], [Inom[23], ns[23]], [Inom[24], ns[24]], [Inom[25], ns[25]], [Inom[26], ns[26]], [Inom[27],
  ns[27]], [Inom[28], ns[28]], [Inom[29], ns[29]], [Inom[30], ns[30]], [Inom[31], ns[31]], [Inom[32], ns[32]]], color = brown,
  symbol = solidcircle, symbolsize = 20, legend = "E =70") :
g3[n] := pointplot([[Inom[22], Z_r[22]], [Inom[23], Z_r[23]], [Inom[24], Z_r[24]], [Inom[25], Z_r[25]], [Inom[26], Z_r[26]],
  [Inom[27], Z_r[27]], [Inom[28], Z_r[28]], [Inom[29], Z_r[29]], [Inom[30], Z_r[30]], [Inom[31], Z_r[31]], [Inom[32], Z_r[32]]],
  color = brown, symbol = solidcircle, symbolsize = 20, legend = "E =70") :
g4[n] := pointplot([[Inom[22], hr[22]], [Inom[23], hr[23]], [Inom[24], hr[24]], [Inom[25], hr[25]], [Inom[26], hr[26]], [Inom[27],
  hr[27]], [Inom[28], hr[28]], [Inom[29], hr[29]], [Inom[30], hr[30]], [Inom[31], hr[31]], [Inom[32], hr[32]]], color = brown,
  symbol = solidcircle, symbolsize = 20, legend = "E =70") :
g5[n] := pointplot([[Inom[22], Ltot[22]], [Inom[23], Ltot[23]], [Inom[24], Ltot[24]], [Inom[25], Ltot[25]], [Inom[26], Ltot[26]],
  [Inom[27], Ltot[27]], [Inom[28], Ltot[28]], [Inom[29], Ltot[29]], [Inom[30], Ltot[30]], [Inom[31], Ltot[31]], [Inom[32], Ltot[32]]]
  , color = brown, symbol = solidcircle, symbolsize = 20, legend = "E =70") :

elif n = 3 then
g0[n] := pointplot([[Inom[33], Pot[33]], [Inom[34], Pot[34]], [Inom[35], Pot[35]], [Inom[36], Pot[36]], [Inom[37], Pot[37]],
  [Inom[38], Pot[38]], [Inom[39], Pot[39]], [Inom[40], Pot[40]], [Inom[41], Pot[41]], [Inom[42], Pot[42]], [Inom[43], Pot[43]]],
  color = coral, symbol = solidcircle, symbolsize = 20, legend = "E =80") :
g1[n] := pointplot([[Inom[33], Dcond[33]], [Inom[34], Dcond[34]], [Inom[35], Dcond[35]], [Inom[36], Dcond[36]], [Inom[37],
  Dcond[37]], [Inom[38], Dcond[38]], [Inom[39], Dcond[39]], [Inom[40], Dcond[40]], [Inom[41], Dcond[41]], [Inom[42],
  Dcond[42]], [Inom[43], Dcond[43]]], color = coral, symbol = solidcircle, symbolsize = 20, legend = "E =80") :
g2[n] := pointplot([[Inom[33], ns[33]], [Inom[34], ns[34]], [Inom[35], ns[35]], [Inom[36], ns[36]], [Inom[37], ns[37]], [Inom[38],
  ns[38]], [Inom[39], ns[39]], [Inom[40], ns[40]], [Inom[41], ns[41]], [Inom[42], ns[42]], [Inom[43], ns[43]]], color = coral, symbol
  = solidcircle, symbolsize = 20, legend = "E =80") :
g3[n] := pointplot([[Inom[33], Z_r[33]], [Inom[34], Z_r[34]], [Inom[35], Z_r[35]], [Inom[36], Z_r[36]], [Inom[37], Z_r[37]],
  [Inom[38], Z_r[38]], [Inom[39], Z_r[39]], [Inom[40], Z_r[40]], [Inom[41], Z_r[41]], [Inom[42], Z_r[42]], [Inom[43], Z_r[43]]],
  color = coral, symbol = solidcircle, symbolsize = 20, legend = "E =80") :
g4[n] := pointplot([[Inom[33], hr[33]], [Inom[34], hr[34]], [Inom[35], hr[35]], [Inom[36], hr[36]], [Inom[37], hr[37]], [Inom[38],
  hr[38]], [Inom[39], hr[39]], [Inom[40], hr[40]], [Inom[41], hr[41]], [Inom[42], hr[42]], [Inom[43], hr[43]]], color = coral, symbol
  = solidcircle, symbolsize = 20, legend = "E =80") :
g5[n] := pointplot([[Inom[33], Ltot[33]], [Inom[34], Ltot[34]], [Inom[35], Ltot[35]], [Inom[36], Ltot[36]], [Inom[37], Ltot[37]],
  [Inom[38], Ltot[38]], [Inom[39], Ltot[39]], [Inom[40], Ltot[40]], [Inom[41], Ltot[41]], [Inom[42], Ltot[42]], [Inom[43],
  Ltot[43]]], color = coral, symbol = solidcircle, symbolsize = 20, legend = "E =80") :

elif n = 4 then
g0[n] := pointplot([[Inom[44], Pot[44]], [Inom[45], Pot[45]], [Inom[46], Pot[46]], [Inom[47], Pot[47]], [Inom[48], Pot[48]],
  [Inom[49], Pot[49]], [Inom[50], Pot[50]], [Inom[51], Pot[51]], [Inom[52], Pot[52]], [Inom[53], Pot[53]], [Inom[54], Pot[54]]],
  color = magenta, symbol = solidcircle, symbolsize = 20, legend = "E =90") :
g1[n] := pointplot([[Inom[44], Dcond[44]], [Inom[45], Dcond[45]], [Inom[46], Dcond[46]], [Inom[47], Dcond[47]], [Inom[48],
  Dcond[48]], [Inom[49], Dcond[49]], [Inom[50], Dcond[50]], [Inom[51], Dcond[51]], [Inom[52], Dcond[52]], [Inom[53],
  Dcond[53]], [Inom[54], Dcond[54]]], color = magenta, symbol = solidcircle, symbolsize = 20, legend = "E =90") :
g2[n] := pointplot([[Inom[44], ns[44]], [Inom[45], ns[45]], [Inom[46], ns[46]], [Inom[47], ns[47]], [Inom[48], ns[48]], [Inom[49],
  ns[49]], [Inom[50], ns[50]], [Inom[51], ns[51]], [Inom[52], ns[52]], [Inom[53], ns[53]], [Inom[54], ns[54]]], color = magenta,
  symbol = solidcircle, symbolsize = 20, legend = "E =90") :
g3[n] := pointplot([[Inom[44], Z_r[44]], [Inom[45], Z_r[45]], [Inom[46], Z_r[46]], [Inom[47], Z_r[47]], [Inom[48], Z_r[48]],
  [Inom[49], Z_r[49]], [Inom[50], Z_r[50]], [Inom[51], Z_r[51]], [Inom[52], Z_r[52]], [Inom[53], Z_r[53]], [Inom[54], Z_r[54]]],
  color = magenta, symbol = solidcircle, symbolsize = 20, legend = "E =90") :
g4[n] := pointplot([[Inom[44], hr[44]], [Inom[45], hr[45]], [Inom[46], hr[46]], [Inom[47], hr[47]], [Inom[48], hr[48]], [Inom[49],
  hr[49]], [Inom[50], hr[50]], [Inom[51], hr[51]], [Inom[52], hr[52]], [Inom[53], hr[53]], [Inom[54], hr[54]]], color = magenta,
  symbol = solidcircle, symbolsize = 20, legend = "E =90") :
g5[n] := pointplot([[Inom[44], Ltot[44]], [Inom[45], Ltot[45]], [Inom[46], Ltot[46]], [Inom[47], Ltot[47]], [Inom[48], Ltot[48]],
  [Inom[49], Ltot[49]], [Inom[50], Ltot[50]], [Inom[51], Ltot[51]], [Inom[52], Ltot[52]], [Inom[53], Ltot[53]], [Inom[54],
  Ltot[54]]], color = magenta, symbol = solidcircle, symbolsize = 20, legend = "E =90")
```

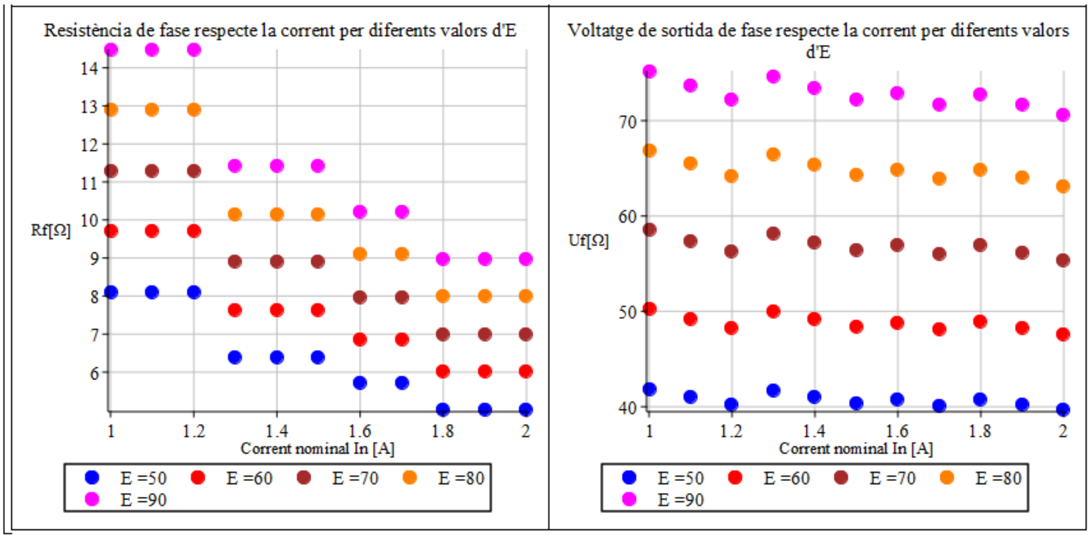
```
end if:

if n = 0 then
g6[n] := pointplot([[Inom[0], Res[0]], [Inom[1], Res[1]], [Inom[2], Res[2]], [Inom[3], Res[3]], [Inom[4], Res[4]], [Inom[5],
   Res[5]], [Inom[6], Res[6]], [Inom[7], Res[7]], [Inom[8], Res[8]], [Inom[9], Res[9]], [Inom[10], Res[10]]], color = blue, symbol
   = solidcircle, symbolsize = 20, legend = "E =50") :
g7[n] := pointplot([[Inom[0], Uf[0]], [Inom[1], Uf[1]], [Inom[2], Uf[2]], [Inom[3], Uf[3]], [Inom[4], Uf[4]], [Inom[5], Uf[5]],
   [Inom[6], Uf[6]], [Inom[7], Uf[7]], [Inom[8], Uf[8]], [Inom[9], Uf[9]], [Inom[10], Uf[10]]], color = blue, symbol = solidcircle,
   symbolsize = 20, legend = "E =50") :

elif n = 1 then
g6[n] := pointplot([[Inom[11], Res[11]], [Inom[12], Res[12]], [Inom[13], Res[13]], [Inom[14], Res[14]], [Inom[15], Res[15]],
   [Inom[16], Res[16]], [Inom[17], Res[17]], [Inom[18], Res[18]], [Inom[19], Res[19]], [Inom[20], Res[20]], [Inom[21], Res[21]]],
   color = red, symbol = solidcircle, symbolsize = 20, legend = "E =60") :
g7[n] := pointplot([[Inom[11], Uf[11]], [Inom[12], Uf[12]], [Inom[13], Uf[13]], [Inom[14], Uf[14]], [Inom[15], Uf[15]],
   [Inom[16], Uf[16]], [Inom[17], Uf[17]], [Inom[18], Uf[18]], [Inom[19], Uf[19]], [Inom[20], Uf[20]], [Inom[21], Uf[21]]], color
   = red, symbol = solidcircle, symbolsize = 20, legend = "E =60") :

elif n = 2 then
g6[n] := pointplot([[Inom[22], Res[22]], [Inom[23], Res[23]], [Inom[24], Res[24]], [Inom[25], Res[25]], [Inom[26], Res[26]],
   [Inom[27], Res[27]], [Inom[28], Res[28]], [Inom[29], Res[29]], [Inom[30], Res[30]], [Inom[31], Res[31]], [Inom[32], Res[32]]],
   color = brown, symbol = solidcircle, symbolsize = 20, legend = "E =70") :
g7[n] := pointplot([[Inom[22], Uf[22]], [Inom[23], Uf[23]], [Inom[24], Uf[24]], [Inom[25], Uf[25]], [Inom[26], Uf[26]],
   [Inom[27], Uf[27]], [Inom[28], Uf[28]], [Inom[29], Uf[29]], [Inom[30], Uf[30]], [Inom[31], Uf[31]], [Inom[32], Uf[32]]], color
   = brown, symbol = solidcircle, symbolsize = 20, legend = "E =70") :

elif n = 3 then
g6[n] := pointplot([[Inom[33], Res[33]], [Inom[34], Res[34]], [Inom[35], Res[35]], [Inom[36], Res[36]], [Inom[37], Res[37]],
   [Inom[38], Res[38]], [Inom[39], Res[39]], [Inom[40], Res[40]], [Inom[41], Res[41]], [Inom[42], Res[42]], [Inom[43], Res[43]]],
   color = coral, symbol = solidcircle, symbolsize = 20, legend = "E =80") :
g7[n] := pointplot([[Inom[33], Uf[33]], [Inom[34], Uf[34]], [Inom[35], Uf[35]], [Inom[36], Uf[36]], [Inom[37], Uf[37]],
   [Inom[38], Uf[38]], [Inom[39], Uf[39]], [Inom[40], Uf[40]], [Inom[41], Uf[41]], [Inom[42], Uf[42]], [Inom[43], Uf[43]]], color
   = coral, symbol = solidcircle, symbolsize = 20, legend = "E =80") :

elif n = 4 then
g6[n] := pointplot([[Inom[44], Res[44]], [Inom[45], Res[45]], [Inom[46], Res[46]], [Inom[47], Res[47]], [Inom[48], Res[48]],
   [Inom[49], Res[49]], [Inom[50], Res[50]], [Inom[51], Res[51]], [Inom[52], Res[52]], [Inom[53], Res[53]], [Inom[54], Res[54]]],
   color = magenta, symbol = solidcircle, symbolsize = 20, legend = "E =90") :
g7[n] := pointplot([[Inom[44], Uf[44]], [Inom[45], Uf[45]], [Inom[46], Uf[46]], [Inom[47], Uf[47]], [Inom[48], Uf[48]],
   [Inom[49], Uf[49]], [Inom[50], Uf[50]], [Inom[51], Uf[51]], [Inom[52], Uf[52]], [Inom[53], Uf[53]], [Inom[54], Uf[54]]], color
   = magenta, symbol = solidcircle, symbolsize = 20, legend = "E =90") :

end if:

n := n + 1 :

end do:

> G0 := plots[display](g0[0], g0[1], g0[2], g0[3], g0[4], axis = [gridlines = [colour = grey, majorlines = 1]], labels
   = ["Corrent nominal In [A]", "P [W]"], title = "Potència respecte la corrent per diferents valors d'E", view = [1 ..2, 120 ..350]) :
> G1 := plots[display](g1[0], g1[1], g1[2], g1[3], g1[4], axis = [gridlines = [colour = grey, majorlines = 1]], labels
   = ["Corrent nominal In [A]", "dc [m^2]"], title = "Diàmetre del conductor respecte la corrent per diferents valors d'E") :
> G2 := plots[display](g2[0], g2[1], g2[2], g2[3], g2[4], axis = [gridlines = [colour = grey, majorlines = 1]], labels
   = ["Corrent nominal In [A]", "ns "], title = "Número d'espires per pol i fase respecte la corrent per diferents valors d'E") :
> G3 := plots[display](g3[0], g3[1], g3[2], g3[3], g3[4], axis = [gridlines = [colour = grey, majorlines = 1]], labels
   = ["Corrent nominal In [A]", "Zr"], title = "Número de conductors per ranura respecte la corrent per diferents valors d'E") :
> G4 := plots[display](g4[0], g4[1], g4[2], g4[3], g4[4], axis = [gridlines = [colour = grey, majorlines = 1]], labels
   = ["Corrent nominal In [A]", "hr [m]"], title = "Altura de la ranura respecte la corrent per diferents valors d'E") :
> G5 := plots[display](g5[0], g5[1], g5[2], g5[3], g5[4], axis = [gridlines = [colour = grey, majorlines = 1]], labels
   = ["Corrent nominal In [A]", "Ltot [H]"], title = "Inductància total respecte la corrent per diferents valors d'E") :
> G6 := plots[display](g6[0], g6[1], g6[2], g6[3], g6[4], axis = [gridlines = [colour = grey, majorlines = 1]], labels
   = ["Corrent nominal In [A]", "Rf[Ω]"], title = "Resistència de fase respecte la corrent per diferents valors d'E") :
> G7 := plots[display](g7[0], g7[1], g7[2], g7[3], g7[4], axis = [gridlines = [colour = grey, majorlines = 1]], labels
   = ["Corrent nominal In [A]", "Uf[Ω]"], title = "Voltatge de sortida de fase respecte la corrent per diferents valors d'E") :
>
> display(Array(1 ..2, 1 ..2, [[G0, G1], [G2, G3]]))
```

> *display*(*Array*(1 ..2, 1 ..2, [[*G0*, *G1*], [*G2*, *G3*]]))

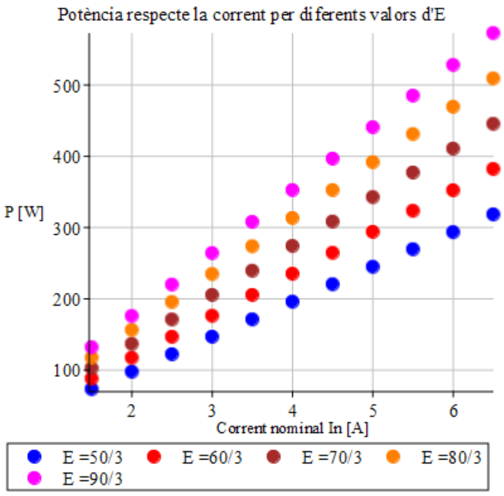


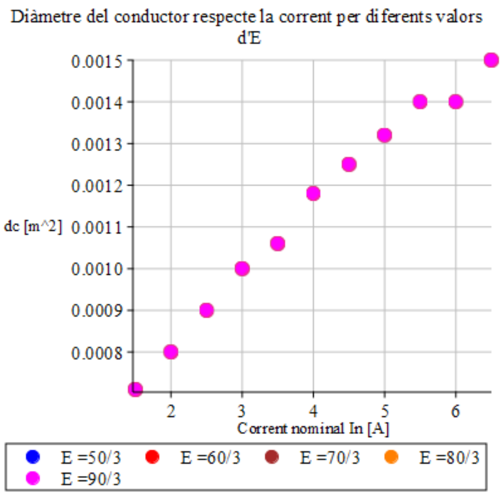

> *display*(*Array*(1 ..2, 1 ..2, [[*G4*, *G5*], [*G6*, *G7*]]))

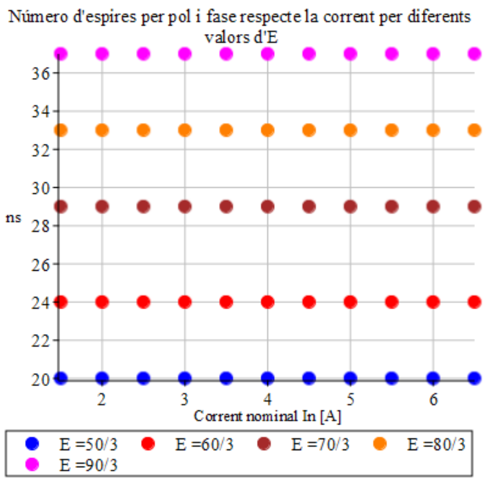


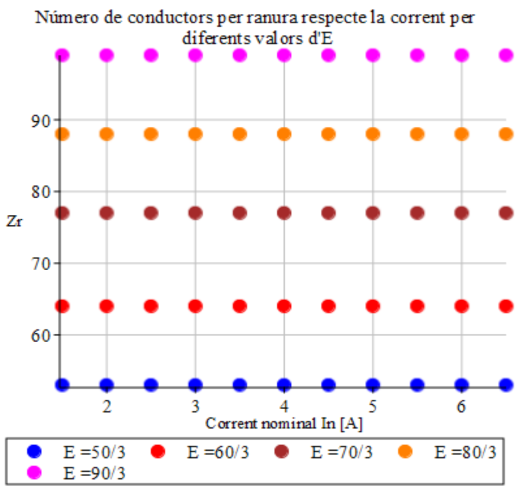


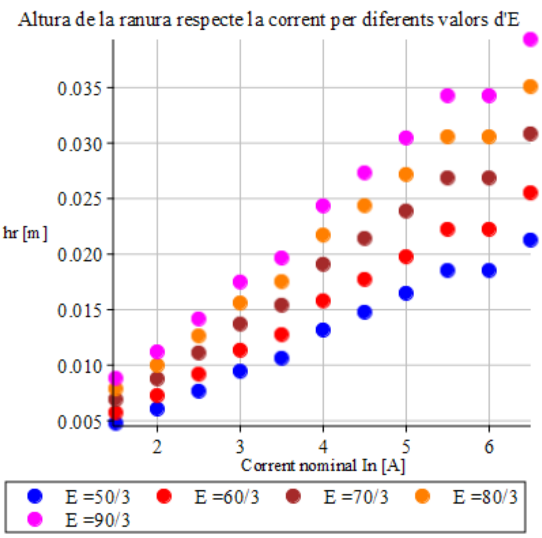

Per aa=3 el procediment es idèntic amb la modificació de la resistència i la inductància que es veu dividida entre 9 i $3^3$ respectivament.

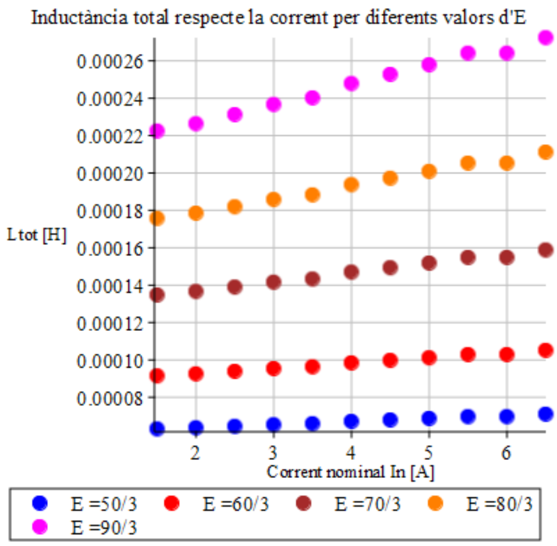


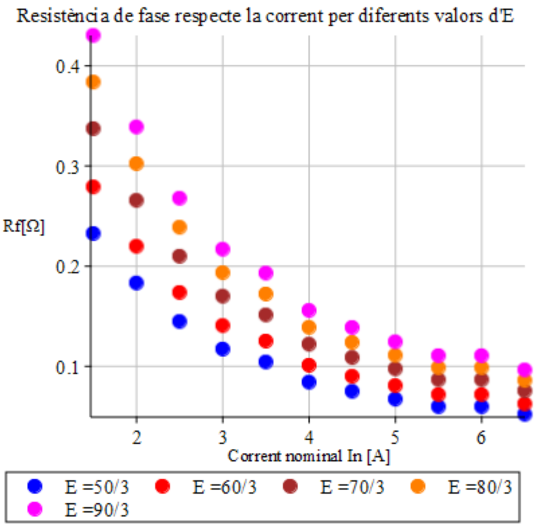



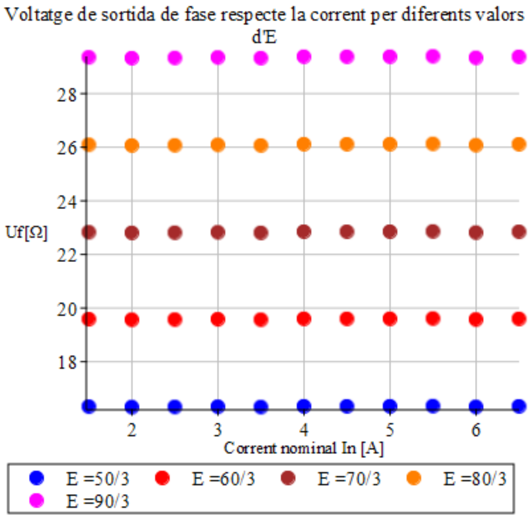




Altura de la ranura respecte la corrent per diferents valors d'E
hr [m]
Corrent nominal In [A]
E =50/3
E =60/3
E =70/3
E =80/3
E =90/3


Inductància total respecte la corrent per diferents valors d'E
Ltot [H]
Corrent nominal In [A]
E =50/3
E =60/3
E =70/3
E =80/3
E =90/3


Resistència de fase respecte la corrent per diferents valors d'E
Rf[Ω]
Corrent nominal In [A]
E =50/3
E =60/3
E =70/3
E =80/3
E =90/3


Voltatge de sortida de fase respecte la corrent per diferents valors d'E
Uf[Ω]
Corrent nominal In [A]
E =50/3
E =60/3
E =70/3
E =80/3
E =90/3

# Annex VI. Resultats de JMAG.

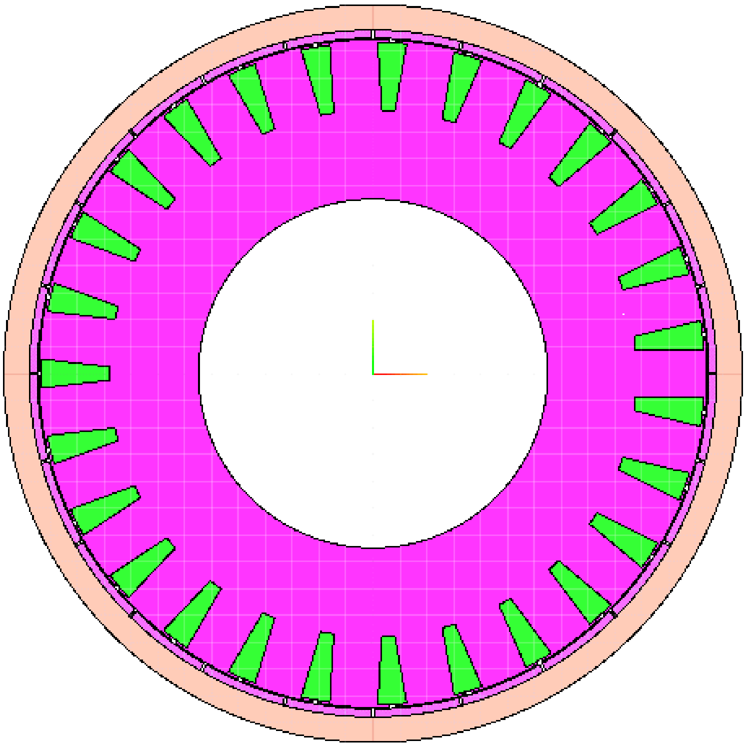


**Figura 1.** Resultat del generador en JMAG (Font: JMAG)

| Machine Constant | | |
|---|---|---|
| Revolution Speed | N, rpm | 100 |
| Inductance | Ld, H | 0.03148 |
| | Lq, H | 0.03031 |
| | Self Inductance, H | 0.02059 |
| | Mutual Inductance, H | -0.0103 |
| Torque Constant | Kt, Nm/A | 13.26 |
| Voltage Constant | Ke, V s/rad | 15.31 |
| Magnetic Circuit | Average Teeth Flux Density, T | 0.9111 |
| | Average Back Yoke Flux Density, T | 0.2348 |
| | Average Gap Flux Density, T | 0.8743 |
| | Magnet Flux Linkage, Wb | 0.9002 |
| Electric Part | Phase Current(RMS), A | 1.553 |
| | Wire Current Density, $A/m^2$ | 3.516e+06 |
| Power | Torque, Nm | 27.75 |
| | Efficiency, % | 90.07 |
| | Power, W | 289.2 |
| | Power Factor | 0.9963 |
| Loss | Copper Loss, W | 27.93 |
| | Iron Loss, W | 4.42 |
| Electric Circuit | Phase Voltage(RMS), V | 69.42 |
| | Line Voltage(RMS), V | 120.2 |

| Dimension | | |
|---|---|---|
| All | Outer Diameter, mm | 275 |
| | Gap Length, mm | 0.5158 |
| | Stack Height, mm | 40 |
| inner_stator : outer_stator_01 | Number of Slots | 27 |
| | Tooth Width, mm | 17.89 |
| | Outside Diameter, mm | 249 |
| | Inside Diameter, mm | 130 |
| | Slot Opening, mm | 2 |
| | Core Back Width, mm | 33.2 |
| | Tooth Tang Depth, mm | 1 |
| spm_outer_rotor : concentrated_rotor | Number of Magnet Poles | 24 |
| | Inside Diameter of Rotor, mm | 256.032 |
| | Outside Diameter of Rotor, mm | 275 |
| | Inside Diameter of Magnets, mm | 250.0316 |
| | Clearance between Magnets, mm | 0.5 |
| external_case : external_case | Case Thickness, mm | 3 |
| | End Cap Height, mm | 10 |
| | Presence of Fins | No Fins |
| shaft : shaft | Shaft Length, mm | 65.85 |

| Winding | |
|---|---|
| Connection Type | Star Connection |
| Series Number | 9 |
| Parallel Number | 1 |
| Number of Turns | 85 |
| Setting Type | Round Wire Dimension |
| Wire Diameter, mm | 0.75 |
| Film Thickness, mm | 0 |
| Number of Strands | 1 |
| Insulation Thickness, mm | 0 |
| Slot-Fill Factor, % | 37.64 |
| Max Slot-Fill Factor, % | 70 |
| Correction Factor | 1 |
| Slot Area, $mm^2$ | 199.5 |
| Conductor Area, $mm^2$ | 37.55 |
| Phase Resistance, ohm | 3.776 |
| Winding | Auto Winding |
| Number of Layers | 2 |
| Coil Pitch | 1 |
| Coil Current Density(@1A), $A/mm^2$ | 2.264 |

| Drive | |
|---|---|
| Mode | Voltage(Sin) |
| Line Voltage(peak), V | 178.4 |
| Current Phase, deg | 0 |
| Maximum Line Current(peak), A | 2.3 |
| X-Axis | Revolution Speed, rpm |
| Loss Factor, W/k rpm | 0 |

| Mass Property | | |
|---|---|---|
| **Total** | Total Weight, kg | 13.72 |
| | Total Volume, $mm^3$ | 1.759e+06 |
| **Stator** | Coil - Mass, kg | 1.352 |
| | Coil - Volume, $mm^3$ | 1.509e+05 |
| | Stator Core - Mass, kg | 9.234 |
| | Stator Core - Volume, $mm^3$ | 1.199e+06 |
| | Part Weight(outer_stator_01) | 10.59 |
| **Rotor** | Rotor Magnet - Mass, kg | 0.6939 |
| | Rotor Magnet - Volume, $mm^3$ | 9.252e+04 |
| | Rotor Core - Mass, kg | 2.437 |
| | Rotor Core - Volume, $mm^3$ | 3.164e+05 |
| | Part Weight(concentrated_rotor) | 3.13 |
| **Inertia** | Rotor Magnet, kg $m^2$ | 0.01111 |
| | Rotor Core, kg $m^2$ | 0.043 |
| | Total, kg $m^2$ | 0.05411 |

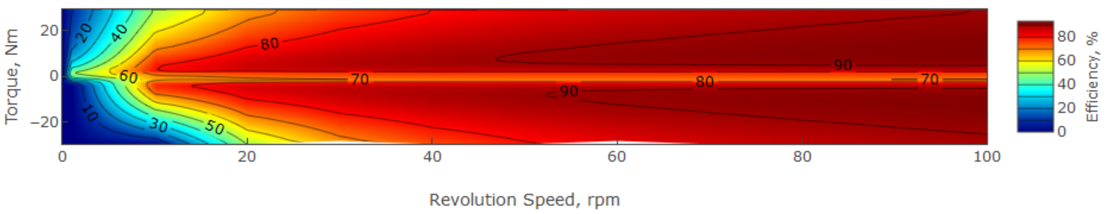
| Materials | | |
|---|---|---|
| **Coil** | Category | Copper |
| | Density, $kg/m^3$ | 8960 |
| | Base Temperature, deg C | 20 |
| | Temperature Correction Factor, ppm/K | 3810 |
| **Stator Core** | Category | JSOL - Steel_Sheets |
| | Product | 50A470 |
| | Density, $kg/m^3$ | 7700 |
| **Rotor Magnet** | Category | JSOL - NdFeB_Magnet |
| | Product | NdFeB_Br=1.2(T) |
| | Base Temperature, deg C | 20 |
| | Temperature Correction Factor, %/K | 0.605 |
| | Magnetization Pattern | Radial |
| | Density, $kg/m^3$ | 7500 |
| **Rotor Core** | Category | JSOL - Steel_Sheets |
| | Product | 50A470 |
| | Density, $kg/m^3$ | 7700 |
| **Common Material Properties** | Iron Loss Correction Factor | 1 |

| Thermal | |
|---|---|
| Ambient, deg C | 40 |
| External Case, deg C | 42.25 |
| Stator Core Outer, deg C | 42.56 |
| Stator Core Inner, deg C | 43.08 |
| Stator Teeth Bottom, deg C | 43.38 |
| Stator Teeth Top, deg C | 43.93 |
| Air Gap, deg C | 43.56 |
| Rotor, deg C | 43.2 |
| Inside Rotor, deg C | 43.02 |
| Magnet, deg C | 43.11 |
| Wire, deg C | 54.77 |
| Inner Air, deg C | 43.65 |

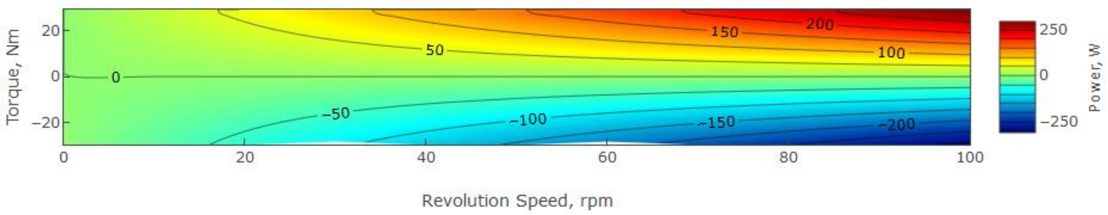
| Thermal | |
|---|---|
| Ambient, deg C | 40 |
| External Case, deg C | 73.14 |
| Stator Core Outer, deg C | 73.45 |
| Stator Core Inner, deg C | 73.98 |
| Stator Teeth Bottom, deg C | 74.28 |
| Stator Teeth Top, deg C | 74.82 |
| Air Gap, deg C | 74.46 |
| Rotor, deg C | 74.09 |
| Inside Rotor, deg C | 73.91 |
| Magnet, deg C | 74 |
| Wire, deg C | 85.66 |
| Inner Air, deg C | 74.54 |

**Taula 2.** Resultats de JMAG (Font: JMAG)

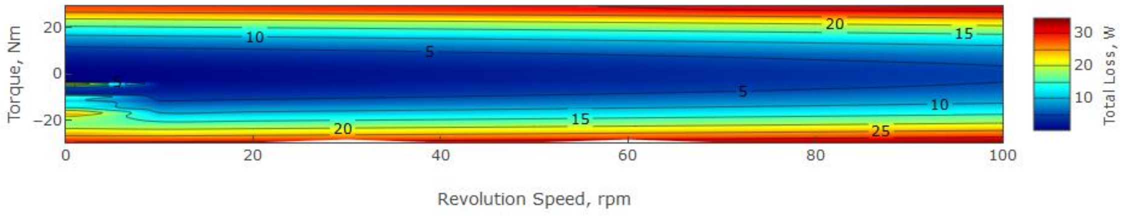
JMAG mostra els mapes per a diferents variables del sistema. Tenint en compte que la màquina considerada és un generador, els valors vàlid seran els situats a la part inferior dels gràfics mostrats a continuació:



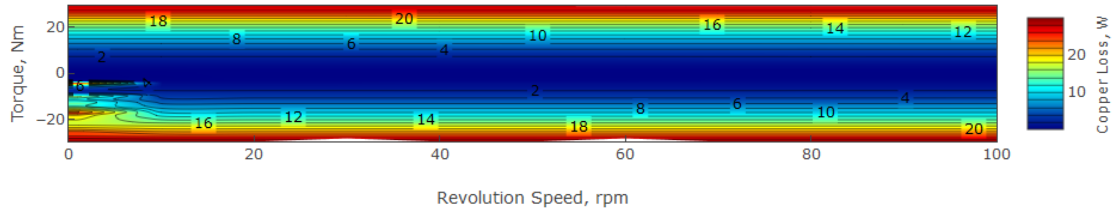

**Gràfica 1.** Mapa de rendiment en funció de la velocitat de rotació (Font: JMAG)



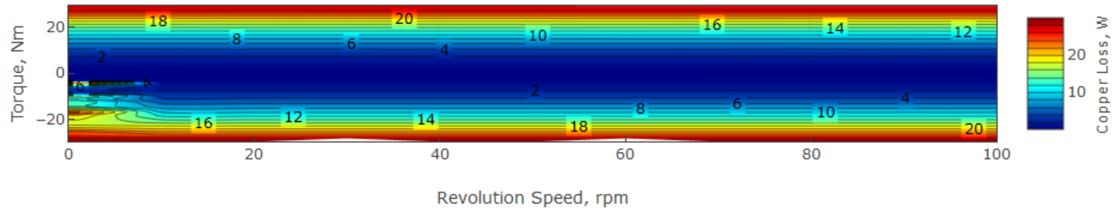

**Gràfica 2.** Mapa de potència nominal en funció de la velocitat de rotació (Font: JMAG)



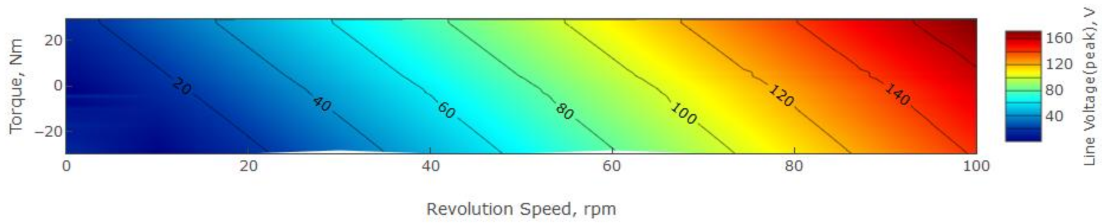

**Gràfica 3.** Mapa de les pèrdues totals en funció de la velocitat de rotació (Font: JMAG)



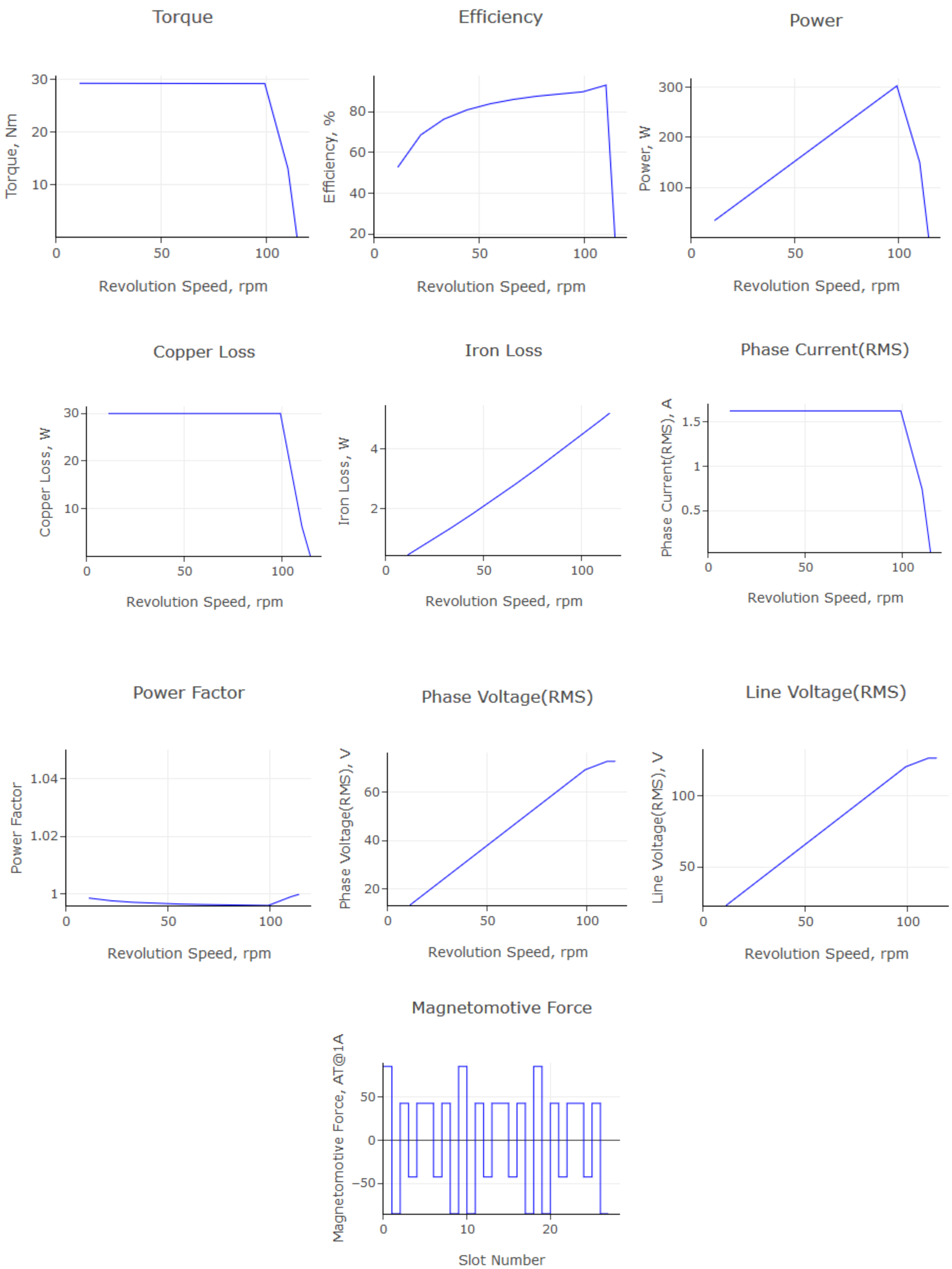

**Gràfica 4.** Mapa de les pèrdues del coure en funció de la velocitat de rotació (Font: JMAG)




**Gràfica 5.** Mapa de les pèrdues del ferro en funció de la velocitat de rotació (Font: JMAG)

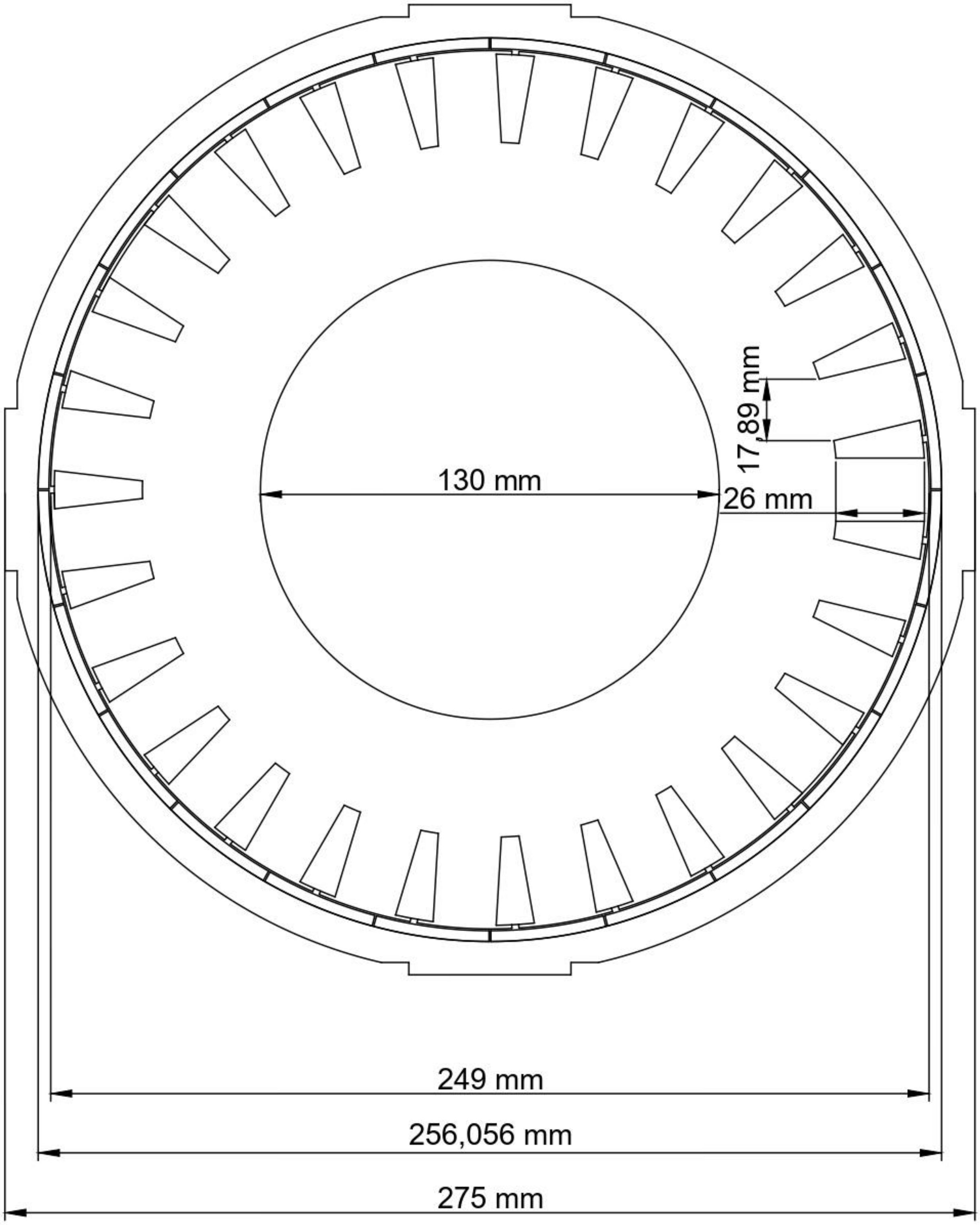



**Gràfica 6.** Mapa del voltatge de línia en funció de la velocitat de rotació (Font: JMAG)

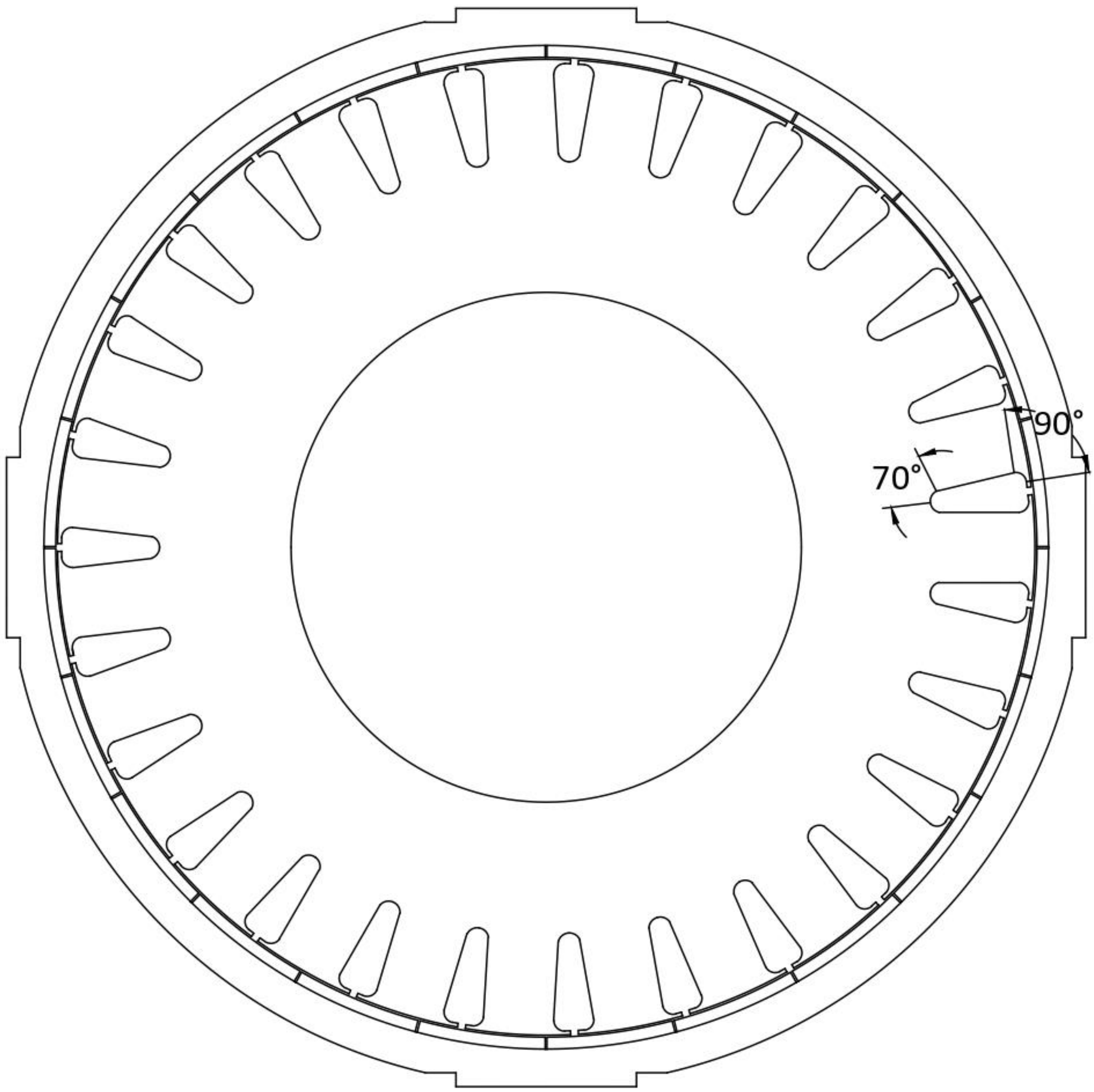



**Gràfica 7.** Resultats gràfics de les variables de JMAG (Font: JMAG)

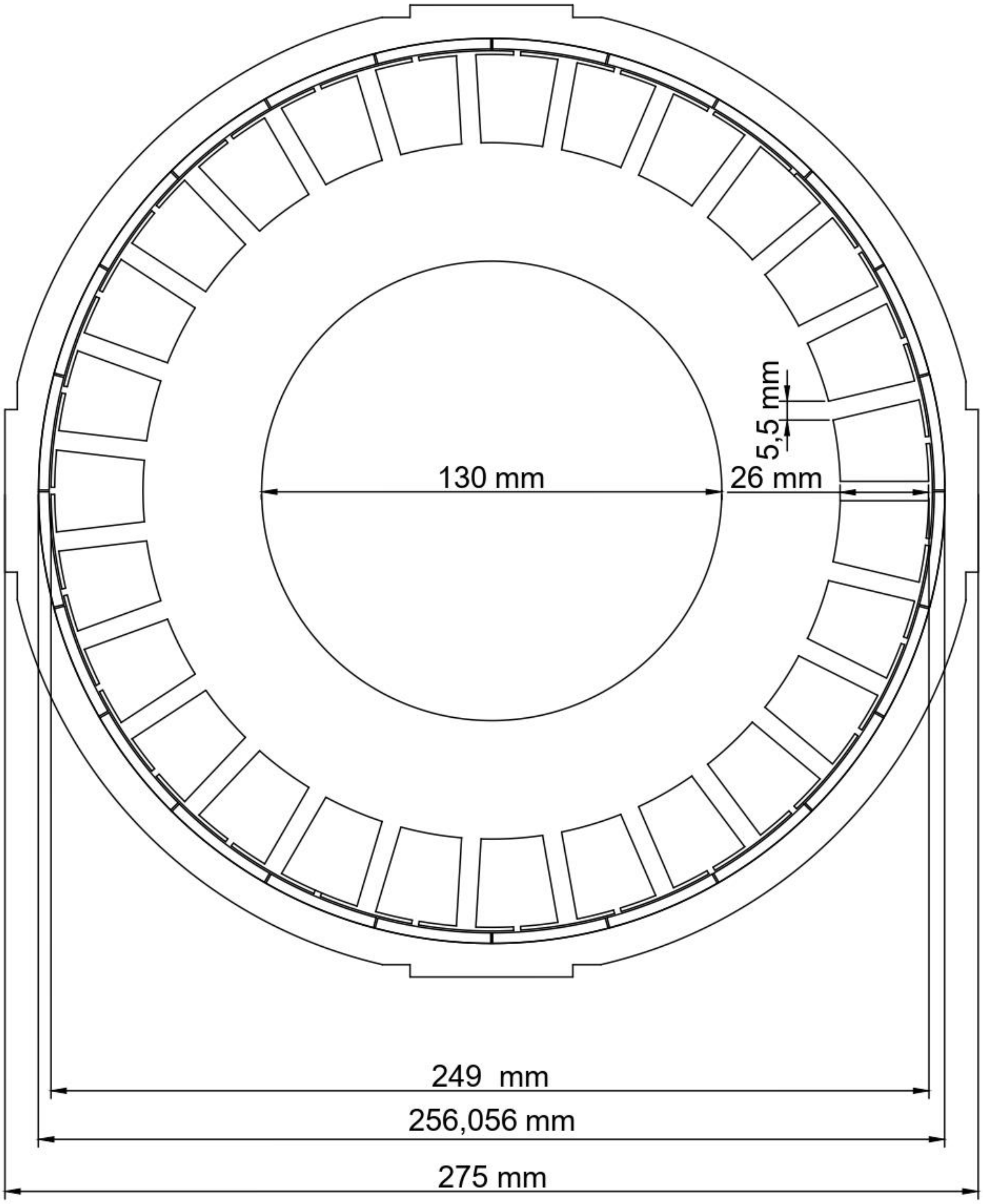
# Annex VII. Plànols en 2D de les possibles estructures del generador



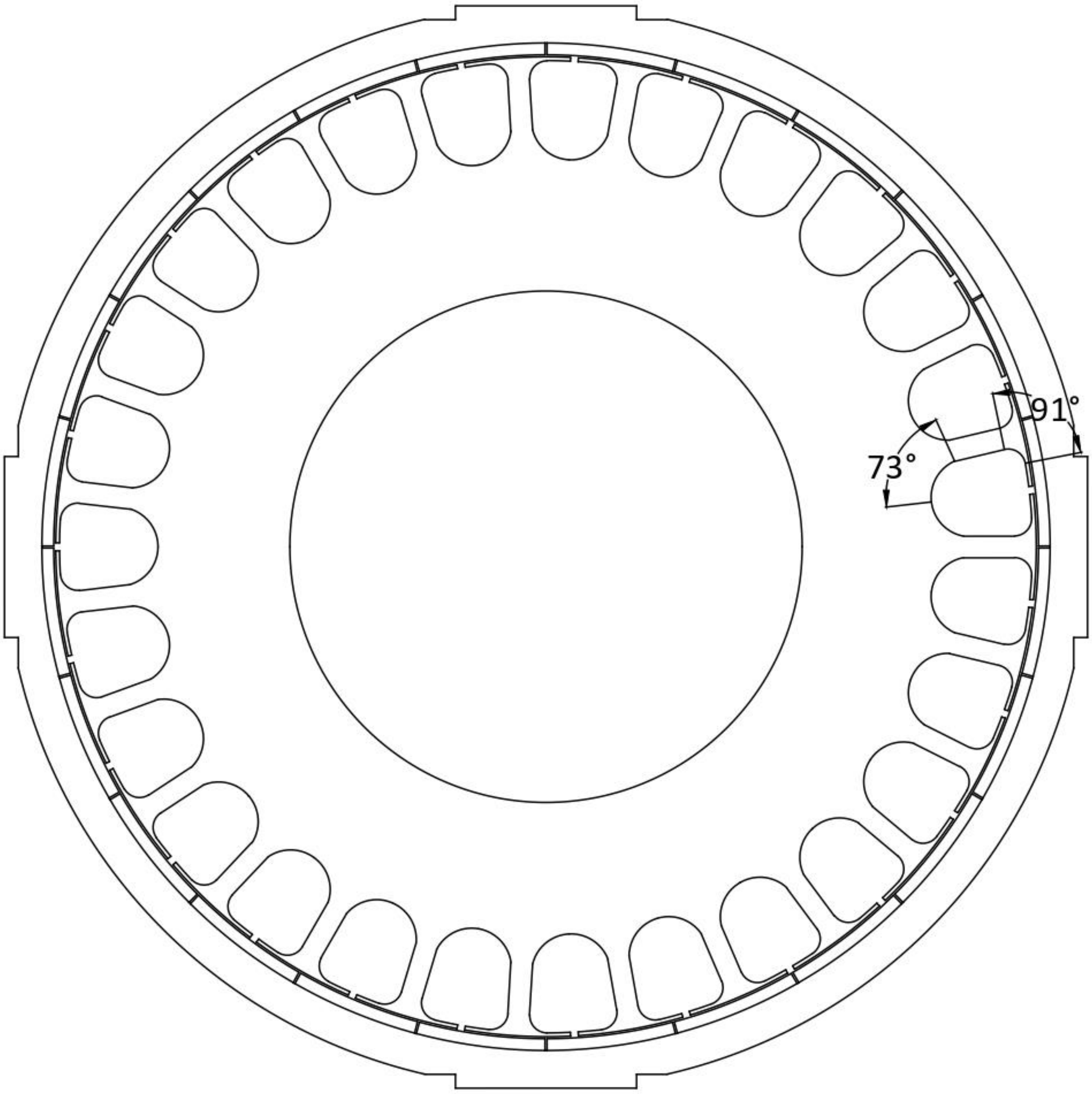

| | | | |
|---|---|---|---|
| AUTORA: Paula Garcia Monterrubio | Data realització: 05/04/2020 | PLÀNOL I | ANNEX : Estructura de ranura rectangular amb un pas de dent de 17,89 mm |
| TUTOR: Ramon Bargalló Perpiña | Data comprovació: 04/06/2020 | | |
| UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH Escola d'Enginyeria de Barcelona Est | Títol: Disseny d'un generador d'imants permanents per a un mini-turbina eòlica d'eix vertical aïllada de xarxa | | ESCALA 1:22 |
| | Observacions: | | |




| | | | |
|---|---|---|---|
| AUTORA: Paula Garcia Monterrubio | Data realització: 05/04/2020 | PLÀNOL II | ANNEX : Estructura de ranura arrodonida amb un pas de dent de 17,89 mm |
| TUTOR: Ramon Bargalló Perpiñà | Data comprovació: 04/06/2020 | | |
| UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH Escola d'Enginyeria de Barcelona Est | Títol: Disseny d'un generador d'imants permanents per a un mini-turbina eòlica d'eix vertical aïllada de xarxa | | ESCALA 1:22 |
| | Observacions: | | |

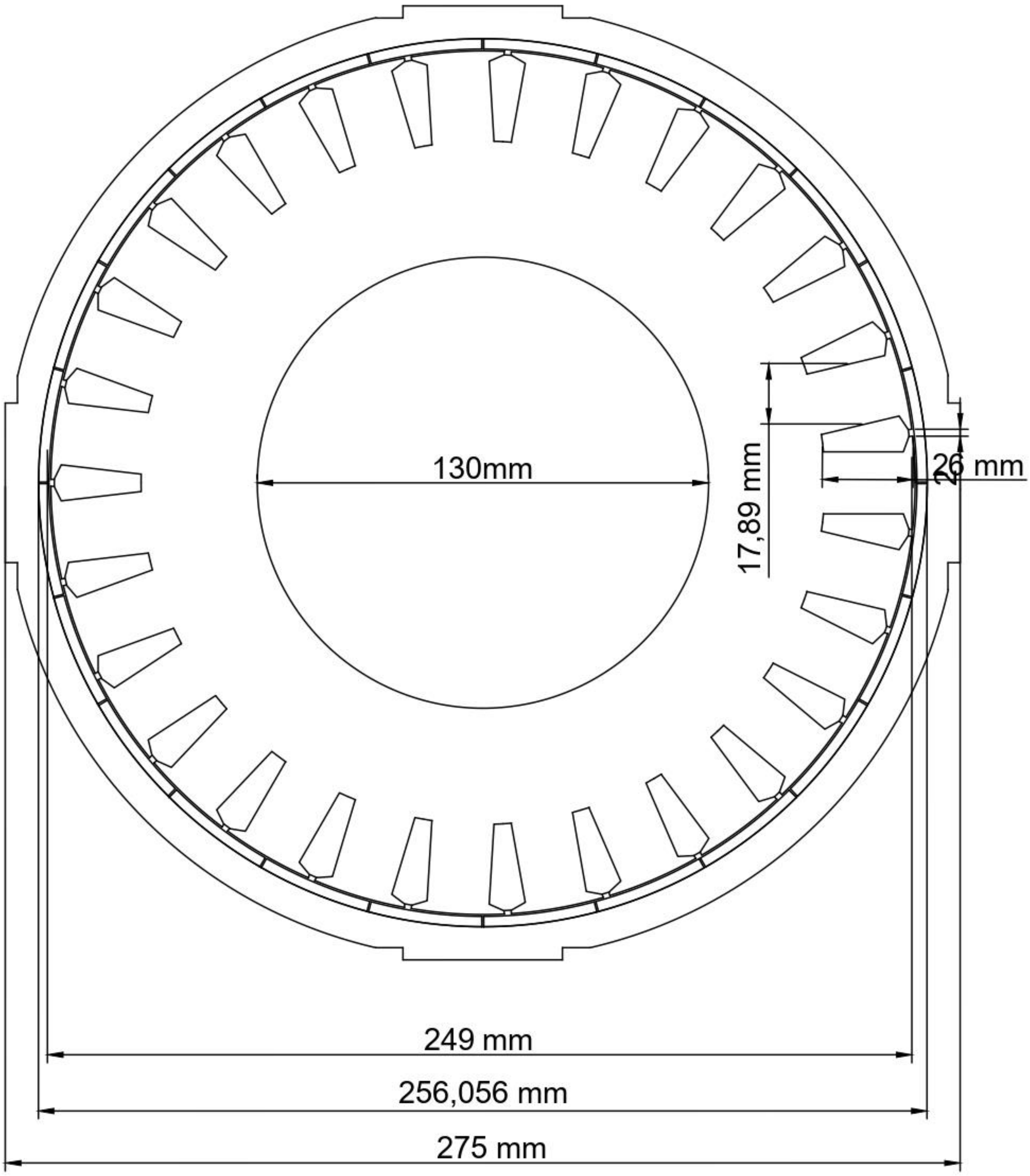



| | | | |
|---|---|---|---|
| AUTORA: Paula Garcia Monterrubio | Data realització: 05/04/2020 | PLÀNOL III | ANNEX : Estructura de ranura rectangular amb un pas de dent de 5,5 mm |
| TUTOR: Ramon Bargalló Perpiñà | Data comprovació: 04/06/2020 | | |
| UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH Escola d'Enginyeria de Barcelona Est | Títol: Disseny d'un generador d'imants permanents per a un mini-turbina eòlica d'eix vertical aïllada de xarxa | ESCALA 1:22 | |
| | Observacions: | | |




| | | | |
|---|---|---|---|
| AUTORA: Paula Garcia Monterrubio | Data realització: 05/04/2020 | PLÀNOL IV | ANNEX : Estructura de ranura arrodonida amb un pas de dent de 5,5 mm |
| TUTOR: Ramon Bargalló Perpiñà | Data comprovació: 04/06/2020 | | |

| | | |
|---|---|---|
| UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH Escola d'Enginyeria de Barcelona Est | Títol: Disseny d'un generador d'imants permanents per a un mini-turbina eòlica d'eix vertical aïllada de xarxa | ESCALA 1:22 |
| | Observacions: | |




| | | | |
|---|---|---|---|
| AUTORA: Paula Garcia Monterrubio | Data realització: 05/04/2020 | PLÀNOL | ANNEX : Estructura de ranura rectangular amb inclinacions i un pas de dent de 17,89 mm |
| TUTOR: Ramon Bargalló Perpiñà | Data comprovació: 04/06/2020 | V | |

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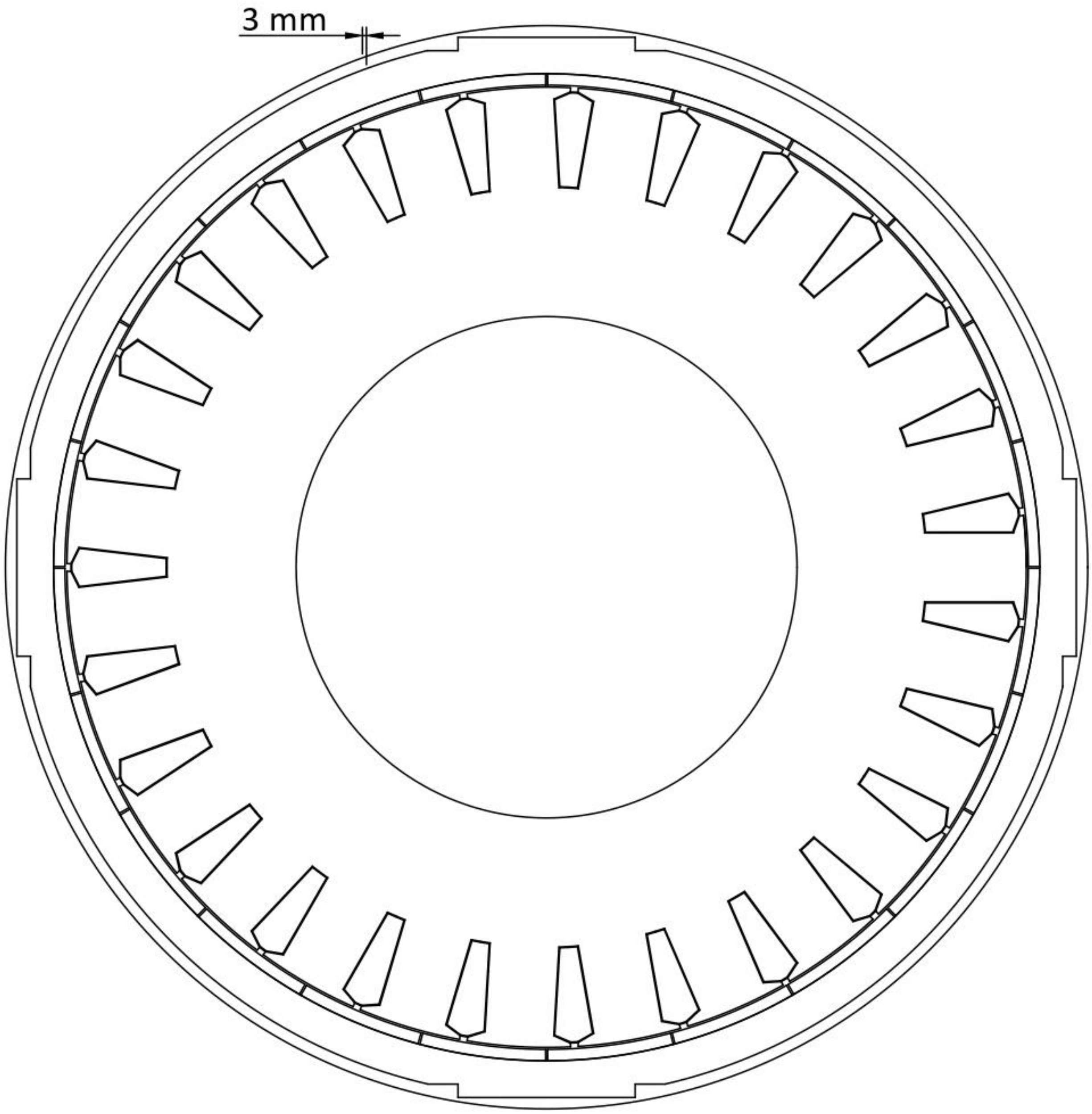
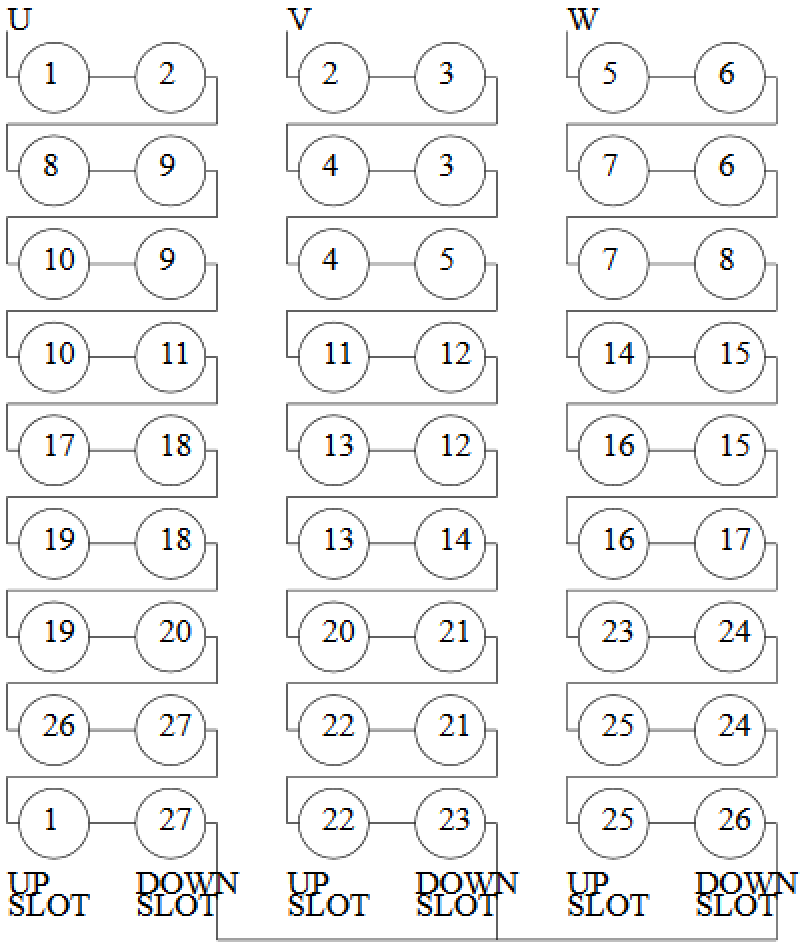
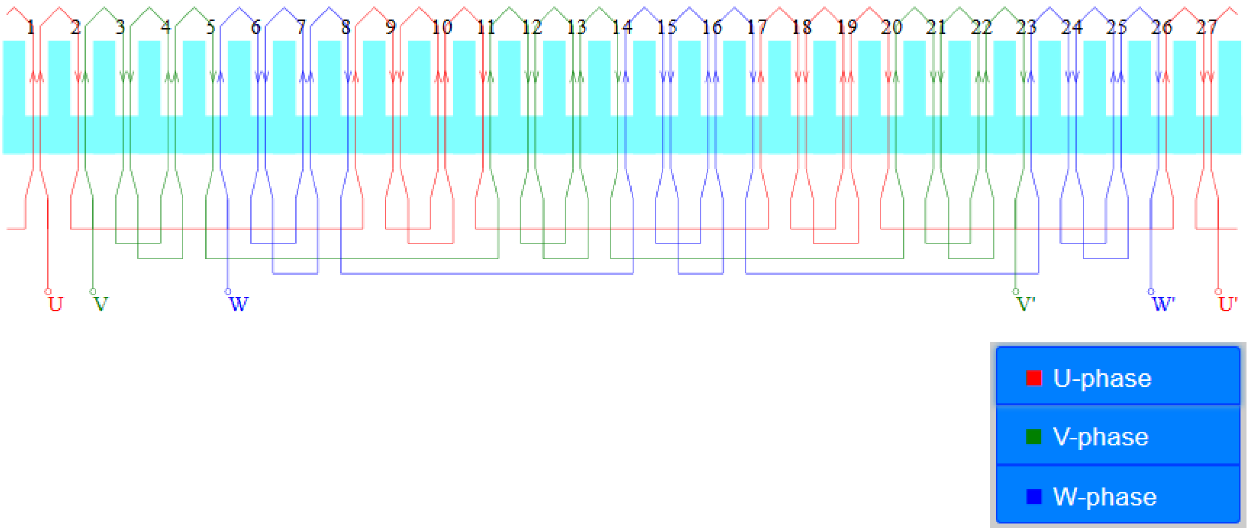
| | |
|---|---|
| Títol: Disseny d'un generador d'imants permanents per a un mini-turbina eòlica d'eix vertical aïllada de xarxa | ESCALA 1:22 |
| Observacions: | |




| | | | | |
|---|---|---|---|---|
| AUTORA: Paula Garcia Monterrubio | Data realització: 05/04/2020 | PLÀNOL | ANNEX : | |
| TUTOR: Ramon Bargalló Perpiña | Data comprovació: 04/06/2020 | VI | Estructura del generador amb carcassa | |
| UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH Escola d'Enginyeria de Barcelona Est | Títol: Disseny d'un generador d'imants permanents per a un mini-turbina eòlica d'eix vertical aïllada de xarxa | | | ESCALA 1:22 |
| | Observacions: | | | |




| | | | |
|---|---|---|---|
| AUTORA: Paula Garcia Monterrubio | Data realització: 05/04/2020 | PLÀNOL VII | ANNEX : Estructura del bobinat |
| TUTOR: Ramon Bargalló Perpiña | Data comprovació: 04/06/2020 | | |

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
Escola d'Enginyeria de Barcelona Est

Títol: Disseny d'un generador d'imants permanents per a un mini-turbina eòlica d'eix vertical aïllada de xarxa

Observacions:

ESCALA 1:22

# Annex VIII. Fitxa tècnica de la xapa estatòrica. M470-50


Electrical Steel | Fully processed
Data sheet isovac 470-50 A | page 1/7 | 01/2018

## isovac 470-50 A

### The perfect solution for direct application

Manufactured in the most modern production lines, this fully processed isovac® grade exhibits highly homogeneous properties across the width and length of the entire strip. The result is excellent and consistent processability in the manufacture of highly efficient electrical components.
Upon request, isovac 470-50 A can be supplied with an electrical steel insulation system and can be used directly in as-delivered condition.

**Convincing advantages:**

» Best processability through consistent mechanical properties and homogeneous, clean surfaces
» Excellent stackability resulting from high dimensional accuracy in rolling direction and perpendicular to rolling direction (thickness tolerance)
» Innovative electrical steel insulation systems upon request

voestalpine Steel Division
www.voestalpine.com/isovac

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Data sheet isovac 470-50 A | page 2/7 | 01/2018

voestalpine supplies isovac 470-50 A, an electrical steel of the highest quality. We offer you a customer-focused overall package of products, service and logistics in addition to all the advantages of our integrated metallurgical facility and Steel Service Centers.

### Grade named according to conventional international standards:

| Grade named according to isovac® | DIN EN 10106 Material No. | DIN EN 10106 Abbreviation | IEC 60404-8-4 | JIS C2552 | GOST 21427.2 | ASTM A677 | AISI | IS648 | GB/T2521.1 |
|---|---|---|---|---|---|---|---|---|---|
| isovac 470-50 A | 1.0812 | M470-50A | M470-50A 5 | 50A470 | 2214 | 47F280 | - | 50C470 | 50W470 |

### Mechanical properties:

Tensile test according to DIN EN ISO 6892-1 and hardness according to DIN EN ISO 6507-1 (Typical values);
Test direction: Transverse

| Grade named according to isovac® | Yield strength $R_{eH}$ [MPa] | 0.2 %-Yield strength $R_{p0.2}$ [MPa] | Tensile strength $R_m$ [MPa] | Elongation $A_{80}$ [%] | Hardness HV5 [-] |
|---|---|---|---|---|---|
| isovac 470-50 A | 330 | 315 | 470 | 33 | 150 |

### Magnetic properties:

in as-delivered condition (Typical values)
Test direction: Mean value from longitudinal and transverse measurements at 50 Hz (60 Hz), single-sheet test

| Grade named according to isovac® | Specific total loss | | | | Magnetic polarization | | | Relative permeability |
|---|---|---|---|---|---|---|---|---|
| | 1.0 T P10 | | 1.5 T P15 | | 2500 A/m J25 | 5000 A/m J50 | 10000 A/m J100 | 1.5 T $\mu_r$ |
| | 50 Hz [W/kg] | 60 Hz [W/lb] | 50 Hz [W/kg] | 60 Hz [W/lb] | [T] | [T] | [T] | [-] |
| isovac 470-50 A | 1.70 | 0.97 | 3.90 | 2.22 | 1.62 | 1.71 | 1.82 | 2100 |

### Physical properties:

Typical values

| Grade named according to isovac® | Density $\rho$ [g/cm³] | Specific electrical resistance $\rho_s$ [μΩcm] | Thermal conductivity $\lambda$ [W/mK] |
|---|---|---|---|
| isovac 470-50 A | 7.76 | 35.8 | 33 |

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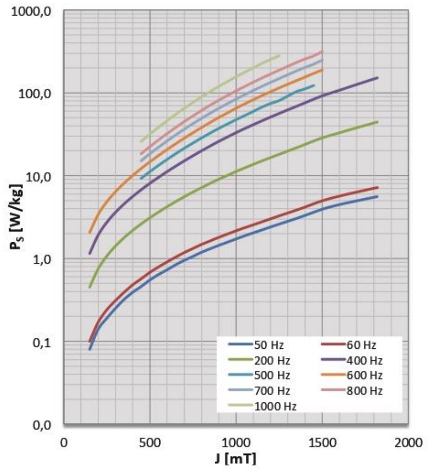
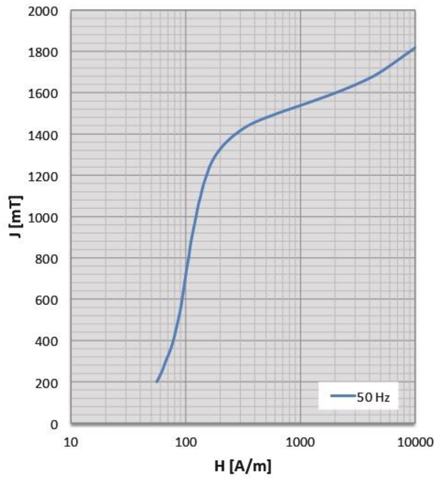
Data sheet isovac 470-50 A | page 3/7 | 01/2018

**Characteristics $P_s$/J loss curve and characteristics J/H magnetization curve**

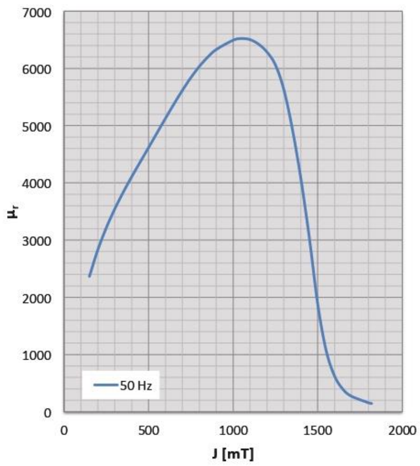
Test direction: Mean value from longitudinal and transverse measurements at indicated frequencies, single-sheet test




**Characteristics $\mu_r$/J permeability curve**

Test direction: Mean value from longitudinal and transverse measurements at 50 Hz, single-sheet test

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Data sheet isovac 470-50 A | page 4/7 | 01/2018

**Frequency dependence of magnetic properties**

Test direction: Mean value longitudinal and transverse at indicated frequencies and polarizations, single-sheet test

| 50 Hz | | | | 60 Hz | | | | 200 Hz | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] | J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] | J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] |
| 150 | 50 | 0.08 | 2368 | 150 | 50 | 0.10 | 2367 | 150 | 53 | 0.45 | 2244 |
| 200 | 56 | 0.14 | 2832 | 200 | 56 | 0.17 | 2829 | 200 | 60 | 0.75 | 2640 |
| 250 | 62 | 0.19 | 3215 | 250 | 62 | 0.24 | 3210 | 250 | 67 | 1.07 | 2955 |
| 300 | 67 | 0.25 | 3544 | 300 | 68 | 0.31 | 3536 | 300 | 74 | 1.41 | 3217 |
| 350 | 73 | 0.32 | 3836 | 350 | 73 | 0.39 | 3826 | 350 | 81 | 1.78 | 3441 |
| 400 | 78 | 0.39 | 4106 | 400 | 78 | 0.48 | 4092 | 400 | 87 | 2.18 | 3638 |
| 450 | 82 | 0.46 | 4363 | 450 | 82 | 0.57 | 4345 | 450 | 94 | 2.62 | 3818 |
| 500 | 86 | 0.55 | 4617 | 500 | 87 | 0.68 | 4594 | 500 | 100 | 3.10 | 3987 |
| 550 | 90 | 0.64 | 4873 | 550 | 90 | 0.79 | 4843 | 550 | 106 | 3.63 | 4148 |
| 600 | 93 | 0.73 | 5128 | 600 | 94 | 0.91 | 5091 | 600 | 111 | 4.22 | 4297 |
| 650 | 96 | 0.84 | 5378 | 650 | 97 | 1.04 | 5332 | 650 | 117 | 4.86 | 4431 |
| 700 | 99 | 0.95 | 5617 | 700 | 100 | 1.18 | 5561 | 700 | 123 | 5.57 | 4545 |
| 750 | 102 | 1.06 | 5838 | 750 | 103 | 1.32 | 5772 | 750 | 129 | 6.34 | 4634 |
| 800 | 106 | 1.19 | 6034 | 800 | 107 | 1.48 | 5957 | 800 | 136 | 7.17 | 4696 |
| 850 | 109 | 1.31 | 6198 | 850 | 111 | 1.63 | 6112 | 850 | 143 | 8.08 | 4728 |
| 900 | 113 | 1.44 | 6329 | 900 | 115 | 1.80 | 6236 | 900 | 151 | 9.06 | 4738 |
| 1000 | 123 | 1.72 | 6492 | 1000 | 124 | 2.16 | 6394 | 1000 | 169 | 11.22 | 4714 |
| 1050 | 128 | 1.88 | 6521 | 1050 | 130 | 2.35 | 6428 | 1050 | 178 | 12.41 | 4691 |
| 1100 | 135 | 2.04 | 6502 | 1100 | 136 | 2.55 | 6414 | 1100 | 188 | 13.69 | 4657 |
| 1150 | 142 | 2.21 | 6423 | 1150 | 144 | 2.77 | 6342 | 1150 | 198 | 15.06 | 4612 |
| 1200 | 152 | 2.40 | 6285 | 1200 | 153 | 3.01 | 6227 | 1200 | 209 | 16.52 | 4568 |
| 1250 | 164 | 2.60 | 6059 | 1250 | 165 | 3.27 | 6044 | 1250 | 220 | 18.09 | 4520 |
| 1300 | 184 | 2.81 | 5625 | 1300 | 183 | 3.54 | 5638 | 1300 | 235 | 19.80 | 4393 |
| 1350 | 217 | 3.04 | 4941 | 1350 | 217 | 3.84 | 4953 | 1350 | 261 | 21.69 | 4123 |
| 1400 | 273 | 3.31 | 4080 | 1400 | 273 | 4.17 | 4088 | 1400 | 302 | 23.82 | 3688 |
| 1450 | 378 | 3.61 | 3049 | 1450 | 378 | 4.57 | 3056 | 1450 | 388 | 26.19 | 2972 |
| 1500 | 634 | 3.93 | 1882 | 1500 | 634 | 4.97 | 1884 | 1500 | 631 | 28.57 | 1893 |
| 1550 | 1155 | 4.21 | 1068 | 1550 | 1156 | 5.33 | 1067 | 1550 | 1154 | 30.77 | 1069 |
| 1600 | 2045 | 4.47 | 622 | 1600 | 2046 | 5.66 | 622 | 1600 | 2054 | 32.96 | 620 |
| 1650 | 3363 | 4.72 | 390 | 1650 | 3358 | 6.00 | 391 | 1650 | 3377 | 35.33 | 389 |
| 1700 | 4993 | 4.96 | 271 | 1700 | 4978 | 6.33 | 272 | 1700 | 5009 | 37.87 | 270 |
| 1799 | 9000 | 5.48 | 159 | 1800 | 9000 | 7.05 | 159 | 1799 | 9000 | 43.27 | 159 |
| 1818 | 10000 | 5.58 | 145 | 1820 | 10000 | 7.17 | 145 | 1819 | 10000 | 44.44 | 145 |

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**Frequency dependence of magnetic properties**

Test direction: Mean value longitudinal and transverse at indicated frequencies and polarizations, single-sheet test

| 400 Hz | | | | 500 Hz | | | | 600 Hz | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] | J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] | J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] |
| 100 | 49 | 0.40 | 1631 | | | | | | | | |
| 150 | 57 | 1.15 | 2084 | | | | | 150 | 63 | 2.06 | 1905 |
| 200 | 66 | 1.92 | 2421 | | | | | 200 | 72 | 3.40 | 2198 |
| 250 | 74 | 2.73 | 2679 | | | | | 250 | 82 | 4.83 | 2417 |
| 300 | 83 | 3.60 | 2883 | | | | | 300 | 92 | 6.38 | 2582 |
| 350 | 91 | 4.55 | 3047 | | | | | 350 | 103 | 8.10 | 2706 |
| 400 | 100 | 5.60 | 3181 | 400 | 108 | 7.48 | 2952 | 400 | 114 | 10.03 | 2797 |
| 450 | 109 | 6.77 | 3291 | 450 | 116 | 9.27 | 3082 | 450 | 125 | 12.21 | 2861 |
| 500 | 118 | 8.08 | 3383 | 500 | 125 | 11.18 | 3177 | 500 | 137 | 14.68 | 2903 |
| 550 | 127 | 9.54 | 3457 | 550 | 135 | 13.31 | 3230 | 550 | 150 | 17.49 | 2925 |
| 600 | 136 | 11.19 | 3513 | 600 | 147 | 15.71 | 3247 | 600 | 163 | 20.67 | 2928 |
| 650 | 146 | 13.03 | 3548 | 650 | 160 | 18.41 | 3235 | 650 | 178 | 24.28 | 2912 |
| 700 | 156 | 15.10 | 3559 | 700 | 174 | 21.43 | 3202 | 700 | 194 | 28.37 | 2879 |
| 750 | 168 | 17.40 | 3547 | 750 | 189 | 24.79 | 3153 | 750 | 211 | 32.98 | 2828 |
| 800 | 181 | 19.97 | 3512 | 800 | 206 | 28.54 | 3093 | 800 | 230 | 38.15 | 2764 |
| 850 | 196 | 22.81 | 3456 | 850 | 224 | 32.67 | 3026 | 850 | 252 | 43.93 | 2688 |
| 900 | 211 | 25.94 | 3388 | 900 | 242 | 37.21 | 2957 | 900 | 275 | 50.34 | 2607 |
| 1000 | 245 | 33.03 | 3243 | 1000 | 282 | 47.40 | 2823 | 1000 | 324 | 65.10 | 2453 |
| 1050 | 263 | 37.01 | 3174 | 1050 | 303 | 53.12 | 2757 | 1050 | 350 | 73.49 | 2384 |
| 1100 | 282 | 41.29 | 3104 | 1100 | 327 | 59.68 | 2678 | 1100 | 378 | 82.58 | 2315 |
| 1150 | 302 | 45.92 | 3032 | 1150 | 353 | 67.19 | 2590 | 1150 | 407 | 92.42 | 2246 |
| 1200 | 322 | 50.93 | 2965 | 1200 | 377 | 74.29 | 2532 | 1200 | 437 | 103.07 | 2186 |
| 1250 | 343 | 56.38 | 2904 | 1250 | 397 | 80.62 | 2508 | 1250 | 466 | 114.59 | 2135 |
| 1300 | 366 | 62.26 | 2824 | 1300 | 433 | 91.43 | 2390 | 1300 | 502 | 126.96 | 2061 |
| 1350 | 395 | 68.62 | 2723 | 1350 | 470 | 103.36 | 2285 | 1350 | 547 | 140.28 | 1964 |
| 1400 | 417 | 75.74 | 2673 | 1400 | 495 | 111.67 | 2249 | 1400 | 574 | 155.04 | 1941 |
| 1450 | 452 | 83.72 | 2553 | 1450 | 555 | 122.58 | 2080 | 1450 | 586 | 171.52 | 1969 |
| 1500 | 646 | 91.85 | 1848 | 1500 | 696 | 136.32 | 1716 | 1500 | 738 | 188.63 | 1618 |
| 1550 | 1156 | 99.55 | 1067 | | | | | 1550 | 1201 | 205.52 | 1027 |
| 1600 | 2062 | 107.46 | 618 | | | | | 1600 | 2072 | 223.44 | 614 |
| 1650 | 3388 | 116.33 | 388 | | | | | 1650 | 3389 | 243.70 | 387 |
| 1700 | 5017 | 125.98 | 270 | | | | | 1700 | 5028 | 265.82 | 269 |
| 1799 | 9000 | 147.04 | 159 | | | | | 1795 | 9000 | 314.80 | 159 |
| 1819 | 10000 | 151.40 | 145 | | | | | 1809 | 10000 | 323.63 | 144 |

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**Frequency dependence of magnetic properties**

Test direction: Mean value longitudinal and transverse at indicated frequencies and polarizations, single-sheet test

| 700 Hz | | | | 800 Hz | | | | 1000 Hz | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] | J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] | J [mT] | H [A/m] | $P_s$ [W/kg] | $\mu_r$ [-] |
| 400 | 120 | 12.16 | 2649 | 400 | 126 | 14.73 | 2529 | 400 | 139 | 20.59 | 2284 |
| 450 | 131 | 15.15 | 2724 | 450 | 139 | 18.40 | 2579 | 450 | 156 | 25.89 | 2298 |
| 500 | 144 | 18.37 | 2767 | 500 | 153 | 22.39 | 2601 | 500 | 173 | 31.67 | 2294 |
| 550 | 158 | 22.04 | 2771 | 550 | 169 | 26.96 | 2587 | 550 | 193 | 38.36 | 2264 |
| 600 | 174 | 26.23 | 2744 | 600 | 188 | 32.22 | 2546 | 600 | 216 | 46.10 | 2215 |
| 650 | 192 | 31.00 | 2696 | 650 | 208 | 38.22 | 2488 | 650 | 240 | 54.98 | 2153 |
| 700 | 211 | 36.40 | 2635 | 700 | 230 | 45.03 | 2421 | 700 | 267 | 65.08 | 2084 |
| 750 | 233 | 42.47 | 2567 | 750 | 254 | 52.70 | 2351 | 750 | 297 | 76.49 | 2012 |
| 800 | 255 | 49.26 | 2496 | 800 | 279 | 61.30 | 2281 | 800 | 328 | 89.30 | 1939 |
| 850 | 279 | 56.82 | 2424 | 850 | 306 | 70.88 | 2212 | 850 | 362 | 103.58 | 1868 |
| 900 | 304 | 65.13 | 2353 | 900 | 334 | 81.44 | 2142 | 900 | 398 | 119.43 | 1799 |
| 1000 | 361 | 84.02 | 2206 | 1000 | 399 | 105.54 | 1993 | 1000 | 475 | 156.17 | 1674 |
| 1050 | 391 | 94.81 | 2136 | 1050 | 434 | 119.29 | 1923 | 1050 | 516 | 177.11 | 1618 |
| 1100 | 422 | 106.77 | 2072 | 1100 | 469 | 134.46 | 1866 | 1100 | 560 | 200.35 | 1563 |
| 1150 | 455 | 119.70 | 2010 | 1150 | 506 | 150.95 | 1809 | 1150 | 606 | 226.42 | 1509 |
| 1200 | 490 | 133.65 | 1948 | 1200 | 545 | 168.74 | 1752 | 1200 | 653 | 253.22 | 1462 |
| 1250 | 527 | 148.79 | 1887 | 1250 | 586 | 187.91 | 1698 | 1250 | 699 | 280.32 | 1422 |
| 1300 | 565 | 165.28 | 1832 | 1300 | 628 | 208.86 | 1648 | 1300 | 757 | 316.55 | 1366 |
| 1350 | 611 | 183.65 | 1758 | 1350 | 679 | 232.48 | 1581 | | | | |
| 1400 | 648 | 202.71 | 1719 | 1400 | 720 | 256.48 | 1546 | | | | |
| 1450 | 661 | 221.72 | 1746 | 1450 | 732 | 279.43 | 1576 | | | | |
| 1500 | 782 | 248.59 | 1527 | 1500 | 830 | 314.86 | 1438 | | | | |

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## Available Dimensions

| Grade named according to isovac® | Delivery form | Width [mm] | Length [mm] |
|---|---|---|---|
| isovac 470-50 A | Wide strip / Slit strip | 19 – 1590 | - |
| | Cut-to-length sheets | 300 – 1590 | 300 – 5000 |

## Deliverable coating systems

| Grade named according to isovac® | Uncoated | C-3 | Backlack | C-5 | C-6 |
|---|---|---|---|---|---|
| isovac 470-50 A | Available | Available | On request | Available | Available |

Available   On request



Please find further information and downloadable files at www.voestalpine.com/isovac

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# Annex IX. Codis del llenguatge LUA

## Annex IX.I Introducció del bobinat de doble capa

```
--1.AUTOMATITZACIÓ DEL DEBANAT DE DOBLE CAPA
-----------------------------------------------------------------------
pi=3.1415926;
Rr=125.0158;--Radi intern del rotor
Re=124.5;--Radi extern de l'estator
Q=27;--Número de ranures estatòriques
g=0.5158;--Dimensions de l'entreferro
N=85;--Número de bobines per ranura
-- Definició dels circuits_KOIL
-- Slot matrix of phase L1: 27 elements.
k_L1 = {2, -2, 1, 0, 0, 0, 0, 0, -1, 2, -2, 1, 0, 0, 0, 0, 0, -1, 2, -
2, 1, 0, 0, 0, 0, 0, -1}
-- Slot matrix of phase L2: 27 elements.
k_L2 = {0, 0, -1, 2, -2, 1, 0, 0, 0, 0, 0, -1, 2, -2, 1, 0, 0, 0, 0,
0, -1, 2, -2, 1, 0, 0, 0}
-- Slot matrix of phase L3: 27 elements.
k_L3 = {0, 0, 0, 0, 0, -1, 2, -2, 1, 0, 0, 0, 0, 0, -1, 2, -2, 1, 0,
0, 0, 0, 0, -1, 2, -2, 1}
--Blockname
blockname="Coure";
R=113;
--Angle entre ranures
angle=(2*pi/Q);
-- Es té en compte que la ranura no s'ha dibuixat centrada a 0 graus
-- El debanat es de doble capa per aquest motiu es distribuirà dos
--'blocklabels' en la ranura.
beta=6.378;
beta1=6.418;
for a=1,Q,1 do
  x=R*cos((a-1)*angle+beta);
  y=R*sin((a-1)*angle+beta);
  x1=R*cos((a-1)*angle+beta1);
  y1=R*sin((a-1)*angle+beta1);
  mi_addblocklabel(x,y);
  mi_addblocklabel(x1,y1);
if ((k_L1[a]==2)or(k_L1[a]==-2))then
    k=k_L1[a]/2;
    circuit="A";

    mi_selectlabel(x,y);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();
    mi_selectlabel(x1,y1);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();

else if ((k_L2[a]==2)or(k_L2[a]==-2))then
    k=k_L2[a]/2;
    circuit="B";

    mi_selectlabel(x,y);
```

```
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();
    mi_selectlabel(x1,y1);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();

else if ((k_L3[a]==2)or(k_L3[a]==-2))then
    k=k_L3[a]/2;
    circuit="C";

    mi_selectlabel(x,y);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();
    mi_selectlabel(x1,y1);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();

else if((k_L1[a]==1)and(k_L2[a]==-1))then
    k=k_L1[a];
    circuit="A";
    mi_selectlabel(x,y);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();
    k=k_L2[a];
    circuit="B";
    mi_selectlabel(x1,y1);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();

else if((k_L2[a]==1)and(k_L3[a]==-1))then
    k=k_L2[a];
    circuit="B";
    mi_selectlabel(x,y);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();
    k=k_L3[a];
    circuit="C";
    mi_selectlabel(x1,y1);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();
    else if((k_L1[a]==-1)and(k_L3[a]==1))then
    k=k_L1[a];
    circuit="A";
    mi_selectlabel(x1,y1);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();
    k=k_L3[a];
    circuit="C";
    mi_selectlabel(x,y);
    mi_setblockprop(blockname,0,1,circuit,0,0,k*N)
    mi_clearselected();
end
end
end
end
end
end
end
```

# Annex IX.II Determinació del flux en funció de la posició rotòrica

```
--2.ANÀLISI EN BUIT--------------------------------------------------
--2.1 Determinació dels fluxos--------------------------------------
--Dades
Q=27;
p=12;
m=3;
anglemec=360/p;
numpoints=72;
step=6;
mi_saveas("tempPMSG1.fem");
--Obrir fitxer
handle=openfile("fluxbuitPMSG.txt","a");
write(handle,"posicio    ","FluxA    ","FluxB    ","FluxC   ","\n");
closefile(handle);
alfa=0;
for n=1,numpoints,1 do
  mi_analyze(1);
  mi_loadsolution();
  handle=openfile("fluxbuitPMSG.txt","a");
  --Llegeix els valors de cada circuit: corrent, tensió i flux
  ia,va,fa=mo_getcircuitproperties("A");
  ib,vb,fb=mo_getcircuitproperties("B");
  ic,vc,fc=mo_getcircuitproperties("C");
  --PosiciÓ
  pos=(n-1)*step;
  --Escriu els resultats en un fitxer
  write(handle,pos," ",fa," ",fb," ", fc,"\n");
  closefile(handle);
  print(pos," ",fa," ",fb," ",fc);
  mo_close();
  --Gira el rotor a la nova posició
  mi_seteditmode("group");
  mi_selectgroup(20);
  mi_moverotate(0,0,step);
end
```

# Annex IX.III Parell de Cogging

```
--2.ANÀLISI EN BUIT------------------------
--2.2 Parell de Cogging--------------------
--Dades inicials
Q=27;
p=12;
MCD=3;
Np=2*p/MCD;
Tcogging=360/(Np*Q);
numpoints=900;
step=0.1388;
--Obrir fitxer
mi_saveas("temp1PMSG.fem");
handle=openfile("coggingPMSG.txt","a");
write(handle,"posicio  ","Mcog  ","\n");
closefile(handle);
alfa=0;
--Bucle
for n=1, numpoints,1 do
  --Calcula
  mi_analyze(1);
  mi_loadsolution();
  handle=openfile("coggingPMSG.txt","a");
  --Càlcul parell de cogging
  mo_groupselectblock(20);
  mo_groupselectblock(15);
  Mcog=mo_blockintegral(22)
  mo_clearblock();
  --Posició
  pos=(n-1)*step;
  --Escriu els reultats en un fitxer
  write(handle,pos," ",Mcog,"\n");
  closefile(handle);
  print(pos," ",Mcog);
  mo_close();
  --Gira el rotor a la nova posicio
  mi_seteditmode("group");
  mi_selectgroup(20);
  mi_moverotate(0,0,step)
end
```

# Annex IX.IV Determinació del parell en funció de la posició rotòrica

```
--3.ANÀLISI EN CÀRREGA-------------------------
--3.1 Parell ----------------------------
--Nombre de punts
Q=27;
p=24; --Pols
pp=p/2;
numpoints=50;
step=1; -- Girem 2 graus a cada iteració.
mi_saveas("tempPMSG.fem");
handle=openfile("ManglePMSG.txt","a");
write(handle,"posicio ","Mangle ","\n");
closefile(handle);
alfa=0;
for n=1, numpoints, step do
      mi_analyze(1);
      mi_loadsolution();
      handle=openfile("ManglePMSG.txt","a");
      mo_groupselectblock(20);
      mo_groupselectblock(15);
      Mangle = mo_blockintegral(22);
      mo_clearblock();
      pos = (n-1)*step;
      write(handle,pos," ",Mangle,"\n");
      closefile(handle);
      print(pos," ",Mangle);
      mo_close();
      --gira el rotor a la nova posició
      mi_seteditmode("group");
      mi_selectgroup(20);
      mi_moverotate(0,0,step);
end
```

# Annex IX.V Determinació del parell girant

```
--ANÀLISI EN CÀRREGA--------------------------------------------------
--3.2 Parell girant
--nombre de punts
numpoints=900;
step=0.1388;
--obrir fitxer fitxer amb les dades
mi_saveas("tempPMSG1.fem");
handle=openfile("parellgirantPMSG.txt","a");
write(handle,"posicio  ","Mgirant  ","FluxA  ","FluxB  ","FluxC  ","Ia
","Ib  ","Ic  ","\n");
closefile(handle);
Imax=2.3;
p=12;
pi=3.14159;
--bucle
for n=1, numpoints,1 do
  --calcula
  pos=(n-1)*step
  angle=pos*pi/180;
  Ia=Imax*cos(p*angle);
  Ib=Imax*cos(p*angle-2*pi/3);
  Ic=Imax*cos(p*angle+2*pi/3);
  mi_modifycircprop("A",1,Ia);
  mi_modifycircprop("B",1,Ib);
  mi_modifycircprop("C",1,Ic);
  mi_analyze(1);
  mi_loadsolution();
  handle=openfile("parellgirantPMSG.txt","a");
  --calcul parell
  mo_groupselectblock(20);
  mo_groupselectblock(15);
  Mgirant=mo_blockintegral(22)
  mo_clearblock();
  --mesurem el flux
  ia,va,fa=mo_getcircuitproperties("A");
  ib,vb,fb=mo_getcircuitproperties("B");
  ic,vc,fc=mo_getcircuitproperties("C");
  --posicio
  --escriu les dades al fitxer
  write(handle,pos,"  ",Mgirant,"  ",fa,"  ",fb,"  ",fc,"  ",ia,"
",ib,"  ",ic,"\n");
  closefile(handle);
  print(pos,"  ",Mgirant);
  mo_close();
  --gira el rotor a la nova posicio
  mi_seteditmode("group");
  mi_selectgroup(20);
  mi_moverotate(0,0,step);
 end
```

## Annex IX.VI Determinació de les inductàncies

```
--CÀLCUL ENERGIA EMMAGATZEMADA(Càlcul inductàncies Ld i Lq)
p=12;
periode=360/p;
step=10;
mi_saveas("temp_inductanciesPMSG1.fem");
handle=openfile("Energia_Entreferro_PMSG.txt", "a");
write(handle, "posicio    ", "Energia    ", "\n");
closefile(handle);
for posicio=0, 360, step do
  mi_analyze();
  mi_loadsolution();
  handle=openfile("Energia_Entreferro_PMSG.txt","a");
  --Calcular
  mo_groupselectblock(15);
  mo_groupselectblock(40);
  mo_groupselectblock(12);
  mo_groupselectblock(20);
  --mo_groupselectblock(50);
  --mo_groupselectblock(60);
  --mo_groupselectblock(70);
  --Energia emmagatzemada
  Energia=mo_blockintegral(2);
  --Escriu els resultats en un fitxer
  write(handle,posicio,"  ",Energia, "\n");
  closefile(handle);
  print(posicio," ",Energia);
  mo_close();
  --gira el rotor a la nova posició
  mi_seteditmode("group");
  mi_selectgroup(20);
  mi_moverotate(0,0,step);
end
```

# Annex IX.VII Determinació de les pèrdues Joule

```
--Pèrdues joule (Pj)---------------------------
--Dades inicials
numpoints=120;
step=1;
mi_saveas("temp_perduesPMSG.fem");
--obrir fitxer
handle=openfile("perduesPMSG.txt","a");
write(handle,"posicio    ","Mgirant     ","Rlosses    ","Totallosses    ","FluxA
","FluxB    ","FluxC     ","Ia     ","Ib     ","Ic     ","\n");
closefile(handle);
Imax=2.3
p=12;
pi=3.14159;
alfa=0;
--bucle
for n=1,numpoints,1 do
  pos=(n-1)*step;
  angle=pos*pi/180;
  Ia=Imax*cos(p*angle);
  Ib=Imax*cos(p*angle-2*pi/3);
  Ic=Imax*cos(p*angle+2*pi/3);
  mi_modifycircprop("A",1,Ia);
  mi_modifycircprop("B",1,Ib);
  mi_modifycircprop("C",1,Ic);
  mi_analyze(1);
  mi_loadsolution();
  handle=openfile("perduesPMSG.txt","a");
  --Calcul parell
  mo_groupselectblock(15);
  mo_groupselectblock(20);
  Mgirant=mo_blockintegral(22);
  mo_clearblock();
  mo_groupselectblock(50);
  mo_groupselectblock(60);
  mo_groupselectblock(70);
  Rlosses=mo_blockintegral(4);
  mo_clearblock();
  mo_groupselectblock(110);
  Totallosses=mo_blockintegral(6);
  mo_clearblock();
  --mesurem el flux
  ia,va,fa=mo_getcircuitproperties("A");
  ib,vb,fb=mo_getcircuitproperties("B");
  ic,vc,fc=mo_getcircuitproperties("C");
      --Escriu els resultats en un fitxer
  write(handle,pos," ",Mgirant," ",Rlosses," ",Totallosses," ",fa," ",fb,"
",fc," ",ia," ",ib," ",ic,"\n");
  closefile(handle);
  print(pos," ",Mgirant);
  print(pos," ",Rlosses);
  print(pos," ",Ironlosses);
  mo_close();
  --gira el rotor a la nova posició
  mi_seteditmode("group");
  mi_selectgroup(20);
  mi_moverotate(0,0,step);
end
```

# Annex IX.VII Determinació de les pèrdues al ferro

```
--Pèrdues al ferro (Pfe)--------------------------------------------
  mi_analyze(1);
  mi_loadsolution();
  showconsole();--Per obtenir la consola de LUA
 --Desactiva el suavitzat de dades
  mo_smooth("off")
  -- Número total d'elements
  numelm = mo_numelements()
  -- DADES DEL GENERADOR--------------------------------------------
  freq=20
  depth=0.040
  -- Inicialització de les pèrdues
  Pfe=0
  --Coefficients de Bertotti M470-50 a 20z
  Kc=0.5428
  Kh=36.9764
  Ka=146.0213
  -- Bucle de cálcul de las pèrdues del fero mitjançant
  -- la suma de les pèrdues de cada elemento del grupo
  ---------------------- FERRO ESTATOR-------------------------------
  for k=1,numelm do
      --p1, p2 i p3: potèncial magnetic en els vèrtex
      --x,y: coordenadres del centroide
      --a: àrea de l'element
      --g:grup de l'element
      --L'estàtor està assignat al grup 110
      p1,p2,p3,x,y,a,g=mo_getelement(k)
       if (g == 110) then
      -- Volum de l'element
             dv = depth*a*mm^2;
      -- Propietats de l'element en el centroide
             a,bx,by,Sig,E,hx,hy = mo_getpointvalues(x,y)
      -- Càlcul del módul de B
            Bxmod=abs(bx)
            Bymod=abs(by)
            Bmod=sqrt(Bxmod^2+Bymod^2)
      -- PÈRDUES MAGNÈTIQUES ESTATÒRIQES (Pfe_estator) (model de Bertotti)
       Pfe=Pfe+(Kh*freq*Bmod^2+Kc*freq^2*Bmod^2+Ka*sqrt(freq^3*Bmod^3))*dv
       end
  end
  --Inicialització de les pèrdues
  Pfr=0
  ---------------------- FERRO ROTOR----------------------------------------
  for k=1,numelm do
       p1,p2,p3,x,y,a,g=mo_getelement(k)
       if (g == 15) then
      -- Volum de l'element
             dv = depth*a*mm^2
      -- Propietats de l'element en el centroide
             a,bx,by,Sig,E,hx,hy = mo_getpointvalues(x,y)
      -- Càlcul del módul de B
            Bxmod=abs(bx)
            Bymod=abs(by)
            Bmod=sqrt(Bxmod^2+Bymod^2);
      -- PÈRDUES MAGNÈTIQUES ROTÒRIQUES (Pfe_estator) (model de Bertotti)
       Pfr=Pfr+(Kh*freq*Bmod^2+Kc*freq^2*Bmod^2+Ka*sqrt(freq^3*Bmod^3))*dv
       end
  end
  print("Pèrdues ferro de l'estàtor:",Pfe)
  print("Pèrdues ferro del rotor:",Pfr)
```