Tesla Model S Induction Motor

RWD 85 Model

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Tesla Model S Induction Motor: RWD 85 Model

Abstract

In this project an induction motor is designed which has
the following specs:

B- Tesla Model S Induction Motor
Design the induction motor that is used in Tesla Model S,
which has a few different variations. To keep things simple,
use the RWD 85 Model, with rear wheel drive, which has the following specs:
Max. Power: 360 hp (270 kW)
Max. Torque: 441 Nm
Top Speed: 225 km/h

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Chapter 1. Introduction

The specs of the induction motor are as follows:

```
% Input Parameters of the
% Tesla Model S Induction Motor
power_max = 270;                % [kW] from project2
torque_max = 440;               % [Nm] from project2
speed_max = 225;                % [km/sa] from project2
m = 3;                          % [-] three phases
p1 = 2;                         % [-] pole pair from Hendershot-FIU-Lecture
power_rated = 288 * 0.746 ;     % [kW] from Hendershot-FIU-Lecture
tire_diameter = 27.7 * 25.4;    % [mm] from
                                % https://tiresize.com/tires/Tesla/Model-S/
                                % https://tiresize.com/tiresizes/245-45R19.htm
gear = 9.73;                    % [-] 9.73:1 (transmission) from
                                % https://en.wikipedia.org/wiki/Tesla_Model_S
speed_rpm_max = (speed_max*10^3/3600)/(tire_diameter*10^-3/2)*(60/2*pi())*gear;
                                % [rpm}
speed_rpm_rated = 6000;         % [rpm] from Hendershot-FIU-Lecture
                                % approx. knee of the torque-speed curve
f1 = speed_rpm_rated*2*p1/120;  % [Hz] frequency of the driver unit
Vd = 400;                       % [V] nominal bus voltage 85kWh from
                                % http://teslatap.com/undocumented/
u0 = 4*pi*10^-7;                % [-]
```

```
input parameters are given above.
calculated values from the input parameters given below
maximum speed of the rotor 1.6292e+05rpm
frequency of the driver 200Hz
rated power of the motor 214.8480kW
```

reference of the taken values are given .m file which is given above.

Chapter 2. Main Dimensions of Stator Core

Dis^2 * L output constant concept is used to determine parameters.

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
neff = 0.96;                % [-] targetted efficiency (IE3)
pwr_factor = 0.88;          % [-] typ. power factor for induction motors
                            % at full load varies between 0.85-0.90
Ke = 0.98 - 0.005*p1;       % [-] Ke defined as E1 / V1n (eq. 14.8)
                            % and approx. given as eq. 14.10
Sgap = Ke * power_rated * 10^3 / (neff * pwr_factor);  % [VA] (eq. 15.2)
stack_aspect = 1.25;         % [-] stack aspect ratio define as
                            % stack length to pole pitch ratio (eq. 14.19)
                            % (table 15.1)
Co = 250*10^3;              % [J/m^3] extracted from figure 14.14
Dis = ((2*p1*p1*Sgap)/(pi()*stack_aspect*f1*Co))^(1/3); %[m] (eq. 15.1)
pole_pitch = pi()*Dis/(2*p1);   % [m] pole pitch (eq. 15.2)
L = stack_aspect * pole_pitch;  % [m] stack length (eq. 15.2)
Ftan_max = torque_max / (Dis/2);% [N] tangential force
Sr = pi()*Dis*L;                % [m^2] surface area
shear_stress_max = Ftan_max / Sr; % [N/m^2], [Pascal] tangential shear stress
Cmech = power_max / (Dis^2*L*f1/p1); % [kWs/m^3] specific machine constant
max_stator_num = round(pi()*Dis/0.007); % [-] max. stator number from
                                        % ee564_basic_machine_design2, 8/23
min_stator_num = ceil(pi()*Dis/0.045);  % [-] min. stator number
Kd = 0.63;                   % [-] for 2p1 pole number (Table 15.2)
Dout = Dis / Kd;             % [m] outer diameter of the stator (eq. 15.4)
g1 = 0.1+0.012*(power_rated*10^3)^(1/3); %[mm] airgap (eq. 15.5)
g2 = 0.18+0.006*(power_rated*10^3)^(0.4);%[mm] airgap from
                                         % ee564_basic_machine_design 16/18
if (g1 > g2)
    g = g1;
else
    g = g2;
end;
g = g * 1.2;                            % [mm] to add safety factor
```

```
main dimensions of the stator are calculated as above

note that targetted efficiency is taken as 0.9600 regarding IE3
and power factor is taken as 0.8800

air gap Sgap = 2.4669e+05 [VA]
inner diameter of stator Dis = 0.2158  [m]
pole pitch = 0.1695 [m]
stack length L = 0.2119 [m]
tangential force Ftan = 4.0777e+03 [N]
tangential shear stress 2.8387e+04 [N/m^2]
```

```
specific machine constant Cmech = 273.6243 [kWs/m^3]
maximum stator number 97
minimum stator number 16
outer diameter of the stator Dout = 0.3426 [m]
air gap g = 1.1937 [mm] with safety factor
```

Chapter 3. The Stator Winding

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
Ns = 2*p1*m*4;           % [-] number of stator slots
q = Ns/(2*p1*m);         % [-] slots per pole per phase
pitch_factor = 5/6;      % [-] to minimize 5th and 7th harmonics
pitch_angle = 5/6*180;   % [°] pitch angle
slot_angle_alpha = 180/(Ns/(2*p1)); % [°] slot angle (eq. 15.7)
Kp1 = sind(pitch_angle/2); % [-] fundamental pitch factor (eq. 15.9)
Kd1 = sind(q*slot_angle_alpha/2)/(q*sind(slot_angle_alpha/2));
                         % [-] fundamental distribution factor (eq. 15.8)
Kw1 = Kp1*Kd1;           % [-] fundamental winding factor

Kp5 = sind(5*pitch_angle/2); % [-] 5th harmonic pitch factor (eq. 15.9)
Kd5 = sind(q*5*slot_angle_alpha/2)/(q*sind(5*slot_angle_alpha/2));
                         % [-] 5th harmonic distribution factor (eq. 15.8)
Kw5 = Kp5*Kd5;           % [-] 5th harmonic winding factor

Kp7 = sind(7*pitch_angle/2); % [-] 7th harmonic pitch factor (eq. 15.9)
Kd7 = sind(q*7*slot_angle_alpha/2)/(q*sind(7*slot_angle_alpha/2));
                         % [-] 7th harmonic distribution factor (eq. 15.8)
Kw7 = Kp7*Kd7;           % [-] 7th harmonic winding factor

Bg = 0.65;               % [Tesla] (e.q. 15.11)
Kst = 0.4;               % [-] so 1+Kst = 1.4
den_shape = 0.729;       % [-] density shape factor fig.14.13, where 1+Kst=1.4
Kf = 1.085;              % [-] form factor fig.14.13
flux_airgap = den_shape*pole_pitch*L*Bg; %[Wb] airgap flux (eq. 15.10)
Vph_rms = 4/pi()*Vd/2*(1/sqrt(2)); %[V] (eq. 8.56 Mohan) rms phase voltage
N_per_ph = Ke*Vph_rms/(4*Kf*Kw1*f1*flux_airgap); % [turns/phase] (eq. 15.12)
a1 = 1;                  % [-] the number of current path in parallel
ns = a1*N_per_ph/(p1*q);% [*] the number of conductors per slot
% to get even number conductors because of double layer winding
if ns<=2
    ns = 2;
else
    ns = ceil(ns);
    if 1 == mod(ns,2)
        ns = ns +1;
    end
end
N_per_ph_req = p1*q*ns;         % [turns/phase] required turns/phase
Bg_req = Bg * N_per_ph/N_per_ph_req; % [Tesla] required Bg
Vll_rms = Vph_rms * sqrt(3);    % [V] line-line rms voltage
Iph_rated_rms = power_rated*10^3/(neff*pwr_factor*sqrt(3)*Vll_rms);
                                % [A] rated phase current (eq. 15.16)
Jcos = 5.5;             % [A/mm^2] current density for 2p1=2,4 (eq. 15.17)
Aco = Iph_rated_rms/(Jcos*a1);  % [mm^2] stator wire cross section
dco = sqrt(4*Aco/pi);   % [mm] wire gauge diameter (eq. 15.19)
ap = 4;                 % [-] number of conductor in parallel
dcop = sqrt(4*Aco/(pi*ap)); % [mm] wire gauge diameter (eq. 15.20)
dcop_sta = 5.189;       % [mm] AWG4 size is chosen by regarding above value
```

```
The number of stator slots (Ns) should be multiple of 12.
By referring the suggested stator slot pitch for induction machines
(7-45mm), Ns should be between 16-97.
Let's choose Ns as 48.
To reduce harmonic frequency components let's use fractional pitch.
5/6 fraction is used to reduce 5th and 7th harmonics.
Note that
5/6 pitch will
minimize the 5th harmonic but not eliminate it as will 4/5 pitch
minimize the 7th harmonic but not eliminate it as will 6/7 pitch

slots per pole per phase is 4
fundamental pitch factor kp1 = 0.9659
fundamental distribution factor kd1 = 0.9577
fundamental winding factor kw1 = 0.9250

Let's investigate 5th and 7th harmonic as well
5th harmonic pitch factor kp5 = 0.2588
5th harmonic  distribution factor kd5 = 0.2053
5th harmonic winding factor kw5 = 0.0531

7th harmonic pitch factor kp7 = 0.2588
7th harmonic  distribution factor kd7 = -0.1576
7th harmonic winding factor kw7 = -0.0408

as can be seen above results, 5th and 7th harmonics
are attenuated to low levels

airgap flux 0.0170 [weber]
phase voltage rms 180.0633 [V]

number of conductors per slot ns = 2
note that it should be an even number as there are two
distinct coils per slot in a double layer winding

number of turns per phase 16
air gap flux density Bg = 0.5193 [Tesla]
rated phase current Iph = 470.7941 [A]

stator wire cross section Aco = 85.5989 [mm^2]
with wire gauge, paralel wire diameter dcop=5.2199 [mm]
AWG4 size is selected (5.1890mm)
```

Chapter 4. Stator Slot Sizing

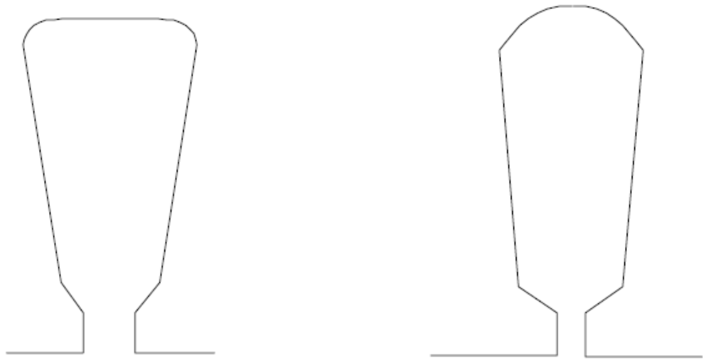


Figure 15.4 Recommended stator slot shapes

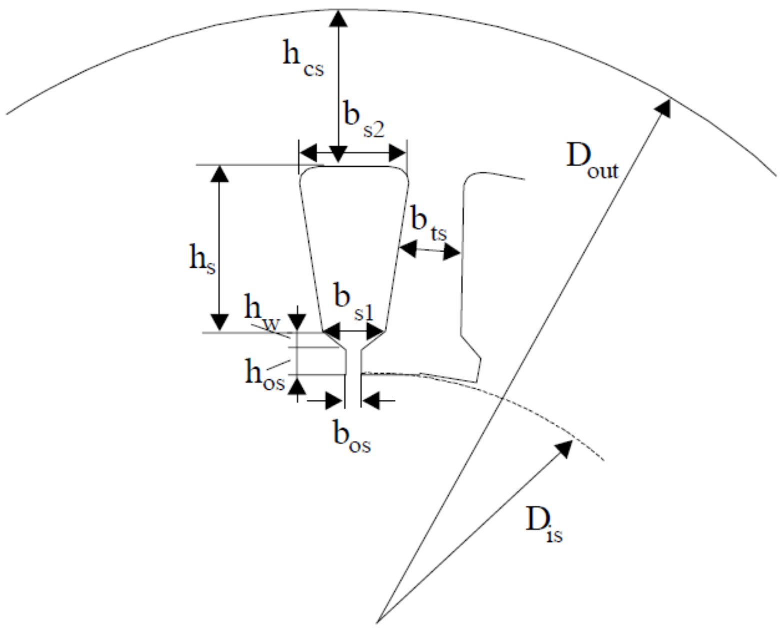


Figure 15.5 Stator slot geometry

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
% stator slot sizing will be determined
Kfill = 0.44;   % [-] slot fill factor for above 10kW
Asu = pi*dcop^2*ap*ns/(4*Kfill); % [mm^2] useful slot area (eq. 15.21)

% see figure stator slot geometry
bos = 2.5*10^-3;    % [m]
hos = 1*10^-3;      % [m]
hws = 4*10^-3;       % [m]
Kfe = 0.96;     % [-]
```

```
Bts = 1.625;     % [Tesla] stator tooth flux density
sta_slot_pitch = pole_pitch/(3*q);   % [m] stator slot pitch (eq. 15.3)
bts = Bg_req*sta_slot_pitch/(Bts*Kfe); % [m] tooth width  (eq. 15.22)
bs1 = (pi*(Dis+2*hos*+2*hws)/Ns)-bts;   % [m] slot lower witdh bs1 (eq. 15.23)
bs2 = sqrt(4*Asu*10^-6*tan(pi/Ns)+bs1^2);% [m] slot upper witdh bs1 (eq. 15.27)
hs = 2*Asu*10^-6/(bs1+bs2);             % [m] slot useful height (eq. 15.24)
Fmg = 1.2*g*10^-3*Bg_req/u0;            % [Aturns] airgap mmf (eq. 15.29)
                                        % note that carter coe. is taken 1.2
Hts = 3100;                             % [A/m] (table 15.4) interpolation
Fmts = Hts*(hs+hos+hws);                % [Aturns] stator tooth mmf (eq. 15.30)
Fmtr = Kst*Fmg - Fmts;                  % [Aturns] rotor tooth mmf (eq. 15.31)
hcs = (Dout-(Dis+2*(hos+hws+hs)))/2;   % [m] stator back iron height (eq. 15.32)
Bcs = flux_airgap/(2*L*hcs);            % [Tesla] back core flux density (15.33)
```

```
Stator slot geometry dimeonsions are shown in figure 15.5.
Asu = 389.0861 [mm^2]
bos = 0.0025  [mm]
hos = 1.0000e-03 [mm]
hws = 0.0040 [mm]
bts =  0.0047 [mm]
bs1 =  0.0094 [mm]
bs2 =  0.0138 [mm]
hs = 0.0335 [mm]
hcs = 0.0249 [mm]

Resultant mmfs
Fmg = 591.9621 [Aturns]
Fmts = 119.3143 [Aturns]
Fmtr = 117.4706 [Aturns]

The back core flux density is calculated as 1.6138T where within 1.4-1.7T.
```

Chapter 5. Rotor Slots

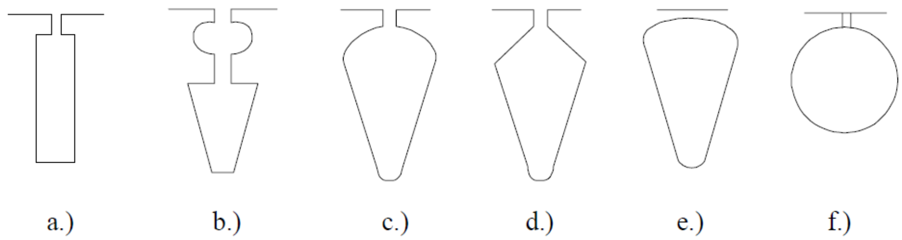


Figure 15.6 Typical rotor cage slots

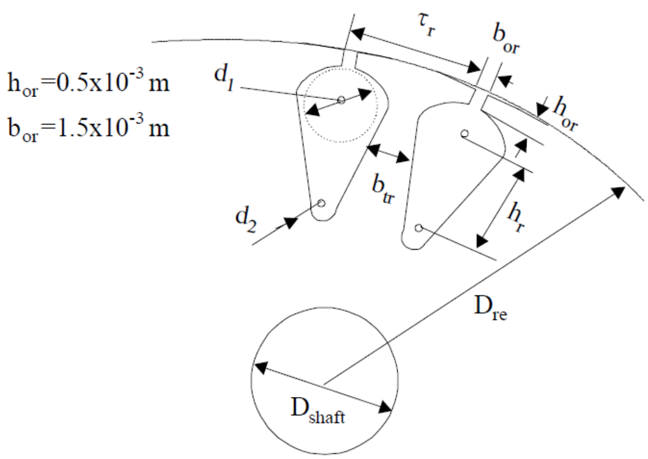


Figure 15.7 Rotor slot geometry

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
% rotor slot sizing will be determined
Nr = 60; % [-] rotor slot number
         % http://keysan.me/presentations/ee564_basic_machine_design2.html#32
         % 17/23 slayt table 7.5 most advantageous slot numbers for rotors
         % with slots skewed for a stator slot pitch 1-2
Ki = 0.8*pwr_factor+0.2; % [-] (eq. 15.35)
Ib = Ki*(2*m*N_per_ph_req*Kw1/Nr)*Iph_rated_rms;
                         % [A] rated rotor bar current (eq. 15.34)
Jb = 3.42; % [A/mm] current density in the rotor bar
Ab = Ib/(Jb*10^6);       % [m^2]rotor slot area (eq. 15.36)
Ier = Ib/(2*sin(pi*p1/Nr)); % [A] end ring current (eq. 15.37)
Jer = 0.75*Jb*10^6;  % [A/m^2] current density in the end ring
Aer = Ier / Jer;     % [m^2] end ring cross section (eq. 15.38)
hor = 1*10^-3;       % [m] refer to figure 15.7
hwr = 4*10^-3;       % [m] refer to figure 15.5
bor = 2.5*10^-3;     % [m] refer to figure 15.7
rot_slot_pitch = pi*(Dis-2*g*10^-3)/Nr; % [m] rotor slot pitch (eq. 15.39)
Btr = 1.675;           % [Tesla] rotor tooth flux density
btr = Bg_req*rot_slot_pitch/(Kfe*Btr); % [m] rotor tooth width (eq. 15.40)
% Let me calculate rotor slot dimensions like stator slot
```

```
br1 = pi*(Dis-2*hor-2*hwr)/Nr - btr; % [m] changed from (eq. 15.23)
br2 = sqrt(4*Ab*tan(pi/Nr)+br1^2);   % [m] changed from (eq. 15.27)
hr = 2*Ab/(br1+br2);                 % [m] changed from (eq. 15.24)
Htr = 4200;                          % [A/m] from table 15.4 interpolation
Fmtr_res = Htr*(hr+hor+hwr); % [Aturns] rotor teeth mmf changed from(eq. 15.30)
Bcr = 1.65;                  % [Tesla] rotor back core flux density
hcr = flux_airgap/(2*L*Bcr); % [m] rotor back core height (eq. 15.46)
Dshaft_max = Dis-2*g*10^-3-2*(hor+hwr+hr+hcr);
                             % [m] max. shaft diameter (eq. 15.47)
b = 1.0*(hr+hor+hwr);        % [m] end rind cross section b (eq. 15.50)
a = Aer/b;                   % [m] end rind cross section a (eq. 15.51)
```

```
Rotor slot geometry dimeonsions are shown in figure 15.7.
But rotor slot geometry type is assumed 15.6d.
And dimension calculations are computed like stator slot as in
figure 15.5.
But this time bs1 and bs2 are reversed.

Ib =  629.9058 [A]
Ab = 1.8418e-04 [m^2]
Ier = 3.0131e+03 [A]
Aer = 0.0012 [m^2]
bor = 0.0025  [mm]
hor = 1.0000e-03 [mm]
hwr = 0.0040 [mm]
btr =  0.0036 [mm]
br1 =  0.0072 [mm]
br2 =  0.0095 [mm]
hr = 0.0221 [mm]
hcr = 0.0243 [mm]

Resultant mmf
Fmtr_res = 113.9060 [Aturns]
so close to calculated as in stator siot sizing part Fmtr=117.4706.

The maximum diameter shaft 0.1105 [m].
```

Chapter 6. The Magnetizing Current

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
% magnetizing current will be determined
y1 = bos^2/(5*g*10^-3+bos);  % [m] (eq. 15.53)
y2 = bor^2/(5*g*10^-3+bor);  % [m] (eq. 15.53)
Kc1 = sta_slot_pitch/(sta_slot_pitch-y1); % [-] (eq. 15.55)
Kc2 = rot_slot_pitch/(rot_slot_pitch-y2); % [-] (eq. 15.56)
Kc = Kc1*Kc2;   % [-] total Carter coefficient Kc
Ccs = 0.88*exp(-0.4*Bcs^2); % [-] subunitary empirical coe. (eq 15.60)
Ccr = 0.88*exp(-0.4*Bcr^2); % [-] subunitary empirical coe. (eq 15.60)
Hcs = 2500;     % [A/m] Hcs value at Bcs (table 15.4)
Hcr = 3460;     % [A/m] Hcs value at Bcs (table 15.4)
Fmcs = Ccs*pi*(Dout-hcs)/(2*p1)*Hcs;
                % [Aturns] stator back core mmfs (eq. 15.58)

Fmcr = Ccr*pi*(Dshaft_max+hcr)/(2*p1)*Hcr;
                % [Aturns] rotor back core mmfs (eq. 15.59)
Flm = 2*(Fmg+Fmts+Fmtr+Fmcs+Fmcr); % [Aturns] magnetizing mmf (eq. 15.52)
Ks = Flm/(2*Fmg)-1; % [-] total saturation factor (eq. 15.61)
Im = pi*p1*(Flm/2)/(3*2^(0.5)*N_per_ph_req*Kw1); % [A] magnetizing current
                                                 % (eq. 15.62)
im = Im/Iph_rated_rms; % [-] relative (p.u) value of Im (eq. 15.62')
```

```
To find magnetizing current first of all magnetizing mmf
should be calculated.
Carter's coefficient is calculated and the result is 1.1297
which was taken 1.2 in eq. 15.29.
Back core mmfs are also calculated.
Fmcs = 193.6720 [Aturns]
Fmcr = 108.5249 [Aturns]
total magnetizing mmf
Flm = 2.2619e+03 [Aturns]
total saturation factor Ks is 0.9105
magnetizing current Im is 113.1641 [A]
relative p.u value of the Im is 0.2404.
```

Chapter 7. Resistance and Inductances

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
% resistance and inductances refer to eq. circuit (figure 15.9)
y = pitch_factor*pole_pitch; % [m] coil span (eq. 15.67)
lend = 2*y-0.02;             % [m] coil end connection length (eq. 15.65)
lc = 2*(L+lend);             % [m] coil length (eq. 15.64)
pco_80deg = 2.1712*10^-8;    % [ohm.m] copper resistivity at @80° (eq. 15.69)
Rs = pco_80deg*(lc*N_per_ph_req)/(Aco*10^-6*a1); % [Ohm] stator resistance
                                                 % (eq. 15.63)
lambdaec = 0.34*(q/L)*(lend-0.64*pitch_factor*pole_pitch);
                             % [-] (eq. 15.79) two-layer, end connection
                             % specific geometric permeance coefficient
Lec = 2*u0*L*N_per_ph_req^2/(p1*q)*lambdaec; % [H] end winding inductance
                                             % derived from (eq. 15.75)
ler = pi*(Dis-(2*g*10^-3)-(3*10^-3)-b)/Nr;   % [m] end ring segment
                                             % (eq. 15.71 & Dre-Der~=3-4mm
pal_20deg = 3.1*10^-8;
pal_80deg = pal_20deg*(1+(80-20)/273);       % [ohm.m] aluminium resistivity
Rer = pal_80deg*(ler/(2*Aer*sin(pi*p1/Nr)^2)); % [ohm] rotor end ring segment
                                               % derived from (eq. 15.70)
mbetas = sqrt((2*pi*f1*u0)/(2*pal_20deg));     % [m^-1] (eq. 15.73)
S = 1;
meps = mbetas*hr*sqrt(S);                      % [-] (eq. 15.73)
Kr = meps;                                     % [-] (eq. 15.72)
Rbes1 = pal_80deg*(L/Ab)*Kr+Rer; % [ohm] rotor bar/end ring segment
                                 % eq. circuit (eq. 15.70)
Rrps1 = (4*m/Nr)*(N_per_ph_req*Kw1)^2*Rbes1; % [ohm] rator cage resistance
                                 % referred to stator at S=1 (eq. 15.74)
Rbesn = pal_80deg*(L/Ab)+Rer;  % [ohm] for rated slip
Rrpsn = Rrps1*(Rbesn/Rbes1);   % [ohm] (eq. 15.87)
```

```
stator resistance is calculated as 0.0039 Ohm.  (cupper at 80°)
End winding inductance Lec 1.8823e-05H
resistance of the end ring of the rotor is 1.4138e-05 (aliminium at 80°)
resistance of the rotor bar/end ring segment
equivalent resistance Rbes1 = 1.6770e-04 [ohm]
rotor cage resistance referred to stator Rrpsn = 0.0025 [ohm]
```

Chapter 8. Losses and Efficiency

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
%losses and efficiency will be calculated
Pco = 3*Rs*Iph_rated_rms^2; % [W] stator winding losses
Pal = 3*Rrpsn*Ki^2*Iph_rated_rms^2; % [W] rotor cage losses (eq. 15.97)
Pmv = 0.012*power_rated*10^3; % [W] mechanical/ventilation losses for p1=2
Pstray = 0.01*power_rated*10^3; % [W] stray losses
yiron = 7800; % [kg/m^3] density
Gt1 = yiron*Ns*bts*(hs+hws+hos)*L*Kfe; % [kg] stator tooth weight
Kt = 1.7;   % [-] (eq. 15.98) core loss augmentation
p10 = 2.5;  % [W/kg} specific losses in W/kg at 1.0 Tesla and 50Hz
Pt1 = Kt*p10*(f1/50)^1.3*Bts^1.7*Gt1; % [W] stator teeth fund. losses
                                      % (eq. 15.98)
Gy1 = yiron*pi/4*(Dout^2-(Dout-2*hcs)^2)*L*Kfe; % [kg] stator back iron weight
                                      % (eq. 15.101)
Ky = 1.75; % [-] influence of mechanical machining
Py1 = Ky*p10*(f1/50)^1.3*Bcs^1.7*Gt1; % [W] stator back iron (yoke) losses
                                      % (eq. 15.100)
Piron1 = Pt1+Py1;   % [W] fund. iron losses
Kps = 1/(2.2-Bts);  % [-] (eq. 15.104)
Kpr = 1/(2.2-Btr);  % [-] (eq. 15.104)
Bps = (Kc2-1)*Bg_req; % [Tesla] (eq. 15.105)
Bpr = (Kc1-1)*Bg_req; % [Tesla] (eq. 15.105)

Gtr = yiron*Nr*btr*(hr+hwr+hor)*L*Kfe; % [kg] rotor teeth weight

Pirons = 0.5*10^-4*((Nr*f1/p1*Kps*Bps)^2*Gt1+(Ns*f1/p1*Kpr*Bpr)^2*Gtr);
                      % [W] tooth flux pulsation core loss constitutes
                      % the main components of stray losses (eq. 15.103)
Piron = Pirons+Piron1; % [W] total iron core loss
Ploss_total = Pco+Pal+Piron+Pmv+Pstray; % [W] total losses (eq. 15.95)
neff_cal = power_rated*10^3/(power_rated*10^3+Ploss_total); % [-]
                                        % efficiency (eq. 15.94)


loss components are calculated in this chapter
stator tooth weight Gt1 = 13.7818 [kg]
stator back iron weight Gy1 = 39.3987 [kg]
rotor teeth weight Gtr = 9.3171 [kg]

stator winding losses Pco = 2.5602e+03 W
rotor cage losses Pal = 1.3721e+03 W
mechanical/ventilation losses Pmv = 2.5782e+03 W
stray losses Pstray = 2.1485e+03 W
stator teeth fund. losses  Pt1 = 810.6309 W
stator back iron (yoke) losses Py1 = 824.7193 W
fund. iron loss Piron1 = 1.6354e+03 W
tooth flux pulsation core loss constitutes the main
components of stray losses Pirons = 133.1240 W
total iron loss Piron = 1.7685e+03 W
total loss Ploss_total = 1.0427e+04 W
efficiency, neff_cal = 0.9537
```

```
Note that calculated efficiency value is so close to the
targeted efficiency which was neff = 0.9600
```

Chapter 9. Operation Characteristics

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
% operating characteristics will be investigated
I0a = (Piron+Pmv+(3*Im^2*Rs))/(3*Vph_rms);  % [A] no load active current
                                            % (eq. 15.109)
Sn = Pal/(power_rated*10^3+Pal+Pmv+Pstray); % [-] rated slip (eq. 15.110)
Tn = power_rated*10^3/(2*pi*(f1/p1)*(1-Sn)); % [Nm] rated shaft torque
                                             % (eq. 15.111)
pwr_factor_cal = power_rated*10^3/(3*Vph_rms*Iph_rated_rms*neff_cal); % [-]
                                            % rated power factor (eq. 15.117)
```

```
The operation characteristics are calculates as below
active no load current I0a = 8.3204A
rated slip Sn = 0.0062
rated shaft torque Tn = 344.0780Nm
rated power factor pwr_factor_cal = 0.8858

note that it is so closed to firt assumption value (0.8800)
```

Chapter 10. Temperature Rise

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
% a coarse verification of temperature rise is given here
aconv1 = 50; % [W/m^2.K] IM with selfventilators (below 100Kw) (eq. 15.123)
            % it is not enough to cool
% http://www.engineersedge.com/thermodynamics/overall_heat_transfer-table.htm
% forced water cooling heat transfer structure should be used
aconv2 = 650; % [W/m^2.K]
acond = 833; % [W/m^2.K] slot insulation conductivity (eq. 15.124)
Als = (2*hs+bs2)*L*Ns;  % [m^2] stator slot lateral area (eq. 15.125)
Kfin = 3;   % [-] finn factor (eq. 15.126)
Aframe = pi*Dout*(L+pole_pitch)*Kfin; % [m^2] frame area including finn area
                                      % (eq. 15.126)
delta_co = Pco/(acond*Als);  % [°] temperature differential between conductors
                             % in slots and the slot wall (eq. 15.121)

delta_frame2 = Ploss_total/(aconv2*Aframe); % [°] frame temperature rise
                             % with respect to ambient air (eq. 15.122)
delta_frame1 = Ploss_total/(aconv1*Aframe); % [°] frame temperature rise
                             % with respect to ambient air (eq. 15.122)

temp_ambient = 40; % [°] ambient temperature
temp_co = temp_ambient+delta_frame2+delta_co; % [°] winding temperature
                                              % (eq. 15.127)
                                              % should be <80°
```

```
temperature rise of the winding will be calculated roughly
note that if selfventilators are used to cool the motor
the frame temperature rise will be delta_frame1=169.3815°
which is not suitable for this motor design
so forced water cool method is used to cool motor.
the frame temprature rise delta_frame2  = 13.0293°
temperature differential between conductors in slots and the slot wall
delta_co = 3.7408°

with ambient temperature 40°
winding temperature will be 56.7701°  < 80°
at rated power (214.8480kW)
```

Chapter 11. Other Parameters

```
% Based on the The Induction Machine Handbook Chapter 14 & 15
% motor weight will be determined
Gyr = yiron*pi/4*((Dis-2*hcr)^2-Dshaft_max^2)*L*Kfe; % [kg] rotor back iron yoke
                                                % weight
weight_rotor = Gtr + Gyr; % [kg] rotor iron weight
weight_stator = Gy1 + Gt1; % [kg] stator iron weight
Kshaft = 1.35; % [-] to connect the load to the shaft there should be
              % available space outside of the shaft
weight_shaft = yiron*pi/4*(Dshaft_max^2)*L*Kfe*Kshaft; % [kg]shaft iron weight

ycopper = 8960; % [kg/m^3] density
weight_sta_co = ycopper*m*N_per_ph_req*lc*Aco*10^-6*a1; % [kg] copper weight

yaliminium = 2700; % [kg/m^3] density
weight_rot_al = yaliminium*Nr*(Ab*L+Aer*ler); % [kg] rotor aliminum bar weight

weight_total = weight_rotor+weight_stator+weight_shaft+weight_sta_co+weight_rot_al
% note that cooling and outside frame and other accessories are not
% included!

Grotor = weight_rotor + weight_shaft + weight_rot_al;   % [kg] total rotor loss

inertia_rotor = 0.5*Grotor*(Dis/2)^2; % [kg.m^2] rotor inertia
```

```
roughly weight and inertia calculations are given above.
weight of the rotor back iron (yoke) Gyr = 19.5901 [kg]
weight of the rotor iron  28.9072 [kg]
weight of the stator iron 53.1805 [kg]
weight of the shaft 20.5409 [kg]
weight of the stator copper winding 34.9268 [kg]
weight of the rotor alinium bars  8.1481 [kg]

total weight of the motor 145.7036 [kg]
Note that in this calculation, cooling, motor frame and other
accessories are not included.

inertia of the rotor is calculated by the formula 1/2*m*r^2
total rotor weight is Grotor = 57.5963 [kg]

inertia of the rotor is 0.3353 [kg.m^2]
```

Chapter 12. Motor Analysis

Note that all the required values for "motoranalysis" program is determined last chapters.

Conductivity of the copper and aliminium is edited explicitly from the internet.

Rotor bar skew angle is taken as 6° i.e. one bar

Figure 12.1. geometry editor

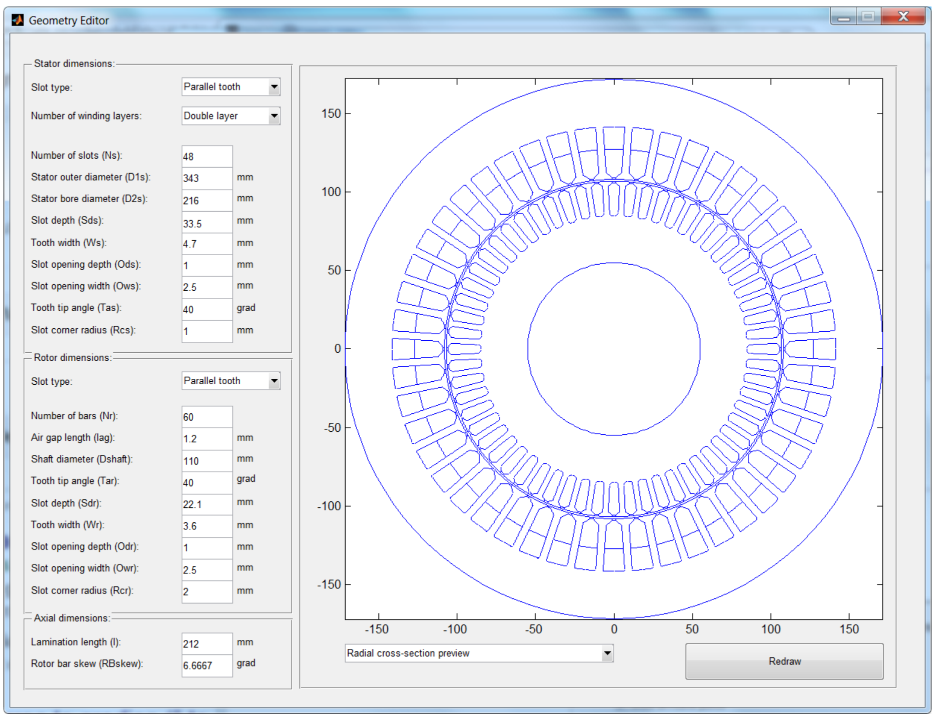


Figure 12.2. stator slot

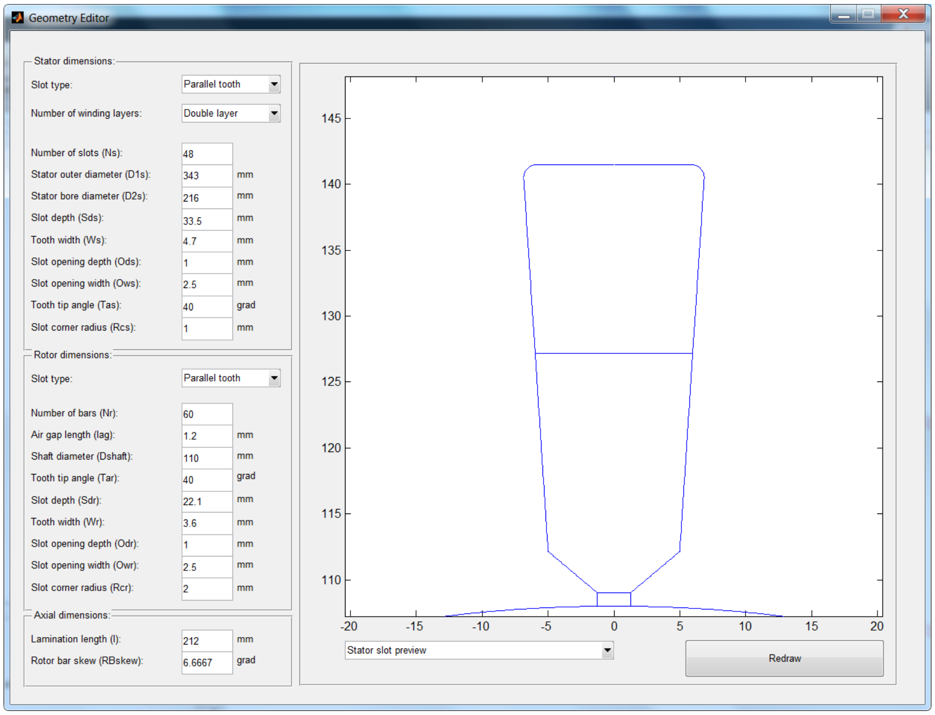


Figure 12.3. rotor slot

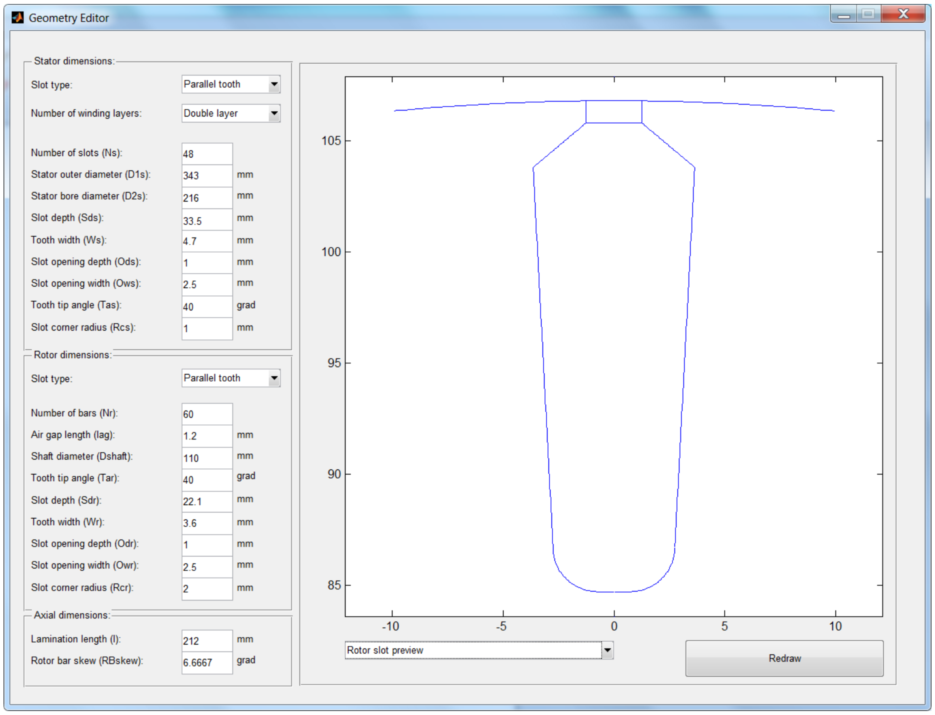


Figure 12.4. winding diagram

Figure 12.5. iron core B-H curve

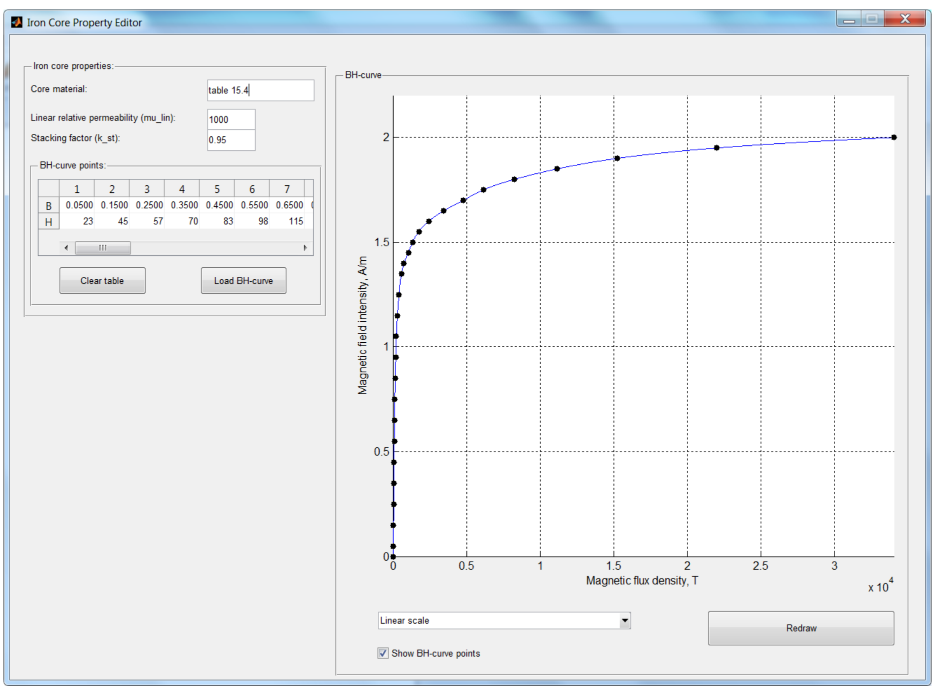
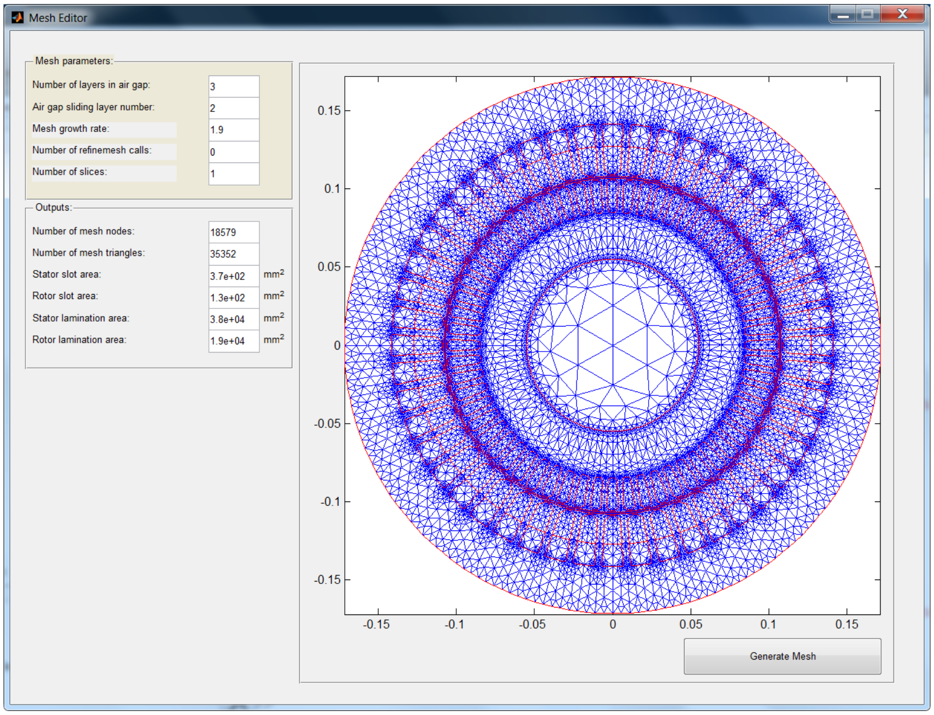


Figure 12.6. mesh editor



Chapter 13. Conclusion

In this project, Tesla Model S Induction Motor (RWD 85 model) is designed, based on the The Induction Machine Handbook Chapter 14 & 15.
Input parameters are taken by investigating the motor on the internet.
Main dimensions are calculated, the number slots of the stator is determined and winding parameters are calculated.