Tesla Model S Induction Motor

RWD 85 Model

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Table of Contents

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; %
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;                  % [-]
```

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
```

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
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

Chapter 4. Stator Slot Sizing

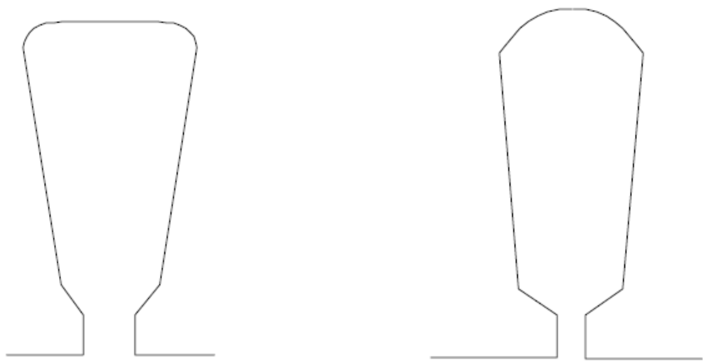

Figure 15.4 Recommended stator slot shapes

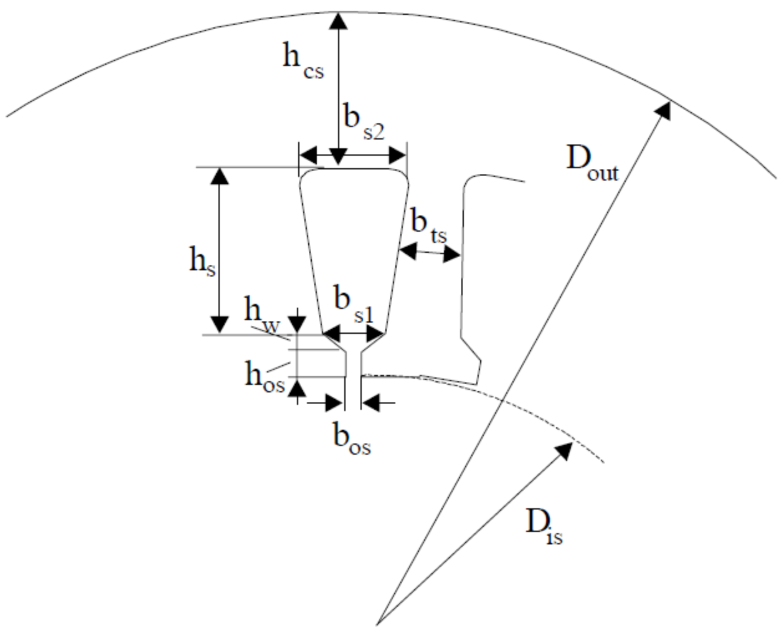

Figure 15.5 Stator slot geometry

```
% 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 = 0.75*10^-3;       % [m]
hw = 2.5*10^-3;         % [m]
Kfe = 0.96;     % [-]
```

```
Bts = 1.55;     % [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*hw)/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)
Hts = 1760;                            % [A/m] (table 15.4)
Fmts = Hts*(hs+hos+hw);                % [Aturns] stator tooth mmf (eq. 15.30)
Fmtr = Kst*Fmg - Fmts;                 % [Aturns] rotor tooth mmf (eq. 15.31)
hcs = (Dout-(Dis+2*(hos+hw+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 = 7.5000e-04 [mm]
hw = 0.0025 [mm]
bts =  0.0049 [mm]
bs1 =  0.0092 [mm]
bs2 =  0.0137 [mm]
hs = 0.0340 [mm]
hcs = 0.0261 [mm]

Resultant mmfs
Fmg = 591.9621 [Aturns]
Fmts = 65.6466 [Aturns]
Fmtr = 171.1383 [Aturns]

The back core flux density is calculated as 1.5402T where within 1.4-1.7T.
```