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To: *Armin Eilaghi*
CC: *Connor Gaudette*
From: *CWC GEN*
Date: *09/10/2025*
Re: *Engineering Calculations Summary*

I. TOP-LEVEL DESIGN

The problem that is being solved is helping the Northern Arizona University (NAU) Collegiate Wind Competition (CWC) team design their future wind turbine by not designing it around commercial permanent magnetic synchronous generators (PMSG), which dictates the wind turbines performance. The solution is to design a PMSG that will have adjustable parameters, like voltage, current, torque, rotational speed, and resistive torques, so the NAU CWC team can easily design their wind turbine.

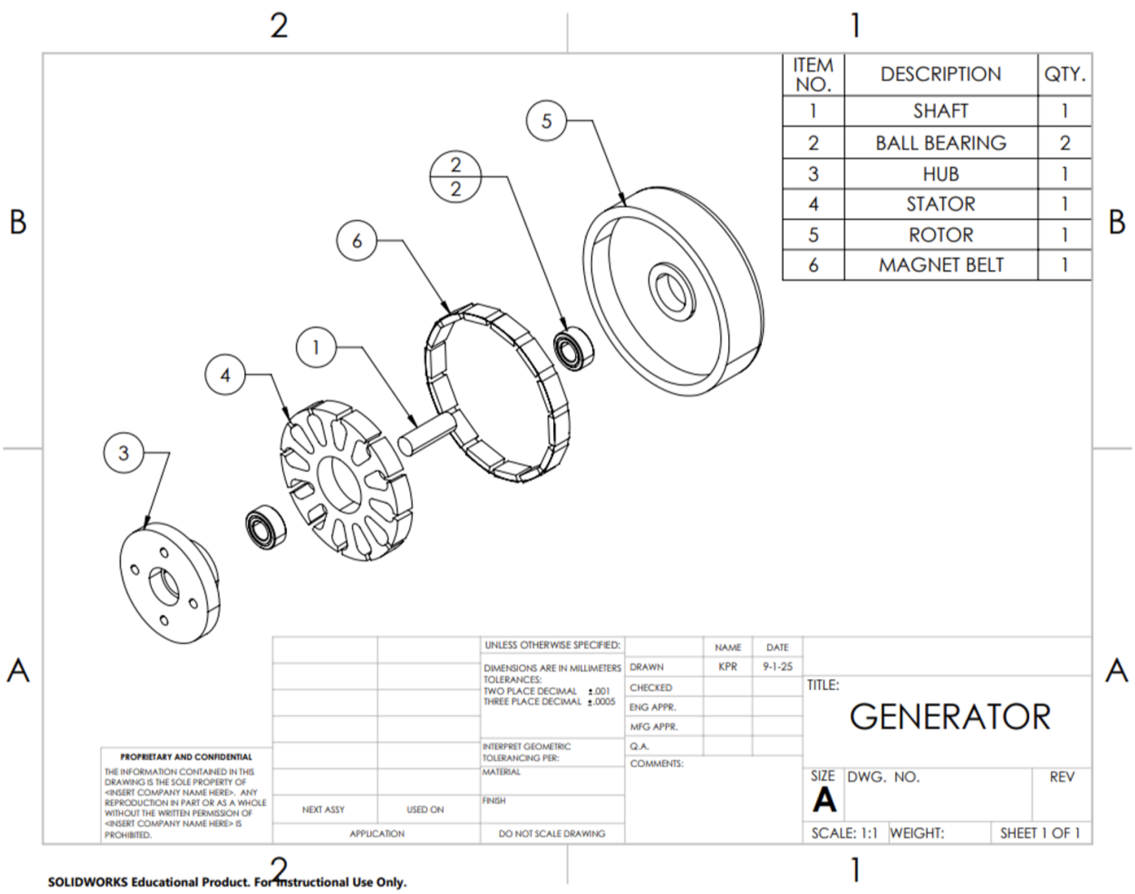

Fig 1. Top-Level CAD of the PMSG

As shown in Fig 1, the PMSG subfunctions consist of the shaft, ball bearings, hub, stator, rotor, and magnet belt. All the subfunctions are integrated together to form a PMSG that has adjustable parameters. Furthermore, item numbers 1, 3, 4, 5, and 6 are integrated together to generate power, where item numbers 3 and 4 are the stator, and item numbers 1, 5, and 6 are the rotor of the PMSG. As for item number 2, the bearings outer race is part of the stator, and the inner race is part of the rotor, which helps differentiate what part will be rotating.

House Of Quality (Minimize or Maximize)			Technical Specifications (How)												Competitive Assessment		
			Maximum 48 Volts	45 cm Roter Diameter of Turbine	Low Total Resistant Torque	Low Kv Rating	Magnetic Flux	Turbine Power	Generator Power	Number of Coils	Tip Speed Ratio	Diemeter of coil	Cut Out Speed	Cut In Speed			
	Customer Requirements (What)	Importance	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Low Voltage	96	9	3	9	9	9	9	9	9	3	9	9	9	1	9	3
2	Small Size	60	3	9	3	1	3	9	3	9	9	9	1	1	1	9	1
3	High Power Generation	100	9	1	9	9	9	9	9	9	9	9	9	9	9	3	1
4	Under Budget	28	1	3	1	1	1	3	3	3	3	3	3	3	1	3	9
5	Ability to change easy	60	1	3	3	9	3	3	9	9	9	9	1	1	3	3	1
6	Up to design standards for CWC	102	9	9	9	9	9	9	9	3	9	9	9	9	9	9	3
7	3 phase AC	34	3	3	3	3	3	1	3	9	1	3	1	1	3	9	9
		Target	48 V	45 cm	2 N-m	150	1-3 T	100 kW	0.5-10 kW	6 coils	7 to 8	0.321-0.644 mm	25 m/s	3 m/s			
		Importance	35	31	37	41	37	43	45	51	43	51	33	33			

Fig 2. Quality Function Deployment

Table 1 and Table 2 will describe the customer and engineering requirements, and their description from Fig 2.

Table 1. Customer requirements and descriptions

Customer Requirements	Description
Low Voltage	Client set safety standard
Small Size	Intended for a small-scale wind turbine
High power	To perform well in the CWC
Under Budget	Limited to funds and donations
Ability to change easily	For future guideline changes and improvements
Up to CWC design standards	Eligible to be used in competition
3 phase AC Generator	Standard small scale generator design

Table 2. Engineering requirements and descriptions

Engineering Requirements	Description
Maximum 48 Volts	CWC guidelines and safety purposes
45 cm rotor diameter of the turbine	CWC guidelines
Low total resistance torque (Nm)	Higher efficiency at lower wind speeds
Low Kv rating	Below 150 is desired, this increases voltage
High magnetic flux (Tesla)	Increases power output
High turbine power output (W)	Output of 1000 kW is desired for the power output
Number of coils	Determined by stator geometry and fill ratio
Tip speed ratio, between 7 and 8	This ratio produces a maximum power output
Diameter of the coil	The gauge to be used in the coil

Cut out speed, 25 (m/s)	CWC guidelines and safety purposes
Cut in speed, 3 (m/s)	CWC guidelines and higher efficiency

II. STANDARDS, CODES, & REGULATIONS

The design of the PMSG is informed by industry standards governing materials, safety, electrical machines, and testing. Each analysis topic connects to specific standards as follows:

- The number of turns in a coil must comply with IEE 112 and IEC 60034 which define test methods and performance requirements for rotating electrical machines [1,2]. This ensures that the coil meets efficiency and reliability requirements. The number of turns must also comply with NEMA MG 1, which provides a guideline for voltage regulation and allowable temperature rise related to coil configurations [3].
- The Magnetic Flux and Generator Power will need to follow IEC 60034, which sets requirements for flux density, efficiency, and vibration in rotating machines [2]. It will also need to follow IEC 61400, which applies to wind turbines and requires generator designs to handle fluctuating loads and variable input conditions [2].
- Wire gauges must follow the NEMA MG-1 standard, which is used to ensure thermal safety and current-carrying capacity [3]. These gauges must also follow IEC Insulation Standards that establish maximum coil operating temperatures based on insulation class [2].
- The Arduino Code and Sensors need to follow IEC 60204-1, which applies to microcontrollers and sensor systems [2].
- The magnet specifications must conform to IEC 60034-1, which ensures that magnet selection supports stable flux linkage and efficiency in rotating machines [2]. Handling strong permanent magnets also requires compliance with OSHA lab safety guidelines to prevent injury.

These standards ensure that each analysis topic is within accepted engineering practices. Collectively, they establish performance limits, material requirements, and safety conditions that guide the PMSG design.

III. EQUATIONS & SOLUTIONS

A. *Magnet and Slot Ratio Analysis #1 (Christian Brown)*

1) **Load case**:

When designing a generator, it is important to consider the ratio of magnets to slots in the steel stator. This impacts the cogging torque, efficiency, and overall performance of a generator. The scale of the generator is also important to consider, allowing for some range of ratios to be evaluated for the task at hand. The equation and data sheet utilized in this analysis are found online [4].

2) **Equations & solutions**:

The fundamental equation for the magnet and slot ratio is as follows:

$$q = \frac{N_s}{N_{ph} * N_m} \tag{1}$$

where q is the magnet and slot ratio; N_s is the number of slots; N_{ph} is the number of phases in the generator; and N_m is the number of magnets. Included in the evaluation of the magnet and slot ratio is the cogging torque. The cogging torque values found are the least common denominator of the number of magnets and number of slots. This should be as high as possible within the design limitations. A spreadsheet is utilized to fully capture the range of values.

Table 3. Cogging Frequency of Multiple Slot Ratios [4]

Cogging frequency Ns	Nm 2	4	6	8	10	12	14	16	18	20	22	24
3	NoSym	NoSym	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	UnBal
6	q > 0.5	12	UnBal	24	q < 0.25	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	UnBal
9	q > 0.5	q > 0.5	18	NoSym	NoSym	36	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	q < 0.25
12	q > 0.5	q > 0.5	UnBal	24	60	UnBal	84	48	UnBal	q < 0.25	q < 0.25	UnBal
15	q > 0.5	q > 0.5	UnBal	q > 0.5	30	UnBal	NoSym	NoSym	UnBal	60	q < 0.25	UnBal
18	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	36	126	144	UnBal	180	198	72
21	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	UnBal	42	NoSym	UnBal	NoSym	NoSym	UnBal
24	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	UnBal	q > 0.5	48	UnBal	120	264	UnBal
27	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	54	NoSym	NoSym	216
30	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	UnBal	60	330	UnBal
33	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	UnBal	q > 0.5	66	UnBal
36	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	72

For the ratio, *q* values between 0.25 and 0.5 are the ones considered as anything else would result in poor performance or an unbalanced generator. The purpose of evaluating the cogging frequency is to reduce the cogging torque as much as possible. These are inversely related, where the higher the cogging frequency, the lower amplitude of the cogging torque.

3) **Minimum factors of safety (FoS)**:

There is no applicable factor of safety when considering the ratio of magnets to stator slots.

4) **How it informed design**:

This evaluation informed the design of the generator by specifying the geometry of the steel stator and the case for the generator. The steel stator will have 12 slots and there will be 14 magnets. This combination gives an acceptable magnet-slot ratio and has a relatively high cogging frequency of 84. This combination works best considering the small-scale size the generator must be made to easily integrate into a CWC turbine.

B. Shaft Analysis #2 (Alonso Garcia)

1) **Load case**:

PMSG performance is critical for CWC high-end wind speeds of 13 m/s [5]. Therefore, the PMSG thrust force will be evaluated with 13 m/s to consider the worst case under normal operation.

2) **Equations & solutions**:

Before discussing the equations and solutions, Table A1, in the appendix, contains the nomenclature for this analysis. The following equations are used that help solve the load case:

$$W = mg \tag{2}$$

$$\sum F = 0 \tag{3}$$

$$\sum M = 0 \tag{4}$$

(2), (3), and (4) are the baseline equations that determine forces and moments for equations later explained, which helps determine the shaft size needed to support the forces.

$$P = T\omega \tag{5}$$

$$Kv = \frac{\omega}{V} \tag{6}$$

$$F_T = \frac{4\pi R^2 \rho U^2}{9} \tag{7}$$

(5), (6), and (7) are equations that help determine a reaction thrust force and reaction torque from the PMSG outputs, like voltage, Kv rating, and power provided. Also, the blade attached to the shaft is considered for determining the thrust force from the wind speeds.

$$S_e = k_a k_b k_c k_d k_e k_f S_e' \tag{8}$$

$$k_a = aS_{ut}^b \tag{9}$$

$$S_e' = 0.5S_{ut} \tag{10}$$

$$d = \left\{\frac{16n}{\pi}\left(\frac{2K_f M_a}{S_e} + \frac{1}{S_{ut}}\left[3\left(K_{fs}T_m\right)^2\right]^{\frac{1}{2}}\right)\right\}^{\frac{1}{3}} \tag{11}$$

$$D = 1.2d \tag{12}$$

$$r = \frac{d}{10} \tag{13}$$

(11), (12), and (13) are equations that determine the shaft geometry for the PMSG final design. For (8), (9), and (10), these are equations that characterize the type of shaft we want, like conditions and material of the shaft.

Before discussing the solution, the solution is shown in Fig A1 in the appendix. The solution was derived by using Matrix Laboratory (MATLAB). In Fig A1, the code near the top initializes variables that will be constant throughout the analysis. Then, it will execute all the equations mentioned before. It provides a shear force diagram and bending moment diagram along the shaft. With these diagrams, it will help solve (11), since this is what will define the geometry of the PMSG shaft. After the program executes, it outputs the shaft diameter, which is 5 mm. The shaft design can be seen in Fig 3.

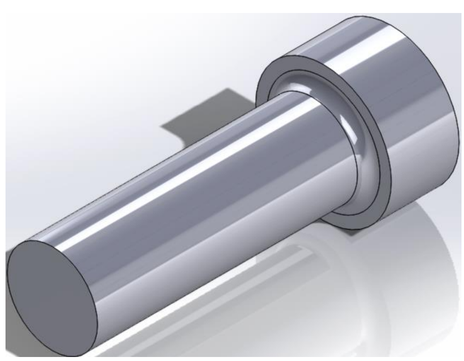

Fig 3. PMSG shaft

3) **Minimum FoS**:

After obtaining a solution for defining the geometry of the shaft, the minimum factor can be determined for this sub-system. After doing hand calculations with the DE-Goodman Criterion equation, it is found that the minimum FoS is 4. Table 2 shows more descriptions based on the shaft and its minimum FoS.

Table 4. Minimum FoS for shaft

Sub-system	Part	Load Case Scenario	Material	Method of calculating FoS	Minimum FoS
Shaft					4
	Shaft	Wind turbine input of 13 m/s	Aluminum	MATLAB Calculations in Fig A1 and Fig A2	4

4) **How it informed design**:

This solution informed the PMSG design by determining how the shaft will look. This also helps determine other parts' geometry of the PMSG, like bearings, casing, stator, etc. With this, it helps choosing other design choices easily.

C. Radial Electromagnetic Loading Analysis #3 (Javan Jake)

1) **Load case:**

Radial electromagnetic loading across the air gap during normal operation. We design for a flux band range of 1.0-1.5T, ideally 1.25T, over an air gap of 0.5mm. This is the dominant radial pressure acting on the rotor magnet sleeve/ring.

2) **Equations & solutions:**

$$B = \mu_0 \cdot \frac{N \cdot i}{g} \tag{14}$$

This equation is to show the simplify equation for Ansys. These equations demonstrate the Magnetic Flux density and Cogging Torque in 3D vector form.

$$p = \frac{B^2}{2\mu_0} \tag{15}$$

Magnetic (Maxwell) pressure on the air gap surfaces using the range of 3 values of Tesla's we gathered.

$$f_r = p(2\pi r) \tag{16}$$

Using (15) we can gather the resultant radial line load on the rotor per unit axial length.

$$\sigma_\theta \approx p\frac{r}{t} \tag{17}$$

Finally, (17) calculates the hoop stress of the sleeve/ring underload with the maximum radius and the thickness of the wall.

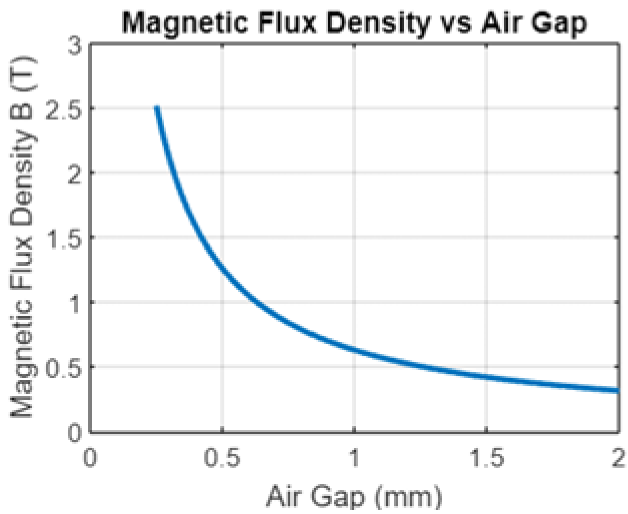

Fig 4. Magnetic Flux Density vs Air Gap

3) **Minimum FoS:**

None specified at this stage. We'll compute FoS once the ring material, thickness, radius, and max RPM is locked in.

4) **How it informed design:**

Our team selected a 5 mm air gap to machine with the current equipment we have. This will give us the highest flux density without increasing cogging torque. Using pressure will help with material selection and if our design for the casing allows for strong rotational force and stress.

Next steps are to find the following calculations:

1) Confirm material of ring/sleeve and max RPM
2) Apply the hoop pressure equation to get peak hoop stress
3) Add rotational stress at max speed and any other stresses that may be included
4) Compute the FoS and adjust thickness or material as needed.

D. Wire Gauge Analysis #4 (Kaitlyn Redman)

1) **Load case**:

The Load Case analyzed is at 10 A because this is the Peak operation for our generator.

2) **Equations & Solutions**:

The equations used are as follows:

$$J = \frac{I}{A} \tag{18}$$

where J is the current density, I is the current running through wire, and A is the cross-sectional area of wire. This equation is used to find the cross-sectional area of the wire so that it can be used to find the diameter.

$$d = \sqrt{\frac{4A}{\pi}} \tag{19}$$

where d is the diameter of wire and A is the cross-sectional area of wire. This equation is used to find the diameter of the wire; it is then cross referenced with the American Wire Gauge (AWG) cart to find the Gauge number needed.

$$R = \rho \frac{L}{A} \tag{20}$$

where R is the resistance of wire, ρ is the resistivity of copper, L is total length of wire, and A is the cross-sectional area of wire. This equation is used to find the resistance so that it can be used to calculate power loss of the wire.

$$P_{copper} = I^2 R \tag{21}$$

where I is the current and R is the resistance of winding. This equation is used to find the power loss of the copper, with the goal of minimizing it as much as possible.

The solutions using the above equations were found to be the following: AWG 16 produced 20.58 V, with a power output of 285 W and a Kv rating of 61.38 RPM/V. While thermally safe, its voltage and torque (0.091 Nm) were too low for our needs. On the other end, AWG 24 reached a high voltage of 41.88 V and 580.31 W of power. However, it produced only 0.11 Nm of torque and would likely overheat due to its high resistance. AWG 22 and AWG 20 performed better, with voltages of 44.65 V and 35.68 V, and torques of 0.96 Nm and 0.57 Nm, respectively. AWG 18 offered a good balance, producing 28.67 V, 397.26 W of power, and 0.18 Nm of torque. Its KV rating of 44.01 RPM/V is ideal for our low-speed generator, and it stays within safe thermal limits.

3) **Minimum FoS**:

Any wire chosen will be covered with high voltage epoxy rated to handle 1600V, given the magnitude of this, the rated voltage for each wire is negligible.

Table 5. Minimum FoS for Wire Gauge

Sub-system	Part	Load Case Scenario	Method of finding FoS	Minimum FoS
Wire Gauge				
	16 AWG	$10A$	$FoS = \frac{I_{allowable}}{I_{operating}}$	160
	18 AWG			160
	20 AWG			160
	22 AWG			160
	23 AWG			160
	24 AWG			160

4) **How it informed design**:

AWG 23 is the most suitable winding choice because its small diameter allows a much higher number of turns per slot, improving magnetomotive force density and voltage control without exceeding the stator's geometric limits. The wire is mechanically flexible, easy to route in tight slots, and enables a higher slot-fill factor than thicker gauges. While its losses at 10 A are significant (6.76 W/m), this can be managed through short conductor lengths and forced cooling. In this application, where compactness, winding density, and manufacturability are critical, the advantages outweigh the penalty, making AWG 23 the best overall compromise.

IV. FLOW CHARTS & OTHER DIAGRAMS

No current design analyses require flow charts or other diagrams.

V. MOVING FORWARD

Moving forward, to finalize the calculations the requirement for the generator is an analysis of the bearings within the stator, rotational force, and find the stress acting on the magnetic ring/sleeve once the final design has been finalized. The purpose of this analysis is to ensure the bearings will withstand the life of the generator and the forces exerted by any use. Also, to make sure the casing of the generator is fit for safety, if the generator is at a risk of high RPM. Additionally, the dynamometer will require further analysis to calibrate the torque transducer. For the 66% build deliverable, analysis of the data from Mad Jenny and Melon Motor will need to be done. This will include processing the raw data of current, voltage, and torque output as sweeps of the rpm are applied. This will be done at multiple points of constant voltage to get characteristic behavior of each of the generators. After the testing procedure and data analysis are solidified, testing the custom generators is next.

APPENDIX

Tables

Table A1. Shaft analysis nomenclature

Variable	Description	Unit
W	Weight force of blade	N
m	Mass of blade	kg
g	Gravitational acceleration	$\frac{m}{s^2}$
F	Force acting on shaft	N
M	Moment acting on shaft	$N-mm$
P	Power produced by shaft	W
T	Torque acting on shaft	$N-mm$
ω	Angular velocity of shaft	$\frac{rad}{s}, RPM$
Kv	Angular speed potential of PMSG	$\frac{RPM}{V}$
V	Voltage output from PMSG	V
F_T	Thrust force from wind turbine	N
R	Blade radius	m
ρ	Air density	$\frac{kg}{m^3}$
U	Air velocity	$\frac{m}{s}$
S_e	Endurance limit	MPa
k_a	Surface condition modification factor	$unitless$
k_b	Size modification factor	$unitless$
k_c	Load modification factor	$unitless$
k_d	Temperature modification factor	$unitless$
k_e	Reliability modification factor	$unitless$
k_f	Miscellaneous-effects modification factor	$unitless$
S_e'	Test specimen endurance limit	MPa
S_{ut}	Ultimate strength	MPa
a	Factor for surface finish	$unitless$
b	Exponent for surface finish	$unitless$
n	Factor of safety	$unitless$
K_f	Fatigue stress concentration factor	$unitless$
M_a	Alternating moment	$N-mm$
K_{fs}	Fatigue stress concentration factor	$unitless$
T_m	Mid-range torque	$N-mm$
D	Thrust lip diameter	mm
d	Shaft diameter	mm
r	Should fillet radius	mm

Figures

Fig A1. Shaft analysis code

```
V = 48; % V
P = 10; % kW
Kv = 150; % Kv Rating
D_b = 45; % cm
m_b = 2; % lb (rough approx from Willy)
h = 7; % cm Distance for aerodynamic forces (thrust)
L_lip = 3; % mm (subject to change)
```

```
L_b_b = 9; % mm (Length from end of bearing to other end of bearing)
L_hub = 3; % mm (Length where connection from blade will occur)
rho_al = 2830; % kg/m^3
Su = 324; % MPa (2011 Aluminum in Table A-22)
Kt = 1.7; % Assuming we're using a rounded filet in Table 7-1
Kts = 1.5; % Assuming we're using a rounded filet in Table 7-1
Kf = Kt; % Quick Conservative test
Kfs = Kts; % Quick Conservative test
a = 2.7; % Table 6-2
b = -0.265; % Table 6-2
Ka = a * Su^b; % Eq. 6-19
Kb = 0.9; % Guess
Kc = 1;
Kd = Kc;
Ke = Kd;
n = 3;
w = 5; % mm
U = 13; % m/s
rho_air = 1.293; % kg/m^3
g = 9.81; % m/s^2
omega = ( Kv * V ) * 2 * pi / 60; % rad/s
T = P * 10^3 / omega; % N-mm
D_b = D_b / 100; % m
R_blade = D_b / 2; % m
m_b = m_b * 0.45359237; % kg
h = h * 10; % mm
L_total = L_lip + L_b_b + L_hub; % mm
FT = get_thrust_force( R_blade, rho_air, U ); % Assuming Betz Limit (a=1/3)
W_blade = m_b * g;
Rx1 = FT;
Ry2 = ( L_b_b - w )^( -1 ) * ( W_blade * ( L_b_b - w / 2 - L_hub / 2 ) + FT * h );
Ry1 = W_blade - Ry2;
d1 = L_lip + w / 2; % mm
d2 = L_b_b - w;
d3 = w /2 + L_hub / 2; % mm
d4 = L_hub / 2; % mm
d = [ d1, d2, d3, d4 ];
Fv = [ 0, Ry1, Ry2, -W_blade ];
Fv_max = max( abs( Fv ) );
figure( "Name", "Torque Diagram")
hold on
% x and y axis line
plot( [ -1, L_total + 1 ], [ 0, 0 ], "black", "LineWidth", 1 )
plot( [ 0, 0 ], [ -T - 1, T + 1 ], "black", "LineWidth", 1 )
% Torque curve
plot( [ 0, 0 ], [ 0, T ], "r", "LineWidth", 2 )
plot( [ 0, L_total ], [ T, T ], "r", "LineWidth", 2 )
plot( [ L_total, L_total ], [ T, 0 ], "r", "LineWidth", 2 )
% Labeling
xlabel( "Length [mm]" )
ylabel( "Torque [N-mm]" )
xlim( [ -1, L_total + 1 ] )
ylim( [ -T - 1, T + 1 ] )
grid on
hold off
figure( "Name", "Shear Force Diagram" ); hold on
plot( [ 0, L_total + 1 ], [ 0, 0 ], "black", "LineWidth", 1 )
plot( [ 0, 0 ], [ -Fv_max - 1, Fv_max + 1 ], "black", "LineWidth", 2 )
figure( "Name", "Bending Moment Diagram" ); hold on
plot( [ 0, L_total + 1 ], [ 0, 0 ], "black", "LineWidth", 1 )
plot( [ 0, 0 ], [ -Fv_max * d2 - 1, Fv_max * d2 + 1 ], "black", "LineWidth", 2 )
L_start = 0;
L_end = 0;
Fv_total = 0;
M = 0;
for i = 2 : length( d ) + 1
    L_end = L_end + d( i - 1 );
    Fv_total = Fv_total + Fv( i - 1 );
    x = linspace( L_start, L_end, 1000 );
    M = M( end ) + Fv_total * ( x - L_start );
    figure( findobj('Name', 'Shear Force Diagram') )
    plot( [ L_start, L_end ], [ Fv_total, Fv_total ], "r", "LineWidth", 2 )
    if i < length( d ) + 1
        plot( [ L_end, L_end ] , [ Fv_total, Fv_total + Fv( i ) ], "r", "LineWidth", 2 )
    end
    figure( findobj('Name', 'Bending Moment Diagram') )
    plot( x, M, "r", "LineWidth", 2 )
    if i == length( d )
        Ma = -M( end );
        plot( [ L_end, L_end ], [ M( end ), M( end ) + FT * h ], "r", "LineWidth", 2 )
        M = M( end ) + FT * h;
    end
    L_start = L_end;
end
figure( findobj('Name', 'Shear Force Diagram') )
xlabel( "Length [mm]" )
ylabel( "Shear Force [N]" )
grid on
figure( findobj('Name', 'Bending Moment Diagram') )
xlabel( "Length [mm]" )
ylabel( "Bending Moment [N-mm]" )
```

```
grid on
Se_prime = 0.5 * Su; % MPa
Se = Ka * Kb * Kc * Kd * Ke * Se_prime; % MPa
d_shaft = ( 16 * n / pi * ( 2 * Kf * Ma / Se + ( 3 * ( Kfs * T )^2 )^( 1 / 2 ) / Su )^( 1 / 2 ) )^( 1 / 3 );
fprintf( "Shaft Diameter: %.2f mm\n", d_shaft )
D_over_d_ratio = 1.2;
D_lip = D_over_d_ratio * d_shaft;
fprintf( "Thrust Lip Diameter: %.2f mm\nThis value is assumed to be\nconservative, so feel free\nto choose a diameter thats\nlower than the value displayed", D_lip )
```

Fig A2. Thrust force calculation code

```
function FT = get_thrust_force( R, rho, V, varargin )
  % Inputs
    % R - Radius of blade, in m
    % rho - Density of liquid, in kg/m^3
    % V - Velocity of liquid speed, in m/s
    % varargin - If you want to change inference factor, a, then put
    % one extra argument in function
  % Output
    % FT - Thrust force acting on wind turbine, in N
  % Description
    % get_thrust_force.m calculates thrust force based on Equation
    % 10.42 found in the Fluid Mechanics book. It does this by assuming
    % Betz Limit. It can have the option to not be based on Betz Limit
    % if you add one extra argument for the inference factor
  a = 1 / 3; % Assuming Betz Limit
  % If changing inference factor, then change it
  if nargin == 4
    a = varargin{ 1 };
  % If too many arguments, keep inference factor the same.
  elseif nargin > 4
    disp( "Too many arguments. Using a = 1/3" )
  end
  % Calculate thrust force
  FT = 2 * pi * R^2 * rho * V^2 * a * ( 1 - a );
end
```

REFRENCES

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