Stress Analysis of a Circular and Pinion Gear on Sea Wave Power Plant Design in Bangka Island

Firlya Rosa, R. Priyoko Prayitnoadi and Aljun Yusuf Gunawan
Department of Mechanical Engineering, Faculty of Engineering, Universitas Bangka Belitung, Bangka, Indonesia

Keywords: Stress analysis, sea wave power plant design, circular gear, pinion gear

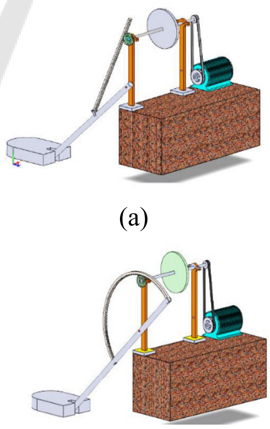
Abstract: Based on data for a maximum wave height of 1.22 m on the Bonded Beach, Bangka Tengah Regency, Bangka Belitung Islands Province, Indonesia, in January 2019, the alternative wave power plants was designed using circular and pinion gear transmission elements as rotation elements. The wave motion moves the buoy, and then the down and up motion is converted into a rotary motion which rotates the generator drive shaft. This study aims to determine the circular and pinion gears' strength in receiving the waves' forces. This research conducted static analysis software using the von mises and safety factor method on circular and pinion gear. From the calculation of the wave force and buoyancy force, the maximum force received by the circular gear is 689.54 N. material of 350 MPa with a minimum safety factor of 1.03 lower than the permitted safety factor so that circular and pinion gear cannot accept the force exerted by the waves.

1 INTRODUCTION

One of the abundant new and renewable energy sources in Indonesia, especially the Bangka Belitung Islands Province with many coastal areas, is the sea. Ocean energy that can be utilized to date consists of sea waves and sea wind. Sea wind could use as an energy source using wind turbines, while ocean waves can be utilized using Wave Energy Converters (WEC) technology which is not harmful to the environment (Drew, et al., 2009).

The use of WEC is influenced by location with a wave period of 2-25 s (Neill, Hashemi, 2018). The buoy is one of the Wave Energy Converters that can be used according to sea conditions and increase energy extraction efficiency (Kim, et al., 2015). For the Bangka Belitung Islands Province, the wave height ranges from 0.1-1.25 m with a period of 1.12 - 3.97 s in December 2018 - April 2019 (Kim, et al., 2015).

Several mechanisms of the WEC tool that are being developed are by utilizing the float moves up and down and then converted into linear force and motion using a link that is connected by a mechanization system using a rack and pinion gear or a system using circular and pinion gear mechanization as shown in Figure 1 (Priyanka, et al., 2019). The selected pinion gears use the involute system because these involute gears are widely used in the industry. In the process of making this type of gear produced by the hob cutter on the hobbing machine has a higher efficiency than other types of gears (Bair, 2004).



(a)

(b)

Figure 1. Sea wave power plant design using :
(a) rack and pinion gear
(Priyanka, et al., 2019),
(Rosa, Prayitnoadi, 2020)
(b) circular and pinion gear
(Priyanka, et al., 2019)

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From the motion simulation results, at a maximum wave height of 1.22 m, it was found that the rotation obtained on the shaft sea wave power plant using rack and pinion gear was 3.47 rpm and on the sea wave power plant shaft using circular and pinion gear was 29.16 rpm (Priyanka, et al., 2019).

Meanwhile, for the static analysis, the strength of the von mises sea wave power plant using rack and pinion gear is 53.14 MPa, smaller than the yield strength of the material with the safety factor that occurs a minimum of 6.59 (Rosa, Prayitnoadi, 2020). By using the same buoy size as the sea wave power plant using rack and pinion of 200x700x1050 mm and ignoring the weight of the buoys with geometry and links made of carbon steel with dimensions ∅100 x 2500 mm (Rosa, Prayitnoadi, 2020), it is necessary to carry out a static analysis on the sea wave power transmission element. Plant using circular and pinion gear.

2 RESEARCH METHODS

2.1 Specification of Circular and Pinion Gear

To transmit the wave force and motion into straight motion and rotational motion, this study uses circular and gear pinion transmission elements with specifications as in Table 1 and the geometry and dimension of the circular and pinion gear as shown in figure 2 and figure 3.

Table 1. Dimension parameters considered on a circular gear

Parameters	Notations	Values
Modul	M	10 mm
System of gear teeth	-	$14\frac{1}{2}°$ Full-depth involute system
Material	-	Steel, carbon
Ultimate tensile strength	σ_{iz}	$420 \frac{N}{mm^2}$
Yield strength	σ_y	$350 \frac{N}{mm^2}$
Mass density	ρ	$7850 \frac{kg}{m^3}$
Pressure angle	ϕ	20°
The diameter of the circular gear	Dp	1900 mm
Number of the circular gear teeth	T_P	95 teethes
The pitch	Dp	200 mm

Parameters	Notations	Values
diameter of the pinion		
Number of pinion teeth	T_P	20 teethes

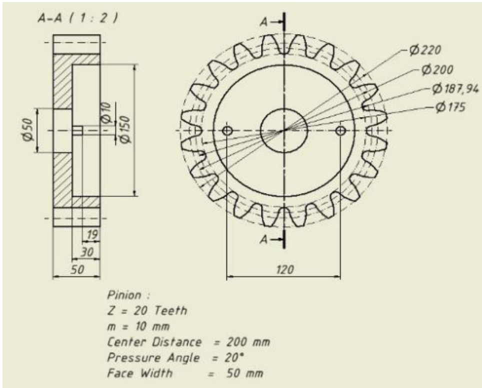

Figure 2. Geometry and dimension of the pinion gear

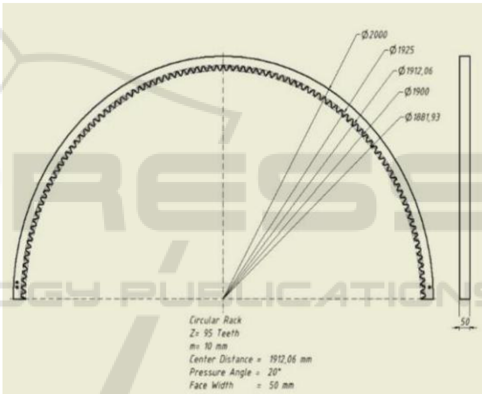

Figure 3. Geometry and dimension of the circular gear

2.2 Parameter Considered

2.2.1 Sea Wave Data

Sea wave is influenced by a wave crest, wave trough, wavelength (L or λ), wave height (H), wave period (T) (Susanto, 2015). Wave height data was measured in January 2019, which was obtained from the Meteorology, Climatology and Geophysics Agency (BMKG) with the Bonded coastal location, Central Bangka Regency, Bangka Belitung Islands Province (Priyanka, et al., 2019), (Rosa, Prayitnoadi, 2020).

2.2.2 Power Wave & Wave Force

Power wave (P_{-wave}) has resulted from the density of seawater (ρ=1030 kg/m^3), gravity (g), wave height

(H) dan wave period (T). While the wave force (F_{wave}) generated from a wave depends on the wave power (P_{-wave}), wavelength (λ) dan wave period (T) (Yusnitasari, Hendrowati, 2012).

2.2.3 Force on the Float

The force generated by the buoy consists of the maximum wave force. The buoyancy force is influenced by the density of seawater (ρ), gravity (g) and the volume of the float submerged in water (V) (Yusnitasari, Hendrowati, 2012) (Journee, Massie, 2001), assuming the volume of the float is submerged at 0.5 buoy height (Rosa, Prayitnoadi, 2020).

2.2.4 Buoy Force

The total force on the buoy is influenced by the wave force, buoyancy force and buoyancy gravity.

- $F_{generated} = F_{wave} + F_{\nabla} + F_{massa}$

2.2.5 Force on Circular Gear

The force that occurs on the link is treated the same as the analysis on the rack and pinion gear, assuming a force with a link angle condition of 35° to sea level with the calculation of the forces on the link as follows (Prayitnoadi, et al., 2019):

- $F_n = \frac{F_{generated} \cdot X_{n1}}{\cos \alpha_{n2} \cdot Y_{n2} - \sin \alpha_{n2} \cdot X_{n2}}$

Table 2. The force that occurs at the maximum wave height on the Bonded coast of Central Bangka Regency, Bangka Belitung Islands Province.

Parameters	Notations	Values
Maximum height of sea wave	Max	1,22 m
Wave force	F_{ave}	287.19 N
Buoyancy force	F_{∇}	689.54 N
Massa (assumed)	F_{massa}	0 N
Forces on buoy	$F_{generated}$	976.73 N
Normal force on a circular gear	F_n	4906.06 N

3 RESULTS AND DISCUSSION

3.1 Modelling

The analysis uses Autodesk Inventor Version 2019 software with a static analysis using parameters as in table 3 and constraints and mesh of the transmission as shown in Figure 4 and Figure 5.

Table 3. Parameters considered of stress analysis

Parameters	Notations	Values
Support on pin	A	-
Detect and Eliminate Rigid Body Modes	-	Yes
Separate Stresses Across Contact Surfaces	-	Yes
Motion loads analysis	-	No
Avg. Element Size (fraction of model diameter)	-	0.1
Min. Element Size (fraction of avg. size)	-	0.2
Grading Factor	-	1.5
Max. turn angle	-	60°
Axial force on circular gear	$W_a=F_{generated}$	4906.06 N=4.91 kN
Pin constraint	A	-
Frictionless constraint	B	-

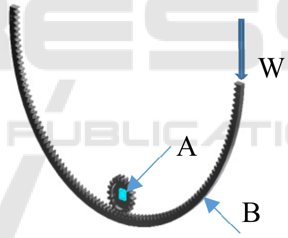

Figure 4. Modelling, load and constraints

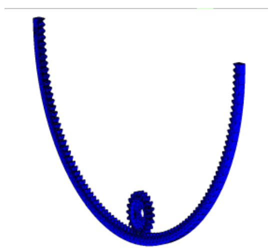

Figure 5. Mesh model

3.2 Static Analysis of Circular and Pinion Gear

3.2.1 Von Mises

The stress on teeth gears is compared to the allowable stress on the material based on yield strength. The static stress analysis uses the Von Mises Stress method due to the material of gear is ductile (Khurmi, Gupta, 2005). Figure 6 shows that the maximum stress occurs at 339.5 MPa in a teeth's pinion gear and the minimum stress occurs at 0 MPa in a circular gear. From this analysis, the stress on pinion gear is smaller than the material yield strength. It means that the pinion gear strength able to withstand the force that occurs.

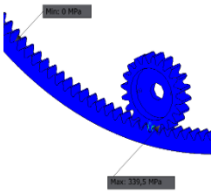

Figure 6. Von mises stress analysis

3.2.2 Safety Factor

For safety purposes, the rotating shaft's safety factor must be more than 1.5 (Suryavanshi, et al., 2017). From the analysis, the minimum safety factor on pinion gear is 1.03, while the maximum safety factor on circular gear is 15. The safety factor on pinion gear is not satisfying, while the safety factor on circular gear fulfils the safety factor.

Figure 7. Safety factor analysis

4 CONCLUSION

The analysis using Autodesk Inventor 2019 software found that the von mises at carbon steel pinion gear with a yield strength of 350 MPa were able to withstand force from sea wave and buoyance force on the Bangka Belitung sea. The minimum safety factor of pinion gear was lower than the safety factor requirement.

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