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The fatigue life prediction of gantry crane with load capacity variation using Ansys Workbench

Lasinta Ari Nendra Wibawa[a, b, 1]

[a]*Department of Mechanical Engineering, Universitas Sebelas Maret, Jl. Ir. Sutami No. 36 Kentingan, Surakarta 57126 , Indonesia*

[b]*National Institute of Aeronautics and Space (LAPAN), Jl. Cilauteureun Cikelet, Garut 44177, Indonesia*

[1]Corresponding author: lasinta.ari@lapan.go.id

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ABSTRACT

The gantry crane is one type of crane that can be used indoors and outdoors. In the LAPAN Garut office, the gantry crane is used for the rocket assembly process before static and flight tests are carried out. The study examines the fatigue life prediction of gantry crane structures using the finite element method. gantry crane structure design uses Autodesk Inventor Professional 2017, while finite element analysis uses Ansys Workbench 2019 R3 software. gantry crane structure is subjected to loads with variations of 7, 8, 9, and 10 tons with the fully-reserved type of loading. Fatigue life prediction using Gerber's mean stress theory. gantry crane structure uses aluminium alloy material. The simulation results show that the structure of the gantry crane with 7, 8, 9, and 10 tons have a minimum fatigue life of up to 11.770 x 10^6, 2.307 x 10^6, 1.055 x 10^6, 0.494 x 10^6 cycles, respectively. While the safety factor of the structure of the gantry crane with 7, 8, 9, and 10 tons have a safety factor of 1.296, 1.134, 1.008, and 0.907, respectively. At a loading of 10 tons, the minimum fatigue life of gantry crane less than 1 million cycles.

ABSTRAK

Gantry crane merupakan salah satu jenis crane yang dapat digunakan di dalam dan di luar ruangan. Di kantor LAPAN Garut, gantry crane digunakan untuk proses perakitan roket sebelum dilaksanakan uji statik dan uji terbang. Penelitian ini mengkaji tentang prediksi umur fatik struktur crane menggunakan metode elemen hingga. Desain struktur gantry crane menggunakan Autodesk Inventor Professional 2017, sedangkan analisis elemen hingga menggunakan perangkat lunak Ansys Workbench 2019 R3. Struktur gantry crane dikenakan beban dengan variasi 7, 8, 9, dan 10 ton dengan jenis pembebanan *fully-reserved*. Prediksi umur fatik menggunakan teori tegangan rata-rata Gerber. Struktur gantry crane menggunakan material aluminium paduan. Hasil simulasi menunjukkan bahwa struktur gantry crane dengan 7, 8, 9, dan 10 ton memiliki umur kelelahan minimum berturut-turut 11,770 x 10^6, 2,307 x 10^6, 1,055 x 10^6, 0,494 x 10^6 siklus. Sedangkan faktor keamanan struktur gantry crane dengan 7, 8, 9, dan 10 ton memiliki faktor keamanan berturut-turut 1,296; 1,134; 1,008; dan 0.907. Pada pembebanan 10 ton, umur fatik minimum gantry crane kurang dari 1 juta siklus.

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1. Introduction

One type of crane that is most commonly used in various heavy equipment industries is gantry crane. gantry crane is a type of crane with a high-level portal that functions to lift heavy objects with the help of an elevator and can move horizontally on a pair of rails along the working area. It is often used in various industries, such as aerospace, transportation [1], construction, and manufacturing [2]. gantry crane is also called portal crane.

The gantry crane construction is usually made of steel [3-5]. The structure of gantry cranes, especially those made of steel material, has several disadvantages. The density of steel (mild steel), which reaches 7.85 gr/cm^3, makes the construction to be overall heavy. This structure needs to be taken into account, considering the lifting capacity of the gantry crane is also affected by the weight of the structure itself. The choice of lighter material is undoubtedly necessary so that the lifting capacity of the gantry crane is more effective than using more substantial material. Also, steel material that has already been exposed to corrosion becomes difficult to predict the real strength.

The use of gantry cranes in LAPAN Garut office, among others, is to assemble rocket components before static and flight tests are carried out. gantry crane is commonly used in LAPAN Garut because it can be placed inside and outside the room. One of the indoor uses is for the rocket integration building (RIB) facility, while the outdoor use is for the rocket static test facility, which is on the launch pad.

The use of gantry cranes for outdoors requires materials that are resistant to corrosion. It is because the location of LAPAN Garut is on the coast of Cilauteureun Beach, making the office environment very high with corrosion rates. Components made of metal, especially iron and steel, are the most dominant materials affected. It is because iron and steel are very easily corroded, even in atmospheric environments. In this study, the gantry crane structure uses aluminium alloy material. aluminium alloy is a material that has a light density, high yield strength, and corrosion resistance.

Gantry crane construction can fail due to various factors. Plastic deformation due to excessive load, lack of maintenance, corrosion, and fatigue are some of the causes of gantry crane's structure failure. Fatigue is the most frequent cause of failure of a component or structure [6]. Fatigue is a type of failure of components due to dynamic loads that fluctuate under the yield strength that repeatedly occur for a long time. Fatigue life analysis is fundamental to predict the age of components or construction. It is essential to do because it can be considered in determining the duration of a component's warranty.

This research aims to investigate the fatigue life of the gantry crane with load capacity variation using Ansys Workbench 2019 R3 software. Ansys Workbench is a type of CAE (Computer-Aided Engineering) software that is very commonly used for finite element analysis of a component or machine element, including the gantry crane structure. In this paper, the variation of load capacity is varied of 7, 8, 9, and 10 Ton.

2. Research Methodology

2.1. Material

The gantry crane structure uses aluminium alloy material. The 3D design of a 9 Ton gantry crane structure is shown in Figure 1. The numbers indicate that the standard and size of the frame is used. Table 1 shows the dimensions of the structure of the gantry crane. Table 2 shows the mechanical properties of aluminium alloys.

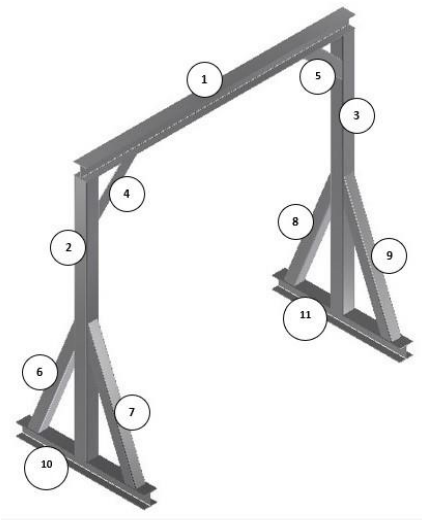

Figure 1. The 3D design of a 9-tons gantry crane structure [7].

Table 1. The dimension of the gantry crane structure.

Description	Standard	Size (mm)
Frame 1	JIS G 3192 H	200 x 200 x 8
Frame 2	JIS G 3466	200 x 200 x 8
Frame 3	JIS G 3466	200 x 200 x 8
Frame 4	JIS G 3466	200 x 200 x 8
Frame 5	JIS G 3466	200 x 200 x 8
Frame 6	JIS G 3466	150 x 150 x 6
Frame 7	JIS G 3466	150 x 150 x 6
Frame 8	JIS G 3466	150 x 150 x 6
Frame 9	JIS G 3466	150 x 150 x 6
Frame 10	JIS G 3192 H	200 x 200 x 8
Frame 11	JIS G 3192 H	200 x 200 x 8

Table 2. Mechanical properties of aluminium alloy.

Parameter	Description
Material	aluminium alloy
Density	2.77 gr/cm³
Yield strength	280 MPa
Ultimate tensile strength	310 MPa

2.2. Software

The dimensions in mm of the gantry crane structure are shown in Figure 2 [7]. The design of the gantry crane structure is made using Autodesk Inventor Professional 2017. Autodesk Inventor Professional software is a type of modelling device that is quite widely used by designers because of the ease in the drawing design process. It is quite practical and time-saving before making it in the form of a physical prototype. One of the main advantages of 3D modelling software is that the area and volume of a design can be easily calculated, even though the design is complex and complicated.

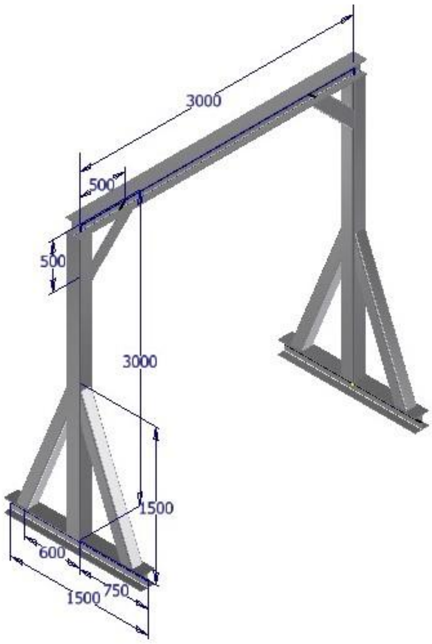

Figure 2. Structure dimensions of gantry crane capacity of 9 tons (in mm) [7].

Fatigue life analysis was performed using the finite element method with Ansys Workbench 2019 R3 software. The finite element method is a numerical mathematical technique for calculating the structural strength of engineering components. It dividing objects into mesh shapes, a smaller element, so that calculations can be arranged and carried out. The finite element analysis software offers an inexpensive solution to analyze gantry crane structure failure problems [8-9].

The boundary conditions of fatigue life analysis using Ansys Workbench are detailed in Table 3. Figure 3 shows the fixed support location on both gantry crane portals. Figure 4 shows the loading location on the gantry crane structure. Relationships between frames are considered bonded contacts [10]. That is, the surfaces between the frames are rigid with each other. This contact can be a welding or adhesive joint.

Table 3. The boundary conditions of fatigue life analysis.

Parameter	Description
Capacity	7, 8, 9, and 10 Ton
Gravity’s Acceleration	9.81 m/s2
Load	68,670; 78,480; 88,290; and 98,100 N
Element size	100 mm
Number of nodes	98,888
Number of elements	17,179
Safety factor	Based on yield strength
Loading type	Fully-reserved
Analysis type	Stress life
Mean stress theory	Gerber
Stress component	Equivalent (von-Mises)
Design life	10^6 cycles

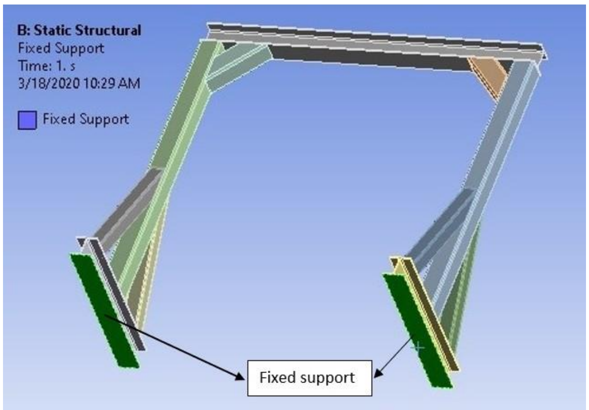

Figure 3. Fixed support location of the gantry crane structure.

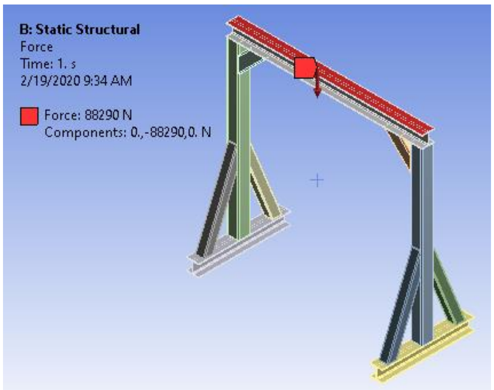

Figure 4. Location of loading of the gantry crane structure.

3. Results and Discussion

3.1. Static stress analysis

The static stress analysis is an analysis of the most common is used in engineering [11], including in the field of gantry crane design [12-16]. It is the most common type of structural analysis using the finite element method [17-19]. Stress, deformation, and safety factor of a part or assembly can be investigated under various load conditions to ensure that failures can be avoided at the design stage.

In brittle material, failure theory usually uses the theory of maximum normal stress and the Mohr-Coulomb theory. The maximum stress theory states that brittle material fails when the maximum principal stress exceeds the maximum tensile strength of the material. While the Mohr-Coulomb theory predicts the failure of brittle material by comparing the maximum principle stress with maximum tensile strength and minimum principal stress with maximum compressive strength [20], however, in ductile material such as aluminium alloy, which applies three-dimensional loads, multiple stresses will occur, which means that at every point in the object, there is the pressure acting in various directions. The failure of ductile material occurs when the maximum von Mises stress exceeds the yield strength of the material based on the energy distortion theory. The von Mises criterion shows that the ductile material yielding when the invariant of the two deviatoric stresses reach a critical value. The von Mises theory is the theory of plasticity that applies best to ductile materials, especially for metal materials such as aluminium alloy.

Figure 5 shows the results of the gantry crane structure simulation of load capacity of 7 Ton. The maximum von Mises stress is 103.20 MPa and is below the yield strength of aluminium alloy material, which is 280 MPa. It means that in the initial cycle, the gantry crane structure will not fail due to the load of 7 ton.

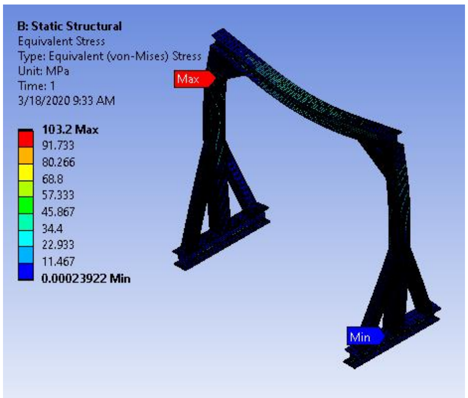

Figure 5. The von Mises stress of gantry crane structure with a load capacity of 7 tons

Deformation is a change in the shape or size of an object due to force or pressure. It is one indicator to determine the strength of the material. The stronger a material, the smaller the value of the deformation that results from the loading process. The weaker material, the higher the value of the deformation resulting from the loading process. The maximum deformation value of the gantry crane with 7 tons loading is relatively small, which is 3.792 mm (Figure 6).

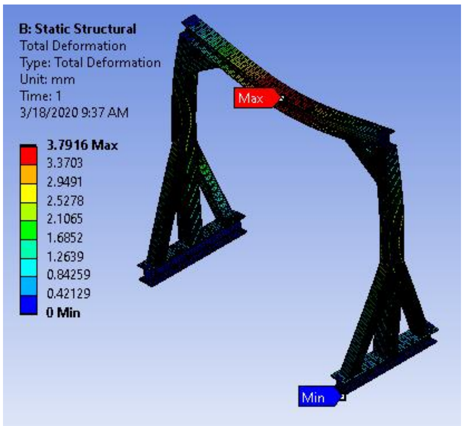

Figure 6. The deformation of gantry crane structure with a load capacity of 7 tons

The safety factor is also an indicator of material strength. It is used to evaluate the safety of a component or structure even though the dimensions used are minimum. The minimum safety factor using Ansys Workbench is calculated as the yield strength of the material divided by the maximum von Mises stress. Safety factor value less than 1 indicates the permanent failure of a design. The simulation results generally show that the gantry crane structure is safe to withstand a load of 7 Ton because the minimum safety factor value is 2.713 (Figure 7). This value exceeds the standard required for a component able to withstand dynamic loads. The dynamic load is the burden that can occur or work suddenly on a structure. The safety factor needed for construction can withstand dynamic loads in the range of values 2-3 [21].

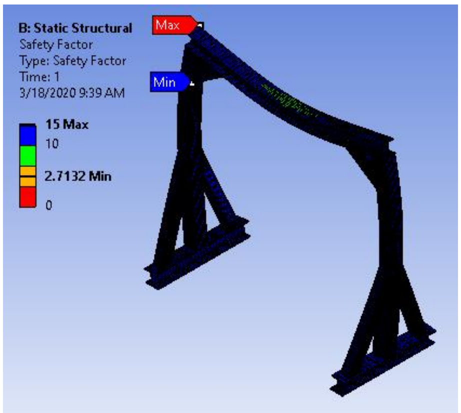

Figure 7. The safety factor of gantry crane structure with a load capacity of 7 tons.

The static stress simulation results are shown in Table 4. The simulation results show that the higher of load capacity, then the higher the maximum von Mises stress and deformation. In contrast, the higher of load capacity, then the lower the safety factor of gantry crane. At a loading of 10 tons, the safety factor of the gantry crane is less than 2. It means that the gantry crane will not be able to withstand dynamic loads. In other words, the gantry crane will also not be able to withstand a fatigue failure of up to 1 million cycles.

Table 4. The static stress simulation results.

Load capacity (Ton)	Maximum von Mises stress (MPa)	Maximum deformation (mm)	Minimum safety factor
7	103.20	3.792	2.713
8	117.94	4.333	2.374
9	132.69	4.875	2.110
10	147.43	5.417	1.899

3.2. Fatigue life prediction

In design science, failure should not occur if the stress received by a structure is below the strength of the material to withstand the load. However, in dynamic or cyclic loading, the structure can fail even though the maximum von Mises stress is smaller than the yield strength of the material. This failure can occur because of the material experiencing fatigue. Fatigue is a failure that occurs as a result of a repetitive burden for a long time. The majority of these failures occur due to fluctuations due to the tensile-compressive stress on the components [22]. The phases of the fatigue process are initial cracking, crack propagation, and final fracture. Initial cracks can occur due to a defect in the production process.

Fatigue failure is different from failure due to static stress. Fatigue failure occurs when the stress at a point changes with time. Therefore, it is crucial to determine the loading method that can be repeated after one cycle. It means that the type of fatigue imposes determines how the load happens over time. In this study, the type of loading selected is fully-reserved loading. It means that the load is applied and then applies the same and opposite load, which will produce a load ratio of -1. In this case, the load amplitude remains constant.

The fatigue life is the number of fluctuating stress and strain cycles of specific properties that the material will maintain before failure [22]. Figure 8 shows the simulation of the fatigue life of a gantry crane structure with a load capacity of 7 tons. Table 5 shows that the structure of the gantry crane with 7, 8, 9, and 10 Ton have a minimum fatigue life of up to 11.770 x 10^6, 2.307 x 10^6, 1.055 x 10^6, 0.494 x 10^6 cycles, respectively. It means that the relationship between load capacities is inversely proportional to the fatigue life of the gantry crane structure. The higher the load capacity, the lower the fatigue life of the gantry crane structure. At a loading of 10 tons, minimum fatigue life less than 1 million cycles.

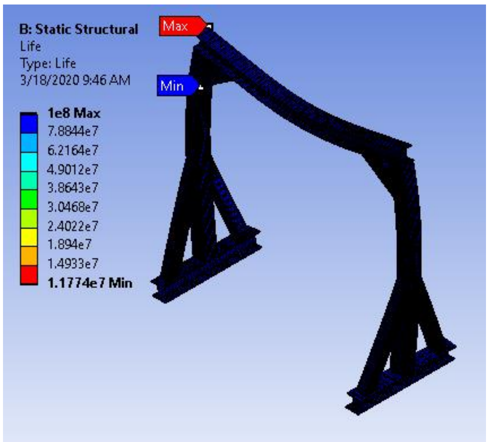

Figure 8. The fatigue life prediction of the gantry crane structure with a load capacity of 7 tons.

Table 5. Effect of load capacity of gantry crane structure on fatigue life.

Load capacity (Ton)	Minimum fatigue life (cycles)
7	11.770 x 10^6
8	2.307 x 10^6
9	1.055 x 10^6
10	0.494 x 10^6

The safety factor is an indicator of material strength. It is used as a method for evaluating the safety of components or structures, even though the dimensions used are minimum. The safety factor value for fatigue life must be higher than one because if less one indicates the design's failure. Figure 9 shows the safety factor for a fatigue life with a load capacity of 7 tons. Table 6 shows that the structure of the gantry crane with 7, 8, 9, and 10 Ton have a safety factor of 1.296, 1.134, 1.008, and 0.907, respectively. It means that the relationship between load capacity is inversely proportional to the gantry crane's safety factor structure. The higher the load capacity, the lower the safety factor of the gantry crane structure. At a loading of 10 tons, a minimum safety factor less than 1, which is 0.907.

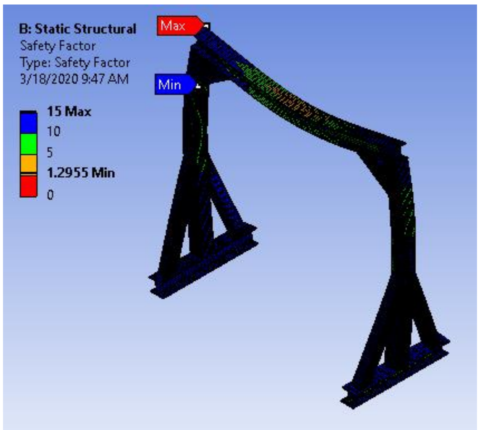

Figure 9. The safety factor of fatigue life of the gantry crane structure with a load capacity of 7 tons.

Table 6. Effect of load capacity of gantry crane structure on the safety factor.

Load capacity (Ton)	Minimum safety factor
7	1.296
8	1.134
9	1.008
10	0.907

4. Conclusion

The simulation results show that the structure of the gantry crane with 7, 8, 9, and 10 tons have a minimum fatigue life of up to 11.770 x 10^6, 2.307 x 10^6, 1.055 x 10^6, 0.494 x 10^6 cycles, respectively. While the safety factor of the structure of the gantry crane with 7, 8, 9, and 10 Ton have a safety factor of 1.296, 1.134, 1.008, and 0.907, respectively. At a loading of 10 tons, the minimum fatigue life of gantry crane less than 1 million cycles.

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