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Fatigue Analysis of a Dual Axis Sun Photovoltaic Tracker by FEA

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Abstract— **Sun tracking system is subjected to a large number of highly variable loads, as the loading of the wind. Then, it is subject to mechanical and aerodynamically cyclic stresses to be inducing the fatigue and shortening the system lifetime. The main objective of this paper is to perform stress and fatigue analysis of the dual axis sun tracking system under cyclic wind loading (variable-amplitude fatigue loads) of the dual axis sun tracking system based on Finite Elements Analysis (FEA). This analysis is FEA were conducted to determine stress distribution, damage factor and fatigue life. The simulation results indicate showed that the stress resistance of the most fragile material is checked with a safety factor higher than 2, the sequence of fatigue events is expected to consume 8.4% of the life of the sun tracking system and this system is likely to fail due to fatigue after 11.905 blocks (repeats). These evaluation results of analysis indicate that sun tracking system satisfies the design requirements of static strength and fatigue strength. The finite element software SolidWorks Simulation was used to determine the stress distribution and fatigue behaviours of the sun tracking system.**

Keywords— **Dual axis sun tracking, fatigue analysis, FEA, SolidWorks**

I. INTRODUCTION

A sun tracking system plays an important role in the development of solar energy applications. It is a device that tracks the movement of the sun. It is typically used for leaving the photovoltaic panels (PV) toward the sun all the day. Sun trackers are generally grouped as two types: one-axis and two-axis tracking devices. For one-axis sun tracker, the tracking system drives the collector about a one axis of rotation until the sun central ray and the aperture area normal are coplanar. In contrast, the two-axis sun tracking system, tracks the sun in two axes such that the sun radiation vector is perpendicular (vertical) normal to the aperture area as to attain 100% energy collection efficiency [1].

The sun tracking works naturally in the outdoor environment, so the structure needs to withstand wind load, snow load, temperature and seismic force. Mechanical fatigue is a subject of great practical importance in the development of statically or dynamically loaded structures. To satisfy fatigue requirements of a sun tracking system, generally, the structure is designed either to keep the stress levels below the endurance limit or to ensure the slow crack growth life of their different parts with a safety factor [2].

Fatigue is one of the main forms of deterioration for structures and can be a typical failure mode due to an accumulation of damage. During the life cycle of a sun tracker, the variable amplitude of the dynamic wind loading on the deteriorated photovoltaic panels defect can lead to fatigue by damage accumulation in structure details. Such damages might develop into micro cracks and lead to serious fatigue failures for sun tracker components or to the whole structure [3]

For understanding, being able to predict and to avoid fatigue, finite element analysis tool (FEA) has been used. This tool can predict stress concentration areas, and can help design engineers to predict how long their designs are likely to last before experiencing the onset of fatigue.

Present dual axis sun tracking system is already exposed in Reference [4]. In current study, the stress and fatigue analysis of this system has been investigated. Firstly, the stress analysis subjected to a critical wind load of 36 m/s (130km/h) has been studied. For second step, the fatigue analysis under variable amplitude of loading based on finite element Analysis was presented. The FEA of this sun tracking is carried out by SolidWorks Simulation software.

II. STRESS ANALYSIS OF DUAL AXIS SUN TRACKING SYSTEM

In order to evaluate the fatigue life of structure, it is necessary to calculate the accurate stress or strain state. Usually, stress analysis can be categorized into static and dynamic analysis according to types of loads. The purpose of a static analysis is to guarantee the strength, stiffness and stability of a structure subjected to external static loading, and structural response is computed by solving equilibrium static equation written as follows [5], [6]:

$$[K]\{u(t)\} = \{f(t)\} \tag{1}$$

Where $[K]$ is the stiffness matrix, $\{u(t)\}$ is the displacement vector and $\{f(t)\}$ is the load vector. The structure of the tracker is analyzed using FEA static method by SolidWorks Simulation software to check the stresses on the sun tracking under maximum wind pressure at 36 m/s. The first step of FEA analysis is to assign a material to the tracker model where Plain Carbon Steel was the chosen material, the selected elastic modulus E = 220 GPa, the Poisson's ratio is 0.28, and the density is $7800\ \mathrm{kg.m^{-3}}$. Then the definition of boundary conditions the base of the bottom assembly is fixed (constraints/fixtures) and Hinges restraints specifies in cylindrical face (principal axis, hydraulic Actuator axis and etc.). The fixtures constrained all translational and all rotational degrees of freedom. Therefore, the sun tracking is stay in a static and fixed position. The weight of the panel together with all the parts (frame) is directly attached to the panel (G) is considered. Thirty six (36) photovoltaic panels are mounted in 12 x 3 matrixes. Each panel weights 8 kg is used in the tracker design respecting the following load condition: (i) the tracker structure weigh is around 1789 kg. Therefore, the constant total dead load of PV panels on the structure is 2077 kg. (ii) Wind loads create a random time-varying loading on the structure. The amount of load subjected on the structure depends on the maximum wind speed (V_{max}) and the angle of attack of the wind, inclination of the solar panels, structural design, geographical factor and proximity with neighborhood structures. It also depends on the density of the air, but the variations due to these factors are assumed to be negligible specifics of each geographical region. Based on this, a maximum wind pressure (P_{max}) [7]:

$$P = 0.5.C_d.\rho_{air}.v_{Wind}^2 \qquad (2)$$

C_d is the drag factor, ρ_{air} is the density of the air and v_{wind} is the wind speed.

The sun tracking structure analysis is designed to operate under extreme climatic loading with maximum wind pressure of 800 N/m² at 36 m/s and elevation rotation angle about 50°.

The FEM discretized system consisted of 217451 nodes and 116520 units for a total of 736837 degree of freedom (DOF). The global size of the unite (77,719 to 388,596) mm. The mesh was completely comprised of solid 3D tetrahedral elements. The model of the sun tracking system, loading and boundary condition and meshed model are shown in Fig. 1 and Fig. 2.

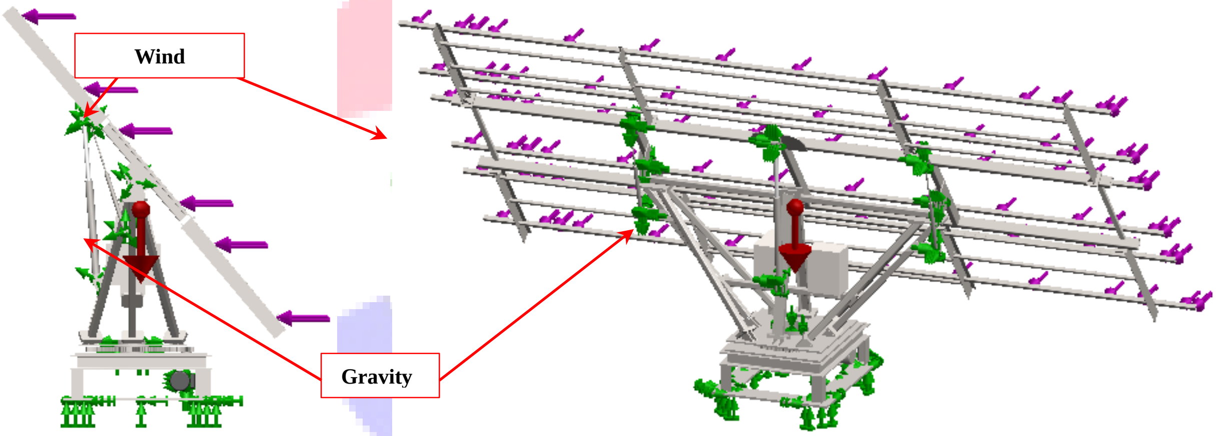

Fig. 1 Loading and boundary condition of the sun tracking system.

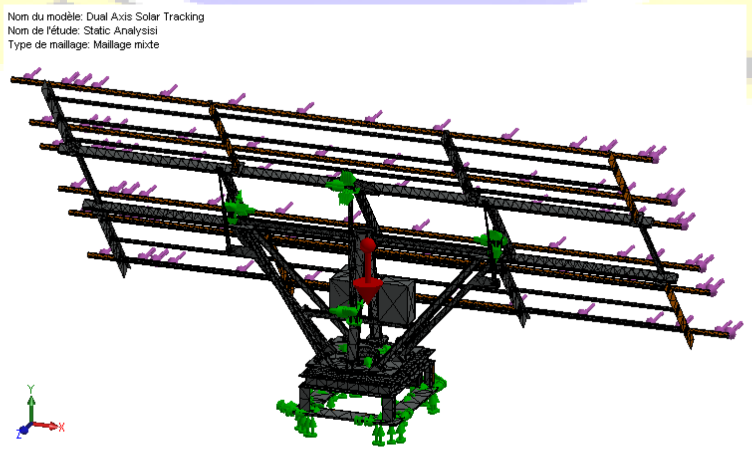

Fig. 2 Finite element mesh model of the sun tracking system.

Stress analysis is performed and the Von-Mises stress is shown in Figure 3. As shown in the figure, the sun tracking maximal Von-Mises stress is 84.16 MPa. This value is distributes in the beam which carries the PV panel. The material of the sun structure is Plain Carbon Steel and its strength limit is 220.6 MPa, and its safety factor is equal to defined to 2.51. So the design of sun tracking system satisfies the strength requirement.

III. FATIGUE ANALYSIS OF DUAL AXIS SUN TRACKING SYSTEM

Sun tracking system structures are subjected to time-varying wind pressures that result in stress cycles at critical structural details. Hence, wind load time history needed to perform a dynamic finite element analysis to obtain stress time histories for fatigue evaluation. The finite element code of SolidWorks Simulation was used to obtain the damage distribution and fatigue life on the sun tracking system.

Constant amplitude fatigue loading is defined as fatigue under cyclic loading with constant amplitude and a constant mean load. However, engineering components are usually subjected to variable amplitude loading which can be defined by complex loading histories of varying cyclic stress amplitudes, mean stresses and loading frequencies. The two main approaches to fatigue life determination, namely, the first is based on stress, the so-called Stress-Life method (S–N curve, nominal stress), also known as a Wöhler curve and the second is based on strain, the so-called Strain-Life method (Local-Stress-Strain) [8], [9].

SolidWorks/Simulation uses S – N curve method. In the case of S – N curve of material and parts, the basic material S – N curve can be is established in current our simulation as depicted in Figure 4. The fatigue damage is assessed using the Rain-flow, the most popular and probably the best method of cycle counting procedure and the Palmgren-Miner linear damage cumulating theory [10]. The material of sun tracking system is Plain Carbon Steel and the Gerber (Generally suitable for ductile materials) mean stress correction method is applied in this analysis, then the formula is [11]:

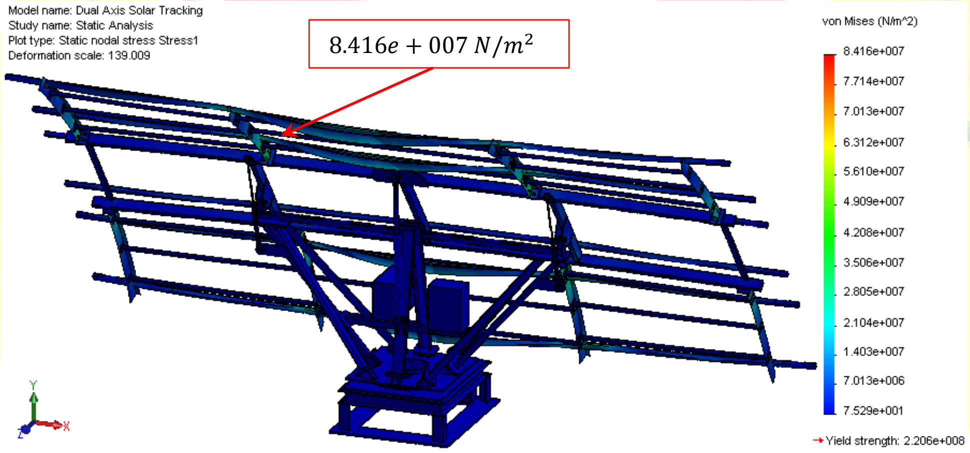

Fig. 3 Von-Mises equivalent stress distribution on the sun tracking system

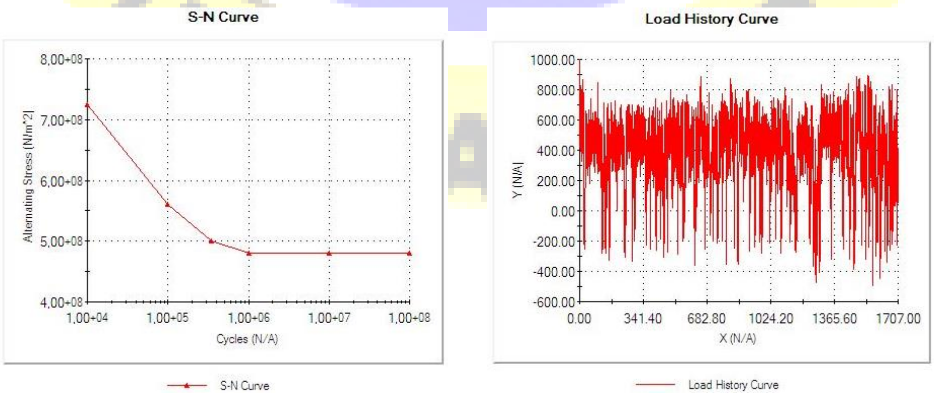

Fig. 4 Damage factor contours of the sun tracking system

$$S_{ca} = \frac{S_a}{1-\left(\frac{S_{mean}}{S_u}\right)^2} \quad (2)$$

Where S_{ca}, S_a, S_{mean} and S_u are the corrected alternating stress (based on zero mean), alternating stress $= (S_{max} - S_{min})/2$, mean stress $= (S_{max} + S_{min})/2$ and ultimate strength respectively.

In the event variable amplitude (and not constant amplitude), the life results given by the fatigue analysis is in terms of blocks instead of cycles, where blocks are defined as the total load history (including the number of repeats of the event in the curve).

Fig. 5 presents the measured fatigue damage of the sun tracking system which is defined as the design life divided by the available life. A value of 1 indicates that the defined fatigue events consume 100% of the life of the sun tracking. It can be seen in this figure, that the maximum damage is occurred about 8.4% in the contact area (principal axis) between the support of the grid (upper frame) and the support in V, this contact area is a hinge (pivot) connection.

Fig. 6 shows the available life for the given fatigue analysis. As it can be seen from the figure, the sun tracking system is likely to fail due to fatigue after 1/(max damage)=0.084=11.905 blocks (repeats) of the specified variable-amplitude loading event.

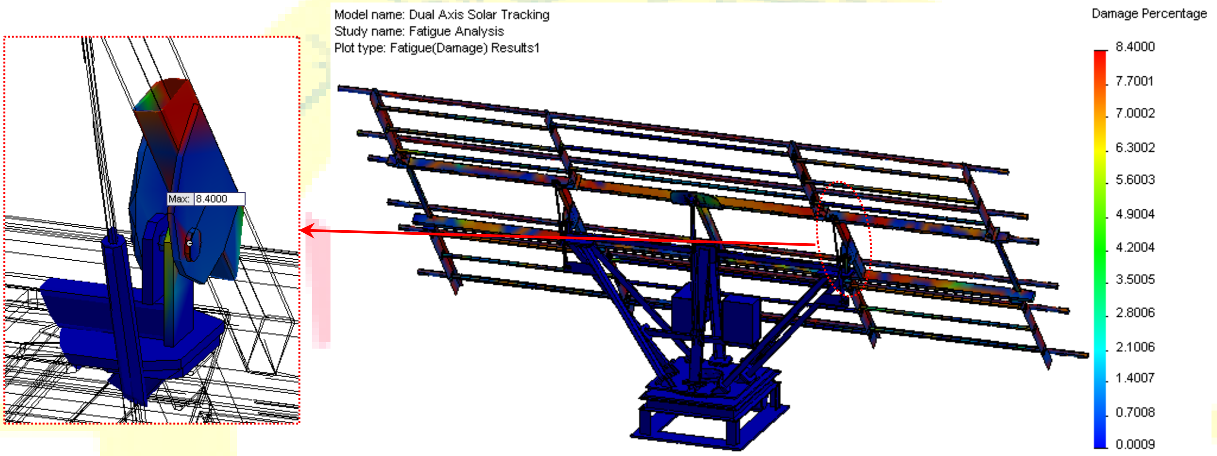

Fig. 5 Damage factor contours of the sun tracking system

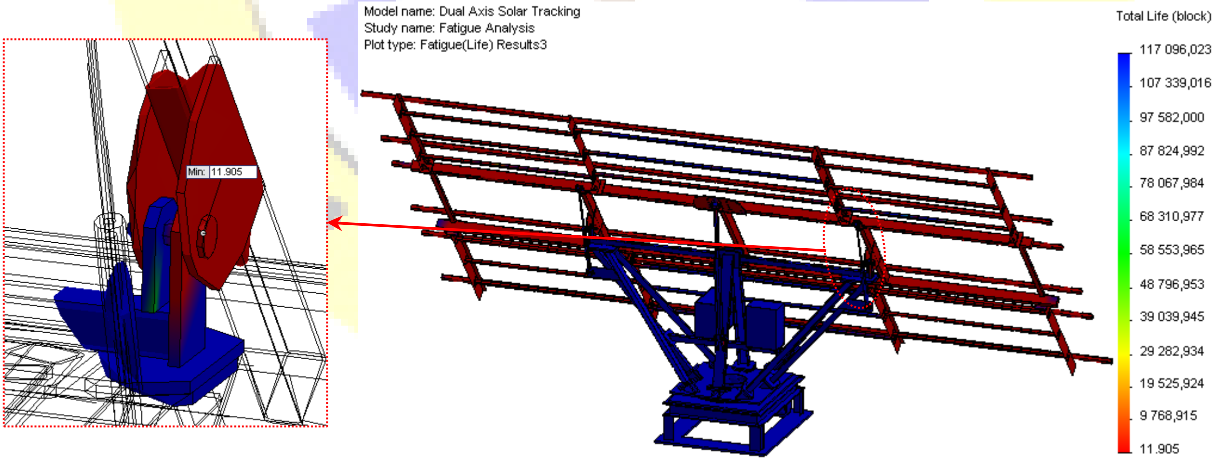

Fig. 6 The fatigue life of the sun tracking system

IV. CONCLUSIONS

This work is focused on stress and fatigue behaviors of dual-axis sun tracking system under variable amplitudes loading based on finite element analysis. The FEA of this sun tracking is carried out by SolidWorks/Simulation software.

The static analysis results showed that the criterion of von Mises resistance of the most fragile material of the sun tracking is checked with a safety factor higher than 2. The fatigue analysis results showed that the sequence of fatigue events is expected to consume 8.4% of the life of the sun tracking system and this system is likely to fail due to fatigue after 11.905 blocks (repeats). These evaluation results of analysis indicate that system satisfies the design requirements of static strength and fatigue strength. This also has laid the foundation for the future structural optimization and dynamics analysis.

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