Mechanical Elements Analysis of Stewart Platform: Computational Approach

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Abstract: ***Because of the mechanical stress importance in the dynamic mechanisms, a Stewart platform is subjected to analysis to extract its critical stress areas in this study. The Stewart platform is an effective mechanism because it has been employed as a stabilizer or motion simulator. When this mechanism is subjected to static and dynamic forces in various applications, its components are at risk of failure in critical stress areas. This issue can be considered when designing, and parts failure can be prevented by knowing the essential points and stress values. This study is modeled the Stewart platform with specific dimensions and mechanical properties in Ansys Inc. and subjected it to static and Modal analysis with a numerical approach. The results present effective parameters that could be used in the mechanical design for this category of this platform.***

Keywords: Stress analysis; Modal; Stewart platform; Numerical

1. Introduction

1.1 Review and background

The Stewart platform is a type of parallel manipulator applied in a wide range of applications [1]. t depends upon the joint's layout could be in these three platform models are indexed with some platform joints–base joints: 6–6, 3–6, and 3–3[2].The literature reveals the tire testing machine was the first application from a similar parallel system by Gough [3]. The Stewart platform was initially proposed in 1965 by Stewart as a flight simulator [4]. For 15 years, there has been no interest in the Stewart platform after the time it was proposed. In 1983, Hunt stated the advantage of the parallel manipulator. At that time, the researchers found this mechanism has high load capacity and is capable of precise positioning [5] and much research was focused on the platform structure. The Stewart platform combines a base, a top plate, and six extensible legs connected to the top plate and base by the spherical or universal joint [6]. This structure causes the platform to be placed in full positioning and orientation condition, which is only a function of the leg length [2] and has a very solid kinematic frame [7]. In contrast to serial manipulators, it has desirable compatibility [8]. Moreover, the Stewart platform's drawbacks are not insignificant and cause obstacles. Form limitation, direct complicated kinematic, control algorithm, and essential of the precise spherical joint are the most impediments [8, 9].

Nevertheless, the Stewart platform's potential was mainly recognized, and the application of this parallel manipulator developed sharply. Camera device stabilizer [10], underground excavator [11], satellite positioning [12] and robot are examples of the most applications. A few industries using the Stewart platform design included aerospace, automotive, transportation, machine tools technology, medical application [2].

1.2 Aim of this study

The studies on the kinematics, dynamics, and control of the Stewart platform are significant, and particularly many models are suggested for the platform control algorithm. However, stress, deformation, energy strain, and many contexts related to mechanical elements have been not considered as much as could see for the above-listed studies.

Stewart platform is a dynamic mechanism with parallel elements. Therefore, all elements are affected by normal and shear stress. In addition to static loads, the dynamics load makes comparable fatigues. The motivation of this study is the analysis of the stress and critical loads in a Stewart platform with a 3–3 joint model. The model is investigated in static conditions to examine the critical stress area and deformation. As well the modal analysis of the platform structure has been inspected. The goal of this study is to mention the critical areas for this stress, deformation, and model frequency, which could be employed for platform designing, and the approach in this paper could be extended for different platform categories. Hence, this work is organized as follows: the methodology is presented in Section 2. In Section 3, the results are provided, and the conclusions are represented in Section 4.

2. Methodology

2.1 Method

A 6-DOF Stewart platform has been drawn in Ansys Inc. workbench and imported into the mechanical section. Table 1 shows the dimensional information for this model. In table 2, the material properties are illustrated for stainless steel. Figure 1 represents the 3D view for the described model.

The platform is combined with a ring in the bottom as a base plate, and six legs control circular top plate legs. Every two legs on one side are joined to the top plate's undersurface and the base ring's upper surface. The legs of the platform consist of two joints on two sides and an actuator in the middle, which can create motion. This platform setup allows the top platform to have a move in x, y, and z-direction and roll, yaw, and pitch rotation. Therefore, the top plate has 6 degrees of freedom. In this work, the platform investigation is in static conditions with zero motion, and the joins and linear leg actuator are assumed fixed and stationary.

Table 1: Element size used for Stewart platform 3D drawing in Ansys Inc.

Element description	Unit	Value
Leg length	mm	1230
Leg diameter	mm	8
Internal height	mm	1200
Top disk diameter	mm	600
Top disk thickness	mm	25
Bottomring externaldiameter	mm	850
Bottomring internaldiameter	mm	550
Bottom ring thickness	mm	30

This model assumes the legs are in stationary condition and loaded on the top plate. This analysis will provide the stress of the elements and deformation of the legs under this load. In order to examine the distinction, two different loads are examined. The statics analysis presents the critical stress area that must be considered for platform design.The platform's modal analysis is also investigated and mentioned the frequency of the platform. It is well stated; the modal frequency benefits the design to understanding the wrecking frequency on the platform structure, and the designer could use it to avoid failure because of the frequency domain in the operating environment.

Table 2: Mechanical material properties for Stewart platform 3D drawing in Ansys Inc.

Properties	Unit	Value
Density	Kg/m^3	7850
Young's Modulus	MPa	2×1^5
Poisson's Ratio	-	0.3
Bulk Modulus	MPa	1.66×1^5
Shear Modulus	MPa	7.69×1^4
Compressive Yield Strength	MPa	2500
Tensile Yield Strength	MPa	2500

2.2 Analysis setup

The model is created in the Ansys Inc. mechanical designer environment, and Figure 1 shows the 3D perspective of the model. The dimension and material properties are reported in Tables 1 and 2. Mesh style Skewness was used, which acceptable range for it was 0 to 0.5. Meshing for the platform is included 2531 elements and 6271 nodes. A uniform load has charged the top plate. The solution runs three times with 2 kPa, 3 kPa, and 4 kPa uniform load, presenting these different loads' distinction and effects.

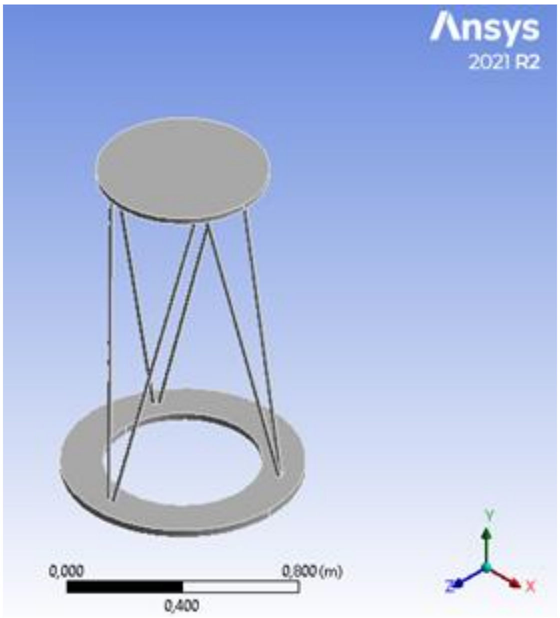

Figure 1: 3D view for Stewart platform, has been drawn in Ansys Inc. workbench.

The gravity affects the problem, and it is included. The base ring is a fixed location. The solution has been executed, and the result for the stress and deformation are presented in section 3. The modal analysis has also been run with the same mesh setup without any external load. Figure 2 represents the meshing of the model.

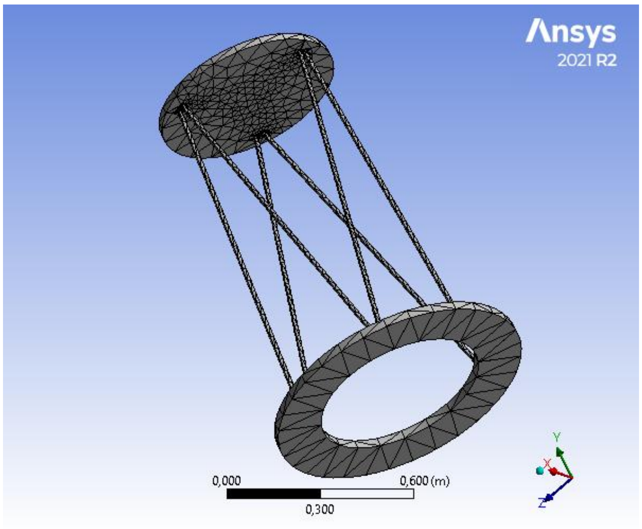

Figure 2: Meshing for the Stewart platform model has been drawn in Ansys Inc. workbench.

3. Results

3.1 Deformation

Because of the load on the top plate and gravity, it is expected to see deformation on the legs for the platform, with specified dimension and material properties. Figure 3 shows the total deformation on a leg increases when the load pressure rises.

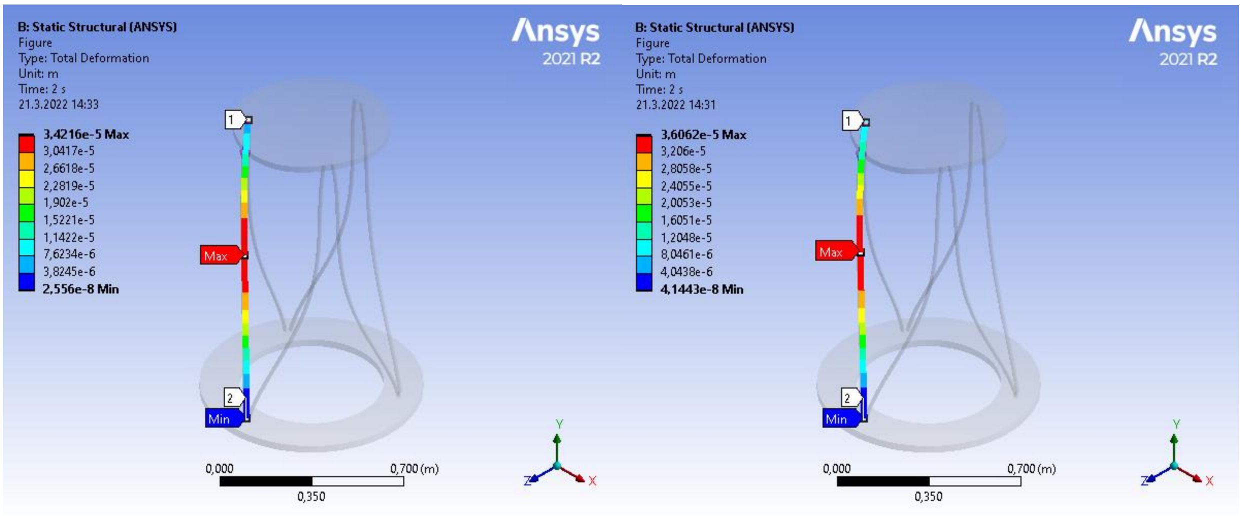

Figure 3: Total Deformation exhibition a platform leg. Left: load 2 kPa. Right: load is 4 kPa. The uniform load has charged to the top plate. Ansys Inc. environment

The result in Figure 3 and Figure 4 illustrates the maximum deformation has occurred near the middle of the leg. The deformation increases from the top plate connected leg joint and reaches the maximum deformation in the middle part. On the other hand, when the load is increased, the total deformation moves from the middle part of the leg to the upper part. It is well known higher load will lead to more deformation, but the location is mostly in the upper part of the leg.

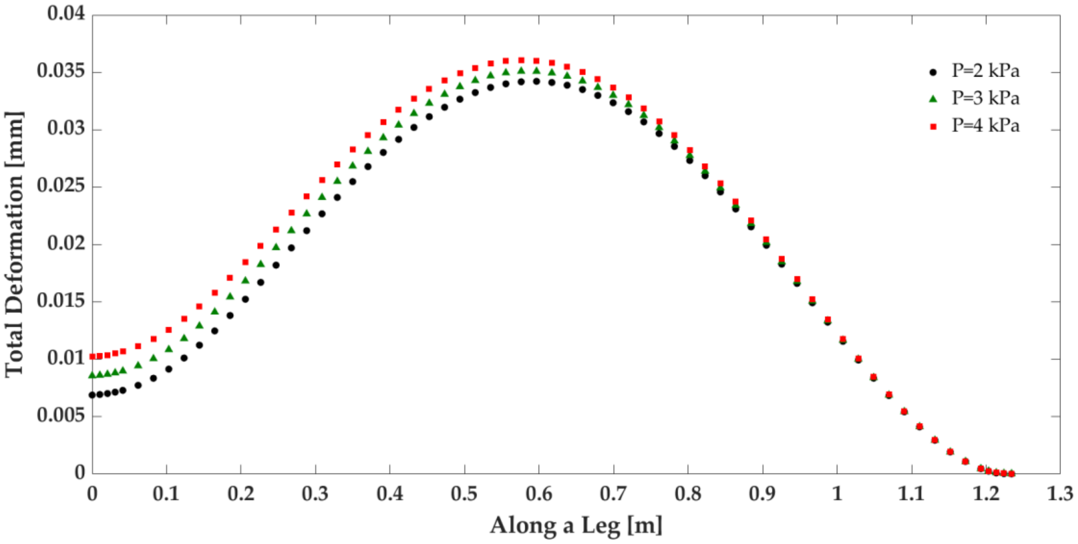

Figure 4: Illustrates the total deformation of a platform leg with three different loads. The maximum deformation happens in the middle and upper parts of the platform leg.

Stewart platform leg is combined of two upper and lower parts and works as an actuator (with different structures, hydraulic or electric actuator).It must be noticed that the upper part faces much more strain, and, in the design, construction must be considered. When the uniform load increased to 3 kPa and 4 kPa, the maximum total deformation is rose 2.6% and 5.5%, respectively, than pressure load 2 kPa.

3.2 Stress

The stress analysis of the Stewart platform leg represents in Figure 5 and Figure 6. As was expected, when the load pressure increases, the stress in the leg goes up. The stress analysis is specified that the middle part of the leg is a critical area with maximum stress. The stress result of the Stewart platform dynamic system specified that there is constant static stress on the leg. When the platform is under dynamic force and periodic force, the static stress must be considered, and it is just added to the dynamic force, which can all lead to fracture.

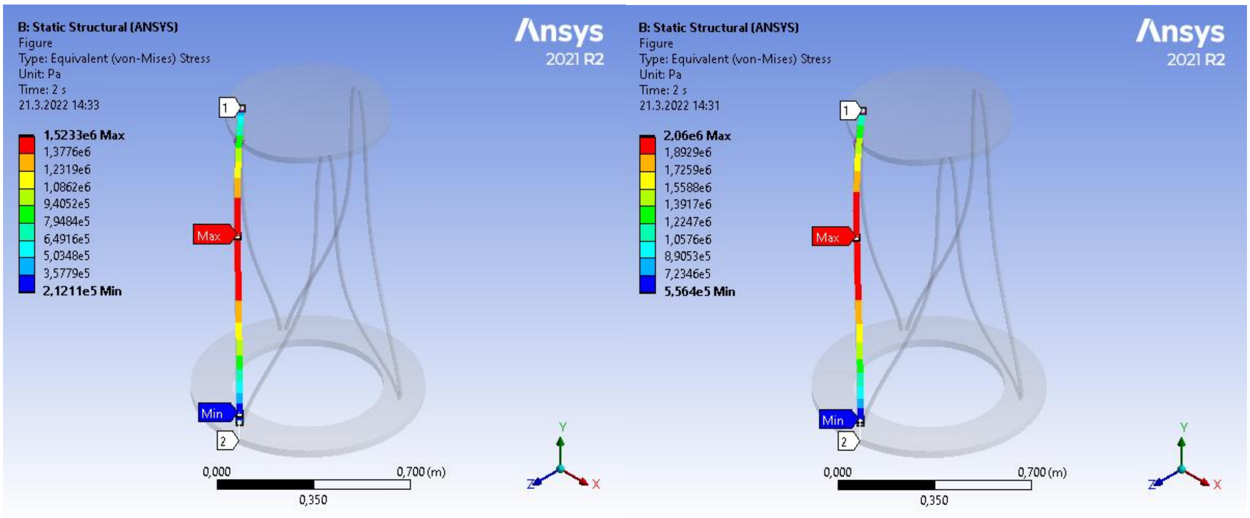

Figure 5: This is a presentation of the platform leg equivalent stress. Left: load 2 kPa. Right: load is 4 kPa. The uniform load has been charged to the top plate. Ansys Inc. environment

The maximum stress in the Stewart platform leg increases 17% and 35% when the uniform load on the top plate surface to 3 kPa and 4 kPa, respectively, relative to the 2 kPa pressure load. The stress analysis observation has been demonstrated that the leg's mid-length is a critical area for the fracture, and most deformation occurs in the upper half of the leg.

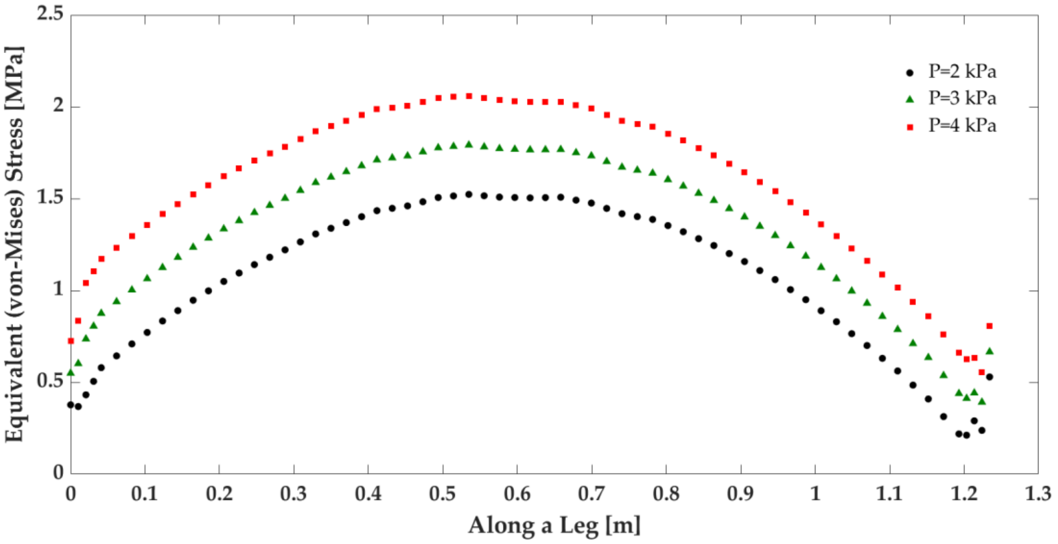

Figure 6: It displays a platform leg equivalent stress along a leg, up to down, with three different loads. The maximum deformation happens in the middle parts of the platform leg.

3.3 Modal analysis

The modal analysis for the Stewart platform in this study was solved for the first six modes. The first three modes are in zero Hz. The frequency for mode 4, 5 and 6 are 0.599 mHz (milli Hz), 0.857 mHz and 1.226 mHz respectively. The Stewart platform deformation in these three modes is illustrated in Figures 7-9.

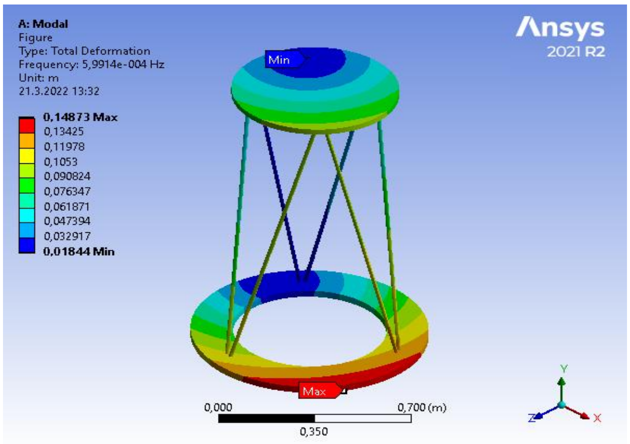

Figure 7: The indication of the modal analysis deformation by related frequency; mode 4

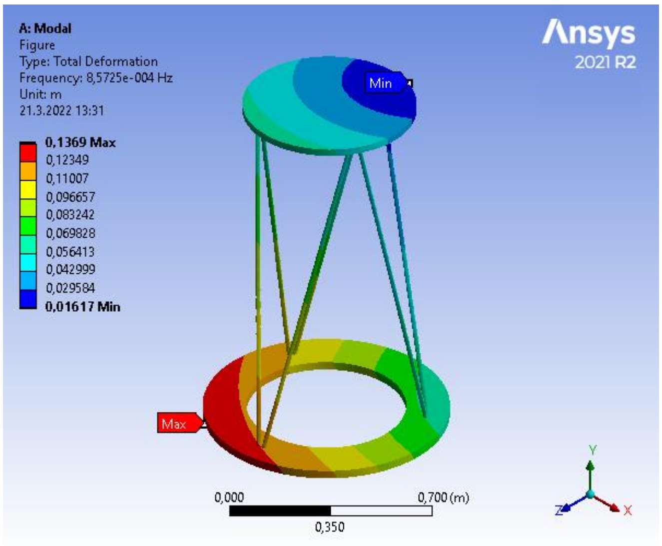

Figure 8: The indication of the modal analysis deformation by related frequency; mode 5

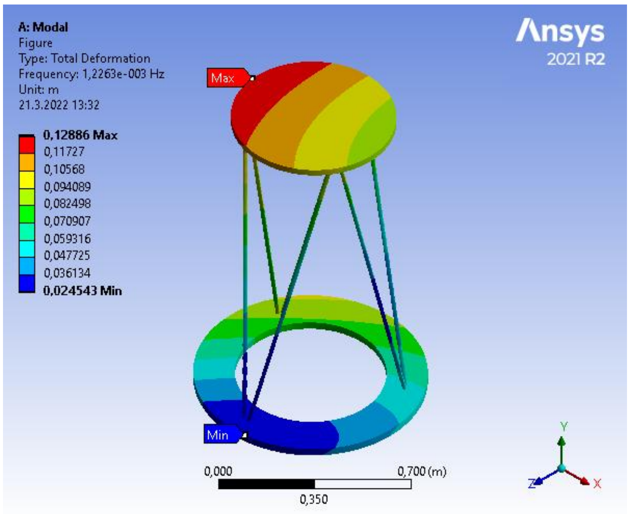

Figure 9: The indication of the modal analysis deformation by related frequency; mode 6

Modal analysis result illustrates that mode 4 is the first frequency that causes the natural mode deformation in the investigated Stewart platform in this work, and it is 0.599 mHz. The modal analysis presents a significant view for the designer and how select platform dimensions and properties to prevent deformation and damage result of frequency. The maximum deformation for modes 4, 5, and 6 is 148 mm, 136 mm, and 128 mm.

4. Conclusion

This work aimed to investigate a Stewart platform via a computational method. In this order, the finite element method (FEM) was employed on the Ansys Inc. environment. The computational solution was carried out with three uniform loads on the top plate of the platform to simulate a loaded platform. The deformation and stress analysis on the static condition is considered to determine the most critical area on the platform leg facing maximum stress or maximum deformation. This area is subject to fatigue or failure under dynamic load. The Modal analysis is specified the beginning frequency mode, which can damage the platform. The result of this study could determine as below:

- The middle of the platform leg area is exposed to maximum stress and deformation
- Higher uniform load on the platform, move the location of the deformation to the upper part of the platform leg.
- The lower mode frequency makes the higher deformation on the platform.

Author Contributions
R. H. contributed with the conceptualization, method, software, data analysis, investigationand writing—original draft preparation. M. R. contributed with the conceptualization, writing—review and editing, and supervision. All authors have read and agreed to the published version of the manuscript.

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