

Design and Analysis of a Cam-Actuated Wearable-Chair

Adinda Hadirah Mohd Zin, Shamsul Anuar Shamsudin, Mohd Nizam Sudin, Mohd Nazim Abdul Rahman, Zairulazha Zainal

Abstract: This work analyzes the feasibility of a design of a foldable chair that is strapped onto the user. It can be used anywhere as the user needs to sit. Many chairless chairs or wearable-chairs have been invented over the years. Here, the focus is on the findings from the simulations and analyses performed to investigate the critical stress area in the design assembly as well as its factor of safety. The simulations included in this paper are motion analysis and stress analysis. The outcome of this investigation is that this design is able to deliver its purpose if it were to be manufactured for safe use by the masses.

Keywords : Cam-actuated, wearable-chair, development, analysis

I. INTRODUCTION

A wearable-chair or chairless chair is one of the useful inventions in recent design history. However, there are not many wearable-chair designs available in current market. The companies involved in the invention and development of such a device are mostly from Switzerland, Japan and Korea.

The world's first chair-less chair was designed by a Swiss design studio, Sapetti and then developed by Noonee in Zurich in 2014. The motivation is to enable the user to sit anywhere at any time without using the hand to carry the chair around [1]. Fig. 1 shows the initial concept considered in this work. Here, the angle between standing and sitting positions is suggested to be 18° .

Stinson [2] reported about the lighter Noonee design and compared it to the tool-holding Fortis developed by Lockheed Martin. The latter is a device that is basically a heavier exoskeleton. However, it can also be carried anywhere and designed for factory workers to be able to walk normally and can sit wherever they have to. The design is also adjustable to suit with the user's height [3]. It has a push button to lock the frame at the desired angle, preventing the device from

touching the ground unless in a static position. The device is also equipped with belts and wraps to secure the device onto the user's legs [1]. Nevertheless, it is not an easy task to design for ergonomics and to let the users move freely when using the chairless chair.

In the end, this innovation contributes in minimizing the negative impact on the industry workers' health and optimize the area in workplace by eliminating the use of conventional chairs.

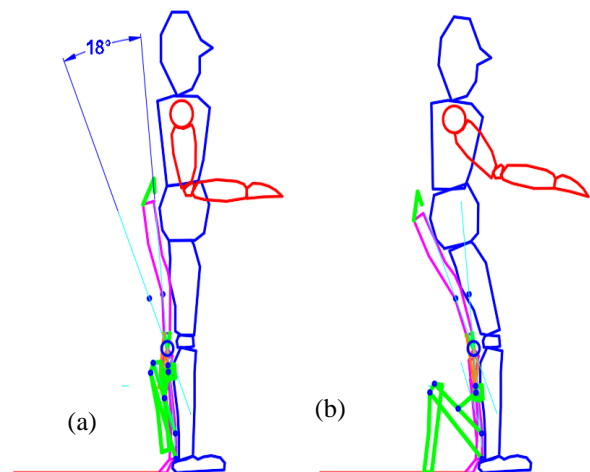


Fig. 1.Initial design of the new chairless chair. (a) The chair is folded when the user is standing. (b) The chair is deployed when the user is resting.

II. DESIGN ASSEMBLY

At first, to achieve the final design, the mechanical engineering design methods were performed, which included survey analysis, functional decomposition, quality functional development, product design specification and concept generation. From the survey, the customer or prospective user requirements could be identified. This is then listed in the House of Quality in Fig. 2 that helps in determining product specifications. Many other criteria were also considered such as specific user needs, manufacturing methods, service life and market segments.

This work considered many subfunctions for the device. There are many options for each subfunctions and these can create many design concepts for this product. Table I shows the morphological chart and the possible solutions they offer. Such an approach is discussed by Pahl, Beitz, Feldhusen and Grote in [4].

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Fig. 3 shows many conceptual designs can be generated from the combinations of the morphological chart, A conceptual design is using product design weighted scoring selection method shown in Ulrich and Eppinger [5], where one concept was chosen to be developed further. SolidWorks 2014 computer aided design (CAD) software was used to draw and assemble the solid model of Wearable-chair. The

sub parts in the design assembly included the cover parts, core parts, seat, cam follower, fasteners and connectors.

The winning concept utilizes a cam to transfer motion from the upper part of the mechanism to the lower that deploys the stand at the back of the device. Details on procedure for cam design can be found in literature like Myszka [6].

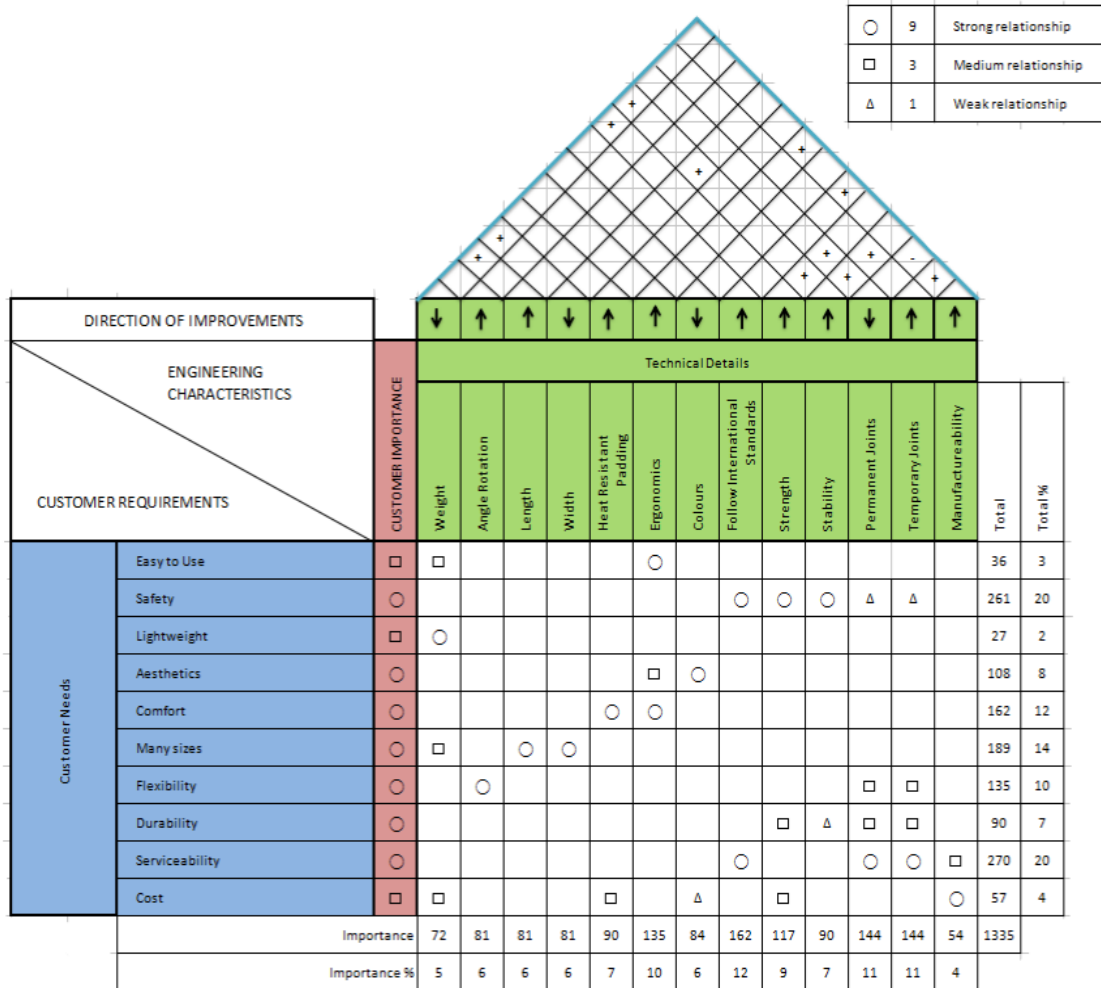


Fig. 2. Project House of Quality.

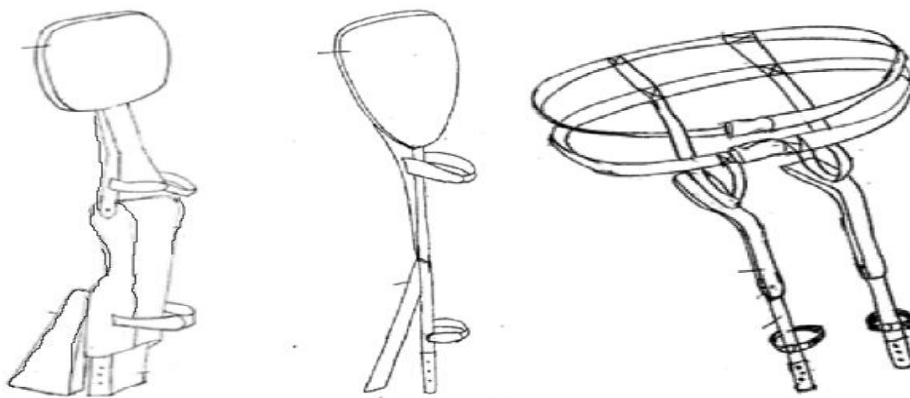















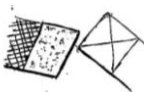



Fig. 3. Three conceptual designs generated.

Table- II: The morphological chart.

Sub-function	Solution			
a. Device position	1.  Behind leg	2.  At front and behind		
b. Seat type	1.  Double flat seat	2.  Single curvy seat	3.  Harness	4.  Single flat seat
c. Height adjuster	1.  Linear position ratchet	2.  Push Button Spring		
d. Stopper	1.  Adjustable	2.  Fixed		
e. Frame	1.  Curved	2.  Plate	3.  Cylindrical	4.  Square/rectangular
f. Harness lock	1.  Bag lock	2.  Velcro	3.  Plastic lock	

Identifying the DOF (degrees of freedom) is to determine the mobility of the design. The calculation of DOF using the Gruebler's Equation involves n , which is the number of links, J_p , the primary joints and J_h , the higher-order joints. The written relation is as in Equation (1). This discussion is found in many literatures like Myszka [6], Uicker, Pennock, and Shigley [7], and Erdman, Sandor and Kota [8].

$$m = 3(n - 1) - 2J_p - J_h \quad (1)$$

The DOF calculated of wearable-chair design is 1, with n ,

J_p and J_h are equal to 6, 6 and 2 respectively. The kinematic diagram with the components for this design are shown in Fig. 4. Nagaraja and Rajesh also used rigid body mechanisms in the scotch-yoke system they built for sawing purpose [9]. However, another work by Solepatil and Deore used compliant mechanisms that are made from a single flexible material designed to achieve high accuracy movements [10], although usually the displacement that could be reached by compliant mechanisms is limited to a smaller range.

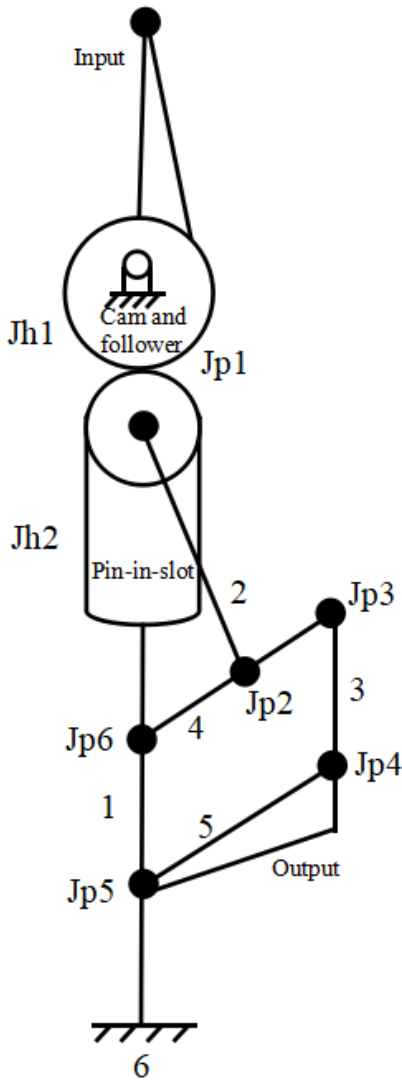


Fig. 4. The wearable-chair kinematic diagram labeled to analyze its mobility.

III. RESULT AND DISCUSSION

The simulations and analyses in this paper discusses the motion analysis and stress analysis. It contains the countermeasure to perform the simulations and the findings on both simulations and analyses involving design usability, maximum stress area and FOS (factor of safety).

In order to eliminate the fixable constraints and unnecessary interactions, the fasteners were excluded from the analyses. The cover parts in the design assembly were also excluded for the simulation results in order to have a clearer view of the wearable-chair mechanisms design assembly simulation results. The mechanisms design assembly used and its BOM (bill of materials) is shown in Fig. 5. Materials used are basically iron, steel, and aluminum for most parts as well as pine wood for the covers.

BOM Table		
ITEM NO.	PART NUMBER	New1/QTY.
1	Support1	1
2	Part2-2	1
3	Part1	1
4	Support15	1
5	Part3	1
6	Support3	1
7	Support6	1
8	Support2	1
9	Part3^Assem2	1
10	Part4^Assem2	1
11	Part5^Assem2	1
12	Support14	2
13	Part1^Assem2	1
14	Part2^Assem2	1
15	Part6^Assem2	1
16	Part7^Assem2	1
17	Core 1	1
18	Lower Cover	1
19	Stand Cover	1
20	Core 2	1
21	Upper Cover	1
22	Seat	1
23	Rod2	1
24	Rod1	2
25	Rod3	1
26	Rod4	1
27	Nut M8	16
28	Countersank Screw	6
29	Nut M13	4
30	Rod5	1

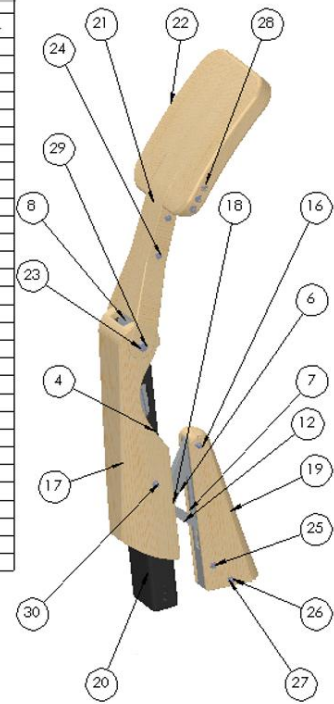


Fig. 5. Mechanisms design assembly of Wearable-chair.

The motion analysis was performed by using SolidWorks software. It was to analyze the usability of this design. This type of analysis is able to predict the motion of the model when load or torque is applied.

In this analysis, a low torque of 100 Nm was applied to the input in which it was supposedly enough to operate the device with gravitational force was in effect. In less than 5 seconds after the simulation was run, the desired motion and position was achieved with no interference during the analysis. The fully-deployed position of the design assembly is shown in Fig. 6.

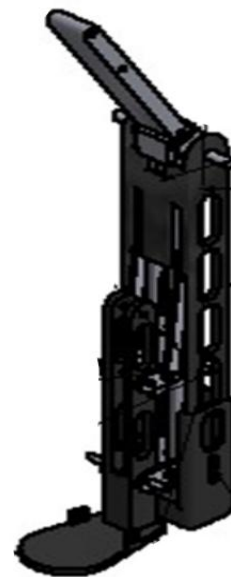


Fig. 6. Final position of the wearable-chair in motion analysis.

In this paper, stress analysis was performed on the design assembly instead of the part design using Autodesk Inventor. It was to obtain the Von Mises stress distribution for the whole design in order to obtain its FOS. Explanation on FOS can be found in Hibbeler [11] and Nisbett and Budynas [12]. The minimum factor of safety, n required for the design to be considered safe is at least 1.

$$n = \frac{S_y}{\sigma_{max}} \quad (2)$$

Recent work on forces in cams can be found in [13], while general finite element analysis on machines parts is shown by the work in [14]. In this present work, the stress analysis was performed by using Inventor 2017 software. Converting SLDASM file type to STEP file type was necessary for further analysis to be done in Inventor 2017.

This device was designed to sustain a weight less than 100 kg. Thus, one side of this device must be able to sustain 50 kg of weight. With a force of 490 N applied to the input in its final position, the Von Mises stress distribution was analyzed as shown in Fig. 7.

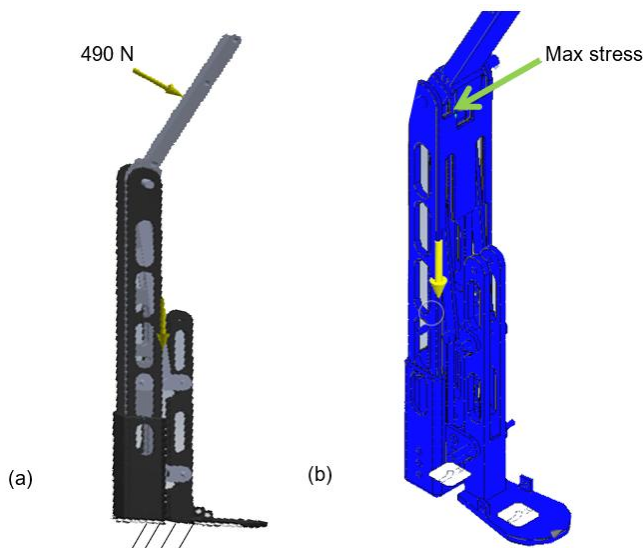


Fig. 7.(a) The boundary condition of the analysis, and (b) the Von Mises maximum stress location.

Fig. 8.

The maximum stress area analyzed in the design occurred in Core1 in Fig. 8 with 317.9 MPa. With iron material of 811 MPa yield stress applied to the Core1, the minimum factor of safety of about 1.7 behind the knee [15].

IV. CONCLUSION

The degrees-of-freedom shows that this design has achieved the desired mobility of 1. Furthermore, the motion analysis results also agreed to the design mobility and that the mechanisms design should be able to function as desired. Only a small maximum stress area was detected during the stress simulation analysis, and it was considered safe.

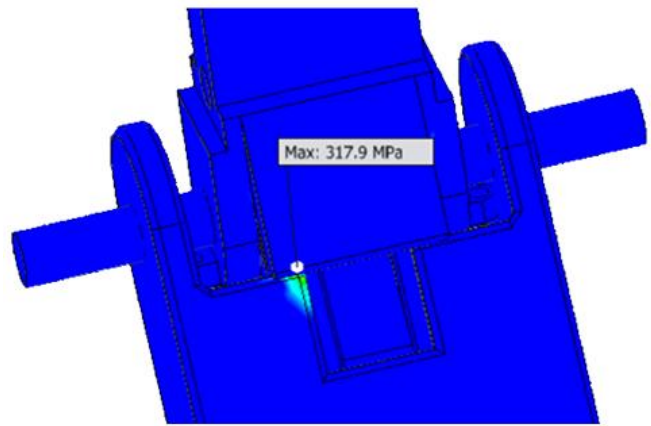


Fig. 9. Maximum stress area in the mechanism design assembly.

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