Design and Analysis of Engine-Generator Assembly for C-Drone

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Abstract: C-Drone is a cargo drone which is expected to handle the payload up to 180kg and cruise up to two hours. However, the C-Drone can only travel for five minutes when the batteries are fully charged. Hence, the purpose of this project is to design and analyse the PCD adapter and boom structure that unite the components as an Engine-generator Assembly which can act as powerplant to charge the C-Drone batteries continuously. By referring to the engineering design process the components for the Engine-generator Assembly are generated. The PCD adapter is designed based on the concept of jaws coupling and the components for PCD adapter are spacer shaft, jaws coupling insert and engine coupling. The material for the spacer shaft is AISI 303 Stainless Steel and Aluminium Alloy-6063 for the engine coupling. Nitrile Butadiene Rubber (NBR) jaws coupling insert is used intermediate between spacer shaft and engine coupling. The overall mass of PCD adapter is 3.803kg. Furthermore, boom structure with high strength and light weight is designed through idea of sheet metal bending to fabricate the subframe. The material used for both boom and subframe are AISI 4140 alloy steel and the mass of boom and subframe are 2.908kg and 1.874kg respectively. Based on the result obtained from simulation analysis, the PCD adapter and boom structure achieved minimum safety factor of 18.829 and 2.936 respectively. Which indicates that the PCD adapter can transmit the torque of $150 NNNN$ from Rotax-912 ULS engine to MP240150 electric motor while the boom structure has sufficient strength to carry the components. The overall dimension for Engine-generator Assembly will be 956.48mm(L)× 575.23mm(W)×439.65mm(H) and the overall mass is 81.288kg. This design is expected to carry mechanical function to charge the C-Drone batteries continuously.

Keywords: C-Drone, PCD Adapter, Boom Structure, Engine-generator Assembly

1. Introduction

Drone is an unmanned aerial vehicle (or UAVs), autonomous aircraft and remotely piloted aircraft [1]. Nowadays, customers tend to buy goods and services from the online shops which provide fast, flexible and free delivery [2]. The development in online shopping system increases the logistics demand all around the world including Malaysia. Hence, new transportation technologies have to be introduced to meet customer's need, deliver cargos in a short time, increase the sales of company and

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supporting their environmentally friendly programs [3]. In the real world, cruising ability of drones are limited by their fuel capacity or batteries capacity [4]. In addition to this, [5] stated that the current UAVs are not able to deliver all packages by itself in a single trip due to the limited range (distance and flight time) and capacity (weight and size). The C-Drone can only travel for five minutes when the batteries are fully charged. Suggestion and countermeasure by [4] are constructing a stationary power replenishment system at a relatively high setup and operation cost.

Engine-generator assembly as the powerplant for the C-Drone is constructed to charge the batteries continuously so that the C-Drone can achieve airborne time of two hours. Rotax-912 aircraft engine is assembled with MP240150 electric motor as the powerplant for the C-Drone. A pitch circle diameter (PCD) adapter is the component need to be designed to transmit the torque from the engine to the electric motor so that the electric motor can act as a generator to continuously charge the batteries. The PCD adapter design must meet with all the requirements and will not affect the performance of the drone. Boom structure that combines the engine and electric motor together to form an engine-generator assembly is the other component need to be designed for this project. The boom structure must have sufficient strength to withstand the load of the engine-generator assembly.

2. Literature Review

Explanation on parameters and specifications of Rotax-912 ULS aircraft engine and MP240150 electric motor were reviewed. The PCD adapter design consideration and the other influences such as natural frequency, resonance and vibration were explained in this chapter. Material such as journal, reference book and websites were reviewed to obtain the information needed for the design. A deeper understanding of mechanical tests such as fatigue test and static test were accomplished. Moreover, importance and effects of coupling which can act as a damper between PCD adapter were reviewed.

2.1 Rotax-912 ULS Aircraft Engine

Figure 1: Rotax-912 ULS Aircraft Engine

Table 1: General Specification of Rotax-912 ULS Aircraft Engine [6]

Parameter	Specifications (units)
Number and arrangement of cylinders	4 cylinder-opposed
Compression ratio	11
Dry weight	56.6 kg
Displacement	1352 cc
Cylinder stroke	61 mm
Cylinder bore	84 mm
Maximum power	100 hp @ 5800 rpm
Maximum torque	128 Nm @ 5100 rpm

2.2 MP240150 Electric Motor

The device used for this case study were TSI VelociCalc Plus air velocity meter and KIMO AMI 310 that collected data for air temperature (°C), radiant temperature, air velocity (m/s) and relative humidity (%).

Table 2: General Specification of MP240150

Electric Motor Parameter	Specification (units)
Speed	6000 rpm
Maximum power	100 kW
Maximum current	400 A
Maximum voltage	400 V
Efficiency	88%
Diameter	240 mm
Length	150 mm
Weight	16 kg

2.3 Spacer Shaft

A spacer shaft is a rigid extension between two shafts with no supports. It is used to transmit the torque from a driver machine to a driven machine. The shaft is the most important component for every mechanical system and machines because it is subjected to torsion, bending and sometimes axial loading. Shaft misalignment is one of the sources of vibration in rotating machinery as the static and dynamic forces are introduced in the system [7]. These may cause partial fatigue and fracture on the shaft, and finally cause overall failures of the propulsion system [8]. The shaft misalignment is defined in terms of angular misalignment and parallel misalignment. Figure 2 shows the angular and parallel misalignments.
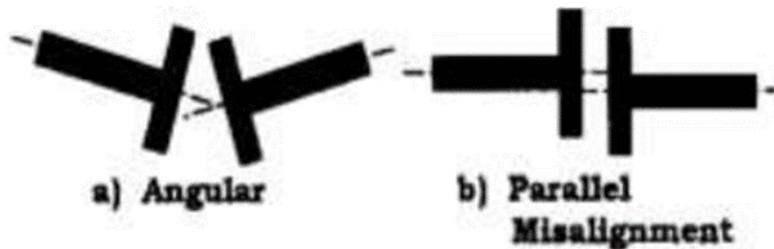
Figure 2: Angular and Parallel Misalignments [7]

2.4 Coupling

Mechanical couplings are important components in transmission system for few purposes such as resolve misalignment issues. Mechanical coupling is needed to connect the driver and driven shafts to provide sufficient mechanical flexibility for the transmission system to tolerate a certain level of misalignment [9]. They conducted a study to measure misalignment forces and the experiment setup is shown in Figure 3 while Figure 4 shown the jaws coupling used for the study. The experiment results proved that the vibration amplitude increases as the misalignment level increases.
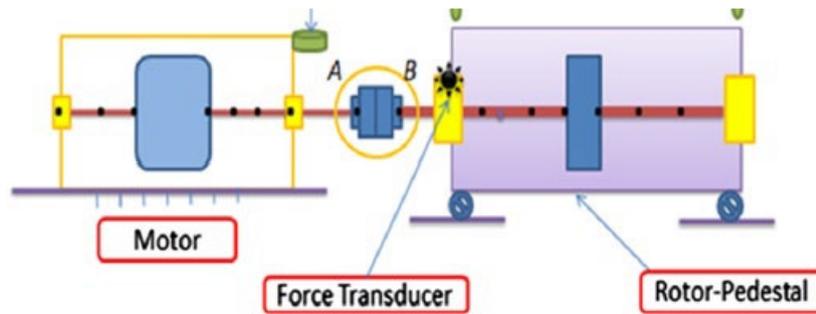
Figure 3: Experimental Setup to Measure Misalignment Forces [9]
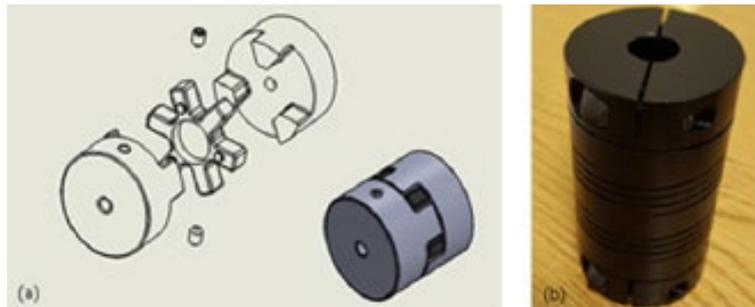
Figure 4: Jaws Coupling Used in Experiment [9]

3. Project Flow

3.1 Flow chart
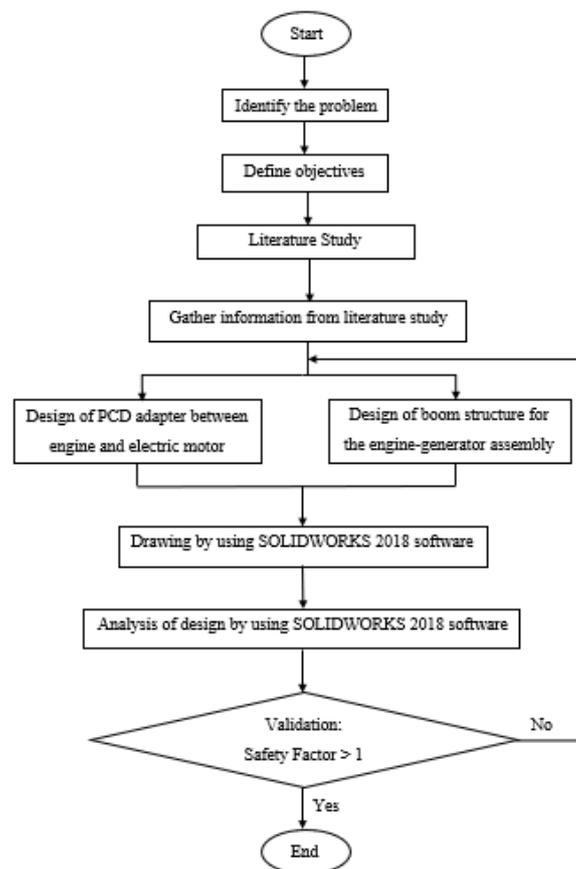
Figure 5: Project Flow Chart

From Figure 5, the project starting with identify the problems and objectives of the project followed by literature review of criteria needed to be focused in designing the spacer shaft and gathering information. Engineering design method was used to design the PCD adapter and boom structure for Engine-generator Assembly. For instance, the design phases such as conceptual design, embodiment design and detail designed were followed.

3.2 Objective tree

Figure 6 shown the Objective Tree of Engine-generator Assembly. The requirements such as function, maintenance, design, price, sustainable and efficiency were listed followed by sub-criterial.
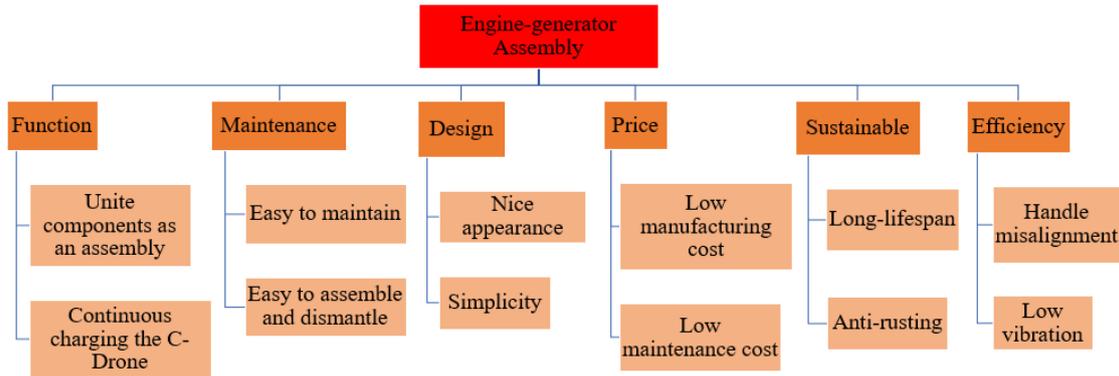
Figure 6: Objective Tree of Engine-generator Assembly

3.3 Product design specification

Creating a Product Design Specification (PDS) is needed at the starting of design because it finalizes the process of establishing the design requirements, prioritizing them, and cast them into a technical framework to establish the design concepts. Table 3 shown the Product Design Specification (PDS) of Engine-generator Assembly.

Table 3: Product Design Specification (PDS) of Engine-generator Assembly

Introduction	
Title	Title
Engine-generator Assembly	Engine-generator Assembly
Design Problem	Design Problem
Project Requirement	
Function	• The PCD adapter must able to transmit torque from engine to electric motor.
	• The boom structure must able to unite the engine and electric motor as an assembly
Maintenance	• The PCD adapter should easy to detach from the assembly when maintenance is needed.
	• Low cost of maintenance
Geometric Limitation	• Able to fit inside C-Drone frame
	• Able to sustain the stress and torque
Operating Environment	• Suitable for any environment
Economic	• Low manufacturing cost
	• Low material cost
Safety	• The PCD adapter would not cause danger to people
Sustainability	• The PCD adapter and boom structure are long-lifespan
Effeciency	• The PCD adapter able to handle misalignment
	• Low vibration in Engine-generator Assembly

3.4 Gather Information

The information related to the design of Engine-generator Assembly was being collected through study of journals on how people designed a shaft and what criteria must be emphasized and concerned. Related studies of spacer shaft design and the analysis carried out by the researchers are crucial.

3.5 Full Engine-generator Assembly

Based on PDS, the concept map for Engine-generator Assembly was produced for idea generation and information organization on design. Figure 7 shown the Black Box Diagram for Engine-generator Assembly.
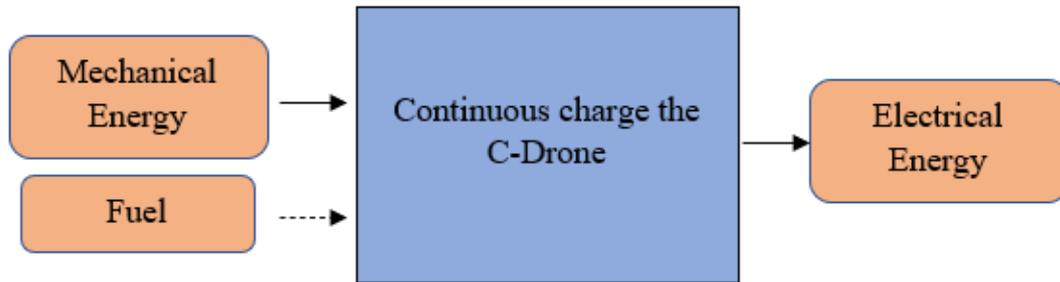
Figure 7: Black Box Diagram for Engine-generator Assembly

Morphological chart was generated to explore combinations to fulfill the same required functionality. There were few combinations made and evaluated to get the best concept for the project. Product sketching was done by referring the concepts selected from the evaluation. Figure 8 shown the product sketching.
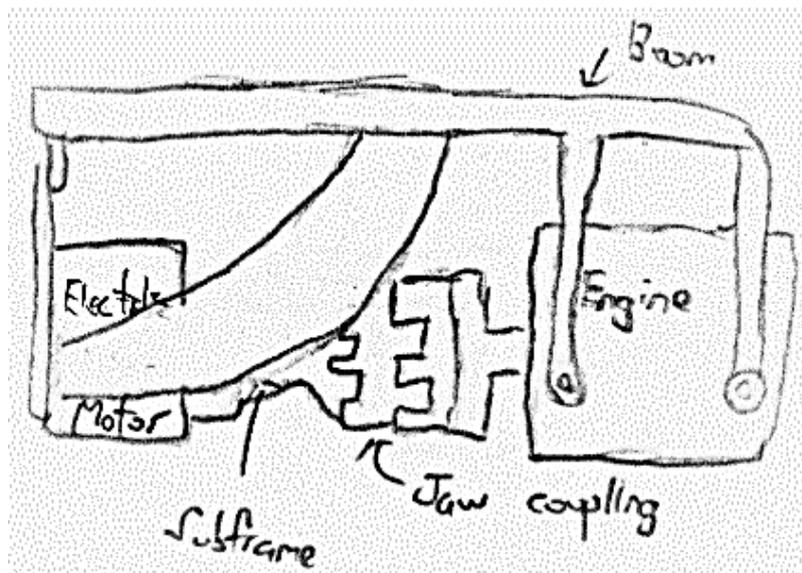
Figure 8: Product Sketching

The schematic diagram was then created to arrange and represent the required functions of physical elements in group. Figure 9 shown the schematic diagram of the Engine-generator Assembly.

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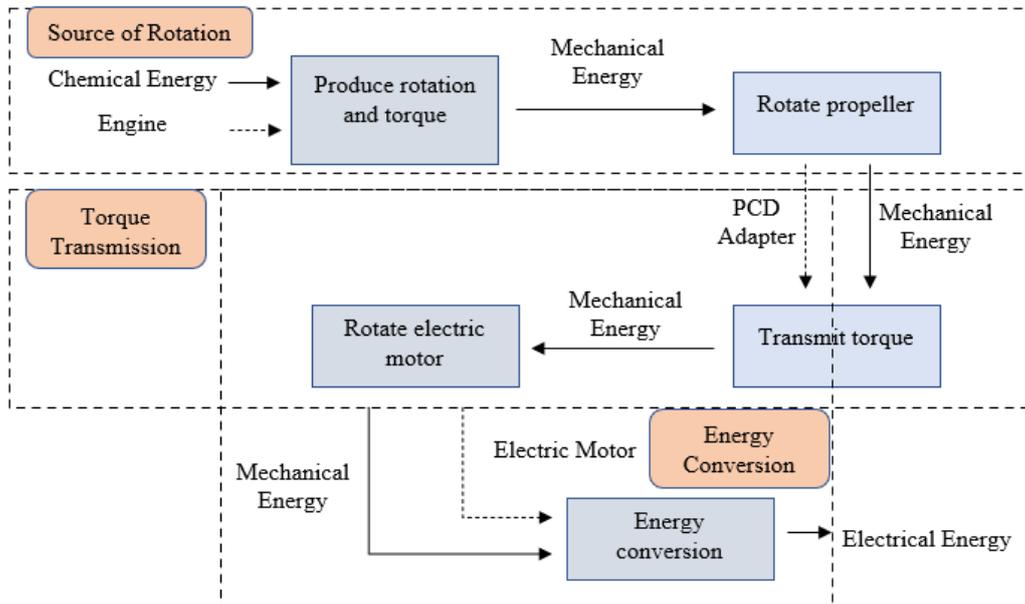
Figure 9: Schematic Diagram of Engine-generator Assembly

Next, the rough geometric layout was created as shown in Figure 10 which is the 3D geometric layout imported from SolidWorks while Figure 11 shown 3D geometric layout of PCD adapter.
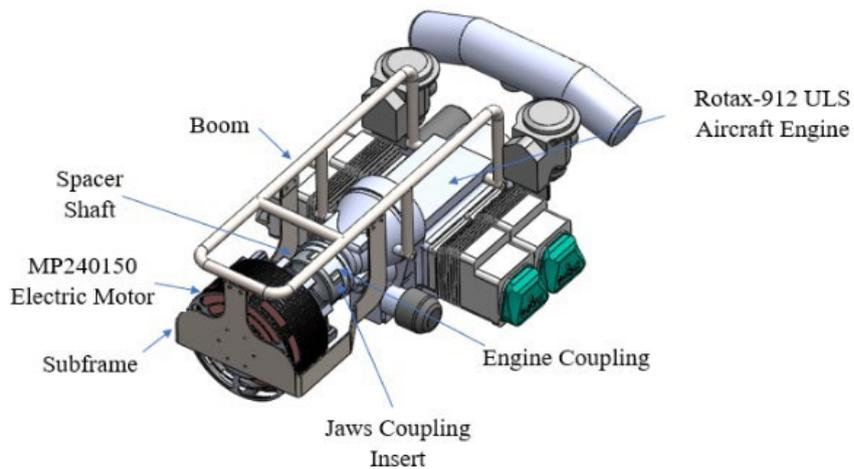
Figure 10: 3D Geometric Layout
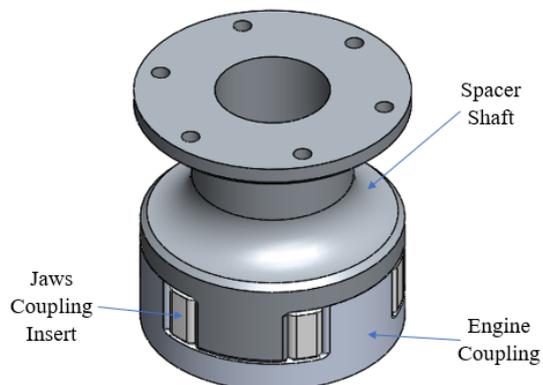
Figure 11: 3D Geometric Layout of PCD Adapter

3.6 Simulation

Simulation were conducted on spacer shaft, engine coupling and then on its combination that is PCD adapter. Static analysis, modal analysis, fatigue analysis and dynamic analysis were conducted on these components. After that, static analysis, modal analysis and dynamic analysis were conducted on the boom structure. Figure 12 shown the simulation of these components.
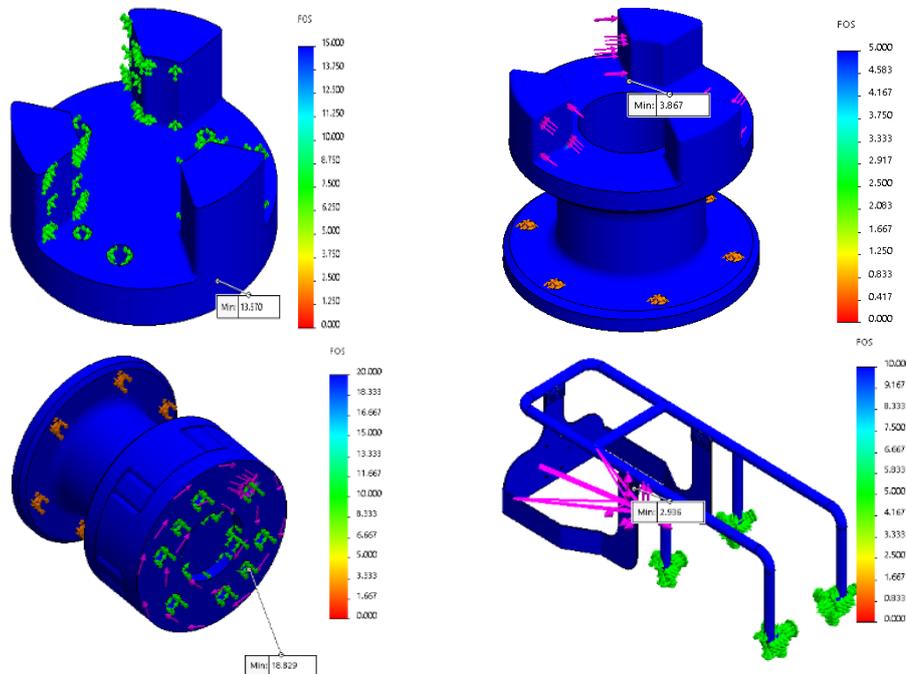
Figure 12: Simulation of Components

3.7 Engineering Analysis

Engineering analysis is important in parametric design to figure out the parameter of component and standard part that needed calculation. Bolt preload exists in the bolt connection when the nut has been properly tightened no matter whether the tensile load is exerted or not. Calculation of bolt preload is important to prevent working load of bolt exceed the preload and cause failure. The equations for bolt preload were shown below and the result was shown in Table 4.

$$F_i = 0.75F_p \qquad \text{Eq.1}$$
$$F_p = A_t S_p \qquad \text{Eq.2}$$
$$T = K F_i d \qquad \text{Eq.3}$$

Table 4: Bolt Preload and Torque to Achieve Preload

Bolt Types	Tensile Stress Area, A_t (mm^2)	Minimum Proof Strength, S_p (MPa)	Minimum Proof Load, F_p (N)	Preload, F_i (N)	Torque to Achieve Preload, T (Nm)
M6	20.1	650	13065	9798.75	11.7585
M8	39.2	650	25480	19110	30.576
M10	61.2	650	39780	29835	59.67
7/16	$0.1187\ in^2 = 76.58$	$85\ kpsi = 586.054$	44880.015	33660.011	74.809

Moreover, Design for Excellence (DFX) method had been carried out and the areas of focus were Design for Manufacture (DFM) and Design for Assembly (DFA).

3.8 Engineering Drawing

Engineering drawings for Engine-generator Assembly were produced by using SolidWorks software. The detail such as dimension, material and geometry of components were clearly stated in the engineering drawing. Figure 13 shown the assembly layout of Engine-generator Assembly.

ITEM NO.	PART NAME	QTY.
1	PCD Adapter	1
2	MP240150 Electric Motor	1
3	Boom	1
4	Subframe	1
5	Rotax 912 ULS Engine	1
6	B18.22M - Plain washer, 10 mm, narrow	4
7	B18.22M - Plain washer, 8 mm, narrow	12
8	Regular LW 0.5	6
9	B18.2.3.5M - Hex bolt M10 x 1.5 x 60 --60N	2
10	B18.2.3.5M - Hex bolt M10 x 1.5 x 45 --45N	2
11	B18.2.3.1M - Hex cap screw, M8 x 1.0 x 20 --20N	6
12	B18.2.4.5M - Hex jam nut, M8 x 1.0 --D-N	6
13	JIS B 1355 Class A 8x26	2
14	HX-SHCS 0.4375-20x1x1-N	6
15	B18.3.1M - 8 x 1.0 x 45 Hex SHCS -- 45NHX	6
16	B18.3.1M - 6 x 1.0 x 16 Hex SHCS -- 16NHX	6
17	B18.22M - Plain washer, 6 mm, regular	6

Figure 13: Assembly Layout

3.9 Product Specification

The final product specification was generated after the detail design and engineering analysis. The function of product specification is to provide the information of product. Table 5 shown the product specification of Engine-generator Assembly and its component.

Table 5: Product Specification

OVERALL PRODUCT SPECIFICATION	DESCRIPTION
Product Name	Engine-generator Assembly
Overall Dimension	956.48mm(L) × 575.23mm(W) × 431.65mm(H)
Overall Weight	81.288 Kg
Overall Cost	*RM* 97450.24

COMPONENT SPECIFICATION		
COMPONENT	SPECIFICATION	DESCRIPTION
PCD Adapter	Overall Weight	3.803 Kg
	Dimension	120mm(L) × 120mm(W) × 120mm(H)
	Material	AISI 303 Stainless Steel Nitrile Rubber (NBR) Aluminium Alloy-6063
	Life Cycle	100,000 million cycles
COMPONENT	SPECIFICATION	DESCRIPTION
Boom Structure	Overall Weight	4.782 Kg
	Dimension	704.45mm(L) × 217.30mm(W) × 231.30mm(H)
	Material	AISI 4140 Alloy Steel

4.   Conclusion and Recommendation

4.1 Objective 1

The first objective of this project was to design the PCD adapter between engine and electric motor to transmit the torque because there was pitch circle diameter difference between engine and electric motor. This objective had been achieved with the aid of engineering design process. The information and idea needed to design the PCD adapter were collected through survey and literature study. Then, concepts were generated, and evaluation of concept was done to come out with the final design which was deemed compatible for solving the project problems. The PCD adapter was designed based on the concept of jaws coupling, in which the jaws coupling insert was clamped by the coupling at the both sides. The jaws coupling insert was able to tackle misalignment problem while transmitting the torque. The overall mass of PCD adapter is 3.803kg and the material used are AISI 303 Stainless Steel and Aluminium Alloy-6063 for spacer shaft and engine coupling respectively. The material chosen for jaws coupling insert is Nitrile Butadiene Rubber (NBR).

4.2 Objective 2

The second objective of this project was to design the boom structure that combine the Engine-generator Assembly. This objective had been accomplished as the boom structure was finally designed to combine the Engine-generator Assembly. In this project, the boom structure was needed to carry the weights of components such as electric motor and PCD adapter. Hence, the strength of boom structure was the main concern during the design process. Continuous improvement had been made to improve the strength of boom structure, improving the geometries of boom structure to reduce stress concentration and achieving weight reduction on the boom structure. Moreover, non-engineering factors were also concerned such as safety of human during assembly and maintenance was considered by preventing any sharping edges that risky to human. At the end, boom structure was designed with high strength and light weight through the idea of sheet metal bending. AISI 4140 Alloy Steel was chosen as the material for both boom and subframe. The mass of boom and subframe are 2.908kg and 1.874kg respectively.

4.3 Objective 3

The third objective of this project was to conduct analysis on both PCD adapter and boom structure. Conducting simulation analysis is important before fabrication to visualize the model in the real application. Reducing the risks to be happened as the components were tested and proven its safeness. As evidence of accomplishment of this objective, simulation analyses were conducted for every component designed and satisfactory results were obtained as shown in part 4.8.5. Once the components were generated by using SOLIDWORKS 2018 software, the components were undergone simulation analysis to determine their performance. There were a lot of knowledges learnt in the process of running simulation analysis. From the simulation conducted, the factor of safety of PCD adapter when handling the torque of 150Nm is 18.829 while the factor of safety of boom structure is 2.936. Proven that both PCD adapter and boom structure are strong to handle the stresses. The overall dimension of Engine-generator Assembly would be 956.48mm(L)×575.23mm(W)×439.65mm(H) and the overall mass is 81.288Kg.

The recommendation for this project is assistance of welding angle clamps is needed to improve the accuracy during welding. Moreover, it is suggested to have a prototype with equally or scaled down dimension and conduct experiment in the future study. Lastly, further research is encouraged to analyse the components by using other engineering simulation software such as ANSYS, MATLAB and others to compare the results.

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