Design and Analysis of Grass Cutting Machine By Using DFMA Method

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Abstract. This paper describes about the implementation of redesign the component of grass cutting machine by using the application of Design for Manufacturing and Assembly (DFMA) methodology. The scope based on the existing grass cutting machine and the appropriate of DFMA methodology. The data was analysed by using Boothroyd-Dewhurst Design for Manufacture and Assembly method to verify the design efficiency, handling ratio and fitting ratio to achieve. The new proposed design of grass cutting machine drawn using CATIA V5 software based. As a result, the assembly time for redesign showed an improvement of 18.68% where the assembly time was reduced from 568.84 s to 462.59 s and design efficiency was increased 8.33% from 24.40% to 34.70%. The total part, handling ratio fitting ratio and cost of existing design is reduced. Eventually, the improvement of redesign grass cutting machine the best design with optimal value is accomplished.

1. Introduction

Design for manufacture and assembly (DFMA) is a combination of design for assembly (DFA) and design for manufacture (DFM). The term DFMA is defined as a set of guidelines developed to ensure that a product is designed so that it can be easily and efficiently manufactured and assembled with a minimum laborious effort, assemble time, and cost to manufacture the product [1-4]. DFA is considering and resolving the possible problems in the assembly process at the early stage of the design which can make sure the part will be assembled with high speed, low cost and productivity [5]. DFM is that by considering the limitations related to the manufacturing at the early stage of the design which is the design engineer can make selection among the different materials, different technologies and estimate the manufacturing time [6,19]. The quality of new product was increased with the good development period including design, technology, manufacturing, service and so on [7-9]. Simultaneously, the cost also decrease, including the cost of design, technology, manufacturing, delivery and technical support. The short developing cycle time, including the time of design, manufacturing preparing, and repeatedly calculation [10-11].
2. Research Objective

The main objective of this research is to analyse design efficiency on current design and redesign of grass cutting machine by using DFMA method. By using the DFMA as the benchmark tool was used to increase the design efficiency and minimize the quantity of part in manufacturing and assembly costing [2-4,20,21].

3. Design For Manufacture and Assembly (DFMA) of Grass Cutting Machine

3.1. CAD Drawing

CAD design is capable of producing the designer with extremely precise designs and prospects. CAD drawing also helps the designer in evaluating the design and redesigning the drawing. Figure 1 shows the first process in Boothroyd-Dewhurst DFMA method is to design the concept [12]. Figure 2 shows the features of current grass cutting machine by using CAD drawing.

![Figure 2. CAD Modelling of Grass Cutting Machine.](image)

3.2. Design For Assembly (DFA)

Design for Assembly (DFA) is an approach to reduce the cost of the product and time of assembly by simplifying the product and process. There are two uses of DFA. It may use to redesign a product already in manufacture or product being remarked or reversed engineering. Beside that DFA may also use for analysis of a product while it is in design [13,14, 18, 22]. The DFA method should be considered at all stages of the design process especially in the early stages [15, 23-25]. In this paper, type of assembly that must be considered is manual assembly by. The manual assembly can be measured by using DFA tool, which is the handling and insertion time table.

Table 1 shows the current quantity parts used, handling time, insertion time, theoretical part count and assembly time for each part for current grass cutting machine. The parts should be consider the orientation of the part rotating (Alpha – α and Beta - β) from X and Y-axis. While handling time and insertion time are selected based on the table estimate time For Manual Handling Time and Manual Insertion Time. The theoretical part count states the important of the part for grass cutting machine. If the part is important to the main function of the grass cutting machine, the value of theoretical part count is 1 and the less important part to the function of the grass cutting machine which is that parts can be eliminated or redesign is 0 [15].
Table 1. Existing Part Assembly Time.

| No | Part Name                | Quantity | Theoretical Part Count | $\alpha$ (°) | $\beta$ (°) | Handling Time (s) | Insertion Time (s) | Total Assembly Time (s) |
|----|--------------------------|----------|------------------------|--------------|------------|------------------|-------------------|------------------------|
| 1  | Bolt M10 X 25            | 1        | 0                      | 360          | 0          | 1.5              | 3.5               | 5                      |
| 2  | Washer                   | 1        | 0                      | 180          | 0          | 1.88             | 2.5               | 4.38                   |
| 3  | Bolt Protection Cover    | 1        | 1                      | 360          | 0          | 1.5              | 1.5               | 3                      |
| 4  | Cutter Holder Cap        | 1        | 1                      | 360          | 0          | 1.5              | 1.5               | 3                      |
| 5  | Cutter Holder            | 1        | 1                      | 360          | 0          | 1.5              | 1.5               | 3                      |
| 6  | Gear Case                | 1        | 1                      | 360          | 360        | 3                | 6                 | 9                      |
| 7  | Bolt M6 X 12             | 2        | 0                      | 360          | 0          | 3                | 7                 | 10                     |
| 8  | Screw M5 X 20            | 3        | 0                      | 360          | 0          | 4.5              | 10.5              | 15                     |
| 9  | Aluminium Pipe           | 1        | 1                      | 180          | 0          | 1.5              | 5.5               | 7                      |
| 10 | Shaft Drive              | 1        | 1                      | 180          | 90         | 1.13             | 5.5               | 6.63                   |
| 11 | Bushing                  | 1        | 1                      | 360          | 0          | 1.5              | 2.5               | 4                      |
| 12 | Flexible Inner           | 1        | 1                      | 180          | 0          | 2                | 5.5               | 7.5                    |
| 13 | Flexible Shaft           | 1        | 1                      | 180          | 0          | 1.13             | 5.5               | 6.63                   |
| 14 | Bolt M6 X 25             | 2        | 0                      | 360          | 0          | 3                | 7                 | 10                     |
| 15 | Safety Guard Bracket     | 1        | 1                      | 360          | 360        | 1.95             | 6                 | 7.95                   |
| 16 | Safety Guard             | 1        | 1                      | 360          | 360        | 1.95             | 5                 | 6.95                   |
| 17 | Handle                   | 1        | 1                      | 360          | 360        | 1.95             | 4                 | 5.95                   |
| 18 | Handle Bracket           | 1        | 0                      | 360          | 360        | 1.95             | 6                 | 7.95                   |
| 19 | Bolt M6 X 45             | 2        | 0                      | 360          | 0          | 3                | 7                 | 10                     |
| 20 | Grip                     | 1        | 1                      | 360          | 360        | 3                | 5                 | 8                      |
| 21 | Joint Pipe               | 1        | 1                      | 360          | 360        | 2.73             | 5                 | 7.73                   |
| 22 | Screw M5 X 10            | 1        | 0                      | 360          | 0          | 1.5              | 3.5               | 5                      |
| 23 | Screw M5 X 25            | 1        | 0                      | 360          | 0          | 1.5              | 3.5               | 5                      |
| 24 | Stop Button              | 1        | 1                      | 360          | 0          | 1.5              | 2.5               | 4                      |
| 25 | Stop Button Bracket      | 1        | 1                      | 360          | 0          | 1.5              | 1.5               | 3                      |
| 26 | Throttle Lever           | 1        | 1                      | 360          | 360        | 1.95             | 6                 | 7.95                   |
| 27 | Bolt M5 X 25             | 1        | 0                      | 360          | 0          | 1.5              | 3.5               | 5                      |
| 28 | Blade                    | 1        | 1                      | 360          | 180        | 1.8              | 6                 | 7.8                    |
| 29 | Shoulder Frame           | 1        | 1                      | 360          | 360        | 1.95             | 0                 | 1.95                   |
| 30 | Lifting Metal            | 1        | 1                      | 360          | 360        | 1.95             | 4.5               | 6.45                   |
| 31 | Shoulder Plate Holder A  | 1        | 1                      | 360          | 360        | 1.95             | 6                 | 7.95                   |
| 32 | Shoulder Plate Holder B  | 1        | 1                      | 360          | 360        | 1.95             | 6                 | 7.95                   |
| 33 | Screw M5 X 12            | 8        | 0                      | 360          | 0          | 12               | 28                | 40                     |
| 34 | Shoulder Plate           | 1        | 1                      | 360          | 360        | 3                | 6                 | 9                      |
| 35 | Bolt M6 X 16             | 3        | 0                      | 360          | 0          | 4.5              | 10.5              | 15                     |
| 36 | Shoulder Belt            | 1        | 1                      | 360          | 360        | 1.95             | 2.5               | 4.45                   |
Table 1. Existing Part Assembly Time (Continued…).

| No. | Part Name                             | Quantity | Theoretical Part Count | α (°) | β (°) | Handling Time (s) | Insertion Time (s) | Total Assembly Time (s) |
|-----|---------------------------------------|----------|------------------------|-------|-------|-------------------|---------------------|------------------------|
| 37  | Engine Base A                         | 1        | 360                    | 360   | 1.95  | 6                 | 7.95                |
| 38  | Engine Base B                         | 1        | 360                    | 360   | 1.95  | 6                 | 7.95                |
| 39  | Cushion Rubber                        | 4        | 180                    | 0     | 6     | 10                | 16                  |
| 40  | Rotating Shaft                        | 1        | 180                    | 0     | 1.5   | 2.5               | 4                   |
| 41  | Bearing                               | 1        | 180                    | 0     | 1.5   | 5                 | 6.5                 |
| 42  | Nut M10                               | 2        | 360                    | 0     | 3     | 7                 | 10                  |
| 43  | Screw M6 X 12                         | 3        | 360                    | 0     | 4.5   | 10.5              | 15                  |
| 44  | Fuel Tank                             | 1        | 360                    | 360   | 3.9   | 13.5              | 6.45                |
| 45  | Lid Tank                              | 1        | 360                    | 0     | 1.5   | 1.5               | 3                   |
| 46  | Fuel Tank Band                        | 2        | 360                    | 360   | 3.9   | 12                | 15.9                |
| 47  | Screw M5 X 20                         | 2        | 360                    | 0     | 3     | 7                 | 10                  |
| 48  | Fuel Pipe Protection Coil             | 1        | 180                    | 0     | 1.5   | 2.5               | 4                   |
| 49  | Fuel Pipe                             | 1        | 180                    | 0     | 1.5   | 2.5               | 4                   |
| 50  | Fuel Pipe Clip                        | 2        | 180                    | 0     | 3     | 5                 | 8                   |
| 51  | Tank Holder Metal                     | 1        | 360                    | 360   | 1.95  | 6                 | 7.95                |
| 52  | Engine Cover                          | 1        | 360                    | 360   | 1.95  | 5                 | 6.95                |
| 53  | Screw M4 X 12                         | 1        | 360                    | 0     | 1.5   | 3.5               | 5                   |
| 54  | Screw M4 X 10                         | 2        | 360                    | 0     | 3     | 7                 | 10                  |
| 55  | Rope                                  | 1        | 180                    | 0     | 1.88  | 2.5               | 4.38                |
| 56  | Recoil Starter Body                   | 1        | 360                    | 360   | 1.95  | 6                 | 7.95                |
| 57  | Starter Handle                        | 1        | 360                    | 0     | 1.5   | 1.5               | 3                   |
| 58  | Starter Rope Reel                     | 1        | 180                    | 0     | 1.88  | 5                 | 6.88                |
| 59  | Screw M5 X 12                         | 1        | 360                    | 0     | 1.5   | 3.5               | 5                   |
| 60  | Cleaner Body                          | 1        | 360                    | 360   | 1.95  | 6                 | 7.95                |
| 61  | Cleaner Fixing Base                   | 1        | 360                    | 180   | 1.5   | 2.5               | 4                   |
| 62  | Cleaner Element                       | 1        | 360                    | 180   | 1.5   | 2.5               | 4                   |
| 63  | Screw M4 X 25                         | 2        | 360                    | 0     | 3     | 7                 | 10                  |
| 64  | Clutch Case                           | 1        | 360                    | 360   | 1.95  | 2.5               | 4.45                |
| 65  | Locking Pin                           | 1        | 360                    | 0     | 1.5   | 1.5               | 3                   |
| 66  | Fan Case                              | 1        | 360                    | 360   | 2.73  | 6                 | 8.73                |
| 67  | Screw M5 X 20                         | 6        | 360                    | 0     | 9     | 21                | 30                  |
| 68  | Muffler                               | 1        | 360                    | 360   | 1.95  | 6                 | 7.95                |
| 69  | Screw M6 X 65                         | 2        | 360                    | 0     | 3     | 7                 | 10                  |
| 70  | Plug Cap                              | 1        | 360                    | 360   | 2.73  | 4                 | 6.73                |
| 71  | Stop Wire                             | 1        | 180                    | 0     | 1.5   | 2.5               | 4                   |
| 72  | Engine                                | 1        | 360                    | 360   | 5     | 8                 | 13                  |
|     | **Total parts**                       | 72       | **50**                 |       |       |                   | **568.84**          |
3.3. Design Efficiency

The important data in the DFA method is the used the "Efficiency of assembly" of the proposed design. Basically, there have two major factors affecting cost of product assemblies or subassembly are:

i) Parts number.

ii) The easy of manual insertion, handling and fastening.

\[ DE = \frac{\text{Theoretical Part Count} \times 3s}{\text{Total Assembly Time} (s)} \]  

\[ DE = \frac{NM}{TM} \times T_a \]

\[ DE = \frac{50}{56.84} \times 3s \]

\[ DE = 0.264 \times 26.4\% \]

Based on the calculation above, the current design efficiency of grass cutting machine is 26.4%. Therefore, the redesign efficiency of grass cutting machine must be higher than the current design efficiency.

3.4. Design for Manufacturing (DFM)

Design for Manufacturing (DFM) is to make easier for manufacturing and concerned with reducing overall part production cost by minimizes complexity of manufacturing operations [16-18]. The DFM will be analysing the material and process used to ease the design for grass cutting machine. Table 2 shows the Manufacturing Process and Material used for Each Part of grass cutting machine.

| No. | Part Name          | Material      | Process       |
|-----|--------------------|---------------|---------------|
| 1   | Bolt M10 X 25     | Carbon Steel  | Machining     |
| 2   | Washer             | Carbon Steel  | Sheet Metal Stamping |
| 3   | Bolt Protection Cover | Carbon Steel  | Sheet Metal Stamping |
| 4   | Cutter Holder Cap | Carbon Steel  | Die Casting   |
| 5   | Cutter Holder     | Carbon Steel  | Die Casting   |
| 6   | Gear Case         | Carbon Steel  | Die Casting   |
| 7   | Bolt M6 X 12      | Carbon Steel  | Machining     |
| 8   | Screw M5 X 20     | Carbon Steel  | Machining     |
| 9   | Aluminium Pipe    | Aluminium     | Hot Extrusion |
| 10  | Shaft Drive       | Carbon Steel  | Hot Extrusion |
| 11  | Bushing           | Carbon Steel  | Die Casting   |
| 12  | Flexible Liner    | Rubber        | Injection Molding |
| 13  | Flexible Shaft    | Carbon Steel  | Die Casting   |
| 14  | Bolt M6 X 25      | Carbon Steel  | Machining     |
| 15  | Safety Guard Bracket | Abs          | Injection Molding |
| No. | Part Name                  | Material       | Process          |
|-----|----------------------------|----------------|------------------|
| 16. | Safety Guard              | Abs            | Injection Molding|
| 17. | Handle                    | Abs            | Injection Molding|
| 18. | Handle Bracket            | Abs            | Injection Molding|
| 19. | Bolt M6 X 45              | Carbon Steel   | Machining        |
| 20. | Grip                      | Rubber         | Injection Molding|
| 21. | Joint Pipe                | Aluminium      | Hot Extrusion    |
| 22. | Screw M5 X 10             | Carbon Steel   | Machining        |
| 23. | Screw M5 X 25             | Carbon Steel   | Machining        |
| 24. | Stop Button               | Abs            | Injection Molding|
| 25. | Stop Button Bracket       | Abs            | Injection Molding|
| 26. | Throttle Lever            | Abs            | Injection Molding|
| 27. | Bolt M5 X 25              | Carbon Steel   | Machining        |
| 28. | Blade                     | Carbon Steel   | Powder Metal     |
| 29. | Shoulder Frame            | Carbon Steel   | Hot Extrusion    |
| 30. | Lifting Metal             | Carbon Steel   | Die Casting      |
| 31. | Shoulder Plate Holder A   | Carbon Steel   | Die Casting      |
| 32. | Shoulder Plate Holder B   | Carbon Steel   | Die Casting      |
| 33. | Screw M5 X 12             | Carbon Steel   | Machining        |
| 34. | Shoulder Plate            | Carbon Steel   | Die Casting      |
| 35. | Bolt M6 X 16              | Carbon Steel   | Machining        |
| 36. | Engine Base A             | Carbon Steel   | Die Casting      |
| 37. | Engine Base B             | Carbon Steel   | Die Casting      |
| 38. | Cushion Rubber            | Rubber         | Extrusion        |
| 39. | Rotating Shaft            | Carbon Steel   | Die Casting      |
| 40. | Bearing                   | Carbon Steel   | Die Casting      |
| 41. | Nut M10                   | Carbon Steel   | Machining        |
| 42. | Screw M6 X 12             | Carbon Steel   | Machining        |
| 43. | Fuel Tank                 | Abs            | Injection Molding|
| 44. | Lid Tank                  | Abs            | Injection Molding|
| 45. | Fuel Tank Band            | Carbon Steel   | Die Casting      |
| 46. | Screw M5 X 20             | Carbon Steel   | Machining        |
| 47. | Fuel Pipe Protection Coil | Carbon Steel   | Machining        |
| 48. | Fuel Pipe                 | Rubber         | Injection Molding|
| 49. | Bolt M6 X 16              | Carbon Steel   | Machining        |
| 50. | Fuel Pipe Clip            | Carbon Steel   | Die Casting      |
| 51. | Tank Holder Metal         | Carbon Steel   | Die Casting      |
| 52. | Engine Cover              | Abs            | Injection Molding|
| 53. | Screw M4 X 12             | Carbon Steel   | Machining        |
| 54. | Screw M4 X 10             | Carbon Steel   | Machining        |
### Table 2. Manufacturing process and material used of grass cutting machine (Continued…).

| No. | Part Name       | Material  | Process     |
|-----|----------------|-----------|-------------|
| 55. | Rope            | Nylon     | Machining   |
| 56. | Recoil Starter Body | Abs | Injection Molding |
| 57. | Starter Handle  | Abs       | Injection Molding |
| 58. | Starter Rope Reel | Abs | Injection Molding |
| 59. | Screw M5 X 12   | Carbon Steel | Machining |
| 60. | Cleaner Body    | Abs       | Injection Molding |
| 61. | Cleaner Fixing Base | Abs | Injection Molding |
| 62. | Cleaner Element | Abs       | Injection Molding |
| 63. | Screw M4 X 25   | Carbon Steel | Machining |
| 64. | Clutch Case     | Carbon Steel | Die Casting |
| 65. | Locking Pin     | Carbon Steel | Die Casting |
| 66. | Fan Case        | Carbon Steel | Die Casting |
| 67. | Screw M5 X 20   | Carbon Steel | Machining |
| 68. | Muffler         | Abs       | Injection Molding |
| 69. | Screw M6 X 65   | Carbon Steel | Machining |
| 70. | Plug Cap        | Rubber    | Injection Molding |
| 71. | Stop Wire       | Rubber    | Injection Molding |
| 72. | Engine          | Carbon Steel | Die Casting |

### 4. Result and Discussion
The assemble and dissemble process of existing design of the grass cutting machine will be identified which parts to undergo redesign process and some part can be eliminated, minimizing, or combined together for achieving higher design efficiency. The parts of the grass cutting machine are evaluated to identify which part has a higher potential to be eliminate or combined. The parts are that not necessary for the existing product of grass cutting machine can also be reduced. Table 3 has shown the assemble of tank and assemble of exhaust before and after redesign.

The shoulder frame was improving the design of addition support to hold the tank for purpose of minimizing the assembly time by eliminates 6 parts from current tank assembly. The tank holder was design for extra support to hold the tank. By doing so, the number of part count has reduced with minimize the time required for assembly. Thus, the design efficiency for the grass cutting machine will be increased.

Next, the improvements were made to the exhaust assembly. The current exhaust assembly was design with 4 parts and combination of three manufacturing process which is die casting, bending and welding. The design is also quite complicated and can be increase the production time of assembly and material cost. Therefore, the redesign of exhaust was made by reducing the manufacturing process with eliminate the bending process. The production time for insertion between parts and material costs were reduced simultaneously. There is also no impact on the function of exhaust.

Table 4 shows the comparison for the part quantity, handling time, insertion time, assembly time, and design efficiency in between the existing design and improved design of grass cutting machine.
Table 3. Comparison between original design and redesign for grass cutting machine.

| Part | Quantity of part | Quantity of screw |
|------|-----------------|-------------------|
| Assemble of Tank | 6 | 4 |
| Assemble of Exhaust | 5 | 1 |

Table 4. Comparison Between Original Design And Improved Grass Cutting Machine.

| Part Quantity | Existing Design | Redesign | Differences | Improvement |
|---------------|-----------------|----------|-------------|-------------|
| Handling Time (s) | 178.79 | 149.53 | 29.26 | 16.37 % |
| Insertion Time (s) | 390.05 | 303.06 | 87.05 | 22.31 % |
| Assembly Time (s) | 568.84 | 462.59 | 106.25 | 18.68% |
| Design Efficiency | 26.4 % | 34.70 % | 8.33 % | 8.33 % |

From the Table 4, there is an increase in design efficiency of 8.33 %; this is due to 8 components part has eliminated during the redesign process. For the percentage of part count, the result is 12.50 % which considered as good outcomes as one quarter of total numbers of the components has eliminated via the redesign process. Based on calculation, the result shows that insertion time being minimized is more than the handling time, which are 87.05 s and 29.26 s respectively. For total assembly time, a total time of 106.25 s is being eliminated. Therefore, the redesign is able to reduce the total production time and minimize the cost by having less part count.

5. Conclusions

This paper presented the redesign of grass cutting machine by applying the manufacturing and assembly design (DFMA) method [26-29]. It can be conclude that the design performance for grass cutting machine of the redesign has been enhanced after the redesign process resulting in reduced part count and overall assembly time. The design efficiency has come out of 26.4 percent of the original design efficiency by 8.33 percent from the report. However, this is not the perfect possible configuration for grass cutting machine, there can be a lot of change. The design consideration of the function of the part and the vibration issue was important in order to prevent the performance of the grass cutting machine. Therefore, some of the screws and bolt can be modified and eliminated by consider the function of that parts.
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