Design for Disassembly in Extension Cable Manufacturing

Tengku Nur Azila binti Raja Mamat, AinulAkmal bin Jaafar, Mohamad Khamil Amin bin Mohamed Taib

Abstract: This research is conducted to propose an extension cable design that meets disassembly concept. At the end of a useful life cycle of extension cables, most of damaged or broken extension cables are thrown away without any consideration to dismantle the product for repair, reuse or any other proper treatment. This is due to the difficulties faced by the users to dismantle the housing of extension cables. With the disassembly concept embedded in the proposed design, repair of damaged or broken extension cable will be easier, and components of extension cables that are still in good condition can be reused. To meet the mechanical and functional properties of the extension cables, analyses on the properties of the mechanism extension cable is applied to the proposed design. Using the simulation function in SolidWorks software, two different simulations are conducted, namely finite element analysis (FEA) and thermal analysis. After the SolidWorks simulation is successfully analyzed, design for manufacturing and assembly (DFMA) analysis is carried out to compare the existing design and the proposed design of the extension cables in terms of costing and assembly efficiency. The results of this research is eventually will lead to a better design of extension cable in meeting the assembly and disassembly purpose. Based on the results obtained, the snap fit mechanism that has been applied on Design B is the best design in this research in terms of DFA index and total manufacturing cost which the value is 30.3 and $1.34, respectively.

Index Terms: Sustainability, green design, disassembly, DFMA.

I. INTRODUCTION

Design for disassembly (DFD) is a concept in which products are designed intentionally for material recovery, value retention, and meaningful next use [1]. In other words, it is an act to show the product can be recycled or reused after the end of its lifetime. Product disassembly is generally concerning on systematic separation of components. Complete product disassembly is meant for remanufacturing, while partial product disassembly is meant for maintenance and repair [2].

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DFD can be applied to all varieties of products that human being use in daily life, such as vehicles, apparels, furniture, and electrical appliances. DFD for vehicles, for example, has recently becoming an interest among researchers. [3], [4] and [5] are among the studies related to DFD for vehicles in Malaysia. In contrast, DFD for electrical appliances are lacking. [6], [7] and [8] have presented their research on DFD related to electrical appliances, while [9] is one of the research conducted particularly related to domestic electrical appliances, which is domestic coffee maker. This research has bring the interest to study on DFD for extension cable.

Extension cable is one the domestic appliances that people often use in home and offices. Extension cables can easily damage as it burns, damaged switches and so on. When repair is needed, the extension cable is difficult to dismantle due to its relatively complex assembly or fitting. It may require some time to dismantle the housing of extension cables by using screwdriver, but sometimes the screw might be loosening. Failure to repair, people tends to throw away the whole extension cable into dustbin, which finally brought to landfill. This is one of the activities that may lead to abundant of e-waste in Malaysia's landfill, as reported by the Department of Environment Malaysia (DOE) that the quantity of e-waste generated from households, commercial and institutions are estimated to reach 53 million pieces in 2020, which is 3.5 times higher than 1995 [10]. Thus, it is our responsibility to salvage the electrical appliances by means of repair and reuse to help reduce the environment impacts of e-waste, particularly in Malaysia.

Thus, the aim of the study is to propose design for disassembly in extension cable manufacturing for easy disassembly and repair or reuse. The proposed design will be analyzed using simulation function in SolidWorks software to study their mechanical properties. Then, total manufacturing cost and DFA index will be calculated to choose the best design.

II. LITERATURE REVIEW

A. Design for Disassembly

DFD is a concept in which products are designed intentionally for material recovery, value retention and meaningful next use. In other words, DFD describes how all parts and components of a product can be reused at the end of its useful life. It is intended to maximize the value and minimize the environmental impact through 6R concept.

B. Extension Cable Power Strip

Extension cable is a length of flexible electrical power cable with a plug on one end and one or more sockets on the other end. While power strip is a block on the end of a power cable with several sockets, usually three or more, that is often arranged in a line. This term is commonly used to indicate the entire unit of a short electrical rope ending in a power strip. This type of extension has so many names such as extension block, power board, power bar and so on. A power strip has a stationary base, at least one rotating base, at least one pintle and a power cable. The rotating base is mounted rotatable on the stationary base [11]. Usually, the power strip housing ismade of plastic, vinyl and rubber. Figure 1 shows one model type of power strip extension cable.

Fig. 1 Power strip extension cable

III. RESEARCH METHODOLOGY

The methodology used in this research is shown in Figure 2 below.

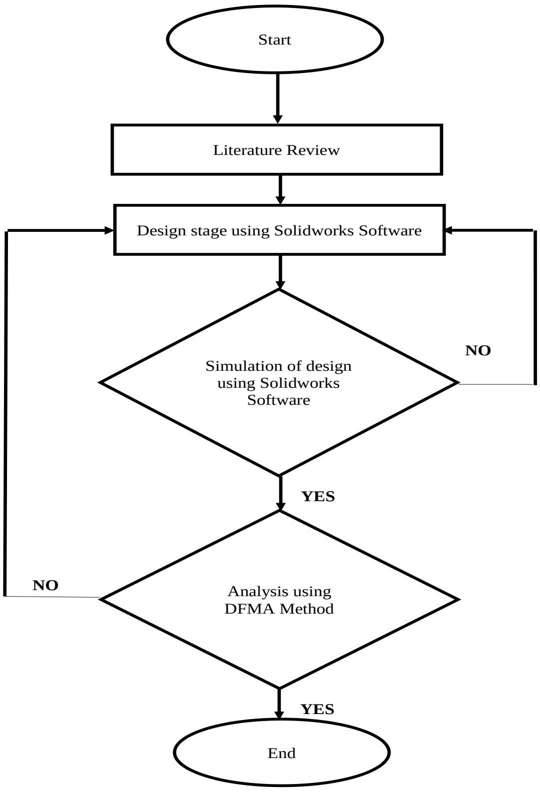

Fig. 2 Research methodology

A. Design

The common pattern or design of the power strip extension cable mostly come together with few screws. In this research, the screws will be eliminated and being replaced by connectors and snap fit mechanism.

There are two designs that will be proposed in this research, which is Design A and Design B. Body of both designs will be similar to the existing design which is normally design in rectangle shape with draft and fillet at the edge. But the difference between these designs are the assembly or joining mechanism. Design A and Design B will be designed without any screw. In contrast, connector and snap mechanism will be applied for assembly and disassembly purpose.

On the other hand, material selection is also an important stage in design process. This is because, material needs to be compatible with the design structure, temperature and its surrounding. Acrylonitrile Butadiene Styrene (ABS) polymer is selected as the material for Design A and Design B. It is an ideal material because of its good surface quality, colorfastness and good dimensional stability [12].

B. SolidWorks Software

The main objective of this software is to develop 3D design of the product and then run simulation analysis. Two different simulation analysis will be conducted in this research, namely finite element analysis (FEA) and thermal analysis.

FEA provides a reliable numerical technique for analyzing the engineering designs. The process starts with the creation of a geometric model which is the housing power strip extension cable [13].

Besides, thermal analysis is carried out to analyze thermally related problems such as overheating, lack of dimensional stability, excessive thermal stresses, and other problems related to the heat flow and the thermal characteristics of a product. By using thermal analysis in SolidWorks, temperature distribution, heat flow in the extension cable, and heat transfer between the extension cable and its environment, can be analyzed.

C. Analysis Comparison using DFMA Method

Design for manufacturing and assembly (DFMA) method is used to reduce the product cost through design and process improvements [14][15].It is a combination of design for manufacturing (DFM) and design for assembly (DFA). DFM method focuses on the individual parts and components with the purpose to reduce or eliminate expensive, complex or unnecessary features. While DFA focuses on the reduction and efficiency of sub-assemblies and assemblies and the assemble time and cost.

In this research, three design will be compared using DFMA method which are the existing product, Design A and Design B. The analysis results will show the product design costing and the assembly efficiency.

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IV. RESULTS AND DISCUSSION

In this section, results and analysis following the research methodology will be presented. It will begin with 3D design using SolidWorks software, SolidWorks simulation, and finally DFMA analysis.

A. Design

1) Design A

Figure 3 shows the proposed design in exploded view. Design A consists of base, top and pin connector of extension cable. In this view, the assembly parts are being animated as in assembly and disassembly. All components are made of ABS material. Figure 4 shows the assembly of components of Design A. In this view, the base and top parts are attached to through pin connectors which is designed for disassembly purpose.

2) Mechanism of Disassembly for Design A

The mechanism used in this design is the pin connector. As for the assembly parts, it consists of 4 connectors to lock the base and top of the extension cable. Both of base and top has the stopper place beside of the lock of pin connector. The pin connector can be assembled and disassembled easily from the base and top extension cable and as shown in Figure 5.

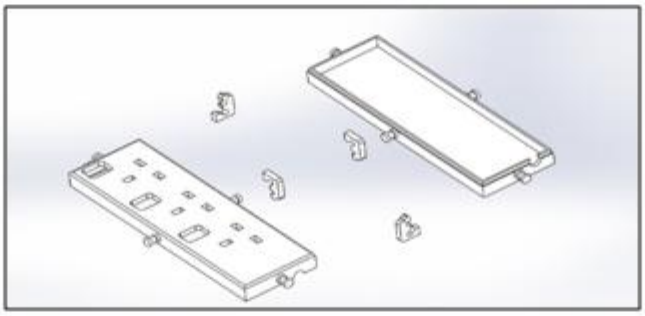

Fig. 3 Exploded view of Design A of extension cable of power strip

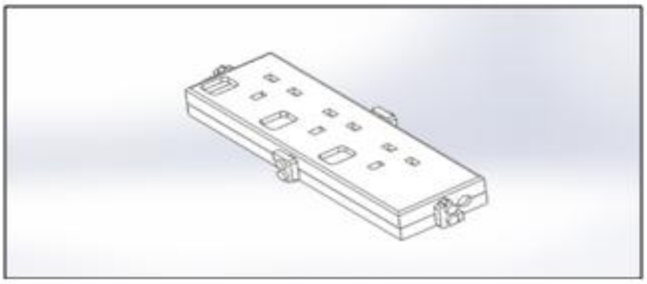

Fig. 4 Assembly parts of Design A for extension cable power strip

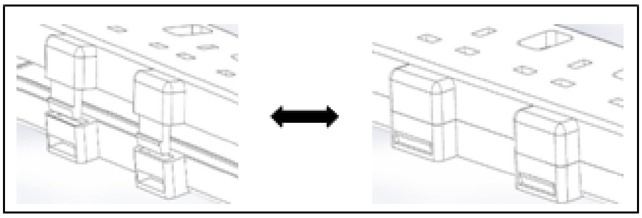

Fig. 5 The mechanism of disassembly Design A which is the pin connector

3) Design B

Figure 6 shows the exploded view of Design. The exploded view gives the details about the flow of assembly extension cable in Design B, which consists of three components namely the rod, base and top.

When assembled, the three components will be attached together as in Figure 7. In Design B, the snap fit mechanism is used for disassembly purpose.

4) Mechanism of Disassembly for Design B

In snap fit fastening, two parts are being mated through an interlocking configuration that is molded into many parts. Many different configurations are possible to accommodate different part designs [16]. In Design B, the snap fit is located at the side of the housing, as shown in Figure 8. There are two types of snap fit which are cantilever beam and the cylindrical(annular) snap fit. Design B used cantilever beam which consists of a hook and groove.

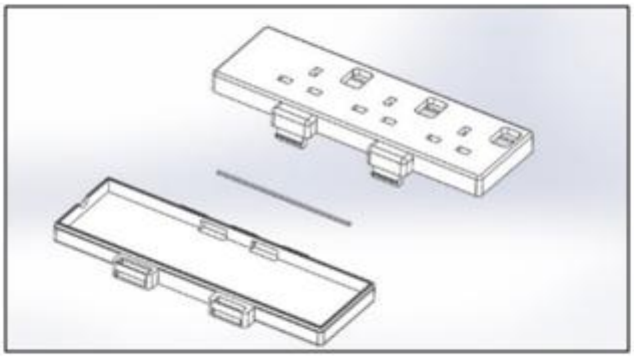

Fig. 6 The exploded view of extension cable Design B

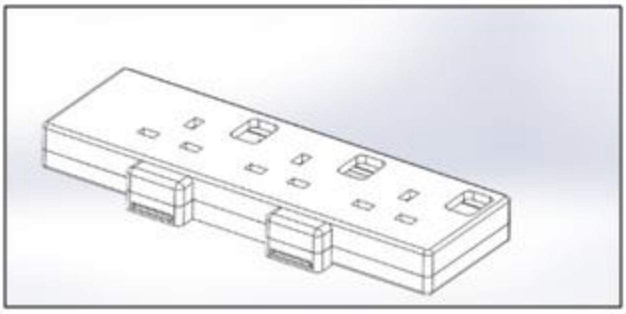

Fig. 7 Full assembly of extension cable design B

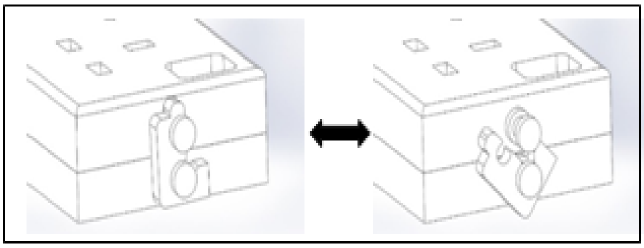

Fig 8 The mechanism of assembly and disassembly in Design B

B. Solid Works Simulation

1) Simulation analysis on Design A

Table 1 shows the results of the simulation in SolidWorks software where FEA is applied on the pin connector of Design A, and the effects of stress, displacement, strain and thermal on the pin connector of Design A are illustrated in Figure 9.

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2) Simulation analysis on Design B

Table 2 shows the results of the simulation in SolidWorks software where FEA is applied on the top extension cable in Design B, and the effects of stress, displacement, strain and thermal on the top extension cable of Design B are illustrated in Figure 10.

Table 3shows the results of the simulation in SolidWorks software where FEA is applied on the base extension cable in Design B, and the effects of stress, displacement, strain and thermal on the top extension cable of Design B are illustrated in Figure 11.

Table. 1 FEA results on the pin connector of Design A

NO	DESCRIPTION	RESULT		UNIT
1	Stress	Maximum	3.279e + 013	N/m^2
		Minimum	1.824e + 013	
2	Displacement	Maximum	5.855e + 010	URES (mm)
		Minimum	8.210e + 009	
3	Strain	Maximum	7.811e + 003	ESTRN
		Minimum	1.010e + 003	
4	Thermal	Maximum	1.001e + 002	Temp (Celsius)
		Minimum	1.001e + 002	

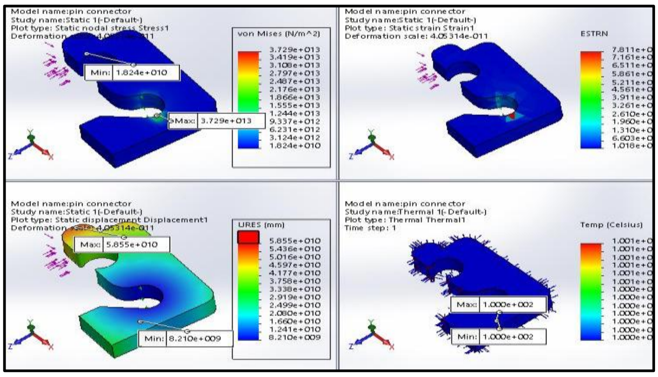

Fig. 9 Illustration of FEA results on the pin connector of Design A

Table. 2 FEA results on the top extension of Design B

NO	DESCRIPTION	RESULT		UNIT
1	Stress	Maximum	9.892e + 012	N/m^2
		Minimum	3.076e + 009	
2	Displacement	Maximum	1.286e + 011	URES (mm)
		Minimum	1.616e + 009	
3	Strain	Maximum	4.992e + 003	N/m
		Minimum	2.539e + 000	
4	Thermal	Maximum	1.000e + 002	Temp (Celsius)
		Minimum	1.000e + 002	

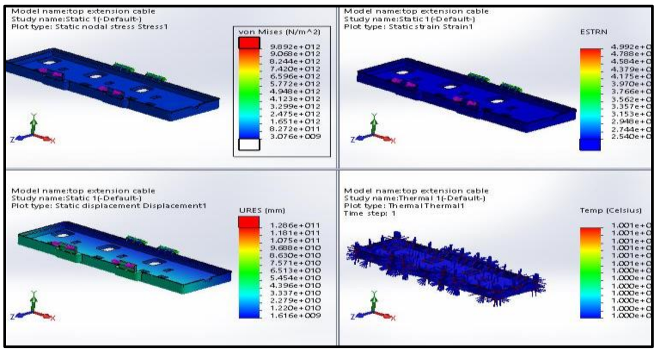

Fig. 10 Illustration of FEA results on the top extension of Design B

Table. 3 FEA results on the base extension of Design B

NO	DESCRIPTION	RESULT		UNIT
1	Stress	Maximum	9.892e + 012	N/m^2
		Minimum	3.076e + 009	
2	Displacement	Maximum	1.286e + 011	URES (mm)
		Minimum	1.616e + 009	
3	Strain	Maximum	4.992e + 003	N/m
		Minimum	2.539e + 000	
4	Thermal	Maximum	1.001e + 002	Temp (Celsius)
		Minimum	1.001e + 002	

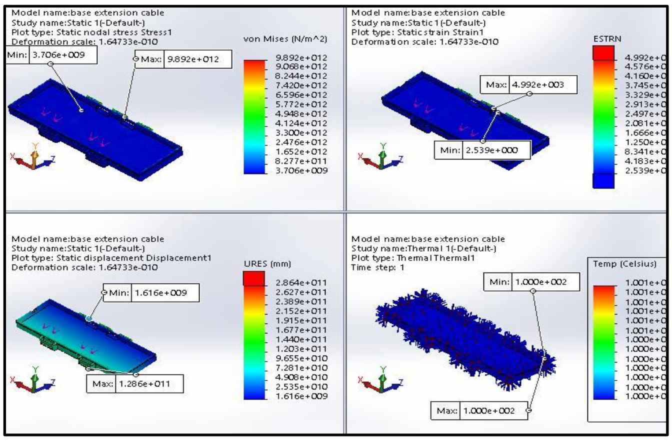

Fig. 11 Illustration of FEA results on the base extension of Design B

3) DFMA Comparison between Existing product, Design A and Design B.

According to Table 4,the existing product consists of three parts which are screw, base and top extension cable. The screws act as fasteners to assemble the extension cable.

Based on Table 5, Design A consists of pin connector, base and top extension cable.

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Next, Table 6 shows that Design B consists of three components which are the rod, base and top extension cable. The pin connector acts as the assembly and disassembly mechanism in Design A, while in Design B, the role is played by the snap fit mechanism.

DFMA analysis is carried out at this stage. The DFA and DFM software are used simultaneously to extract the DFA index and costing values for the three designs, which the details are displayed in Table 7.

Based on the table, the existing design has the highest number of entries. This is because existing product using repeated screw in assembly, while Design B has the lowest number of entries. Consequently, the existing design recorded the longest time for total assembly labor time.

DFA index for the existing design is recorded as 5.7, which is the lowest among the three designs. Design A and Design B recorded DFA index as 19.7 and 30.3, respectively. Theoretically, the higher the value of DFA index, the higher the efficiency on the assembly of the product. Thus, Design B has the highest efficiency to be assembled.

As for the total manufacturing cost, Design A recorded the highest value that is $1.86 per product. While the existing product shows the second highest value and Design B with the lowest value, which are $1.57 and $1.34 per product, respectively. Design A get the highest value of total manufacturing cost because of the size of pin connector and material cost, while Design B gets the lowest total manufacturing cost because of lesser part to assemble by using snap fit mechanism.

V. CONCLUSION

In conclusion, the results obtained have fulfilled the research objectives, which are to design an extension cable that meet design for disassembly, to analyze the mechanical properties of the extension cable using FEA in SolidWorks software, and to compare between the existing product extension cable and the proposed design using DFMA method in term of DFA index and total manufacturing cost incur.

For the first objective, Design A and Design B were sketched and designed using SolidWorks software. Instead of using screws as fastener in the extension cable, new mechanism is applied on the proposed designs to meet disassembly concept. Design A consists of four pin connectors attached to the base and top of the power strip extension cable. Design B applies the snap fit mechanism. It consists of the base, top and rod part. Both base and top parts have snap fit mechanism where the top has a latch mechanism while the base has a hole that lock the latch.

Table. 4 Product worksheet for existing product

No	Name	Type	Repeat count	Total count	Securing method	Minimum items	Minimum part criteria
1	Existing product	Main					
2	Base extension cable	Part	1	1	Sep. op	1	Base part
3	Top extension cable	Part	1	1	Sep. op	1	Assembly
4	#3 slotted flat head screw	Part	8	8	Thread	0	Fastens
5	Totals for existing product			10		2	

Table. 5 Product worksheet for Design A

No	Name	Type	Repeat count	Total count	Securing method	Minimum items	Minimum part criteria
1	Design A	Main					
2	Base extension cable	Part	1	1	Sep. op	1	Base part
3	Top extension cable	Part	1	1	Sep. op	1	Assembly
4	Pin connector	Part	4	4	Sep. op	0	Connects
5	Totals for design A			6		2	

Table. 6 Product worksheet for Design B

No	Name	Type	Repeat count	Total count	Securing method	Minimum items	Minimum part criteria
1	Design B	Main					
2	Base extension cable	Part	1	1	Sep. op	1	Base part
3	Top extension cable	Part	1	1	Sep. op	1	Assembly
4	Rod	Part	1	1	Sep. op	0	Connects
5	Totals for design B			3		2	

Table. 7 The executive summary of comparison DFMA on existing product, Design A and B

	Existing product	Design A	Design B
Product life volume	100,000	100,000	100,000
Number of entries (including repeat)	10	6	3
Number of different entries	3	3	3
Theoretical minimum number of items	2	2	2
DFA index	5.7	19.7	30.3
Total weight, kg	0.17	0.18	0.15
Total assembly labor time, s	102.40	29.70	19.35
Total cost for manufactured items (including tooling), $	0.56	1.57	1.15
Total assembly labor cost, $	1.00	0.29	0.19
Other operation cost per product, $	0.00	0.00	0.00
Total manufacturing piece part cost, $	0.45	0.98	0.87
Total cost per product without tooling, $	1.46	1.28	1.06
Assembly tool or fixture cost per product, $	0.00	0.00	0.00
Manufacturing tooling cost per product, $	0.11	0.58	0.28
Total cost per product, $	1.57	1.88	1.34

The second objective has also successfully achieved. The mechanical properties of the proposed designs are analyzed by using SolidWorks software simulation. Stress, strain, displacement and thermal analysis is being drawn out from the research. For Design A, analysis is applied on the pin connector while for Design B, analysis is applied on snap fit mechanism at the top and base parts.

Finally, DFMA analysis is applied to compare DFA index and total manufacturing cost for the existing design, Design A and Design B. Based on the results obtained, the snap fit mechanism that has been applied on Design B is the best design in this research in terms of DFA index and total manufacturing cost which the value is 30.3 and $1.34, respectively.

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