A DFA Analysis Applied to Evaluate and Improve the Assemblability of an Automated Plasma Cutting Machine

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Abstract

This paper focuses on the analysis of a plasma cutting machine according to DFA and studies its benefits. The machine was built from zero in different stages by faculty members and students, some units were added later but a few analyses were realized in order to improve its function and debug errors. Currently the pieces of the machine are not quantified and identified, common parts are not standardized, the assembly process is ambiguous therefore almost every component can be assembled with wrong components, and the assembly has components that can be integrated in just one in order to reduce the number of components.

Introduction

The plasma cutting machine has been under developing through various student projects from trajectory path generation, motion control and part design, among others. Besides that this piece of equipment is just at developing stage it was believed that taking into account the design for assembly considerations will benefit the final design, of the complete product. This paper discuses our finds during the implementation of the DFA as the base methodology to foresee already design problems and help to evaluate new design modifications to it.

The DFA index E_{ma} is obtained by dividing the minimum part count N_{min} by the time required to assembly the total product, in this case the plasma cutting machine t_{ma} and multiplying by the basic assembly time t_a for one part that presents no handling, insertion or fastening difficulties, about 3 seconds [1].

$$E_{ma} = N_{min} t_a / N_{min} \qquad (1)$$

Figure 1 shows the subject under study, a plasma cutting machine. It consist essentially of a light aluminum structure, a cable carrier chain type component holding the plasma cable, a control box, and two axes, X and Y, where axis X is mounted over the Y axis. Each axis has a stepper motor directly connected to a power screw that converts the circular motion into linear one. When the motor in the Y axis turns, it pushes or pulls the X axis, and when the Motor in the X axis turns, it moves the cutting tool along the X axis. The motors turns are coordinated through computer software to accomplish a desired trajectory over the working piece and, if the plasma is turned on, it cuts the metal plate underneath.

The project main activities involved gathering of DFA related information, understanding of the plasma cutting function, machine disassembly to component identification and quantification, analysis of the components according to DFA, generation of the evaluation matrix according to DFA, identify the improvement opportunity, redesign of components, reevaluate indexes, assembly machine, verify function.

Fig. 1. Two views of the XY plasma cutting machine

Plasma cutting machine dissection

The first activity was to identify and quantify all the components of the cutting system. Table 1 lists all the identified components as proposed by the DFA methodology. It can be observed, form this list, the lack of standardization of fasteners and materials. Of special interest is the plasma torch holder that puts together several components through screws and nuts of different sizes. These components are an example for re-design were components could be integrated into just one and reduce the number of fastening elements and the associated assembly steps required [1][2][3].

On the search for the DFA index

Each component was analyzed based on DFA procedure. An example of this analysis is the component identified as 07, a metal bracket that joins components 1 and 5, as shown in Figure 2. Component 5 is the Xs axis motor support and 1 is part of the base frame of the Xs axis. Component 07 is made of steel, component 5 is made of wood and 1 is made of aluminum. The values for Component 07 on each column of the DFA matrix, in this example are, RP=1 because component 07 is unique, the handling time TH=1.95 because thickness=40mm, size=120mm and symmetry=720 (part has to be rotated 360 in both α and β angles in order to be oriented for assembly). Finally, the insertion time TI=5.2 because there is not any visualization problem but there is not any feature to help with aligning the component 07 on component 13 but a separate fastening operation is required for this assemble.
To improve the DFA index it was proposed to integrate components for this subassembly. At present moment there are different materials but there is no restriction for this, it was due to development of prototypes, an ABS plastic is considered to develop the new component for this integration.

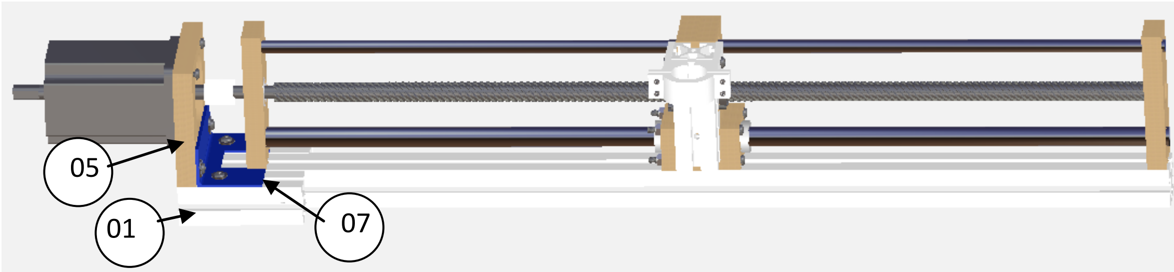

Fig. 2. X axis assembly.

Figure 3 depicts an exploded view of the components that are part of the motor support. It consist of the three components described before, one torqspline support, four button head screws 1/4-20x3/8, two button head screws 1/4-20x1/2, two button head screws 1/4-20x1, four 1/4 washers, 6 Drop in T-nuts and two 1/4-20 hex nuts, for a total of 26 components.

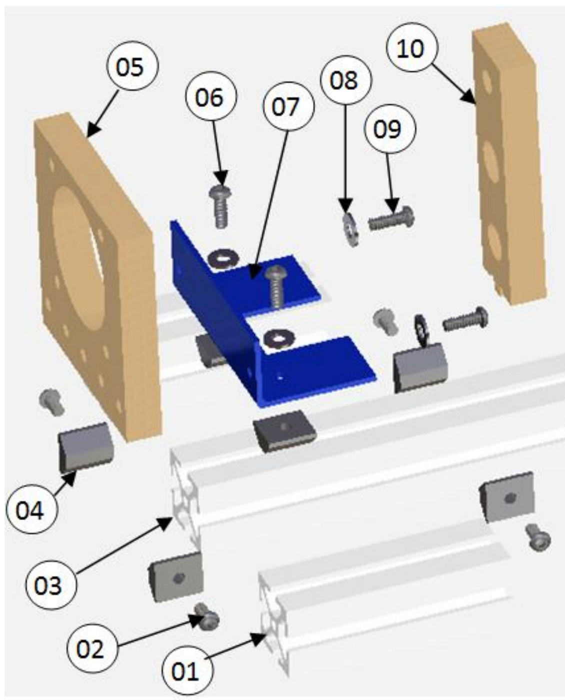

Fig. 3. Motor support assembly.

Table 1 shows the worksheet analysis for the motor support assembly. The base component is a piece of aluminum extrusion, component 03. To start the assembly, Two Screws (02) are slightly inserted into a two drop in T-nuts (04) and these nuts are placed into a side grove of the base component. Component 01, another aluminum extrusion component, is slide along the base part placing the screws into one of the aluminum extrusion groves. Component 01 is secured in place using a hex key to fastening the screws, this operation requires first aligning the screws and the tool hole access on component 01. The base part is turned and the previous operation is repeated to add another 01 component to the base, in the other side of it.

Next the motor support 05 and bracket 07 are joined using two screws, two washers and two hex nuts. These joined components are placed and held in position to be added to the base parte using two screws, two washers and two drop in T-nuts. Motor support 05, besides base component, is considered minimum part count because it should help to isolate motor vibration.

Finally component 10 is just added inserting on the base and through the bracket.

Table 1. Analysis of old motor support assembly.

Part ID	No. of items (RP)	Tool acuire time (TA)	Hand-ling time TH	Insert -ion time TI	Total time TA+RP* (TH+TI)	Mini-mum Part Count	
03	1	0	1.13	0	1.13	1	Place base part
04	6	0	1.5	2.6	24.6	0	Add
02	4	0	1.8	5.2	28	0	Add and screw
01	2	2.9	1.13	29	63.16	0	Add and screw fasten
05	1	0	1.5	5.2	6.7	1	Add and hold down
07	1	0	1.8	5.2	7	0	Add and hold down
08	4	0	1.69	1.5	12.76	0	Add
06	2	2.9	1.8	5.2	16.9	0	Add and screw fasten
09	2	2.9	1.8	5.2	16.9	0	Add and screw fasten
10	1	0	1.95	1.5	3.45	0	Add
	24				180.6	2	Totals

According to equation (1) The DFA index is

$$2 \times 3/180.6 = 0.0332 \text{ or } 3.3\%$$

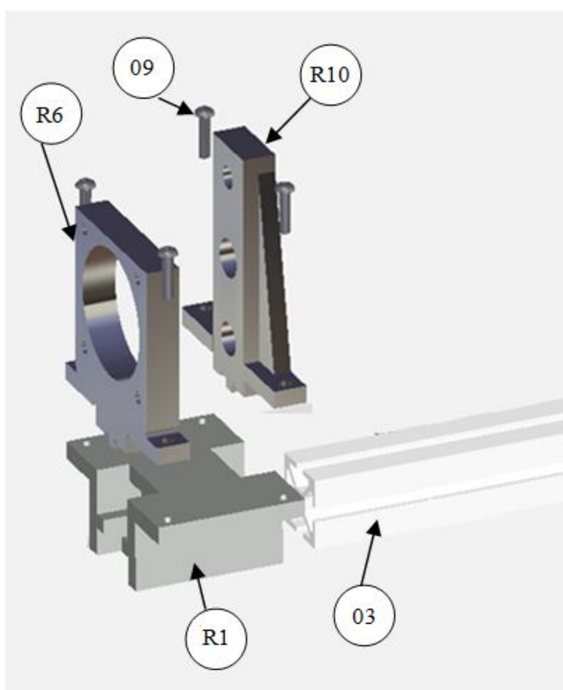

Fig. 4. Motor support redesign.

Components 01, 05, 07 and 10 do not meet any of the criteria required to be considered as separated parts. The redesign integrates components 01 and 07 as a first approach to improve the DFA index. This redesign provides threaded holes to secure components 05 and 10 that at present moment are let as separated components. The savings in time are 131.4s of assembly time, which account for 72.8% of the total. Drop in T-nuts, washers and four screws were eliminated. The proposed design changes are illustrated in Fig. 4.

The complete analysis for the motor support assembly redesign is given in Table 2. Total time is now 49.8s and the DFA index is increased to 12.2% an increase of more than 300%. It can be observed that integrating components R1, R5 and R10 into just one there will be no screws required and minimum part count will be 2 and only one operation will be require to assembly this integration that could increase the DFA index up to 100%.

Table 2. Analysis of new motor support assembly.

Part ID	No. of items (RP)	Tool acquire time (TA)	Hand-ling time TH	Insert -ion time TI	Total time TA+RP* (TH+TI)	Mini-mum Part Count	
3	1	0	1.13	0	1.13	1	Place base part
R1	1	0	1.5	2.6	4.1	1	Add
R5	1	0	1.5	5.2	6.7	0	Add and hold down
9	2	2.9	1.8	5.2	16.9	0	standard operation
R10	1	0	1.95	1.5	3.45	0	Add and hold down
9	2	2.9	1.8	5.2	16.9	0	standard operation
	8				49.18	2	Totals

2 x 3/49.18 = .1222 or 12.2%

Analysis of Torch Holder Subassembly

Similar procedure was applied to analyze another subassembly of the X-axis. This subassembly moves along the X-axis while motor rotates. The movement is accomplished through a torqspline screw and a nut fixed to the torch support that is able to slide on a set of parallel bars using linear ball bearings. The torqspline screw, torquespline nut, aluminum extrusion, button head screw and nuts are components bought out. The main body of the support consisted of components and two components, maid in house, joined whit four screws and nuts. Also this component is made in house. The redesign focused primarily in the integration of these components into just one, eliminating the four screws and nuts but also component was redesign to replace four screws and nuts for just two to increase standardization and reduce part count. Figure 5 shows both the old and new torch support assembly. Before there were 43 components and a DFA index of 7.07% and, after redesign, 26 components and a DFA index of 11.51%. The redesign basically integrated four components (04, 17) into one (02), four screws (08) and nuts (19) were eliminated during the integration. The redesign also included the replacement for four screws (13) and nuts (11) for only two screws (10) and nuts (06).

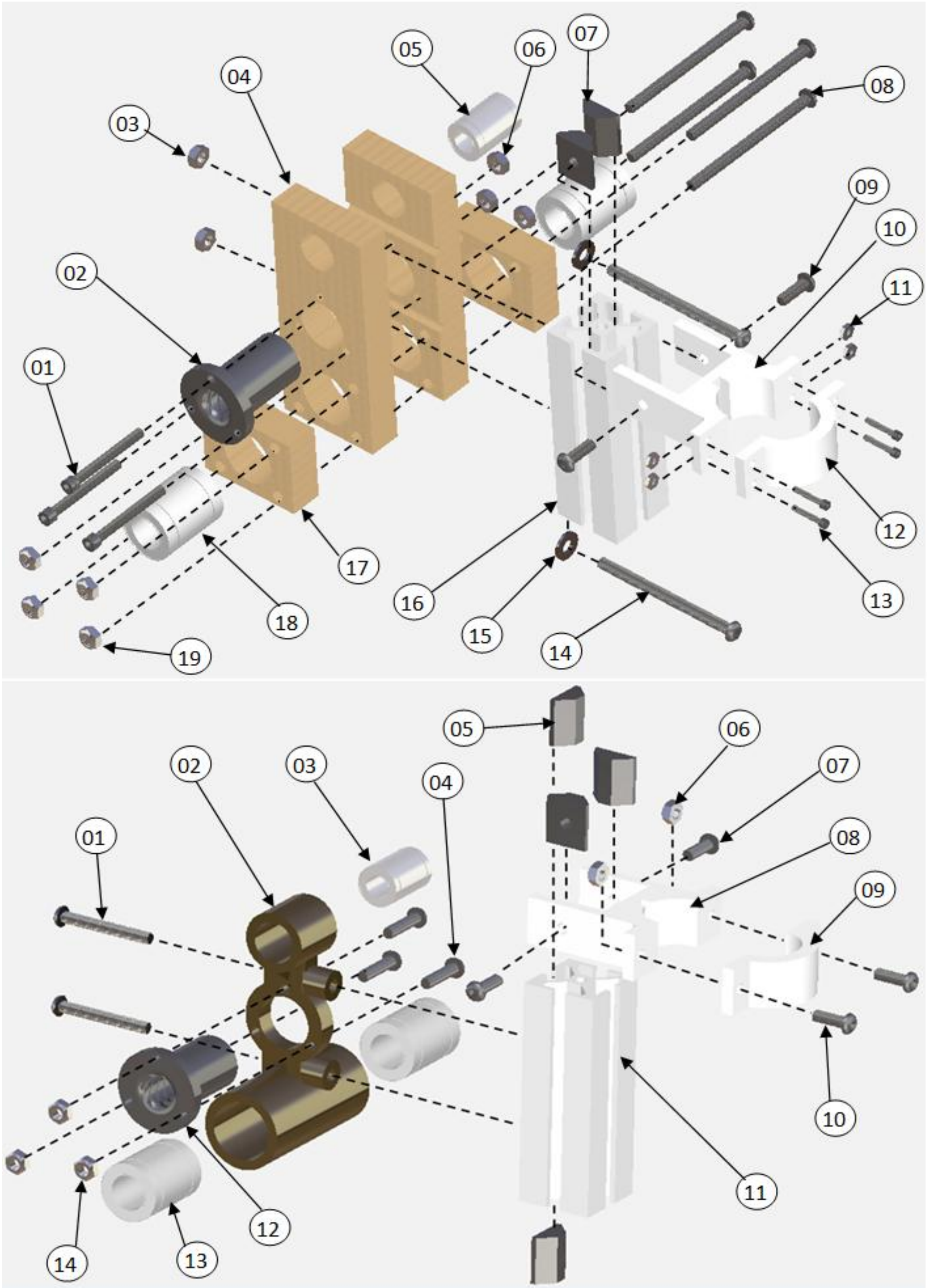

Fig. 5. Torch holder subassembly old and new designs.

Table 3. Analysis of tool holder assembly, old and new.

Part ID	No. of items (RP)	Tool acquire time (TA)	Hand-ling time TH	Insert -ion time TI	Total time TA+RP* (TH+TI)	Mini-mum Part Count	
17	1	0	1.5	0	1.5	1	Base part
04	2	0	1.95	1.5	6.9	0	Add
17	1	0	1.5	1.5	3	0	Add
08	4	0	1.5	1.5	12	0	Add
19	4	2.9	1.13	5.2	28.22	0	Add and screw fasten
15	2	0	1.69	1.5	6.38	0	Insert washer into screw
14	2	0	1.13	5.2	12.66	0	Add
03	2	2.9	1.13	5.2	15.56	0	Add and screw fasten
16	1	0	1.13	5.2	6.33	0	Add
	0			4.5	4.5	0	Fasten
09	2		1.5	1.5	6	0	Add
07	2	2.9	1.5	5.2	16.3	0	Add and screw fasten
10	1	2.9	1.95	1.5	6.35	1	Add and screw fasten
12	1		1.8	2.6	4.4	0	Add and hold
13	4		1.5	1.5	12	0	Add
11	4	2.9	1.13	5.2	28.22	0	Add and screw fasten
02	1		1.5	1.5	3	0	Add
01	3		1.5	1.5	9	0	Add
06	3	2.9	1.13	5.2	21.89	0	Add and screw fasten
05	1		1.13	1.5	2.63	1	Add
18	2		1.13	1.5	5.26	2	Add
	43				212.1	5	Totals

Old design efficiency = 5 x 3/212.1 = 0.0707 or 7.07%

02	1	0	1.5	0	1.5	1	Base part
01	2	0	1.95	1.5	6.9	0	Add
05	2	2.9	1.5	5.2	16.3	0	Add and screw fasten
11	1	2.9	1.13	5.2	9.23	0	Add and screw fasten
05	2		1.5	1.5	6	0	Add
07	2	2.9	1.5	5.2	16.3	0	Add and screw fasten
08	1	2.9	1.95	1.5	6.35	1	Add and screw fasten
09	1		1.8	2.6	4.4	0	Add and hold
10	2		1.5	1.5	6	0	Add
06	2	2.9	1.13	5.2	15.56	0	Add and screw fasten
12	1		1.5	1.5	3	0	Add
04	3		1.5	1.5	9	0	Add
14	3	2.9	1.13	5.2	21.89	0	Add and screw fasten
03	1		1.13	1.5	2.63	1	Add
13	2		1.13	1.5	5.26	2	Add
	26				130.32	5	Totals

New design efficiency = 5 x 3/130.32 = 0.1151 or 11.51%

Conclusions and further developments

The DFA index is a measure that has helped us to objectively measure the design proposals from the point of view of assembly and gives us an indication where more development should take place to improve the assemblability. The methodology helps to clarify where components should be integrated and avoid the proliferation and all the related problems to management of these components.

The benefits of increasing the DFA index are not easy to evaluate because there are activities that probably will not been foreseen but parts count reduction, assembly time minimization are just a point of an iceberg that expose all those hidden costs associated with assembly and management due to component proliferation.

In both assemblies discussed here DFA index was increased from 3.3% to 12.2% and from 7.07% to 11.51%. They could seem low but these values indicate that more aggressive redesign is needed in order to achieve higher DFA efficiency. Even tough, part count was reduced from 24 to 8 and from 43 to 26, a reduction of 66.7% and 32.6% respectively.

Also the number of the steps of the motor support subassembly went down from 10 to 6 , and the old tool holder assembly requires 21 operations to put it all together while the new tool holder assembly requires 15.

We have learn that taking into account the DFA index will help designers to better understand how their design proposals will impact the total assembly and it could be used to lead for better design and elimination of unnecessarily isolated components.

Further analysis includes the cost estimation of the designs to complement the time savings with cost savings. In the case discussed here, the machine is under development and, cost estimation will be a main source of information to evaluate the design.

References

[1] Boothroyd, G., Dewhurst, P., and Knight, W., Product Design for manufacture and Assembly. New Yok: Marcel Dekker, Inc., (2002)

[2] Mital, A, Desai A, Subramanian, A., and Mital, A. Product Development: A Structured Approach to Design and Manufacture. Butterworth-Heinnemann, (2009)

[3] Kevin, O. and Wood, K. Product Design: Techniques in Reverse Engineering and New Product Design. Prentice Hall, (2001)