Design of an Automated Paper Cutting Machine

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Abstract

This paper aims to present the process of designing and fabricating an automated paper cutting machine. The work presented is the result of the graduation project in mechanical engineering program that follows design process sequence including benchmarking, conceptual design, product development and fabrication of the prototype.

Keywords
Paper Cutting Machine, Design Process, Quality Function Deployment Analyses, QFD.

1. Introduction

Having an electric paper cutting machines in the market today have made the process of paper cutting easier and faster. These machines resulted in a efficiency improvement compared to the manual ones, since manual paper cutters lack safety for the user and automation. Users of an automated paper cutting machines usually are companies that cut big amounts of papers in the same size, such as printing shops, newspaper printing factories or photographers. The companies who produce automated paper cutting machines are concerned about the customers' needs and satisfaction, because it has a direct influence on the increment of market share and sales volume (Slocum, 2007).

The motivation behind this research project was the need for designing and manufacturing a paper cutting machine that will address certain needs, like safety, cutting speed, cutting accuracy, size of paper, noise level of the machine etc. Hence, this project can be considered as redesign project that expected to minimize efforts required for paper cutting process (Budynas and Nisbett, 2014).

Generally, the cutting process aims to apply enough shear force to achieve separation of the paper. Separation will occur when shearing stress, caused by applied shearing force, will exceed the ultimate shearing strength of the material. According to Gray's historical account, the first guillotine type paper cutter, shown in Figure 1a, was produced in 1855 in Germany. It was patented earlier by Guillaume Massasoit in 1844, and it is a one-armed paper cutter (Etherington and Roberts, 1981). Later, different types of cutting machines where developed including rotary cutter, shown in Figure 1b, which contains a round cutting blade that slides on a rail and cuts from both directions (Liu et al., 2018).

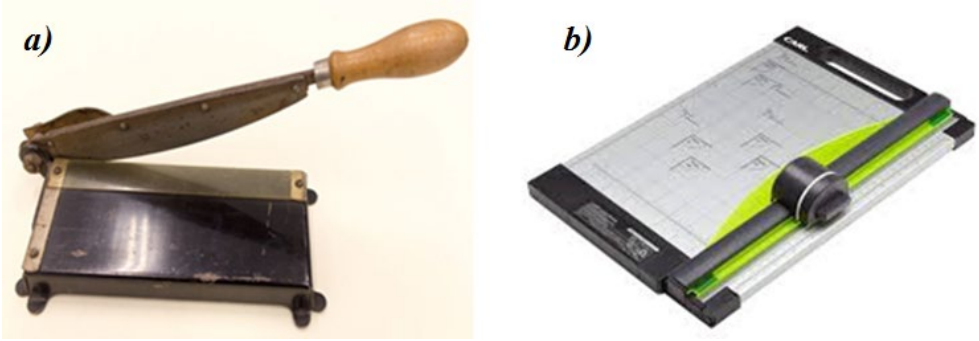

Figure 1: a) One-armed paper cutter; b) Rotary paper cutter.

However, together with technological progress and increasing demand of higher volumes of papers to be cut automatic machines with different actuation types like hydraulic, pneumatic and electric gradually replaced manual cutters (Lee and Jan, 2009). A big variety of these machines included not only different type of actuation, but also different type of paper feeding and cutter synchronizing systems, such as Geneva mechanisms, Scotch Yoke mechanism and four bar mechanism. (Shekhar et al., 2021). The design process of the automated cutting machine started with a benchmarking and product development phase, where customer requirements, engineering specifications and targets for future design were set (Gundogdu and Kahraman, 2019). As an output of the product development phase the house of quality, shown in Figure 2, was developed.

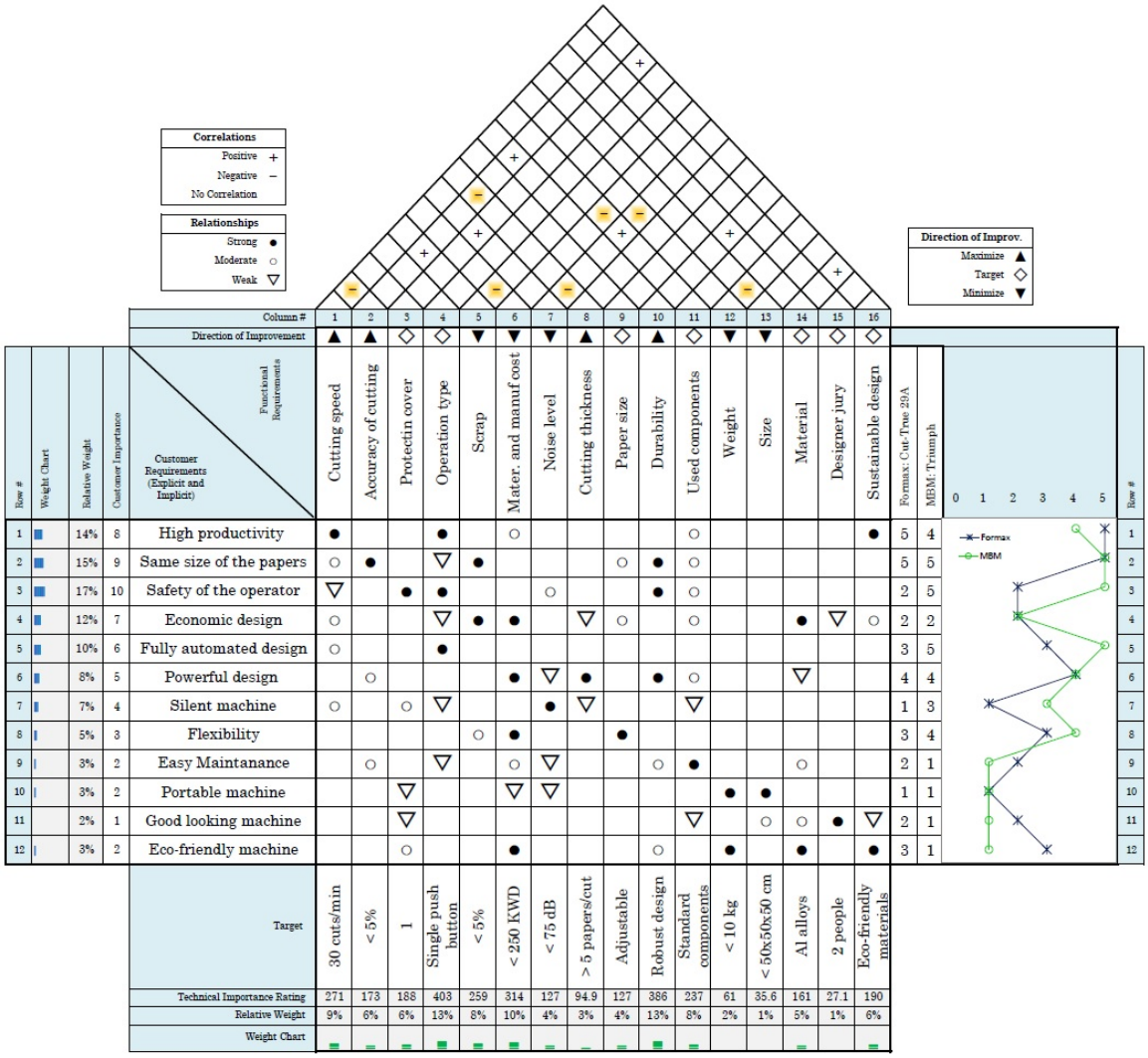

Figure 2: House of quality for an automated paper cutting machine

2. Conceptual Design

Based on defined customer requirements and developed engineering specifications functional decomposition of the machine was performed and below conceptual design solutions were developed. The machine was decomposed into following systems: paper feeding system, motor drive system, synchronization mechanism, and cutting mechanism.

2.1 Paper feeding system

The aim of the feeding system is to supply paper to the cutting blade at required speed and frequency. To perform this task system should contain paper roll, rubber rollers and a stand table that will ensure the alignment of the paper. The paper will be placed between rubber rollers, one of the rollers will be actuated to feed the paper along stand table right to the cutting blade.

2.2Motor drive system

The aim of the motor drive system is to supply energy source required to actuate all systems of the machine. To perform this task a DC motor with torque of 0.084 Nm, 100 rpm and 12V is selected. The motor will actuate the shaft that will be connected to set of gears or chain and feeding mechanism. Since, the motor is expected to actuate whole machine, it requires a suitable torque rather than fast speed. Required energy will be supplied to the motor by 12V and 2A battery. This selection is based on customer requirement to have a portable paper cutting machine.

2.3Synchronization mechanism

The aim of the synchronization mechanism is to adjust and synchronize paper feeding and cutting operations. Based on the kinematic analysis of the machine, paper feeding is expected to have intermittent motion and actuation of the cutting blade can be performed by periodic continuous motion. To perform the intermittent motion either Geneva mechanism or programmed stepper motors can be used. The advantage of the Geneva mechanism is that it does not require additional motor and can be actuated by main drive system. The intermittent motion is provided by Geneva wheel that will actuate feeding mechanism and adjust accurate and repeated sizing of the paper. By adjusting number of slot on Geneva wheel, cutting period and size of the paper can be controlled (Figliolini and Angeles, 2002).

2.4Cutting mechanism

The aim of the cutting blade is to apply sufficient shear force and cut the paper. To perform this action sharp blade was selected to reduce the contact area and increase shearing stress on the cutting line. The selected blade should be actuated and synchronized with paper cutting mechanism in order to perform cutting operation at desired frequency and speed. External force, such as spring force, is required to bring cutting blade to initial position after cutting stroke.

Based on functional decomposition analysis presented above, two conceptual designs where proposed, as shown in Figure 3. Design 1 is actuated by a linear actuator (either electric or pneumatic), the motion is directly transferred to cutting blade that is limited with guides to ensure accuracy and precision during cutting. Design 2 is actuated by an electric motor; the motion is transferred to a cutting blade through an elastic connection and to Geneva wheel through chain connection. Both designs are using rubber rollers to feed paper, however Design one requires separate motor and a control unit to perform an intermittent motion of the paper, while, Design 2, performs this motion through Geneva mechanism. Several analyses, such as cost analysis, evaluation of the manufacturability, evaluation of the complexity of the design where applied to both conceptual designs and based on the decision matrix Design 2 was selected for prototype manufacturing.

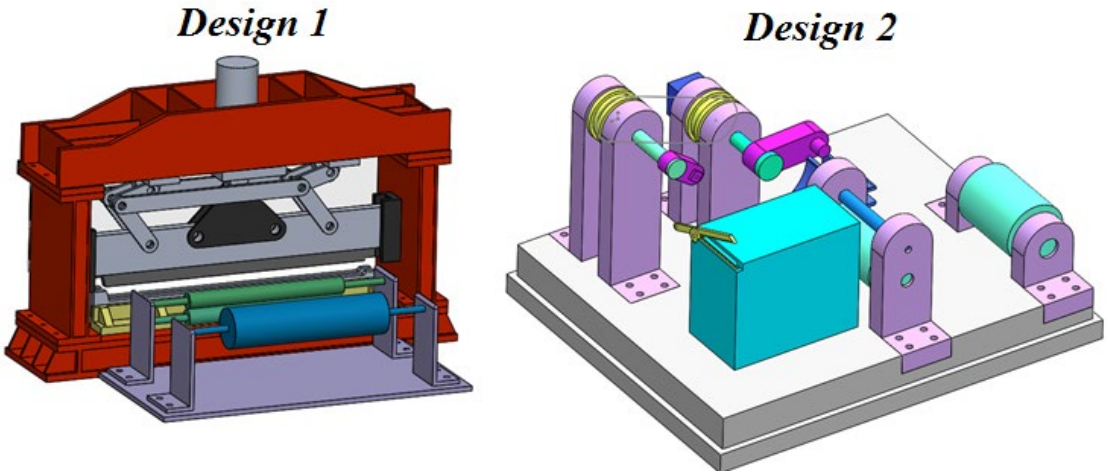

Figure 3: Conceptual designs for an automated paper cutting machine

3. Manufacturing of Prototype

The manufacturing of the prototype was performed considering customer requirements and cost efficiency. Critical parts, such as Geneva wheel and stands where manufactured from Aluminum by sequence of milling, drilling and bending processes. To reduce the material cost whole assembly was built on wooden platform and to ensure the safety of the operator, whole machine was covered by Plexiglas protecting shield.

Figure 4: Manufactured prototype

4. Testing of Prototype

The testing of the prototype was performed based on the set targets. The importance of criteria was set based on customers rating. The weighted result, presented in Table 1, showed that manufactured prototype addressed all customer requirements and scored 97%. Further developments were proposed to enhance performance of the paper cutting machine and increase safety of the operator.

Criteria	Target	Score [1-10]	Weight	Final Score	Measurements and comments
Safety	Total safety of the operator	9	10	90	**OK.** Design is safe, while operated with closed cover only. As further development the switch button can be introduced that will prevent device from running when cover is open. Meanwhile, "Don't operate without cover!" warning can be added.
Accuracy	± 5%	10	9	90	**OK.** Measured accuracy ± 1%
Productivity	> 30 [cuts/min]	10	8	80	**OK.** Measured productivity 60 cuts/min
Scrap	< 5%	10	7	70	**OK.** Measured scrap 0%
Automation	- Fully-	10	6	60	**OK.** Fully automated
Cutting thickness	> 5 paper/cut	10	5	50	**OK.** Measured 6 paper/cut
Cost	< 250 KWD	10	4	40	**OK.** Real cost 158.2 KWD
Noise level	< 75 dB	10	4	40	**OK.** Measured 58 dB
Adjustable paper size	- Available -	8	3	24	**OK.** There is a possibility to do adjustment in paper size, but as the further development a driving wheel with larger number of pins can be proposed
Easy maintenance	---	9	2	18	**OK.** As a further development the fastener of scissors can be replaced with standard one
Portable	< 10 kg	10	2	20	**OK.** Portable less than 10 kg
	Total:		**60**	**582/60**	**=9.7**

Table. 1: Testing and evaluation of prototype

5. Conclusion

This paper highlights the idea that engineers are capable of modifying existed ideas into more advanced ones. It also contains mechanical design used to perform a successful design, that's why can be beneficial for those who are interested in mechanical design projects. As a result, it presents an application of the design process on the example of automated paper cutting machine. The a real prototype that addressed all customer requirements was manufactured and further modifications were proposed based on test results in order to enhance performance of the design and increase safety of the operator.

Acknowledgement

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Biography

Sara AlDrais since childhood, Sara Aldrais liked to discover how the world worked especially the machines, and this has translated into her love and passion for mechanical engineers. She earned her Bachelor in mechanical engineering degree from the American University of the Middle East in 2020. After obtaining the certificate, she became a member of the Kuwait Society of Engineers. Moreover, during her academic career at the university, she accomplished many projects that contributed to its development in all scientific and practical terms, and in the junior year, she and her collaborating team conducted an experiment in the material science subject entitled "Woven Carbon Fiber Epoxy Fracture Testing". The results of this successful experiment were written in a paper and it was published as a scientific journal on the Science Direct website with help of the professor. And in her final academic year, she and her ambitious team members wanted to relive the experience and achieve success again, so they did an interesting graduation project that was an automatic paper-cutting machine.

Fatmah AlZhraa Ibrahim is a freshly graduated with a Bachelor degree in mechanical engineering from Kuwait. She graduated from American University of the Middle East in 2020. While in engineering college, she tended to work hard with passion no matter how big is the pressure. As a result, in her junior year, she and her group members did an experiment that its results were shown in scientific paper and published with a title "Woven Carbon Fiber Epoxy Fracture Testing" that is available in science direct. From this experience, she and her group members have an ambition to repeat this success through their senior project with the same tone of harmony, accuracy, and understanding.

Nourah AlFouderi got her bachelor degree in mechanical engineering from the American University of the Middle East. After graduating, Noura became a member and part of the Kuwait Society of Engineers to help her community and try to apply what information she has learned during studying in real life contributing with other engineers from different fields. During her studying journey in the university, Noura has participated in more than one academic fair, she has presented some of the project she was working on during the semester. Nourah has a scientific paper entitled "Woven Carbon Fiber Epoxy Fracture Testing". She has participated in the student election to be part of the engineering society, this participation came as a result of her passion to work hard, communicate with others and to help other students.Noura and her colleagues worked as a group to apply what skills they have learned while studying mechanical engineering in a project named "An automated paper cutting machine" as their graduation project.

Ali Mamedov received his B.Sc. degree in mechanical engineering from Yıldız Technical University, Istanbul, Turkey, in 2010, M.Sc. and PhD degrees in mechanical engineering from Istanbul Technical University and Koç University, Istanbul, Turkey, in 2011 and 2015, respectively. At the same time he worked as a research and teaching assistant in Manufacturing and Automation Research Center, in Koç University between 2011 and 2015 years. After attaining PhD degree he has joined Kanca Forging Inc., the biggest hot metal forging company in Turkey, as a research and development engineer, where he was in charge of project development and implementation, and have performed technical customer representative tasks for Delphi Technologies. In 2017, he joined the Department of Mechanical Engineering in American University of the Middle East, Kuwait, as an Assistant Professor. He has more than 20 publications in international journals, conferences, and books. His research interests include advanced manufacturing, micro milling and forging. Beside academic studies, Dr. Mamedov is performing the role of the expert in European Education, Audiovisual and Culture Execution Agency, where his main role is evaluating projects submitted under the scope of Capacity Building Field of Higher Education.