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Article

Shortening the Cycle Time of the Fiber Ribbon Orientation Process for Wavelength Selective Switch Production using Design for Assembly and Disassembly Concepts

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Abstract. The primary objective of the research was to shorten the cycle time of a particular process used in producing a new Wavelength Selective Switch (WSS) product by a multinational electronic manufacturing corporation. In recent years, the case study company has encountered difficulties with process cycle time exceeding predefined takt time when establishing a new production process for the freshly launched item. To identify areas for improvement, the study leveraged industrial engineering techniques, such as the Yamazumi Chart, line balancing (workload leveling) analysis, and method time measurement. After the production process data was thoroughly analysed, cycle time reduction opportunities emerged. After that, the jig design used in the present investigation was developed based on the highly effective and widely recognized mechanical engineering concepts of Design for Assembly (DFA) and Design for Disassembly (DFD). The aim was to confidently eliminate non-value-added processes in the fiber ribbon orientation step, resulting in increased efficiency and improved outcomes. The study reported a significant reduction of 87% in the cycle time required. The results also demonstrated that implementing certain methodologies could reduce the cycle time. In addition, this finding held significant importance for the industry, as it could lead to increased efficiency and productivity, ultimately leading to cost savings of 12% of its total production.

Keywords: Lean manufacturing, cycle time reduction, Yamazumi chart, line balancing technique, method time measurement (MTM-1), design for assembly (DFA), design for disassembly (DFD)

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1. Introduction

1.1. Company Profile

The investigation was carried out at one of the manufacturing facilities of a multinational electronics manufacturer. Its headquarters are located in the United States of America. This facility, which has about 60,000 square metres, is anticipated to be valued at 400 million baths by 2023. There are approximately 1,500 workers spread throughout various departments such as operations, finance, and research and development (R&D). Despite a variety of products being produced at this plant, the focus of this research is the Wavelength Selective Switch (WSS), one of the most produced items.

A Wavelength Selective Switch (WSS) is used in Reconfigurable Optical Add/Drop Multiplexers (ROADMs) systems. Its main function is to boost the utilisation of optical data and route the optical data to de/multiplex into a designated port. For this reason, WSS is a critical device to maintain the calibre of commercial ROADM systems [1]. Various technologies, such as Liquid Crystal on Silicon (LCoS) and Microelectromechanical Mirrors (MEMS), are involved in the design of WSS [2].

ROADMs are a crucial technology that forms the foundation of the next generation of advanced optical networks [3]. With the increasing popularity of cloud services, social networks, and mobile connectivity, there is a growing demand for higher performance and functionality of WSS. This includes multiple bandwidth options and routing flexibility. Developers working on WSS need to buckle up and start refining their specifications urgently. Moreover, the case study factory is currently dealing with a shorter takt time, which unequivocally demands a reduction in the cycle time for the WSS process analyzed in this research.

Although the electronics sector often concentrates on innovation and research and development (R&D) for improved product functionality, there has not been a great deal of discussion about adopting DFA and DFD to improve manufacturing operations in this domain. In turn, these aforementioned tools and methodologies are employed in this investigation to examine the practicability and efficacy of their application in actual industry settings. Note that several pseudonyms might be used in place of confidential information, which is forbidden from a publication such as names of process steps, materials, etc.

1.2. Problem Statement

Figure 1 illustrates that the factory is facing a problem at hand. Despite the takt time being set at 240 minutes, the cycle time for Process X is way off the mark at 266 minutes. This implies that the process is currently running slower than the pace at which the customer demand needs to be met. To fulfill the customer demand, it is essential to reduce the cycle time to less than the takt time [5].

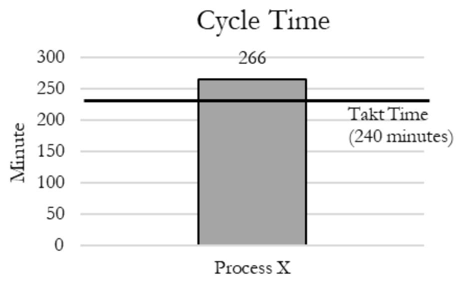

Fig. 1. Process X's cycle time (Source: the case study company).

Figure 2 shows the Yamazumi chart for Process X, which displays the process steps and time. The purpose of using Yamazami is to allow scholars to understand which sub-process step has the highest potential for time reduction. While the process cycle time presents the all-time consumed for Process X, the Yamazumi chart elaborates on it in small portions. It also highlights the process that presents a challenge for reducing cycle time [6]. There are eight steps in Process X. The first step, which takes 16 minutes, is material preparation concerning all the components and chemicals employed in this process. An operator working on this step will begin attaching materials after all materials and chemicals have been transferred to Process X's workstation. This process takes about 25 minutes to complete. Component mounting is the next stage, which takes 40 minutes to finish. After that, the installation of the parts takes 60 minutes. The second set of materials is mounted after the installation process, which takes 50 minutes. This accomplishes the main assembly.

The operator can now start working on the fiber ribbon connection portion of the task. It takes 30 minutes for the operator to splice the fiber ribbon and another 15 minutes for labeling. The product's physical form is now equivalent to the finished item. Its 500-centimetre-long fiber ribbon necessitates testing, as there is an opportunity for breakage. The degree of damage must be considered when determining whether the fiber ribbon may be reworked inside or not. However, not every case is going to be resolvable. Moreover, reworking is, in all cases, time-consuming and undesirable. As a result, before moving on to the next step, the fiber ribbon must inevitably be properly orientated.

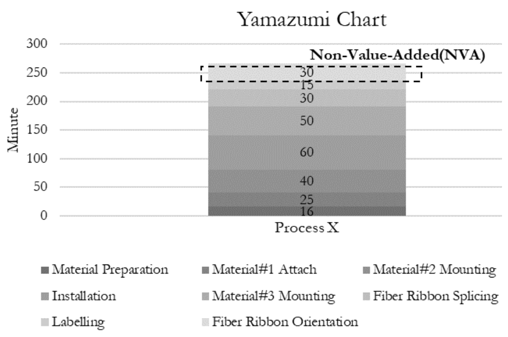

Fig. 2. Process X's Yamazumi Chart (Source: the case study company).

The fiber ribbon needs to be bent into a 10-centimeter spool during the orienting process, with terminals spaced 50 centimetres apart from the connector. By contrast, the one that is 40 centimetres away from the module is the closest (Fig. 3). When a part alters in regards to its functionality or physical state, that is considered a value-added operation while being produced [7]. Hence, its orientation is non-added value. After that, the fiber ribbon is cut and circulated throughout the WSS production line. As an aspect of the quality control loop, this process is necessary to have the fiber ribbon ready to connect to the tester in the subsequent step [8]; but it must additionally take the least amount of time. The fiber ribbon arrangement can cut down on the amount of time needed at this stage, taking roughly 30 minutes. If this is done effectively, Process X's cycle time will be shorter than the takt time.

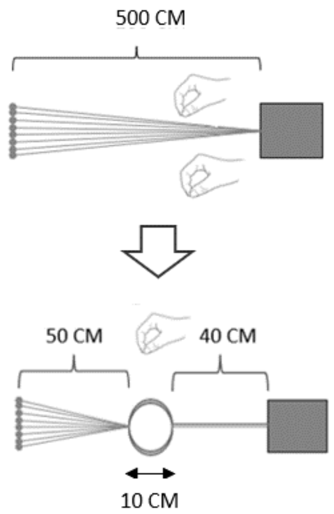

Fig. 3. Fiber ribbon before and after orientation (source: the case study company).

1.3. Research Objective

The objective of the research is to speed up the WSS manufacturing cycle time to satisfy customer demands. To be able to accomplish this, Process X's cycle time needs to be lowered from 266 minutes to 240 minutes, which is equal to or less than the predefined takt time. The target of the cycle time reduction strategy is to cut Process X's non-value-added fiber ribbon orientation step's duration by at least 26 minutes. As a result, the process time as a whole gets better by cutting the cycle time in this stage.

1.4. Expected Outcome

The expected outcomes of the research are as follows:

(1) To decrease Process X's cycle time by reducing the non-value-added time during the fiber ribbon orientation.

(2) To apply DFA and DFD to the just-developed jig to increase the speed at which fiber ribbons are aligned.

(3) To save production operation and machinery costs by creating the jig following the DFA and DFD concepts.

The remaining sections of this work are organized as follows. Section 2 is dedicated to the literature review related to this research. The topics discussed in Section 3 are directly related to a detailed discussion of the research methodology. Section 4 presents the findings obtained from the investigation. Finally, concluding thoughts and areas for future research are presented in Section 5.

2. Literature Survey

2.1. Cycle Time

Cycle time in manufacturing significantly impacts a company's profitability. In manufacturing, there are many ways to improve the cycle time, such as replacing the current machines with higher-capacity ones, adding more machines, and adding human resources. However, the fundamental method that should be considered is to optimize the motion economy as it enhances the effectiveness of manual production time, which is beneficial and cost-effective [9]. The cycle time is divided into desired and actual cycle times. While design cycle time is a result of available time divided by factory demand, the exact cycle time can be defined by using the time that each process must be met or the amount of time the operator spends to complete his part of the operation (equally distributed work), or assuming the work is evenly balanced then divide the labor time by the number of operators, or counting the time that the finished good takes, or taking the time of the slowest process. The cycle time is correlated to work in process (WIP) or so-called inventory per Little's law, where throughput (the average output per unit time) equals WIP divided by the cycle time. Regardless of the calculation methods, the less cycle time, the larger the production per unit of time [10]. Cycle time is crucial; if the product cannot be produced within the timeline, the company may not be able to deliver units in time, resulting in a canceled order. In contrast, if the product is produced too fast, the finished goods pile up inventory too early, which is costly to a company. The most suitable cycle time equals takt time, i.e. the customer's required time. For instance, the customer determines the delivery time; 20,000 cars are sold monthly. It means a thousand vehicles must be manufactured daily, assuming 20 monthly workdays. The number of working hours per day is eight; thus, a thousand cars must be built in 480 minutes. As a result, one car must be completed in 0.48 minutes. Every component in the manufacturing process must have its cycle time notion defining the time required to produce it, or the demand must be noticed [11].

2.2. Line Balancing

Line Balance and Yamazumi chart are introduced to allow scholars to understand the processing time

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consuming graphically. This could benefit cycle time improvement, especially in the processes that show challenges, such as insufficient time to meet customer demand. Line Balance graphically presents the time taken for each step. Line balance could be illustrated in various ways; the basic one could be drawn in Fig. 4. where workstations are listed at the bottom of the chart (X-axis). The stations are placed from left to right. Each bar represents the job cycle time for one unit at each process. Takt time is shown as a line across the graph; the methods with cycle time over takt time are visibly seen. At the same time, the bars lower than the takt time are highlighted, and the operator working on these stations must wait for other processes to complete their jobs [5]. Another way to present the line balance is in Fig. 5. The line balance is drawn so that the selective factors depending on the purpose are underlined [12]. In Fig. 5, the main factors, such as the X-axis and Y-axis data, remained unchanged. At the same time, more information is added for specified purposes depending on the project scope and the intention of each study.

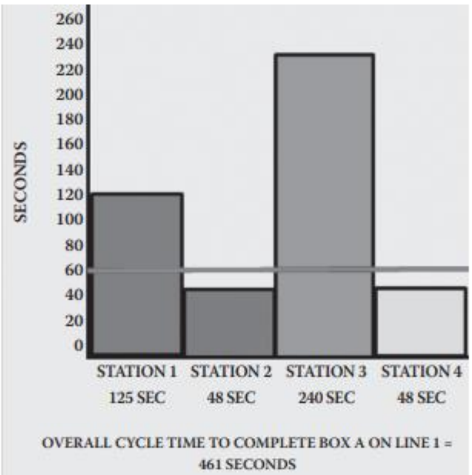


Fig. 4. Line Balance [5].

In Fig. 5, the X-axis identifies the station or process where the first process is placed on the left (near origin) while the other stations are on the right; the latest station is the last one on the right. The Y-axis presents the time used for each process, time of the work content (Ts), repositioning time (Tr), takt time (Tt), and idle time when there is no workload. Nevertheless, the bottleneck station that represents the challenging process of meeting customer demand consists of the least idle time; sometimes, the bottleneck stations are over the customer demand time (takt time). This line balances interests in locating the bottleneck station and providing data illustrating the idle and response times. If a station has a higher number than the other stations, that station shall be initially improved [12].

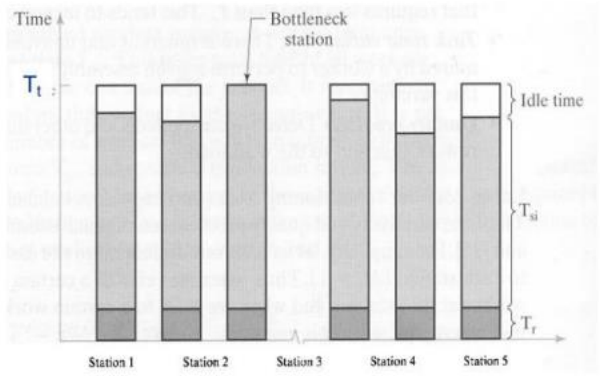


Fig. 5. Line Balancing [12].

2.3. Yamazumi Chart

The line-balancing tactic is good for overview visualization; however, each working activity must declare the process details. Yamazumi chart helps rebalance work content by elaborating on each detail in a specific workstation. This way, scholars understand better where the improvement should be started. The word "Yamazumi" is from Japanese and means to stack up. The cart is continued and stacked with other jobs until the work content reaches the total process cycle time. A takt time is expected to be drawn as a line across the chart to know where the takt time is. The stations with a lower cycle time than the takt time contain waiting time (waste). The Yamazumi chart shows that differentiation of each cycle time enhances ideas for scholars to balance the overall process. Moreover, the information on the lead time of each sub-process presented can be used as valuable information to discuss an improvement roadmap for the procedure. Comparing the line balance (Fig. 4.) and the Yamazumi chart (Fig. 6), it was found that the Yamazumi chart covers more details of the same process. Station 1, shown in the line balance, only provides station 1's cycle time, and that is over the takt time, while the same station presented by the Yamazumi chart explains that there are four sub-processes at station 1, each process takes time unevenly the longest time is at the gather flat cardboard at 40 seconds. The other processes are getting the bin, placing it, and moving it to the line, which takes 20 seconds, 30 seconds, and 35 seconds, respectively. The cycle time of each station will be sufficient to allow the scholar to move the work content to have a better line balance by allocating specified tasks to different operators or stations [5]. However, the Yamazumi chart cannot display the sequence of each work element. For example, from Fig. 6, the question about moving the bin to the line that occurs before or after the gathering of flat cardboard could not be raised by solely seeing the chart.

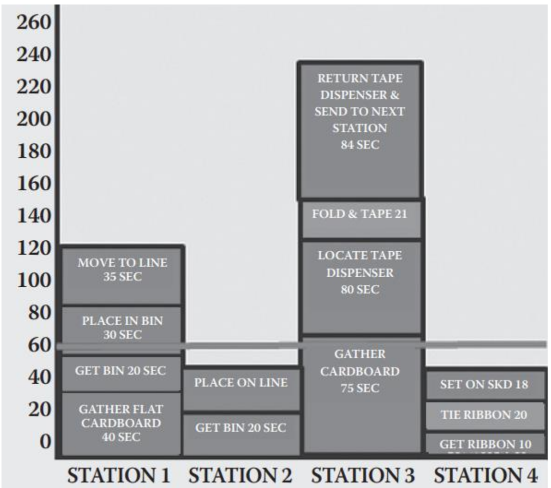


Fig. 6. Yamazumi Chart [5].

2.4. Standard Work Combination Sheet

Details of the time spent on each process step in the particular bar chart assist in seeing wastes such as transportation and unnecessary movements. In process step improvement intensive, besides evaluating the process in 4M (i.e. man, machine, material, and method), FMEA [13], and Value Stream Mapping (VSM) [14], criteria can be adapted to ensure the efficiency of causes and effects on each working step [15], the standard work combination sheet is an effective tool to document tasks that each operator does by sequence [16]. The elements include machine time, walking time, manual operating time, and waiting time. Figure 7 presents the mentioned example of cardboard preparation. All the steps are gathered, and each symbol presents the type of work element. Moreover, the value-added (V/A) and the non-value-added (NVA) are presented. The total V/A of the cardboard preparation is only 15 seconds, while the NVA is about 85 seconds. The standard work combination sheet highly benefits work sequence improvement activities because the NVA is illustrated much more clearly than the line balance and the Yamazumi chart [17]. Its takt time is shown to remind scholars of the target of the process cycle time [5].

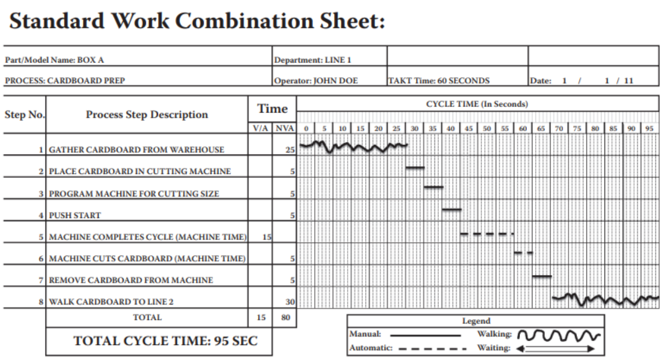


Fig. 7. Standard Work Combination Sheet [5].

2.5. Wastes in Lean

Lean categorizes activities that create waste in production into seven types: overproduction, inventory, transport, motion, waiting, unnecessary processes, and manufacturing defective units [18]. Overproduction is waste that is produced too much. Overproduction increases the risk of damaged finished goods, such as expiration. Moreover, the excessive production requires inventory management, which costs the company. In Kanban, Just-In-Time at Toyota claims that the most common waste in many productions is the over-speed of work progression. In general, the waiting time is consigned. Still, the operator proceeds with the work too fast, creating unnecessary stock on hand (work in process units) that requires extra work to manage administrative work, transport of the stock, etc. It also blinds the waiting time in that process. Consequently, finding its waste over time will become more complex [16]. Inventory needs facilities and a management system where most inventory only creates value once the product is sold. Transportation is a waste and can be reduced by a proper layout design. Motion is a waste of searching for tooling that generates non-value added (NVA) for the product. Waiting is a waste and could be improved by improving job allocation and training operators to have multiple skills. Unnecessary processes make the process too long. An example of an unnecessary process is deleting hundreds of junk emails. Scrap and rework are wasted as the material cannot be sold, and the company must allocate resources to this activity where no added profit is gained [14].

2.6. Methods-Time Measurement

The Methods-Time Measurement (MTM) is a way of classifying time for specific sequences depending upon the method introduced for the activities. It is a handy tool for manual cycle time reduction, jig design, and process design. Each basic movement is assigned standard time values (pre-) determined by the influencing variables recorded. The purpose of the motion study is to enhance productivity [18]. MTM can analyze manual work processes and develop standard manual work from the primary system: MTM-1. Industrial engineers worldwide accept the MTM more than other predetermined times systems. It can be used to build the work block for different types of production. In the early 1990s, the MTM became a productivity management system rather than a traditional system to describe and quantify time consumption in manual processes. Today, MTM is a comprehensive tool for companies to design content and time of the process. The MTM can allow the process to be right at the start, which is more cost-effective than traditional process designs such as Stopwatch Time Study, Sampling of Activity, Video Recording, Standard Data, etc. This is essential for a firm to remain competitive [19].

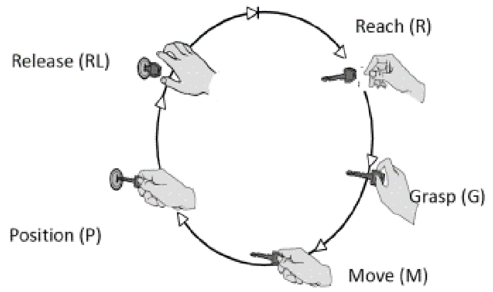


Fig. 8. MTM-1 Basic Motion [20].

Figure 8 illustrates the connection among the five Basic Motion systems, starting from reach (R) until release (RL) [20]. MTM and Lean aim for improvement indifferent approaches. While the Lean technique strives to generate the most excellent possible efficiency by reducing supplies and wasted time, reducing human resources, and shortening cycle time to meet demand, MTM focuses on avoiding waste in the value-added chain by applying suitable tools and methods based on the standard time. MTM provided solid time consumed in a particular action; for example, reaching a fixed object 40 centimeters away takes 11.3 TMU, while reaching the same object whose location is varied in the same distance takes 15.6 TMU. MTM provides the time of each activity per its distance. There are five types of reach: reach to a fixed object, reach to vary location object, reach to a jumbled object, reach to a small object, and reach to the indefinite location to get a hand in position for body balance. This could be a helpful guideline for designing jigs, workstations, etc. The unit used in MTM is TMU, where 1 TMU is equal to 0.036 seconds. The conversion of the MTM time can be found in Table 1 [20].

Table 1. MTM-1 conversion factor [20].

Time Units			
TMU	seconds	minutes	hour
1	0.036	0.0006	0.00001
27.8	1		
1,666.7		1	
100,000			1

2.7. Design for Assembly (DFA)

Excessive use of material and unproductive operation could occur if the DFA aspect is not considered [21]. Handling and insertion are the two operation keys in the manufacturing process, whether manual or automatic. The DFA offers qualitative recommendations to reduce the number of parts. This not only enhances assembly productivity but also reduces assembly cost because the cost of assembly varies directly on how many parts must be assembled and whether it is easy to handle (e.g. moved, aligned, preposition, etc.) and insert (e.g. fastened, placed, fitted, etc.). For example, product A has 60 parts, and the same product but a different version has only 15 parts, so the fewer parts, the less assembly cost. Figure 9 presents how design adjustments could reduce the part for the same product. It is noticeable that the number of screws is decreased; however, no effect on its functionality. Minimize the time of manual handling. The part will be easy to handle when it can be grasped and controlled using only one hand without a jig. Manipulation is unnecessary if symmetric with a suitable size and thickness. The rotational symmetry parts are preferred in DFA as they usually take less assembly time. Rotation symmetry is the part that does not require axis orientation and usually takes less time to handle than the ones that do not have this figure. For example, keys usually have no end-to-end symmetry. It must be rotated to the right side before unlocking the doors [22].

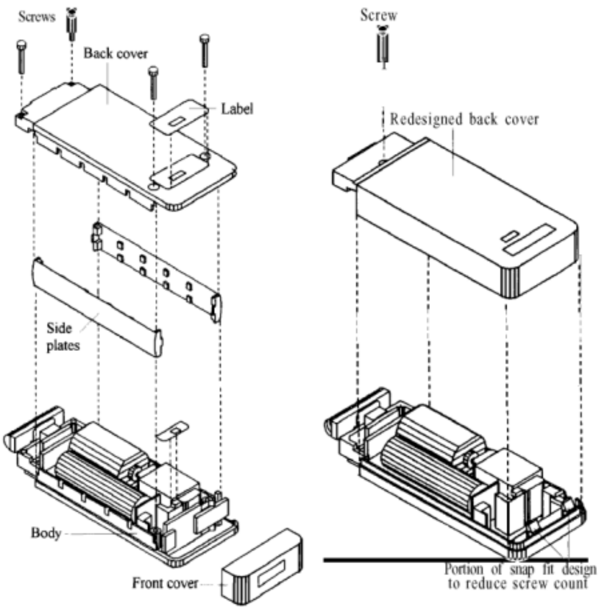


Fig. 9. Example of reducing part by design [21].

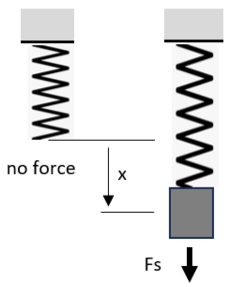
2.8. Design for Disassembly (DFD)

Traditionally, the focus of product development has been limited to Design for Assembly (DFA) and Design for Manufacturing (DFM). These two concepts have existed since 1970 and have become widely accepted as the idea supports the manufacturing and implementation of the products. Moreover, they are driven fundamentally by the consideration of economic aspects. Until the pressures from the legislators and consumers drive the importance of the Design of Disassembly (DFD) before the environmental impacts, taking the example of the car scrap number in Europe as an example, it is noticeable that the trend of scrapped cars increases linearly, starting at 10 million in 1990 and ending at around 17 million in 2015 [23]. Indeed, the DFD helps extend the product's life cycle by increasing the opportunity to recycle and reuse. To date, some disassembly techniques have developed, for example, improvement of the fastening method to integrate only partially, modular design for easy handling, and control of material variation [24]. There will be a better benefit to disassembly if the product uses the same material and the same function at most [25]. In the area of reuse and recycling, major obstacle factors are [26]:

- Joining method. Assembly design aims to simplify assembly and connection safety. Thus, connections are hard to lose.
- Variety of Material. Some materials cannot be reused or recycled. However, from the performance perspective, the designer selects many types of material.
- Design of the process. Sometimes, functional optimization creates many dismantlement steps that are not always necessary.
- Contamination and corrosion from daily operations can cause physical damage to the parts.

2.9. Hooke's Law

Experiments and observations of the spring's stresses and strains determine its characteristics. The force used to change the spring's length varies directly with each spring constant, and its change is distinct compared with when the spring is freeloading [27]. The formula of spring characteristic per Hooke's Law is Fs = kx, as shown in Fig. 10, where Fs is the force on the spring, k is the spring's characteristic factor, and x is the distance that the spring is extended or compressed. The formula determines the initial spring selection, decreasing the variation time [28]. If a spring is not selected according to this concept, it will be chosen randomly, which will cost in the design's prototype phase.



Fs = kx

Fig. 10. Spring behavior [27].

2.10. Pugh Concept Selection Matrix

Typically, a concept is initiated from several sources, especially in a team working environment where more than one division oversees a particular project. Some ideas are from the inspiration and vision of each person; some are from research such as benchmarking, and others are from reverse engineering, brainstorming, patent searches, consultants, and literature. A Powerful option screening concept is commonly known as the Pugh Concept Selection Matrix (PCSM) or Pugh Matrix. Depending on the project, the matrix can be extensive for the one related to making or buying in supply chain and capital investment; such a project usually includes rating, a list of critical to quality (CTQ), and trade-offs to evaluate each concept. In an extensive project, creating the matrix begins with identifying the CTQ and priority using Kano analysis and CTQ flow-downs. Then, the team shall conduct high-level brainstorming to meet the CTQ and critical factors, and the concepts are generated based on the design terms. Finally, the concepts will be evaluated using the benchmarking approach. [30]. In this study, the practical matrix is used. This matrix defines the selection criteria and all possible variations. Each variation will be marked in the score as positive, negative, or zero. While the positive is equal to one, the negative is equal to minus one, and there is no score for zero. Sometimes, the reference could be noted along with other alternative ideas. An example of the application of the Pugh Matrix is presented in Fig. 10. This concept is beneficial for the conceptual design phase to determine the prototype [31].

	Alternative Concept				
Selection Criteria	A	B	C	D	E
Criteria#1	+	+	-	-	-
Criteria#2	-	+	-	-	+
Criteria#3	0	+	+	+	+
Criteria#4	0	0	0	-	+
Criteria#xx	0	0	0	-	-
Pluses	1	3	1	1	3
Sames	3	2	2	0	0
Minuses	1	0	2	4	2
Net	0	3	-1	-3	1
Rank	3	1	4	5	2
Continue?	No	Yes	No	No	No

Fig. 10. Example of Pugh Matrix [29].

3. Research Methodology

Figure 11 shows the approach to be pursued in this study, i.e. process analysis, solution proposition, and analysis of results. It starts with comprehending the requirements and the existing state of affairs, and then the study kicks off with an observation of the fiber ribbon alignment procedure. Throughout this investigation, numerous process observations were made, with the initial goal being to better understand the fiber ribbon alignment procedure and provide relaxation to the operator. Communication is essential during this step. A face-to-face meeting between the operator, her mentor, and the process engineer is arranged to ensure the operator feels secure. The intent, scope, and lead time of the activity must all be stated in the meeting. Moreover, the team was briefed on the following matters, i.e. a jig will be created to accelerate the fiber ribbon orientation process; observation scope; current and target lead time; face-to-face communication will be the norm; and observation method, such as using a video to capture the procedure or testing the jig prototype using the real product at the workstation, will be discussed. In addition, the team is informed that management has authorised the observations.

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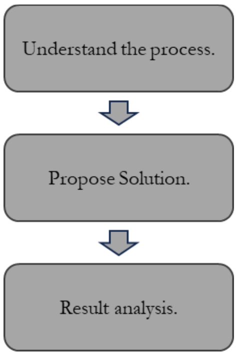

Fig. 11. Methodology.

Subsequent observations centre on comprehending the intricate process flow. Engaging the process engineer makes this step practicable. The design concept will be decided upon unless the process and constraint are in line with the process engineer. Thus, the schedule is set up ahead of time. Together with the researcher, the process engineer oversees the process being carried out.

The second observation highlights certain challenges with fiber ribbon orientation, including estimating the start and ends of the ribbon. There are numerous fiber ribbon sets. As no guideline to explain how to forbid the fiber ribbons from being crossed, the operator may occasionally inadvertently break the ribbons. The operator selects the fiber ribbon to be connected to the terminal on an individual basis in the subsequent procedure of Process X. It is observed that the work involved in the following step is improved through the proper orientation of the fiber ribbon. This also causes less chance of the fiber ribbon breaking. In general, machine structure may occasionally cause operational difficulties in the production process necessitating a preferable of having an oriented fiber ribbon in the production process.

Certain information might need to be verified because the electronic manufacturing process is typically complicated. All operators operate in this manner if there is any uncertainty or ambiguity regarding any aspect of the process, such as whether humans vary it. The best course of action during uncertain times is to review the process with the process engineer. However, the process engineer's working schedule, product availability, etc. are typically constrained. As such, it is imperative to exercise extreme caution when observing although the total number of observations is unrestricted. As a result, visits should be postponed until all information has been obtained and understood.

3.1. Production Process Analysis

The three primary steps of the fiber ribbon orientation process are broken down into an overall workflow that is described in Fig. 12. The first fiber ribbon that is put on the workbench is reached by the operator first. The operator needs to align each of the eight fiber ribbons manually. There are no restrictions on the sequencing; the operator is free to begin at any fiber ribbon. After reaching the fiber ribbon, the operator grasps, advances, and positions it such that it is in the centre of the working table.

Next, in Step 2, the operator has to estimate the beginning of the curving location without guidance and arrange the fiber ribbon. Due to the breakable fiber ribbon, this step takes a long time. Despite the fiber ribbon is not fragile, it should be handled carefully to avoid any damage. The operator is required to estimate the diameter of the cycle herself when curling the fiber ribbon. This step requires the operator to perform duties extremely cautiously. The fiber ribbon will be overly constrained if the circle is too tiny. On the other hand, according to the data provided by the process engineer and others, if the cycle's diameter is excessively huge, it won't be appropriate for the conditions of operations in the process that follows. The correct diameter of the cycle of the fiber ribbon is about 10 cm.

The oriented fiber ribbon will be set aside on the workbench once the first orientation is complete. The operator will start working on a new fiber ribbon until all eight of them are aligned. After everything is finished, the fiber ribbon bundle is wrapped in a plastic tube before the unit is advanced to the next process.

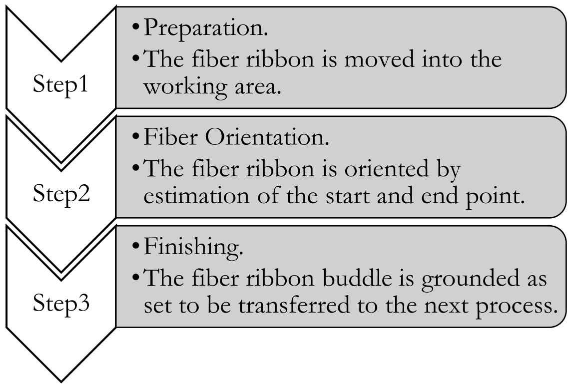

Fig. 12. Fiber ribbon orientation process flow.

Because the fiber ribbon is 500 cm long and has eight sets, it is apparent that the second step in orientation takes a significantly longer period. The operator carries the fiber ribbon in this step with their left hand while estimating the start point of the next orientation with their right hand by slowly sliding it down the fiber. The variation in the diameter of every orientated fiber ribbon is the result of estimation made without the use of a jig. As it comes into contact with machinery in the next process, assistance could be essential. At times, the operator handling the process that follows needs to realign the fiber ribbon so that its diameter is no more than 10 cm to prevent the aforementioned failures. This production problem not only causes poor quality but also makes the process's total cycle time longer. As a result, this is part of the delay time that made the company postpone the shipment schedule to the clients.

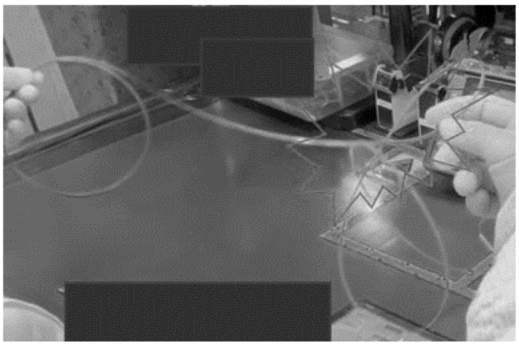

Fig. 13. Example of cross fiber ribbon while orientation.

Figure 13 shows the process barrier that currently exists. Usually crossed, the fiber ribbon needs significant time to uncross. These occurrences are recorded as delay time. The operating time of the current process is 7.76 minutes, the transportation time is 3.44 minutes, and the delay time is 15.28 minutes, according to the overall observation time. As a result, this procedure currently has a cycle time of 26.48 minutes overall.

3.1.1. Need for a jig

Applying the tooling design concept from other industries, the requirements are classified into four categories: performance, reliability, features, and safety [29]. The process engineer and the mechanical engineer who participated in this study agree on these criteria.

Table 2. Jig requirement for the fiber ribbon orientation.

#	Criteria	Description
1	Performance	The fiber ribbon is oriented quickly.
2		Strong structure.
3		Easy to set up.
4	Reliability	Easy to manipulate.
5		Prevent complex movement.
6	Features	Electrostatically discharged material.
7		Able to release the fiber ribbon.
8	Safety	Prevent finger pinching.
9		No sharp edges.

Table 2 shows the overall requirements. For performance, the jig must help the operator arrange the fiber ribbon to shorten its cycle time. The whole process of the fiber ribbon orientation currently takes 30 minutes. The jig must reduce the cycle time by being a guideline for fiber orientation. The operator does not have to consistently estimate the starting and ending points on the fiber ribbon on every fiber ribbon. Moreover, it could reduce the crossed fiber ribbon in the current process. The jig structure (body and spring) must be strong. The spring set must hold its body weight and have enough space for the press length when the operator releases the fiber ribbon after finishing orientation. The shape of the jig and the material define the jig's weight. Weight must not be a constraint of handling and manipulation. The design of its structure must also be durable. The set-up time should be much less or zero. Otherwise, it becomes another non-value added to the process. The set-up time is when the operator must prepare the jig. The set-up time is sometimes manageable by parallel running it and other processes like turning on the oven while preparing the equipment and material. But there are some activities where simultaneous work is impossible, like using a computer to send an email. The computer must be turned on and boosted entirely before sending the email. Parallel jobs are not compatible with this jig. The purpose of this study was to not require any kind of set-up. It is expected that the cycle time is most improved in this manner.

Regarding reliability, this topic focuses on enhancing the manual operation of the fiber ribbon orientation process. Thus, the subjects are easy to manipulate and do not create complex movements. The manipulation in this process is handled with one hand. The jig should not be easy to slip; in other words, the hole for the finger's rest must be deep enough. Yet, it must be in balance with the body's strength. The complex movement of using the jig is any movement that needs to be ergonomically for manual operation—for example, the twisting of the hands and the bending of the fingers. In addition, the jig should be able to be used effectively so that the operator can only hold it still in one hand and use the other hand to curve the fiber ribbon.

About features, apart from releasing fiber, it is critical for the jig that it is made from electrostatically discharged material (ESD) due to the production requirement. It is commonly known in electronic production that the discharge ability of material impacts the quality. It could make the product malfunction. The release feature is essential for this process because the fiber ribbon must be moved into a tray and transferred to the following procedure. If the fiber ribbon cannot be removed from the jig, it will obstruct production resulting in the work cannot be continued.

The jig must be safe for the operator and the product. The jig must not pinch the operator's fingers. It is a good idea to have the fingers rest area. The jig should also consider the damage to the product. It should not have a sharp edge that may cut the fiber ribbon. Instead, all sharp edges (if any) must be filleted. The material used to create the jig must be strong and not contaminate the process. WSS production is sensitive; using the material according to the company's regulations is critical. Thus, the scope of the material is limited. Scholars should confirm this with the company. After statements of each criterion are declared, the team applies DFA and DFD to select the most suitable idea through brainstorming with all stakeholders.

3.2. Proposed Solutions

The solutions are brainstormed and captured systematically. The jig must release the fiber ribbon after orientation, and the jig size must be adjustable. Therefore, the jig's design must be considered its primary structure and size adjustment mechanism.

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3.2.1. Main jig structure

Table 3. Alternative design of the jig structure.

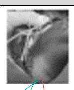
Design Function	Component	Alternative 1		Alternative 2
Fiber ribbon holder	Jig's body			
Material	Jig's body	Standard material		
Release and hold	Spring	Standard spring		
Finger rest	Finger holder			

Table 3 contains two concepts for the fibber ribbon holder and the jig's body design. The first design is a body made from solid material and jointed using a spring structure, while the other jig's body concept is one piece of a jig made from foam. The material must be used in one that aligns with company regulations. Spring should be a commercial one, not a customized design. There are three ideas for the finger holder: the first is to separate each finger, the second is to combine the finger rest area with a narrow space, and the last one is to have sufficient area for some flexibility.

Table 4 presents six alternative designs for the jig's structure. All alternative ideas are gathered into the Pugh Matrix to select the most suitable design for the jig (Table 3). Each requirement will be reviewed. If the design enhances the requirement set at the beginning, the design will be scored as "+" referring to a positive mark. In contrast, if the design is against the requirement, it will be scored as "-" referring to a negative mark. The design could acquire "0" referring to neither positive nor negative to the requirement.

Table 4. Plug Matrix for the main jig structure.

Selecting Criteria		Design Concept					
		I	II	III	IV	**V**	VI
1	Performance	0	-	0	-	**+**	-
2		+	-	+	-	**+**	-
3		+	0	+	0	**+**	0
4	Reliability	+	-	0	-	**+**	-
5		0	-	+	-	**+**	-
6	Features	+	-	+	-	**+**	-
7		+	-	+	-	**+**	-
8	Safety	0	+	+	+	**+**	+
9		+	+	+	+	**+**	+
Pluses		6	2	7	2	**9**	2
Sames		3	1	2	1	**0**	1
Minuses		0	6	0	6	**0**	6
Net		6	-4	7	-4	**9**	-4
Rank		3	4	2	4	**1**	4
Continue?		No	No	No	No	**Yes**	No

The design concept V secures the highest net mark. In this concept, the jig is made from solid material with a standard spring structure, and its finger rest is a large-size concept. As a result, it is the first rank that will be continued to the produce and trial accordingly. This design concept should be able to enhance the fiber orientation process time as its solid body guides the fiber ribbon loop. In addition, it does not require setup because it can be used promptly. It is easy to manipulate as it has a sufficient finger rest size, so there is no need to position it to rest the finger. In contrast, the other two finger rest designs are too small and may require an eye check to rest the finger properly. Thus, it prevents complex movement. Moreover, its design is based on the DFA concept for the symmetric shape, which also enhances the ease of manipulation and prevents complex movement. Alternative 2's design body is soft and made from foam. Even though it is a one-piece design, by testing, it cannot release the fiber ribbon quickly. It creates complex movement that consumes time to orientate the fiber ribbon. Concept V is made from an electrostatically discharged material. Its spring structure allows an effective releasing process. As a result, there is no sharp edge on the body of the jig.

3.2.2. Spring structure

The spring set must support the press and release function of the jigs. The operator is much more comfortable using it without difficulty. The spring design is vital for the jig; it must be designed carefully. The spring set's too-soft structure will weaken the jig to hold its self-weight. The jig will be pressed by its weight. As a result, it will not be able to release the fiber ribbon. In contrast, if the spring set is too strong, the operator will not be able to use it effectively, which will cause production delays. Table 5 classifies the requirements for the spring structure into four categories: performance, reliability, features, and safety, which could be explained as follows:

Table 5. Requirement for spring structure.

#	Criteria	Description
1	Performance	Able to hold the jig's weight.
2		Strong structure.
3		Able to be used effectively.
4		Easy to set up.
5	Reliability	Easy to manipulate.
6		Prevent complex movement.
7	Features	Electrostatically discharged material.
8	Safety	Prevent finger pinching.
9		Do not damage the fiber ribbon.
10		Do not generate contamination.

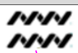
Performance. The spring set can hold the jig weight. At the beginning of the orientation process, the jig is used as a holder for the fiber ribbon. It is not pushed during this step. If the spring cannot hold the jig's weight, its release length will be decreased. It will not be able to move, so it cannot release the fiber ribbon and may cause fiber damage from sliding the fiber ribbons of the jig. Thus, the spring must be able to hold the jig weight. Spring should have a strong structure. The structure must not break while using it. This is fundamental to all tooling design per DFD. If the jig breaks easily, it requires high maintenance. If it is unfixable, it must be repurchased often, which is also costly [19]. Spring must be set to be used efficiently. The operator must be able to manipulate it using one hand because she must use the other hand to orientate the fiber ribbon. If the jig needs two hands to manage, it will not suit the process. Spring is easy to set up. The purpose of this jig is to reduce the cycle time of the Mechanical Assembly process. The tooling should not create any work for the process. The tooling should be able to be used promptly. The force that is required to push it must be less likewise.

Reliability. The critical criteria for the spring design are that spring can efficiently be handled/manipulated and spring sets prevent operators from making complex movements per DFA theory. Spring can efficiently be handled/manipulated. When pushing the jig, the decreasing length should be constant every time. The spring should require little effort to control—the more force needed to push it, the more complex the manipulation. Spring sets prevent operators from making complex movements. Complex movement will be required if the spring is too hard or soft. The one that is too hard needs much force to push it. It may require the force of two hands to delay the working process. The too-soft one may be unable to hold its load, so the operator may need to keep it with her finger, etc.

Features. The critical criteria for the spring design are that the spring set material must be electrostatically discharged. Spring set material must be electrostatically released. This is the regulation from the company. Obeying this regulation is necessary for the tool to be approved for use in the production process.

Safety. The critical criteria for the spring design are that the spring set prevents fingers from getting pinched, the spring set does not damage the fiber ribbons, and the spring set must not generate contamination.

Table 6. Alternative design of the spring structure.

Design Function	Component	Alternative 1	Alternative 2
Body	Structure		
Material	Structure	Plastic	Stainless Steel
Spring	Shape	□	O

The alternative of the spring structure designs is written along with their possible material and the shape of the spring guide. Table 6 summarizes the alternative solution for the body, the material, and the spring shape. The body could have either only spring or spring with the middle pillar. Two springs are required based on the jig's body; thus, both alternatives are designed towards this concept. The material can be either plastic or stainless steel. Even though more types of material are available, these two types are commonly used in the company. Thus, only two types of spring material are shown. The shape of the spring can be either square or circular.

Table 7. Plug Matrix for the spring structure.

Selecting Criteria		Design Concept					
		I	II	III	IV	V	VI
1	Performance	0	0	0	0	0	**0**
2		-	+	-	+	+	**+**
3		-	+	-	+	+	**+**
4		-	+	-	+	+	**+**
5	Reliability	-	+	-	+	+	**+**
6		-	+	-	+	+	**+**
7	Features	+	0	+	0	0	**0**
8	Safety	-	+	-	+	+	**+**
9		-	-	-	0	-	**+**
10		-	-	-	-	+	**+**
	Pluses	1	6	1	6	7	**8**
	Sames	1	2	1	3	2	**2**
	Minuses	8	3	8	1	1	**0**
	Net	-7	4	-7	5	6	**8**
	Rank	5	4	5	3	2	**1**
	Continue?	No	No	No	No	No	**Yes**

Using the Pugh Matrix (Table 7), the score is filled in for each design concept. The Pugh Matrix is used widely in many sectors to identify the most suitable solution for an area, such as resource allocation [27] and instrument capability review [28]. The highest score is the solution that will be used to create the prototype of the spring set. The DFD and DFA are the guidelines for evaluating each concept per the selection criteria. This case is concept VII because it covers most of the selection criteria at a net score of 8, ranking first. The structure can hold the body's weight better than using only a wire spring without a spring guide. Regarding DFA, the spring can damage the fiber ribbon because of its tangled structure. The shape of the coil determines the shape of the pillar guide, which is best as a cylinder. After all, it does not damage the fiber ribbon and is safe for operators' fingers. The type of material selected according to DFD is stainless steel, which is much more durable than plastic. Moreover, it requires less maintenance. Thus, it is more environmentally friendly by not changing the spring often.

3.2.2.1. Spring selection

After the spring structure concept is agreed upon, the specification spring is selected based on Hooke's law k=mg/x [32], where x = preload at 2 mm. The weight of one side of the jig is 180 grams. Thus, the k spring can be calculated as follows.

$$k = mg/x \text{ N/mm}$$

$$k = (180/1000) * 9.81/2 \text{ N/mm}$$

$$k = 0.89 \text{ N/mm (total)}$$

$$k = 0.45 \text{ N/mm for one spring}$$

The calculated k is 0.45 N/mm to select the closest k from the spring constant. From the spring constant, the WF type is the nearest figure (Table 8). To facilitate the strength of the spring, the maximum diameter is selected. Thus, the spring is WF16-15. The spring's length is 15 mm because of the constraint from the jig's dimension. This spring chosen will be used for the prototype jig.

Table 8. Spring Constant [33].

Spring constant — D12, D14 and D20 are not available for WT type.

Type	D	N/mm {kgf/mm}	Fmax.
WY	3–8	0.1 {0.01}	F=L×75%
	10–16	0.2 {0.02}	
WR	3–16	0.3 {0.03}	F=L×60%
	18–27	0.5 {0.05}	
WF	3–16	0.5 {0.05}	F=L×45%
	18–27	1.0 {0.1}	
WL	2	0.5 {0.05}	F=L×40%
	3–16	1.0 {0.1}	
	18–27	2.9 {0.3}	
WT	3–4	1.5 {0.15}	F=L×40%
	5–16	2.0 {0.2}	
	18–27	3.9 {0.4}	
WM	3–4	2.0 {0.2}	F=L×35%
	5–16	2.9 {0.3}	
	18–27	4.9 {0.5}	
WH	4	2.9 {0.3}	F=L×30%
	5–12	5.9 {0.6}	
	13–16	9.8 {1.0}	
	18–27	14.7 {1.5}	
WB	3	3.9 {0.4}	F=L×25%
	4	4.9 {0.5}	
	5–12	9.8 {1.0}	
	13–16	19.6 {2.0}	
	18	29.4 {3.0}	
	22–27	29.4 {3.0}	

3.2.2.2 Spring Structure Design

The spring guide follows the DFA symmetry theory, a round shape so the machine shop can produce it more easily. Moreover, it will not cut or damage the fiber ribbon. To sustain the press function, the core body (18 mm) of the spring guide's length equals its arms (9 mm). All screws use the same part number to limit variation of type and material used. The size of the screw should be appropriate with the spring guide; in this case, the diameter of the screw is 2 mm. The dimensions of the spring set are presented in Fig. 14.

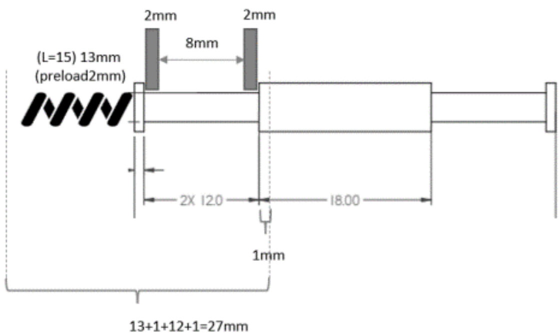


Fig. 14. Dimension of the spring structure.

Figure 15 presents the final design of the spring set, which has a spring guide in the middle and wire spring WR5-15 support at both terminals. In the trial test using the WF16-15, the operator cannot press the jig quickly. The spring is too hard, and the dimension of 16 is too big. The two alternative springs are selected from the configured specifications. Because the first trial spring is too hard, the smaller constant K is set for 0.3 (WR type). The desired diameter is 5 mm. The length remains at 15 mm. The other one's constant K is selected for 0.3 (WR type). The preferred diameter is 8 mm, length is 15 mm.

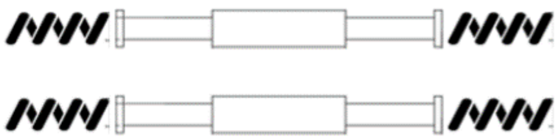


Fig. 15 Dimension of the spring structure.

Figure 16 shows the final concept of the jig structure with the final spring structure, the initial design of the jig that a prototype will be made.

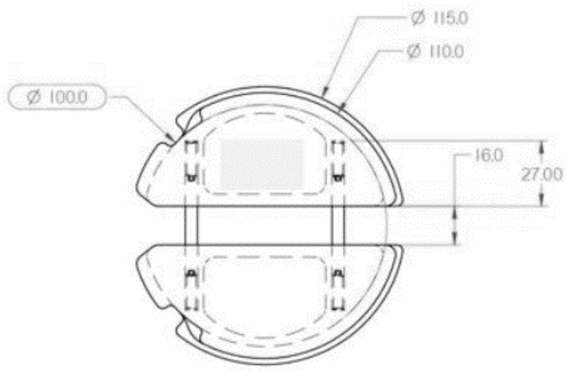


Fig. 16. The final design of the jig.

This model uses the DFA symmetry concept, so the upper and lower parts are symmetrical. This reduces machine costs and reduces cycle time in operation. The CNC machine needs only a one-dimensional program, and the operator uses the tool without side confirmation. The strength of the structure is a priority; the finger holder will not be thoroughly drilled. This way, the jig strength is increased. Because of the location of the finger holder, instead of having one big spring in the middle, a smaller set of springs is selected. It takes about two weeks to make the prototype. After it is delivered to the company, the trial is started.

3.2.3. Trial of the jig

Figure 17 demonstrates how the first trial might be made better. The jig's strength is acceptable. It can support the jig's weight. It is also simple for the operator to control and press. Its shape, meanwhile, is inappropriate since it puts stress on the fibre ribbon. As a result, the second trial will involve an adjustment to this issue.

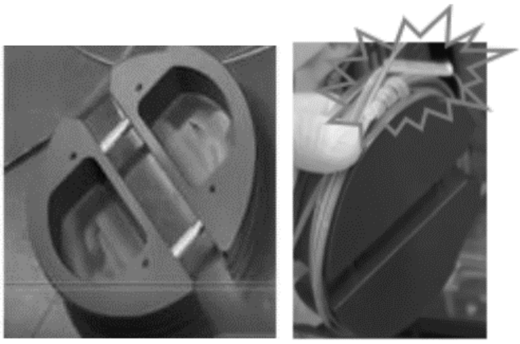


Fig. 17. The first trial of the jig.

Figure 18 shows that the shape of the jig is adjusted to be square to release the stress that occurred in the first trial, but the concept of symmetry remains. This helps minimize its cost. However, the jig is hard to release the fiber ribbon. This is dangerous for the fiber ribbon, as it could crack or break.

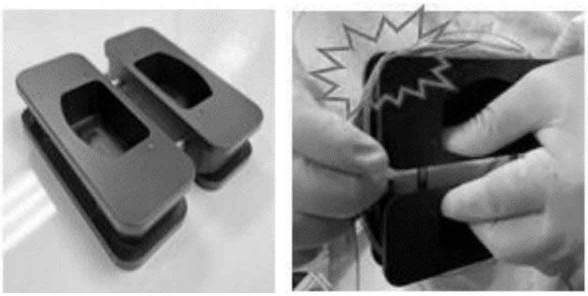


Fig. 18. The final design of the jig.

Figure 19 shows that the tool's shape is adjusted to reduce the fiber ribbon guide to only one side. This also increases visibility for the operator using this jig. This design meets all the requirements. Noticeably, the operator works much better than when not using the jig.

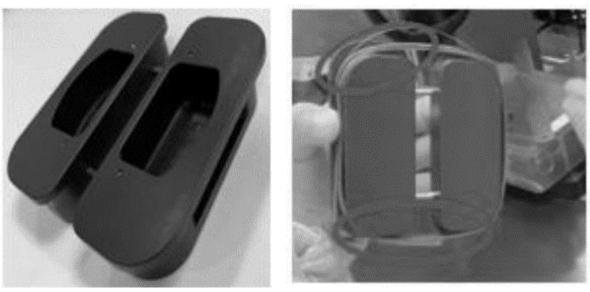


Fig. 19. The final design of the jig.

Finally, Fig. 20 illustrates that the jig is improved during the trial processes. However, solving the initial problem may give rise to a different problem. Based on the study, trial#2 solves the issue of the stress on the fiber ribbon but creates a new problem: the fiber ribbon struck at the jig's shoulder. It takes several trials to reach the desired condition, even if suitable theories are considered during the design phase.

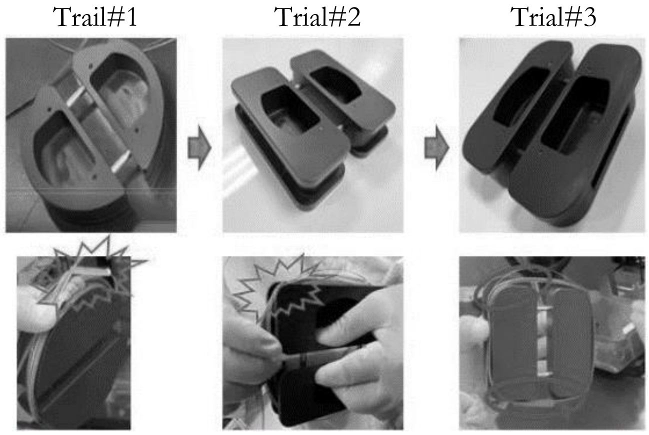


Fig. 20. The final design of the jig.

4. Analysis of Results

4.1. Theory Application

After running the trial three times, the final design uses standard material with a spring set with the spring guide in a cylinder shape (Fig. 18). Regarding the trial result, it is suitable for the fiber ribbon orientation. The theories of the Design for Assembly (DFA) and Design for Disassembly that are applied are as follows.

- *Symmetric*: The jig's upper and lower parts are symmetrical, and both spring sets are balanced in location and size.
- *Ease of manipulation*: The jig can be used with one hand. No setup is required, and it must be used promptly.
- *Allocate a suitable number of parts per their functionality*: The spring sets are located only on both sides of the jig, using only two screws as guide pins to lock the press and release positions.
- *Avoid blind spot*: The operator can see all the fiber ribbons on the jig.

4.2. Process Improvement

Before implementing (Fig. 21) the jig, the operator must estimate each cycle's starting and ending point of each cycle. The operator uses the left hand to hold the fiber ribbon and the right hand to the side to estimate the point to orientate the fiber ribbon. Because the estimation is done without any guidelines, the operator must adjust the dimension of each cycle constantly until it is correct. This process is considerably slow to prevent damage to the fiber ribbon. This operation must be repeated on all fiber ribbons.

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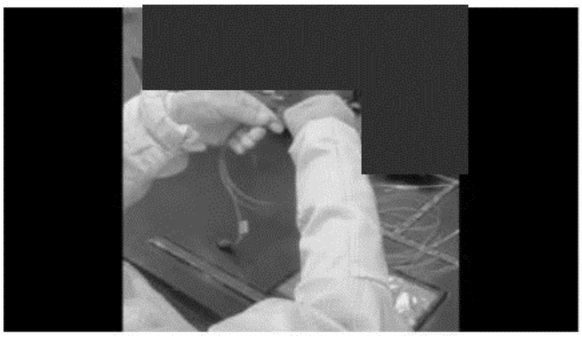

Fig. 21. The fiber ribbon orientation process without the jig.

Figure 22 illustrates that the operator works smoother without searching for the curve position on the fiber ribbon. The operator does not need to estimate the curvature herself as the jig guides the stop position automatically. These reduce the time required for the process. Based on observation, there is less fatigue on the operator's hands and arms. As a result, the operator could work more effectively. In addition, the size of the jig is adequate so it can be kept on the workstation without being an obstacle to the normal process. This is good for production management. After implementing the tool, the flow process chart of the fiber orientation shows that the overall cycle time is reduced to about 4 min. The delay in searching for the position to curve is reduced from 15.28 sec to only 0.24 sec, approximately 98%. It is noticeable that the operator sometimes needs to be more familiar with the tooling. Because the operator is still searching for the fiber ribbon at the end, the starting location of placing the tool could be more effective as well. It should be in the working area, so the operator spends no time grabbing it. Yet, the jig significantly reduced the operation time during the early implementation.

Fig. 22. The fiber ribbon orientation process with the jig.

4.3. Cycle Time Improvement

Interestingly, its non-value-added time decreased significantly from about 30 minutes to about 4 minutes or around 87%. Adding the jig to the process did not increase the time spent on other sub-processes within Process X.

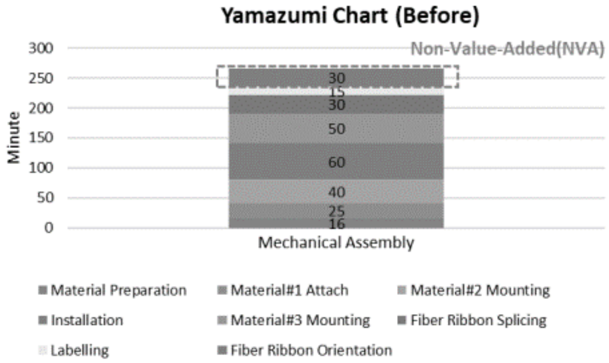

Fig. 23. Yamazumi chart before improvement.

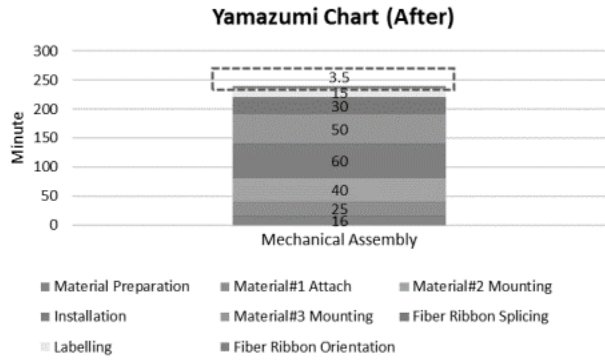

Fig. 24. Yamazumi chart after improvement.

From the overall cycle time, the mechanical assembly process now takes around 3.6 hours, with jig and operator skills increasing in the material preparation step. Meanwhile, the case study company improves other processes; all cycle times are below takt time (Figs. 23 and 24).

4.4. Cost Benefit

The Fiber Ribbon Orientation reduces the cycle time of the Mechanical Assembly Process. Thus, operators and engineers can be more utilized/allocated to work on new products or processes. If the operator's wage is assumed to be about 900 USD per month, and the salary of one engineer is approximately 1,500 USD. The jig reduces the working time by almost 30 minutes, which means about 3.75 USD per unit for the operator and 6.25 USD per unit for the engineer. For one day, this working station's capacity is about six units. Thus, the saving cost per day could be (3.75+6.25) * 6 = 60 USD per day or 1800 USD per month (about 750,000 THB per year). Moreover, the DFA reduces the cost of jigging production. The symmetry concept minimizes the price of the machine shop, and CNC milling machines require less position set-up, both physically and software-wise. This could save around 12% (Tables 9 and 10).

This research found that symmetry is the most important technique for time reduction among the four techniques. It enhances the ability to manipulate, avoid the blind spot, and manufacture. Allocating suitable parts benefits jig manufacturing and maintenance.

Table 9. Cost of jig without applying DFA and DFD.

No	Description	Unit Price	Qty	Total (THB)
1	CNC milling machine	3,840	2	7,680
2	Material	1,000	2	2,000
3	Spring set	1,100	1	1,100
			Sum	10,780

Table 10. Cost of jig with applying DFA and DFD.

No	Description	Unit Price	Qty	Total (THB)
1	CNC milling machine	3,200	2	6,400
2	Material	1,000	2	2,000
3	Spring set	1,100	1	1,100
			Sum	9,500

4.5. Recommendation

4.5.1. Work instruction

To keep the fibre ribbon orientation process taking the appropriate amount of time and upholding the jig's proper usage practices, a work instruction must contain written instructions on how to utilise the jig. This idea is still widely accepted today; therefore, all industrial processes should include work instructions for every activity. Good work instruction, however, could differ in many ways. The difficulties in developing work instruction are captured in a study. There are five major categories, each having a subtopic, i.e. the intrinsic; the representational difficulty; the information is unmatched; the information is dubious; and the information is inaccurate. These need to be thoroughly examined since they may create delays or product issues [35]. Since the work instruction is only intended for training purposes, having one of high quality is essential.

4.5.2. Training

The operator spends some time looking for the fibre ribbon position at the end of the operation in reference to the water flow process chart. If the operator receives appropriate training packages as their proficiency with manual labour increases, this incident will be lessened. It is therefore essential to instruct operators on how to utilise the jig. Additionally, a work instruction must document the appropriate usage of tools. The new operator could efficiently learn the job in this way. Because of the operator's increased proficiency, the material preparation step takes noticeably less time. Concerning the Yamazumi Chart, this process's cycle time was shortened to 13 minutes (Figs. 24 and 25).

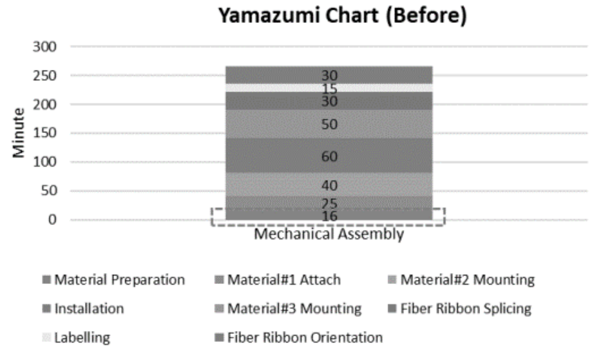

Fig. 24. Before training.

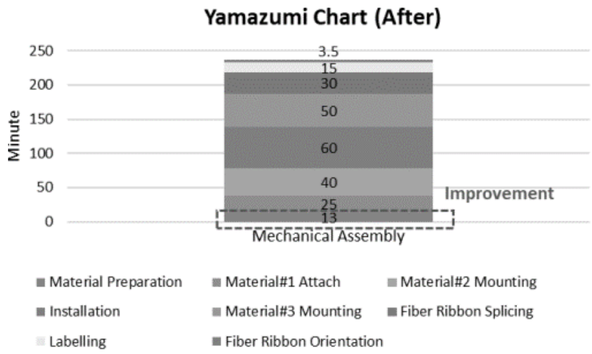

Fig. 25. After training.

Therefore, it is a good idea to ask the operator if any areas need improvement throughout training. Additionally, the training ought to be ongoing rather than one-time. There ought to be assessment standards that demonstrate each operator's comprehension level. In addition, clear communication efficiently increases the operator's knowledge of the work because it is essential to training [36].

4.5.3. Preventive maintenance

Both the workstation and the machine should always be operational. If these things are not prepared for use, the process is halted. It has an immediate impact on the process's cycle time. The machine's downtime may be minimised by carrying out the preventative maintenance programme. When the shift is being changed, or when the machine is not being used, the technician should inspect it. The industrial process might function smoothly in this fashion. Examples of preventive machine maintenance schedules are provided in the following images. First, there are the job-based completion times (Fig. 26). The machine-based completion times is the second one (Fig. 27). Preventive machine maintenance is defined as a job-based completion time if the job machine removal time is not included in the job. On the other hand, if the machine removal time is not included in the task, preventative machine maintenance is referred to as machine-based completion times. The machine removal time is indicated by the shaded boxes [37].

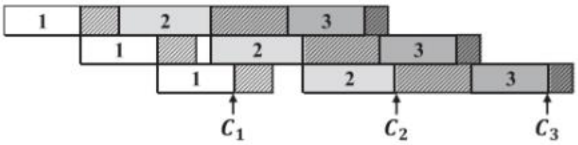

Fig. 26. Job-based completion times.

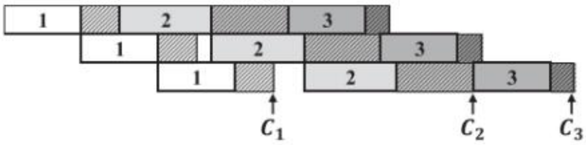

Fig. 27. Machine-based completion times.

5. Conclusion

All things considered; the study produces the outcomes that are intended. Throughout the design phase, DFA and DFD were applied in the study. The part's structural design uses the DFA's symmetry notion [22]. To reduce the costs of the CNC milling process, the jig shapes are deliberately constructed with the same side on both sides. This saves 11% of its total production. Furthermore, according to MTM-1 theory [20], the operator can function efficiently since the precise geometry of both sides removes the need for that confirmation step. Without this notion, production would be excessive, the designer might combine designs, and the fiber ribbon orientation procedure would take a long time. This saves 12% of its manpower cost.

A further great illustration of applying the DFA approach is the reduced number of parts. There are myriad methods for designing a jig. Without this idea, the design might include more than just the tooling structure's two sides. Four body parts could be used to build the jig. One may only employ the wire spring for the press and release functions if the tangle-induced spring structure is not noted, making damaging the fiber ribbon simple. A key insight from the DFA is total cost management, i.e. the least expensive assembly item is the minor assembly part. In addition, saving costs also benefit from the design and part commonality.

When DFD is taken into account, the material's durability is high. For instance, the primary structure of the jig is made of solid material rather than tape-wrapped foam. Compared to foam, the rigid material lasts longer. Additionally, the product life cycle and the jig life cycle ought to be identical. As a result, the jig will require less maintenance throughout this time. Similarly, the entire spring set is chosen to be made of stainless steel. Without the DFD concept [34], one could opt for plastic, which is less expensive than stainless steel but requires frequent replacement. The spare part for replacing the spring set is expensive, and there is no jig for the fiber ribbon orientation process. As a result, the non-value-added process keeps recurring. Without the DFA and DFD concepts, excessive parts could occur.

A suggestion for further research could be varying the different operators using the jig design per DFA and DFD. For example, there are differences in age, gender, and height. Understanding the curtain factors is the most effective way to design a jig to match each operator in a particular team or geography.

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