SETUP TIME REDUCTION IN A CNC PRODUCTION FACILITY THROUGH REDESIGN OF JIGS AND FIXTURES

LAM PEI XIAN

A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons) Industrial Engineering

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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ID No. : ___________________________

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"SETUP TIME REDUCTION IN A CNC PRODUCTION FACILITY THROUGH REDESIGN OF JIGS AND FIXTURES"** was prepared by **LAM PEI XIAN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Industrial Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ___________________________

Supervisor : Dr. Joshua A/L Jaya Prakash

Date : ___________________________

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ABSTRACT

Jigs and fixtures play an important role in manufacturing. Its function is to arrange the material in a definite position, so the machine tool is able to cut the required path on the workpiece. The case study of this research is conducted in Company "X". One high demand product is "Y" which is the focus of this research. This product is consists of three machining steps, where the first step is the bottleneck. The existing problem for first step of product "Y" is setup time too long. Four techniques of setup time reduction were introduced in this research which are Kaizen, just-in-time (JIT), single minute exchange of dies (SMED), and jig and fixture design. The differences between each technique were explained to decide the best method for setup time reduction. A high demand product was selected for setup improvement. The setup procedures were studied carefully and analysed to identify underlying problems of current setup. After the new jig fabrication, an improved analysis was conducted again. Few suggestions were proposed in order to simplify or eliminate the bottleneck procedures. Time study of redesigned jig showed that the machine setup time was improved. Objectives of this research were achieved by redesigning the current jigs and fixtures. Three recommendations for future research are proposed in the last section of thesis.

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LIST OF SYMBOLS / ABBREVIATIONS

CAD	Computer aided design
CNC	Computer numerical control
GA	Generic algorithm
JIT	Just-in-time
PSO	Particle Swarm Melkote
ROI	Return on investment
SMED	Single minute exchange of dies
TPM	Total productive maintenance

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the background of computer numerical control (CNC) machine, principles of jig design and examples of jig design. The problem statements are explained and objectives are stated.

1.2 Background of CNC machines

CNC is a term that describes the automation of machines that is operated by computer and the motion is controlled along multiple axes to carve out objects from the surface of raw material (Daniel & Kelly, 2009). In the early 1950s, the first NC machine was launched at Massachusetts Institute of Technology (M.I.T.), USA. From this beginning, CNC technology had a significant growth on the manufacturing field around the world (Newman et al., 2008). It advanced the operations and manufacturing flexibility from low capacity production to high capacity assembly, from micro- to multi-meter sized products and from soft to hard materials. Since the 1970s, CNC technology has evolved towards modern and reliable CNC machine with various capabilities such as milling, turning, laser cutting, drilling, grinding and water-jet cutting (Suh, 2001).

In machining, it is essential to ensure high quality of products as it will affect the properties of machined parts and manufacturing costs (Davim, 2001). Investment in CNC technology helps to improve product quality where the goal is to accomplish the coordinate geometry accurately and refining the cutting abilities (Watts et al., 2015). Sun et al. (2001) speculated that most manufacturers were willing to invest in CNC technology and replace their antiquated machines. Organizations that invested in CNC technology benefit significantly from improvement on production performances and competitive priorities compared to non-CNC user companies (Diaz et al., 2003). Industries lacking CNC technology will have fewer strategic alternatives and radically narrow their business areas. In other words, they fail to promote new capabilities and may affect their competitive advantages (Diaz et al., 2003). Gordon and Sohal (2001) stated that a firm with high investment in CNC technology shows better performance in its financial profit as CNC machines are able to produce goods with high accuracy, reliability and productivity (Jayendran, 2006).

Since the early 1980s, CNC merchants promoted programming standard, namely G and M codes formalized as ISO 6893 to program a cutting path (Newman et al., 2008). Firstly, the design of products will be converted into coordinates by using Computer Aided Design (CAD) software and stored in a CAD file. A new program will generate path codes through Computer Aided Manufacturing (CAM) software to control the type of motion of the cutter (Venkatesh et al., 2005). Other characteristics of CNC machines include changing of tools, tool chains and adjusting spindle speed and feed rate.

With the progress of time, the popularity of CNC machines is increasing in manufacturing industries. One of the reasons is the higher flexibility of machines in simplifying the setup procedures and improved operators' skill for controlling the machines. It enables the workpiece and machine tools interface from various angles and various speed and feed rate (Koc & Bozdag, 2006). Therefore, a CNC machine is able to conduct different types of operations economically, efficiently and effectively. CNC technology empowers an industry to adapt the rapidly changing markets and offers a shorter product cycle time by fabricating high quality products (Zhang et al., 2003).

1.2.1 Setup operations of CNC

For every CNC machine, the setup and machining operations are significantly different with each other but there are general common procedures for all. The setup steps included are interpreting machining scopes of the components based on the engineering drawing, identify type of material of the product, pre-setting the spindle speed and feed rate, loading jig and workpiece onto machine, and adjustment of position and height of workpiece (Koc & Bozdag, 2006).

For CNC operators, engineering drawing is the first or only source of information about what the final product is to be (Smid, 2010). Therefore, the first step is evaluating the features of engineering drawing and determining a method to machine the product. The outcome of this evaluation will decide the machining sequences which affect the product quality, total machining time and production costs. For most modern industries, the major problem is lack of people who can develop the solution of machining for example orientation of workpiece, machining sequences, cutting tools and workpiece clamping (Shin et al., 2007).

Next, the information of material should be identified by its type, shape, size and condition (Ward & Duray, 2000). The different types of material offer different levels of hardness and toughness. These properties would be considered by the programmer when selecting the cutting tools. The shape of raw material provides a parameter for design and selection of the jig and fixtures. Furthermore, the programmer will generate the CAM codes based on the size of material about the how much should be removed.

In order to fix and stabilize the correct position of workpiece, the preparation of part holding or jigs and fixtures, is needed so that the machine tool can performs the desired machining. When the workpiece is loaded onto the jigs, the datum point is selected by controlling an edge indicator using the geometry information of the workpiece and jigs (Kang et al., 2008). From an engineering point of view, jigs and fixtures are the most appropriate tools to clamp workpiece. When large batches of identical parts are produced, it is preferable to use the jigs and fixtures to reduce the setup time and increase the machine tool's utilization (Liqing & Kumar, 2005). Jigs and fixtures reduce the repeatability of choosing speed and feed, reduce high speed of movement between parts to be machined and increase utilization of tool changing system, thus lead to setup time reduction (Lagace & Bourgault, 2003).

1.2.2 Principle of jig and fixture design

Jigs and fixtures play an important role in manufacturing. Its function is to arrange the material in a definite position, so the machine tool is able to cut the required path on the workpiece (Liqing & Kumar, 2005). In most CNC production, the reference surfaces and preset datum point are designed onto the workpiece relating to its programming. With the assistance of jigs and fixtures, the cutting edge is specified relative to the surface of workpiece. However, the reference surfaces of jig might be used when it is relatively difficult to set the workpiece reference surfaces. In these cases, jig and fixture are considered as the referring coordinate path of machine (Kakish et al., 2000).

One of the common error sources in machining process is the failure in orientation of jigs and fixtures. It often manifests as clamping problems of the fixtures and deformation of workpiece and jigs. The jigs deformations are mostly caused by clamping and machining forces (Fallah & Arezoo, 2013). Researchers mainly focused on fixture structure in order to reduce these errors. Kaya (2006) proposed jigs and fixtures design by using generic algorithm (GA) to reduce the elastic deformation at different sections of the jig and workpiece under various forces. He presented the position and numbers of locators and clamps are the important design parameters for optimization of fixture layouts. One of the advantages of GA is it can be employed for a wide variety of problems in various industries. The major problem of applied GA is the difficulties in choosing the various parameters (Nalbandh & Rajyaguru, 2012).

Dagalakis et al. (2005) applied finite element analysis (FEA) to optimize locators and clamps arrangement and predict the occurrence of workpiece deformation when the jigs are used. It used a computer aided engineering software, Ansys to examine whether workpiece will break, wear out or machining according the path it was designed. This method is relatively low investment and offers a rapid calculation time for most simulations. However, it is still an approximate technique and highly dependent on computer for the calculations. Deng and Melkote (2006) optimized clamping force of jigs and fixtures by using Particle Swarm Optimization (PSO) technique. A forced vibration model was used to conduct stimulation about the dynamic machining conditions of fixture and workpiece where machining forces and speeds are vary during the process. The collected data helps to determine the optimum clamping force, and thus ensure the stability of jigs and fixtures. Compared with other improvement techniques, the calculation of PSO is simple, easy and had bigger optimization ability. However, PSO method always faced the problem in partial optimism as it affects the accuracy of simulation results (Rini et al., 2011).

Another error is known as fixture geometrical error which is the inaccurate orientation of the workpiece resulting in low quality of workpiece machining (Fallah & Arezoo, 2013). Many solutions for jig design to minimize the locators' error have been suggested in some cases, the jig errors wouldn't affect the workpiece features significantly and the parts might be machined in the tolerance range of dimensions (Marin & Ferreira, 2003). Raghu and Melkote (2004) explained the clamping sequence of jigs and fixtures will lead to wrong position of workpiece. They also studied how the fixture geometric error will affect the workpiece locating error. Qin et al. (2006) introduced a mathematical approach to analyse the effect of geometric errors on fixture position and orientation errors of the workpiece. They simulated a fixture model for investigating the possible fixture errors to improve product quality. Tian et al. (2001) investigated a feature-based approach in designing an optimum jig and fixture layouts. They suggested a best workpiece locating configuration to reduce the possibility of error resulted from the locating points of the workpiece machined. All the methods mentioned above are only to predict whether the locating of workpiece is feasible or not. The outcomes of these methods are frequently used to form an ideal jig design but don't dedicated recommendations about error compensation of the machined jig.

Zero deformation error is nearly impossible to achieve and subjected to deform since the jigs are always in direct contact with the surface of workpiece. The more feasible solution is repairing the jigs frequently to retain their original design and tolerances. The maintenance cost of jig, re-setup cost and other variable costs would be added in the machining costs (Vichare et al., 2010). For a good jig design, there will not be fixture error and the clamped workpiece is always located in a correct position and being machined according to program instructions.

1.3 Problem statement

The case study of this thesis is conducted in Company "X". It is a SME precision engineering manufacturer located in Ipoh. Their principal activity is to manufacture machine parts and components mainly used in harbour overhead crane parts. Company "X" is organized in a job shop layout and each products will undergo different processes referring to the customer requirements. One high demand product is "Y" which is the focus of this thesis.

Product "Y" is a major product of company "X" and its production operates daily. This product is consists of three machining steps, where the first step is the bottleneck. The existing problem for first step of product "Y" is setup time too long. Thus, different methods for improving the setup processes are sought after. Initially, two machines are allocated for "Y". However, this solution is not effective during peak season of customer orders as Company "X" needs more machines to support other products. Furthermore, a more experienced operator is assigned to conduct the machine setup of product "Y". Similarly, it is not a good solution since the result obtained does not shows a significant improvement on setup time. The last method is to buy a more efficient machine tool from different suppliers to simplify the setup procedure. This method does not offer a significant improvement and often, the new machine tool increases the setup time of product “Y”.

Generally, setup operations are ad-hoc and without any standard operation procedures. It depends on the experiences and skills of workers on the production floor. Company “X” realized that the lack of technical expertise is the major reason of longer setup time for product “Y” and had assigned their most skilled and conscientious workers to work on this product. During the setup process, the operator used too much time to load the jig onto the machine, and a lot of time consumed to adjust the location of workpiece while in contact with the jig. Due to the insufficient information in the jig design, the workers are unable to create a new jig and are forced to satisfy the current production with the existing jig.

Another problem of the current jig for product “Y” is related to geometrical errors on the positioning of the workpiece, which may results in inaccurate machining of the workpiece dimensions. In order to overcome this issue, the operator applied levelling and alignment techniques onto the workpiece. It is to ensure the workpiece was located in parallel and perpendicular directions to the jig and machine table respectively. Generally, the operator will repeat the levelling and alignment procedures twice to increase the accuracy of workpiece position. However, it is possible to have one instead of several procedures. Therefore, the proposed solution is redesign the machine jig to reduce loading time and improve levelling and alignment procedures.

1.4 Objectives

The objectives of this thesis are stated as following:

(a) To identify the underlying problems in the current jig design.
(b) To propose the new jig design that can solve the problem in objective 1.
(c) To fabricate a new machining jig based on the redesign drawing.
(d) To test the new jig and record the setup improvement in production.

1.5 Scopes

There is no analysis for mechanical testing to check the maximum force and deformation that can be sustained by the components of redesigned jig. The reason is the redesigned jig follows the standard jig design template in Company "X" that ensures the jigs are rigid and stable to support the workpieces' weight. Every jig and fixture is required to undergo maintenance (or replacement) after certain period of usage, and the period between maintenance is dependent upon the sustainability of the jigs. Additionally, the redesigned jig has minor changes in the design of locator, base plate and support but not a complete overhaul of the current design. Hence, simulation experiment is not required to be conducted to test the performance of the redesigned jig before the jig fabrication.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of several research that has taken place in relation to the current study. It introduces different techniques of setup time reduction in CNC manufacturing. Each of the techniques is explained in this chapter. Then, the advantages and disadvantages of each technique are also explained.

2.2 Kaizen

Manufacturing industries aim to improve productivity, enhance competitive advantage and retain market share through continuous improvement (Jagdeep & Harwinder, 2009). In any manufacturing facility, the types of activity were divided into three categories: value added, necessary but non-value added and non-value added, or called pure wastes (Poppendieck, 2002). Elimination of waste is one of the main concerns to maximize the profitability and overall performance of an organization. Taiichi Ohno, the Chief Engineer of Toyota identified seven classes of waste in 1978 (Koskela et al., 2013). These are over-production, unnecessary inventory, transportation, unnecessary motion, waiting, defects and over-processing. To become a lean organization, many tools were introduced with the purpose of eliminating the seven wastes and thus improving the utilization of resources.

Kaizen is a widely applied technique in different industries to promote continuous improvement in productivity, technology and quality. Kaizen is a Japanese word means “change for better” and the term was created by Masaaki Imai in 1970s. In fact, Kaizen concept originated in 1950s by Sakichi Toyoda, the establisher of Toyota Industries Co.Ltd.. Sakichi named this method as Toyota Production System for developing small and continuous change which leads to business growth and improvement achieved. Started from 1986, Kaizen philosophy was introduced to the globe and today, various firms implemented this concept in its production floor for ensuring continuous improvement (Brunet & New, 2003).

Kaizen concept not only increases machine productivity, but helps to fabricate high quality products with less efforts and values (Farris et al., 2008). One of the objectives for Kaizen is eliminate wastes in an organization through process improvement. It examines every detail of the processes from machine setup until finished product. It usually focuses on machine performance improvement such as decrease in setup time, elimination of wastes and reduction in machine breakdown. Therefore, problems can be easily determined at an early stage and solved by conducting brainstorming from top management to operators. As a result, Kaizen helps to enhance the teamwork, participation and empowerment of employees in an organization’s problem solving.

However, there are some difficulties faced by an organization when applying Kaizen methodology (Brunet & New, 2003). Firstly, Kaizen aims to make changes in production or management and it is difficult or may causes problems if the members are not ready to conduct the changes. For an organization that needs to implement Kaizen, it must be willing to accept changes as well as communicate it effectively with the employees. Secondly, Kaizen concept requires a long time to monitor and maintain after the implementation. Otherwise, all the changes and improvements may returns back to the old methods. In addition, it is difficult to change people’s attitude and mind-set to accept Kaizen philosophy that requires the involvement of all employees.

Burns (2000) reviewed Kaizen philosophy in the management of Weston EU organization, a manufacturing sub-contractor. The author started with internal and external activities analysis and described internal procedures as new setup time. Then, ECRS (eliminate, combine, reduce/rearrange and simplify) concept described as a Kaizen tool and used to make further setup improvement in 70 capital equipment CNC machines. After the implementation, the changeover time was reduced, customer orders for variety of products were fulfilled and the problems in machine loading were resolved.

Lee (2000) explained Kaizen approach at Nichols Foods, a product manufacturer for vending, food service and retail markets. The author used 5S (sort, set in order, shine, standardize and sustain) technique to develop continuous improvement strategy in the firm. Firstly, the work environment for the workers was cleaned and improved to prevent machine and equipment deterioration. Then, the author provided team training for motivating the workers to work hard and excellence. The result of this implementation shows a reduction in machine setup time, improvement in machine productivity and decrease in rejection of product quality.

Dehghan et al. (2006) researched a case study conducted by National Productivity Improvement Program (NPIP) in Chaharmahal-Bakhtiari Agriculture Firm. The authors described 5S and process improvement as Kaizen tools practiced for setup time reduction. The improvements included eliminating of work procedures and rearranging of workstation and tools. After implementing Kaizen, the machine setup time reduced by 16% and the movement of operator decreased by 11.7%.

Upadhye et al. (2010) implemented Kaizen at M/S TCL, a supplier of auto components in North India. The authors introduced SWOT (strength, weakness, opportunity, threat) analysis and SAP (situation, actor, process) analysis to maximize the firm’s strengths and eliminate its weaknesses to obtain the peak values of the business. Based on the information of the analysis, the author carried out brainstorming involving the employees on how to improve the weakness of the firm. For instance, workers suggested to add racks beside machine for keeping all necessary tools. As a result, the machine setup time was reduced from 10 hours to 5 hours and the wastes of motion were eliminated.

Rajenthirakumar and Thyla (2011) presented a Kaizen methodology to improve machine setup time and productivity in an automotive component manufacturer. The authors introduced brainstorming session to identify various non-value added procedures and determine various improvement methods. Next, the authors constructed simulation model to test the feasibility of each method. The authors decided to standardize the height blocks for machining by building materials to the fixture for easily fit with respective height blocks. As a result, setup time reduced from 46.92 minutes to 12.58 minutes and machine productivity increased by 32%.

Adams et al. (2014) explored the combination of Kaizen methodology and simulation model for setup time reduction in a high precision aerospace manufacturer. The authors presented that simulation can be used to predict and assess the outcomes of different methods for setup improvement. Based on the simulation result, the author found that the most efficient method is rearranging part handling and routing from workstation to storage. After the implementation, machine setup time reduced significantly and the travel distance of operator decreased from 1600 feet to 160 feet.

2.3 Just-in-time (JIT)

JIT was first implemented by Taiichi Ohno at Toyota Motor Company in the 1960s for controlling and monitoring the production processes to produce goods at high quality, right quantity and right time (Yavuz & Akcali, 2007). By conducting the JIT, Toyota encouraged the involvement of each individual for maximizing productivity and work efficiency to meet orders at the required time. Nowadays, most organizations apply JIT philosophy to reinforce its competitiveness in the global marketplace by improving productivity and eliminating wastes.

By implementing JIT system, the machine setup time can be reduced as it eliminated many wastes such as the waste of motion from workstation to storage area. Under JIT philosophy, the operators will only produce right quantity of products thereby results in low inventory level leads to minimize inventory holding costs. Similarly, low inventory of products can save more spaces of an organization. As JIT philosophy promoted the “right first time” theory, the product inspection and rework can be eliminated (Shah & Ward, 2002).

The main difficulty of JIT implementation is resistance of human nature to make changes. There are two common resistances: emotional resistance and rational resistance (Levary, 2007). Some of them had psychological feeling such as anxiety about what is going to happen after the changes. Besides, rational resistance happened when the employees received very less information to conduct the changes perfectly. As mentioned above, JIT required the involvement and commitment from top management until operators to produce and maintain the changes. In order to have success JIT system, the relationship between managers and operators is vital to maintain well.

As presented in the Toyota Production System, Kaizen and JIT were applied to achieve different outcomes (Ahmed et al., 2005). The main purpose of Kaizen is to enhance the job satisfaction, safety and work opportunity of employees. On the other hand, JIT aims to improve organization’s flexibility and process smoothness through several activities. Secondly, Kaizen is a strategy where requires the teamwork of employees to focus on continual improvement on their work standardization to improve the overall performances. JIT is a simple methodology to fabricate goods by pulling components based on customer demand instead of pushing components based on project demand. Therefore, it results the right parts were produced at the right amount and right time. Examples of lean tools based on the JIT manufacturing are: pull system, takt time, continuous flow and etc.

Schroeder et al. (2001) reviewed that the combination of JIT and Total Productive Maintenance (TPM) to reduce setup time through maximizing equipment effectiveness in an electronic manufacturing plant. The authors emphasized that a proper training for operator is important to reduce the production wastes and the time required for machine setup. Furthermore, the authors focused on equipment maintenance to eliminate wastes caused by equipment problems such as unnecessary setup and adjustment time during processing. After the implementation, setup time was reduced by 49%, production cost was decreased by 62% and machine productivity increased by 27%.

Fullerton et al. (2002) described a combination of JIT and TPM concepts in electronic manufacturing organizations to improve the firm's production performances. A training program was implemented by the authors to educate the operators became multi-function of different operation skills. It involved the importance of tools and equipment maintenances to reduce the frequency of machine breakdown, thus eliminated the waiting time during the setup procedures. The authors also explained the standardization of works in production floor helped to streamline elements of an advanced production flow. After the improvement, the frequency of machine breakdown was decreased by 67%, the machine setup time was reduced by 71% and the productivity was increased by 74%.

Ahmed et al. (2005) explained the JIT and TPM adoptions in Malaysian SMEs to improve machine setup time through eliminating wastes and performing preventative maintenance. The authors purposed to execute a training programme for operators about how to reduce manufacturing wastes and increase overall equipment effectiveness. One of the ways to improve equipment effectiveness is enhancing the knowledge and understanding of operators regarding the significance of equipment maintenance. Finally, the machine setup time reduced by 12% and productivity increased as the frequency of machine breakdown was eliminated from 53 to 21 times.

Doolen and Hacker (2005) researched a case study of JIT and TPM philosophies in an Italian manufacturer to enhance its competitive advantages. One of the improvement approaches is redesign the production lines to eliminate unnecessary wastes and reduce machine setup time. The authors promoted the involvement of top management and employees in a training programme to improve their empowerment and responsibility for equipment maintenance. Finally, the machine setup time was decreased by 59% and results in reduction of manufacturing cost.

Landry (2008) conducted the JIT implementation at electronic and electrical manufacturer in Hong Kong which faced problems with long machine setup time and low productivity. The author explained the best method for setup improvement is conducts as much of setup procedures as possible when machine is in operation. In addition, SMED methodology introduced in this case to separate the internal and external setup. It presented machine maintenance is important to reduce setup time, since the machine always available in a good condition. In the end, the machine setup time was decreased to less than 10 minutes.

Dowlatshahi and Taham (2009) studied JIT and TPM implementations at SMEs in India to eliminate wastes and reduce setup time. The authors described some setup time reduction methods, for example conduct preventative maintenance, form a professional setup team, documenting details of setup, allocating tools properly and recording complex setups by video capture. Besides, the authors emphasized the efforts and involvement of top management and machine operators are important to make success implementation. As a result, the machine setup time was decreased by 58% and production wastes were reduced significantly.

2.4 Single minute exchange of dies (SMED)

One of the common productivity improvement methods is SMED methodology, which reduces setup time from hours to minutes and thus increases productivity of a machine (Pellegrini et al., 2012). The first SMED method is invented by Shigeo Shingo (1950) at Toyo Kogyo’s Mazda plant in Hiroshima. He suggested to sort all the bolts and dies and placing the required tools in boxes to reduce the waste of motions. In 1969, Shingo visited Toyota Motor Company’s main plant and performed SMED to reduce setup time from four hours to three minutes. SMED continued to develop as one of the main elements of the Toyota Production System.

By implementing SMED, setup time can be minimized considerably even when number of setups increased. This resulted in small-sized production lots and contributed to low inventory level. As setup procedures are simplified, setup errors can be reduces and the elimination of trial runs lowers the incidence of components rejected. Other benefits include: increased product quality, simplified housekeeping and elimination of need for skilled workers. Traditionally, setup time was regarded as a fixed element in operation. As Shingo published that the setup time can be reduced dramatically, the believe that setup time is a variable and can be frequently improved is gaining confidence (Kumar, 2012).

According to Shingo's implementation, there are four conceptual stages involved in setup improvements (Kumar, 2012). The first stage of SMED is to collect and analyze the actual setup procedures in great detail. The second stage is differentiating between internal and external setup. There are two fundamentally different types of setup, inside exchange of die (IED) and outside exchange of die (OED). IED can be described as an activity performed only when a machine is stopped. OED is the activity conducted while a machine is in operation. The third stage is converting internal elements to external. It can be achieved by re-examining operations and then finding solutions to convert internal setups to external. The fourth stage is to streamline all aspects of setup operation by eliminating, simplify and reduce any step which considered as unnecessary (Sundar et al., 2014).

There are a few main challenges of SMED (Moreira & Pais, 2011). Firstly, the actual setup operations and workshop conditions needed to study in detail before implemented the SMED methodology. Otherwise, there may be mistakes on setup steps identification. Secondly, the distinction between internal and external setup is difficult but important to achieving SMED. The setup operations only can be streamlined once this two stages are completed.

Basically, SMED is a part of JIT manufacturing, but the difference between them is about the method of implementation (Pecas & Henriques, 2006). JIT is only a methodology to guide the production to fabricate products when they are needed. It suggested that machine and equipment maintenances are the major issues of setup time reduction. In turn, SMED is a tool with the purpose of minimizing machine setup time. It included four techniques of setup improvement and must be part of any setup improvement project. Therefore, SMED is the most efficient and simple way to reduce machine setup time compared to JIT manufacturing.

Kais and Kara (2007) conducted an implementation of SMED in a packaging organization which faced problems with high production lead times, extended customer order delays and high inventory levels. Besides the general procedures of SMED, the authors claimed that the machine maintenance, organization and workplace housekeeping are important elements to reduce setup time. This stage ensures that all parts and tools are where they should be and that they are functioning properly. As a result, the machine down time was decreased from 113.75 hours to 59.75 hours and production rate was increased from 17 to 44 rolls per month.

Kusar et al. (2010) reviewed that the combination of SMED methodology and improvements to the machines are most efficient for setup time reduction in a jet machine. The authors defined teamwork is vital in the execution of a SMED system. Team formation helps to develop strengths and manage weaknesses of a member, and so work with a higher contribution to the team. The SMED team consists of eight members with different roles: team leader, team moderator, setup operator, protocol writer, time recorder operator, photographer, cameraman and drawer of paths. In the end, total machine setup time was reduced from 119.97 minutes to 43.77 minutes.

Pellegrini et al. (2012) explained the application of SMED to reduce setup time in a CNC turning machine of a manufacturing company. After the SMED implementation, the authors recommended to build a “standard operating procedure” for every setup activity, and thus works can be standardized and make improvements effective over time. The authors conducted brainstorming ideas on how to streamline and improve both processes. By implementing SMED methodology, the machine setup time was minimized from 1 hour and 25 minutes to 47 minutes.

Adanna and Shantharam (2013) researched that a setup time reduction in an automobile equipment manufacturing organization by using SMED system. The authors defined the SMED methodology as ECRS for this implementation. ECRS process worked to eliminate unnecessary procedures, combine several processes to save time, reduce several activities and simplify complex processes. In the end, the firm reduced total setup time from 24.065 minutes to 14.416 minutes and machine productivity was increased by 65.38%.

Stadnicka (2014) explored the system of SMED used in a CNC turning lathe machine of a production company. The author combined SMED with risk analysis to identify which operation may cause the risk of elongating the setup time and the factors for low machine productivity. One of the risk analysis examples is failure mode effects analysis (FMEA) used after the setup procedure analysis and after the elimination of external activities. In addition, the author involved setup standardization to reduce the repeatability of processes. After the SMED system, the distance movement of operator was shortened from 110 meters to less than 15 meters. The setup time reduced from 1 hour 12 minutes to 44 minutes which is equal to 38% time saving.

Che Ani and Shafei (2015) reviewed SMED methodology to eliminate the high changeover time during changing model in a CNC facility. The authors introduced a conventional process, Plan-Do-Check-Act (PDCA) cycle that can be worked with SMED method to get from “problem-faced” to “problem-solved”. It is an iterative checklist of four steps from defined problem, executed plan, measured outputs and lastly revised the plan. Furthermore, the authors purposed to use working instruction and drawer tool cabinet to minimize setup errors and unnecessary movements. Finally, the machine productivity was increased from 93% to 95.6% and setup time reduced from 4 hours 9 minutes to 2 hours 58 minutes.

2.5 Jig and fixture design

Jigs and fixtures are the essential tools which are used to facilitate manufacturing repetitive components within defined tolerances. Generally, it is designed to fabricate large batch size of identical parts and ensuring interchangeability of products. Jig is a work holding tool that supports a workpiece and gives a direction to cutting tool for the desired manufacturing operations (Nanthakumar & Prabakaran, 2014). A fixture similar to a jig, the difference is fixture does not guide a cutting tool for the operations (Kaija & Heino, 2006). Fixtures will only provide a reference surface to the workpiece and each fixture is built only for a specific product.

Jigs and fixtures decrease machine setup time and increase productivity by reducing the tasks of marking, orientating, alignment, levelling and setting for each workpiece. The high precision of jigs and fixtures design facilitates the production of large batches of products with high accuracy of dimension and high quality. Furthermore, jigs and fixtures are used to standardize the setup procedures and thus unskilled or semi-skilled machine operator can easily use the fixtures. By using jigs and fixtures, some heavy and complex design of parts can be readily machined after clamping. From all the listed advantages above, it leads to the reduction of labour cost, rework and product inspection.

When implementing SMED tool, the converting of internal to external setup is the most important stage to reduce machine setup time significantly. In other words, SMED implementation will considers as an unsuccessful activity when the conversion stage is fails. Next, SMED is difficult to apply when all steps of the current process are external setups. Thus, jig and fixture was introduced as a tool to eliminate internal setup and further reduce external setup time. In addition, SMED required a long period of time to conduct the four conceptual stages whereas jig and fixture is always designs according to the workpiece structure, clamps and supporters (Joshi, 2010).

Hunter et al. (2005) described the process of machining jigs and fixtures design to reduce machine setup time. The authors claimed that jigs and fixtures are used to standardize the setup procedures as it eliminates the errors of personal marking, orientating and often checking. The five stages of design are: identify skills required for fixture design, define the functions and uses of fixture, design fixture based on requirements, creation of detailed fixture design, and test and evaluate the fixture design. In the end, the machine setup time was reduced by less than 50% and product quality improved.

Joneja and Chang (2010) explained the fixture planning and design to reduce the time and number of setup for manufacturing prismatic structures. The authors declared that the setup, sequences and fixture planning are correlated. It started from selection of tools to avoid the collision between fixture and tool path and then decided the sequences of setup and operation. Lastly, a fixture was constructed based on the geometry coordinates and orientation of workpiece. All of these procedures give a standardization of setup thereby the process can be simplified and machined setup time can be minimized by less than 50%.

Timasani et al. (2011) conducted the implementation of quick change jaw and fixture concept to reduce setup time considerably in a turning centre of an Indian SME. This concept is described as a fixed jaw or base plate connected to the body of chunk or onto the machine table and a moveable jaw is always changed to accommodate the different products. Thus, it is able to minimize the replacement of whole chunk or fixtures for different products. By implemented the new design, the average machine setup time reduced from 108 minutes to less than 16 minutes and the unnecessary wastes eliminated by 40%.

Zhou et al. (2011) presented the jigs and fixtures design techniques to produce large-sized and complex aircraft components in an aircraft structural parts manufacturer. The author explained jigs and fixtures are the easiest approach for machining a heavy and complex part to shorten setup time. The design processes consist of three stages, which including setup planning, fixture planning and fixture configuration design. It started from identification of workpiece’s orientation, understanding the tasks for each setup, followed by determining the clamping and locating points on the workpiece. Lastly, a set of fixture with clamping devices, locating devices and base plate is produced. After the implementation, the machine setup time was decrease by 90% and the complex structures were machined easily.

Pattantyus (2013) implemented the jig design and shadow board techniques to reduce setup time in a manufacturing firm. Before the improvement, the operators used much time to set and cut different standard dimension of bar stock and each of the stop distance is measured by measuring tape. Then, the author built simple jigs with standard cut dimensions to simplify the setting process. Furthermore, a shadow board was designed to store all the jigs, thereby eliminating the waste of motions to get the setup tools. As a result, the productivity was improved as a consequence of reduction in setup time.

Okpala and Okechukwu (2015) reviewed the importance and elements of jigs and fixtures in manufacturing operations in order to reduce machine setup time. In the structures of jig and fixture, clamping and locating devices are the major concerns of design because both are controlling the right orientation of workpiece. Clamping devices used to apply pressure and hold the workpiece against the locating devices, and thus fix it in the right direction for the cutting tool. The locating devices such as pin and supporter, are designed to easily locate the orientation of workpiece. The authors emphasized that jigs and fixtures are used to minimize the tasks of dimension checking, orientating, marking, punching, levelling and alignments. Therefore, the machine setup time can be reduced.

Table 2.1: Practices or techniques associated in setup time reduction

Setup Tools	Practices	Kaizen literature						JIT literature						SMED literature						Jig & fixture design literature					
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Kaizen	SWOT				√																				
Kaizen	SAP				√																				
Kaizen	Simulation					√	√																		
JIT	TPM							√	√	√	√		√												
SMED	Machine maintenance											√		√											
SMED	Team formation														√			√							
SMED	SOP															√									
SMED	PDCA cycle															√			√						
SMED	FMEA																	√							
Jig & fixture design	Setup planning																				√		√		
Jig & fixture design	Quick change jaw & fixture																					√			
Common	Organization & housekeeping				√		√							√					√					√	
Common	Brainstorming				√	√										√		√							
Common	5S		√	√												√		√							
Common	ECRS	√															√								
Common	Standardization					√		√	√									√		√	√	√	√	√	√
Common	Process improvement			√							√														

References: (1) Burns (2000); (2) Lee (2000); (3) Dehghan et al. (2006); (4) Upadhye et al. (2010); (5) Rajenthirakumar and Thyla (2011); (6) Adams et al. (2014); (7) Schroeder et al. (2001); (8) Fullerton et al. (2002); (9) Ahmed et al. (2005); (10) Doolen and Hacker (2005); (11) Landry (2008); (12) Dowlatshahi and Taham (2009); (13) Kais and Kara (2007); (14) Kusar et al. (2010); (15) Pallegrini et al. (2012); (16) Adanna and Shantharam (2013); (17) Stadnicka (2014); (18) Che Ani and Shafei (2015); (19) Hunter et al. (2005); (20) Joneja and Chang (2010); (21) Timasani et al. (2011); (22) Zhou et al. (2011); (23) Pattantyus (2013); (24) Okpala and Okechukwu (2015)

2.6 Findings of literature review

This review shows Kaizen is the most common tool of setup time reduction. There are many research conducted based on the Kaizen philosophy to improve their overall production performance. This concept is widely used by most of the manufacturing industries because (1) it can be implanted to any improvement process, (2) it required less investment in equipment or facility to achieve the desired outcome and (3) it involved each employee in process of change. Moreover, jig and fixture design is the least employed method to minimize machine setup time. In the past, there are few study performed which relates to jig and fixture design for the purpose of reducing setup time. The reasons are (1) jig and fixture may difficult to design for complicated process, (2) it only valid to use for certain product and (3) extra raw materials and times are required to fabricate a jig and fixture.

As mentioned in the previous sections, the main focus of Kaizen is to improve employee performances for solving various organization problems. JIT promoted "right first time" concept to eliminate waste of motion of operator, so the machine setup time can be reduced. Between the two methods, JIT is better to apply in setup time reduction. On the other hand, SMED is a tool that clarified with four important techniques to perform in any setup improvement projects. Thus, SMED is more efficient to minimize setup time compared to JIT. Sometimes, SMED is fails to implement when the whole setup process is consists of external setups. Then, jig and fixture is a more useful tool compared to SMED as it can eliminates internal setup and further reduce external setup time.

Compared to jig and fixture design, Kaizen is less effective to reduce machine setup time. In all the Kaizen literature, it only build a concept of "change for better" but does not include any specific techniques or methods for setup improvement. Jig and fixture is a solid body to simply and standardize the setup processes and easier to use by operator. Secondly, Kaizen is difficult to implement since it always encouraged top management and employees work in a team and conduct brainstorming to solve problems. For jig and fixture, few of employees are only required to involve in the design process. In addition, Kaizen is an extremely time-consuming method as a long time required for monitoring and maintaining after the implementation. By implementing jig and fixture, a significant improvement can be obtained immediately as the setup process is simplified.

Similarly, the involvement of employees is the main difference between jig and fixture design and JIT. With a jig and fixture implementation, it can save a lot of times and also avoids to get into a heated argument between top management and operators. Furthermore, the setup improvement methods that proposed by JIT are eliminate waste of motion and perform machine maintenance. These methods may not applicable for some industries if there is no waste of motion or machine performance is maintains well. Therefore, jig and fixture is better than JIT since it works directly with a workpiece and has a high flexibility in design based on the workpiece structure.

In fact, Kaizen, JIT and SMED are difficult to achieve a significant improvement if jig and fixture is not used in the manufacturing process. The primary premise of setup time reduction is designs a special tool to simplify or eliminate any unnecessary setup steps. Kaizen, JIT and SMED focuses on the elimination of raw materials and tools preparation process. For jig and fixture, it started with a study of workpiece structure to determine the best way of setup and machining processes. It functions to position and fix the orientation of workpiece to make the workpiece adjustment easier and simplify the setup procedures.

Among the four setup methodologies, jig and fixture design is the most efficient method for machine setup time reduction. Firstly, it is more simple and cost-effective to invest in the entire production process. This method does not required high involvement of all employees, whereas the design of jigs and fixtures are fully depend on the sequences of operation and capacity of that machine. The design considerations of jig and fixture are referred as guidelines during the design process and thus making the jig and fixture less costly.

Meanwhile, jig and fixture is the best tools in mass production to maintain a low product rejection rate due to high and uniform quality of goods are produced. Since the product quality is consistent and maximized, the inspection activities can be eliminated and high amount of time was saved. Furthermore, use of jig and fixture make a high standardization and efficiency of work and thus setup procedures were simplified. Next, jig and fixture offers a good and easy way for operator to position a workpiece onto the machine in minimum time.

CHAPTER 3

METHODOLOGY

3.1 Introduction

As shown in Figure 3.1, this research started with literature review. Important theories and relevant findings were studied and summarized. The research framework was developed based on a case study in Company “X”. A high demand product was selected for setup improvement. Definition of target setup time gives an encouragement to conduct improvement. The setup procedures were studied carefully and analysed to identify underlying problems of current setup. Some of the processes were eliminated by redesign the existing jigs and fixtures. After the new jig fabrication, an improved analysis was conducted again.

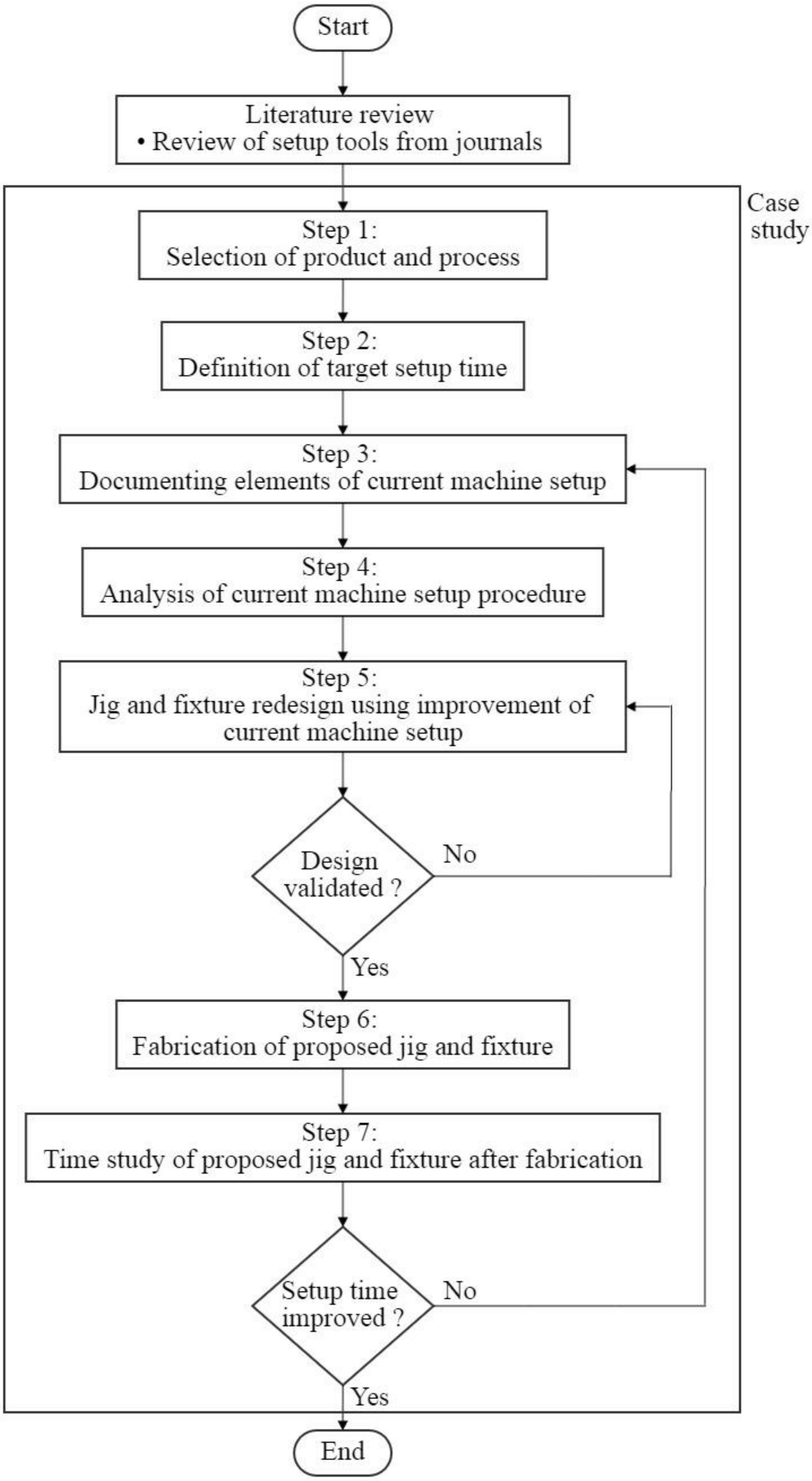


Figure 3.1: Flow chart

3.2 Selection of product and process

In the first stage, a product was selected for reduction of machine setup time by considering the predefined criteria such as longest machine setup time, high demand product, frequency of setups and bottleneck of processes. A short period of observation (1 week) was carried out to define the products which have long setup time (more than one hour). Next, the first three highest demand products were chose from the defined items. From these three items, a product with largest frequency of setup (per day) was selected as the focus of this thesis. If the final selected product is consists of more than one machining steps, the bottleneck of processes was determined based on the setup time of each step. From the result of observation, this research focused on a reduction of setup time for first machining step of product “Y”. The reasons for this selection are: longer setup time, one of the high demand products for Company “X” and first step is the bottleneck of processes.

3.3 Definition of target setup time

Kusar et al. (2010) described that the definition of target setup time is important and it acts as a motivation for the implementer to perform a better setup improvement. Generally, manufacturing industries required their employees to eliminate the machine setup time by 50% of current value during the first round of implementation. From the basic steps in setup procedure, the 50% of total setup time is belongs to the trial runs and adjustments operation. The length of this operation depends on the skill of operator to adjust the equipment accurately. Therefore, the proportion of time for this operation is easier to minimize by increasing the precision of the equipment. In this research, the target time needed for setup can be reduced by 25% to 50% of the current setup time.

3.4 Documenting elements of current machine setup

After determining the target time, a time motion study was conducted on the current machine setup process. The sequences and exact time required for each setup step are identified and measured. A list with the details of setup procedure is a common tool for recording the sequences and execution time of machine setup. All the elements and microelements of setup are listed in the notes, which include the actual sequences of the machine setup with the exact time needed. After recording the elements of setup, the data will be arranged into the monitoring paper. The monitoring paper is a form that contained all the necessary information for assessing and controlling the current machine setup. The data included the sequence number, a brief description, individual time and histogram of task times for each machine setup step.

After the time study, a motion study was conducted to define wastes of motion of machine setup operator. A list of paths is prepared based on the floor plan of workplace. The movements of the operator during setup are drawn onto the list of paths with a continuous line. According to the continuous analysis of machine setup elements and the list of paths moved by setup operator, all the unnecessary movements can be eliminated and created a new motion path. Then, a high-definition camera was used to take photos of machine setup procedure in detail. The photos helped to visualize the actual setup process instead of words.

An additional tool is a video camera, to videotape the entire machine setup. The film started to record at the beginning of first setup procedure until the end of last process. Therefore, the whole setup procedures can be reviewed several times and analysed effectively. The video film was shown to the operators for providing them an opportunity to point out their opinions which lead to useful suggestions. In many cases, these suggestions can be adopted on the spot.

3.5 Analysis of current machine setup procedure

In this section, the current machine setup operation was analysed and discussed. Product “Y” is consists of three machining steps, where the first step is the bottleneck among the others. Based on the data collected, the total setup time for product “Y” is 1.65 hours and all the time consuming procedures are related to the available jig and fixture. The setup steps are involved: machine cleaning, load and position jigs onto the machine, lifting workpiece onto the jigs, conduct levelling along z-axis, alignment along x and y-axis and set a centre point of workpiece.

The highest time consumed in current setup method is loading and adjusting the distance between two pieces of jigs onto the machine table to fix the position and height of the workpiece. After the jigs loading, the operator conducted workpiece levelling in z-axis direction and ensured the correct alignment along x and y-axis positions. This process repeated several times until the workpiece was located correctly. All the steps listed above are potentially to simplify or eliminate in this research.

The suggestion for a new jig and fixture is consists of four locators and four clamps, and each locator is placed nearby the clamp. Since there is no changing part of the jig, all the components are welded on the base plate according to the dimensional requirements. Due to the locating problem of jig on machine bed, step clamp, step block and flange nut were used to clamp the jig in a precise location onto the machine table.

3.6 Jig and fixture redesign using improvement of current machine setup

Before started the redesign process, there are a lot of design considerations in jig and fixture. The main structure of jig and fixture must be strong and tough to withstand the clamping force and machining vibrate, so that prevented the deformation of jig and fixture. It suggested that the jig and fixture can be constructs from simple sections, and then connected the parts with welded or screws. If the parts are constantly fastened with the jig, it may be welded, otherwise, the parts can be screwed onto the jig for frequent removing.

The main design consideration in clamping components is the capability to resist the forces developed vibration during the machining process. In addition, the position of clamps should be located nearby the strongest clamping force, which is the supported part of workpiece. If the clamping works on unsupported part, the workpiece will be bends and influences the accuracy of workpiece dimension. Basically, the locations of clamps are not designed to hinder the path of workpiece loading and unloading.

Locating elements are described as placing the workpiece correctly with respect to dimensional requirements of the workpiece. Firstly, the locator was designed by considering the easiest way to load and unload workpiece with minimum movements and efforts. After loading the workpiece onto the locators, it is securely engaged with clamps to ensure no motion around and along x, y and z-axis. In order to make the setup easier, redundant locator is avoids to build onto the jig and fixture. Redundant locators are locators provided are more than the number of locators required. In this research, the new jig and fixture was redesigned by referring the considerations listed above.

3.7 Validation of jig and fixture design

Before fabrication of new jig and fixture, the proposed design was verified and validated by the supervisor of “Company X”. Firstly, the supervisor reviewed the drawing of jig and fixture to examine the dimension of structure with high accuracy. Next, the 2D drawings of jig and workpiece are combined by using AutoCAD to test and ensure all the locators and clamps are not obstructed the machining path of workpiece. Thirdly, the strongness and toughness of each component in jig and fixture were checked based on its thickness or diameter. This is to ensure the redesign structure is capable to resist clamping force and machine vibration. Lastly, the new jig and fixture must be validated in each machine (either in horizontal or vertical direction of machine bed).

3.8 Time study of proposed jig and fixture after fabrication

According to the AutoCAD drawing generated in the previous stage, the new jig and fixture was fabricated through CNC machining, assembly and welding processes. To be success in the new jig and fixture, a precision tolerance detailed machining is required for the entire fabrication process. By using the redesigned jig and fixture, a time motion study was performed on the improved jig and fixture to measure the degree of improvement. All the tools stated in 3.4 were used to record the details of improved machine setup.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The background information and uses of product “Y” were explained in the first part of this chapter. Next, the current setup and machining processes were presented. The setup processes were analysed and few suggestions were proposed in order to simplify or eliminate the bottleneck procedures. In this chapter, the function of each component in the redesigned jig was discussed. Five considerations in validating the redesigned jig were listed and explained. Time study of redesigned jig showed that the machine setup time was improved. Lastly, the time required for return on investment (ROI) was determined.

4.2 Setup process of product “Y”

“Y” is a component of crane spreaders, welded at the top and middle of its main body. After assembly, the spreaders are put into services to handle shipping containers. One example of its usage is in the lifting arm of a Kalmar reach stacker forklift (Figure 4.1). This equipment effectively solved cargo handling problems and is use in terminals, ports, heavy industries and distribution centres. The function of “Y” is designed to improve the flexibility and increase driving efficiency of a reach stacker forklift. It helps to rotate and tilt a container for easy and quick handling in any situation. Therefore, the forklift has the smallest turning radius in the facility for better manoeuvring in narrow spaces.

Figure 4.1: Kalmar reach stackers forklift *(from www.gs-limited.net)*

The spreader can be rotated in any direction since a gearwheel is connected between “Y” and the body of spreader (Figure 4.2). Then, a container can be rotated and shipped lengthwise to transport it into and through cramped spaces (Figure 4.3). In Figure 4.4 and 4.5, dual motors are attached on “Y” to supply energy and gears are installed at the bottom of motors to control the movement of spreader rotation. The head mounting of “Y” is linked with the lifting arm to tilt the spreader at an angle to the side (Figure 4.4). Referring to Figure 4.6, the tilt feature enables easy container loading for the convenience of operations.

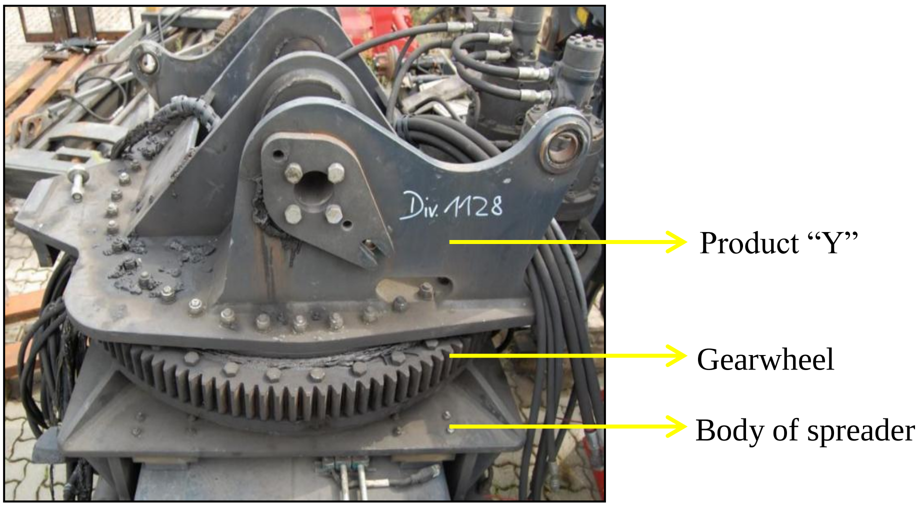


Figure 4.2: Side view of product “Y” *(from www.hinrichs-forklifts.com)*

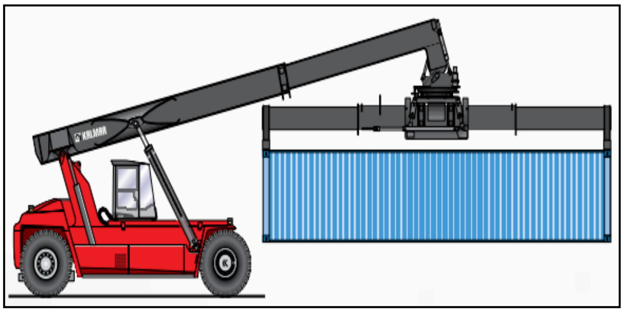


Figure 4.3: Example of container rotation *(from www.kalmarglobal.com)*

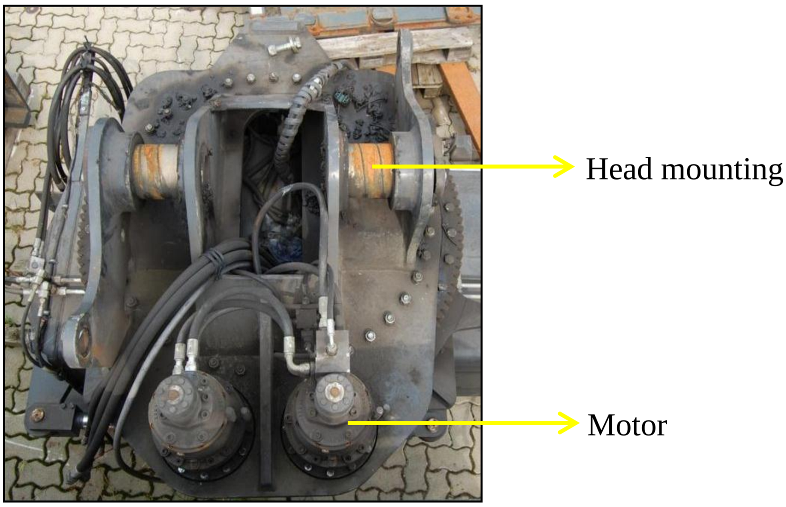


Figure 4.4: Top view of product "Y" *(from www.hinrichs-forklifts.com)*

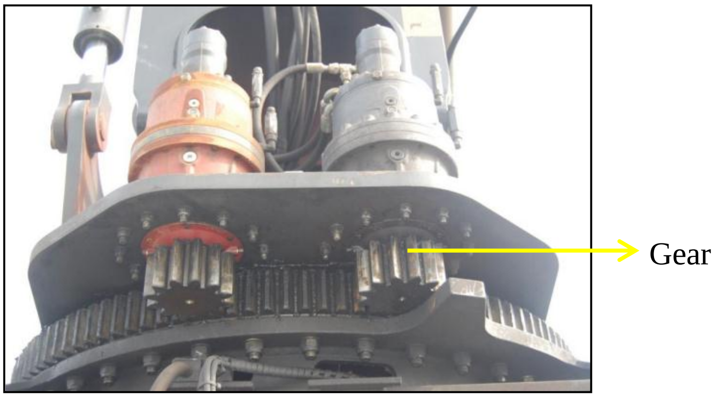


Figure 4.5: Bottom view of dual motors *(from www. hinrichs-forklifts.com)*

Figure 4.6: Lilt container at an angle *(from www.kalmarglobal.com)*

In Company "X", "Y" is a high demand product. The production operated 8 hours/shift, 2 shifts/day, 6 days/week and 45 weeks/year. From the past records, the average monthly demand for product "Y" is 20 units and the current daily production rate for a completed "Y" is one unit. In theory, if the product consists of more than one manufacturing operation, the batch size is minimized as small as possible to avoid scheduled delay at the next process. Therefore, the setup frequency becomes higher as batch size is reduced. As the total required processing time for a completed "Y" was 11.15 hours, the minimum frequency of setup is one per day, in order to meet the customer demand.

To have a finished product "Y", three machining steps with different procedures are required. The machine that is used to produce "Y" is called Agma Six Meters Double Column Machining Centre (Figure 4.7). The size of the machine is 6200mm length and 2800mm width. In Step 1, the setup processes consist of cleaning machine, loading and positioning two pieces of jigs onto machine, lifting workpiece, levelling along z-axis, alignment along x and y-axis and setting a centre point of workpiece. The average setup time required for this step was 1.65 hours. For Step 2 and 3, the setup processes are similar but different types of jig are used. The processes included: cleaning machine, loading and positioning jigs, lifting workpiece and setting a centre point. The setup time for Step 2 was 1.22 hours and for Step 3 was 1.03 hours.

Figure 4.7: Machine operated for processing “Y”

In setup of step 1, the bottleneck procedures are loading and positioning the jigs, workpiece levelling and alignment in different axes. For the process of jigs positioning, the operator measured and maintained a constant distance between the two pieces of jigs to support the corners of “Y”. During the levelling and alignment procedures, the operator repeated the measurements several times in order to have a correct position of the workpiece. The overall setup time of these three procedures was 0.87 hour. In step 2, the procedure with longest setup time was loading and positioning the jigs. Similarly, a distance was measured and adjusted as two pieces of jigs were used in this step. The time that consumed in this process was 0.42 hour. For step 3, the largest setup time procedure was workpiece positioning which used 0.33 hour to ensure a right orientation of workpiece. In this process, the operator spent a lot of time to screw 12 pieces of flange nuts to the clamps onto the jig.

The machining processes for Step 1 involved: surface milling, boring, point marking, drilling, chamfering and tapping. The average machining time was 3.25 hours. For Step 2, the processes included drilling, roughing and boring. This step was spent 2.67 hours for machining. The process of Step 3 is milling 2 slots of Ø280mm, and it takes 1.33 hours to complete the machining.

In summary, the setup time percentages of total processing time per unit are 14.8% for Step 1, 10.94% for Step 2 and 9.24% for Step 3. The highest percentage and largest processing time in Step 1 indicate that this stage is the bottleneck of processes and having longer setup time compared to Step 2 and Step 3. All the data are summarized in Table 4.1.

Table 4.1: Average time required for each process of product "Y"

Step	Average Setup Time, T_S (hours)	Average Machining Time, T_M (hours)	Average Total Required Time, $T_P = T_S + T_M$ (hours)	Percentage of Setup Time per Unit, ($\frac{T_S}{T_P}$ X 100%)
1	1.65	3.25	4.90	14.80 %
2	1.22	2.67	3.89	10.94 %
3	1.03	1.33	2.36	9.24 %
Total	**3.90**	**7.25**	**11.15**	**34.98%**

4.3 Target setup time reduction

Referring to section 4.2, there are three bottleneck procedures in Step 1 and both show potential to be modified by redesigning the jig and fixture. In the current setup, two pieces of jigs are used and are involved in all the steps. By redesigning the structure of jig, the improvements can be significant. Firstly, the jigs positioning process can be simplified by reducing the number of jigs to one piece. Therefore, the jigs loading time can be decreased from 0.4 to approximately 0.2 hour and eliminate the distance adjustment step between the two pieces of jigs. Secondly, the levelling and alignment processes can be streamlined by designing additional locators. The new locator acts as a reference point for operator to place the workpiece in parallel or perpendicular position corresponding to the machine table. Thus, the setup time for levelling and alignment processes can be reduced from 0.47 to approximately 0.24 hour.

Table 4.2: Target value of setup time reduction

Procedures	Current setup time (hour)	Target setup time (hour)	Time reduced (hour)
Loading and positioning jigs onto machine	0.40	0.20	0.20
Levelling along z-axis	0.27	0.14	0.13
Alignment along x and y-axis	0.20	0.10	0.10
Total	**0.87**	**0.44**	**0.43**

By completing the listed improvement methods above, the overall setup time is estimated to reduce from 0.87 hour to 0.44 hour. By applying some simple calculation, the minimum percentage for reduction is 26.06% of the current setup time. In this research, the target is set to reduce setup time by 25% to 50% of current value.

Average current machine setup time = 1.65 hours

Minimum percentage of setup time reduction = $\frac{0.43}{1.65}$ X 100%

= 26.06%

4.4 Elements of current machine setup

During the time motion study, all setup tasks are listed according to its sequences and the exact time are recorded. Since all the machines operated in Company “X” are semi-automated, the time required for each process may vary when operated by different people. A total of eleven (1 set from initial observation and 10 sets for calculating the mean setup time) data sets were collected to increase the tendency to cluster around a certain value. Then, the mean and standard deviation of each setup process were calculated and listed in the monitoring paper (Table 4.3). Mean serves as a central value for all data collected. Standard deviation shows the degree of dispersion of the data from the average. As shown in Table 4.3, the alignment process has the highest dispersion or variability in its setup task time. This is followed by machine cleaning and jigs loading. An example of eleven data for alignment process was shown in Chart 4.1.

Table 4.3: Average time required for each setup procedures

MONITORING PAPER			
No.	**Description**	**Mean setup time (hour)**	**Standard deviation (hour)**
1	Machine cleaning	0.37	0.10
2	Loading and positioning jigs onto machine	0.40	0.09
3	Lifting workpiece onto the jigs	0.25	0.07
4	Levelling along z-axis	0.27	0.07
5	Alignment along x and y-axis	0.20	0.11
6	Setting centre point	0.16	0.06

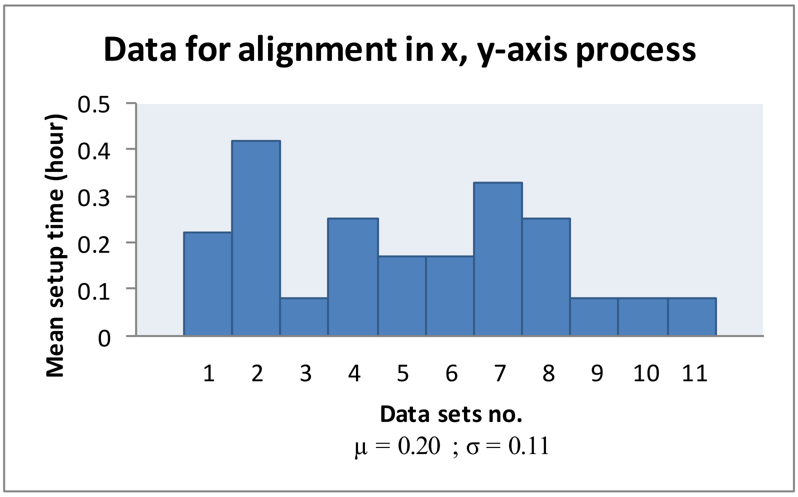


Chart 4.1: Histogram of setup times for alignment process

At the first stage of setup, the operator cleaned the machine (i.e.: removing metal chips from previous machining process). The operator used a minimum 0.25 hour to clean up the machine. The average setup time for first task was 0.37 hour.

The second stage of setup is loading and adjusting the jigs onto the machine bed. The current jigs consist of two parts which are the left and right support of the workpiece. As shown in Figure 4.8, the jigs were located opposite the machine operated (Machine 12). The letter "A" is indicates the location of placing the unprocessed product "Y". Referring to path 1, the operator walked from Machine 12 to the location of jigs after cleaned machine. An electric lifting equipment was used to hold and transfer the first piece of jig onto the machine table (Path 2). For path 3 and 4, the operator repeated the movement of path 1 and 2 to transfer the second piece of jig onto the machine bed. Before placing it onto the machine table, one pair of key slots was removed from each piece of jig based on the direction of machine bed (Figure 4.9). The other pair was used for slotting the jigs onto the machine table and ensured that both jigs were placed in parallel (Red rectangle in Figure 4.10). After loading, the operator measures and adjusts the distance between the two jigs at 890mm in order to position the workpiece correctly onto it (Figure 4.10). The average time spend in this process was 0.4 hour.

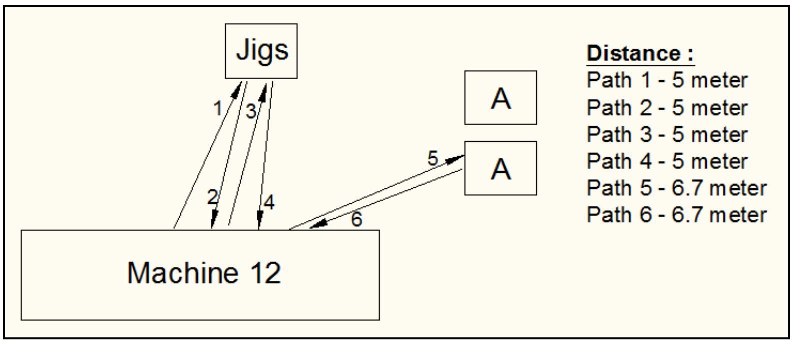


Figure 4.8: List of paths and distances made by setup operator

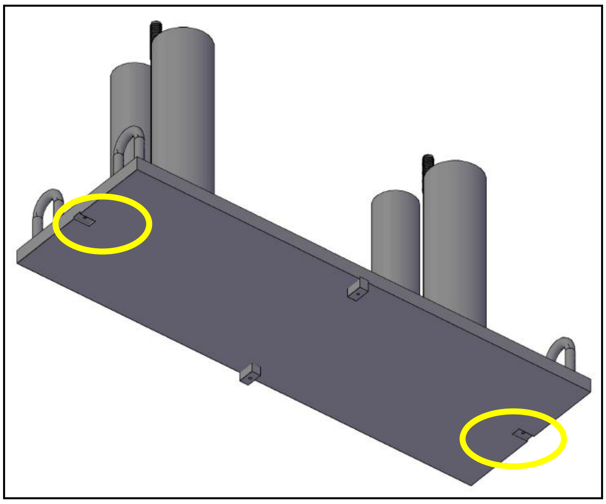


Figure 4.9: Removed one pair of key slots

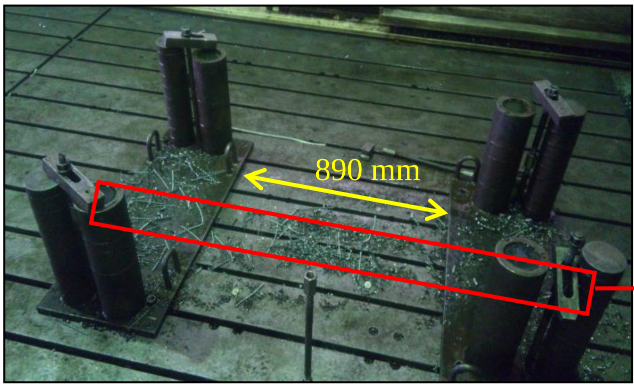


Figure 4.10: Arrangement of jigs onto the machine

The third stage is loading the workpiece by lifting equipment and placing it onto the jigs (Figure 4.11). Referring to Figure 4.8, product “Y” is placed beside the machine operated (Machine 12). After the jigs loading and distance setting, the operator moved from machine to the placement of “Y” (Path 5). The path 6 indicated the movement of workpiece transferred from its original place onto the machine. Four pieces of step clamps and flange nuts were tightened to the clamps around the corners of jigs. For the first round of workpiece clamping, the nuts were not tightened fully in order to adjust the correct position of workpiece during the levelling and alignment procedures. For this stage, the average setup time was 0.25 hour.

Figure 4.11: Placement of “Y” onto the jigs

The fourth stage is to conduct workpiece levelling along the z-axis for checking the surface flatness of bottom plate of “Y”. The purpose of levelling is to minimize the distortion effects of preceding processes for improving the positioning accuracy of workpiece. To form a completed structure of “Y”, a lot of components were welded together according the required dimensions (Figure 4.12). When a material or part is cut or assembled by any thermal processes, it will cause temperature difference within the workpiece and leads to thermal distortion at its surface as the workpiece cools (Figure 4.13). Thus, the workpiece will not be perfectly flat. A dial indicator was used to conduct flatness measurement. The uses of flatness measurement are divided into two categories: positioning and resurfacing of workpiece.

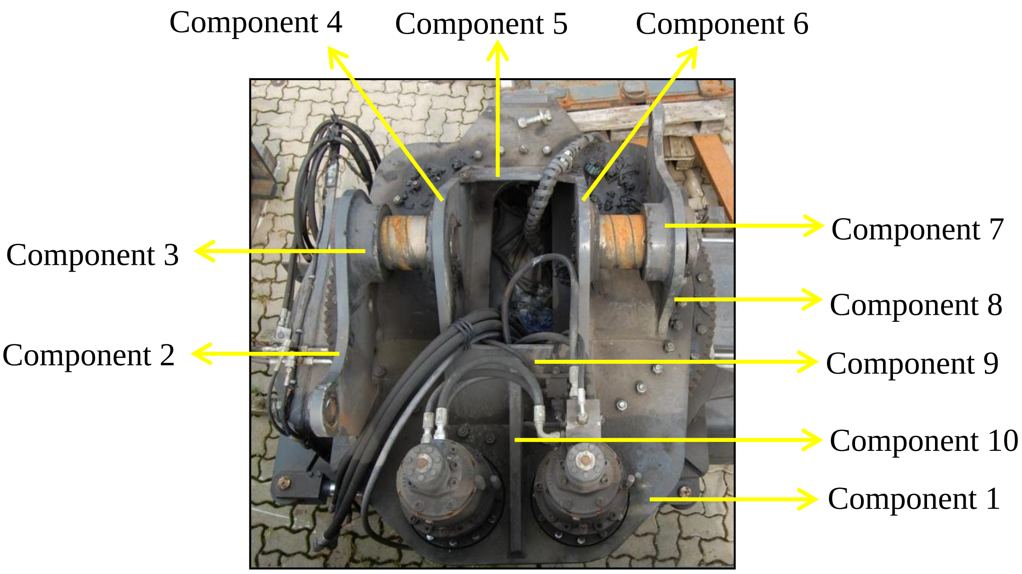


Figure 4.12: Components to form a “Y” *(from www.hinrichs-forklifts.com)*

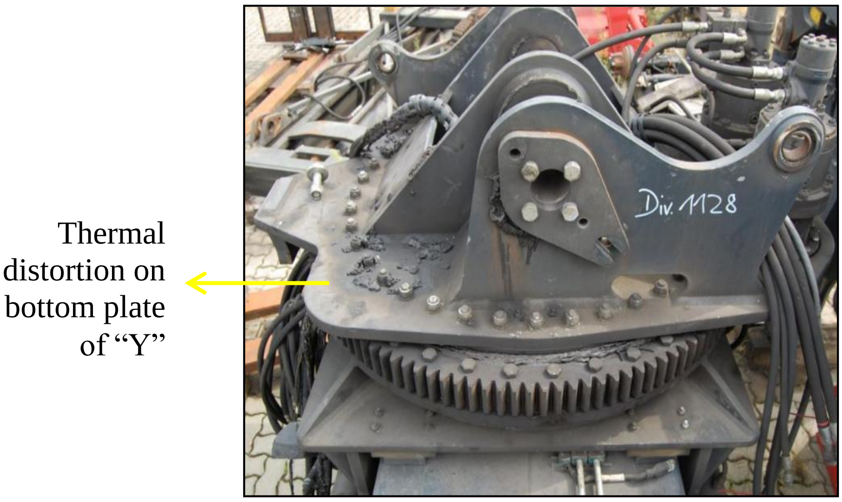


Figure 4.13: Occurrence of thermal distortion *(from www.hinrichs-forklifts.com)*

Before starting the flatness measurement, a reference point (0.00mm) was located and regarded as a perfectly flat surface of workpiece (Figure 4.14). For the process of workpiece positioning, the operator measured few points of the outer area on the workpiece and compared these points (-0.10mm) with the reference point (Figure 4.15). Next, the screws or nuts were tightened to clamps until reached the maximum allowable reading (0.00mm) (Figure 4.16).

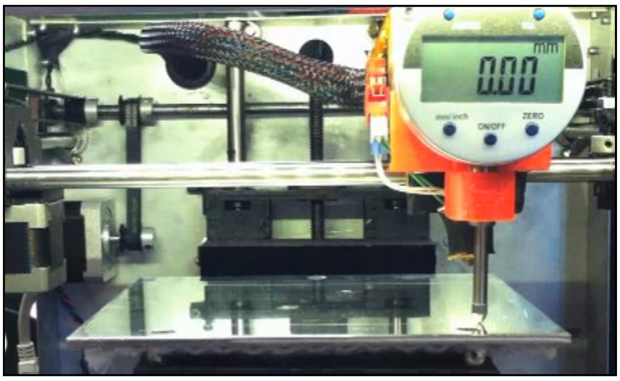


Figure 4.14: Reference point was determined by using dial indicator *(from www.thingiverse.com)*

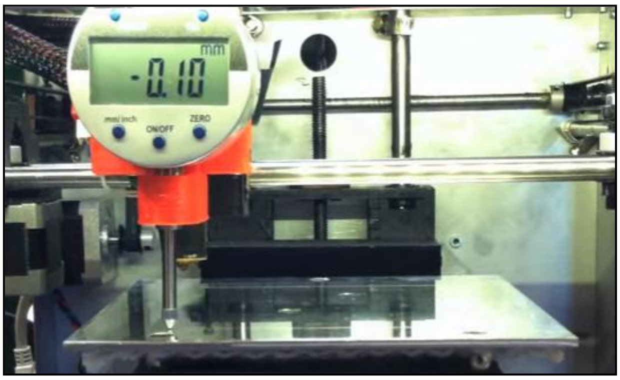


Figure 4.15: Point measured on outer area of workpiece *(from www.thingiverse.com)*

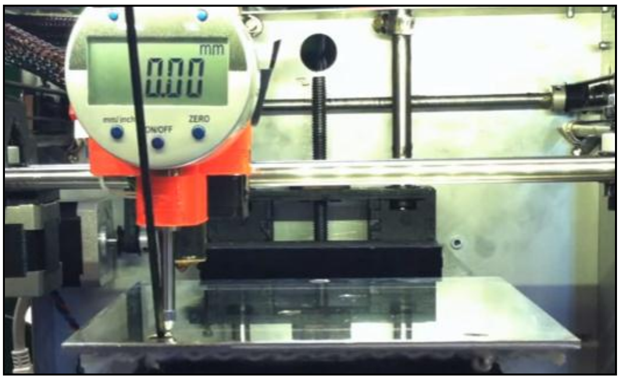


Figure 4.16: Tightened the screw until reached maximum allowable reading *(from www.thingiverse.com)*

As the structure of “Y” is made by welding, the initial flatness of bottom plate was affected and became uneven like a waveform shape. The invisible change of surface flatness is only indicated by levelling process with the use of a dial indicator. In Figure 4.17, the shape of the bottom plate is no longer flat after the welding action. Then, a reference point was taken (point A in Figure 4.18) in anywhere of bottom plate, excluded from the area of circular slot (Figure 4.19). This point is referred as a neutral centreline to the surface of bottom plate. For the purpose of workpiece positioning, additional four points (point B, C, D & E) that near the clamps of jigs were measured and compared with the point A. Next, the flange nuts were tightened again until reached the maximum allowable reading but not screwed fully to allow adjustment during the alignment procedure. This levelling task was repeated again after the alignment procedure to ensure the readings of dial indicator were remain unchanged after conducted the workpiece alignment.

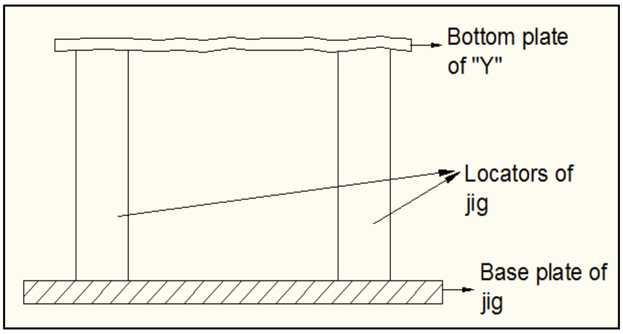


Figure 4.17: Example of leveling procedure

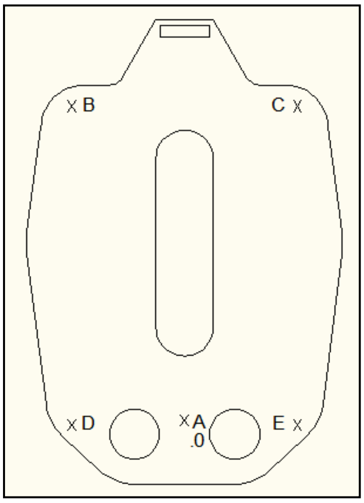


Figure 4.18: Reference points during workpiece positioning procedure

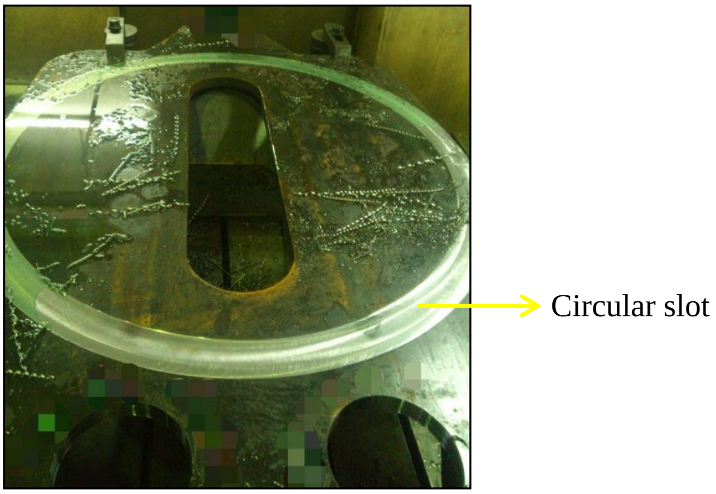


Figure 4.19: Example of circular slot with 0.2mm depth from reference point

In the workpiece resurfacing process, the operator may measures any point on the part based on the area of resurfacing. The purpose of resurfacing is to ensure the workpiece has an ideal surface flatness after any thermal processes. This can be done by using dial indicator to determine the required depth of cut and generated G-code to define the Z motion dimension. Referring to Figure 4.20, the first gauge indicated the point measured was 0.002 inches higher than the reference point whereas the second gauge shown the other point was 0.003 inches lower than the reference point. In order to have a flat surface of workpiece, the ideal depth for resurfacing was 0.003 inches from the reference point.

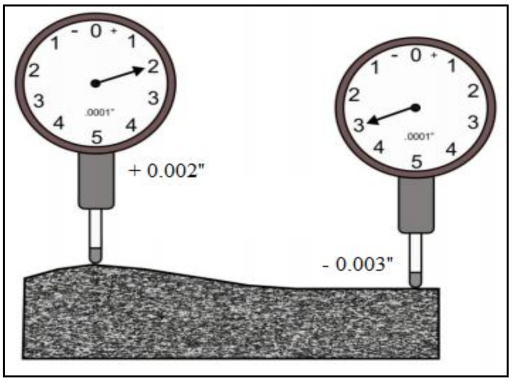


Figure 4.20: Example of flatness measurements using dial indicator *(from www.pmpa.org)*

The levelling measurement was also applied for the resurfacing of circular slot on the bottom plate. This slot is used to fix the gearwheel for spreader rotation. Referring to Figure 4.21, the point F, G and H obtained different value from centreline since different portions of plate were compressed or stretched about its centreline. The measured values of F, G and H are used to decide the depth of cut for milling the circular slot. The operator assigned the z-coordinate of largest indication value (point H) as the z-axis coordinate of centre point. Based on the dimension requirement in product “Y”, the depth of circular slot cannot be more than 0.2mm with respect to the level of reference point (point A). The operator used G-code to finalize the depth of cut be Z-0.8. The average setup time for the whole levelling procedures was 0.27 hour.

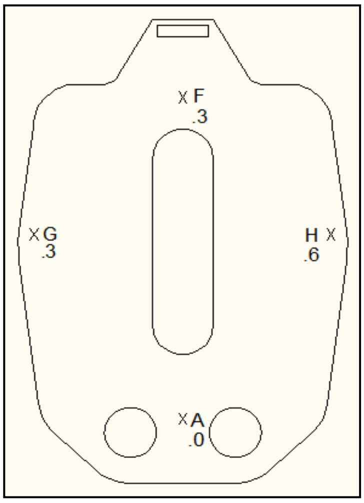


Figure 4.21: Reference points during workpiece resurfacing procedure

The fifth stage of setup is performing alignment of the workpiece along x and y-axis positions. This action is to ensure the workpiece is placed in parallel and perpendicular to jigs and machine bed. Similarly, this process is carried out by using dial indicator. As shown in Figure 4.22, the dial indicator was placed at the centre bore of product "Y" to align the workpiece position. The dial indicator was moved along from point 1 to 2 with several times until the dial indicator shows a constant reading. After finished alignment, the nuts were tightened fully to fix the position of workpiece. The average setup time for this stage was 0.2 hour.

Point 1

Point 2

Figure 4.22: Conduct workpiece alignment by using dial indicator

The last setup process in Step 1 is locating a centre point of workpiece by using edge finder. This tool is widely used to determine the edges and thus the centre of workpiece can be easily located. The operator used edge finder to spindle around the back side of the bore (point 3 in Figure 4.23) on y-axis until the cylinder body runs off to the side (Figure 4.24). It continues to move towards the front edge of the bore (point 4) and so the midpoint of y-axis is defined by the machine. The same procedure was repeated on x-axis (point 5 & 6) and the midpoint of x-axis is determined. Lastly, the operator identified the centre values of x and y-axis and reset these coordinates be (0, 0) as the centre point of workpiece. The required time for this process was 0.16 hour.

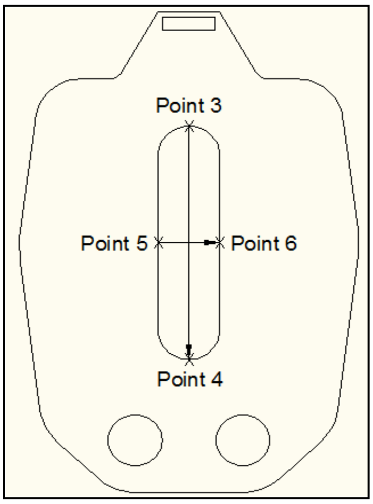


Figure 4.23: Point located to determine centre point of workpiece

Figure 4.24: Example of cylinder body of edge finder runs off to the side *(from www.tormach.com)*

4.5 Analysis of current machine setup procedure

Referring to section 4.4, there are six setup procedures in Step 1 and three out of six procedures are considered as bottleneck processes. The three bottleneck procedures are: loading and positioning of jig and fixture, workpiece levelling along z-axis and aligning the workpiece in parallel or perpendicular to x-axis and y-axis. All three procedures are conducted with the available jig and fixture and used 0.87 hour which equals to 52.7% of the total setup time. Therefore, the best method to reduce machine setup time is redesign the current jig and fixture that is able to simplify or eliminate the three bottleneck procedures listed above. The other three procedures are also important but the time required cannot further reduce as both were operated without related to the jig and fixture.

4.5.1 Loading and positioning of jig and fixture

The second stage of setup is started with loading the two pieces of jigs and fixtures onto the machine. From Figure 4.25a, it shown that the operator moved four times to transfer the two pieces of jigs from its location to the machine operated and total distance travelled was 20 meters. Before placing the jigs onto the machine table, one pair of key slots was removed from the bottom of each piece of jig and thus two pairs of key slots were removed from the current jigs and fixtures. For the current jigs, it is only used on certain machines as the size of key slot on bottom of jigs is same with the size of T-slot table. Besides, the internal and external thread of key slot and screw are subjected to wear because of the frequent removing and tightening of the screw to the key slot. The average time required for this process was 0.35 hour. When the jigs were ready on the machine, the operator measure and adjust the jigs in a distance of 890mm to support the periphery of workpiece. The mean time used for measurement was 0.05 hour. With a detailed analysis, the machine setup time can be reduced by restructuring the processes of jigs loading, key slot removing and distance measuring.

The first suggestion for redesigning a jig and fixture is to combine the two jigs to one. With one piece of jig and fixture, the number of paths moved by operator for jig loading can be reduced from 4 to 2 times and the distance travelled is minimizes from 20 to 10 meters (Figure 4.25). Besides, the process of key slot removing can be eliminated by changing the method of jig positioning. In the redesigned structure, the jig can be positioned by using the step clamp and step block to hold it at a desired position onto the machine table. This method is the simplest and easiest way to use for direct holding the jig compared to slot the jig onto the machine table. Therefore, less time is requires for positioning the jigs onto the machine table. Since the new jig is designed to have the length of original jigs plus the distance of 890mm, the task for distance measuring can be eliminates. By redesigning the jig and fixture, the setup time for second stage can be minimized from 0.4 hour to approximately 0.2 hour.

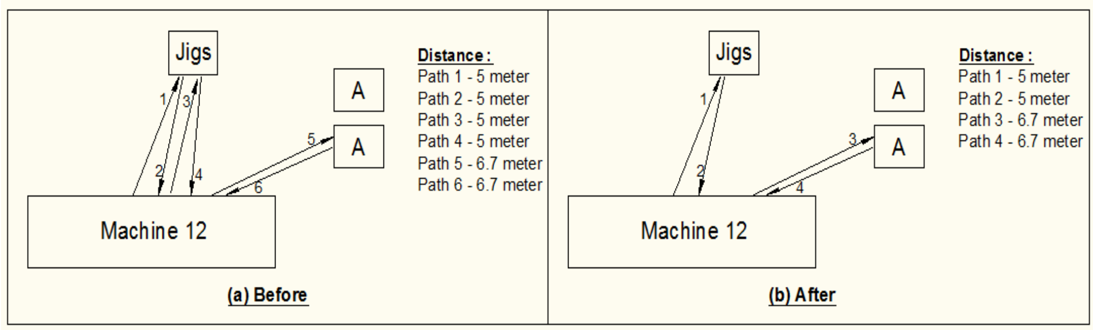


Figure 4.25: Comparison of movements made by setup operator between before and after improvement

4.5.2 Workpiece levelling and alignment along different axes

In the levelling process, the task of workpiece positioning took up more time compared to resurfacing. During the workpiece positioning process, the operator used dial indicator to obtain the measurement several times in order to achieve a desired correctness of position of the workpiece. For the first time of positioning measurement, the operator measured the flatness of workpiece on each corner and followed by tightening the flange nuts to the clamps to fix the position of workpiece. The second time of positioning measurement was performed to confirm each point measured on the corners are achieved the maximum allowable reading after tightened the nuts. Next, the alignment process was started to adjust the position of workpiece in parallel or perpendicular to x and y-axis. This measurement task was repeated several times along the centre bore of “Y” until a constant reading was shown in the dial indicator. After the alignment procedure, the operator conducted the third time of positioning measurement to ensure the readings of level still remained the same.

To reduce the times of levelling and alignment measurements, additional locators are suggested to design in the new jig and fixture. A locator functions to ensure the workpiece is precisely positioned and firmly supported. It makes the workpiece is easily loaded onto the jig and fixture. The new locators can be designs to have a slot on its top and welds it in parallel on the bottom plate of jig. The slots on locators are used to mount the workpiece in parallel once the workpiece is positioned on the jig and fixture (Figure 4.26b). With this design, the alignment task can be simplified since the position of workpiece is almost in parallel during the first time positioning on the jig. Then, the third time of positioning measurement can be eliminated as less adjustments are conduct during the alignment procedure. Therefore, the setup time for levelling and alignment processes can be reduced significantly.

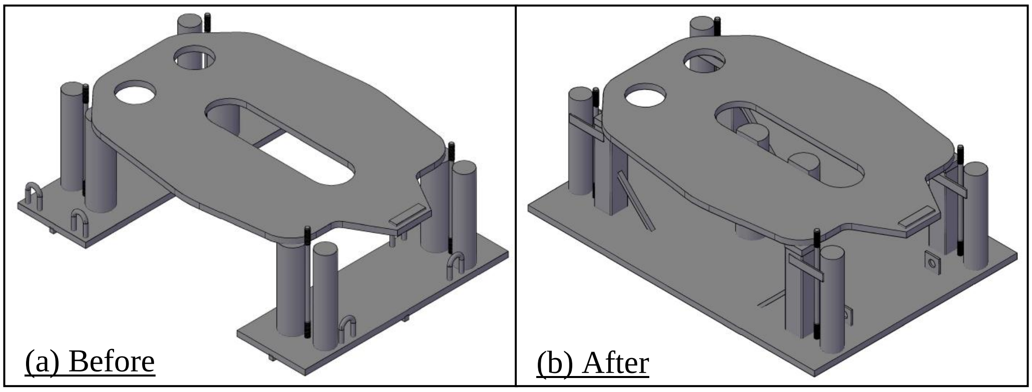


Figure 4.26: Comparison of workpiece positioning between before and after improvement

4.6 Jig and fixture redesign using improvement of current machine setup

Referring to Figure 4.27, the structure of current jigs and fixtures was separated into two parts to sustain the placement of the workpiece. The length and width of base plate for each piece of jig are 400mm and 1200mm respectively. Each piece of jig consists of two locators, two supports, two clamps, four handles and four key slots. Firstly, two sling belts were used to connect the four handles for lifting up each jig and fixture. Then, a pair of key slot was removed from the bottom of each jig and the remaining pair was used to slot the jig onto the machine bed. The locators act as a reference surface to accurately position the workpiece onto the jigs. To hold the workpiece at a desired position, the clamping device used is called a strap clamp. As shown in Figure 4.28, the strap clamp holds the workpiece by using a piece of flange nut and step clamp. One end of step clamp was used to hold the workpiece and the other end was placed on the support as a fulcrum.

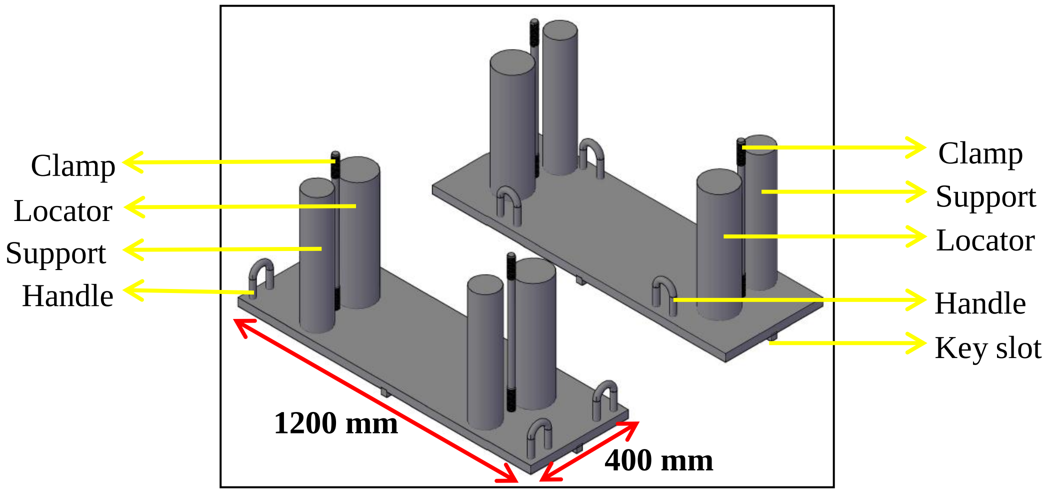


Figure 4.27: Three dimensional view of current jigs and fixtures

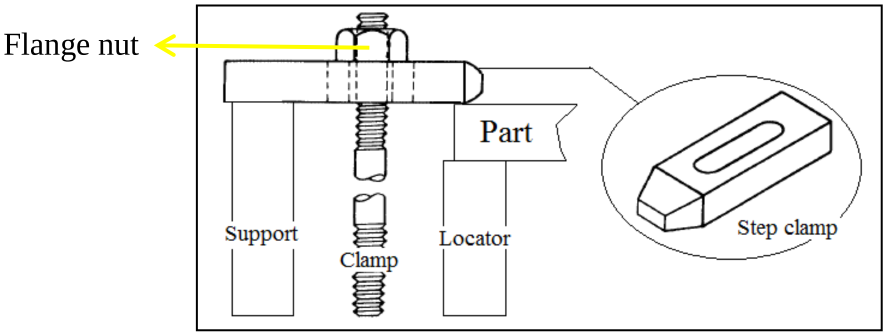


Figure 4.28: Clamping method of strap clamp

Based on the analysis in section 4.5, the structure of jig and fixture is redesigned by eliminating the piece of jig and adding locators onto the jig. In Figure 4.29, it shows that the new jig and fixture is constructed on a piece of base plate. The length of new base plate is the combination of original length of current jigs plus the distance of 890mm. Then, the dimensions of new base plate are 1690mm length and 1200mm width. In order to prevent the deformation of jig, the material used to form the base is a steel plate with thickness of 30mm.

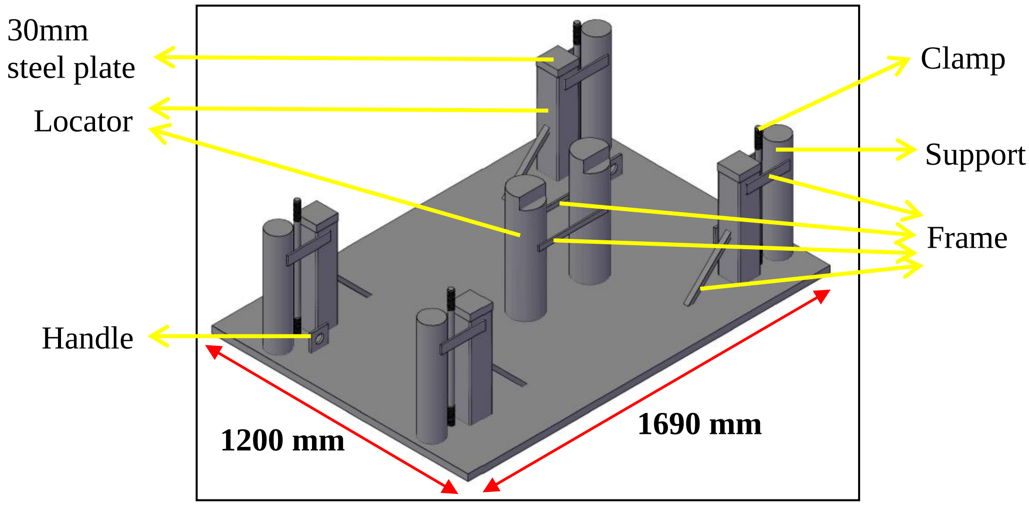


Figure 4.29: Three dimensional view of redesigned jig and fixture

In the redesigned jig and fixture, there is no key slot screwed at its bottom of base plate in order to simplify the jig positioning process. The method of jig positioning is changed to use clamping parts for holding the base plate onto the machine table. Referring to Figure 4.30, a T-slot nut is inserted into the slot of machine table and followed by screwed a stud into the nut. As the jig is positioned correctly, a step clamp is placed through the stud to hold the jig. One end of clamp is positioned onto the base plate of jig and the other end with steps is placed on the step block as a support of clamp. Next, a flange nut is tightened to the stud to restrict the movement of base plate. The same procedures are repeated three times to clamp the other edges of base plate.

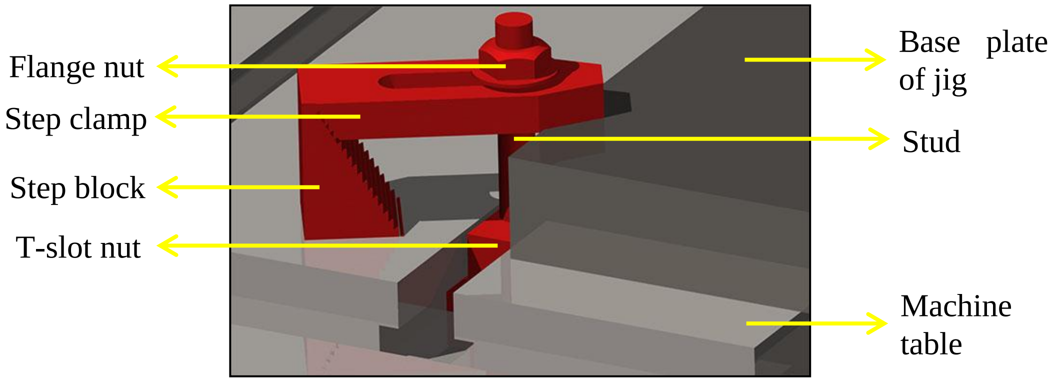


Figure 4.30: Equipment used for jig positioning *(from www.cnccookbook.com)*

Compared to the current jigs, the handles of new jigs are designed to locate at the inner side of supports (Figure 4.31). Each handle is welded as far as possible from others to make loading the jig and fixture in equilibrium, easier and safer. Meanwhile, the ability of handle is considered to ensure it is sufficient to withstand the lifting force from sling belt and to avoid loss connection between the handles and lifting equipment. These designs make the processes of distance measuring, jig positioning and jig loading become more simple and faster.

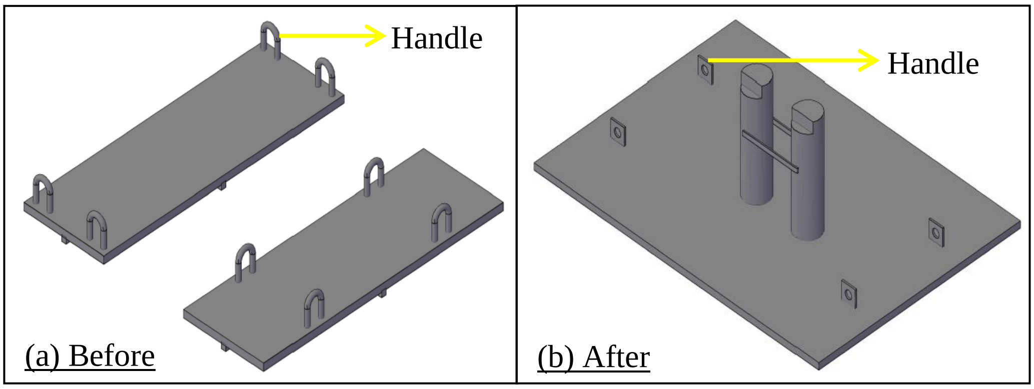


Figure 4.31: Comparison of handle design between before and after improvement

Similarly, the positions of locator, clamp and support remained unchanged. The distance between the clamp and the locator is equal that between the clamp and the support. The only difference is the material of locator was changed from shaft to square hollow section (Figure 4.32). The purpose of this design is to reduce the overall weight of the new jig and fixture. Since the hollow body of locator might not be rigid enough to withstand the clamping and cutting forces, a 30mm steel plate is welded at the top of locator to increase the surface area of contact of the workpiece. The common method for positioning a locator is referring to the edges of workpiece, so that fewer locators are required and ensures full contact of workpiece over the locating surfaces.

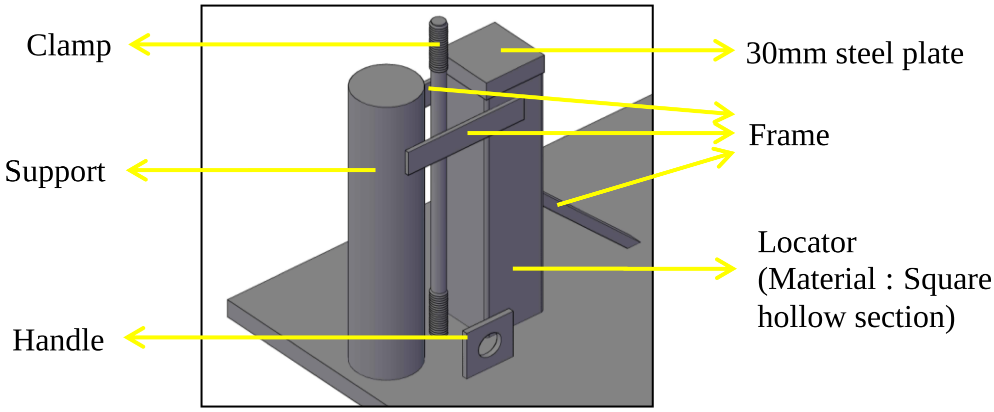


Figure 4.32: View of components on redesigned jig and fixture

The designs of clamp and support are same with the current jigs and fixtures. When the workpiece is positioned correctly onto the locators, the clamps are used to restrict the movements of workpiece in any directions. In Figure 4.33, it shown that how the clamping force is produced in this arrangement of locator, clamp and support. As the clamp is positioned at the centre between locator and support, the force produced by the flange nut when tightening will distribute equally at both ends of the step clamp. Thus, the force helps to hold the workpiece against locator and also maintains the stability of step clamp on the support. Furthermore, there are added three frames at the sides of locator to avoid distortion or bend of the locator (Figure 4.32).

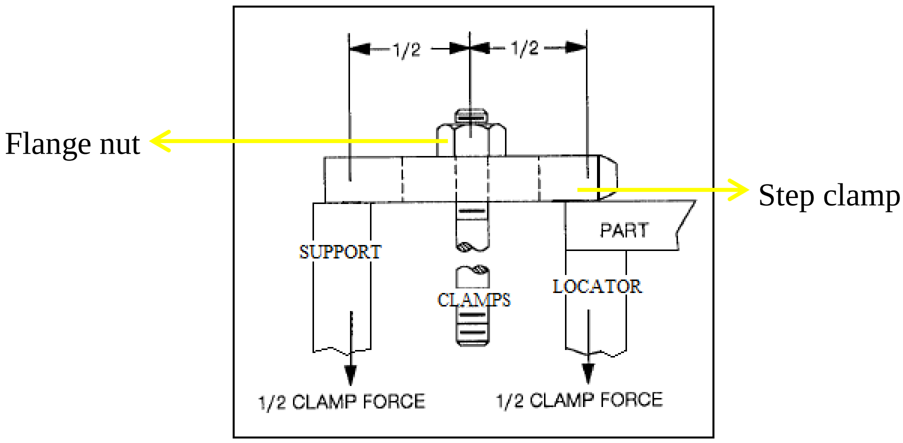


Figure 4.33: Clamping forces produced on support and locator

The last consideration of redesign the jig and fixture is the way to position the additional locators for reducing the need of levelling and alignment processes. In some cases, if a workpiece has hole or bore on its surface, the hole or bore provides the best references to place the locator for positioning the workpiece. Therefore, two additional locators are designed to position at the centre of jig to hold the centre bore of the workpiece (Figure 4.34). In order to make the workpiece alignment easier, the new locators are milled with a slot at its surface to hold the workpiece accurately. It also acts as a reference line to maintain the workpiece in parallel or perpendicular position once positioning the workpiece onto the jig. Referring to Figure 4.29, a frame is welded between the two locators to avoid bending of locator during the workpiece positioning task.

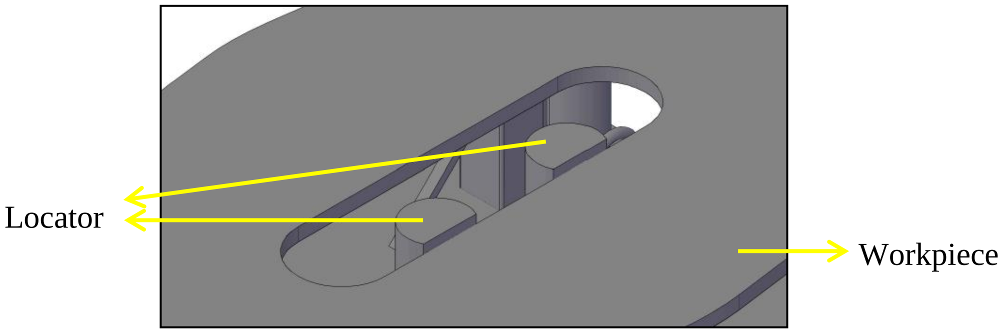


Figure 4.34: Additional locators on redesigned jig and fixture for ease of alignment

4.7 Validation of jig and fixture redesign

There are five main considerations in validating a jig and fixture design: dimensional accuracy of structure, ability to support workpiece, safety issues during the operation, size within specifications of machine table used and the ability to reduce machine setup time. Workpiece requirements are the major influence on the design of jig and fixture. It is ensured that the workpiece is fully supported and clamped without interference of the required machining paths and cutting tools. In Figure 4.35 to 4.37, the outlines of workpiece and machining paths are combined with the structure of jig to illustrate all the components would not obstruct the machining operation on the workpiece.

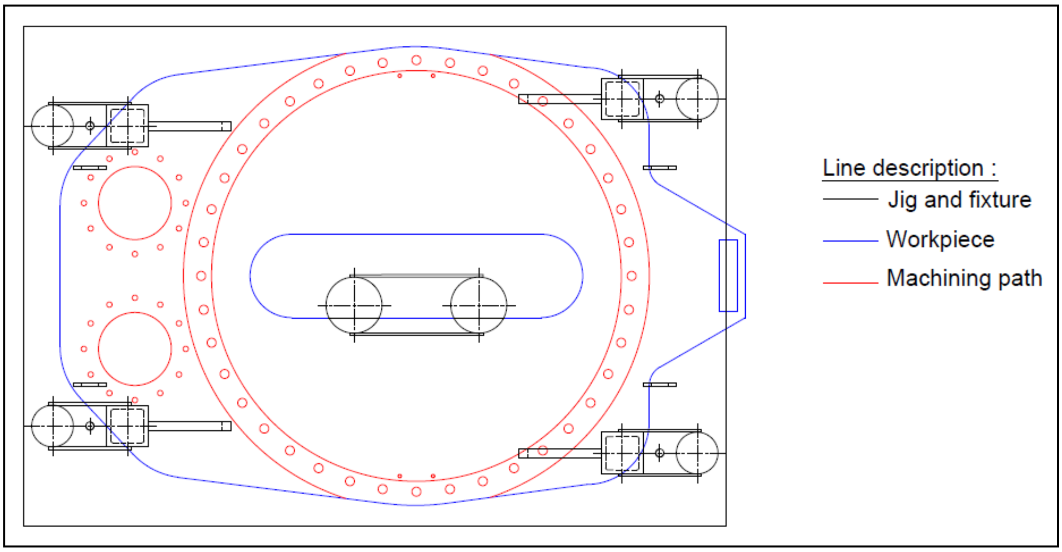


Figure 4.35: Dimensional validation of jig and fixture (Top view)

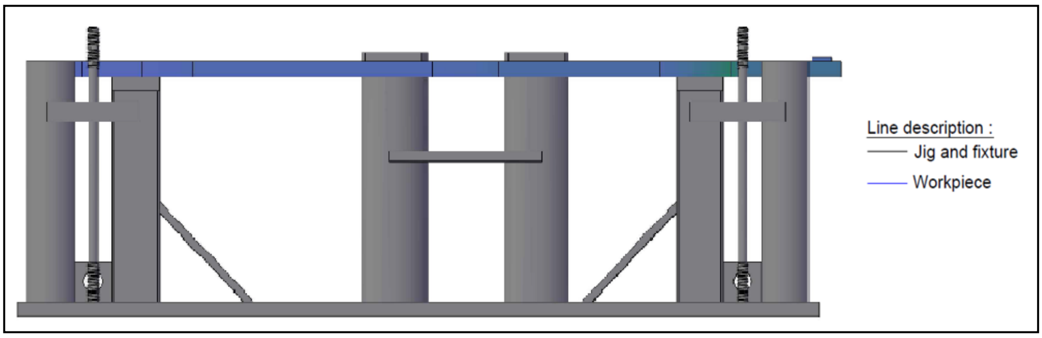


Figure 4.36: Dimensional validation of jig and fixture (Front view)

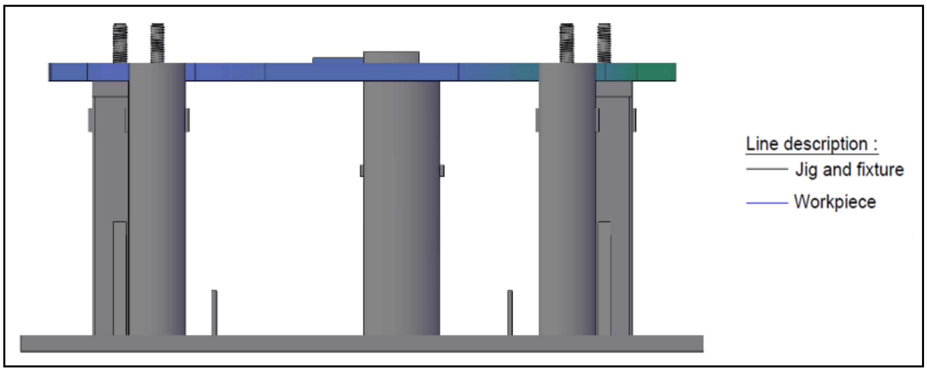


Figure 4.37: Dimensional validation of jig and fixture (Side view)

The ability of base plate, locator, support and clamp is important to withstand the large clamping force and cutting force. In addition, the basic rule for designing a jig is the base plate must be strong and rigid enough to resist the forces from locators, clamps, supports and other components. Without these specifications, the parts are easy to bend and distort and affected the accuracy of jig and fixture. As mentioned in Chapter 1, there is no analysis for mechanical testing to check the maximum force and deformation that can be sustained by the components of jig. Since the redesigned jig follows the standard jig design template in Company “X”, the ability of each component in redesigned jig and fixture is checked by the experienced supervisor based on its thickness or diameter.

Safety is another issue to consider when designing the jig and fixture. As the structure of redesigned jig is constructed on a large base plate, it is heavier than the current jigs and fixtures. The lifting equipment and sling belts used must be capable to hold the redesigned jig and sufficient to withstand the weight of redesigned jig. The lifting capacity of equipment is 3-tons (2721.55 kg) and that of sling belt is 1.5-tons (1360.78 kg). As the total weight of the redesigned jig is 755 kg, the lifting equipment and sling belt are able to use for loading the redesigned jig.

Since every model of CNC machine has different sizes of machine table and T-slot and different value of maximum load on machine table, it is important to ensure the redesigned jig is able to be use in each single machine. The work table size of machine operated to produce “Y” is 6000mm length and 2600mm width and the maximum load on work table is 16,000 kg. As the size of redesigned jig is 1690mm length and 1200mm width and its weight is 755 kg, it is capable to be positioned onto that machine table.

The last consideration is to examine whether the machine setup time can be reduced by using the redesigned jig. The main focuses of the redesigned jig are to simplify the jig loading and positioning processes and eliminate the multiple times of levelling and alignment processes. Firstly, it combined the two pieces of jigs into one to make the loading time and distance travelled by operator for jig loading became shorter. Next, the key slot removing process is eliminated since the method of redesigned jig positioning is modified by using step clamp and step block to position the jig onto the machine table. Thirdly, the process for distance measuring between the jigs is eliminated as the pieces of jig reduced to one. Furthermore, additional locators are welded in parallel at the redesigned jig and fixture to reduce the times of levelling and alignment measurements. The function of locators is to align the workpiece in parallel once the workpiece is positioned on the redesigned jig. Then, the redesign jig and fixture is valid when the three bottleneck processes are simplified or eliminated.

4.8 Time study of redesigned jig and fixture

Referring to Figure 4.38, the redesigned jig was fabricated through assembly, welding and CNC machining. Firstly, the bill of material is prepared based on the design of new jig. The materials are then assembled onto the base plate of jig according to the dimension listed for each component. After assembly, the welding process was started by welding the base plate and other components to fix its desired position. As each component is cut by thermal process, the surface of each component is uneven. The purpose of CNC machining onto the redesigned jig is to ensure each locators and support has the same level of flatness to position the workpiece.

Figure 4.38: Real view of redesigned jig and fixture

By using the redesigned jig and fixture, a time motion study was conducted to determine the degree of improvement of machine setup time. Similarly, each setup task and its exact time required are listed in the monitoring paper (Table 4.4). Comparing all the data collected before and after improvement, there is only small a difference for the task of machine cleaning, workpiece lifting and centre point setting. As mentioned in section 4.4, the time required for each task may vary since the machine is semi-automated and operated by different workers. A total of eleven data sets were collected to obtain the average setup time for each procedure. The aim of redesign the jig is to minimize the current machine setup time by simplifying or eliminating the three bottleneck procedures, within are loading and positioning of jigs onto machine, workpiece levelling along z-axis and workpiece alignment along x and y-axis.

Table 4.4: Comparison of average time required for each setup procedures between before and after improvement

MONITORING PAPER			
No.	**Description**	**Mean setup time before improvement (hour)**	**Mean setup time after improvement (hour)**
1	Machine cleaning	0.37	0.34
2	Loading and positioning jigs onto machine	0.40	0.23
3	Lifting workpiece onto the jigs	0.25	0.20
4	Levelling along z-axis	0.27	0.16
5	Alignment along x and y-axis	0.20	0.08
6	Setting centre point	0.16	0.18
Total setup time required		***1.65***	***1.19***

After redesigned the jig and fixture, the time spend in the jig loading and positioning process is reduced from 0.4 to 0.23 hour. This process started with loading the redesigned jig from its location to the machine operated. The total time consumed and distance travelled for jig loading are decreased as the piece of jig is reduced to one. It followed by inserting the T-slot nut and stud into the slot of machine table and placed them near to the sides of redesigned jig. After the redesigned jig is correctly positioned, a step clamp is placed horizontally to clamp the jig by its one end and the other end is held by the step block (Figure 4.39). Next, a flange nut is tightened to the stud above the step clamp to restrict the movement of jig. The same clamping method is also applied to the other three sides of jig.

Figure 4.39: Redesigned jig clamping onto the machine table

Similarly, the levelling procedure is divided into two parts: workpiece positioning and resurfacing. After the workpiece is positioned onto the redesigned jig, a reference point is pointed in anywhere of bottom plate of workpiece. The operator started the first positioning measurement to measure the flatness of workpiece on each corner. Then, the flange nuts are tightened again to the clamps until achieved the maximum allowable reading but not screwed fully to allow adjustment during the next procedure. It followed by conducting the second time of positioning measurement to ensure all points measured are reached the maximum allowable reading after tightened the nuts. The same procedure of resurfacing task is performed after confirmed that all points measured are in the same level along the z-axis. Compared to the current jigs and fixtures, the redesigned jig eliminates the third time of positioning measurement as new locators are added to minimize the adjustment actions during the alignment procedure. Therefore, the setup time for levelling process is decreased from 0.27 to 0.16 hour after improvement.

The next improvement is the time of alignment measurement is reduced. The new locators are designed to have a slot on its top surface and welded in parallel on the base plate of jig. It acts as a reference surface to make the workpiece easily positioned in parallel to machine table’s axes. Thus, less adjustments and alignment measurements are conducted to obtain a constant reading on dial indicator. The setup time for this process is minimized from 0.2 to 0.08 hour.

4.9 Discussion

The purpose of redesign of the current jigs and fixtures is to simplify or eliminate the bottleneck processes and thus reduced the machine setup time. The bottleneck processes are: loading and positioning of jigs onto the machine table, workpiece levelling along z-axis and workpiece alignment in parallel or perpendicular to machine table's x-axis and y-axis. The first change in redesigned jig is the combination of 2 current jigs to one. The second change is elimination of all the key slots at the bottom of jigs and replaced by using step clamp, step block and flange nut to hold the position of redesigned jig onto the machine table. The third change is added two locators at the centre of redesigned jig to ensure the position of workpiece is almost in parallel to machine table's axes once the workpiece is positioned onto the jig. The details of all setup tasks before and after improvement are summarized in Table 4.5. In the table, the certain steps eliminated are denoted by " - ".

Table 4.5: Summary of each setup task before and after improvement

No.	Setup procedures	Current jigs and fixtures (Before improvement)	Redesigned jig and fixture (After improvement)	Reason
1	Machine cleaning	Clean up the machine (i.e. removing metal chips from previous machining process)	Same procedure with the current jigs and fixtures.	-
2	Loading and positioning jigs onto machine			
	(a) Jigs loading	Operator moved 4 times to transfer the 2 jigs from its location to the machine operated and total distance travelled is 20 meters.	Operator moved 2 times to transfer the redesigned jig to the machine and the distance travelled is 10 meters.	Combined the two jigs to one.
	(b) Key slot removing	One pair of key slot is removed from each jig, the remaining pair is used to slot the jig onto machine table.	No key slot designed on the jig. Step clamp and step block are used to hold the jig onto the machine table.	This process is replaced since the thread of key slot and screw are subjected to wear because of the frequent removing and

				tightening of the screw to the key slot.
	(c) Distance measuring	Operator measured and adjusted the jigs in a distance of 890mm to position the workpiece correctly onto it.	-	This process is eliminated since the new jig is designed to have the length of original jigs plus the distance of 890mm.
3	Lifting workpiece onto the jigs	Workpiece is loaded from its original place onto the machine. Flange nuts were tightened to the clamps to fix the position of workpiece.	Same procedure with the current jigs and fixtures. Pay more attention when positioning the workpiece to avoid impact on the components of jig.	Additional locators are welded at the centre of redesigned jig to hold the centre bore of the workpiece.
4	Levelling along z-axis			
	(a) 1st positioning measurement	Operator measured the flatness of workpiece on each corner and followed by tightening the flange nuts to the clamps.	Same procedure with the current jigs and fixtures.	-
	(b) 2nd positioning measurement	Performed to confirm each point measured on the corners is achieved the maximum allowable reading after tightened the nuts.	Same procedure with the current jigs and fixtures.	-
	(c) Resurfacing	3 points measured to decide the depth of cut for milling the circular slot.	Same procedure with the current jigs and fixtures.	-
	(d) 3rd positioning measurement	To ensure the readings of level still remained the same after the alignment procedure.	-	Less adjustments are conducted during the alignment procedure.
5	Alignment along x and y-	Repeated several times along the	The times of alignment is	Additional locators are

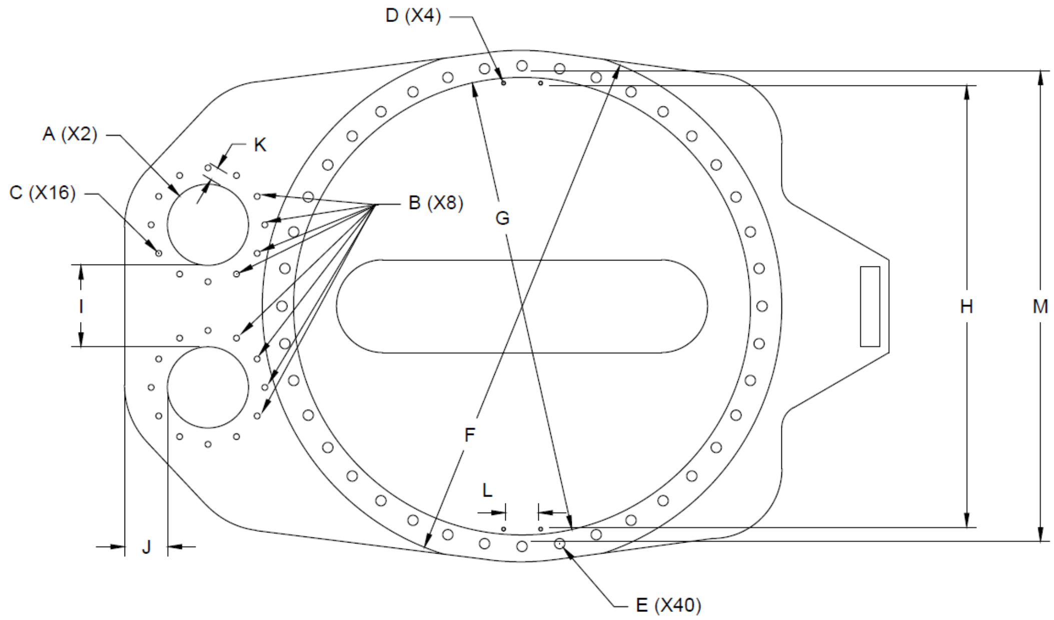
	axis	centre bore of workpiece to adjust the position of workpiece in parallel or perpendicular to x and y-axis.	reduced.	designed to align the workpiece almost in parallel during the first time positioning on the jig.
6	Setting centre point	Edge finder is used to determine the edges of the bore along x and y-axis and thus the centre of workpiece can be easily located.	Same procedure with the current jigs and fixtures.	-

Referring to section 4.8, the improved machine setup time is 1.19 hours and thus the total setup time reduced is 0.46 hour. By applying simple calculation, the percentage of setup time reduction is 27.88% after using the redesigned jig in Step 1 of "Y" production. This calculated percentage proved that the target setup time reduction in section 4.3 is achieved. In Table 4.6, the details of quality inspections after Step 1 machining for product "Y" by using current and redesigned jigs are recorded. It showed that the quality of workpiece is maintained after the improvement.

$$\text{Total machine setup time reduced} = 1.65 - 1.19 = 0.46 \text{ hour}$$

$$\text{Percentage of setup time reduction} = \frac{0.46}{1.65} \times 100\% = 27.88\%$$

Table 4.6: Quality inspections of workpiece before and after improvement



Location	Specification (mm)	Tolerance range (mm)	Current jigs and fixtures (Before improvement)	Redesigned jig and fixture (After improvement)
A	Ø175	+0.039 - 0.014	175.017	175.006
B	M12	Pass / Fail	Pass	Pass
C	Ø12.5	+0.180 +0.000	12.570	12.520
D	G 1/8”	Pass / Fail	Pass	Pass
E	Ø22	+0.500 - 0.500	22.003	22.005
F	Ø1120	+3.000 - 3.000	1120.015	1120.020
G	Ø985	+0.000 - 0.090	984.992	984.992
H	951.2	+2.000 - 2.000	951.212	951.191
I	175	+0.100 - 0.000	175.019	175.015
J	92.5	+0.800 - 0.800	92.510	92.495
K	28.75	+0.500 - 0.500	28.801	28.766
L	71.2	+0.800 - 0.800	71.205	71.207
M	1013	+0.200 - 0.200	1013.022	1013.031

Since the redesigned jig was fabricated through several processes and constructed by different types of material, the manufacturing cost of redesigned jig is considered to determine its return on investment (ROI). By using the current jigs and fixtures, the daily production rate is 1.43 parts. When the selling price of “Y” is RM 1,200 per part, the daily revenue of “Y” production is RM 1,716. The material cost of redesigned jig is RM 1,840, welding cost is RM 200 and machining cost is RM 820. Thus, the total manufacturing cost is RM 2,860. By using the redesigned jig, the daily production rate is increased to 1.50 parts and the daily revenue is raised to RM 1,800. When compared the performances of current and redesign jig, the extra revenue of “Y” per month is RM 1,890. Therefore, the time required for return on investment (ROI) is 1.51 months.

Using current jigs and fixtures

$$\text{Production rate of “Y”} = \frac{\text{Available time}}{\text{Total production time}}$$

$$= \frac{16\ \text{hours/day}}{11.15\ \text{hours/part}}$$

$$= 1.43\ \text{part/day}$$

Selling price of “Y” = RM 1,200 /part

Daily revenue of “Y” = 1.43 part/day X RM 1,200 /part

= RM 1,716 /day

Using redesigned jig and fixture

$$\text{Production rate of “Y”} = \frac{16\ \text{hours/day}}{(11.15 - 0.46)\ \text{hours/part}}$$

$$= 1.50\ \text{part/day}$$

Daily revenue of “Y” = 1.50 part/day X RM 1,200 /part

= RM 1,800 /day

<u>Return on investment (ROI) of redesigned jig and fixture</u>

Manufacturing cost of redesigned jig = Material cost + Welding cost + Machining cost

= RM 1,840 + RM 200 + RM 820

= RM 2,860

Extra revenue of "Y" = RM 1,800 /day – RM 1,716 /day

= RM 84 /day

= RM 84 /day X 6 days/week X 3.75 weeks/month

= RM 1,890 /month

Return on investment (ROI) = $\dfrac{\text{RM } 2860}{\text{RM } 84/\text{day}}$

= 34.05 days

= $\dfrac{34.05 \text{ days}}{6 \text{ days/week X } 3.75 \text{ weeks/month}}$

= 1.51 months

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In a modern manufacturing environment, organizations must be responsive to the requirements of the customers and their specific needs and to fluctuating global market demands. To maintain its competitiveness in market share, the manufacturing firms must be conducted with a minimum amount of wasted resources. The main focus of this research is to reduce the setup time for the first machining step of a high demand product, “Y”. The proposed solution is redesigns the current jigs and fixtures to simplify the setup procedures.

The objectives of this thesis are determines the underlying problems in the current jigs and fixtures and propose new jig design in order to overcome the problems listed. With the assistance of current jigs, there are six setup procedures in Step 1 and three out of six procedures are considered as bottleneck processes. The first bottleneck process is jig loading and positioning onto the machine table. This task is the highest setup time consumed in Step 1. The operator loaded up the 2 jigs to remove a pair of key slots and then transferred the jigs onto the machine bed. When the jigs are ready on the machine, the operator measured and adjusted the jigs in a distance of 890mm to support the workpiece. The second bottleneck process is workpiece levelling along the z-axis. This stage involved minimum three times of positioning measurements to ensure the workpiece is precisely positioned. The third bottleneck process is workpiece alignment along the x and y-axis. This measurement task is repeated several times until the position of workpiece is in parallel or perpendicular to x and y-axis.

In order to solve these problems, the new jig is designed to combine the two current jigs to one. It reduces the number of paths moved by operator and makes the distance travelled for jig loading became shorter. With a piece of jig and fixture, the distance measuring task is eliminated. The key slot removing task is also eliminated and the method of jig positioning is replaced by using step clamp, step block and flange nut to hold it at a desired position onto the machine table. Besides, two additional locators are designed to weld in parallel at the centre of redesigned jig to reduce the several times of levelling and alignment measurements. With the new locators, the position of workpiece is almost in parallel once it positioned onto the redesigned jig. Thus, less alignment measurements and adjustments are performed to correct the position of workpiece. Then, the third time of positioning measurement is eliminated as less adjustments are conduct during the alignment procedure.

By using the redesigned jig and fixture, the machine setup time is reduced from 1.65 to 1.19 hours. The percentage of setup time reduction is 27.88% which achieved the target setup time reduction. Furthermore, the daily production rate of “Y” is improved from 1.43 to 1.50 parts and the daily revenue is increased from RM 1,716 to RM 1,800. Then, the extra revenue of “Y” is RM 84 per day. As the total manufacturing cost of redesigned jig is RM 2,860, the time required for return on investment (ROI) is 1.51 months.

There are few recommendations for conducting future research. In order to achieve a higher daily production rate of “Y”, the total setup time per part can be further reduces by applying the same methodology to study the setup processes in Step 2 and 3. Referring to section 4.2, the setup time for Step 2 was 1.22 hours and 1.03 hours for Step 3. In Step 2, the bottleneck procedure was loading and adjusting the two pieces of jigs in a certain distance. For Step 3, the longest setup time procedure was workpiece positioning to clamp the workpiece in position onto the jig. Therefore, the suggested method is to redesign the jigs and fixtures of these steps to minimize its setup time.

The second recommendation is to study the effect of different improvement method such as increasing the number of operators to assist in the process of machine cleaning, jig clamping and workpiece positioning. In the current setup process, the average time that is consumed in the machine cleaning task was 0.37 hour which is the second setup bottleneck. Generally, with more operators to clean the machine operated, this task can be conducted faster. In the jig clamping and workpiece positioning processes, the flange nuts were tightened to the clamps to hold the parts at a desired position. When more operators assist in the clamping work, these processes can be completed in shorter time.

The third recommendation is investigates the outcome of combination of jig redesign and different setup tool. In Chapter 2, four setup tools are researched to reduce machine setup time, those are Kaizen, JIT, SMED, and jig and fixture design. When combining Kaizen and jig redesign, the management can apply 5S technique as a Kaizen tool to sort the required tools in order for further reducing the machine setup time. By using JIT and jig redesign, the machine setup time can be further reduced as it eliminates many wastes such as the waste of motion from workstation to storage area. With SMED and jig redesign, the streamlining stage of SMED can be applied to eliminate, simplify and reduce any step which is considered unnecessary.

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