RDU150802

DEVELOPMENT OF FORCE AND TEMPERATURE CONTROLLED FRICTION STIR WELDING MACHINE (FSW) FOR DISSIMILAR METAL JOINING APPLICATION

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RESEARCH VOTE NO:
RDU150802

PROTOTYPE RESEARCH GRANT SCHEME

(PRGS)

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2018

ABSTRACT

DEVELOPMENT OF FORCE AND TEMPERATURE CONTROLLED FRICTIO9N STIR WELDING MACHINE (FSW) FOR DISSIMILAR METAL JOINING APPLICATION

(keywords; Friction stir welding, dissimilar welding, force, temperature)

The first patent application of Friction Stir Welding (FSW) was filed in the United Kingdom in December 1991 which was invented by Wayne Thomas at TWI. The FSW process is currently patented by TWI in most industrial country and licensed for over 183 users. Friction stir welding and its variants friction stir spot welding and friction stir processing are used for the following industrial applications such as shipbuilding and offshore, aerospace, automotive, rolling stock for railways, general fabrication, robotics, and computers. Development of the process is underway in many companies, research institutes and universities throughout the world, and the activity level is growing. Applications have been reported in most industry sectors. In this report, design and fabrication of the FSW machine were exposed along with the results for the dissimilar metal welding.

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ABSTRAK

Paten pertama *Friction Stir Welding* (FSW) telah difailkan di United Kingdom pada Disember 1991 yang telah dicipta oleh Wayne Thomas di TWI. Proses FSW kini dipatenkan oleh TWI di kebanyakan negara industri dan berlesen untuk lebih daripada 183 pengguna. Kimpalan pengadukan geseran (FSW) dan variasi geseran geseran tempat kimpalan dan pemprosesan kacau geseran digunakan untuk diaplikasikan pada perindustrian seperti pembinaan kapal dan luar pesisir, aeroangkasa, automotif, stok rolling untuk keretapi, fabrikasi am, robotik, dan komputer. Pembangunan proses kimpalan sedang dijalankan di banyak syarikat, institut penyelidikan dan universiti di seluruh dunia, dan tahap aktiviti penyelidikan kimpalan FSW semakin berkembang. Permohonan telah dilaporkan dalam kebanyakan sektor industri. Dalam laporan ini, rekabentuk dan fabrikasi mesin FSW telah didedahkan bersama dengan keputusan kimpalan untuk logam yang berbeza.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter introduces literature background related to the dissimilar metal welding by using Friction Stir Welding (FSW) method. FSW welding method is a joining between two metals at the solid state condition.

1.2 BACKGROUND

The first patent application of Friction Stir Welding (FSW) was filed in the UK in December 1991 and was invented by Wayne Thomas at TWI. Initially the process was regarded as a laboratory curiosity, but it soon became clear that the process had much to offer in the fabrication of aluminium alloys. As it is a solid state process, it was found that 2xxx and 7xxx series alloys, which are difficult to fusion weld because of their solidification characteristics, could be easily welded. Other materials suitable for joining by this process were soon identified and successful welding was quickly demonstrated.

The FSW process is currently patented by TWI in most industrial country and licensed for over 183 users. Friction stir welding and its variants friction stir spot welding and friction stir processing are used for the following industrial applications such as shipbuilding and offshore,aerospace,automotive, rolling stock for railways, general fabrication, robotics, and computers.

Today, development of the process is underway in many companies, research institutes and universities throughout the world, and the activity level is growing. Applications have been reported in most industry sectors. Some examples include marine deck panels and hulls, high-speed trains and lightweight automotive structures. The aerospace sector recognized FSW as a viable joining process and applications include structural and non-structural assemblies. The first civil aircraft with a significant number of structural friction stir welds, the Eclipse 500 executive jet, made its first flight in August 2002. Use of the process to repair fusion welded joints has also been demonstrated. A number of the machines delivered for use in the aerospace and other industries.

1.2.1 Current research of FSW

In the last 15 years, friction stir welding has developed from a laboratory curiosity to an important fabrication technique for many aluminium alloys. Industrial implementation so far has been limited almost exclusively to thin section materials, *i.e.* up to 20mm thick. Recent trials have shown that welds in excess of 20mm in a single pass can be made, opening up the technology to new applications.

TWI Technology Centre, the development programme, the process parameters, tooling design and give an insight into the metallurgical and hardness properties of a series of welds in a range of 20mm thick aluminium alloys.

A common Triflat TM design FSW tool (Figure 1) was used for all of the welds. The tool design was based on current best practice for welding AA7075, as this was believed to be the most challenging material within the trials. The general features of the tool include a 40mm diameter scrolled shoulder with a tapered, threaded Triflat TM 19.5mm long probe.

Fig. 1 Illustration of FSW tool showing the scrolled shoulder and Triflat TM probe design used for the welding trials

The machine used for this work was a precision spindle FSW machine (Figure 2) manufactured for TWI by Transformation Technologies Inc in the USA. This machine was developed for friction stir welding of high temperature materials and incorporates a highly concentric spindle (spindle run-out < 10μm). The machine is designed to withstand high forces with very low structural deflection, deflecting less than 0.8mm in the Z-axis at the full downforce of 100kN and deflecting less than 0.3mm in the X-axis at the full traverse force of 45kN. The machine is also very well instrumented to monitor force, torque, speeds and distances.

Fig. 2 Precision FSW machine that was used

A steel jig with horizontal hydraulic and mechanical vertical clamping was used to hold the material during the welding cycle. A 2 mm steel backing shim was placed underneath the plates during welding to prevent direct tool contact with the jig base.

1.4 OBJECTIVES

The core objectives of the study are:

i. to design and develop a table top FSW machine for dissimilar welding application.
ii. to evaluate weld ability of similar and dissimilar welding using FSW machine.

CHAPTER2

DESIGN, SIMULATION AND FABRICATION

2.1 PHASE 1: DESIGN OF STRUCTURE AND CALCULATION

In this chapter, the design and calculation of the axial force or force on z-axis are explained. In addition, the calculation of welding force or force on x-axis also need to considered. All calculations are important in order to decide the specification of motors for x,y and z axis. Table 1 shows the terms that used in calculation of FSW andTable 2 shows the equation used to find the force and torque. In this chapter the root diameter of the ball screw should be determined. This is important to find the correct ball screw for the machine.

Table 1 Terms in FSW

Term	**Unit**
Tool rotational speed	rpm
Welding speed	mm/min
Plunge depth	mm
z-axis / axial force	kN
y-axis / welding force	kN
Motor torque	N.m

Table 2 Equation used to find force and torque

Term	Unit	Equation
Traverse force, F_n	N	$F_n = m \times g$
Friction force, F_f	N	$F_f = \mu_f \times F_n$
Total output torque, m_f	N.m	$M_f = \frac{C}{2\pi\mu_t} \times (F_n + F_f)$

2.1.1 *Axial Force / downwards force / z-axis*

The Axial force/downwards force/z-axis is necessary to maintain the position of the tool at or below the material surface. Some friction-stir welding machines operate under load control but in many cases the vertical position of the tool is preset and so the load will vary during welding. Table 3 show the value of parameter to calculate the Axial force / downwards force / z-axis.

Table 3 Parameters of downforce force for z-axis

Parameter	Value
Mass	1000 kg
Transmission effiency, μ_t	0.8
Coefficient of friction, μ_f	0.2
Pitch of ball screw, C	5 mm

$$F_n = m \times g = 10000N$$

$$F_f = \mu_f \times F_n = 2000N$$

$$M_f = \frac{C}{2\pi\mu_t} \times (F_n + F_f) = \mathbf{11.94\ N.m}$$

2.1.2 *Transverse Force / x-axis*

The transverse force acts parallel to the tool motion and is positive in the traverse direction. Since this force arises as a result of the resistance of the material to the motion of the tool it might be expected that this force will decrease as the temperature of the material around the tool is increased. Table 4 shows the value of parameter to calculate the Traverse force / x-axis.

Table 4 Parameters of transverse froce for x-axis

Parameter	Value
Mass	1500 kg
Transmission effiency, μ_t	0.8

Coefficient of friction, μ_f	0.2
Pitch of ball screw, C	5 mm

$$F_n = m \times g = 15000N$$

$$F_f = \mu_f \times F_n = 3000N$$

$$M_f = \frac{C}{2\pi\mu_t} \times (F_n + F_f) = \mathbf{17.94\ N.m}$$

2.1.3 Root Diameter of Ball Screw

Root diameter is the minimum diameter of the screw measured at the bottommost point of the threads. Both ball-circle and root diameters are important when calculating application characteristics and sizing parameters for factors such as column loading and critical speed.

In this subchapter, the root diameter of ball screw need to calculate to make sure the ball screw that we use in machine can withstand the force that we apply in process. This calculation is important to make sure the ball screw that we apply in the machine not break down during the process. Table 5 show the equation used to find root diameter.

Table 5 Equation used to find root diameter

Term	Unit	Equation
Traverse force, F_n	N	$F_n = m \times g$
Friction force, F_f	N	$F_f = \mu_f \times F_n$
Max force applied on axis ball screw	N	$F_r = F_f + F_n$
Root diameter	mm	$D_{min} = \left(\frac{F_r L^2}{9.8m} \times 10^{-3}\right)^{\frac{1}{4}}$

2.1.3.1 Root Diameter of x-axis

A ball screw consists of a threaded shaft and a nut, and either one can act as the traversing component. Ball screws work in a similar fashion to ball bearings, where hardened steel balls move along an inclined-hardened inner and outer race. Table 6 show the parameter that used in equation to find root diameter for x-axis ball screw. Shaft length of x-axis ball screw, L_x are 1500 mm based on design that we have done.

Table 6 Parameters of root diameter for x-axis

Parameter	Value
Friction coefficient, μ	0.08
Mounting method coefficient, m	10.2
Shaft length of x-axis ball screw, L_x	1500 mm

$$F_f = \mu_f \times F_n = 1200N$$

$$F_r = F_f + F_n = 16200N$$

$$D_{min} = \left(\frac{F_r L^2}{9.8m} \times 10^{-3}\right)^{\frac{1}{4}} = \mathbf{24.6\ mm}$$

2.1.3.2 Root Diameter of y-axis

A ball screw consists of a threaded shaft and a nut, and either one can act as the traversing component. Ball screws work in a similar fashion to ball bearings, where hardened steel balls move along an inclined-hardened inner and outer race. Table 7 show the parameter that used in equation to find root diameter for y-axis ball screw. Shaft length of y-axis ball screw, L_y are 750 mm based on design that we have done.

Table 7 Parameters of root diameter for y-axis

Parameter	Value
Friction coefficient, μ	0.08

Mounting method coefficient, m	10.2
Shaft length of y-axis ball screw, L_y	750 mm

$$F_f = \mu_f \times F_n = 800N$$

$$F_r = F_f + F_n = 10800N$$

$$D_{min} = \left(\frac{F_r L^2}{9.8m} \times 10^{-3}\right)^{\frac{1}{4}} = \mathbf{15.7\ mm}$$

2.1.3.3 Root Diameter of z-axis

A ball screw consists of a threaded shaft and a nut, and either one can act as the traversing component. Ball screws work in a similar fashion to ball bearings, where hardened steel balls move along an inclined-hardened inner and outer race. Table 8 show the parameter that used in equation to find root diameter for z-axis ball screw. Shaft length of z-axis ball screw, L_z are 450 mm based on design that we have done.

Table 8 Parameters of root diameter for z-axis

Parameter	Value
Friction coefficient, μ	0.08
Mounting method coefficient, m	10.2
Shaft length of z-axis ball screw, L_z	450 mm

$$F_f = \mu_f \times F_n = 800\ N$$

$$F_r = F_f + F_n = 10800\ N$$

$$D_{min} = \left(\frac{F_r L^2}{9.8m} \times 10^{-3}\right)^{\frac{1}{4}} = \mathbf{12.2\ mm}$$

2.2 PHASE 2: COMPUTER AIDED DESIGN (CAD)

This table top FSW have small size compared to conventional friction stir welding machine and suitable use in education environment or small room. But, its capability is same as conventional friction stir welding machine. It's have four axes (x-axis, y-axis, z-axis and α-axis).

Figure 3 shows isometric view of complete FSW machine. Figure 4 shows front view and side view of the design. During welding a number of forces will act importantly. A downforce force to maintain the position of the tool at or below the material surface. The transverse force acts parallel to the tool motion. Torque is required to rotate the tool, the amounts of which will depend on the down force and friction coefficient (sliding friction).

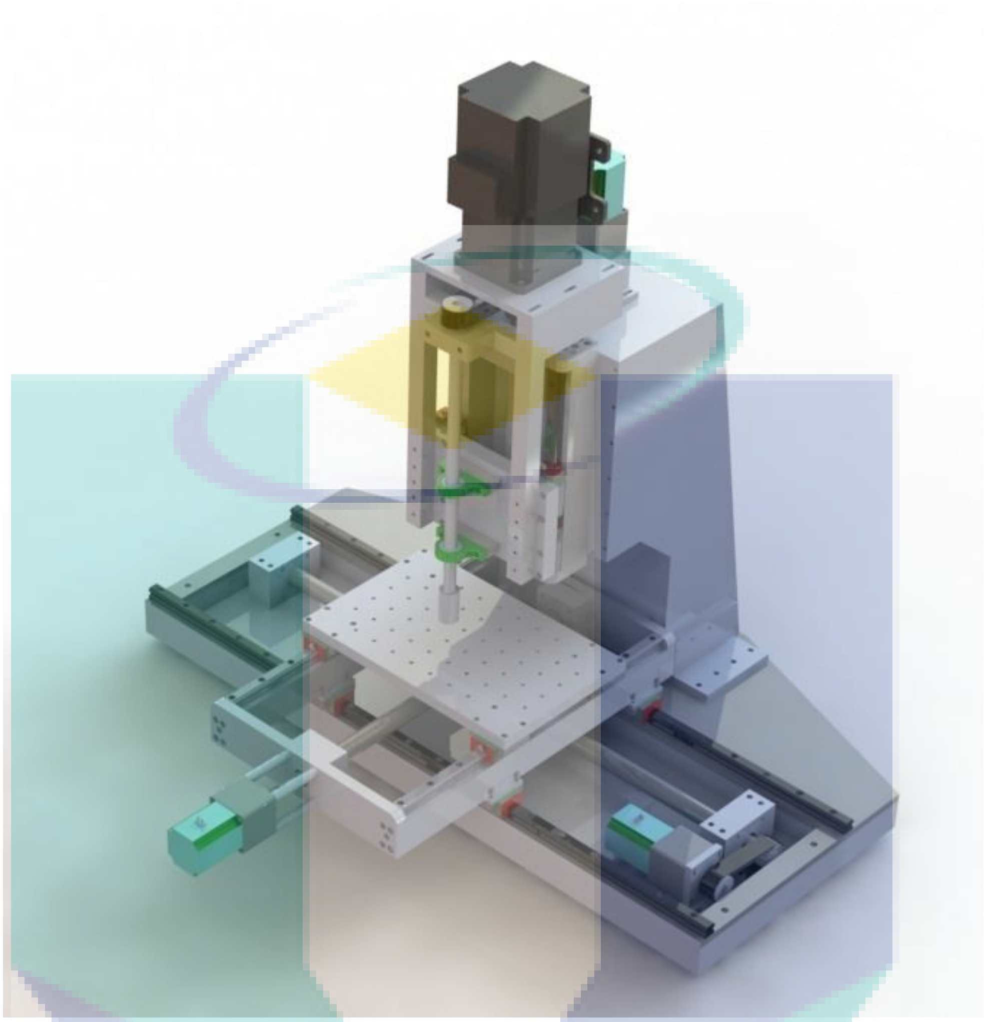


Fig. 3 Isometric view of designed structure

(a)

(b)

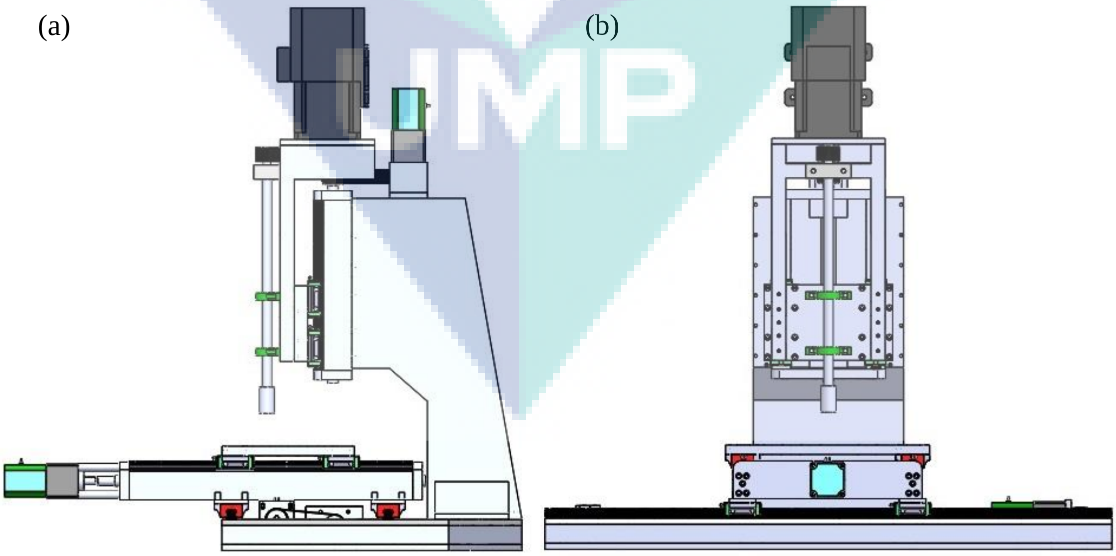


Fig. 4 Side view (a) and front view (b) of designed structure

2.3 PHASE 3: FABRICATION OF MAIN STRUCTURE

The reason we choose this design because it can withstand with the force that appllied on it during welding process. The force were estimated based on the calculation that were done in Subchapter 3.1. force that appllied for the simulation purposes is 15000 N.

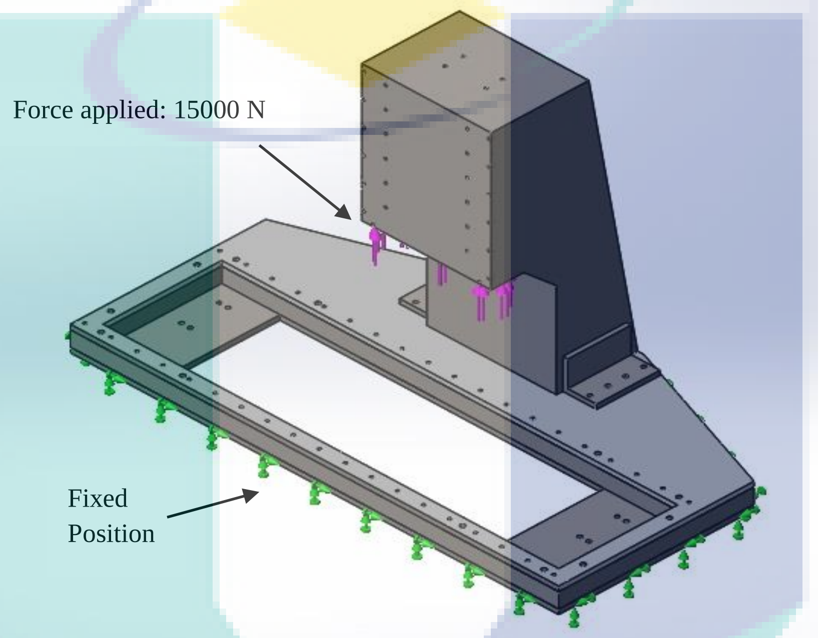


Fig. 5 Position of force applied

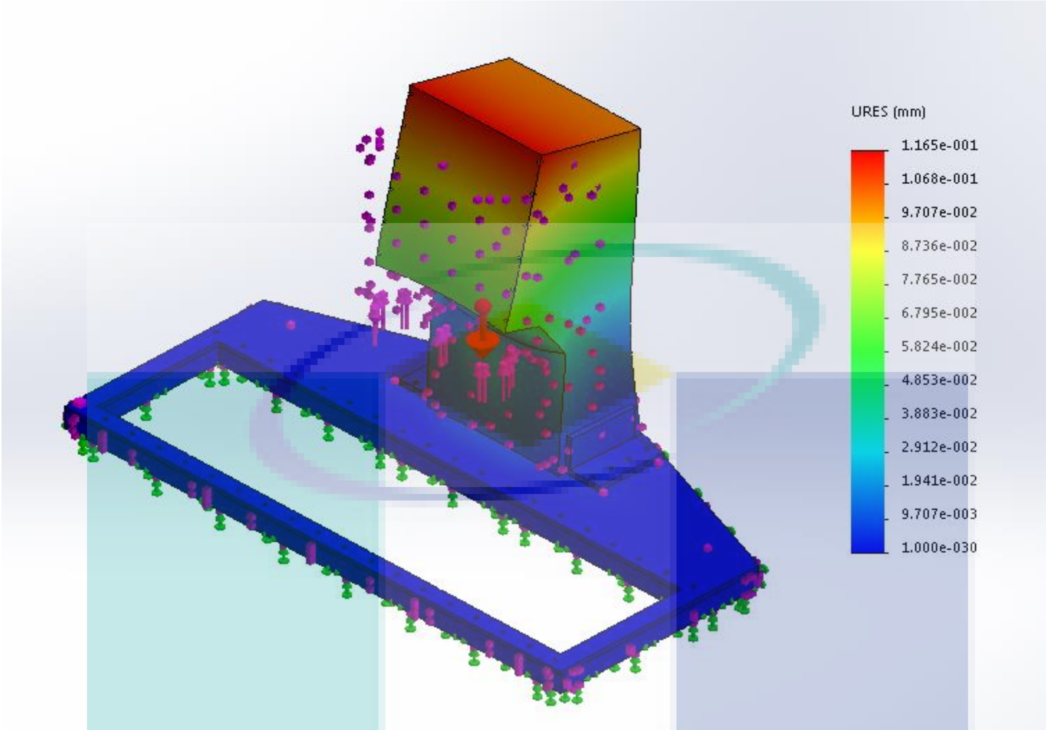


Fig. 6 Maximum displacement

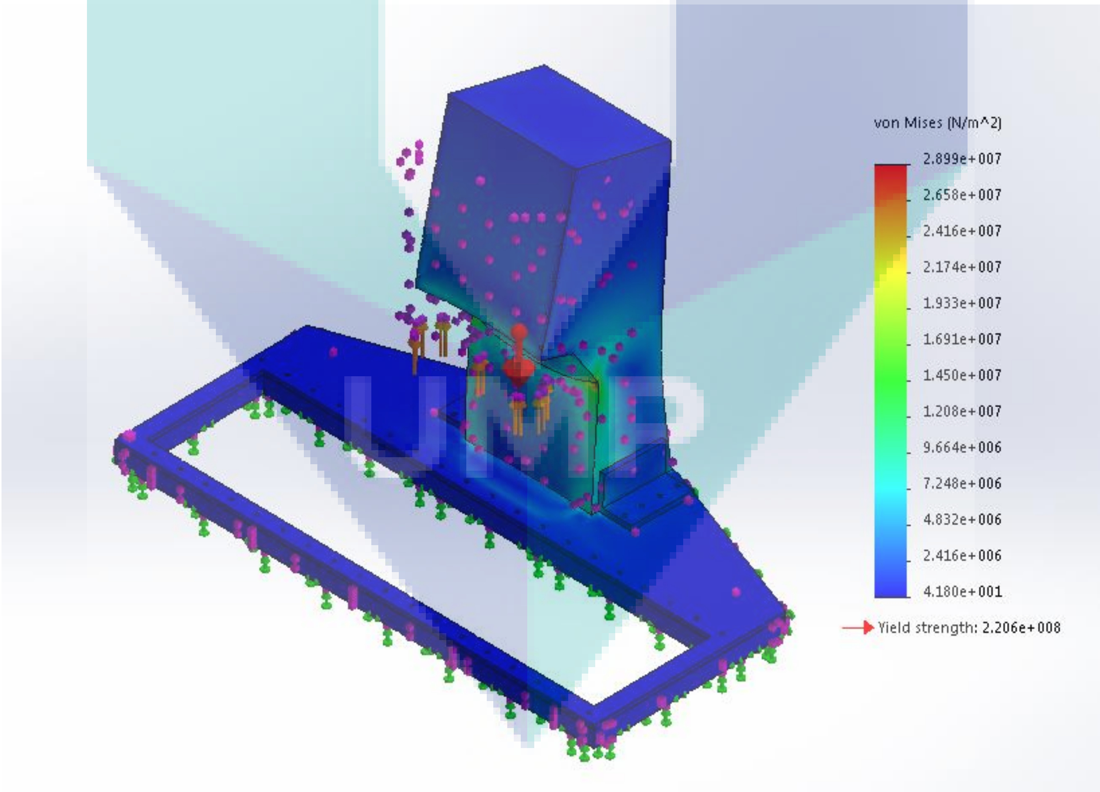


Fig. 7 Yield Strength

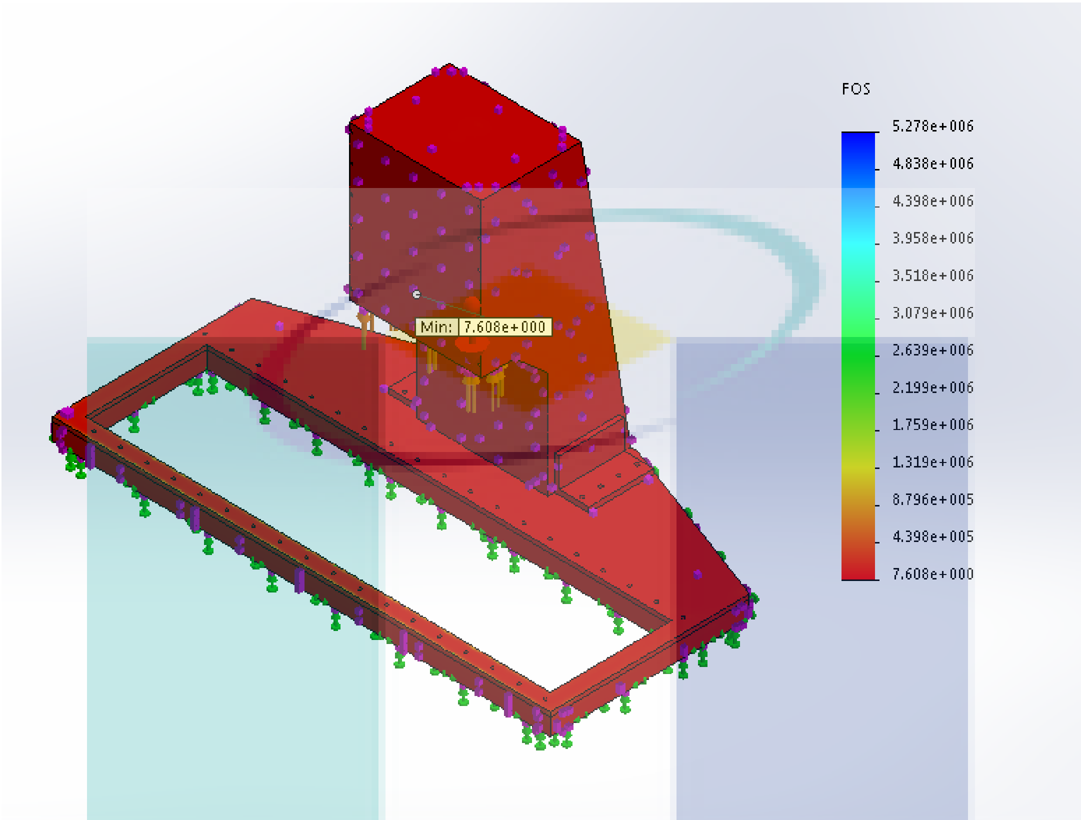


Fig. 8 Min factor of safety (FOS)

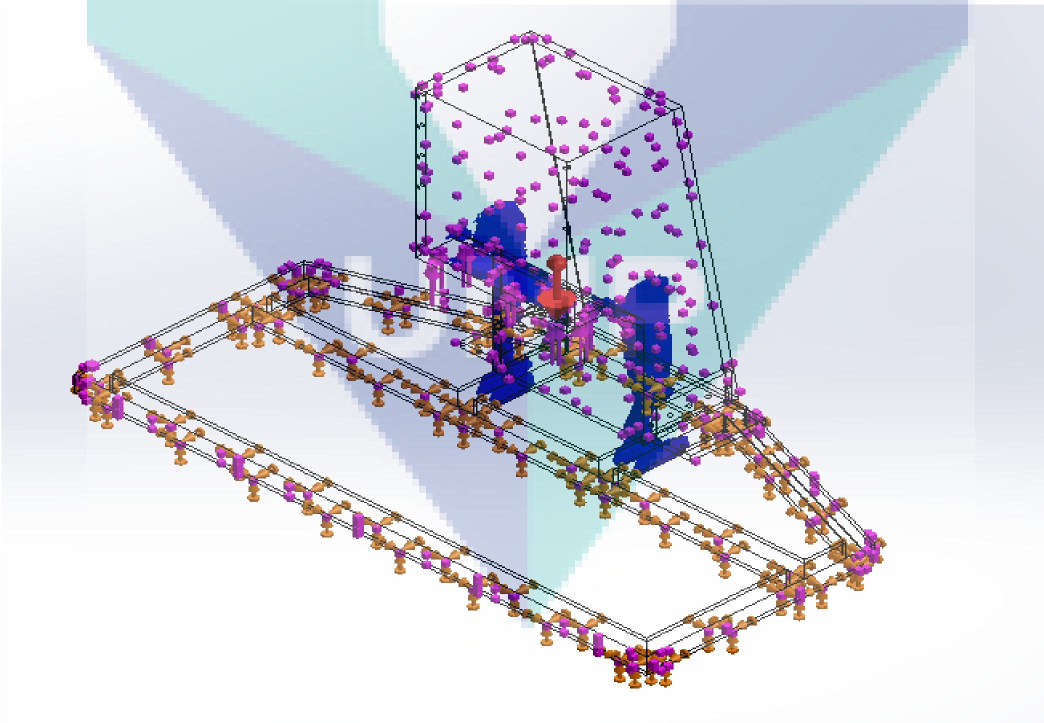


Fig. 9 Region that carry the most load

Based on analysis, the maximum displacement is 0.000116482 m and Yield strength of this machine is 2.206 x 10^8 N/m^2 that shown in Figure 6 and Figure 7. Therefore, during process of welding the vibration that will occured are small in scale because the maximum displacement occur should be very small.

This machine is totally safe and strong because based on analysis shown in Figure 8 the Factor of Safety (FOS) is 7.6085. Step motor, servo motor, ball screw, bearing, rail and block are selected based on force and torque. Figure 9 shown the region or part that carried most load during welding process.

After the drawing and simulation using Solid work software were carried out, the fabrication of frame was started. All of fabrication is done in FKM laboratory and using all the equipment that we have here. The frame is such as Figure 10. The painting is important to avoid the machine from corrosion and it can be used for the long time. The painting process also was done here in FKM laboratory. Figure 11 show painting process that done by one of the staff.

Fig. 10 Main Frame

Fig. 11 Painting process

The painting process take about one week to be done and the result is superb as shown in Figure 12. This FSW machine is weigh about 400kg in estimation and need strong table to put it. The table need to get modification to withstand the weight of the frame. Figure 13 shows the student weld the table for the FSW machine and paint in black.

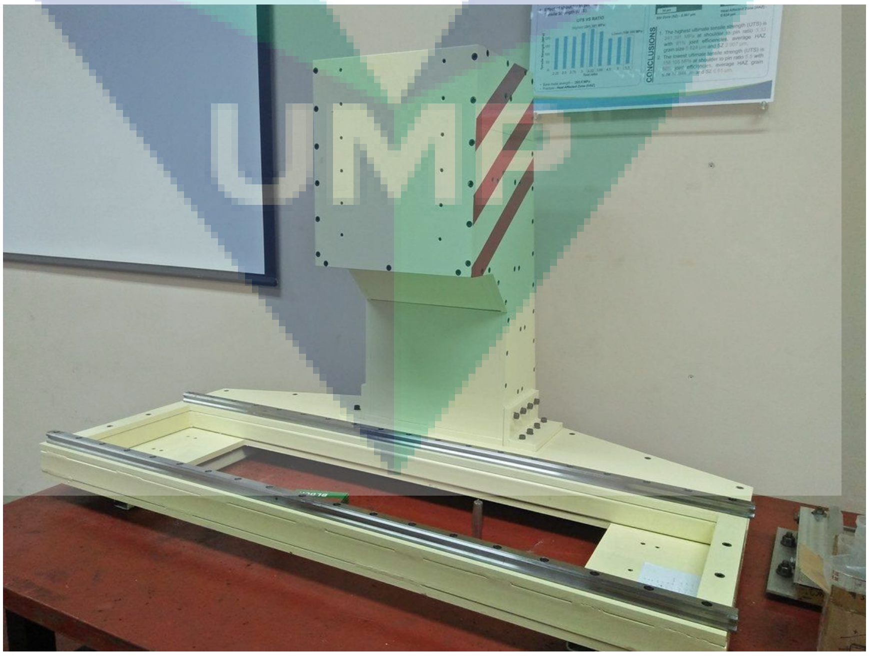


Fig. 12 Post-painted Frame

Fig. 13 Fabrication of Table FSW

2.4 PHASE 4: DEVELOPMENT OF CONTROL SYSTEM

In this subchapter, we describe a general process for designing a control system. A control system consisting of interconnected components is designed to achieve a desired purpose. To understand the purpose of a control system, it is useful to examine examples of control systems through the course of history. These early systems incorporated many of the same ideas of feedback that are in use today. The development of control system included the stepper motor, servo motor, ball screw, bearing, rail and block, tension and compression sensor, temperature sensor, and CNC software. All this will explain below.

2.4.1 Stepper Motor

Stepper motor was chosen based on calculation that have done in Subchapter 3.1.2. Based on calculation the min torque that required in welding process is plus minus 18 Nm. This step motor use in movement of x-axis, y-axis and z-axis. The brand of the stepper motor that we use in FSW machine is Oriental Motor (M) SDN. BHD.

The specification of the step motor as Table 9 and Figure 14 shows the step motor. This step motor was choosing because the torque based on calculation is about 18 Nm and the torque of this model are twice of the calculation.

Table 9 Specification Step Motor from Oriental Motor (M) SDN. BHD

Model	RKS596MC-PS25-3
Torque	36 Nm
Power Supply Input Frequency	50/60 Hz
Power Supply Input Voltage	200-240 V
Power Supply Input Power	3.0 A
Speed	0-120 rpm
Mass	4.9 kg

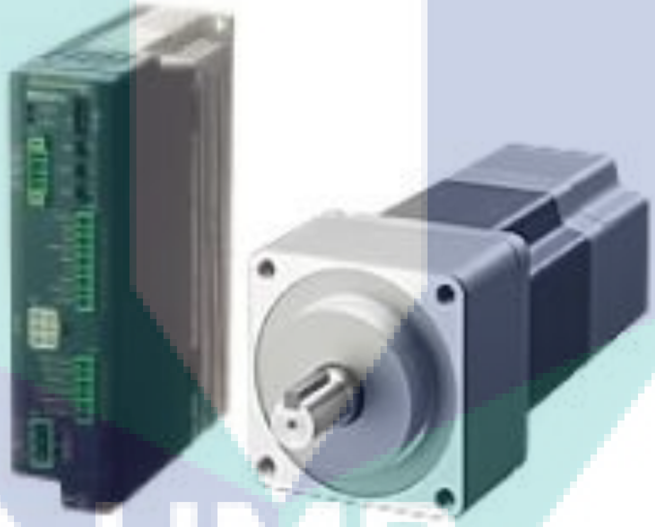


Fig. 14 Step Motor from Oriental Motor (M) SDN. BHD

2.4.2 Permanent Magnet Synchronous Servo Motor

Servo motor was selected based on calculation that have done in sub-chapter 2.1.1. Based on calculation the min torque that required in welding process is 12 Nm. This servo motor use as rpm motor. The brand of the stepper motor that we use in FSW machine is Guangzhou GEMA Electric Machine Co. Ltd. The specification of the step motor as table 10 below and Figure 15 show the servo motor.

Table 10 Specification Servo Motor from Guangzhou GEMA Electric Machine Co. Ltd

Model	JYS100A2P2
Torque	14.8 Nm
Power Supply Input Frequency	50 Hz
Power Supply Input Voltage	220 V
Power Supply Input Power	7.9 A
Speed	1500 rpm
Mass	30 kg
Power	2.2 kw

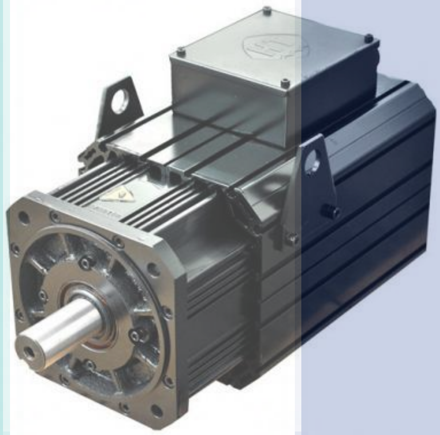
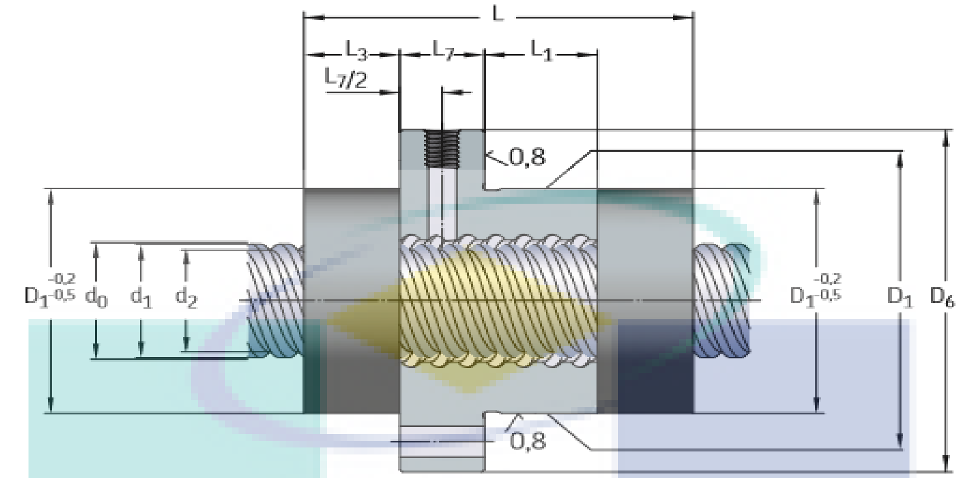


Fig. 15 Servo motor from Guangzhou GEMA Electric Machine Co. Ltd

2.4.3 Long lead rolled ball screws SL / TL

Calculations have been done in sub-chapter 2.1.3 for the selection of the ball screw. Model of ball screw that we choose is SL40X20R from SKF and it has 40 mm of root diameter. The minimum diameter of all ball for x-axis, y-axis and z-axis are 24.6 mm, 15.7 mm and 12.2 mm respectively. The benefits using this brand are lubrication hole for grease nipple or for SKF SYSTEM 24 automatic lubrication kit and standard protection at each end of the nut with composite wipers integrated into recirculation caps (NOWPR). It has high rotational speed up to nd_0 = 90 000, resulting in high linear speed up to 110 m/min and nut design well suited for transport or positioning screw applications requiring high velocity such as woodworking, some functions in plastic injection presses, pick and place etc. Dimension of the ball screw shown as Figure 16.



Nominal diameter	Lead (right hand)	Nut SL (with play) Basic load ratings dynamic	static	Std play	TL (with backlash elimination) Basic load ratings dynamic	static	Preload torque zero play	Number of circuits of balls	Inertia	Grease	Weight	Screw Mass	Inertia	Grease	Designation
d_0	P_h	C_a	C_{oa}		C_a	C_{oa}	T_{pr}								
mm	mm	kN		mm	kN		Nm	–	kgmm^2	cm^3	kg	kg/m	kgmm^2/m	cm^3/m	–
25	20	22,8	51,5	0,08	12,6	25,8	0,04-0,36	4x1,7	480	3	0,57	3,3	215	3,4	**SL/TL 25x20 R**
	25	22,3	50,6	0,08	12,3	25,3	0,04-0,36	4x1,7	400	3,6	0,66	3,2	210	3,3	**SL/TL 25x25 R**
32	20	25,4	65,2	0,08	14	32,6	0,05-0,45	4x1,7	550	3,4	0,7	5,1	530	4,4	**SL/TL 32x20 R**
	32	26,1	69,3	0,08	14,4	34,7	0,05-0,50	4x1,8	450	4,5	0,7	5,4	600	4,3	**SL/TL 32x32 R**
	32	26,1	69,3	0,08	14,4	34,7	0,05-0,50	4x1,8	450	4,5	0,7	5,4	600	4,3	**SLD/TLD 32x32 R**
	40	12,6	29,8	0,08	6,9	14,9	0,05-0,50	4x0,8	515	3	0,65	4,9	490	4,4	**SL/TL 32x40 R**
40	20	41,3	128,8	0,08	22,8	64,4	0,05-0,55	4x2,7	1 420	6,6	1,2	8,2	1 380	5,5	**SL/TL 40x20 R**
	40	51,7	130,5	0,1	28,5	65,3	0,05-0,55	4x1,7	3 300	12,5	2,4	8,1	1 330	5,2	**SL/TL 40x40 R**
50	50	92,9	235,1	0,12	51,2	117,6	0,1-0,9	4x1,7	6 060	19,4	3,3	13,2	3 560	6,4	**SL/TL 50x50 R**

Fig. 16 Dimension of SL40X20R from SKF (cont)

2.4.4 Self-aligning ball bearings

Self-aligning ball bearing was used since it accommodates static and dynamic misalignment and the bearings are self-aligning like spherical roller bearings or CARB bearings. It has excellent high-speed performance and self-aligning ball bearings generate less friction than any other type of rolling bearing, which enables them to run cooler even at high speeds.

Due to low heat generation the bearing temperature is lower, leading to extended bearing life and maintenance intervals and will minimum the number of maintenance. Self-aligning ball bearings have low minimum load requirements and very loose conformity between balls and outer ring keeps friction and frictional heat at low levels. Lastly, self-aligning ball bearings can reduce noise and vibrations levels, for example, in fans. Dimension of the Self-aligning ball bearings from SKF shown as Figure 17 below.

SKF self-aligning ball bearings

Principal dimensions			Basic load ratings		Fatigue load limit	Speed ratings		Designations
			dynamic	static		Limiting speed	Reference speed	
d	D	B	C	C_0	P_u			
mm			kN		kN	r/min		–
10	30	9	5,53	1,18	0,061	36 000	56 000	1200 ETN9
30	62	16	15,6	4,65	0,24	15 000	24 000	1206 ETN9
30	62	16	15,6	4,65	0,24	15 000	24 000	1206 EKTN9
40	80	18	19,9	6,95	0,36	11 000	18 000	1208 ETN9
40	80	18	19,9	6,95	0,36	11 000	18 000	1208 EKTN9
45	85	19	22,9	7,8	0,4	11 000	17 000	1209 ETN9
45	85	19	22,9	7,8	0,4	11 000	17 000	1209 EKTN9
45	100	25	39	13,4	0,7	8 500	12 000	1309 ETN9
45	100	25	39	13,4	0,7	8 500	12 000	1309 EKTN9
45	85	23	32,5	10,6	0,54	10 000	15 000	2209 ETN9
45	85	23	32,5	10,6	0,54	10 000	15 000	2209 EKTN9
25	52	18	14,3	4	0,21	9 000		2205 E-2RS1TN9
25	62	24	19	5,4	0,28	7 500		2305 E-2RS1TN9
30	62	20	15,6	4,65	0,24	7 500		2206 E-2RS1TN9
35	72	23	19	6	0,31	6 300		2207 E-2RS1TN9
40	80	23	19,9	6,95	0,36	5 600		2208 E-2RS1TN9
50	90	23	22,9	8,15	0,42	4 800		2210 E-2RS1TN9
50	90	23	22,9	8,15	0,42	4 800		2210 E-2RS1KTN9
50	110	40	43,6	14	0,72	4 000		2310 E-2RS1TN9
50	110	40	43,6	14	0,72	4 000		2310 E-2RS1KTN9
25	62	24	17,8	5	0,26	7 500		BJ2-4103

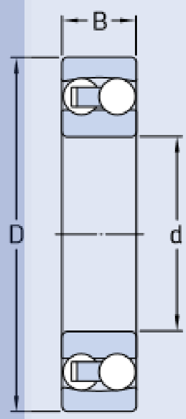
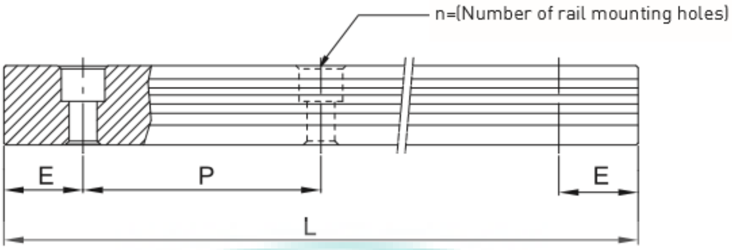


Fig. 17 Self-aligning ball bearings from SKF

2.4.5 Rail and Block

The rail and block from HIWIN Corp was decided to be used. The model is HG Series- Heavy Load Ball Type Linear Guideway. Features of HG Series are it have self-aligning capability and interchangeability. It also has high rigidity in all four directions and have high dust proof accessories.

It also can achieve long life with high speed, high accuracy and smooth linear motion. The dimension of the rail show as Figure 18 while dimension of the block show as Figure 19.



Item	HG15	HG20	HG25	HG30	HG35	HG45	HG55	HG65
Standard Length L(n)	160 (3)	220 (4)	220 (4)	280 (4)	280 (4)	570 (6)	780 (7)	1,270 (9)
	220 (4)	280 (5)	280 (5)	440 (6)	440 (6)	885 (9)	1,020 (9)	1,570 (11)
	280 (5)	340 (6)	340 (6)	600 (8)	600 (8)	1,200 (12)	1,260 (11)	2,020 (14)
	340 (6)	460 (8)	460 (8)	760 (10)	760 (10)	1,620 (16)	1,500 (13)	2,620 (18)
	460 (8)	640 (11)	640 (11)	1,000 (13)	1,000 (13)	2,040 (20)	1,980 (17)	
	640 (11)	820 (14)	820 (14)	1,640 (21)	1,640 (21)	2,460 (24)	2,580 (22)	
	820 (14)	1,000 (17)	1,000 (17)	2,040 (26)	2,040 (26)	2,985 (29)	2,940 (25)	
		1,240 (21)	1,240 (21)	2,520 (32)	2,520 (32)			
			1,600 (27)	3,000 (38)	3,000 (38)			
Pitch (P)	60	60	60	80	80	105	120	150
Distance to End (E_s)	20	20	20	20	20	22.5	30	35
Max. Standard Length	1,960 (33)	4,000 (67)	4,000 (67)	3,960 (50)	3,960 (50)	3,930 (38)	3,900 (33)	3,970 (27)
Max. Length	2,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000

Fig. 18 Dimension of HG Series- Heavy Load Ball Type Linear Guideway rail from HIWIN Corp (cont)

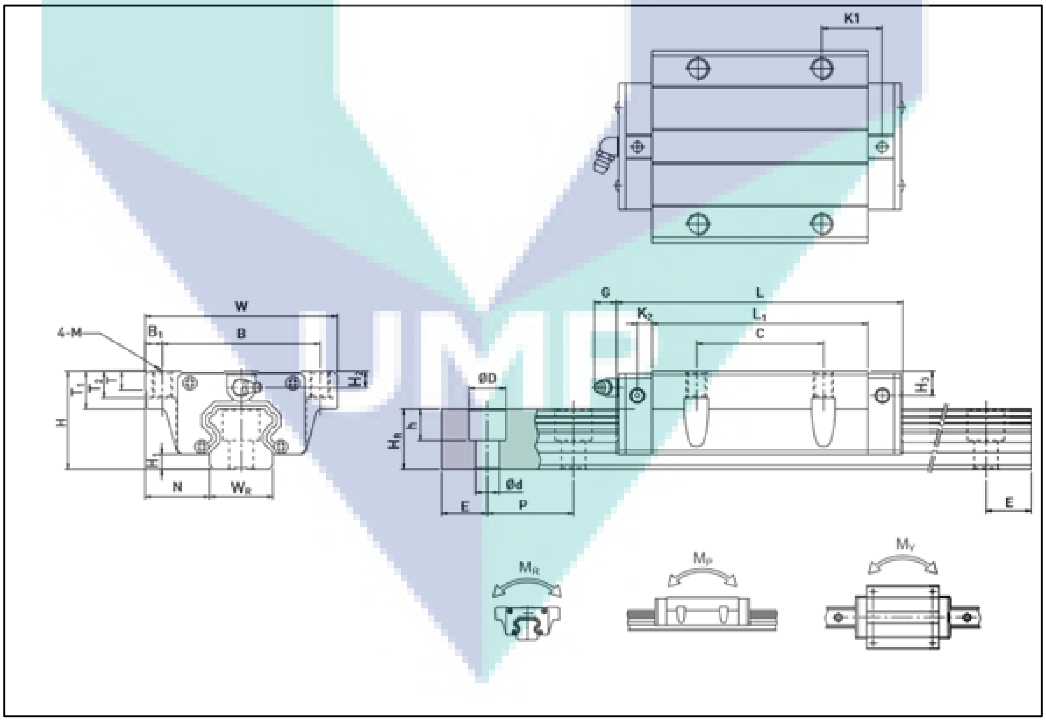


Fig. 19 Dimension of HG Series- Heavy Load Ball Type Linear Guideway block from HIWIN Corp

Model No.	Dimensions of Assembly (mm)			Dimensions of Block (mm)															Dimensions of Rail (mm)							Mounting Bolt for Rail	Basic Dynamic Load Rating	Basic Static Load Rating	Static Rated Moment			Weight	
																													M_R	M_P	M_Y	Block	Rail
	H	H_1	N	W	B	B_1	C	L_1	L	K_1	K_2	G	M	T	T_1	T_2	H_2	H_3	W_R	H_R	D	h	d	P	E	(mm)	C(kN)	C_0 (kN)	kN-m	kN-m	kN-m	kg	kg/m
HGW15CC	24	4.3	16	47	38	4.5	30	39.4	61.4	8	4.85	5.3	M5	6	8.9	6.95	3.95	3.7	15	15	7.5	5.3	4.5	60	20	M4x16	11.38	16.97	0.12	0.10	0.10	0.17	1.45
HGW20CC	30	4.6	21.5	63	53	5	40	50.5	77.5	10.25	6	12	M6	8	10	9.5	6	6	20	17.5	9.5	8.5	6	60	20	M5x16	17.75	27.76	0.27	0.20	0.20	0.40	2.21
HGW20HC								65.2	92.2	17.6																	21.18	35.90	0.35	0.35	0.35	0.52	
HGW25CC	36	5.5	23.5	70	57	6.5	45	58	84	10.7	6	12	M8	8	14	10	6	5	23	22	11	9	7	60	20	M6x20	26.48	36.49	0.42	0.33	0.33	0.59	3.21
HGW25HC								78.6	104.6	21																	32.75	49.44	0.56	0.57	0.57	0.80	
HGW30CC	42	6	31	90	72	9	52	70	97.4	14.25	6	12	M10	8.5	16	10	6.5	10.8	28	26	14	12	9	80	20	M8x25	38.74	52.19	0.66	0.53	0.53	1.09	4.47
HGW30HC								93	120.4	25.75																	47.27	69.16	0.88	0.92	0.92	1.44	
HGW35CC	48	7.5	33	100	82	9	62	80	112.4	14.6	7	12	M10	10.1	18	13	9	12.6	34	29	14	12	9	80	20	M8x25	49.52	69.16	1.16	0.81	0.81	1.56	6.30
HGW35HC								105.8	138.2	27.5																	60.21	91.63	1.54	1.40	1.40	2.06	
HGW45CC	60	9.5	37.5	120	100	10	80	97	139.4	13	10	12.9	M12	15.1	22	15	8.5	20.5	45	38	20	17	14	105	22.5	M12x35	77.57	102.71	1.98	1.55	1.55	2.79	10.41
HGW45HC								128.8	171.2	28.9																	94.54	136.46	2.63	2.68	2.68	3.69	
HGW55CC	70	13	43.5	140	116	12	95	117.7	166.7	17.35	11	12.9	M14	17.5	26.5	17	12	19	53	44	23	20	16	120	30	M14x45	114.44	148.33	3.69	2.64	2.64	4.52	15.08
HGW55HC								155.8	204.8	36.4																	139.35	196.20	4.88	4.57	4.57	5.96	
HGW65CC	90	15	53.5	170	142	14	110	144.2	200.2	23.1	14	12.9	M16	25	37.5	23	15	15	63	53	26	22	18	150	35	M16x50	163.63	215.33	6.65	4.27	4.27	9.17	21.18
HGW65HC								203.6	259.6	52.8																	208.36	303.13	9.38	7.38	7.38	12.89	

Fig. 20 Dimension of HG Series- Heavy Load Ball Type Linear Guideway block from HIWIN Corp (cont)

2.4.6 Tension and Compression Load Cell

The LCM Systems DCE load cell shown as Figure 20 has been developed for applications that require the measurement of tensile and compressive forces, where space is limited. As with most LCM products there are special variants that are available for this product. Popular variants include different thread sizes, integral connectors and high temperature versions. The DCE can be supplied on it is own or integrated with any of the wide range of instrumentation products available from LCM Systems. Specification and dimension of the tension and compression show as Figure 21 and Figure 22 respectively.

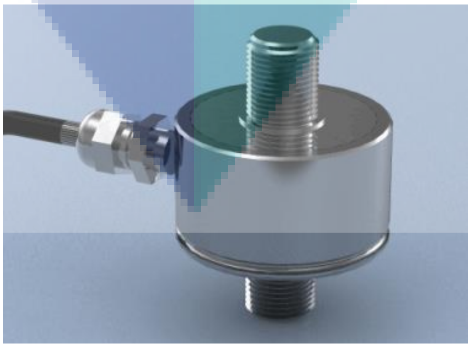
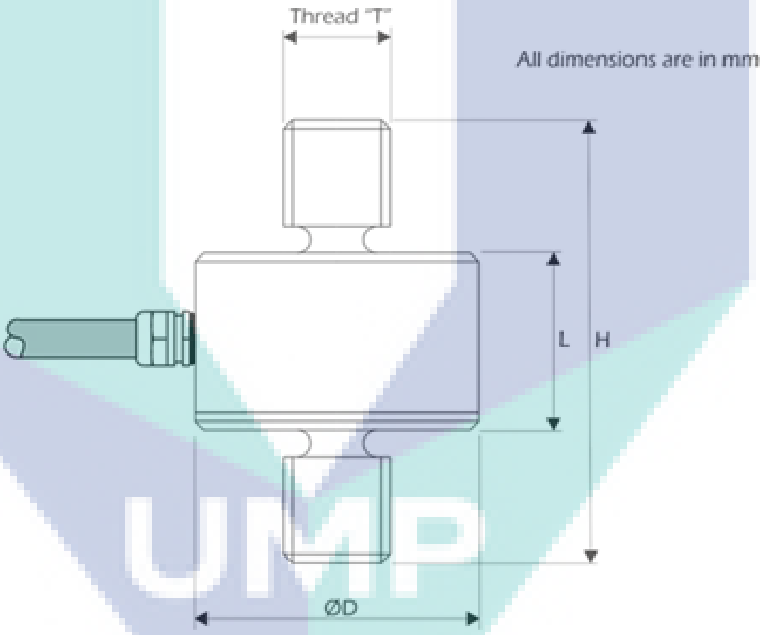


Fig. 21 Tension and Compression Load Cell

Rated load (Newtons)	100, 250, 500 750
(Kilonewtons)	1, 2.5, 5, 7.5, 10, 25, 50
Proof load	150% of rated load
Ultimate breaking load	>300% of rated load
Maximum side load	10% of rated load
Output	1.5mV/V at rated load (nominal)
Non-Linearity	<±0.25% of rated load
Non-Repeatability	<±0.1% of rated load
Excitation voltage	10vdc recommended, 15vdc maximum
Bridge resistance	350Ω (25kN and 50kN: 700Ω)
Insulation resistance	>500MΩ @500vdc
Operating temperate range	-20 to +70°C
Compensated temperature range	-10 to +50°C
Zero temperature coefficient	<±0.01% of rated load/°C
Span temperature coefficient	<±0.01% of rated load/°C
Environmental protection level	IP65
Connection type	2 metres 4-core screened PVC cable
Wiring connections	+ve supply: Red -ve supply: Blue +ve signal: Green -ve signal: Yellow

Fig. 22 Specification of Tension and Compression Load Cell



Rating	Part Number	Thread "T"	ØD	L	H	Weight (g)	Resolution
100N	DCE-100N	M4 x 0.7	20	13	29	30	0.1N
250N	DCE-200N	M4 x 0.7	20	13	29	30	0.2N
500N	DCE-500N	M4 x 0.7	20	13	29	30	0.5N
750N	DCE-750N	M4 x 0.7	20	13	29	30	1N
1kN	DCE-1KN	M5 x 0.8	20	13	33	30	0.001kN
2.5kN	DCE-2.5KN	M5 x 0.8	20	13	33	30	0.002kN
5 kN	DCE-5KN	M10 x 1.0	32	20	45	45	0.005kN
7.5kN	DCE-7.5KN	M10 1.0	32	20	45	45	0.01kN
10kN	DCE-10KN	M12 x 1.75	38	22	52	45	0.01kN
25kN	DCE-25KN	M20 x 1.5	38	24	84	45	0.02kN
50kN	DCE-50KN	M24 x 2.0	38	30	102	45	0.05kN

Fig. 23 Dimension of Tension and Compression Load Cell

2.4.7 Temperature Sensor

The temperature that were used in this machine is Infrared Thermometer CTLM-2HSF300-C3 as Figure 23. Non-contact infrared temperature sensors from Micro-Epsilon are being used on a range of medium and high frequency induction heaters in order to measure the temperature of metal components during heat treatment. The sensors were selected due to a range of factors, including low cost, compactness and interchangeability. Specification of Infrared Thermometer CTLM-2HSF300-C3 show in Figure 24.

Fig. 24 Infrared Thermometer CTLM-2HSF300-C3

Model	CTLM-1LSF150-C3	CTLM-1HSF300-C3	CTLM-1H1SF300-C3	CTLM-2LSF150-C3	CTLM-2HSF300-C3	CTLM-2H1SF300-C3
Optical resolution	150:1	300:1		150:1	300:1	
Temperature range [1]	485 to 1050°C	650 to 1800°C	800 to 2200°C	250 to 800°C	385 to 1600°C	490 to 2000°C
Spectral range	1µm			1.6µm		
System accuracy [2]	±(0.3% of reading +2°C)					
Repeatability [2]	±(0.1% of reading +1°C)					
Temperature resolution	0.1°C	0.2°C		0.1°C	0.2°C	
Response time (90% signal) [3]	1ms					
Emissivity/gain [1]	0.100 to 1.100					
Transmissivity/gain [1]	0.100 to 1.000					
Signal processing [1]	peak hold, valley hold, average; extended hold function with threshold and hysteresis					
Certificate of calibration	optional					
Outputs/analog channel 1	0/4 to 20mA, 0 to 5/10V, thermocouple J, K					
Outputs/analog optional	relay: 2 x 60VDC / 42VAC; 0.4A; electrically isolated					
Alarm output	open - collector (24V/ 50mA)					
Outputs/digital optional	USB, RS232, RS485, CAN, Profibus DP, Ethernet					
Output impedances current output / voltage output	mA max. 500Ω (with 5 - 36VDC) mV min. 100kΩ load impedance; thermocouple 20Ω					
Inputs	programmable functional inputs for external emissivity adjustment, ambient temperature compensation, trigger (reset of hold functions)					
Cable length	3m (standard), 8m, 15m					
Power supply	8 to 36VDC; max. 160mA					
Laser	class II (635nm), 1mW, ON/OFF via controller or software					
Protection class	IP65 (NEMA-4)					
Ambient temperature	sensor: -20°C to 85°C (50°C with Laser ON) controller: 0°C to 85°C					

Fig. 25 Specification of Infrared Thermometer CTLM-2HSF300-C3

Storage temperature		sensor: -40°C to 85°C controller: -40°C to 85°C
Relative humidity		10 to 95%, non condensing
Vibration	sensor	IEC 68-2-6: 3 G, 11-200Hz, any axis
Shock	sensor	IEC 68-2-27: 50 G, 11ms, any axis
Weight		sensor: 600g; controller: 420g

[1] Adjustable via controller or software
[2] ε = 1, response time 1s; at ambient temperature: 23 ±5°C
[3] with dynamic adaption at low signal levels

Fig. 26 Specification of Infrared Thermometer CTLM-2HSF300-C3 (cont)

2.4.8 Mach 3 CNC Software

Mach3 turns a typical computer into a CNC machine controller. It is very rich in features and provides a great value to those needing a CNC control package. Mach3 works on most Windows PC's to control the motion of motors (stepper & servo) by processing G-Code. While comprising many advanced features, it is the most intuitive CNC control software available. Mach3 is customizable and has been used for many applications with numerous types of hardwares.

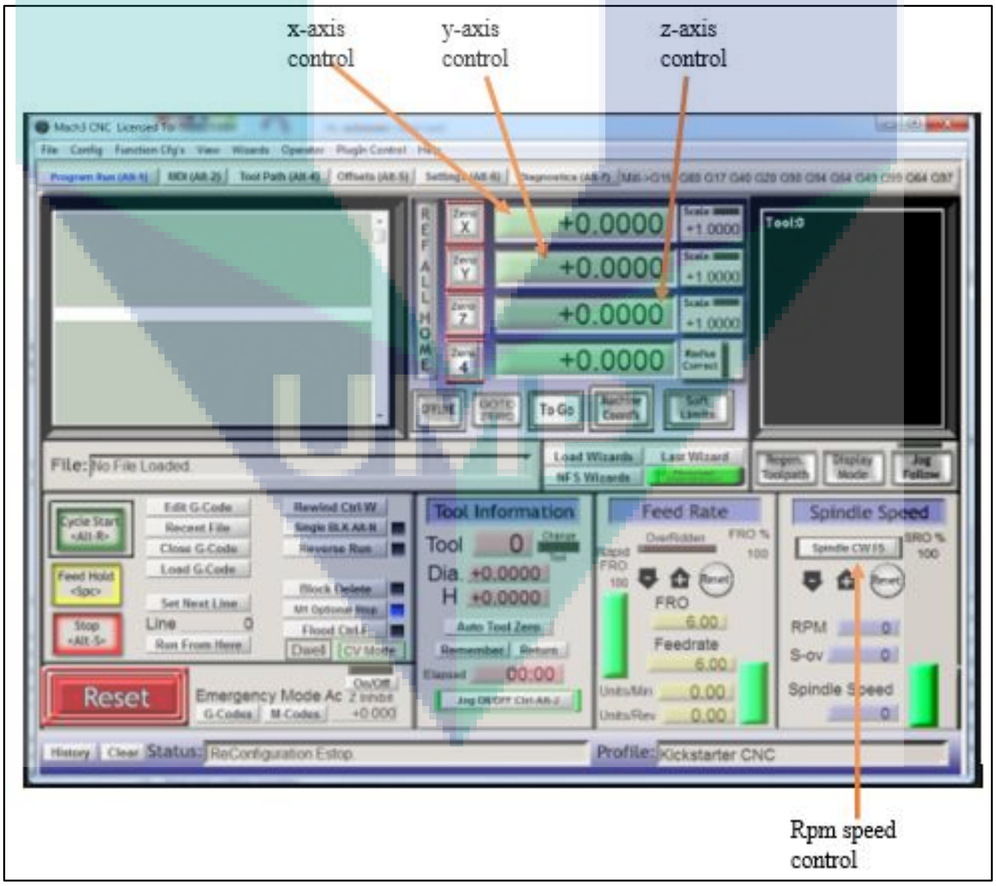


Fig. 27 Interface of Mach 3 CNC Software

2.5 PHASE 5: INTEGRATION OF CONTROL SYSTEM TO THE FSW STRUCTURE

Integration of Control System to the FSW Structure is the process of bringing together the component sub-systems into one system (an aggregation of subsystems cooperating so that the system is able to deliver the overarching functionality) and ensuring that the subsystems function together as a system, and in information technology as the process of linking together different computing systems and software applications physically or functionally, to act as a coordinated whole.

2.5.1 Control Panel Box

This control panel box includes all the controller of the machine, cables, USB port, and main switch. It also consists of the motor driver for the servo and step motor. It has fan to cooling system as shown in Figure 26.

Fig. 28 Control Panel Box

Wiring diagram for the control panel box is shown in Figure 27 where it was built for the PLC system of this machine using components such as stepper and spindle drivers.

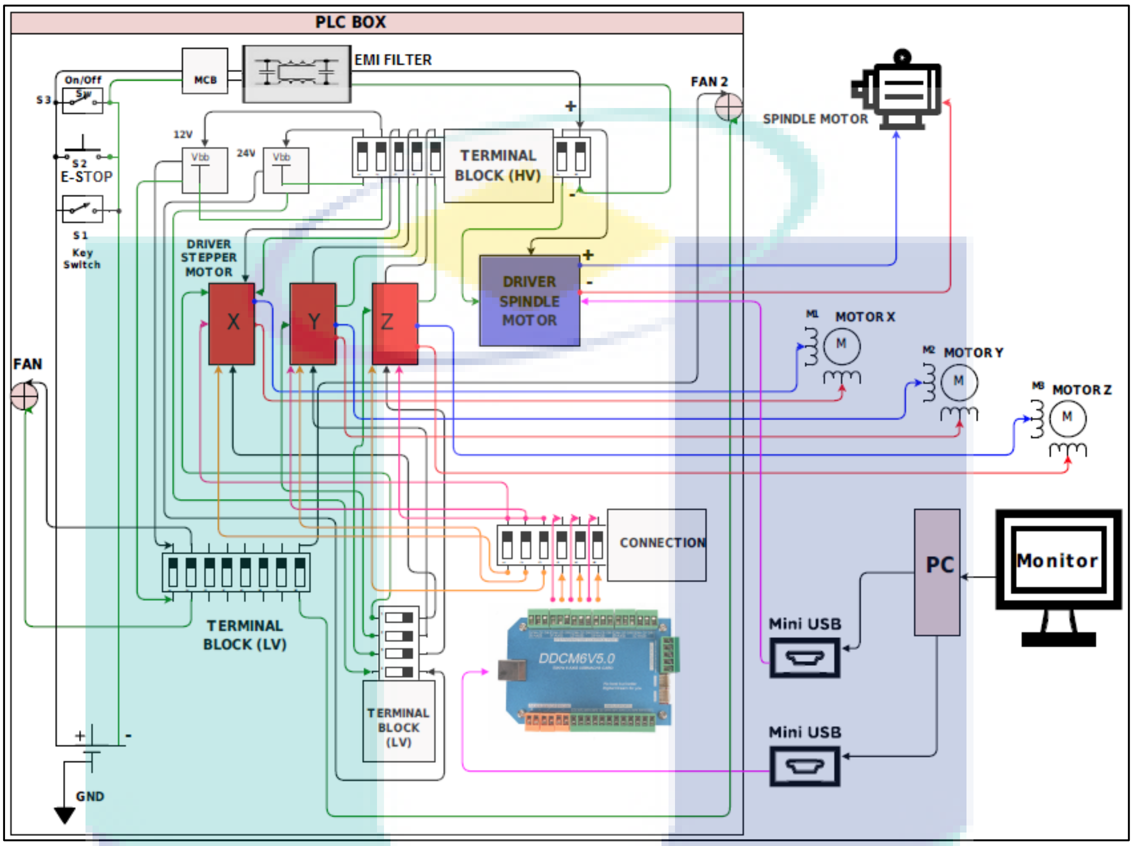


Fig. 29 Wiring Diagram for PLC Sytem.

2.6 PHASE 6: JIG, CLAMPS DESIGN AND FABRICATION

Jig and clamps is important during the welding process. This jig and clamps is use to hold the specimen during welding process. This jig and clamps design was based on table of the FSW machine. This design made using Solid work software and its fabrication made by CNC machine that we have here in FKM laboratory.

Figure 28 shows the final design of the jig and clamp that using the Solid work software. For the final product, we use two types of materials (stainless steel and aluminium). The position of the stainless steel and aluminium was show in Figure 29.

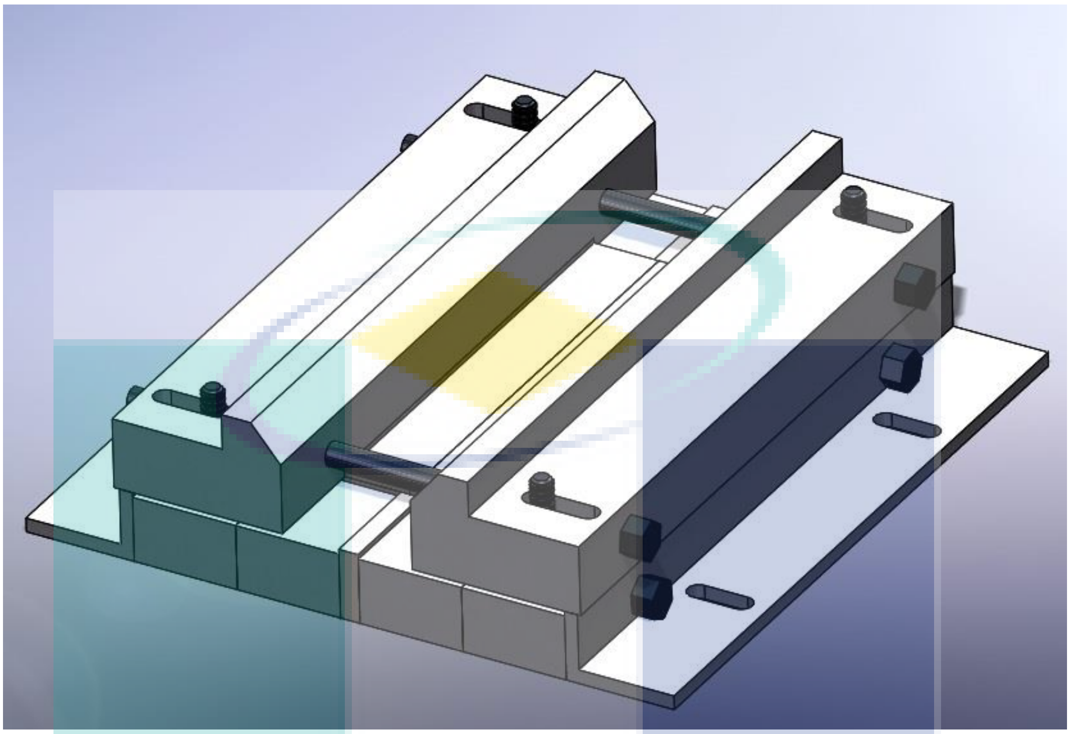


Fig. 30 Design of Jig and Clamp in Solid work Software

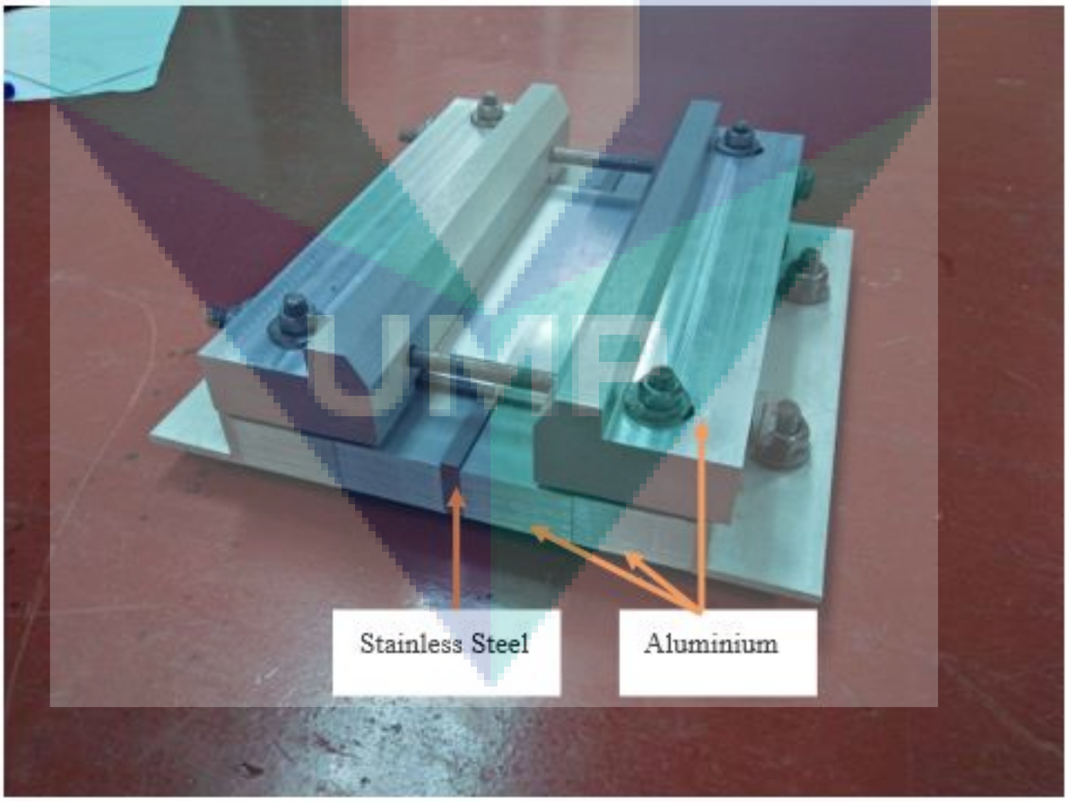


Fig. 31 Final Product of Jig and Clamp

2.6.1 *Machine Assembly*

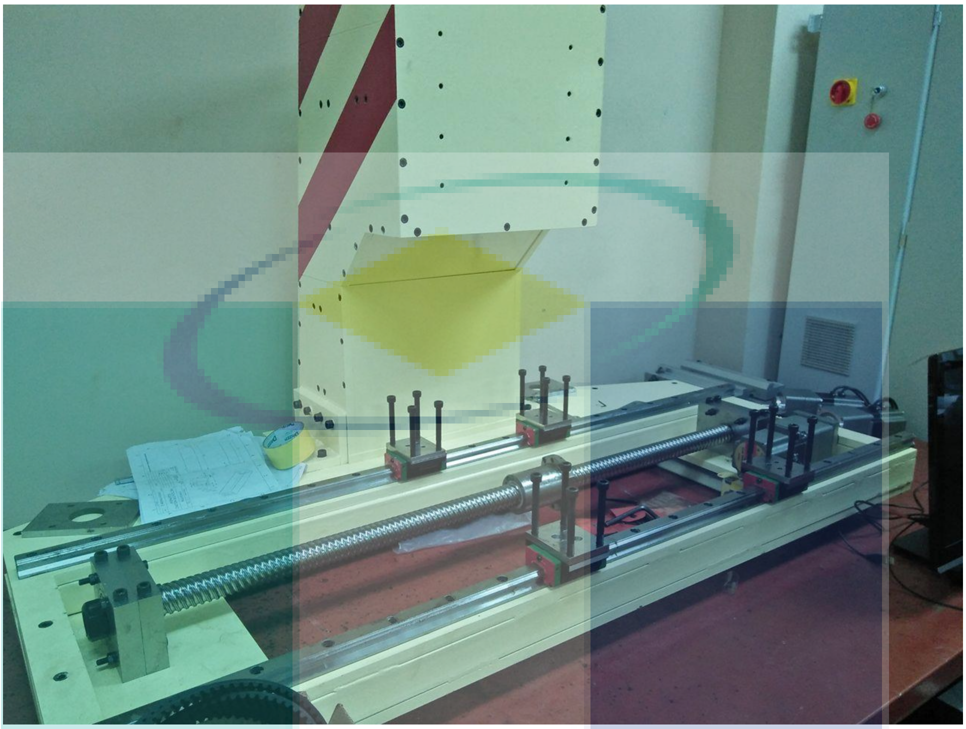


Fig. 32 Assembly of x-axis Ball Screw

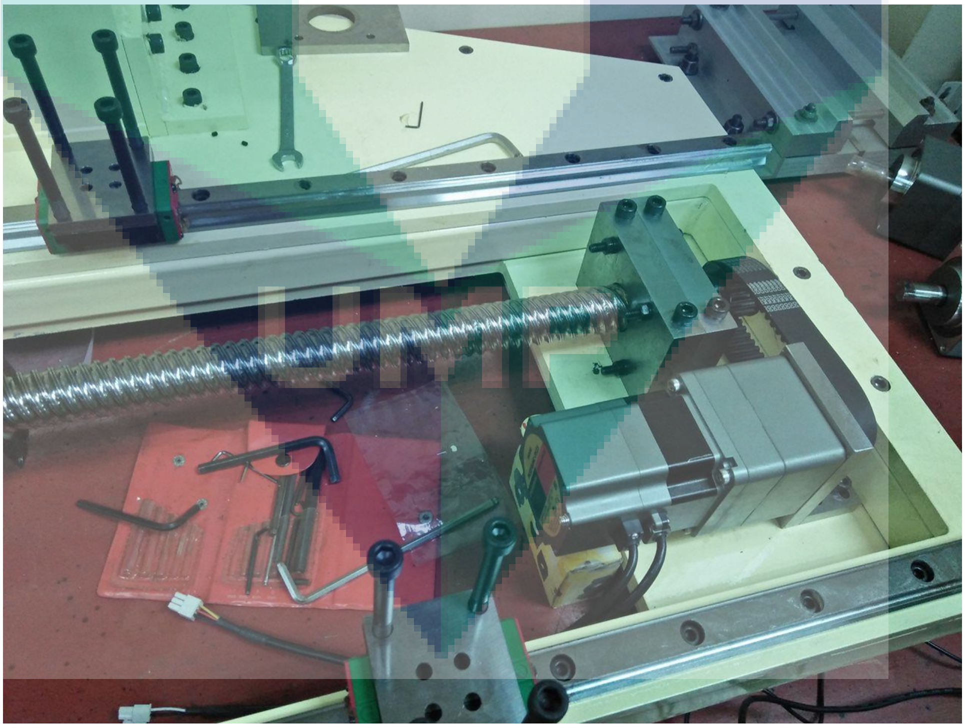


Fig. 33 Assembly of x-axis Stepper Motor

For the assembly parts, the machine was still under progress. The rail guide had been attached to the main frame of this machine as shown in Figure 30. As observed, the base plate for the jig attachment had been added at the rail. In addition, the ball screw thread also had been attached for the x-axis of the machine. Figure 31 shows the stepper motor that had been placed at its position along with the belting.

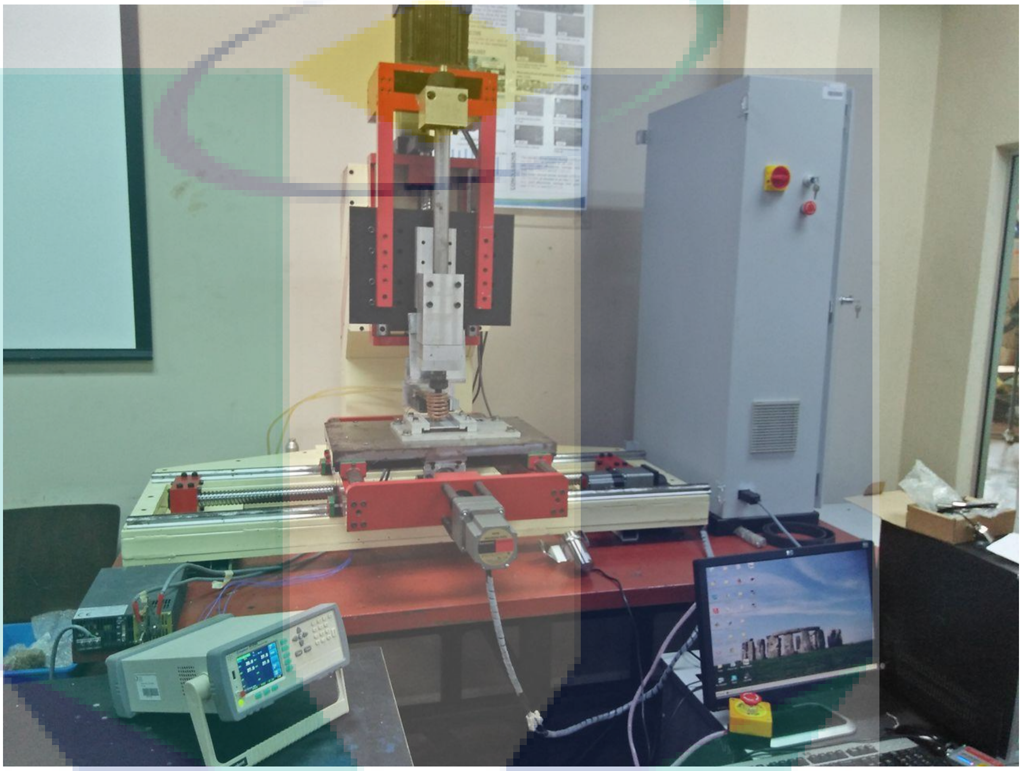


Fig. 34 Full Assembly Machine

Figure 32 shows the full assembly of the machine. All the mechanical parts of the machine are full attached to its position. We have 3 stepper motor for the x, y and z axis and single servo motor for the rotation of the tool. For the safety, we have two emergency stop buttons in case of accident happen. The tension and compression load cell and infrared thermometer are attached to get data of force and temperature during experiment.

CHAPTER 3

TESTING AND RESULT

3.1 RESULTS FOR SIMILAR AND DISSIMILAR WELD

Figure 33 shows the joining between two similar metals Al 6061. The thickness of this Al 6061 is 2mm. To this testing we use 1100rpm of rotating speed and 100mm/min for welding speed.

Figure 34 shows the joining between two dissimilar metals, Al 6061 and Al 7075, and the thickness of this specimen are 2mm. The parameters for this testing are 1000rpm of rotating speed and 100mm/min for welding speed.

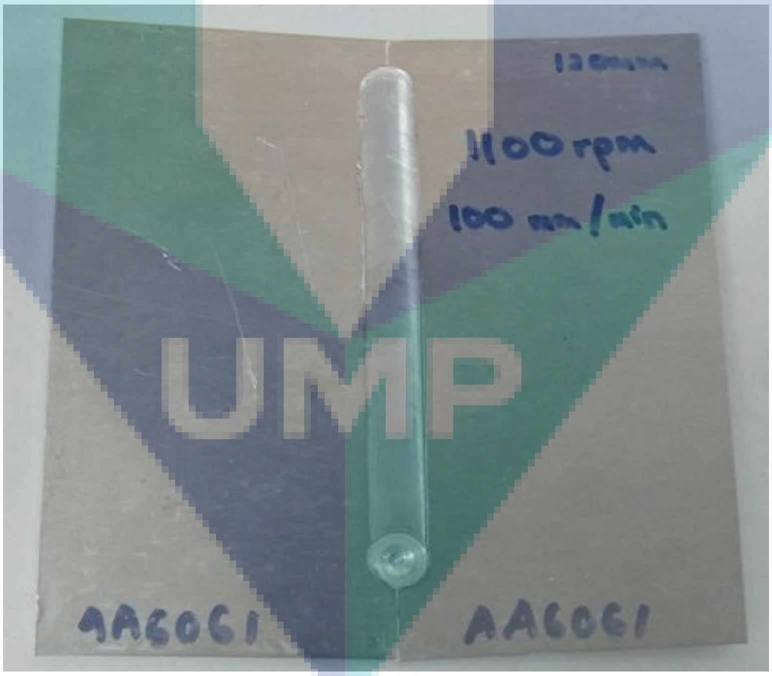


Fig. 35 Similar metal joining, Al 6061 (thickness 2mm)

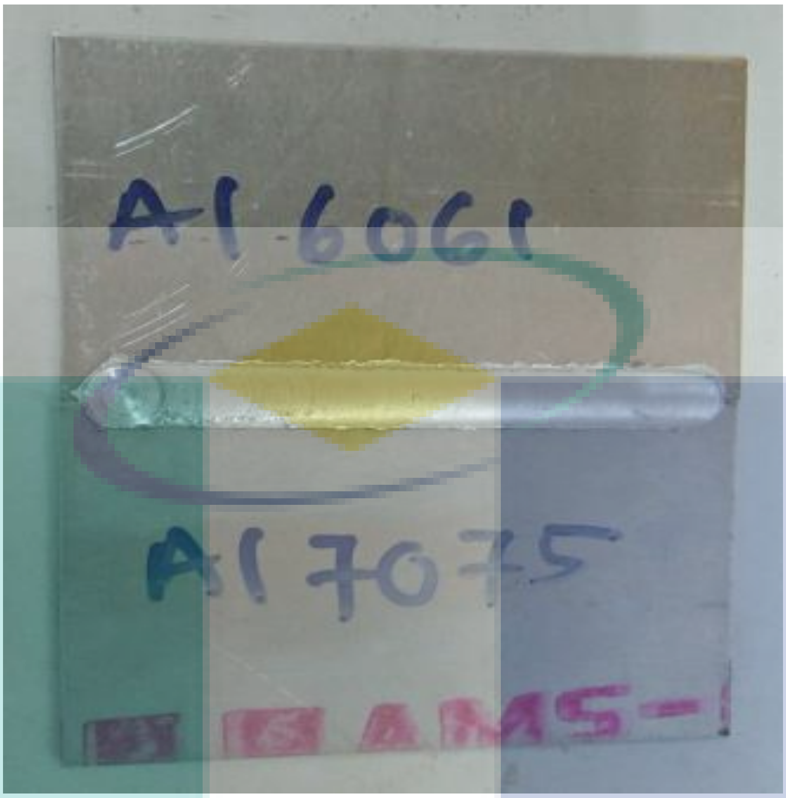


Fig. 36 Dissimilar metal joining, Al 7075 and Al 6061 (thickness 2mm)

For Figure 35, we use 1100rpm for rotating speed and 90mm/min for welding speed. The materials that use for this testing are Al 7072 and Al 6061. The materials are 4mm thickness.

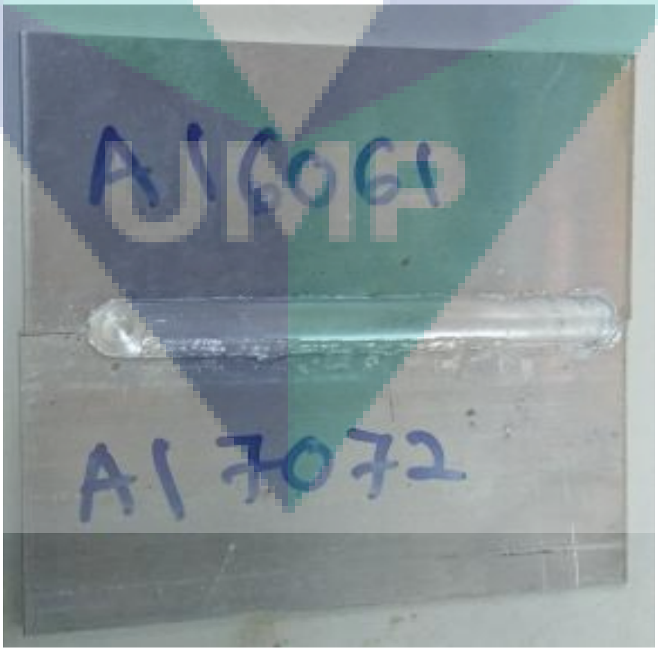


Fig. 37 Dissimilar metal joining, Al 7072 and Al 6061 (thickness 4mm)

CHAPTER 4

CONCLUSION

3.1 CONCLUSION

The machine already completed, all parts already been attached to the machine and working properly. The dissimilar type of Aluminum Alloys has been successfully welded by this FSW machine. Tools and special clamp also has been developed for the dissimilar alloys welding.

Overall, the team feels the project has been successfully completed. A great deal of knowledge has been gained through the trials of this project, this lessons will be invaluable in future endeavours.

CHAPTER 5

RESEARCH OUTPUT

5.1 List of Published Papers

1. Mohammed M. Hassan, M. Ishak, M.R.M. Rejab (2017), *Influence of machine variables and tool profile on the tensile strength of dissimilar AA-7075-AA6061 friction stir welds*, The International Journal of Advance Manufacturing Technology (90), 2605-2615.
2. Mohammed M. Hassan, M. Ishak, M.R.M. Rejab (2017), *Effect of backing material and clamping system on tensile strength of dissimilar AA7075-AA2024 friction stir welds*, The International Journal of Advance Manufacturing Technology (91), 3991-4007.
3. Z.C. Nik, M. Ishak, N.H. Othman (2017), *The effect of tool pin shape of friction stir welding (FSW) on Polypropylene*, IOP Conference Series: Materials Science and Engineering 238 (1)
4. Mohammed M. Hassan, M. Ishak, M.R.M. Rejab (2015), *A simplified design of clamping system and fixtures for friction stir welding of aluminium alloys*, Journal of Mechanical Engineering and Sciences, (9), 1628-1639.
5. Mohammed M. Hassan, M. Ishak, M.R.M. Rejab (2018), Effect of pin tool flute radius on the material flow and tensile properties of dissimilar friction stir welded aluminum alloys, The International Journal of Advanced Manufacturing Technology, https://doi.org/10.1007/s00170-018-2426-7

5.2 List of Conferences

1. 3rd International Conference on Mechanical Engineering Research (ICMER2015)/ Kuantan, Pahang, Malaysia. 18-19 August 2015.
2. 2nd International Conference on Automotive Innovation and Green Energy Vehicle (AiGEV2016)/ Malaysia Automotive Institute (MAI), Cyberjaya, Selangor, Malaysia. 2-3 August 2016.

5.3 List of Awards

1. *Silver Medal* in the Citrex 2017 Exhibition. UMP, Gambang, Malaysia. Design of FSW machine.
2. *Bronze Medal* in the Citrex 2017 Exhibition. UMP, Gambang, Malaysia. Design of backing plate and clamping system.

5.4 Paten

1. Clamping Jig For Dissimilar Friction Stir Welding, PI 2017700587.