CHAPTER 2

LITERATURE REVIEW

2.1 Conceptual Review

Fatigue tensile machine required to understand about testing specimen to get cyclic loading. Fatigue will be affected on any part of component that moves such as automobile, fuselages and aircraft wings. Therefore, there are three type of causes fatigue factors which are maximum tensile stress, large enough variation and large number of cycle when applied stress[1].

Moreover, the mechanisms that relate to the fatigue tensile machine are gripping, alignment, motor, and susceptibility of tensile under cyclic loading.It is the main reason for fatigue result or report. There are several numerical fatigue damages that had been analyzed for experimentally to observe their fatigue occur on material [2]. The purpose of the observation to analyze the structural of specimens when applied stress with cyclic loading.

In this chapter,study about the existing machine that required on market and analyzed the concept of design for more information of specifications. The design of the machine concentrated on gripper design, specimen geometry and type of motor that may take for design. This study summarizes on published literature review with relating to the fatigue tensile machine.

2.2 Fatigue Tensile

The purpose of fatigue tensile is to create the stress cyclic while force on material operates with repeatedly such as tensile process. This process are enable for student or engineer estimates their lifetime of structure [3]. Failure due to fatigue occur when stress are applied below the yield strength. If the material was processed repeatedly with loaded and unloaded which 85% of its yield strength, the material fail in fatigue if the loaded complete in cycle. Moreover if the steel elongates approximately 30% on tensile test, there is no evident in appearance of fatigue fracture. There are three stages on fatigue failure which is crack initiation, crack propagation, and fast fracture[4].

In this study, fatigue damage growths are different alternative to addressing the phenomenon. Residual tensile need to focus based on stress strain curve by fatigue material. Based on analysis of material, large strain and high strain rates are important in military applications. Fatigue may effect on structural of material behavior and structure will be different if under extreme loading [3]. Figure 2.1 shows the schematic illustrating of cyclic loading parameter that can be defined as distribution force that changes over time in repetition.

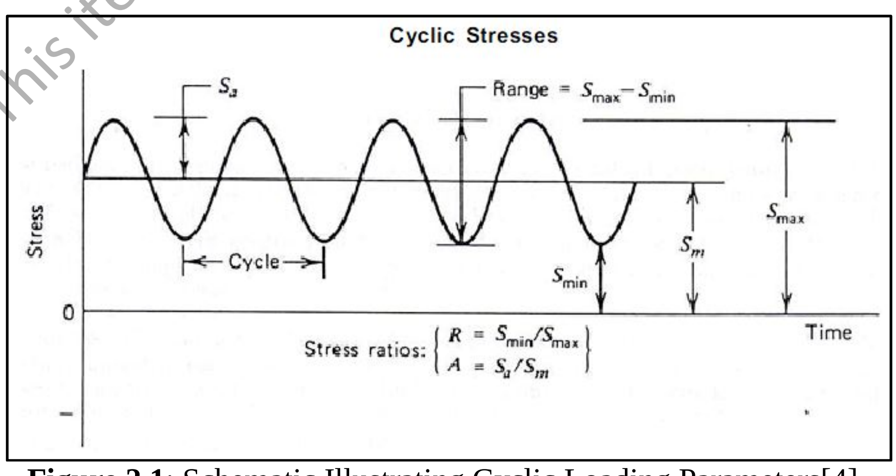

Figure 2.1: Schematic Illustrating Cyclic Loading Parameters[4].

The accompanying parameters are used to distinguish fluctuating stress cycle:

Mean stress (σ_m):

$$\sigma_m = \frac{S_{max} + S_{min}}{2} \tag{2.1}$$

Stress range (σ_r):

$$\sigma_r = \sigma_{max} - \sigma_{min} \tag{2.2}$$

Stress Amplitude (σ_a):

$$\sigma_a = \frac{S_{max} - S_{min}}{2} \tag{2.3}$$

Stress Ratio (R):

$$R = \frac{S_{min}}{S_{max}} \tag{2.4}$$

The Fatigue Life (N_f) of a part is characterized by the total number of stress cycles to bring about failure. Fatigue Life can be isolated into three stages:

$$N_f = N_i + N_p \tag{2.5}$$

Crack initiation (N_i) is cycle that initial to crack and it is shown as defect on a surface scratches. Crack growth (N_p) is cycle that crack start to spread in stable to a critical size. Rapid fracture is critical crack that start to spread with rapidly when the crack of length able to reach on critical value[4].

2.3 Fatigue Tensile machine

Fatigue tensile machine is a machine that was used to apply repeated cyclic on the test specimen. Figure 2.2 shows the rotation of motor make the cyclic loading occur on the specimen. Specimen will be push and pull motion with repeatedly to get a fatigue process. The structural of specimen will be affected with crack and when it achieve at critical limit the specimen will be fractured. Crack will start to growth on stress concentrate to surface when fatigue occurs on specimen. Figure 2.3 shows micro fatigue test with a small size of test specimen. This machine illustrates the CAD model and completed Micro Fatigue Test Rig to evaluate 200 µm thick 304 SS specimen. The MFTR comprises of a piezo electric actuator which operates in the range of 0 – 180 µm linear displacement with a resolution of 1.8 nm.

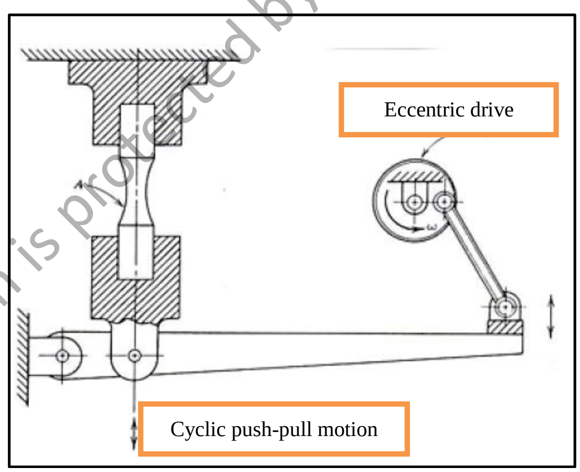

Figure 2.2: Direct Force Fatigue Testing Machine[4].

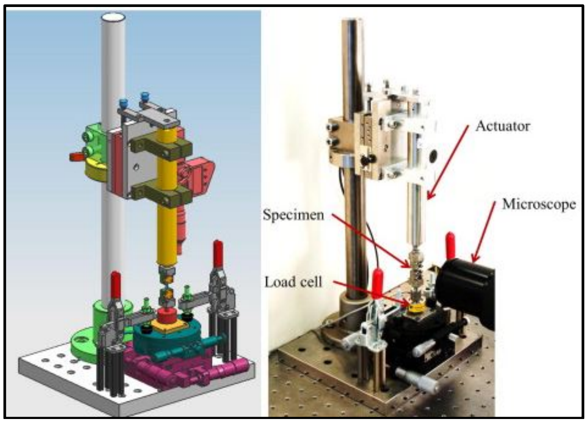

Figure 2.3: Micro Fatigue Test [2].

There are two types of specimen that were examine in tensile and fatigue tensile such as SAE 4340 steel bars with diameter 14mm. The steel bar had different composition such in Table 2.1 to differentiate the strength level. The strain rate of tensile test that were conducted are $2 \times 10^{-4} s^{-1}$ and fatigue test with frequency 20 kHz up to 10^{9} cycles with very high cycle using ultrasonic fatigue test [5]. Tables 2.2 shows the heat treatment procedure for SAE 4340 steel.

Table 2.1: Chemical composition of SAE 4340 steel[5].

C	Mn	Si	P	S	Cr	Ni	Mo	Cu	As
0.42	0.66	0.25	0.009	0.014	0.74	1.41	0.17	0.11	0.014

Table 2.2: Heat treatment procedures of SAE 4340 steel.

No	Quenching	Tempering
A	Preheating to 850˚C	180 ˚C tempering for 120 min
B	For 10min and quenching in oil	250 ˚C tempering for 120 min
C		350 ˚C tempering for 120 min
D		420 ˚C tempering for 30 min
E		500 ˚C tempering for 30 min

Moreover, at the middle of specimen using compressed air to prevent from sample heating occur. Electron backscattered diffraction (EBSD) were used for microstructures of specimen. Figure 2.4 shows type of specimens that had been analyzed with tensile test and fatigue test[5].

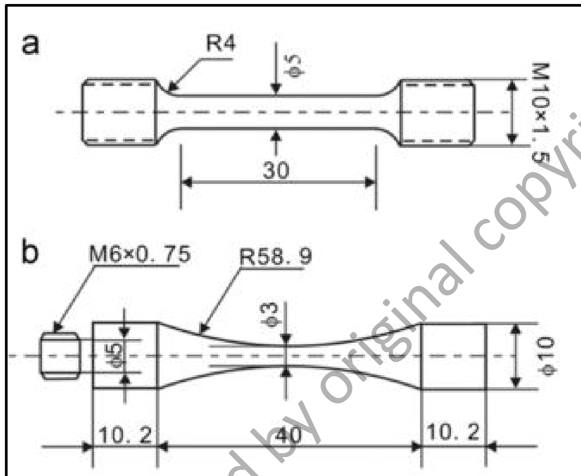

Figure 2.4:(a) Tensile Strength and Fatigue Tensile [5].

To determine crack that occur on structural specimen will use microscope or high speed camera to capture initiation. Stress damage will be evaluated by Palmgren-Miner rule (P-MR) method. P-MR will be defined as damage per given stress which known as fraction of fatigue life [6]. There are three stages that fracture will produce during fatigue occur which is crack initiation, crack grow, and fracture. Figure 2.5 shows the crack start occur from beginning to the end.At the minimum cross section, crack initiation will be observed on specimen. Crack grow will be observed where it does not traverses directly to the minimum cross section and crack will start to spread with linearly [2]. Figure 2.6 shows the sequence of event observed by fatigue cycles from the crack initiation to the final failure.

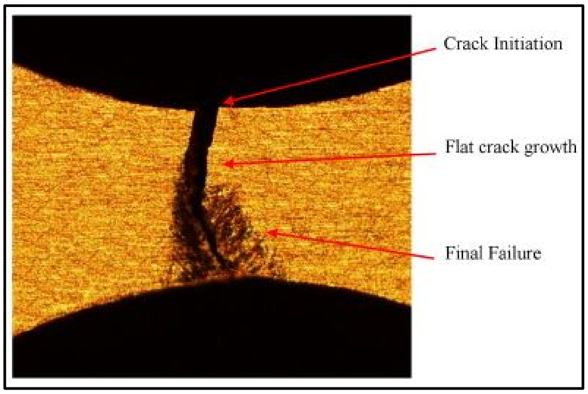

Figure 2.5: Crack Initiation, Crack Growth, Final Failure [2].

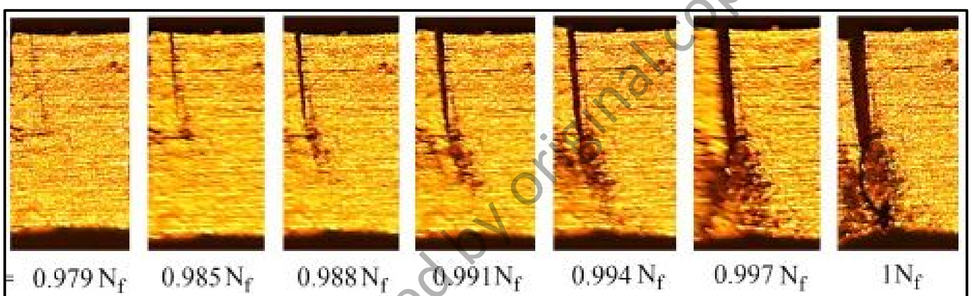

Figure 2.6: Sequence of Event Observed by Fatigue Cycles [2].

2.4 Mechanism of Fatigue Tensile Machine

Mechanism of fatigue tensile machine will be defined as part component of the machines. There are several parts that had been in market with the different specification. Most of it have a same function but different characterized and specification of product. The mechanism of machine is the main part on the design to figure out their function and specifications.

2.4.1 Gripper Mechanism

In the fatigue tensile machine, gripper is the main part function to hold the specimen during fatigue tensile process. There are many type of grip configuration that was used in tensile. Specific design is limited to relatively low material strength for the collet and the holder can be spread open under heavy load disrupt the uniformity of the load. Figure 2.7 shows type of gripper mechanism that was used in fatigue tensile machine.

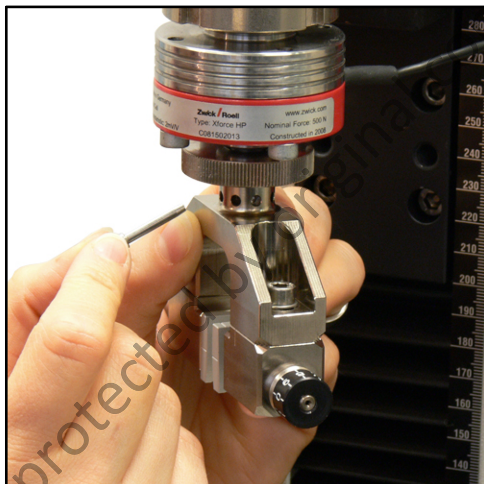

Figure 2.7: Screw Grips[7].

Screw grip function when applied force by manually which is using via an electric motor. The grip only used for smaller test load from 20N to max 50kN and thinner specimens such as wire, films, fibers, and so on. Gripping force based on the screw torque and grasp consistence. The uses of this gripper are easy to operate. Contingent upon sort these grips have an axial bearing in the grasping unit for expanded holding powers[7]. Table 2.3 shows the specifications of screw gripbased on their criterion.

Table 2.3: Specification of Screw Grips.

Type	Description
Force maximum	50 kN
Motor	Electric motor
Size of specimen	Asymmetrical specimen
Material of specimen	Fine wire, fiber, films

Wedge screw grips as shown in Figure 2.8 consolidate the mechanical properties of screw grasps and wedge grasps. The gripping force is generated by the wedge action and the actual size is proportional. The maximum of grips is 50kN while it remains on the small load of specimen. It is operates by pneumatic motor where it open and close the grip. The surface pressure will be low if the larger grip to grip is separation allowed [8]. Table 2.4 shows type of specification wedge screw grips.

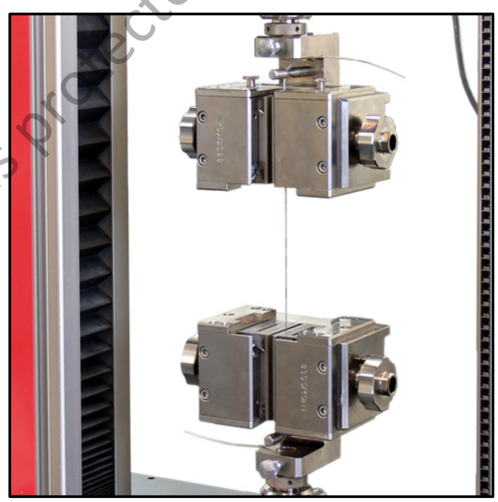

Figure 2.8: Wedge Screw Grips[8].

Table 2.4: Specification of Wedge Screw Grips.

Type	Description
Force maximum	50 kN
Motor	Pneumatic motor

Size of specimen	Wide range of material
Material of specimen	Fine wire, fiber, films, steel, aluminum

Pincer grips as shown in Figure 2.9 are used for the highly ductile of elastomers and plastic. This gripper produces an energetic of gripping where it will increase the gripping force while making the test. It is proportional to tensile force from gripping force. These grippers are easy to use and manage while making testing. The function of lever is to open and closed the pincer grips. Moreover, these grips also typically good in high temperature and low all of the height which make the grips suitable with the temperature chambers [9]. Table 2.5 shows type of specification pincer grips.

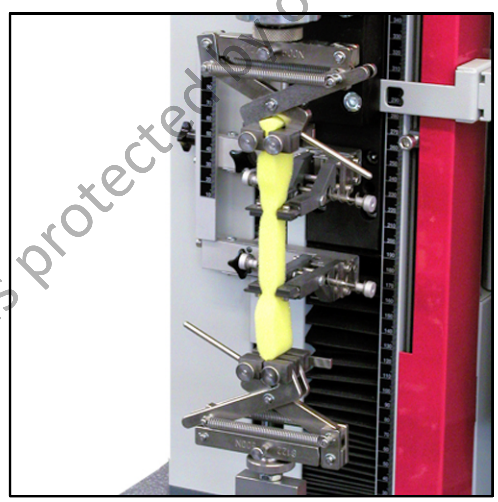

Figure 2.9: Pincer Grips[9].

Table 2.5: Specification of Pincer Grips.

Type	Description
Force maximum	30 kN
Motor	Pneumatic motor
Size of specimen	Wide range of material
Material of specimen	Plastic and elastomers

2.4.2 Summary

Based on all type of gripper, screw gripper are suitable for this machine design. The specification fulfills the criteria of the concept machine design. Maximum load for this gripper is 50 kN where it is suitable for a mini machine. The size of gripper is suitable to locate on machine design where it fulfills the specification size of machine design.

2.4.3 Motor Mechanism

Motor operates as electrical machine that transform electrical energy to the mechanical energy. Most of the electric motor work through the magnetic field and winding current to create power inside of the motor. A servomotor is a particular sort of motor that is joined with a rotating encoder or a potentiometer to shape a servomechanism. Most of stepper motors are regularly controlled by open-loop, despite the fact that the potential loss of synchronism breaking points operation far from resonances and high acceleration. Servomotor using closed loop where it will use sensor for sufficient precision. Sensorsare not used inmini machine because to reduce cost and need more space to place it [10]. Figure 2.10 shows type of motor that suitable for mini fatigue tensile machine where it has a high torque to operate.

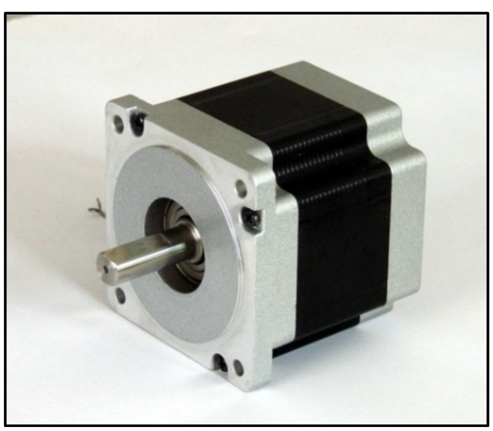

Figure 2.10: NEMA 34 Rotary Stepper Motor[11].

This motor has three type of specification which is single length, double length, and triple length. Each type has a different specification such as maximum torque, weight, and resistance. Based on this motor, it is typically has a high torque output. Table 2.6 shows specification for each motor with the different of length[11].

Table 2.6: Motor Specification[11].

6.3 Amp motors	Single length	Double length	Triple length
Part number	M-3424-6.3	M-3431-6.3	M-3447-6.3
Holding torque, N-cm	296	450	920
Detent torque, N-cm	7.7	10.0	14.0
Rotor inertia, kg-cm^2	1.0	1.6	3.4
Weight, grams	1700	2400	4000
Phase current, amps	6.3	6.3	6.3
Phase resistance, ohms	0.25	0.35	0.50
Phase inductance, mH	1.6	3.3	6.6

Based on three specifications, triple length has the highest torque than others motor. The advantage of this motor is not too noisy and smooth with accurate microstepping. Furthermore this motor also have high power and rare earth magnet design[12].

Figure 2.11: NEMA 23 Rotary Stepper Motor[12].

Figure 2.11 shows stepper motor that particular suited with OEM applications. The function of this motor is same with motor NEMA 34 but different torque, speed and power[12]. Table 2.7 shows the specification for each criterion of motor where it have single, double and triple of length.

Table 2.7: Motor Specification[12].

2.4 Amp motors	Single length	Double length	Triple length
Part number	M-2218-2.4S	M-2222-2.4S	M-2231-2.4S
Holding torque, N-cm	64	102	169
Detent torque, N-cm	2.7	3.9	6.9
Rotor inertia, $kg\text{-}cm^2$	0.18	0.26	0.468
Weight, grams	480	600	1000
Phase current, amps	2.4	2.4	2.4
Phase resistance, ohms	0.95	1.2	1.5
Phase inductance, mH	2.4	4.0	5.4

2.4.4 Summary

Based on two type of stepper motor, NEMA 34 is suitable on this machine design. The chooses is because the value of holding torque is higher than others which is 9.2 Nm. There are three types on NEMA 34 which is single, double and triple length. Triple length suitable on the specification design which fulfills the criterion of design concept.

2.4.5 Bearing Slider

Bearing slider is defined as freely movement with one direction and it moves with the drive mechanism. It also called as ball slides. On tensile machine, bearing slider was functioned as a holder of gripper which moves on Y axis. Friction was reduced and part of mechanism moved with smooth precision motion if using bearing component. There are several types of bearing slider with different characteristic.

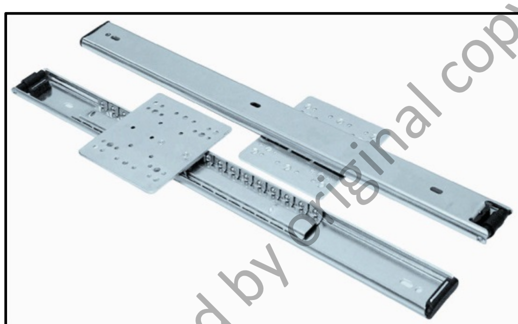

Figure 2.12: Drawer Slider[13].

Figure 2.12 shows type of ball bearing slide which function as movement with one direction with mechanism. Most of the industrial will choose this type based on their weight capacity and load balance that will carry when movement. This type has a low friction and smooth movement in one motion. The ball bearings also are not too expensive in manufacture. Table 2.8 shows the specification of drawer slider.

Table 2.8: Specification of Drawer Slider.

Item specifics	Descriptions
Type	Slide
Classification	8 inches
Type of ball	Ball bearing
Length	20 cm
Installation	Side mounted

Figure 2.13:LGB Rail Slider[14].

Figure 2.13 shows type of rail slider which same function as drawer slider where the different is this linear roller bearing will carry more high capacity. There are four rows in recirculating roller that were connecting with rail. The bearing will carry high load capacity and more precision[14]. The LGB ranges are lightweight and compact in size which it designed to fit in small space envelopes. The rails are supplied hard anodized with counterbored fixing holes. Table 2.9 shows the specification of LGB rail slider.

Table 2.9: Specifications of LGB Rail Slider.

Item specifics	Descriptions
Space envelope width	43 mm
Closed length	150 – 3000 mm
Maximum load capacity	400 – 0 kg/pair
Material	Aluminum
Number of beams	1
Height	65mm

2.4.6 Summary

There are two types of slider to be chosen which are drawer slider and LGB rail slider. Based on two type slider, the cheapest price is drawer slider but the maximum load for machine design is not suitable to make fatigue tensile test. LGB rail slider will be chosen based on specification that suitable on machine design. The designed also fit in small space machine design.

2.5 Existing Product

Existing product development will be investigated and research thoroughly considered procedure of advancement where design are upgraded and renovation with lower cost. It will be benefit to both of company and buyers which give increase the benefit of company. There are some designs that were released on market for fatigue tensile but the cost is too expensive to buy. Fatigue tensile machine were study and analyze by searching the previous of existing product. There are several type of machine now in market but most of it have different their criterion and different specification. Size of specimens refers to the type of machine that fully their specification and type of material that need to be tested.

The creation of product with new or different characteristics it offers new or additional benefits to the customer. Product development may involve modification of an existing product or its presentation or formulation of an entirely new product that satisfies a newly defined customer want or market niche. Proper product development ensures the end product will support all requirements while meeting all codes required of particular type of product.

Figure 2.14 shows servohydraulic fatigue test machine produce high speeds, high load and affordable. This machine acquired high efficiency of frequency and capable in micron level control. The machine has a quiet power supply and no need for air of water cooling. It is ideal for classroom or lab usage. It is based on the latest 2370 Series Digital Servocontroller with high speed 24 bit measurement and control capabilities. This machine also has a portable system which is feature lockable wheel and wide range of test specimen. These machines are suitable for the lab space because the size of machine is bigger [15]. Table 2.10 shows the specification of servohydraulic fatigue test machine.

Figure 2.14: 910 Servohydraulic Fatigue Test Machine [15].

Table 2.10: Specifications of 910 Servohydraulic Fatigue Test Machine.

Model	910LX5	910LX10	910LX15	910LX20	910LX25
Force rating	± 5 kN	± 10 kN	± 15 kN	± 20 kN	± 25 kN
Stroke	± 25 mm (± 1”)				
Distance between columns	400 mm (16”)				
Vertical test space	500 mm (20”) – longer columns option				
Footprint	600 × 500 mm (24” × 20”)				

This machine as shown in Figure 2.15 operates for static, dynamic and fatigue test system. Besides, these machines are low cost, free of maintenance and it eliminates the noisy sound of pump and oil. Cyclic to failure are determined by run load or strain control cyclic fatigue test. These machines are wide of spectrum load, strain and stroke. The 810 test system is used to characterize and test materials, device and components over a wide spectrum of load, strain and stroke. Each system is configured from a wide number of actuators and transducers to serve specific customer needs. These machines are suitable for the lab space because the size of machine bigger [16].Table 2.11 shows the specification of 810 family electrodynamics fatigue test machines.

Figure 2.15: 810 Family Electrodynamic Fatigue Test Machines [16].

Table 2.11: Specification of 810 Family Electrodynamic Fatigue Test Machines.

Series	E4 Family	E5 Family
Max force	± 15.3 kN	± 30.5 kN
Max velocity	950 mm/s	1 m/s
Stroke	Most common ± 75 mm – optional strokes ± 225	
Position resolution	0.1 micron	
Speed range	0.00001 to 15 Hz	

Figure 2.16 shows mini machine that were designed to work with microscopes and it extremely low capacity of waterproof load cell and force are measure less than 50 grams only. Few materials testing systems are able to measure very low forces and small

displacements on samples that can often be difficult to hold. Furthermore, many researches also have a need to record microscopic material behavior while the sample is under load. The lines of expert 4000 series micro test systems are ideally suited to meet these demanding testing requirements. The clamping mechanism was designed by university development and it only test low force tension fatigue test. These machines are only capable with wood fiber specimen with low force [17]. Table 2.12 shows the specifications of expert 4000 mini machine.

Figure 2.16: Expert 4000 Mini Machine [17].

Table 2.12: Specifications of Expert 4000 Mini Machine.

Specifications	Description
Design	Miniature design, fit in the palm hand
Test	Tension, compression, and bend test
Capacities	5 kN, capable of milligram low force testing
Speeds	500 mm/min

2.6 Finite Element Analysis

Finite element analysis defined as a numerical method and traditionally a branch of solid mechanics. Nowadays, a commonly used method of finite element analysis is for multiphysics problems. There is several type of area where FEA can be applied. First, structure analysis and it can be applied on cantilever, a bridge, and an oil platform. Second is solid mechanics where it can be applied on gear and an automotive power train. Lastly, dynamics where it can be applied on vibration of sears tower, earthquake and bullet impact. Other than that, FEA also will be applied on thermal analysis, electrical analysis and biomaterials. All of it will be analyzed by using finite element analysis. Figure 2.17 shows type of FEA that had been analyzed by simulation.

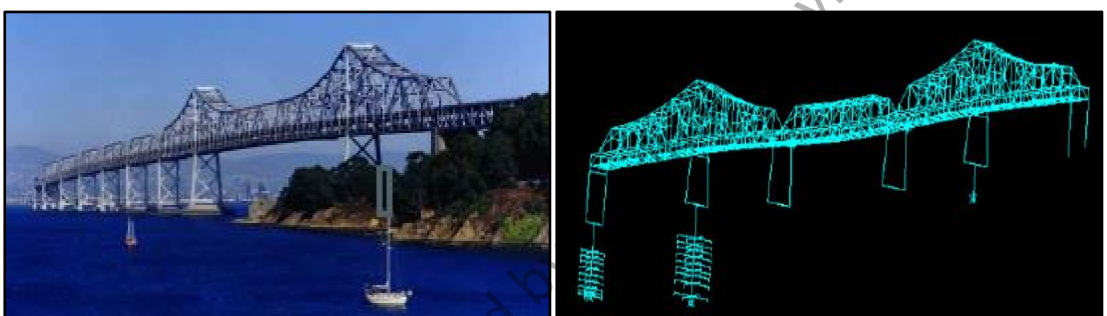

Figure 2.17: FEM simulation of the damage of San Francisco Oakland Bay Bridge caused by the 1989 Loma Prieta earthquake.

The purpose of using finite element analysis is to analyze stress analysis for trusses, beams and other simple structures which are carried out based on dramatic simplification and idealization. Design is based on the calculation results of the idealized structure and a large safety factor 1.5-3 given by experience. Design geometry is a lot more complex and the accuracy requirement is a lot higher. It is because to understand the physical behaviors of a complex object such as strength, heat transfer capability and fluid flow. It is to predict the performance and behavior of the design to calculate the safety margin. Design geometry also to identify the weakness of the design accurately.