DESIGN AND DEVELOP INSTRUMENTATION SYSTEM FOR FREE FALL IMPACT MACHINE

RAHMAT HIDAYAT BIN ARIFAI

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR OF MECHANICAL ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH

2022

DECLARATION

I thus certify that the project progress report titled "Design and Develop Instrumentation System for Free Fall" submitted to Universiti Malaysia Sabah is an original work under the supervision of Dr Choong Wai Heng. I also verify that the work described here is all mine, except citations and summaries from sources that have been properly attributed.

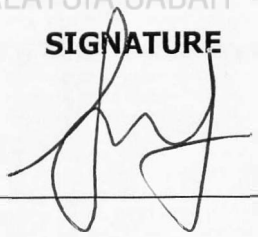
18th July 2022

RAHMAT HIDAYAT BIN ARIFAI
BK18110129

CERTIFICATE

NAME	**: RAHMAT HIDAYAT BIN ARIFAI**
MATRIC NUMBER	**: BK18110129**
TITTLE	**: DESIGN AND DEVELOP INSTRUMENTATION SYSTEM FOR FREE FALL IMPACT MACHINE**
DEGREE	**: BACHELOR OF MECHANICAL ENGINEERING (HONOURS)**
VIVA DATE	**: 25TH JULY 2022**

CERTIFIED BY:

SUPERVISOR	**SIGNATURE**
DR. CHOONG WAI HENG	

ACKNOWLEDGEMENT

First and foremost, I want to give The Almighty God a thousand thanks and praises for showering me with blessings throughout my life and for giving me His gifts of health and wealth, which allowed me to finish my senior project. I have been extraordinarily fortunate to have received help from many figures and individuals during these two semesters of my senior year to complete my study.

I owe a huge debt of gratitude to my supervisor, Dr Choong Wai Heng, for serving as a source of hope and providing consistent inspiration and guidance during the Final Year Project (FYP). Without his judgment and confidence in me to accept me as his FYP student, this project would not be accomplished. Additionally, his advice and guidance helped me to carry out the research project.

Last but not least, I want to thank my family and friends especially my final year project mates Fadzlih, Nurapiqkah and Adiba Farhana for providing me with the continuous emotional support and practical assistance I needed to complete my thesis. Memories and experiences shared and gained in such a little amount of time helped me get through the tough times. I also want to express my gratitude to everyone who was directly or indirectly participated in this study.

Rahmat Hidayat bin Arifai

18th July 2022

ABSTRACT

Development of instrumentation system for free-fall impact machine was carried out. The instrumentation system was developed to obtain experimental data on impact energy absorbed by polymer composite material. During the development of the instrumentation system, the development standard was taken into consideration where the standard of ASTM D7136/D7136M was being used in this project. Besides, the SOLIDWORKS software was used to model and verify the mechanical component using the CAE application. The component of the instrumentation is including the load cell that detects the impact force on the specimen and the signal amplifier that amplified the output signal. As result, a graph of force against time was displayed digitally with the use of a data acquisition system. Therefore, the constructed instrumentation system for the free-fall impact machine was able to measure up to 9.5 kN of impact force and 33.86 J of impact energy. The coefficient of a variant of data produced from this instrumented free-fall impact machine is below 5%. The accuracy of the impact energy instrumentation system shows a small error percentage which is below than 3% percentage between 0.2m to 0.4m of drop height.

ABSTRAK

Pembangunan sistem instrumentasi untuk mesin hentaman jatuh bebas telah dijalankan. Sistem instrumentasi dibangunkan untuk mendapatkan data eksperimen mengenai tenaga impak yang diserap oleh bahan komposit polimer. Semasa pembangunan sistem instrumentasi, piawaian pembangunan telah diambil kira di mana piawaian ASTM D7136/D7136M digunakan dalam projek ini. Selain itu, perisian SOLIDWORKS digunakan untuk memodelkan dan mengesahkan komponen mekanikal menggunakan aplikasi CAE. Komponen instrumentasi termasuk sel beban yang mengesan daya hentaman pada spesimen dan penguat isyarat yang menguatkan isyarat keluaran. Hasilnya, graf daya melawan masa dipaparkan secara digital dengan menggunakan sistem pemerolehan data. Oleh itu, sistem instrumentasi yang dibina untuk mesin hentaman jatuh bebas mampu mengukur sehingga 9.5 kN daya hentaman dan 33.86 J tenaga hentaman. Pekali varian data yang dihasilkan daripada mesin impak jatuh bebas berinstrumen ini adalah di bawah 5%. Ketepatan sistem instrumentasi tenaga impak menunjukkan peratusan ralat yang kecil iaitu di bawah peratusan 3% antara 0.2m hingga 0.4m ketinggian jatuh.

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LIST OF SYMBOLS

m	-	Mass
F	-	Force
E	-	Energy
v	-	Velocity Final
t	-	Time
a	-	Acceleration
u	-	Velocity Initial
s	-	Displacement
h	-	Height
J	-	Joule
R	-	Resistance
V	-	Voltage
I	-	Current

LIST OF ABBREVIATIONS

3D	-	3 Dimension
MDF	-	Medium-density fiberboard
GFRP	-	Glass Fiber Reinforced Polymer
COV	-	Coefficient of Variance
STD	-	Standard of Deviation
CAE	-	Computer Aided Engineering
ASTM	-	American Society for Testing and Materials
FoS	-	Factor of Safety

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CHAPTER 1

INTRODUCTION

1.1 Overview

Generally, a polymer is a natural or manmade substance that is made up of very big molecules called macromolecules that are multiples of smaller chemical units called monomers. Many components found in living creatures are polymers such as proteins, nucleic acids, and cellulose. Besides, it also serves as the foundation for minerals like diamond and quartz, as well as man-made materials like concretes, glass, rubbers, plastic, and papers. Polymers are useful in product manufacturing since they can be implemented in various things such as the chassis of Formula One car that is made from carbon fiber to reduce the weight of the car, safety helmets that are worn to protect the head of any workers from fall impact object and used in the 3D printing process as the filament of the machine (Britannica, 2021).

Since the polymer is one of the important elements in product manufacturing, therefore a testing machine is needed to test the strength and the durability of the polymer so that the polymer can be designed without any material wasting. For example, in the process of designing a safety helmet, the designer should do testing and research on what is the optimized thickness, polymer mixture and ratio of blended polymer of the safety helmet to make sure the material wasting can be prevented in safety helmet

production. Research on the effect of falling weight impact on industrial safety helmets used in conjunction with eye and face protection devices was done by Krzysztof (Baszczyński, 2018). The researcher used striker impact that can produce a maximum force of 800 N to the industrial safety helmet to test the strength and durability of the product (Baszczyński, 2018).

There are two types of polymer testing methods that are being used by the researchers such as 'gas-gun' which the testing is done with a high speed of small masses and another method is a testing that is done with a low speed, but greater masses called as free fall or weight drop impact test. In this project, the focus of the study is a free-fall impact machine with a low speed but greater masses of the impactor. A free-fall impact testing machine uses a certain weight that is dropped downward without any additional force on it and will be only gravity that is acting on it (Gunawan et al., 2011).

The free-fall impact machine is used widely in material testing such as to measure the impact resistance of concrete that was done by Xue-Chao Zhu (Zhu et al., 2015). In the testing process, a series of drop-weight impact test was carried out with four different masses of drop hammers which is 0.875 kg, 0.8 kg, 0.675 kg, and 0.5 kg. The result of the experiment is the impact resistance is fail to follow a normal distribution (Zhu et al., 2015).

The other examples of drop weight machine test applications are used for composite materials testing. A study was done by (Junior, 2013) about composite material and its impacts on laminated structures. The study outcomes are developed a simple design of impact machine and were successfully achieved. The machine was able to project a range of 20 J to 90 J which was obtained from several drop heights with different weights (Junior, 2013). ASTM D7136/D7136M-07 was used to determine the extent of the damage resistance of composite material reinforced polymer in this project. According to the ASTM D7136/D7136M-07, a rectangular flat plate composite material

is subjected to a concentrated impact caused by a weight attached to a hemispherical impactor.

Therefore, the focus of this project is to design and develop an instrumentation system for the free-fall impact machine. The instrumentation is expected to be able to measure the impact energy of the free-fall event that is absorbed by the specimen, especially polymer composite material. The material properties which is the impact strength of the material can be determined from the data that was measured by the instrumentation. Besides, the behavior of the testing material on the free-fall impact event can be analyzed from this testing machine. The reference to designing and developing this instrumentation is from an article with the title 'Designing and Manufacturing of a Drop Weight Impact Machine' prepared by (Taheri-Behrooz et al., 2013). According to (Taheri-Behrooz et al., 2013), the machine should evaluate the energy absorption of composite materials under impact load; the load-time graph is drawn using the machine's output, and the specimens' energy absorption is determined with the use of various sensor systems and data acquisition system.

1.2 Problem Statement

A free-fall impact machine to measure the object's ability to resist a high rate of loading when two objects striking to each other. Thus, the impactor and the load will be the only part moving down to the specimen that is in static condition. Therefore, there will be two possibilities after the impact condition where the first one is the specimen is broken thus the impactor will come down and stop while the other one is the impactor will bounce back and make another impact on the specimen.

In the Faculty of Engineering of Universiti Malaysia Sabah, there is an existing free-fall impact machine that was used to do the drop test on the composite material. The free-fall impact machine has an impactor with a mass of 8.5 kg and the frame structure of the machine allows to make a drop with a maximum height of 0.7m from

the fixture base. However, the problem with this machine is there is no sensor on it. The experimental impact force is not able to be measured with the instrumentation installed.

Thus, due to this limitation on the existing free-fall impact machine, a suggestion to upgrade the machine was proposed. The upgrade suggested is to install instrumentation to the existing machine with the implementation of sensors such as the load cell, the data logger and the signal amplifier of the machine so that the experimental impact force can be determined from the machine. Therefore, the modification of the existing machine will be conducted to make sure the instrumentation and data acquisition system can be installed properly. The instrumentation will be constructed based on the ASTM D7136/D7136M.

1.3 Research Objectives

The main objective of this project is to upgrade the existing Free Fall Impact Machine to an instrumented Free Fall Impact Machine for testing the polymer material's impact-resistant property. The main objective can be further specified into the following specific objectives:

i) To verify the physical Free Fall Impact Machine structural performance through CAE application;
ii) To develop the impact energy measurement system; and
iii) To validate the measurement system for reliability and limitation.

1.4 Scope of Works

To conduct this project, a background study of the free-fall impact machine should be carried out which includes reviewing the past research papers and articles that provide a basic idea or understanding of the project. The literature review is one of the important

things that need to be done to get an understanding of how previous research conducted the free-fall impact machine testing.

The scope of work of this project is generally based on the design and development of an impact energy measurement for an existing free-fall impact machine in FKJ, UMS. Thus, the structural performance of the existing machine was conducted first to verify the physical condition of the testing machine. Thus, the CAE application was used as the simulate the estimation of stress and deflection of the critical part of the existing machine. The critical is the fixture base and the impactor. Besides, the structural assessment also verifies whether the existing machine is based on the ASTM D7136 standard or not.

In the development of the instrumentation process, the scope will be to do the fabrication of an impact energy measurement system for the existing free-fall impact machine according to the model that has been designed in SolidWorks by using suitable material, suitable electronic components, and other miscellaneous components. The sensors such as Load Cell is implemented and the data output from it will be evaluated accordingly. The instrumentation's performance evaluation also should be able to carry out after the machine has done the testing and tuning process. Finally, the documentation of this project will be done and arranged accordingly for future references.

1.5 Research Methodology

The project shall be carried out according to the set of methodology as follows:

i) Literature review

Past research on the design and development of instrumentation of free-fall impact machines is required to be reviewed and studied. It will help to get an understanding of the process behind the research, how the design will be conducted and how to evaluate

the performance of the machine when it is ready to be used. Thus, a literature review will demonstrate what has been learnt from other research that will be used as the starting point for the new idea.

ii) Mechanical design of free fall impact machine

The design of the free-fall impact machine will be based on the ASTM D37136/D7136M. As stated in the objective, the existing machine of free-fall impact machine will be used to be installed with the instrumentation. Thus, the verification of the mechanical of the existing free-fall impact machine requires making sure the existing machine is reasonable to be used again. The critical part such as the fixture base and the impactor will be evaluated in this methodology by using the CAE application. The physical condition of the fixture base and impactor also need to be considered.

iii) Impact energy measurement system

After the verification of the structural performance of the existing machine, the measurement of the impact energy system is designed according to the references from the literature review. The concept of the simply supported beam was considered as the reference to be used in the impact energy measurement system. Besides, the instrumentation also needs to use electrical components such as the load cell, signal amplifier, data logger and a computer to determine the impact energy value from a free fall impact. Thus, the data sheet of the electrical component also needs to be studied to make a user of the electrical component and provide the expected output data.

iv) Performance evaluation of instrumentation system for free fall impact machine

The performance instrumentation system of the free-fall impact machine will be evaluated such as the accuracy of the impact energy. The theoretical value will be compared to the experimental value for impact energy. Impact energy from experimental value will be determined by using a force sensor which includes the usage of a load cell at the sensor. Thus, an electrical connection will be set up to make sure

the force sensor can record more data in a millisecond and is expected to produce a graph of impact force against time in a millisecond. To test the force sensor, a steel plate will be tested as the specimen, and validation can be made by comparing the experimental result with the theoretical value of the impact force. The data will be extracted accordingly, and all work will be well documented.

The project shall be conducted according to a set methodology, and it can be elaborated as a methodology flow chart shown in Figure 1.1 below.

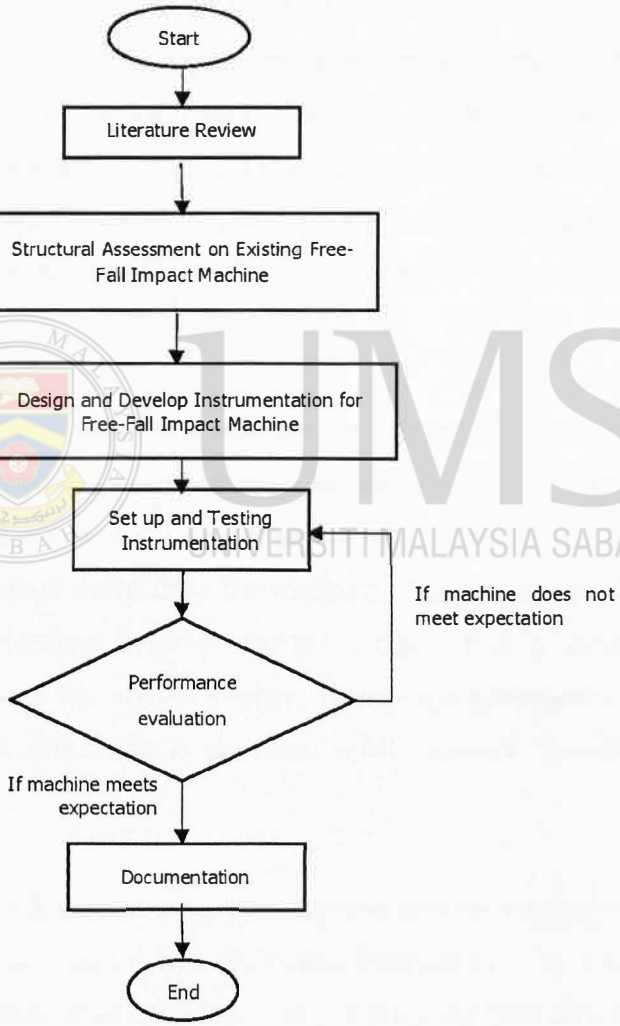

Figure 1.1: Flowchart of Project Methodology

1.6 Thesis Organization

The thesis is organised as:

Chapter 1, the introduction to the free-fall impact machine was well elaborated which include the background, the importance and the application of the free-fall impact machine. The objective of the project is also listed here together with the methodology, flowchart, and scope of work.

In chapter 2, several varieties of free fall impact machines created by different universities and industrial technology businesses are evaluated and addressed in this chapter, as well as the mechanical design of the free-fall impact machine and its benefits and drawbacks. Data extraction from the load cell system and other performance criteria are also being discussed. In general, the purpose of this chapter is to analyse and describe the background knowledge that was used to develop the free-fall impact machine.

Chapter 3, the existing free-fall impact machine in FKJ, UMS is elaborate, especially on the critical component of the machine. The critical component is including the fixture base of the machine and the impactor because both of these components are responsible for the impact event from the machine. The fixture base functions to mount the specimen in position and the impactor is the object that is released from a certain height that will generate the impact energy. Thus, each component was designed in a 3D model and a CAE simulation is executed on it to verify the virtual model of this component.

In chapter 4, the methodology of designing and developing the instrumentation and the data acquisition system was elaborate. Instrumentation is consisting of a load cell and a signal amplifier where the load cell is the sensor that converts the mechanical force into an analogue signal and the signal amplifier is to amplify the signal produced to be more useful data. Besides, the data acquisition system is a device that processes

sampling signals that gauge actual physical events and converts the resulting samples into digital numeric values that a computer can manipulate. The calibration and testing of the instrumentation and data acquisition system are also elaborate in this chapter.

Chapter 5 is elaborated on the outcomes of the preceding chapters' performance evaluation and assessment findings are compiled and compared to be validated and analysed. This part also discussed how the existing fixture base and impactor will influence the measurement of impact force results. Besides, the reliability and accuracy of the data from instrumentation and data acquisition system are being analysed.

Chapter 6 is concluding the project findings, as well as a list of the project's goals that were met. This part also went through the improvements and suggestions that should be made for future projects.

1.7 Summary

The background, importance, and application of the free-fall impact machine were well-explained in Chapter 1, which included the background, importance, and application of the free-fall impact machine. The project's goal, as well as the methodology, flowchart, thesis organisation and scope of work, are all elaborated.