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Development of Dental Material Testing Equipment

by

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Abstract

For this project Dental Material Testing equipment will be developed based on the rolling ball technique introduced in [1]. This technique has been proven reliable in producing surface wear on the dental specimen.

The equipment will be developed to run as an embedded system in which PIC 17C756A microcontroller (PIC MCU) is used as the main controller to control the equipment. For this equipment, the components that the PIC MCU is controlling are a DC motor and an encoder to roll the ruby ball on the dental specimen, an LVDT to measure the wear of the specimen and the communication between a Personal Computer and the PIC MCU itself. Then the embedded system based on this PIC MCU is also designed to be able to integrate more peripheral components in the future such as temperature sensor and water pump control unit to make the rig more automated. Then a customised PCB board to mount all the electronic components are designed and fabricated.

A Graphical User Interface (GUI) based on Windows 98 platform is also designed for the user to enter parameter to run the equipment and to monitor the data produced by the equipment in which the GUI will be the only interface between the user and the equipment. Also, in order to improve the wear depth measurement performed by the equipment, the design of the mandreal coupling and the mandreal that could reduce the misalignment in the mechanical parts is also developed. The misalignment of mechanical parts in this equipment can contribute to the oscillation in the wear depth measurement and the effects of 2 misalignment types are simulated.

Once each of the individual components are developed (GUI, real-time software for PIC MCU, electronic circuit, mechanical parts), they are integrated and tested to form a complete Dental Material testing equipment that ready to perform the surface wear test of the dental material.

Acknowledgements/Dedication

'In the name of Allah, the Most Gracious, Most Merciful'

I would like to take this opportunity to thank Dr. Bicker, the supervisor of this project who has allowed and helped me continuing this project up to this stage. Undeniably, I have gained tremendous skills and understandings in the process of developing a complete functioning mechatronic system, in which I strongly believe that the experience gained will definitely help in pursuing my PhD. Indeed, it is quite a tough and challenging experience going through the process of finding and gathering information 'here and there' to make the system work, yet at the end it is quite enjoyable. Again, thanks to Dr. Bicker for his support and advice, technically or motivationally, for me to complete this project.

Also I would like to dedicate my appreciation to Christ Marshall who has given me a lot of technical support especially in the Windows programming as well as the PIC MCU real-time programming. All the advice and opinions shared really help me in doing the project. Also, I would like to thank my other lab partners Abdul for Borland book, Paul for EZ PC technical advice, Steve for the discussion on real-time protocol and serial data management, Xu and my other coursemates for coming to my desk and asking about my project. I really appreciate for the interest and some of the comments do trigger new ideas for me.

Then, last but not least, I also want to appreciate my family at home for allowing me to be another year abroad to fulfil my dream of obtaining this MSc. Also, a very special appreciation is dedicated to a special person, Norazah, for patiently waiting and monitoring my progress throughout the year. I really appreciate for the care and the cookies you sent during the Eid.

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Chapter 1 Introduction

For producing a surface fatigue on dental restorative material, the technique of cyclic rolling ball on the dental specimen has been proven effective to simulate this type of fatigue [1]. The ruby ball will be kept rolling on the flat surface of the specimen with a light force is applied to the specimen, and as the number of ball cycle increases, a crack will occur on the specimen surface and cause material loss. This material lost is then called the wear of the dental material and the measurement of the wear depth vs. time can be obtained for the analysis of surface fatigue occurrence over time. This rolling ball technique is a favoured method to produce the surface wear for dental material due to the following reasons [1]:

1) The technique of applying light compressive stress while repetitively rotating the ball on the dental specimen will guarantee that the loss of material is due to only surface fatigue.

2) The stress applied can be distributed over time in more than 10 million cycles of rolling ball.

3) The result is reproducible with the same condition that is set previously.

4) Less dental specimens are required to performed the surface fatigue test

Due to these distinct advantages, two versions of the equipment implementing this rolling-ball technique to produce surface fatigue on dental material have been designed and tested in University of Newcastle Dental School. Both of this equipment has shown quite satisfying result in which with further improvement in the design and control of the equipment a more reliable result can be produced. As there is a need to improve the existing equipment, especially in term of automating the process of measuring the wear depth produced by the rolling ball and accurately counting the number of cycles made by the ball, a new version of the testing equipment is designed and developed in this project. This new equipment is designed based of its two previous versions in which the distinct different between this new equipment with its predecessor is the electronic control unit of this new equipment which will be developed based on PIC 17C756 series microcontroller. By using mirocontroller as the main controller for the equipment, other than its cheap price, the system will be more flexible in term of expanding its functionality to meet any new add-on requirement of the equipment or the improvement of the dental material testing procedure.

1.1 Overview of dental material testing equipment design

The first version of the equipment developed to implement the rolling-ball technique is shown in Figure 1.1 below. For this equipment, a flat dental specimen is placed in the PTFE mounting jig which is then mounted to one end of glass rod and on the other end of the rod, an adjustable load is mounted to apply the force on the specimen. In the middle of the road, a frictionless hinge is placed which balances the load and the specimen-PTFE rig assembly. The weight and the position of the load on the rod will determine the magnitude of the force applied on the specimen. Then on top of the specimen, a ruby ball constrained in a mounting part called V-groove rotor is placed in which the rotor is mounted directly to a DC motor. Figure 1.2 illustrates the structure of the equipment in side view.

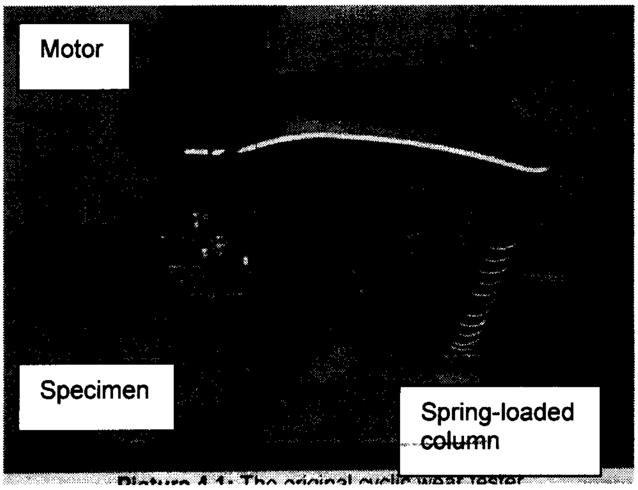


Figure 1.1. The first version of the Dental Material Testing Equipment

As the DC motor rotates, the ruby ball in the V-groove rotor will rotate producing circular track on the specimen and over time, the loss of material will occur at the track producing surface wear of the specimen. Then, the specimen will be removed from the PTFE mounting and stylus profilometer is used to measure the wear depth. To control the speed of DC motor, a direct voltage regulator is used in which the speed will be proportional to the voltage applied.

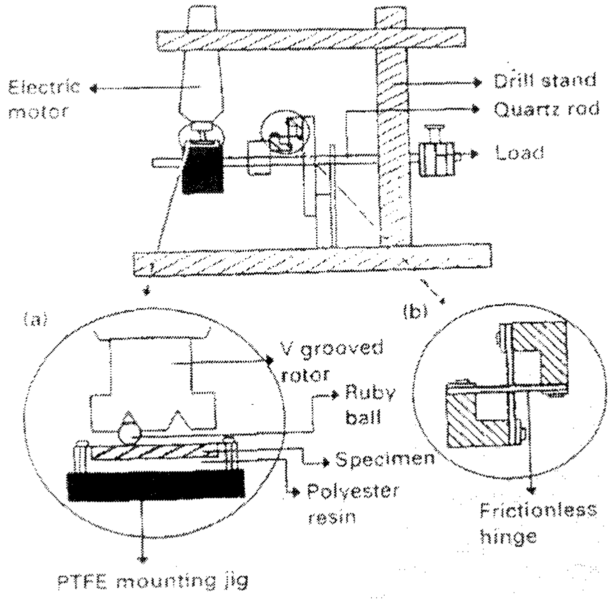
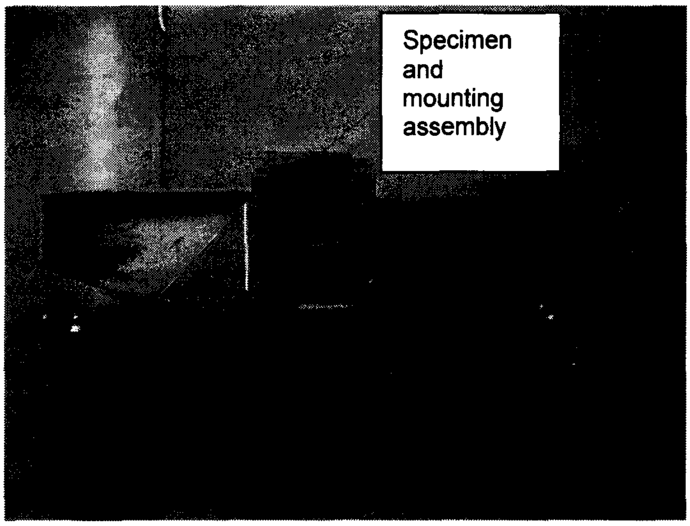


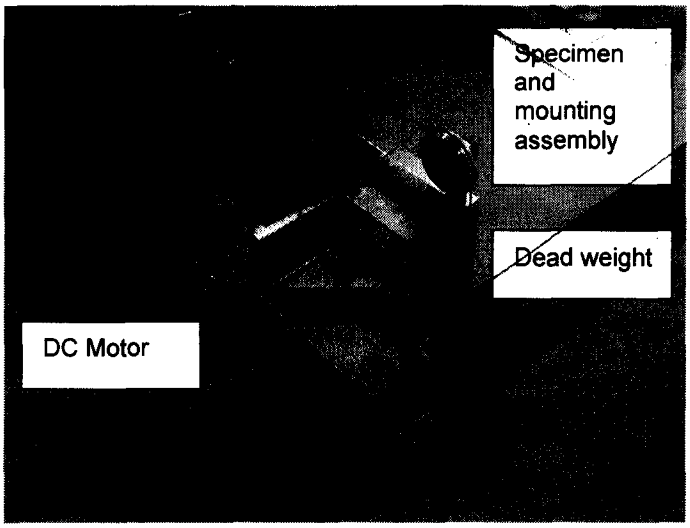
Figure 1.2. Sideview of the equipment.

This first equipment has 2 significant disadvantages, which are the open loop control of the DC motor speed and the offline measurement of the wear depth of the specimen. To set the speed of the DC motor for this equipment, a voltage regulator is adjusted and a strobosobe is used to check the rotational speed of the rotor [1]. The voltage regulator is then adjusted until the desired rotor speed is obtained. As this speed adjustment is finished, a tachometer is used to verify the rotor speed. For the measurement of the wear, the specimen will be removed from the PTFE mounting and once the measurement has been taken, the specimen will be placed back onto the mounting rig. The procedure of this off-line measurement technique might cause the original wear track is not exactly aligned with the V-groove rotor and this will produce a new circular track of wear, which is undesirable for the wear analysis. Besides these 2 disadvantages, it is observed that from the measurement of the wear depth of the specimen, an oscillation pattern of wear is occurring. This might be due to the mechanical structure of the equipment in which when the motor rotates, the 2-support spring-loaded columns will vibrate and cause uneven force applied on the specimen.

By taking consideration of these disadvantages, a second version the equipment has been developed in which the almost 100% of the mechanical structure has been revised and the PMAC card has been chosen as the main controller. For the structure of the equipment, the specimen is mounted in a plastic mounting and the assembly is mounted to a linear bearing which allows the specimen to only move in one linear direction. A dead weight is mounted to the assembly by a link of steel wire to apply the compressive force on the specimen as the weight is pulling the specimen against the ruby ball in the V-groove mandreal. Also, a Linear Variable Differential Transformer (LVDT) is incorporated and mounted to this specimen assembly block to measure the wear produced by the ruby ball on-line: measurement taken while the motor is still rotating and the specimen is still in the equipment. Figure 1.3 below shows this second version of the equipment.



a) Top view



b) Full view

Figure 1.3. The second version of the dental material testing equipment

For the control unit of the equipment, an electronic circuit for the DC motor, encoder and the LVDT has been designed to interface these peripheral components to the PMAC card. The PMAC card is then installed in a PC in which then user can change the motor speed by entering the parameter in the PC. Also, the wear measured by the LVDT will also be displayed in the PC screen.

This new design has solved majority of the problems encountered in the first design. With the use of encoder, the motor speed is now controlled in closed loop and the actual cycle the motor has made can be captured. The LVDT introduced allows the online measurement of the wear produced on the specimen and indeed, this is a major impropment since the specimen now can be used for longer time without being removed from the equipment. This will reduce the number of specimens used for testing which is a very favourable to Dental School. The wear result obtained from this equipment has shown improvement in term of the specimen wear depth relation with the number of cycle the ball made. The vibration in the wear depth has not been observed but it is noticed that the direct connection of the motor shaft to the V-groove mandreal has caused some interference in measurement in which as the motor rotates, the motor shaft extends due to the increase of temperature of the motor [3]. Also what is called Beating effect has also been observed which further cause variation in the wear measurement.

In term of its control circuit, the PMAC card is a universal microprocessor based hardware designed for many types applications. For this Dental Material testing equipment, the full features provided by the card are not used and this will be quite a costly controller for this equipment (the average price for PMAC card is in the range of hundreds to thousands pound depending on the features of the card).

In this project, a solution to the problems faced in the previous version of the equipment is looked by implementing designed change in its electronic controller unit as well improvement in its mechanical structure. For the controller unit, PIC 17C756A microcontroller has been used as the central controller to all the peripheral devices connected to the equipment, which then totally eliminates the use of PMAC card. Then, all the interface circuits of the devices are designed specifically to interface to this PIC microcontroller and a piece of hardware unit dedicated to fulfil the equipment requirement is developed. Then, a new Graphical

User Interface based on famous Window 98 operating system in which the user can change the parameter for the equipment in PC is also developed to increase the friendliness of the equipment to the user at Dental School. For mechanical design, a suggestion made by Heslop and Steuwer in [3] to separate the motor from the mandreal to improve the online wear depth measurement has been implemented.

1.2 Project specifications and objectives

By referring to the previous development of the Dental Material testing equipment, the scope of this project will involve hardware and software development of the controller, the development of the software of the Graphical User Interface, the design, fabrication and assembly of the product-related mechanical parts for the equipment and the integration of these individual components to form complete equipment. Figure 1.4 below shows the general view of this new equipment.

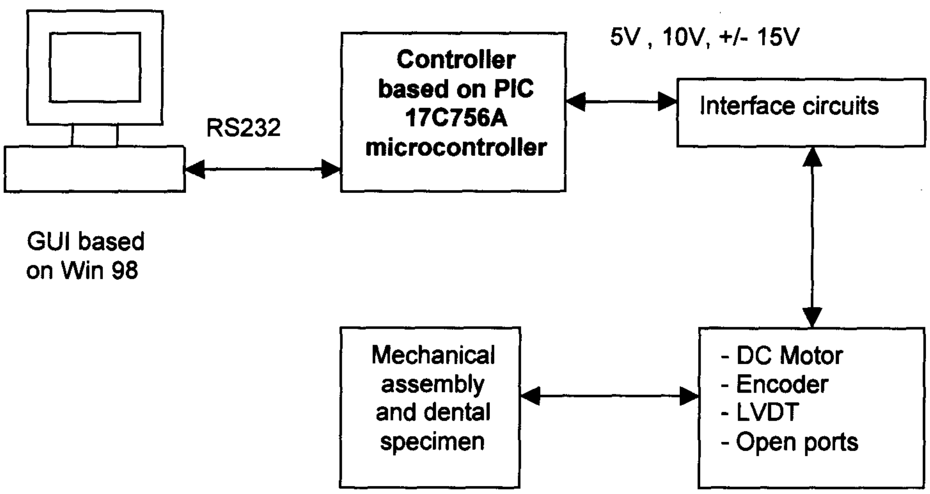


Figure 1.4. General view of components of Dental Material testing Equipment

Based on this figure, it is obvious that the development process involves 3 distinct areas which are mechanical, electronics and software for PIC MCU and Window 98. Thus, an organised and phase-by-phase development of each individual task for each component of the equipment that is needed to be accomplished should be planned. By looking at this requirement, the objectives of this project can be outlined as follows:

1) To build a Graphical User Interface based on Windows 98 operating. The GUI built will be the terminal for sending control parameter to the PIC MCU controller and receiving and displaying parameters from PIC MCU. The GUI should be user friendly in term its overall look and functionality to ease the users to control the equipment.

2) To write a communication protocol between the GUI and the PIC MCU for data transmission. RS 232 protocol has been chosen for this project in which data is sent in ASCII character with 8-N-1 byte structure. This means that prior to sending parameters between the PIC MCU and GUI, both of these components should convert the parameters to ASCII code and reconvert the data to its original value at both ends for further process.

3) To set-up a microcontroller hardware system based on PIC 17C756A microcontroller. This process involves writing the real-time software to control the peripheral components such as the DC motor, encoder, linear differential variable transformer (LVDT), Universal Synchronous Asynchronous Universal Terminal (USART) and input/output ports.

4) To design the interface circuit for interfacing the peripheral components to PIC MCU. The PIC MCU operates at 5V and the interface circuit will do the signal processing to match this 5V voltage of PIC MCU to the voltage level of the peripheral component. Also, this interfacing circuit will do signal filtering of the raw signal obtained from the components. The design of the interface circuit should be performed in parallel with the development of the real-time software of the PIC MCU to match and optimise the code and functionality offered by the PIC MCU.

5) To design and fabricate the Printed Circuit Board (PCB) to mount these interface circuits and the PIC MCU as one complete embedded hardware dedicated for this equipment.

6) Simulation of kinematic of the ruby ball movement in the V-Groove mandreal of the equipment in order to obtain accurate relation between the motor position/speed and the surface wear produced by the ruby ball. With this simulation result, the significance of proper alignment between dental specimen, ruby ball and mandreal can be observed in

which the effect of misalignment of these components that cause oscillation of the measurement can be observed.

7) The design, assembly and fabrication of the product-related mechanical parts for the equipment. The basic frame of the equipment is ready and the mounting of the dead weight, motor pulley system, LVDT mounting and the mandreal coupling are designed to fit this basic frame.

8) To integrate all of these electronics and mechanical parts to form a complete Dental Material Testing Equipment.

1.3 Thesis Outline

This thesis is written for the project containing six chapters in which each chapter will describe the detail of related information and work involved in developing this Dental Material Testing Equipment. The arrangement of the chapters and the sub-chapters is concentrated on giving detail explanation of the equipment in term of its control and mechanical parts as complete system while highlighting the critical problems that will affect the system.

Chapter 1 is dedicated for the explanation of the fundamental components that build-up the complete system. The review of the 2 previous versions of the equipment is covered in which the problems faced in each version of the equipment are highlighted. Based on these problems and the additional requirements needed to automate the testing equipment, a proposal of new complete equipment based on PIC MCU microcontroller is suggested to be developed in this project. The design specifications for the controller and the mechanical parts are explained and the objectives that need to be achieved to complete the equipment are also outlined.

Chapter 2 involves the explanation of the importance of eliminating any misalignment in the mechanical parts of the system, especially the mandreal mounting and the mandreal. The overview of the kinematic of the ruby ball movement in the V-Groove mandreal is covered and the relation of this movement with the total circular path made by the ball on the speciment is developed. Then, each effect of the misalignment (top and bottom misalignment) in the measurement of the wear depth is simulated by using MATLAB. Based on this simulation result, the relation between the magnitude of the misalignment and the severeness of the wear depth produced by the LVDT reading can be clearly seen. Then, the detail of the mandreal coupling and mandreal design is covered in order reduce this misalignment effect.

In Chapter 3, the detail design of the controller is covered in which the main component of the controller, PIC 17C756A microcontroller, is discussed first. Then, by knowing the functions and the requirement supported by the PIC MCU, interface circuits for other peripheral components such as DC motor, encoder, LVDT and serial interface are designed with the detail explanation of selection of both passive and active components used. The trade-off between the selections of components is also discussed.

In this project, two kinds or software codes are developed which are the GUI code in Windows 98 operating system and the real-time code for the PIC MCU. The architecture of both of the software codes developed for this project is covered in Chapter 4. The flow charts of each component of the software are also shown to provide a clear illustration of the sequence and interaction between each code segment.

Chapter 5 discusses the development process of the equipment and the test results obtained at each development stage are explained. This involves the development of the software codes and electronics circuit and verifying each component at smaller scale which is vital to ensure that when all the components are combined, a satisfactory and realiable results can be obtained. Also, the problems faced at these stages are highlighted and the solution found is discussed.

Lastly, in Chapter 6, the discussion regarding the project accomplishment and the result obtained are discussed. Then, by looking at the last accomplishment obtained at the end of the project term, suggestions of further improvements that can be made are covered. Then, this chapter will conclude the thesis with a conclusion about the project as whole.

Chapter 2 Mechanical design of the rig

One of the main challenges of this project is the design of the mechanical parts and the assembly of the equipment because the surface wear that is going to be produced and measured is in the range of micrometers (micron) [1]. Thus, a very small vibration of the equipment, a slight misalignment in mechanical parts assembly or even a small dimension error of the part occured during parts fabrication will contribute to oscillations of the LVDT reading which then might cause unreliable wear depth measurement. As highlighted in Chapter 1, the first version of this equipment has to be redesigned because there is some vibration in the equipment that produced uneven wear depth on the material and oscillation of LVDT output. Then, in the second version of the equipment, the data produced by the LVDT shows a linear relationship between the ball cycle and the wear depth produced, in which it should be a-quadratic-like relationship [1].

Hence, in order to obtain a very reliable and accurate wear depth measurement, the mechanical structure and the parts of the equipment have to be designed in such a way to reduce all of these effects, which then will reduce the oscillation on the LVDT reading. However, in real mechanical parts assembly, misalignment can never be avoided. These are due to limited precision that can be achieved in parts machining and fabrication and also the environmnent factor such as humidity and temperature variation that can alter the dimension and structure of the rig. However, with a tight control of tolerances of parts fabricated, these misalignments can be reduced but then this will incur a high manufacturing cost (more accurate precision machining and high skill machinist).

In this chapter, a few of critical mechanical parts assembly that contribute to the oscillation of the LVDT output will be highlighted and the simulations of the effect will also be demonstrated to illustrate the criticalness of each effect. Then all of these effects will be combined and the simulation of the total oscillation in the equipment can be observed. Afterwards, the design of the mandreal and mandreal mounting that could minimise these oscillation effects will be discussed.