

DESIGN AND IMPLEMENTATION OF A WEAR TESTING RIG

K M S Soyjaudah and H Ramasawmy

Abstract $\frac{3}{4}$ Mechanical devices sometimes fail because of the wear in the moving parts due to friction. This results in significant amount of investment to replace the worn out parts. The wear testing rig is a device to simulate wears in the laboratory. This paper presents a design and implementation project, where the student is required to develop a system to control a wear testing rig by the use of a 486 based PC. In such a project the student applies a top-down systems approach to produce a working system. It also involves hardware-software co-design such that knowledge from a number of engineering disciplines is necessary for arriving at a workable solution. An exercise of this type enables the student to realise the advantage of logically analysing the system requirements according to functional areas, rather than having subjective ideas of the solution at the beginning.

Index Terms $\frac{3}{4}$ Design and implementation, PC based, top-down approach, wear-testing rig,

INTRODUCTION

Moving parts of mechanical devices fail after some time because they are subject to wear. Wear is the progressive loss of material from the surface of a body due to friction. It is responsible for the large sums of money spent on spare parts, repairs and down times. Modern engineering education devotes a particular interest in the study of friction and wear.

Tribologists study causes and mechanisms of wear in daily applications. To investigate the individual effects of varying conditions, tribologists use simulation. The factors such as load, speed, type of material, size of specimen, temperature, humidity among others can thus be varied and the effects of each on wear observed individually. Wear testing rigs are devices used to simulate wear in the laboratory.

A wear testing rig is a simple apparatus designed to make two or more surfaces in contact move relative to each other under controlled conditions. Essentially, wear testing rigs enable the recreation of the real life conditions under which wear occurs and the observation of their effects on samples of commonly used or newly designed materials and lubricants.

This paper presents a project involving the design and implementation employing a top-down methodology to develop a 486 PC based wear testing. In this project the student has to do hardware-software co-design by using his

knowledge from a number of engineering disciplines to arrive at a workable solution. Such an exercise enables the student logically analyse the system requirements according to functional areas by rejecting preconceived solutions ideas at the beginning.

The paper is organized as follows: we first highlight the major aspects of the top-down systems approach commonly employed in the development of such a project at final year undergraduate level. This is followed by the conceptual design and implementation and evaluation of the proposed methodology for the development of a 486 PC based wear testing rig.

TOP DOWN SYSTEM APPROACH

Students are generally advised to follow a generic top-down systems approach in their design and implementation projects. The student is given specifications of the project. He has to identify, without being influenced by pre-conceived ideas of possible solutions the fundamental problems that need to be addressed. The student then probes more deeply into the problems to be solved. He analyses each problem at hand and breaks them into progressively more detailed functional requirements that has to be designed and implemented eventually. The student continues with a thorough analysis of all design alternatives for both hardware and software modules such that the final proposed design and implementation is well justified in terms of all predefined criteria such as functionality, size and cost of the final product. As the proposed application involves the use of hardware and software components, the designer has to translate the functional requirements into an algorithmic development, as well as circuit design schematics that reflect the proposed solution. An important aspect of the implementation stage is the identification of the hardware and software platforms that will support the final design. These involve the judicious choice of hardware components as well as the programming language for coding the developed algorithm. Testing and evaluation aim at both verifying the performance of the implemented system against specifications, and confirming the validity of the initially defined problems. Any mismatch in the process of validation and verification is corrected by appropriately modifying the problem definitions, introducing new system parameters, considering other design alternatives or refining the existing solution.

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CONCEPTUAL DESIGN

There are essentially two main types of actuation, namely rotary and reciprocating and wear testing rigs are found to have mainly these two types of sliding frictional motion between surfaces under test. The features offered in commercially available wear testing machines are numerous and some of them optional for the tribologists to pick for a customized version of the device. The most common features not all necessarily offered on the same apparatus are:

1. Standard loads up to 150N
2. Rotational speeds up to 1500 rpm
3. Continuous wear depth measurement option
4. Complete software to set up experiments, handle, store and analyze data with real time display of measurement data
5. Removable upper wear specimen (pin) for in-process measurements
6. Variable test path radius
7. Automatic stop when the coefficient of friction reaches a threshold value or when a specified number of turns is reached
8. Enclosure so that controlled atmospheres of varying humidity or composition can be used
9. Specialized versions developed for high temperature operations of up to 150 degrees Celsius, where a heating module is added to heat the sample under test
10. Special versions developed for high vacuum testing

In this project the pin-on-disk is chosen because it a simple method which facilitates the study of friction and wear behaviour of almost every solid-state material combination, with varying time, contact pressure, velocity, temperature, humidity and lubricant.

Development of the overall system calls for expertise in various areas of Electrical Engineering, namely Power Electronics, Electronic System Design, Circuit Theory, C Programming, Microprocessor Programming, Interfacing and Instrumentation. Modules covering these subject areas are thoroughly covered during the first three years of a B.Eng. (Hons.) course in Electrical and Electronic Engineering, and hence offer the necessary pre-requisites for undertaking the project at final year level. Above all, the project work is backed by systems engineering lectures, where the student is exposed to the structured approaches [1-3] or problem solving, through case studies. In the process, students become proficient in all aspects of the design, implementation and testing phases for both hardware and software-based systems.

Specifications

The choice of the features listed below in the proposed wear testing machine was determined by order of importance and constrained by the facilities available at the university. The following features were selected:

1. Speed control of the rotating disk
2. Variation of the radius of wear tracks
3. Lifting of the pin off the disk at the end of the experiment
4. Capturing the temperature near the tip of the pin
5. Capturing the coefficient of friction between pin and disk

Since a pc is used to control the operation of the machine, the data captured by the sensors are displayed on the screen in real time.

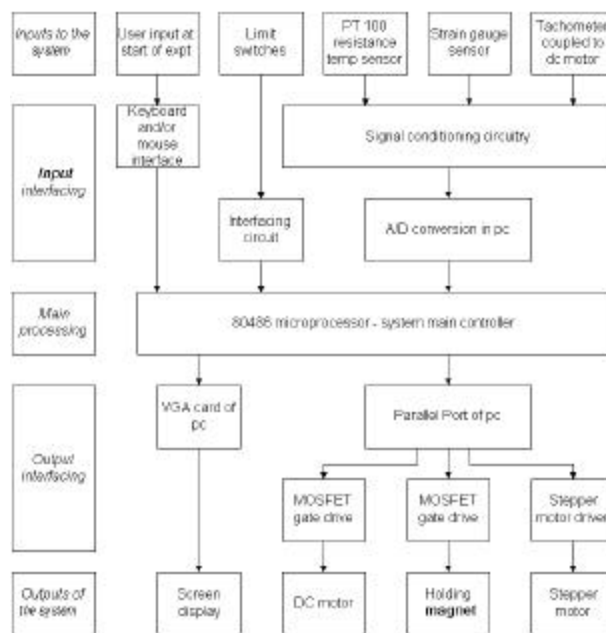


FIGURE 1.
BLOCK DIAGRAM OF THE PROPOSED WEAR TESTING RIG

PROBLEM DEFINITION AND FUNCTIONAL REQUIREMENTS

A functional block diagram of the conceptual design of the proposed pc-based wear testing rig is given in figure 1. This shows the inputs, the input interface, the processing, the output interface and the outputs of the system respectively.

To implement the above-proposed features we require three actuating devices :

1. Dc motor to rotate the disk
2. Stepper motor for reciprocating arm motion
3. Electromagnet to lift the pin at the end of experiments

three sensors:

1. Tachogenerator to read speed of rotating disk
2. Platinum resistance sensor to measure temperature near location wear friction occurs
3. Strain gauges to measure force acting on the arm to deduce coefficient of friction

and a 486 based computer equipped with a 1GB hard disk drive and 8MB of volatile random access memory. This computer has a free ISA (Industry Standard Architecture) slots on its motherboard on which the analogue to digital converter card can be fitted. The parallel port of the computer is used as the input-output device to communicate with the wear testing machine.

The speed control of dc motors does not involve the complex inverters required as in the case of ac motors. The basic concept in the design of dc motor controllers is that the speed is approximately proportional to the voltage applied to the motor. A dc motor, rated 24V, 27A, equipped with its reduction gearbox and tachogenerator, is chosen. This choice is constrained by the availability of such motors on the local market.

The tachogenerator fitted with the motor generates 20V/1000 rpm. Since the output voltage of the tachogenerator during operation will exceed the maximum value which can be fed to the A/D card, some potential divider circuit is used

To control the stepper motor, a low cost stepper motor driver kit was obtained from Oatley Electronics, Australia. This kit functions similarly to some previous stepper motor driver kits (up to 100V, 4A max with good heat sinking) but has improvements to the driver electronics that can allow larger motors to be driven more efficiently. The controller has much reduced loading on the computer parallel port, with opto-isolation between the stepper driving circuit and the computer. The kit can drive up to two 4, 5, 6 or 8 wire stepper motors from a PC parallel port (DB25 connector included). A separate power supply is needed for the motors. The energise-to-hold electromagnet provides optimum performance when used with its armature although suitable for holding any smooth ferrous surface of adequate thickness. The remanence (about 5% of holding force) may be reduced by fitting non-magnetic shims between the magnet and the armature. This should easily lift the arm when energised at the end of experiments.

To sense the temperature near the tip of the pin of the wear testing machine a platinum resistance sensor is used. The PT100 sensor (is an economical precision temperature measurement device. The thin film glass coated Pt100 elements have 10mm leads for ease of connection and are of small physical size (2x10mm) for fast thermal response. The PT100 sensor follows BS 1904 standard and is designed to operate in the range of -50 to 500 °C, the resistance at 0 °C being 100 ohms.

To deduce the coefficient of friction during the experiments, the force acting on the arm has to be measured and a strain gauge is quite suitable.

DESIGN AND IMPLEMENTATION

The speed control of the rotating disk of the wear testing machine is the most critical part of the design since the

essence of the machine is to simulate wear by friction between a vertical pin and a rotating disk. It is clear that without this functional part, the wear-testing rig would not be operational.

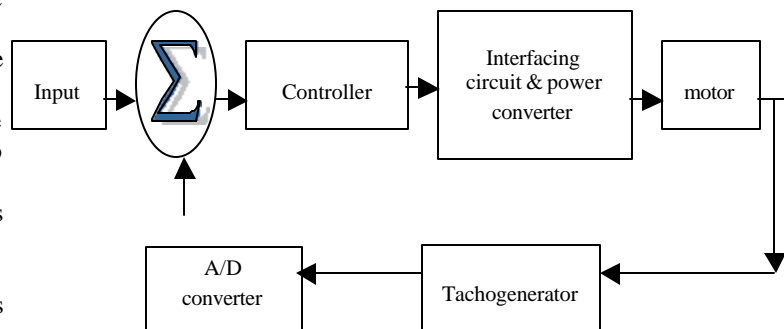


FIGURE 2.
BLOCK DIAGRAM OF SPEED CONTROL

The design involved various subparts, including a special power supply circuit together with the heat sinks required to cool the rectifying diodes and the power MOSFET used in the power converter.

The speed control of the disk requires some form of feedback to compare with the desired reference. The feedback in the speed control system was obtained from a tachogenerator whose output was converted into digital form and read by the computer. Figure 2 shows the block diagram for speed control.

The controller is implemented purely in software, using C programming language. The interface circuitry used is opto-isolated gate drives to switch the power MOSFET in the power converter supplying the dc motor. The pattern in which the controller switches the power MOSFET in the power converter determines the voltage fed to the motor and hence its speed. The resulting speed of the motor in turn is captured by the tachogenerator and transmitted to the controller through the A/D converter. The controller uses this feedback from the tachogenerator and compares it with the user input to determine whether to decelerate or accelerate the motor by sending the appropriate signals to the power converter via the power MOSFET gate drive. The power source for the dc motor is implemented by using a conventional step-down transformer and bridge rectifier. An output filter smooths the bridge rectifier output. In the power circuit shown in figure 3, the 30mF capacitor was added for smoothing the output voltage of the bridge rectifier implemented by the 4 RURG5060 rectifying diodes.

The voltage fed to a dc motor is approximately proportional to the angular speed of the motor. The back emf is directly proportional to the speed of rotation of the motor, and the product of armature voltage with armature current becomes smaller and smaller compared to the value of the back emf

as the size of the motor increases. Hence, the approximation becomes more accurate as the size of the motor increases. Using this approximate relationship, it can be deduced that if the voltage can be varied then the speed of rotation can be varied accordingly. To vary the voltage fed to the dc motor, pulse width modulation is used.

Heat Sink for the IRF150 Mosfet and Rectifiers

Due to the large currents flowing in the circuit, and the expected resulting heat dissipation, a heat sink is required for the MOSFET. Since the switching frequency is above 1kHz and the duty ratios intended for use are above 20%, the steady-state model for heat flow was used. The total power loss in the MOSFET is 52.4 W. Figure 4 gives the steady state model for the heat sink requirement with the following requirement:

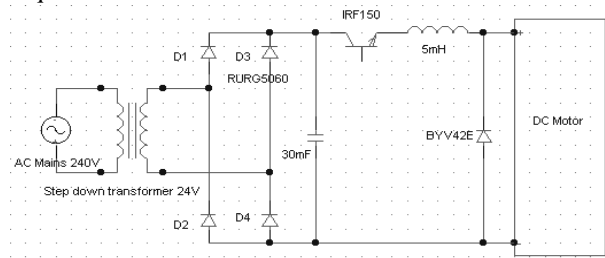


FIGURE 3
POWER CIRCUIT TO SUPPLY THE DC MOTOR

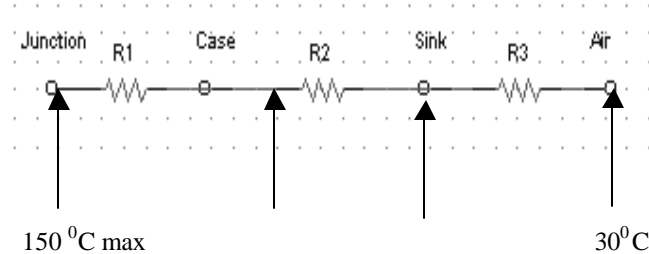


FIGURE 4
STEADY-STATE MODEL FOR HEAT SINK REQUIREMENTS

Thermal resistance from junction to case, $R1 = 0.83 \text{ }^{\circ}\text{C/W}$
 Thermal resistance from case to sink, $R2 = 0.5 \text{ }^{\circ}\text{C/W}$
 Difference in temp = Power dissipation x Thermal resistance. Thus $R3 = 0.96 \text{ }^{\circ}\text{C/W}$. To avoid unnecessary risks of overheating of the MOSFET, a heat sink with rating smaller than $0.96 \text{ }^{\circ}\text{C/W}$ is chosen.
 The diodes in the bridge rectifier each have a duty cycle of 0.5. Thus, using the same model as in the case of the MOSFET, the heat sink ratings were obtained as 15 W. and for difference in temperature a value of $8.5 \text{ }^{\circ}\text{C/W}$ is obtained for the heat sink rating of the rectifying diodes.

GATE drive circuit for MOSFET

The function of a gate drive is to provide the necessary gate charge to turn the MOSFET on within desired time. The

signals sent from the control circuit cannot provide the necessary current and voltage to allow rapid charging and discharging of the MOSFET input capacitance. Hence there is a need for a driver stage between the control circuit and the power circuit. Moreover the driver stage should also limit the rate of change of current during switching to prevent over-voltage spikes across the MOSFET and thus adequate resistance is needed at the output of the gate drive. Also the input capacitance of the device should be able to discharge quickly to achieve fast turn-off. Hence the driver stage should also have a high current sinking capability. In the gate drive circuit shown in figure 5, it can be observed that the MOSFET input capacitance will be charged through resistor R1 but discharged through the forward biased 1N4002 diode. Thus, the driver stage fully achieves its functions.

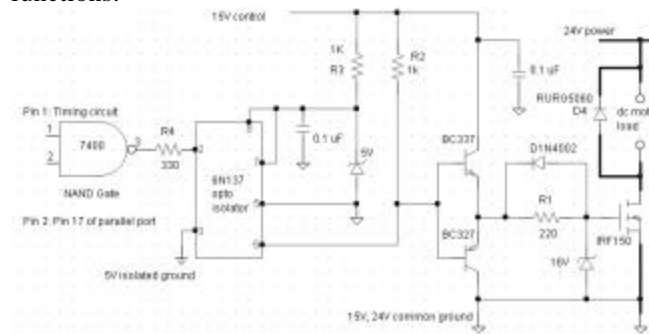


FIGURE 5
GATE DRIVE FOR IRF150 MOSFET

The purpose of the opto-isolator is to electrically isolate the control circuit from all the remaining interfacing and power circuit. This ensures that in the event of a failure, the fault is not propagated back to the control circuit. The NAND gate is used for safety reasons. The first input comes from the timing circuit, which actually generates the pulse train that controls the pulse width modulation. The second input to the NAND gate is an enable signal from the parallel port of the pc. In the event that the motor needs to be powered down, a logic 0 to this input will ensure the MOSFET is OFF no matter what pulse train is sent from the timing circuit.

Limit Switch Interface Circuit

As a measure of safety, it was intended to fix a few limit switches at strategic locations on the wear testing machine. In the event that the arm goes out of its way and hit any limit switch it would cause the process to stop. To read the state of those limit switches on the parallel port, a debouncing circuit was designed for the interfacing. This is shown in figure 6

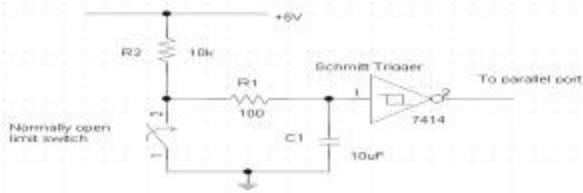


FIGURE 6
DEBOUNCING CIRCUIT FOR LIMIT SWITCH

This circuit has a time constant of about 1 millisecond, which is quite sufficient.

Gate Drive for the IRF510 Mosfet

To trigger this MOSFET itself, a gate drive circuit similar to the one for the IRF150 is used. The difference is that only one input would be required to energize the magnet and hence a NOT gate would replace the 2-input NAND gate of the speed control gate drive circuit.

Platinum Resistance Sensor Circuit

To measure the temperature near the location where friction occurs in the machine, a platinum resistance element was chosen. It has a resistance of 100 ohms at 0°C and this increases linearly with temperature to about 300 ohms. A Wheatstone bridge circuit was used to detect the variation in resistance in such a way as to preserve the linearity. The output voltage of the bridge then required some signal conditioning and amplification before being sent to the A/D card. Figure 7 shows the circuit used to implement the temperature detector. The bridge output voltage, V is given as

$$V = 5 \left[\frac{R1}{(R1 + R4)} - \frac{R2}{(R2 + R3)} \right]$$

This clearly would not give a linear relationship between R1 and V. However, by choosing the ratio of R3/R2 to be 100, as can be seen in the circuit, a fair linearity could be achieved

Strain Gauge Sensor Circuit

As for the Pt resistance sensor, the readings from strain gauges, used in the machine, are obtained from bridge circuits and amplified. The difference is that some measure had to be taken for temperature compensation for the strain gauges. This is because the change in resistance due to strain is so small that a change in ambient temperature would cause an undesirably comparable change in resistance, thus leading to erroneous readings. To cater for this temperature compensation, a second identical strain gauge was used instead of a fixed resistor R4. The second strain gauge would always remain unstressed, but at the same temperature as the first one, so that any change in ambient temperature would cause an identical change in resistance of both strain gauges, thus nullifying the unwanted effect. Without this precaution, a difference in

ambient temperature would induce the experimenter in error by giving a value of strain even when the strain gauge was not stressed at all.

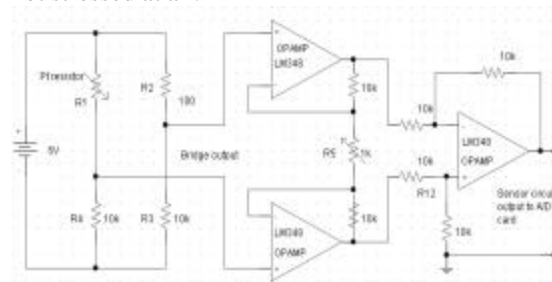


FIGURE 7
TEMPERATURE DETECTOR CIRCUIT

Tachogenerator Circuit

The tachogenerator was the only active transducer used as sensor. As such, it did not require a Wheatstone bridge but the expected output was too high to be fed to the A/D card. Some simple potential divider circuit and proper signal conditioning was required. The circuit used is shown in Figure 8.

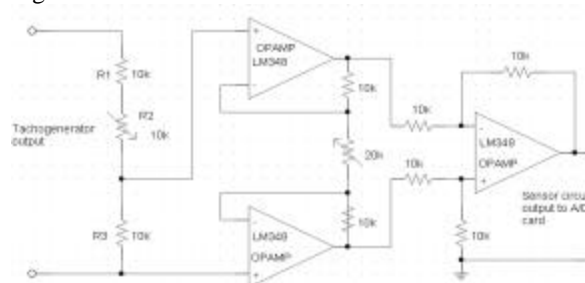


Figure 8 Tachogenerator for speed sensor circuit

The variable resistors were added to add flexibility and the possibility to vary and adjust the final output of the whole circuit. The desirable range of the output was again 0 to 5V.

SOFTWARE DEVELOPMENT

Figure 10 gives the flow chart of the software based control program. At the start, the user inputs the desired speed of rotation of the main motor and the duration of the experiment. The program does not activate the actuating device until the user has properly entered these inputs. Once the machine has started, the user can observe the readings on the screen but cannot alter the values entered while the program is running. Hitting any key on the keyboard will disable the main motor and lift the arm. As a measure of safety, limit switches is provided. If any one of them is hit, the main motor is disabled and the processt brought to a premature end. In the event that neither the keyboard nor any of the limit switches are hit, the program will automatically stop after the time set

SYSTEM INTEGRATION AND TESTING

A modular approach [4,5] is also used in the testing phase of the implemented system. Tests are performed at three levels, namely on the hardware modules, the software components and the final system which integrates the hardware and software. This type of approach, enables the student to quickly and effectively locate any source of error or fault condition and take necessary corrective measures at the relevant level of the design process. Limit switches are included as safety measure, that is if the arm goes out of its way and hit any limit switch the process is stopped. Gate drive circuits and appropriate heat sinks are used with the mosfets. Temperature rise caused by friction and Friction are measured respectively by platinum resistance and strain gauge with appropriate amplification circuits. On testing it was observed that the system performed satisfactorily.

REFERENCES EVALUATION OF SYSTEMS APPROACH

One of the most important objectives of the design/implementation project is to develop students' skills in order to make them to become proficient in all aspects of the development process, that is, from problem definition and identification of functional requirements, to planning, design, implementation and testing of the proposed solution. Another key objective is to enable students to master hardware and software development tasks and methodologies in order to ensure that they acquire the necessary competence prior to entering the job market as fresh engineers. Project supervisors and external examiners, as well as past graduates tend to confirm the effectiveness and appreciation of the proposed systems approach for project design and implementation. Course evaluations reveal better students' satisfaction with the top-down approach methodology with such design projects. Moreover, the positive impact on students' achievements has also boosted their interest in postgraduate studies and research.

CONCLUSION

In this paper, the design and implementation of a wear testing rig has been presented with the aim of illustrating the top-down systems approach that students are encouraged to use when working on their final year projects. This methodology has been well received by students as it helps them realise that the formulation of a solution to a design problem can be done effectively by applying structured solving techniques. The objective of enhancing their hardware and software design/implementation skills has also been achieved to a large extent. By focusing on this kind of approach, the knowledge and capabilities acquired can

readily be transferred and applied to more complex research based projects.

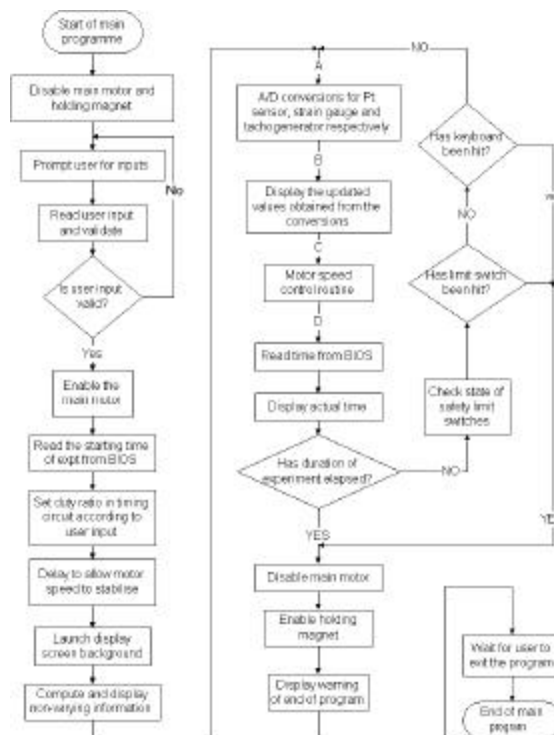


FIGURE 10:
FLOWCHART OF THE CONTROL PROGRAM

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