بسم الله الرحمن الرحيم

Sudan University Of Science And Technology

College Of Graduate Studies

DESIGN AND IMPLEMENTATION OF AN AIRCRAFT GAS TURBINE ENGINE TEST SYSTEM

تصميم وتنفيذ منظومة اختبار محرك طائرة غازي توربيني

A Thesis Submitted to the College of Graduate Studies & Scientific Research in Partial Fulfillment of the Requirements for the Degree of M.Sc in mechatronic Engineering

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بسم الله الرحمن الرحيم

آيـة قرآنية

قال تعالى:

{ إنَّ فـي خلْقِ الـسَّموات والأرضِ واختلافِ الـلَّيلِ والـنَّهارِ لآياتٍ لأولـي الألـباب * الَّـذيـن يَـذْكُرونَ الله قـيامـاً وقـعوداً وعلـى جُنوبـهم ويـتفكَّرونَ في خلْقِ الـسَّـموات والأرضِ ربَّـنـا مـا خـلَقْت هذا بـاطلاً سـبحانَك فَقِنَا عذابَ الـنَّار }

صدق الله العظيم

آل عمران آية 190-191

Dedication

I would like to dedicate this thesis to my parents whose words of encouragement and push still rings in my ears.

I also dedicate this thesis to my friends, colleagues who have supported me throughout the process; I will always appreciate all they have done.

Acknowledgements

First and foremost, praise be to ALLAH who gave me the power to complete this project.

Then I would like to express my heartily gratitude to my supervisor, Dr. Al khidir tay alla, for the guidance and support given throughout the progress of this project.

My appreciation also goes to my family who has been so tolerant and supports me all these years. Thanks for their encouragement, love and emotional support that they had given to me.

Also my great appreciation is dedicated to my friends Eng. Akram Mohammed Abdalla , Mosab Ahmad osman & Mustafa Alzain and those who were involved directly or indirectly with this project. There is no such meaningful word than…..Thank You So Much.

Abstract

Because of the significant importance of the gas-turbine engines as it is the core of the aircraft, the engine health status should be tested periodically. Testing methodologies are needed to conduct the engine tests required as a part of airworthiness certification.

In this project a data acquisition system was developed as a gas turbine engine testing system. This system was developed to monitor the engine parameters to determine its condition and to control the engine starting components according to specific sequence. A PIC microcontroller from Microchip was used as the heart of the data acquisition system. Internal analog to digital converters acquired data from the analog signals . The analog signals gathered from temperature, tachogenerator, throttle, and pressure sensors will be transformed into digital format and then the corresponding data will be sent serially to the PC through the microcontroller serial port. After the data was received by the PC, visual basic program was designed to convert, scale, and display these data . After the data was displayed the system will analyze and compare these data with standard values according to the current position of the throttle. If there is an abnormal values the system will provide automatically a trouble shooting list in order to determine where the problem is.

The developed test system had been applied successfully and the results are accurate, reliable and acceptable.

المستخلص

نسبة لأهمية المحركات التوربينيه باعتبارها العنصر الأساسي في الطائرة, يجب اختبار حالتها وأداءها بصورة دورية. من هنا نبعت أهمية إيجاد طرق اختبار للمحركات كواحدة من متطلبات الصلاحية الجوية بعد أي عملية صيانة للمحرك.

في هذا المشروع تم تصميم منظومة اختبار لمحرك الطائرات التوربيني , هذا النظام صمم لعرض وتحليل معاملات المحرك ومن ثم تحديد صلاحيته و التحكم في تشغيل مكونات منظومة بدء التشغيل بتسلسل محدد ,في هذه المنظومة استخدم المتحكم الدقيق PIC من شركة Microchip لتجميع البيانات ' يتم تحويل إشارات المتحسسات التماثلية إلى رقمية باستخدام محول التماثلي إلى رقمي الموجود داخل المتحكم الدقيق, بعد انتهاء عملية التحويل يقوم المتحكم الدقيق بإرسال القيم الرقمية إلي جهاز الحاسوب عن طريق المنفذ التسلسلي. يقوم الكمبيوتر باستقبال القيم الرقمية المرسلة من المتحكم الدقيق ومن ثم معالجتها وعرضها باستخدام برنامج Visual Basic. بعد عرض البيانات يقوم النظام بمقارنة القيم المعروضة مع القيم القياسية المخزنة مسبقا وبناء علي ذلك يتم تحديد صلاحية المحرك, في حال كانت القيم المعروضة غير مطابقة مع القيم القياسية لسبب ما يقوم النظام بعرض لائحة تحتوي علي المسببات المحتملة وكيفية معالجتها.

تم تجربة النظام المصمم بنجاح وكانت النتائج مرضية ودقيقة ومقبولة.

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List Of Abbreviations

AC	Alternative Current
ADC	Analogue To Digital Convertor
CPU	Center Processing Unit
DAQ	Data Acquisition
DC	Direct Current
DSP	Digital Signal Processing
EMF	Electro Motive Force
EPR	Engine Pressure Ratio
IC	Integrated Circuit
GUI	Graphical User Interface
LCD	Liquid Crystal Display
LVDT	Linear Variable Differential Transformer
Op - Amp	Operational Amplifier
PC	Personal Computer
RAM	Random Access Memory
RVDT	Rotary Variable Differential Transformer
RPM	Revolution Per Minute
EGT	Engine Gas Temperature
USB	Universal Serial Bus

CHAPTER ONE

INTRODUCTION

1.1 Overview

The most widely used form of propulsion system for modern aircraft is the gas turbine engines. They are used as a propulsion system to generate thrust or torque to move an airplane through the air.

Turbine engines come in a variety forms such as: turbojet, turbo shaft, turbofan, and turboprop engines. Each engine has a combustion section, a compressor, a turbine and an inlet and a nozzle.

To determine the status and health of the engine numerous indicators and sensors are used such as rotational speed, temperature, pressure…. etc.

1.2 Literature Review

Many efforts and researches have been done to develop data acquisition and testing systems for gas turbine engines ,below are some of similar works:

P.K.S. Shrivastava, R.P. Arora (1989) designed A Microprocessor-Based System for Monitoring Gas Turbines. in this research the development and testing of hardware and software for a microprocessor based monitoring system for gas turbines is described. The operators of gas turbines can be trained to monitor running hours, slip between high and low pressure compressor spools and torque on the reduction gear-box under various conditions of operation. The system will replace the traditional method of monitoring these parameters which are more time consuming and error prone [1] .

David May , Steven Farber, and Vincient Poirier (2003), designed a comprehensive monitoring system for gas turbine engines. The main objective of the design was to produce a system capable of detecting and recording only special conditions or events. As a sample engine, the SR-30 gas turbine was used. A simulation of the engine using GSP software provided a model. The model was used to determine the healthy operation of the engine. The integration of a developed algorithm has enabled the system to be used for aerodynamic component monitoring, as well as, mechanical systems monitoring [17] .

David Clifton, (January 2006) designed a Condition Monitoring system of Gas-Turbine Engines, This report described preliminary research into condition monitoring approaches for modern gas-turbine aircraft engines, and outlines plans for novel research to contribute to machine learning techniques in the condition monitoring of such systems.

A framework for condition monitoring of aircraft engines is introduced, using signatures of engine vibration across a range of engine speeds to assess engine health. Inter- and intra-engine monitoring approaches are presented, in which a model of engine normality is constructed using vibration data from other engines of its class, or from the test engine itself, respectively.

Results of inter-engine analysis of final engine vibration tests prior to their release into service are presented, showing that the approach described within this report provides a more reliable estimate of engine condition than manufacturers conventional engine vibration tests, leading to better discrimination between good and bad engines. Intra-engine analysis of an engine undergoing cyclic endurance testing, in which a set operational manoeuvre is performed repeatedly, shows that the method described in this report provides early warning of engine failure that eventually resulted in a hazardous engine fire, undetected by engine developers until it had to be shut down manually [10].

O.Maheshwari, M.Mohana Arasi, S.M.Ramesh C.Lakshmi, (2014) designed measurement system for Wind Turbine Using Microcontroller as Data Acquisition. In this paper [2] the various parameters of wind are measured and monitored by setting up a system. The parameters are pressure, current ,voltage and direction. The interface to personal computer (pc) is done using a microcontroller which is used as a data acquisition system and proteus design suite is used for simulation. The idea of using microcontroller as a data acquisition is economic and more convenient for the users [2].

1.3 Problem Definition

Testing methodologies are needed to conduct the engine tests required as a part of airworthiness certification, maturity, and validity assessment of a turbine engine after maintenance and reduce time and numbers of flights test.

As well as traditional mechanical instruments performance is usually affected by the mechanical friction, humidity, and sensing elements deformation. The effect of these factors becomes obvious when the operation life time of the instrument is increased, making the instrument indication unreliable.

This research study will be allocated particularly for helicopter GTD-350 turbo shaft engine.

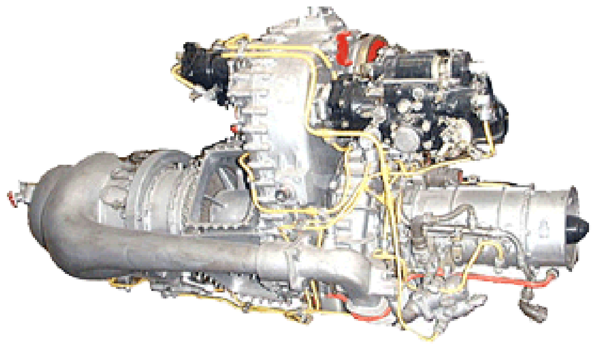


Figure (1.1) GTD-350 turbo shaft engine

1.4 Research Objectives

- Propose a testing system to provide engine information such as performance, operability and reliability (after maintenance to reduce time and number of aircraft flight tests).
- Propose electronic engine starting system to replace the traditional analog starting system (generate sequence of starting commands).

- Propose a computerized instrumentation system with a convenience display method.
- Implement the whole system.

1.5 Methodology

The system was developed to monitor the engine parameters to determine its condition. A PIC microcontroller from Microchip was used as the heart of the data acquisition system. Internal analog to digital converters acquired data from the analog signals . The analog signals gathered from temperature, tachogenerator, throttle, and pressure sensors and transformed into digital format, then the corresponding data was sent serially to the PC through the microcontroller serial port. After the data was received by the PC, a visual basic program was designed to converts, scales, and displays the data . After the data was displayed the system will analyze and compare the data with standard values according to the current position of the throttle. If there is an abnormal values the system will provide automatically a trouble shooting list in order to determine where the problem is.

1.6 Thesis layout

This thesis is organized as follows:

Chapter one introduces the work including the problem definition, objective of the work and methodology. Types and parts of aircraft turbine engines and its instruments are described in chapter two. Chapter three introduces the theoretical background of the measurement systems. Chapter four describes the implementation of hardware and software. Chapter five describes the steps of carrying out the experiments and discusses the result obtained. Chapter six presents conclusions and recommendations.

CHAPTER TWO

AIRCRAFT ENGINE

2.1 Introduction

An aircraft is able to fly by gaining support from the air, or in general the atmosphere of a planet. It counters the force of gravity by using either static lift or by the dynamic lift of an airfoil, or in a few cases by jet engines downward thrust. Aircrafts consist of several parts: wings (fixed or rotary), fuselage, landing gear, tail group, propulsion engines, and control surfaces.

Heavier-than-air flight is made possible by a careful balance of four physical forces acting upon an aircraft: lift, the upward acting force; drag, the backward acting, or retarding force of wind resistance; weight, or gravity, the downward acting force; and thrust, the forward acting force. For flight, an aircraft's lift must balance its weight, and its thrust must exceed its drag. A plane uses its wings for lift and its engines for thrust. Drag is reduced by a plane's smooth shape and its weight is controlled by the materials it is constructed of.

2.2 Propulsion System

An aircraft propulsion system generally consists of an aircraft engine and some means to generate thrust, such as a propeller or a propulsive nozzle. Propulsion system must achieve two requirements: the thrust balance the drag of the airplane when the airplane is cruising. And the thrust must exceed the drag of the airplane for the airplane to accelerate. In fact, the greater the difference between the thrust and the drag, called the excess thrust, the faster the airplane will accelerate.

2.3 Gas Turbine Engines

Gas turbine engines are widely used in aircraft to generate the required thrust, including airplanes and helicopters, including turbo shaft and turbo prop craft, and are even employed to power missiles. Because of the safety requirements demanded by the operation of such craft, and the reliability necessitated, testing must be done routinely to ensure that the engine operation is sufficient.

Generally, gas turbine engines operate by igniting a mixture of injected fuel and compressed air within a combustion chamber or assembly and then channeling the output of exiting combustion gases to drive a turbine stage. The engine can be mounted within an outer housing. The outer housing can include a duct formed in part by an inner housing, through which a flow of air is directed. The airflow can be directed with a fan to exhaust with a portion of the airflow being directed to a high-speed compressor. Air from the compressor is directed to a combustor for combustion with injected fuel. Additionally, some engines will route air not taken up by the compressor to exhaust in order to increase thrust.

Gas turbine engines generally operate by using a continuous combustion process. The inlet air temperature and pressure is raised by a compressor, after which the air is moved into a burner or combustion chamber. Fuel is injected into the chamber and then combusted to raise the air temperature. The heated fuel air mixture, now under a high pressure and at a high temperature, is expanded and cooled through a turbine. The turbine speed can be controlled by the amount of fuel that is injected into the combustion chamber, and the amount of high pressure air which passes through there. Gas turbine engines may have a single moving rotor or can contain multiple rotors, such as, for example, wherein the engine includes a gas generator rotor and a power turbine rotor. Although these rotors may be the only moving parts, gas turbine engines must rely on a variety of parameters to function and meet the load and operating demands [21].

2.4 Turbo Shaft Engine

The Turbo-shaft engine is a form of gas-turbine engine, which is widely used in helicopters. It operates like a turboprop system. However, it does not have a propeller but drives the helicopter rotor instead. The turbo-shaft engine is designed to keep the speed of the helicopter rotor independent from the rotating speed of the gas generator. It allows the rotating speed of the rotor to remain constant even when the rotating speed of the generator is varied to adjust the amount of power it produces.

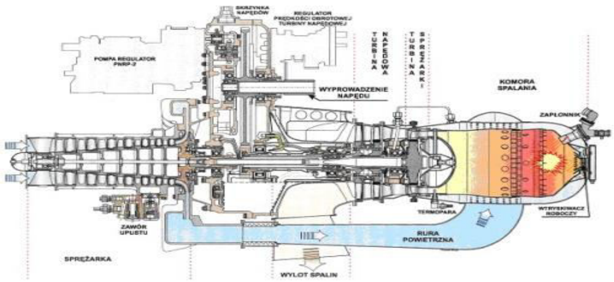


Figure (2.1) Turbo shaft engine

2.5 Gas turbine engine Parts

Gas turbine engine consist of four main parts : compressor, turbine, combustion chamber, nozzle

2.5.1 Compressor

The compressor is the first component in the jet engine core. The compressor is made up of fans with many blades attached to a shaft. The compressor squeezes the air that enters it into progressively smaller areas, resulting in an increase in the air pressure. This results in an increase in the energy potential of the air. The squashed air is forced into the combustion chamber.

2.5.2 Combustor

In the combustor the air is mixed with fuel and then ignited. There are as many as 20 nozzles to spray fuel into the airstream. The mixture of air and fuel catches fire. This provides a high temperature, high-energy airflow. The fuel burns with the oxygen in the compressed air, producing hot expanding gases.

The inside of the combustor is often made of ceramic materials to provide a heat-resistant chamber. The heat can reach 2700°.

2.5.3 Turbine

The high-energy airflow coming out of the combustor goes into the turbine, causing the turbine blades to rotate. The turbines are linked by a shaft to turn the blades in the compressor and to spin the intake fan at the front. This rotation takes some energy from the high-energy flow that is used to drive the fan and the compressor. The gases produced in the combustion chamber move through the turbine and spin its blades. The turbines of the jet spin around thousands of times. They are fixed on shafts which have several sets of ball-bearings in between them.

2.5.4 Nozzle

The nozzle is the exhaust duct of the jet engine. This is the jet engine part which actually produces the thrust for the plane. The energy depleted airflow that passed the turbine, in addition to the colder air that bypassed the engine core, produces a force when exiting the nozzle that acts to propel the engine, and therefore the airplane, forward. The combination of the hot air and cold air are expelled and produce an exhaust, which causes a forward thrust. The nozzle may be preceded by a mixer, which combines the high temperature air coming from the jet engine core with the lower temperature air that was bypassed in the fan. The mixer helps to make the jet engine quieter.

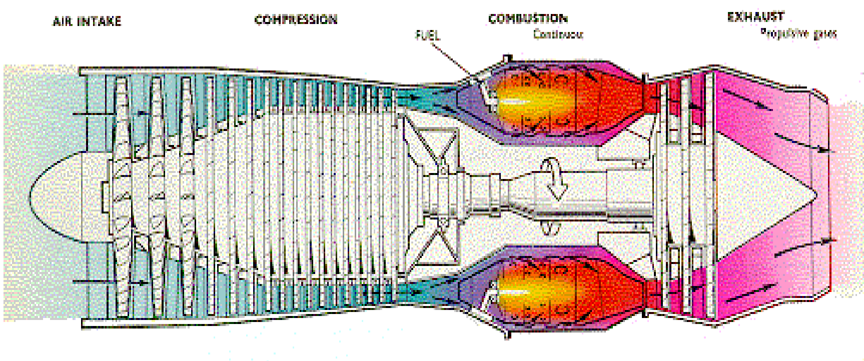


Figure (2.2) Gas turbine engine parts

2.6 Engine Instruments

The aircraft is an integral composed of a number of independent, interacted and interrelated systems. Among them, the engine is a very important one. It is therefore necessary to often pay attention to its operation. The engine instruments are so designed that they can measure and indicate the parameters of the engine rotational speed, fuel quantity, fuel pressure, oil pressure, exhaust gas temperature, etc.

2.7 Engine Operation Parameters

Engine operational parameters are: temperature, rotational speed, emission , fuel flow, air pressure [5]

i. Temperature

Thermocouples with signal conditioning are often used to monitor temperatures at various, points inside and outside the engine. Since thrust is fundamentally dependent on temperature differentials, engine temperatures are used to measure the effectiveness of engine design.

ii. Air Pressure

The efficiency of the jet engine is, in part, determined by air pressures at various stages inside the engine. Engine pressure ratio (EPR) is a parameter used in engine efficiency thrust calculations. Transducers measure pressure at points in the intake, compressor and turbines.

iii. Fuel Flow

Fuel efficiency is calculated by measuring fuel flow. Flow transducers can output a set of pulses proportional to the fuel flow rate.

iv. Vibration

At high speeds, small vibrations can cause a turbine engine to self destruct. Digital signal analyzers (spectrum analyzers) are used to measure the vibration signature of rotating engine parts. Real-time monitoring allows the user to instantly see the vibration signatures produced by the engine while under test.

v.Emissions

Carbon monoxide, carbon dioxide, smoke and various other gases are by products of the engine combustion process. The concentration of these gases is measured using transducers. These transducers output is in mv. These signals can be sensed, linearized and correlated with other engine test parameters by the data acquisition system. Environmental regulations continue to increase the importance of these measurements.

vi.Speed

The rotational speed of the jet turbine is another parameter monitored in an engine test. Speed transducers usually output pulses with a frequency proportional to the speed of rotation. A counter is used to measure the frequency.

2.8 Aircraft Test Systems

Ground testing widely used for a new engine design or an engine that has undergone significant structural modification, is a prerequisite before any flight-test program can begin. In turn, ground testing follows and complements an extensive structural modeling program, which encompasses flight loads, material fatigue, structural dynamics, airborne and structure borne acoustics and more. Furthermore, testing systems can be used as a diagnostic system in the maintenance of gas turbine engines.

A variety of engine tests are performed to maintain the engine operative condition. Testing engine is achieved by attaching sensors to the engine in-order to obtain engine operational parameters. These operational parameters are compared with standard ones to determine whether the engine meets the specified parameters for operation. As well as, recheck parameters which appear to be excessive or out of the expected range. However, this will require a recheck of additional values as well, necessitating a repeat of the entire test procedure.

Testing requires more than one instrument. The instruments are used to obtain engine operational parameters under controlled conditions. These operational parameters are used to provide further information concerning test parameters. Furthermore, testing is required ascertain a given parameter.

A change in the engine operation and the engine testing environment can affect the parameters being analyzed. The environment are, particularly: the surrounding temperature and atmospheric pressure. The test results obtained must be considered with respect to the atmospheric and temperature conditions at the taken time. For example, if the surrounding air temperature increases or decreases by even a couple of degrees, the engine operating requirements may also be altered. In such a circumstance, if the operator did not note a temperature change in the environment throughout a testing cycle, the engine might be passed or failed, incorrectly.

From the above points there must be a real time analysis system to provide visual information representative of a grouping of results for an engine being tested.

2.8.1 Example of engine test systems

ETS 2000 is a data acquisition and control system, specifically designed to perform aircraft engine testing (turbo-fan and turbo-prop). This system architecture main capabilities are: real time data acquisition, monitoring and control as well as processing, analysis and report of the acquired data.

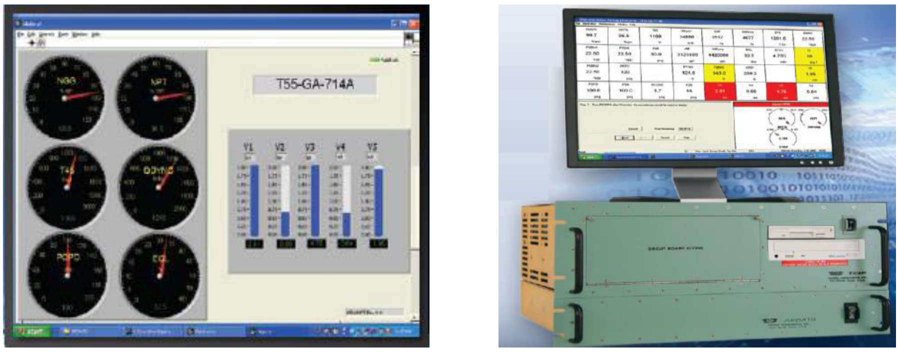
System architecture is both modular and distributed, and consists of the data acquisition system and the supervisor and control system. Furthermore, the system has a data server, containing all the relevant data, which ensures efficient data management and backup.

The data acquisition system provides sensor and actuator interface, allowing real time communication with the supervisor and control system [18].

ASE2000LX system is designed for a wide range of turbine engine testing, from APUs to large turbofan engines. The system is capable of supporting many different engine platforms to meet complex engine testing requirements. It integrates data acquisition, engine control, and facility control in a single system and is typically used in our commercial engine test facilities [19].

H355 Series engine Test Cell Instrumentation Package Developed by Howell provides an adaptable, internet protocol (IP) based platform for accurately testing and monitoring gas turbine engines.

This cell is equipped with Referred Engine Diagnostic Data (REDD) analysis program is a comprehensive thermodynamic analysis program that identifies abnormal engine operation by comparing actual engine performance with expected engine performance. Summarized performance reports make engine condition determination easy. Good engine performance tracking is simplified with a quantified ranking of engine condition. Weak engines are highlighted for attention. Probable causes of substandard performance are identified, providing the mechanic with a logic path for repair [16].



Figure(2.3) H355 Series engine Test system

Most test systems performs the following:

- Monitor and display engine, facility and calculated parameters
- Scale, convert and calibrate inputs to engineering units
- Alert the operator of unsafe conditions
- Remind the operator when transducers need calibration
- Provide virtual instrumentation for visual reference and rate of change information
- Parameter inputs and channel assignments are software configurable
- Printed Circuit Boards carry their own calibration allowing for off-site calibration
- Prompts the operator through test procedures
- Engine application software
- Standard or customized printed reports
- Engine diagnostics using Howell's patented Referred Engine Diagnostic Data analysis program
- Second Liquid Crystal Display to enhance data presentation
- Integrate able with other vendor's systems

Chapter Three

Electronic Engine Measurement System

3.1 Introduction

The general measurement system consists of four stages: sensing, signal conditioning, signal processing and data presentation. The purpose of this chapter is to discuss the principles and characteristics of sensing elements used in turbo shaft engine , study methods of conditioning sensing stage output for further processing. Finally, present the structure of microcontrollers and software used.

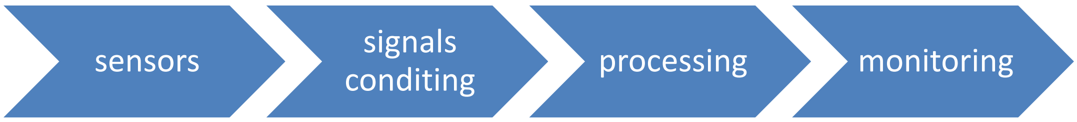


Figure (3.1) Measurement system stages

3.2 Sensing stage

The sensing element is the first element in the measurement system, it is in contact with, and draws energy from, the process or system being measured. The input to this element is the true value of the measured variable.

The sensing elements are classified according to whether the output signal is electrical, mechanical, thermal or optical. Elements with an electrical output are further divided into passive and active. Passive devices such as resistive, capacitive and inductive elements require an external power supply in order to give a voltage or current output signal; active devices, e.g. electromagnetic and thermoelectric elements, need no external power supply [6]

3.2.1 Resistive metal and semiconductor sensors for temperature measurement

The resistance of most metals increases reasonably linearly with temperature in the range −100 to +800 °C. The general relationship between the resistance R_T Ω of a metal element and temperature T °C is a power series of the form

$$R_T = R_0(1 + \alpha T + \beta T^2 + \gamma T^3 + \ldots) \qquad (3.1)$$

Where: R_0 Ω is the resistance at 0° C and α, β, γ are temperature coefficients of resistance. The magnitude of the non-linear terms is usually small [6]

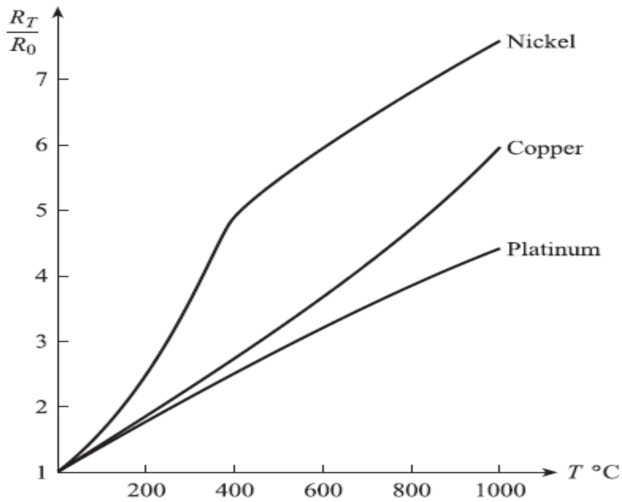


Figure (3.2) Resistance/temperature characteristics of commonly used metals

3.2.2 **Thermoelectric sensing elements**

Thermoelectric or thermocouple sensing elements are commonly used for measuring temperature. If two different metals A and B are joined together, there is a difference in electrical potential across the junction called the junction potential. This junction potential depends on the metals A and B and the temperature T °C of the junction, and is given by a power series of the form:

$$E_T^{AB} = a_1T + a_2T^2 + a_3T^3 + a_4T^4 + \ldots \qquad (3.2)$$

The values of constants a_1, a_2, etc., depend on the metals *A* and *B*

A thermocouple is a closed circuit consisting of two junctions (Figure 3.3) , at different temperatures T_1 and T_2 °C. If a high-impedance voltmeter is introduced into the circuit, so that current flow is negligible, then the measured electromotive force (e.m.f) is, to a close approximation, the difference of the junction potentials, i.e. Thus the measured e.m.f. depends on the temperatures T_1, T_2 of both junctions. In the following discussion T_1 will be the temperature to be measured, i.e. the temperature of the measurement junction, and T_2 will be the temperature of the reference [6]

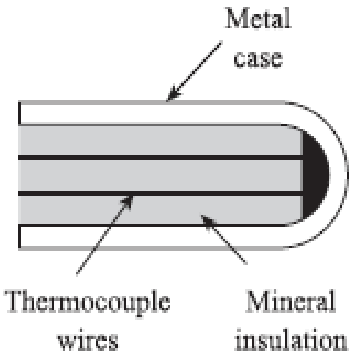


Figure (3.3) thermocouple junctions

3.2.3 Tachometer

Tachometer generators (or tachogenerator) are electromechanical devices which generate a voltage proportional to their shaft speed. They are used to power tachometers and to measure the speed of motors, engines, and other rotational devices [13].

Figure(3.4) tachogenerator

The majority of modern tachogenerators are permanent magnet types. These devices use a rotating armature, one end of which is attached to a machine shaft, to measure rotational speed. The armature rotates within a fixed magnetic field, so that its rotation induces electromotive force (voltage) proportional to the shaft's speed. The armature contacts are connected to a voltmeter circuit, which converts the voltage into a speed value.

3.3 signal conditioning

This stage is manipulating an analog signal in such a way that it meets the requirements of the next stage for further processing. Most common used is an analog-to-digital converter.

Signal inputs accepted by signal conditioners include DC current or voltage, AC current or voltage, frequency and electric charge. Sensor inputs can be accelerometer, thermocouple, thermostat, resistance thermometer, strain gauge or bridge, and Linear variable differential transformer (LVDT) or Rotary variable differential transformer (RVDT). Specialized inputs include encoder, counter or tachometer, timer or clock, relay or switch, and other specialized inputs. Outputs for signal conditioning equipment can be voltage, current, frequency, timer or counter, relay, resistance or potentiometer, and other specialized outputs.

Signal conditioning can include amplification, filtering, converting, range matching, isolation and any other processes required to make sensor output suitable for processing after conditioning.

It is primarily utilized for data acquisition, in which sensor signals must be normalized and filtered to levels suitable for analog-to-digital conversion so they can be read by computerized devices. Other uses include preprocessing signals in order to reduce computing time, converting ranged data to boolean values, for example when knowing when a sensor has reached certain value.

3.3.1 Filtering

Filtering is the most common signal conditioning function, as usually not all the signal frequency spectrum contains valid data.

3.3.2 Amplifying

Signal amplification performs two important functions: increases the resolution of the input signal, and increases its signal-to-noise ratio for example, the output of an electronic temperature sensor, which is probably in the millivolts range is probably too low for an analog-to-digital converter (ADC) to process directly. In this case it is necessary to bring the voltage level up to that required by the ADC.

Commonly used amplifiers on signal on conditioning include sample and hold amplifiers, peak detectors, log amplifiers, antilog amplifiers, instrumentation amplifiers and programmable gain amplifiers [19].

3.3.3 Instrumentation amplifiers

An instrumentation (or instrumentational) amplifier is a type of differential amplifier that has been outfitted with input buffer amplifiers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedances. Instrumentation amplifiers are used where great accuracy and stability of the circuit both short and long-term are required.

Although the instrumentation amplifier is usually shown schematically identical to a standard operational amplifier (op-amp), the electronic instrumentation amp is almost always internally composed of 3 op-amps. These are arranged so that there is one op-amp to buffer each input (+,−) and one to produce the desired output with adequate impedance matching for the function [11].

The most commonly used instrumentation amplifier circuit is shown in the figure (3.5). The gain of the circuit is

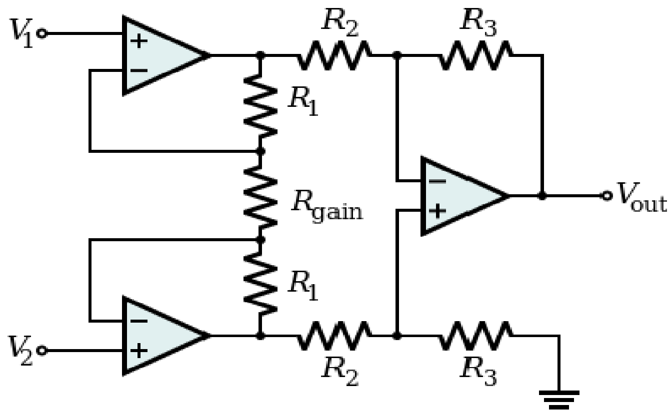


Figure (3.5) instrument amplifier diagram

$$v_{out} = (v_2 - v_1)\left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2} \qquad (3.3)$$

3.3.4 Current to voltage converters

A variety of transducers produce electrical current in response to an environmental condition. Photodiodes and photomultipliers are such transducers which respond to electromagnetic radiation at various frequencies ranging from the infrared to visible to γ-rays.

A current to voltage converter is an op amp circuit which accepts an input current and gives an output voltage that is proportional to the input current. The basic current to voltage converter is shown on Figure (3.6) This circuit arrangement is also called the trans resistance amplifier [19]

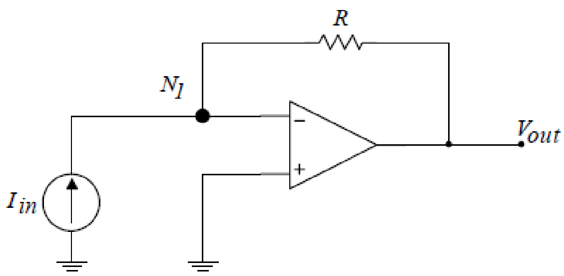


Figure (3.6)current to voltage convertor circuit

$$v_{out} = -RI_{in} \quad (3.4)$$

The gain of this amplifier is given by R. This gain is also called the sensitivity of the converter. Note that if high sensitivity is required for example 1V/µV then the resistance R should be 1 MΩ. For higher sensitivities unrealistically large resistances are required.

A current to voltage converter with high sensitivity may be constructed by employing the T feedback network topology shown on Figure (3.7)

In this case the relationship between Vout and I1 is

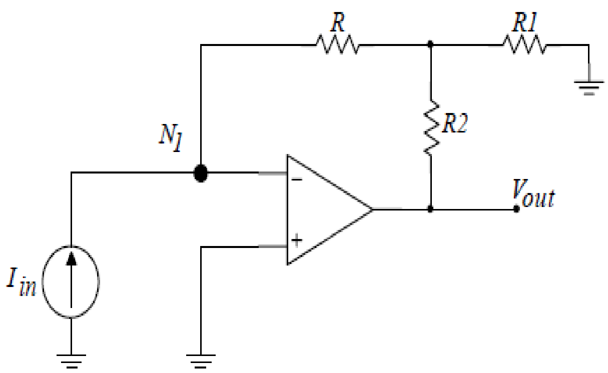


Figure (3.7) high sensitivity current to voltage convertor circuit

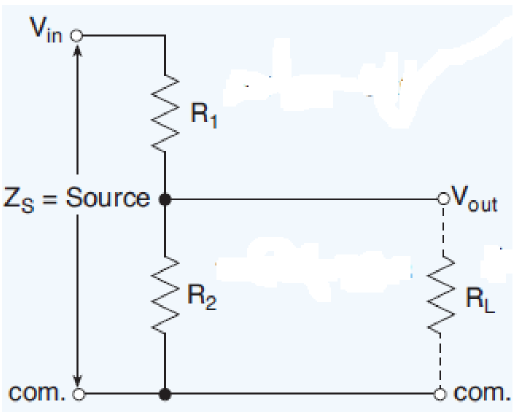
$$V_{out} = -\left(1 + \frac{R2}{R1} + \frac{R2}{R}\right) I_1$$

3.3.5 Attenuation

Most data acquisition system inputs can measure voltages only within a range of 5 to 10V. Voltages higher than this must be attenuated.

3.3.5.1 Voltage Dividers

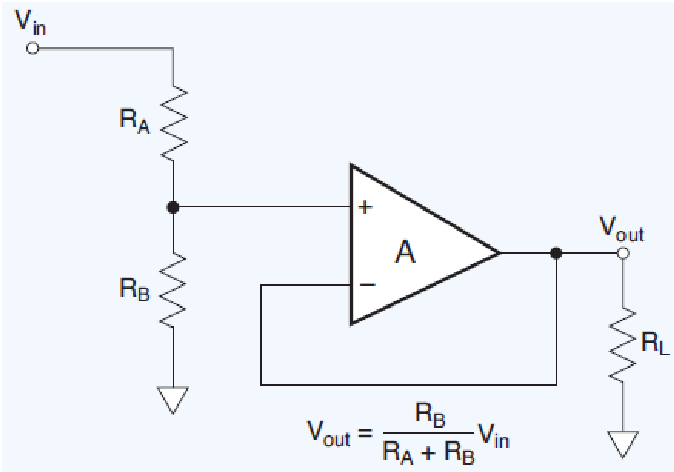
Straight forward resistive dividers can easily attenuate any range of voltages as shown in Figure (3.8), but two drawbacks complicate this simple solution. First, voltage dividers present substantially lower impedances to the source than direct analog inputs. Second, their output impedance is much too high for multiplexer inputs. For example, consider a 10:1 divider reading 50V. If a 900 kW and a 100 kW resistor are chosen to provide a 1 MW load to the source, the impedance seen by the analog multiplexer input is about 90 kW, still too high for the multiplexed reading to be accurate. When the values are both downsized by a factor of 100 so the output impedance is less than 1 kW, the input impedance seen by the measured source is 10 kW, or 2 kW/V, which most instruments cannot tolerate in a voltage measurement. Hence, simple attenuation is not practical with multiplexed inputs [6].



Figure(3.8)Voltage Divider

3.3.5.2 Buffered Voltage Dividers

The low impedance loading effect of simple voltage dividers can be overcome using unity-gain buffer amplifiers on divider outputs. A dedicated unity-gain buffer has high-input impedance in the MW range and does not load down the source, as does the network in the previous example. Moreover, the buffers' output impedance is extremely low, which is necessary for the multiplexed analog input.



Figure(3.9) Buffered Voltage Dividers

$$V_{out} = V_{in} \frac{R_2}{R_1 + R_2} \qquad (3.5)$$

3.3.6 Isolation

When isolation is required frequently, data acquisition inputs must measure low-level signals where relatively high voltages are common, such as in motor controllers, transformers, and motor windings. In these cases, isolation amplifiers can measure low-level signals among high common-mode voltages, break ground loops, and eliminate source ground connections without subjecting operators and equipment to the high voltage. They also provide a safe interface in a hospital between a patient and a monitor or between the source and other electronic instruments and equipment. Yet other applications include precision bridge isolation amplifiers, photodiode amplifiers, multiple-port thermocouple and summing amplifiers, and isolated 4 to 20 mA current-control loops [9].

A unity gain amplifier is an electronic amplifier circuit that doesn't amplify. In other words, it has a gain of 1. The output voltage in a unity gain amplifier is the same as the input voltage.

unity gain amplifier provides one important benefit: It doesn't take any current from the input source. Therefore, it completely isolates the input side of the circuit from the output side of the circuit. Op amps are often used as unity gain amplifiers to isolate stages of a circuit from one another.

Unity gain amplifiers come in two types: voltage followers and voltage inverters. A follower is a circuit in which the output is exactly the same voltage as the input. An inverter is a circuit in which the output is the same voltage level as the input but with the opposite polarity.

3.4 Processing

3.4.1 Analog-to-Digital Converters

Analog-to-Digital Converters (ADCs) transform an analog voltage to a binary number (a series of 1's and 0's), and then eventually to a digital number (base 10) for reading on a meter, monitor, or chart. The number of binary digits (bits) that represents the digital number determines the ADC resolution. However, the digital number is only an approximation of the true value of the analog voltage at a particular instant because the voltage can only be represented (digitally) in discrete steps. How closely the digital number approximates analog value also depends on the ADC resolution

3.4.2 **Microcontroller**

Microcontroller is a small computer on a single integrated circuit containing a processor core, memory and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems.

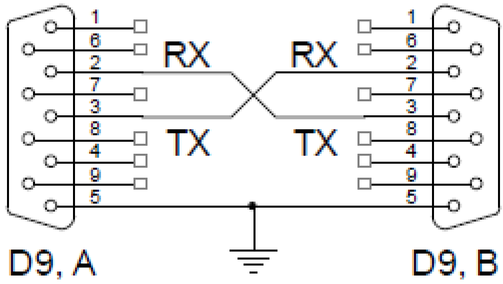
Some microcontrollers may use four-bit words and operate at clock rate frequencies as low as 4 kHz, for low power consumption (single-digit milliwatts or microwatts). They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt;

3.4.3 Serial communication RS232

A popular way to transfer commands and data between a personal computer and a microcontroller is the use of standard interface, like the one described by protocols RS232 (older) or USB (newer). This chapter is devoted to communication conforming to RS232 protocol, the hardware for such interface is provided on board. An example will be presented showing the processing of commands received through RS232 interface, and sending of a string of numbers using the same interface [8].

The protocol RS232 defines the signals used in communication, and the hardware to transfer signals between devices.

The standard defines voltage levels V(0) to be at least +5V at the transmitting end of the line TX, and can be degraded along the line to become at least +3V at the receiving and of the line. Similarly voltage level V(1) must be at least -5V at TX, and at least -3V at RX. The standard also defined the upper limit for these voltages to be up to ±15V. Logic high is transferred as V(0). The microcontroller cannot handle such voltage levels, so typically a voltage level translator is inserted between the microcontroller and the connector where the RS232 signals are available. The connectors are typically so-called D9 connectors, and the electric wiring in between two connectors at devices A and B is shown in Fig. 2, for two female type connectors at both devices.



Figure(3.10) serial communication connector DB9

3.5 data presentation

The data presentation element is the final element in the measurement system, its function being to communicate the measured value of the variable to a human observer. It is important that the measured value is presented as clearly and easily as possible, otherwise the value registered by the observer may be different.

3.5.1 Visual basic language

A programming language and environment developed by Microsoft. Based on the BASIC language, Visual Basic was one of the first products to provide a graphical programming environment and a paint metaphor for developing user interfaces. Instead of worrying about syntax details, the Visual Basic programmer can add a substantial amount of code simply by dragging and dropping controls, such as buttons and dialog boxes, and then defining their appearance and behavior.

Although not a true object-oriented programming language in the strictest sense, Visual Basic nevertheless has an object-oriented philosophy. It is sometimes called an event-driven language because each object can react to different events such as a mouse click.

Since its launch in 1990, the Visual Basic approach has become the norm for programming languages. Now there are visual environments for many programming languages, including C, C++, Pascal, and Java. Visual Basic is sometimes called a Rapid Application Development (RAD)system because it enables programmers to quickly build prototype applications.

Visual Basic has the following features :

- Full set of objects - you 'draw' the application
- Lots of icons and pictures for your use
- Response to mouse and keyboard actions
- Clipboard and printer access
- Full array of mathematical, string handling, and graphics functions
- Can handle fixed and dynamic variable and control arrays
- Sequential and random access file support
- Useful debugger and error-handling facilities
- Powerful database access tools
- ActiveX support
- Package & Deployment Wizard makes distributing your applications simple

CHAPTER FOUR

SYSTEM IMPLEMENTATION

4.1 Introduction

The general operation principle of the system is that, the sensors sense oil temperature, oil pressure, turbine gas temperature, and engine rotation speed. Then the values of these parameters sent to the microcontroller built-in ADC after conditioning. The microcontroller transfers the corresponding data of engine parameters serially to the PC through RS232 protocol. The computer receives data and then calculates the corresponding values of engine speed, temperature ,and oil pressure according to the mathematical equations that describe the relation between sensors signals and parameters values . The PC display and analysis data using a visual basic program to simulate the real instruments and to provide a graphical user interface window (GUI), which allow the user to control the test events. Figure (4.1) shows block diagram of the implemented system, which contain

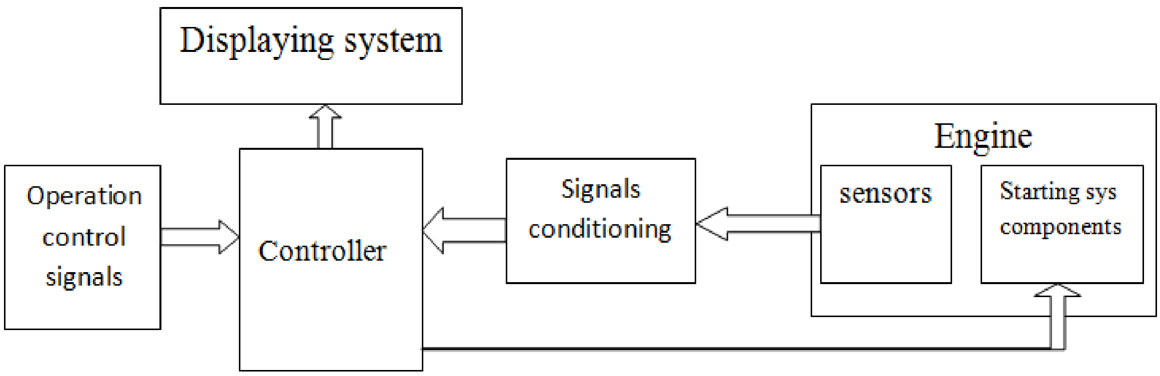


Figure (4.1)General System Block Diagram

4.2 Hardware Implementation

In this research the system will be designed using the following hardware:

1. Microcontroller.
2. Max232 chip.
3. sensors (Oil Pressure, Oil temperature, Engine gas temperature (EGT) and rotational speed (RPM))
4. Relays
5. Operational amplifiers
6. rectifiers
7. Personal computer (PC).

4.2.1 Sensors and conditioning circuits

4.2.1.1Rotational speed measurement

a. Sensor

drag-type tachometer indicator are installed to serve measuring GTD-350 engine gas generator shaft rotational speed . The transmitter is essentially a three phase AC generator. The voltage across the clamps between each two phases of the transmitter loaded by meter with 60 % against the meter scale (1500 RPM of transmitter rotor) is within the range of 10.5 to 12.5 V after continuous operation of the meter during one minute [13].

b. Conditioning

To convert an AC signal to DC one, a three phase rectifier is used, voltage divider also used to attenuate the signal range from (0 - 25V) to a range suitable for ADC (0 - 5v)

From equation (3.5)

$$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$$

$$R_1 = \frac{R_2 * V_{in}}{V_{out}} - R_2 = R_2 * (\frac{V_{in}}{V_{out}} - 1)$$

$$V_{out} = 5 \qquad V_{in} = 25$$

$$R_1 = R_2[\frac{25}{5} - 1]$$

$$\therefore \frac{R_1}{R_2} = 4$$

Suitable resistance for this relationship ($R_1 = 4R_2$)

$$R_1 = 1K\Omega , \qquad R_2 = 4K\Omega$$

For Isolating purpose use LM 358 op-amp as a unity gain amplifier figure (4.2) to avoid voltage divider impedance drawbacks. Also a unity gain amplifier doesn't take any current from the input source

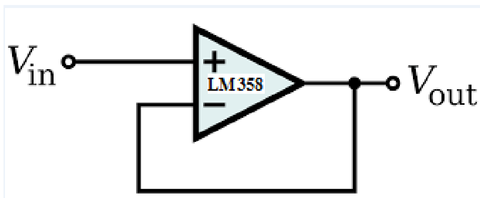


Figure (4.2) unity gain amplifier

4.2.1.2 Engine Gas temperature

a. Sensor

In GTD-350 engine thermocouples are intended for measuring turbine inlet gas temperature. Eight parallel-connected thermocouples are connected with the thermometer by compensating leads. The compensating leads and thermocouples are made from alumel and chromel. The wires at the section from thermal elements to the connecting block are joined into two wire bundles: one containing eight chromel wires and the other eight alumel ones. The thermometer indicator is essentially a magneto electric [13].

The thermometer characteristics are :

- measurement range 200 to 1100 °C
- Operating measurement range 450to1000°C
- Thermocouples Output voltage 4 mv to 44 mv

b. Conditioning

To amplify thermocouple signal from voltage range in mv to ADC range using three operation amplifier as an instrument amplifier.

From equation (3.3)

$$v_{out} = (v_2 - v_1)\left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2}$$

$v_{out} = 5 \quad ,(v_2 - v_1) = 44\ mv \quad ,R_1 = R_2 = R_3 = 100\ k\Omega$

$$Gain = \frac{v_{out}}{v_2 - v_1} = \frac{5}{44\ m} = 113$$

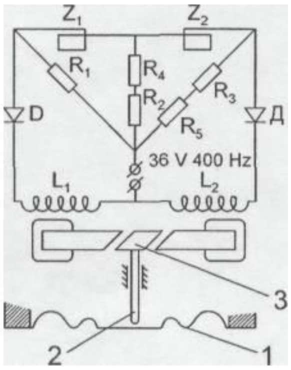
$$113 = \left(1 + \frac{200k}{R_{gain}}\right)$$

$$R_{gain} = 1.78k\Omega$$

4.2.1.3 Oil pressure measurement

a. sensor

The flux-gate pressure gauge is intended for measuring of the engine oil pressure. As showing in figure (4.3)



Figure(4.3) Pressure Gauge

Pressure variation deforms the membrane 1. Deformation is transmitted through rod 2 to the armature 3 which changes air clearances of the magnetic cores in the circuits of coils (L_1 and L_2). In so doing, the clearance in one circuit increases and in the other circuit - decreases. Clearance variation results in change of the coil inductance and this, in its turn, causes redistribution of currents in the logo meter frames ($Z_1$and Z_2). For rectifying the current, two semiconductor rectifying cells D are included into the circuit. The pressure gauges are supplied with the 36V/ 400Hz [13].

The thermometer characteristics are :

- The set is supplied with an AC voltage of 36 V 400 Hz ±2 %.
- The pressure gauge current consumption does not exceed 0.15 A
- Measurement range 0 to 8 kg/cm^2
- Operating measurement range 1.5 to 6.5 kg/cm^2

b. Conditioning

Using full wave rectifier to convert sensor signal (AC current) to (DC current)

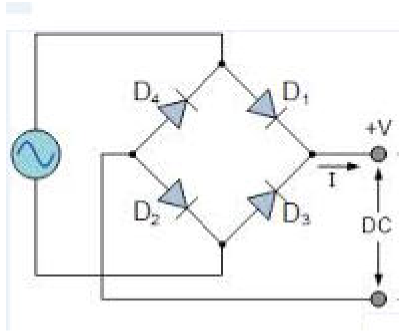


Figure (4.4) full wave rectifier

After rectifying the signal should be Converted from current to voltage by using (lm 358) operational amplifier with feedback resistance 33 Ω , from equation (3.4)

$$v_{out} = -RI_{in}$$

$$v_{max} = -33 \times 0.0975$$

$$v_{max} = -3.22\ v$$

$$v_{min} = -33 \times 0.066$$

$$v_{min} = -2.18\ v$$

For the highest possible accuracy, the signal should be amplified so that the maximum and minimum voltage range of the conditioned signal equals the maximum and minimum input range of the analog-to-digital converter (ADC), using LM-358n as non-inverting amplifier and differential amplifier

- maximum input range of the analog-to-digital converter (ADC) = 5v
- voltage range of the conditioned signal range from (2.18v to 3.22v)

To calculate suitable amplifiers gain , resistances values calculated as follow

From the straight line equation

$$\frac{y - y_1}{x - x_1} = \frac{y_2 - y_1}{x_2 - x_1} \qquad (4.1)$$

take :

$x = v_{in}$,　　　　$y = v_{out}$

$x_1(v_{in\,min}) = 2.12$,　　$x_2(v_{in\,max}) = 3.22$

$y_1(v_{out\,min}) = 0,$　　　$y_2(v_{out\,max}) = 5$

$$\frac{y-0}{x-2.18} = \frac{5-0}{3.22-2.18}$$

$$1.04y = 5x - 10.9$$

$$y = 4.8x - 10.48$$

For the purpose of making the absolute limit equals 5 (reference voltage in differential op-amp) multiplying by($\frac{10.48}{5} \times \frac{5}{10.48}$)

$$y = \frac{10.48}{5}[2.29x - 5] \qquad (4.2)$$

Non inverting amplifier

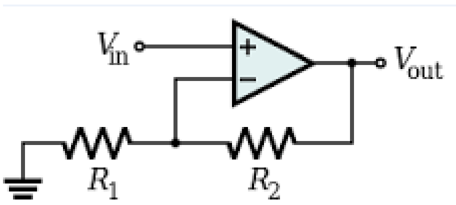
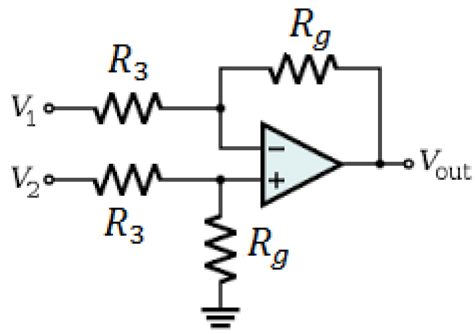


Figure (4.5) Non inverting amplifier

$$v_{out} = \left[1 + \frac{R_2}{R_1}\right] v_{in} \qquad (4.3)$$

$$gain = 1 + \frac{R_2}{R_1}$$

Differential amplifier



Figure(4.6) Differential amplifier

$$v_{out} = \frac{R_g}{R_3}(v_2 - v_1) \qquad (4.4)$$

From comparison between equation (4.2) & (4.4)

$$y = \frac{10.48}{5}[2.29x - 5] \qquad (4.2)$$

$$v_1 = 5$$

$$v_2 = 2.29x \qquad (4.5)$$

$$\frac{R_g}{R_3} = 2.1$$

$$\therefore R_g = 82k\Omega\,, \qquad R_3 = 39k\Omega$$

From equation (4.3) and (4.5)

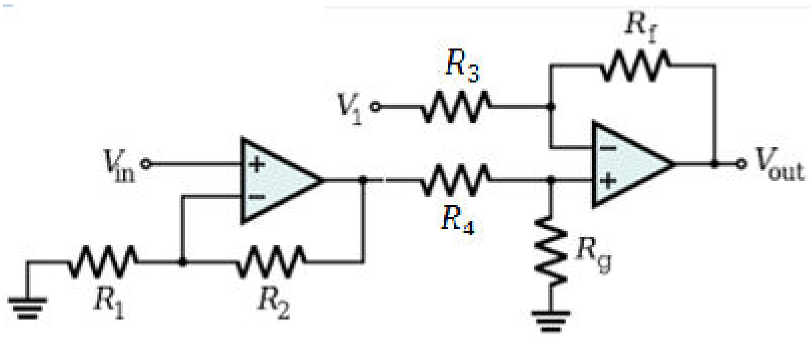
$v_2 =$ non inverting amp v_{out}

$$v_2 = 2.29v_{in}$$

$$\therefore 1 + \frac{R_2}{R_1} = 2.29$$

$$\therefore \frac{R_2}{R_1} = 1.29$$

$$R_1 = 12k\Omega\,, \qquad R_2 = 15k\Omega$$



Figure(4.7) connecting non inverting op amp with differential op amp

4.2.1.4 Oil temperature measurement

a. sensor

The thermometer used to measure GTD-350 engine oil temperature. Thermometer set includes: the logometric indicator, type TUE , and sensor, with the nickel-wire resistor arranged inside it and sensitive to temperature variation. The element resistance at a temperature of 0 °C makes up 90.1 ±0.15 Ω and at a temperature of 100 °C - 129.8 ±0.44 ohms. The resistor forms one of the bridge arms. Change of this element resistance caused by temperature variation results in deflection of the logometric indicator pointer [13].

Measurement range from minus 70 to+150 °C

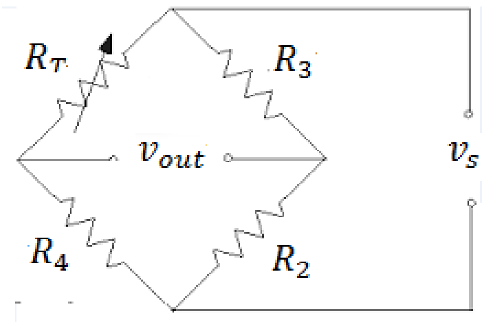
Operating Measurement range from minus 40 to +150 °C

b. Conditioning

Deflection bridges are used to convert the output of resistive sensors into a voltage signal. In a resistive or Wheatstone bridge all four branches are pure resistancesR_1 to R_4. Output of the bridge can be calculated according to:

$$v_{out} = v_s \left(\frac{R_1}{R_4 + R_1} - \frac{R_2}{R_2 + R_3} \right) \qquad (4.6)$$

In order to design a single element bridge we need to specify the three parameters v_s , R_4 and R_3/R_2 . The three parameters can be specified by considering the range and linearity of the output voltage and electrical power limitations for the sensor. Thus if T_{min} and T_{max} are minimum and maximum values of the measured temperature variable, and R_{Tmin} and R_{Tmax} are the corresponding sensor resistances, for the bridge output voltage to have a range from v_{min} to v_{max} the following conditions must be obeyed:



Figure(4.8) Thermal resistor deflection bridge

$$v_{min} = v_s \left(\frac{R_{Tmin}}{R_4 + R_{Tmin}} - \frac{R_2}{R_2 + R_3} \right) \qquad (4.7)$$

$$v_{max} = v_s \left(\frac{R_{Tmax}}{R_4 + R_{Tmax}} - \frac{R_2}{R_2 + R_3} \right) \qquad (4.8)$$

we require v_{min} = 0, the bridge balanced when *T*= T_{min}; in this case [4.7] reduces to:

$$\frac{R_4}{R_{Tmin}} = \frac{R_3}{R_2} \tag{4.9}$$

Output voltage for metal resistance sensor bridge:

$$v_{out} = v_s \frac{R_2}{R_3} \alpha T \tag{4.10}$$

Temperature coefficient (α) of nickel = $6.41*10^{-3}$

$v_{out} = 5v$ (ADC $maximum$ $volt$age)

$$5 = 24 \times \frac{R_2}{R_3} \times 6.41 \times 10^{-3} \times 150$$

$$\frac{R_3}{R_2} = 4.8$$

To calculate R_4 Compensating R_3/R_2 ratio in equation (4.9)

$$R_4 = \frac{R_3}{R_2} \times R_{Tmin}$$

$$\therefore R_4 = 4.8 \times 90.1 = 433\Omega$$

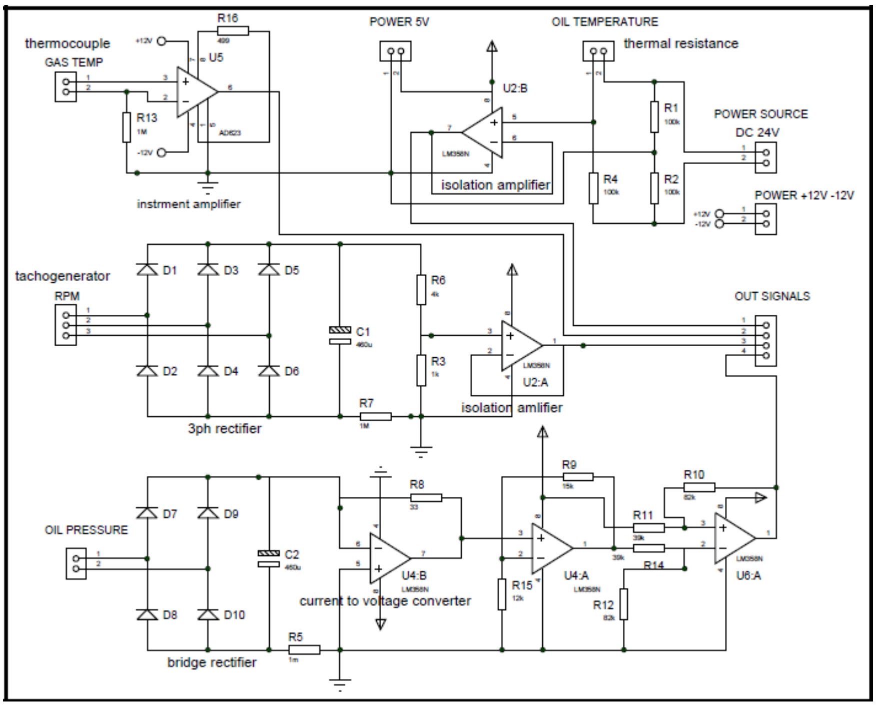


Figure (4.9) Signal conditioning circuit diagram

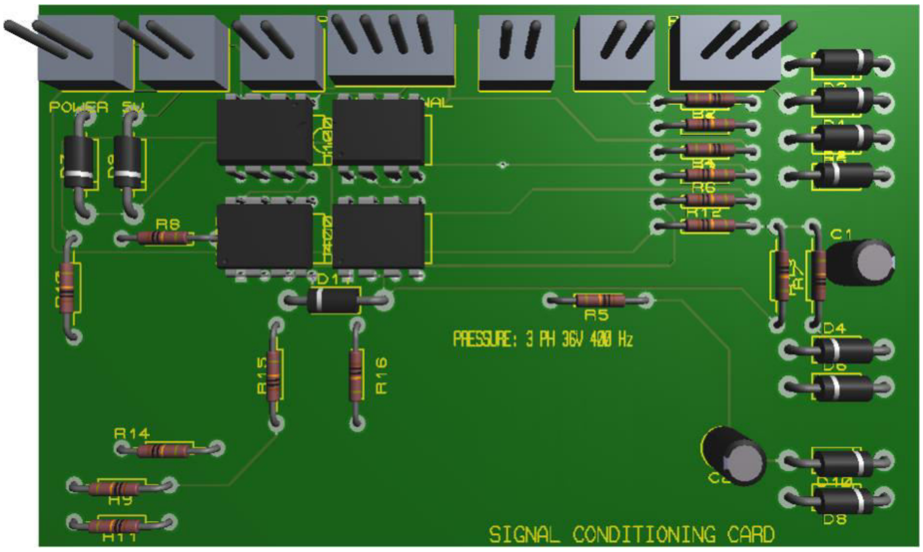


Figure (4.10) Signal conditioning circuit PCB

4.2.2 Data acquisition circuit

The data acquisition system has been developed using PIC16F877A which has five input/output ports, eight analog input channels and an internal crystal oscillator. The main function of the microcontroller is to receive the control command from the PC and generate the starting sequence signals and send it to the output interface card, also it is used to acquire the analog signals and send the equivalent digital values to the PC through the serial port, the control signal of Pin 25 (TX) of PIC16F877A is used to send the serial data to the PC through the MAX232 driver. The MAX232 converts the TTL signal from the microcontroller into RS232 voltage level. Since the PIC16F877A has an internal oscillator of 4MHz, so it works without any external clock. I/O pins AN0, AN1, AN2 to AN7 of the microcontroller are used as the analogue inputs. The MAX232 driver IC uses some external capacitors to enhance the RS232voltage level. A 9 Pin D Type female connector is used to connect to the COM port of the PC.

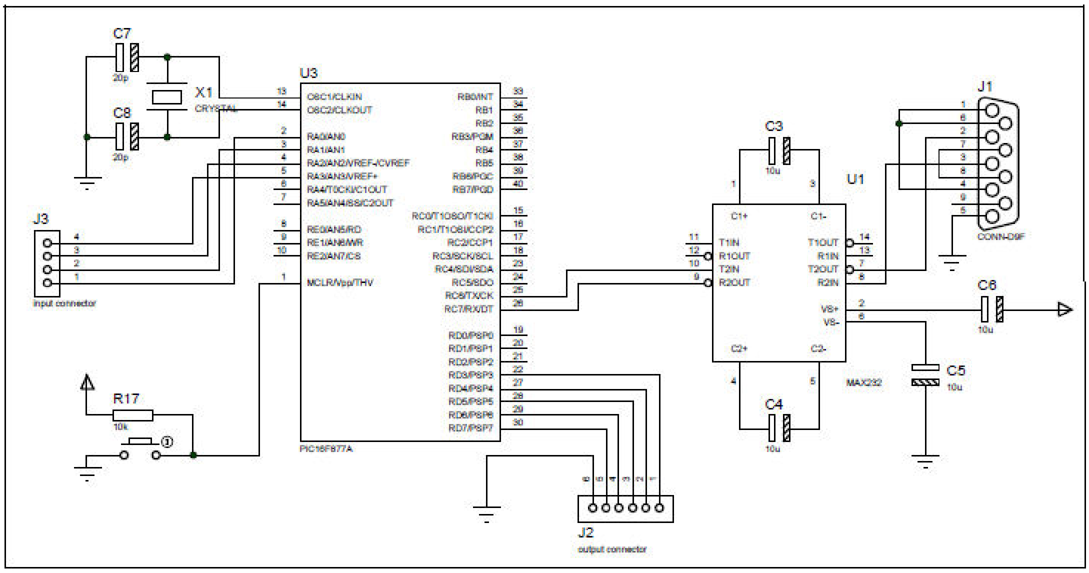


Figure (4.11) Data acquisition and processing circuit diagram

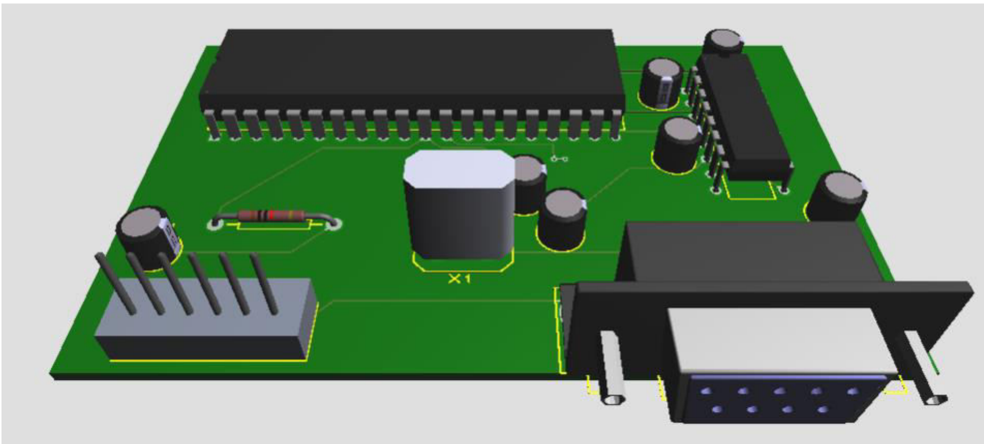


Figure (4.12) Data acquisition and processing circuit PCB

4.2.3 Engine Starting Control circuit

The original engine starting system depends on a constant speed DC motor engaged to cams to control the on and off status of engine starting components, The designed engine starting control system was built using PIC16F877A microcontroller to execute operator control command (start, stop, cold start) , also the system used to generate starting sequence timing signals relative to the engine starting system components operation priority (fuel pump, starter, ignition unit, and fuel valves) to replace the old starting box [13].

Starting system sequence:

- In the First second, voltage is supplied to the starter-generator excitation winding and ignition unit
- Second second , power is supplied to the starter-generator armature via the starting resistor.
- Third second, fuel supply is started through solenoid valve in pulsating flow
- Fourth second, the full battery voltage of 24 V is supplied to the starter-generator.
- Eleventh second, current regulator gets connected to the starter-generator excitation winding circuit and fuel is supplied through solenoid valve in continuous flow till the 30th second
- Thirty second, the engine starting fuel electromagnet, starter-generator armature, ignition unit and the starting system are switched off Disconnection of Starter-Generator from Power Source. Fast Reset of Starting System Accessories.

Output card:

The Output card consists of

- Photo couplers
- ULN 2003A
- Relays
- Connectors
- Indication LEDs

The circuit receives the control signal from the microcontroller to activate the corresponding component (fuel pump, starter, ignition unit, and fuel valves) according to the sequence mentioned above. Five opticouplers are used to isolate the microcontroller pins from the other circuit components. Also an ULN 2003 driver is used to isolate the 12V circuit from the 5V circuit

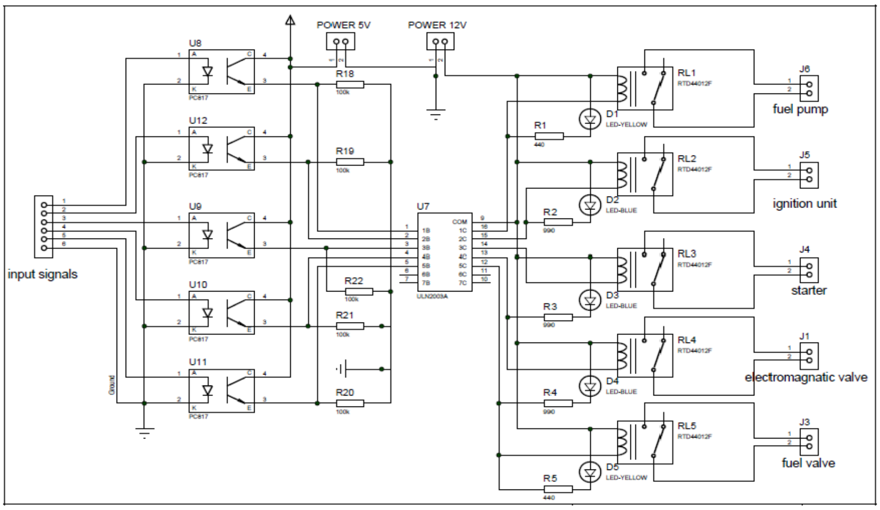


Figure (4.13) Engine starting control circuit diagram

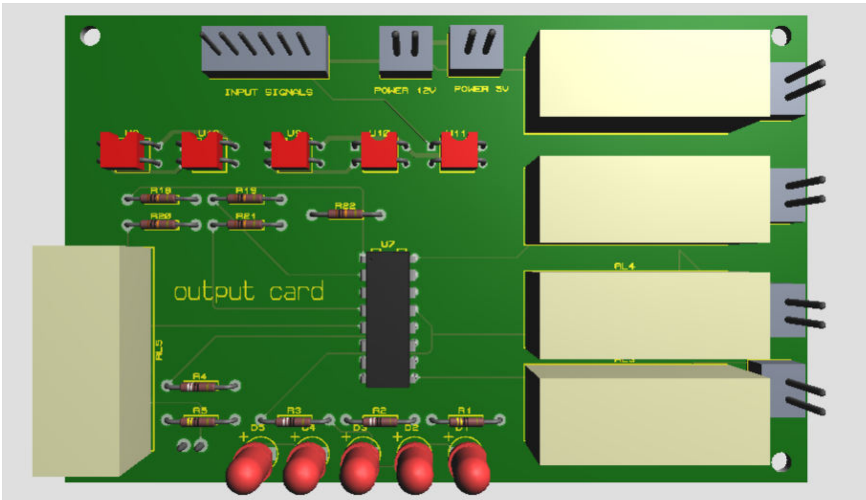


Figure (4.14) Engine starting control circuit PCB

4.3 Software Implementation

For the proper functioning of the test system, a firmware was developed and burnt into the microcontroller and an application program is also developed in Visual Basic 6.

4.3.1 Firmware

A (C)program was written in Mikro C pro compiler for proper ADC conversion at a fixed sampling rate and sending the digitized data serially to the PC, also it receives the engine starting control system inputs and sends the required signals to the control system and generates the sequence of starting signals . The program was compiled to make a hex file. Then the hex file will be burnt into the PIC16F877A microcontroller using PICkit2 programmer. The flowchart of the program developed is given in Fig(4.15)

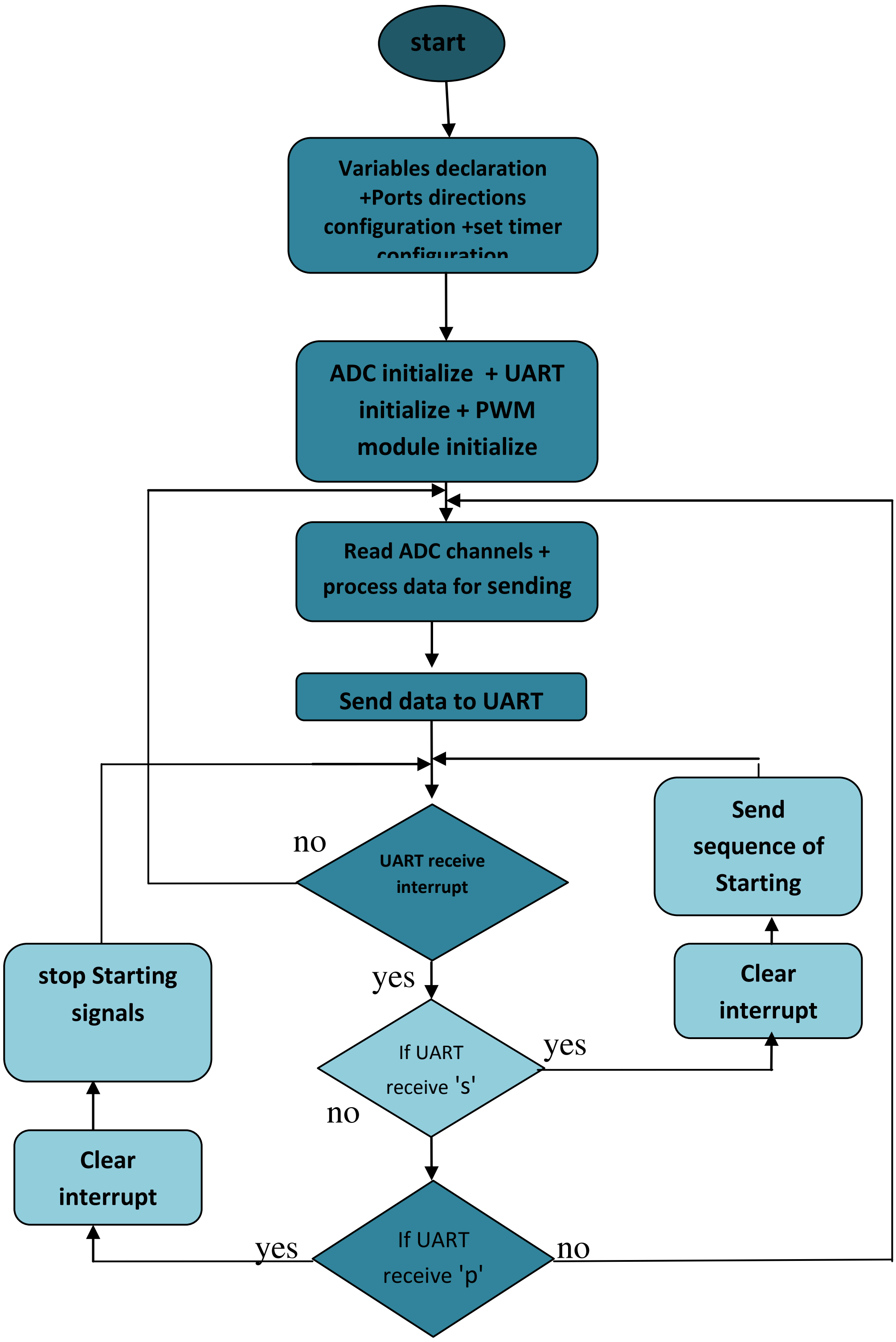


figure (4.15) C program flow chart

4.3.2 Graphical user interface

Also a graphical user interface was designed using visual basic 6.0 to enable the operator to control engine operation and to display the engine parameters: RPM, oil pressure, oil temperature, and engine gas temperature in graphical and numerical manners as shown in figure (4.6). furthermore the visual basic program analyze data and determine the state of the engine In case of failures or improper engine operation state, the software provides a related troubleshooting list in order to help the user to determine the fault location.

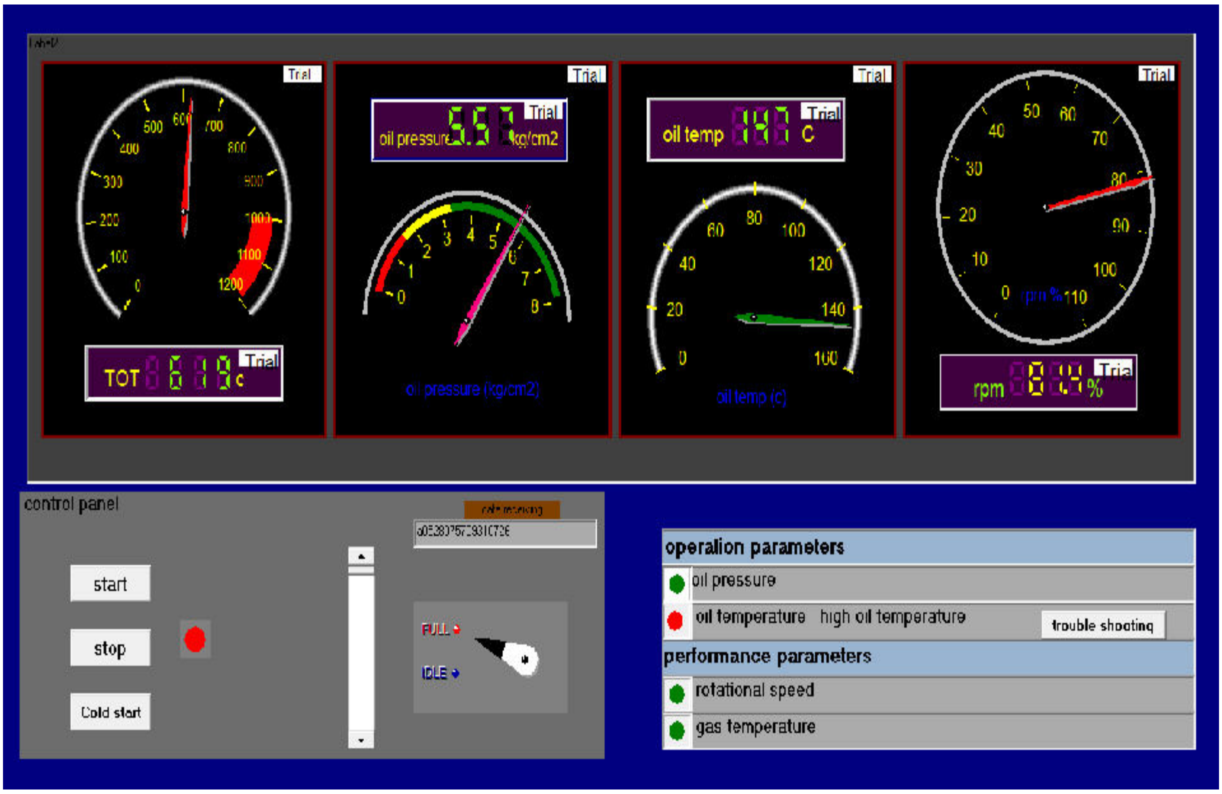


Figure (4.16) The system graphical user interface GUI

The main visual basic program is described by the following flow chart:

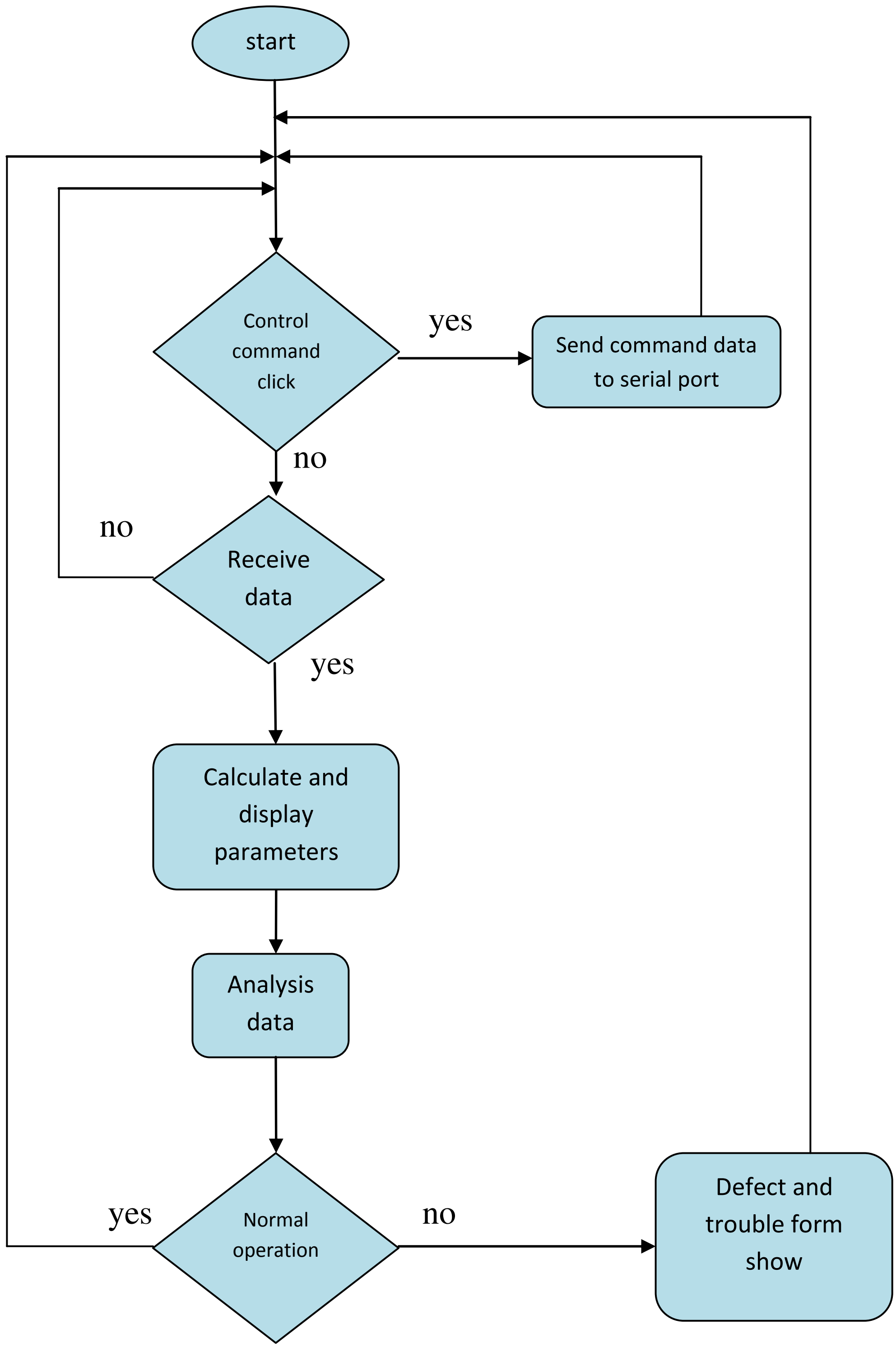


Figure (4.17) visual Pasic Program Flow Chart

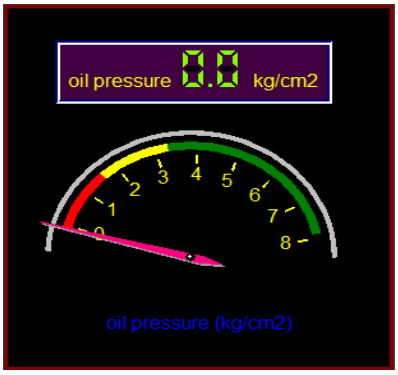
4.3.3 Parameters Displaying

When the data sent by the serial port from the microcontroller to the computer, it will be received in the visual basic program, a special library called MSComm is used to communicate through the serial port of the PC with the microcontroller. The acquired data is then analyzed and split into four values each value has four digits; since the values sent from the microcontroller's ADC has 10 bit resolution that means the maximum value for each parameter is 1023. The engine parameters will be calculated and displayed as follow:

a. Oil pressure

Full scale = 1023/127.875 = 8

Oil pressure values = Oil pressure received data /127.875

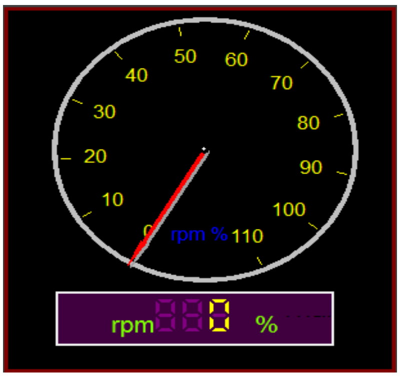


Figure(4.18) oil pressure virtual indicator

b. Engine RPM

Full scale = 1023/9.3 = 110

RPM values = RPM received data / 9.3

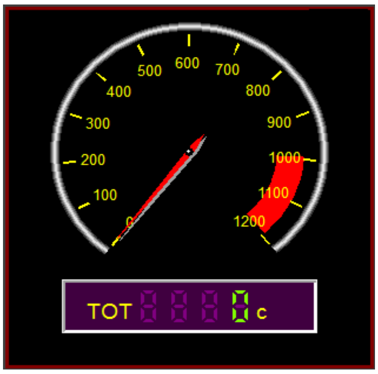


Figure(4.19) RPM virtual indicator

c. Engine gas temperature

Full scale = 1023/0.8525=1200

EGT values = EGT received data / 0.8525

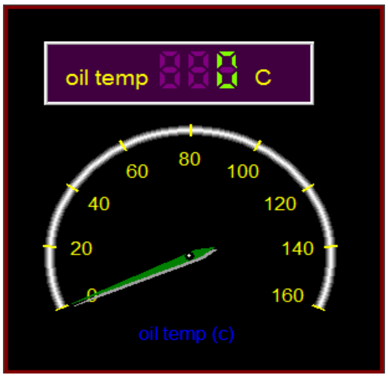


Figure(4.20) Gas temperature virtual indicator

d. Oil temperature

Full scale = 1023/6.82=150

Oil temperature value = Oil temperature received data /6.82



Figure(4.21) Oil temperature virtual indicator

4.3.3 data analysis

After displaying engine parameters values the program compares these values with the permissible values in specific regime to determine the serviceability of the engine. In case of unacceptable parameters during engine operation the program will show hazard message. When the user press (trouble shoot) button the program will show new form containing the expected causes and suggested solutions.

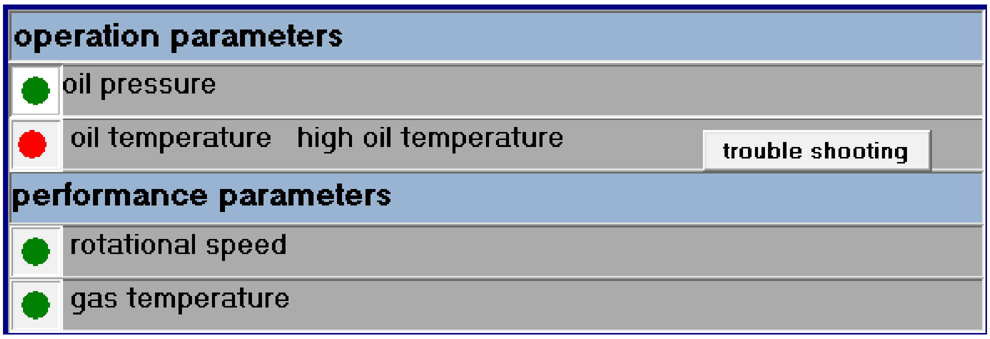


Figure (4.22) Operation note Window

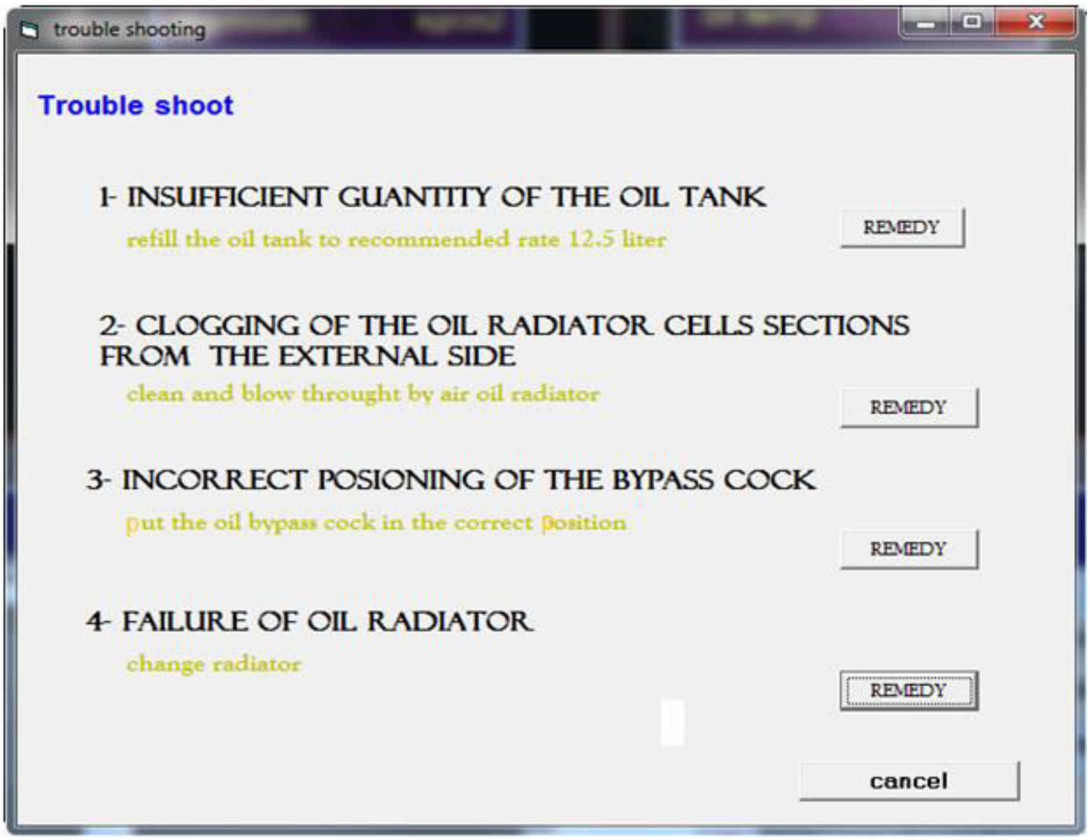


Figure (4.25) Engine oil temperature trouble shooting window

CHAPTER FIVE

EXPERIMENTS AND RESULTS

5.1 Introduction

After system hardware and software was implemented, some experiments had been carried out In order to calibrate transducers and to determine the accuracy of the complete system.

5.2 Calibration of Instruments and a Check of Associated Systems

Calibration is used to check an instrument's measurements against an accepted known standard and to eliminate unacceptable measurement errors. Instruments should be calibrated over the expected range of operation. calibration of individual instruments is necessary and can be performed in place or in the instrumentation laboratory **.**

Instrument calibration plus system checks ensure acceptable measurement accuracy within engine acceptance testing limits specified in the overhaul manual or other documents

5.3 RPM measuring Calibration

In order to ensure the value of engine RPM percentage (%) reading, a calibration process should be carried out.

A standard rpm calibration unit (КТУ-1М) had been used as a reference for calibration purpose.

5.3.1 Tachometer Calibration Method

Three phase AC motor used as a source of rotational movement and connected with standard tachogenerator by transmission shaft figure (5.1), the motor speed is controlled manually. Standard tachogenerator generate ac voltage proportional to the motor speed and send this signals to tester indicator .

In this test output voltage of tachogenerator was connected to the testing unit indicator and the designed measurement system at the same time, the measured values of indicated rpm of the designed system were compared with the values of this reference system. Tables (5.1) show the accuracy of the designed system compared to the reference system.

Table (5.1) Comparison between measured and reference rpm reading

Tacho voltage after conditioning (v)	Reference RPM (%)	Measured RPM (%)	RPM Error	ERROR%	FSD%
0	0	0	0	0	0
0. 59	15	14.2	0.2	1.3	0.18
0.85	20	20.1	0.1	0.5	0.09
1.1	25	25.4	0.4	1.6	0.3
1.34	30	30.6	0.6	2	0.5
1.59	35	35.5	0.5	1.4	0.4
1.84	40	40.0	0	0	0
2.07	45	45.1	0.1	0.2	0.09
2.29	50	50.3	0.3	0.6	0.27
2.52	55	55.3	0.3	0.54	0.27
2.75	60	60.7	0.7	1.1	0.6
2.97	65	65.5	0.5	0.7	0.4
3.19	70	70.2	0.2	0.28	0.18
3.41	75	75.0	0	0	0
3.63	80	79.7	-0.3	-0.37	-0.27
3.86	85	84.1	-0.5	-0.58	-0.4
4.14	90	88.5	-0.9	-1	-0.8
4.37	95	92.3	-1.3	-1.33	-1.12
4.52	100	97.4	-1.9	-1.9	-1.7
4.76	105	102	-2	-1.9	-1.8

Figure (5.1) Tachometer testing device

Figure (5.2) Tachometer calibration process

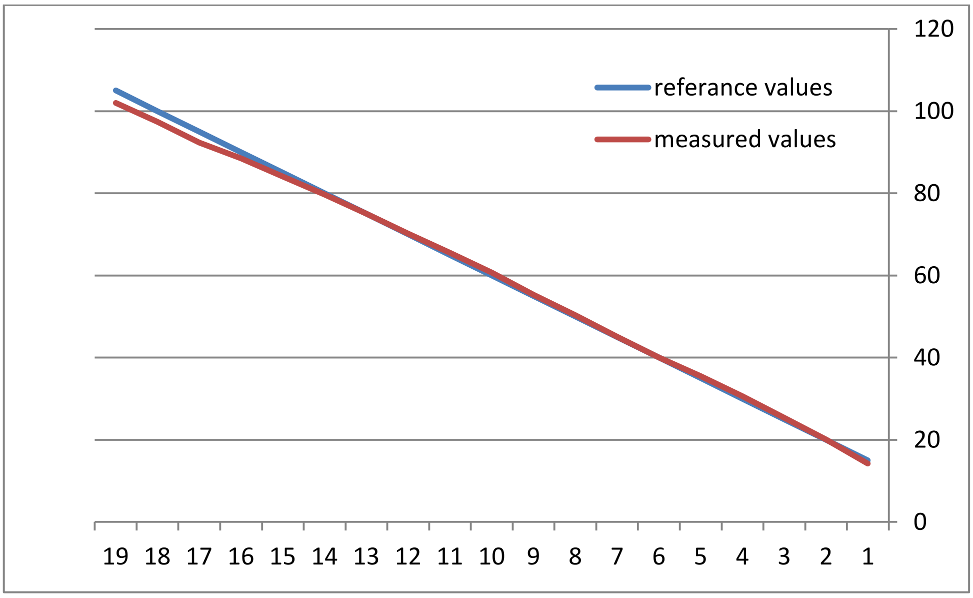


Figure (5.3) Tachometer reference reading versus measured reading

5.4 EGT reading Calibration

In order to ensure the value of turbine gas temperature reading, a calibration process should be carried out. A thermometer check device (УПТ-1M) was used as a reference for calibration purpose.

5.4.1 EGT meter Calibration Method

turbine Gas temperature indicator test unit essentially is a voltage source with standard temperature indicator, it send electrical signals similar to thermocouple output voltage in millivolt.

In this test the testing signals connected to the testing unit indicator and the designed measurement system at the same time, The measured values of indicated temperature of the designed system were compared with the values of this reference system. Tables (5.2) shows the accuracy of the designed system compared to the reference system.

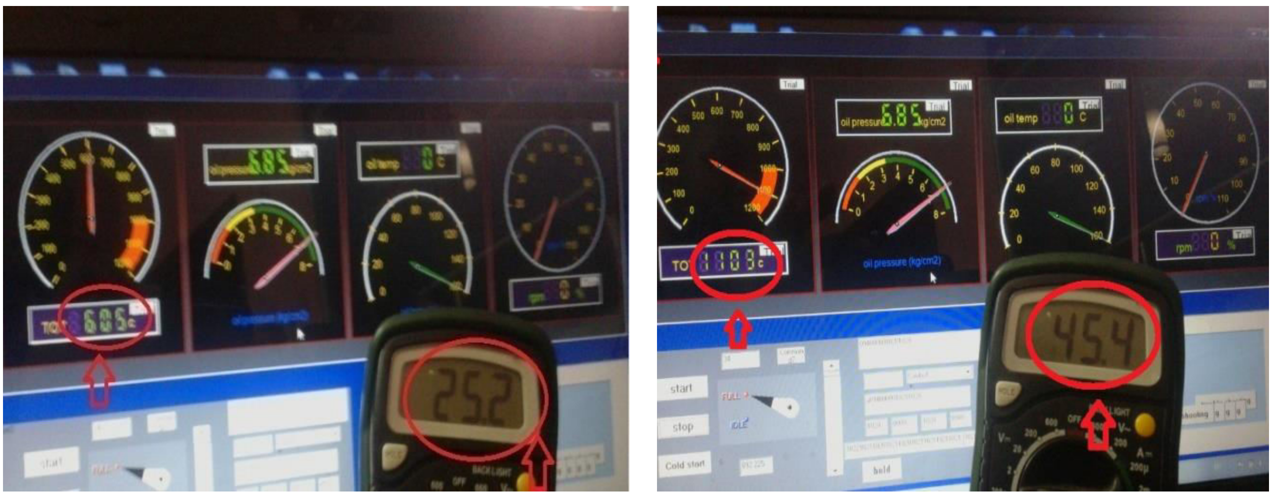


Figure (5.4) Gas temperature indicator calibration process

Table (5.2) Comparison between measured and reference temperature reading

Testing signal	Reference temperature (C°)	Measured temperature (C°)	Temperature Error	ERROR%	FSD%
0.39	0	0	0	0	0
2.436	50	55	5	10	0.45
4.509	100	106	6	6	0.54
6.540	150	155	5	3.3	0.45
8.539	200	201	1	0.5	0.09
10.561	250	250	0	0	0
12.624	300	303	3	1	0.27
14.713	350	351	1	0.28	0.09
16.820	400	400	0	0	0
18.941	450	448	-2	-0.44	- 0.18
21.071	500	506	6	1.2	0.54
23.203	550	558	8	1.4	0.72
25.330	600	605	5	0.8	0.45
27.447	650	660	10	1.5	0.9
29.258	700	702	2	0.28	0.18
31.628	750	754	4	0.53	0.36
33.685	800	813	13	1.6	1.17
35.718	850	866	16	1.8	1.44
37.725	900	916	16	1.7	1.44
39.708	950	960	10	1	0.9
41.665	1000	1013	13	1.3	1.17
43.595	1050	1053	3	0.2	0.27
45.497	1100	1105	5	0.4	0.45
47.367	1150	1158	8	0.6	0.72

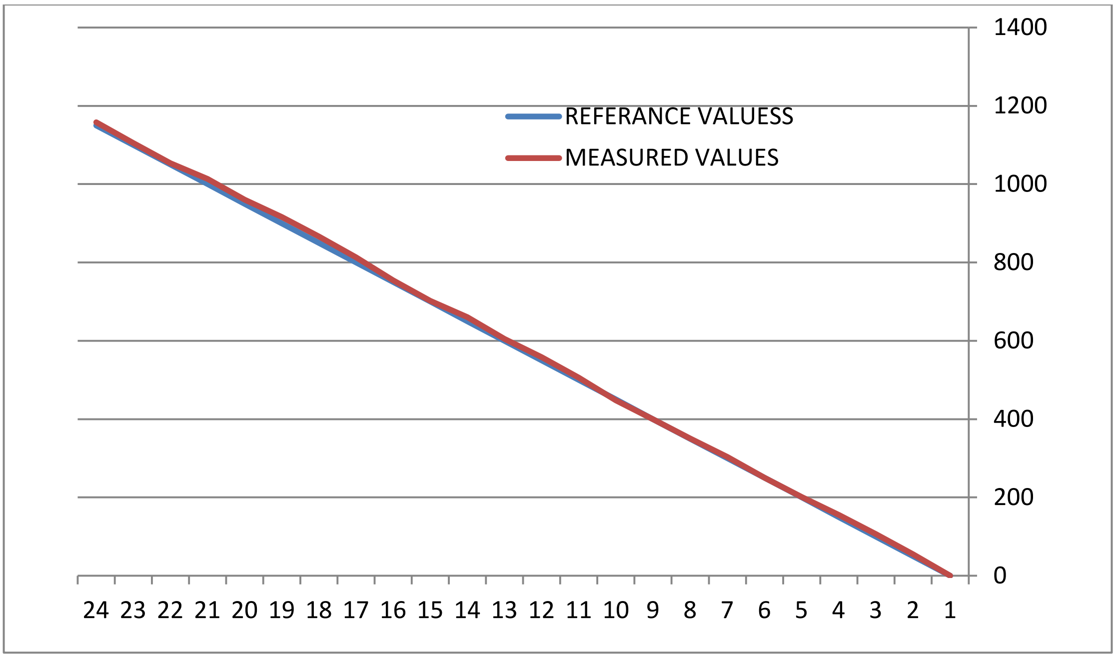


Figure (5.5) Gas temperature reference reading versus measured reading

5.5 Oil pressure indicator

To test and calibrate oil pressure measurement used oil pressure test unit figure (5.6), this tester consist of oil tank and hand pump with standard pressure gage, The pressured oil was applied to both standard gage and oil pressure sensor which was connected with designed system

Figure (5.6) Oil pressure testing unit

table (5.3) Comparison between reference and measured oil pressure

	Reference pressure (kg/cm²)	Measured pressure (kg/cm²)	Pressure Error	Error%	FSD%
1	0.5	0.48	-0.02	- 4	- 0.25
2	1.0	0.97	-0.03	- 3	- 0.37
3	1.2	1.15	0.05	4.1	0.62
4	1.5	1.51	0.01	0.66	0.12
5	2.0	2.0	0.0	0	0
6	2.3	2.22	0.08	3.4	1
7	2.8	2.86	0.06	2.1	0.75
8	3.5	3.54	0.04	1.1	0.5
9	4.8	4.77	0.13	2.7	1.62
10	5.2	5.39	0.19	3.6	2.37
11	5.6	5.72	0.22	3.9	2.75
12	6	6.20	0.20	3..3	2.5

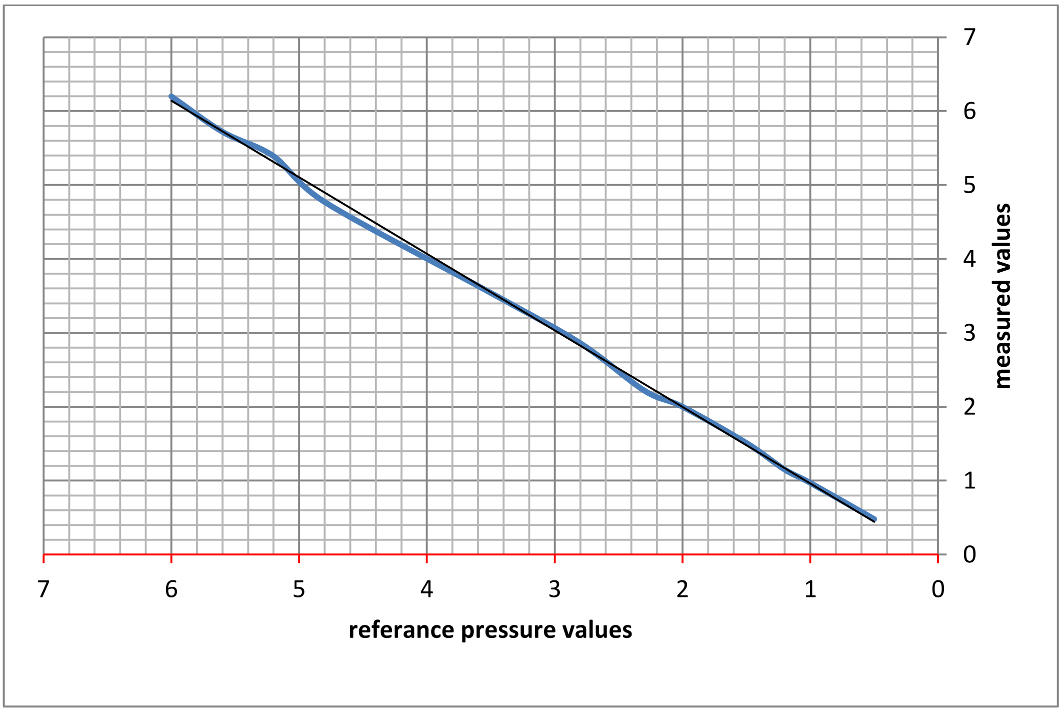


Figure (5.7) Oil pressure reference reading versus measured reading

5.6 Results Analysis

The engine test system has been designed and implemented successfully with satisfactory results.

From Table 5-1 we conclude that:

- The engine rotational speed (RPM) operation range is (0 –110%).
- For RPM between 10 – 60% , the indication has a mean error 0.27%, For RPM between 60 – 100% , the indication has a mean error 0.55%, For RPM between 100 – 110% , the indication has a mean error 0.55%, compared with the reference system.

From Table 5-2 we conclude that:

- The gas turbine temperature operation range is (200–1100 °c)
- For temperature between 450 – 750°c , the indication has a mean error +5.5°c for temperature between 750 – 1000°c , the indication has a mean error +11.8°c for other measurement range , the indication has a mean error +7.5°c compared with the reference system.

From Table 5-3 we conclude that:

- The oil pressure indicator operation range is (0 – 8 kg/cm^2)
- Operating measurement range 1.5 to 6.5 kg/cm^2 reading has a mean error within operating measurement range +1.29 %.
- Reading error within other measurement range +0.32 %.

CHAPTER SIX

CONCLUSION AND RECOMONDATION

Conclusion

Gas turbine engines are widely used in aircraft, including airplanes and helicopters, including turbo shaft and turbo prop craft, . Because of the safety requirements demanded by the operation of such craft, and the reliability necessitated, testing must be done routinely to ensure that the engine operation is sufficient

A variety of engine tests are performed in order to maintain the engine in an operative condition. Usually, testing can be performed by attaching instruments to various locations on the engine to obtain readings of engine operation parameters. The values obtained from the readings must then be compared to determine whether the engine will meet the specified parameters which enable it to be placed in operation.

In this project a data acquisition system was developed as a turbo shaft engine testing system, This designed system perform the following:

- Monitored and displayed engine parameters
- Scale, convert and calibrate inputs to engineering units
- Provided virtual instrumentation for visual reference and rate of change information
- analyzed engine parameters based on the current engine operation regime.
- Alert the operator of unsafe conditions with expected causes and suggested solutions.
- developed an electronic engine starting system using PIC microcontroller to replace the traditional engine starting system.

In order to determine the reliability and the accuracy of the system several tested has been carried out and the results are acceptable.

All the errors are lying within the allowable errors that described by the engine manufacturer, appendix[C] .

The designed system is considered as a cost effective system, flexible, reliable and accurate comparing with the old analog engine test systems.

Recommendations

This work is recommended the following for future works:

- Considering the effect of the atmospheric and ambient temperature conditions in the time at which the test was carried out.
- Adding an electronic throttle systems .
- In order to get an accurate diagnosis and real data the system must be connected with simulated load .
- Including measuring the torque of the engine during testing.
- Including more parameters (sensors).

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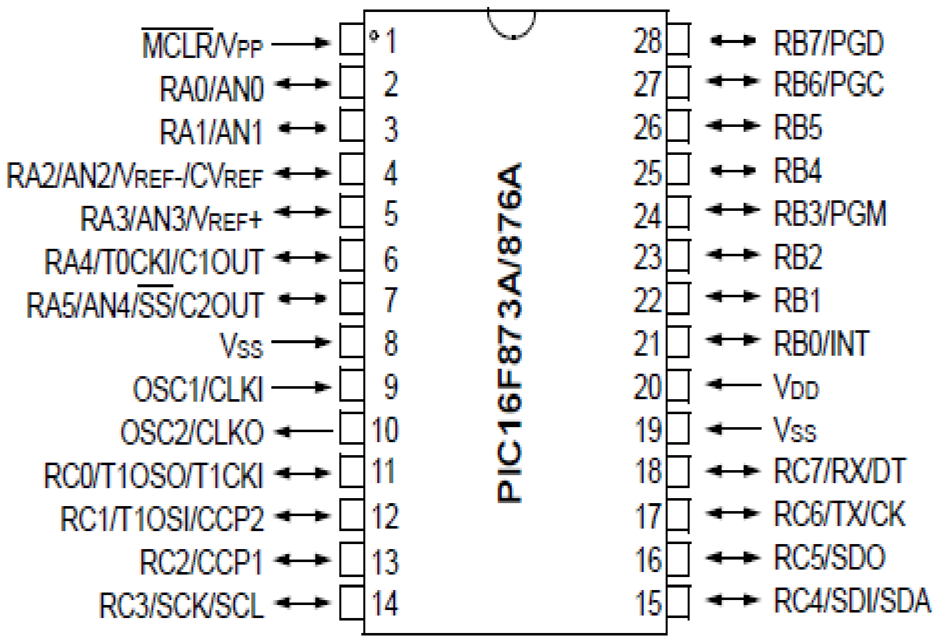
Appendix A

Microcontroller PIC16f877A pin diagram



Appendix B

Table of Voltage Calibration Values in mV for ITG-1 Meters

Scale marks under check	Meter ambient air temperature										
	15	16	17	18	19	20	21	22	23	24	25
200	7.53	7.49	7.45	7.41	7.37	7.33	7.29	7.25	7.21	7.17	7.13
300	11.61	11.57	11.53	11.49	11.45	11.41	11.37	11.33	11.29	11.25	11.21
400	15.80	15.76	15.72	15.68	15.64	15.60	15.56	15.52	15.48	15.44	15.40
500	20.05	20.01	19.97	19.93	19.89	19.85	19.81	19.77	19.73	19.69	19.65
600	24.31	24.47	24.23	24.19	24.15	24.11	24.07	24.03	23.99	23.95	23.91
700	28.55	28.51	28.47	28.43	28.39	28.35	28.31	28.27	28.23	28.19	28.15
800	32.72	32.68	32.64	32.60	32.56	32.52	32.48	32.44	32.40	32.36	32.32
900	36.77	36.73	36.69	36.65	36.61	36.57	36.53	36.49	36.45	36.41	36.37
1000	40.72	40.68	40.64	40.60	40.56	40.52	40.48	40.44	40.40	40.36	40.32
1100	44.56	44.52	44.48	44.44	44.40	44.36	44.32	44.28	44.24	44.20	44.16

Appendix C

C.1 Tachometer reading errors

Measurement range, RPM, %	Tachometer set errors at temperatures:		
	+20+5 °C	+50+5 °C	-60+5 °C
10 to 60	±1.0	±1.5	±2.5
60 to 100	±0.5	±1.0	±1.5
100 to 110	±1.0	±1.5	±2.5

C-2 Gas Thermometer type ITG-1 Reading Errors

Measurement range PC)	Environmental temperature					
	+20±5 °C		+55+5 °C		-55+5 °C	
	Indicator error	Set error	Indicator error	Set error	Indicator error	Set error
450 to 750	±12°C	±17°C	±22 °C	±30 °C	±32 °C	+40 °C
750 to 1000	+15 °C	±20 °C	±25 °C	±33 °C	±35 °C	±43 °C
Within other ranges	±30 °C	±35 °C	±45 °C	±55 °C	±65 °C	±75 °C

C-3 Pressure gage type DIM-8 Reading errors

Reading error within operating measurement range ±4 %, maximum

Reading error within other measurement range ±6 %, maximum

Appendix D

Visual Basic Code

```
Dim aver As Integer
------------------------------------------------------------------------------------
  'Open trouble shooting form
Private Sub Co1_Click()
Form3.Show
End Sub
Private Sub Co2_Click()
Form4.Show
End Sub
Private Sub Co3_Click()
Form5.Show
End Sub
Private Sub Command5_Click()
Form6.Show
End Sub
Private Sub Command6_Click()
Form7.Show
End Sub
 ------------------------------------------------------------------------------------
Private Sub Form_Load()
'serial port initialization
M2.CommPort = 2
M2.RThreshold = 17
M2.InputLen = 18
M2.SThreshold = 1
M2.PortOpen = True
aver = 0
sss = 0
End Sub
------------------------------------------------------------------------------------
' Engine Control commands
Private Sub Command1_Click()
M2.Output = "S"      'send "S" via serial port
LED1.LEDStatus = LEDStatusOn     'make led1 on
End Sub
Private Sub Command2_Click()
```

```
M2.Output = "P"                    'send "P" via serial port
LED1.LEDStatus = LEDStatusOff      'make led1 of
End Sub
Private Sub Command3_Click()
M2.Output = "t"    'send "t" via serial port
End Sub
Private Sub LED4_Resize()
LED4.BackColor = green     ' illuminate led4  with green color
End Sub
-------------------------------------------------------------------------------------------
'Main data analysis and displaying program
Private Sub M2_OnComm()
If M2.CommEvent = comEvReceive Then   ' if serial port received bytes
t1.Text = M2.Input       'show received bytes on( t1) text box
T7.Text = Mid$(t1.Text, 1, 1)     ' divide the received bytes (packet) into
                                          Several bytes
If T7.Text = "a" Then
T8.Text = Mid$(t1.Text, 2, 16)
M2.RThreshold = 17
M2.InputLen = 17
t2.Text = Mid$(T8.Text, 1, 4)
t3.Text = Mid$(T8.Text, 5, 4)
t4.Text = Mid$(T8.Text, 9, 4)
t5.Text = Mid$(T8.Text, 13, 4)
T6.Text = T6.Text + t3.Text
aver = aver + 1
T10.Text = aver
If aver = 7 Then
T11.Text = (Mid$(T6.Text, 1, 4) - -Mid$(T6.Text, 5, 4) - -Mid$(T6.Text, 9, 4) - -
Mid$(T6.Text, 13, 4) - -Mid$(T6.Text, 17, 4) - -Mid$(T6.Text, 21, 4) - -
Mid$(T6.Text, 25, 4)) / 7
rpm.HandValue = T11.Text / 10           'show rpm value on rpm indicator
T12.Text = T11.Text / 9.3
pressure.HandValue = t5.Text / 10.23     'show pressure value on pressure
                                                 indicator
n2.Value = t5.Text / 130.23
T12.Text = T11.Text / 9.3
If T12.Text > 80 Then
N1.Value = T12.Text + 1.5
Else
N1.Value = T12.Text
```

```
End If
If T12.Text < 35 Then
N1.Value = T12.Text + 0.7
Else
N1.Value = T12.Text
End If
aver = 0
T6.Text = ""
Else
oiltemp.HandValue = t4.Text / 10.23     'show oil temperature value on the
indicator
tot.HandValue = t2.Text / 10.23   'show turbine temperature value on the
                                            indicator
N4.Value = t2.Text / 0.8525
If S1.SelectionCaption = "FULL" Then
End If
   'Data analysis program
If n2.Value < 1.5 Then
If N1.Value > 40 Then
Co1.Visible = True
Label4.Caption =    "oil pressure   low oil presser"
LED4.Visible = True
n2.BlinkEnabled = True
End If
Else
Co1.Visible = False
Label4.Caption = "      oil pressure"
LED4.Visible = False
n2.BlinkEnabled = False
End If
If t4.Text > 890 Then
Co2.Visible = True
Label5.Caption = "       oil temperature   high oil temperature"
LED5.Visible = True
Else
Label5.Caption = "       oil temperature "
LED5.Visible = False
Co2.Visible = False
End If
If N1.Value < 67 Then
```

```
If t2.Text > 500 Then
Command5.Visible = True
Label8.Caption = "      increase of gas temperature in starting"
LED6.Visible = True
LED8.Visible = False
Else
Label8.Caption = "      gas temperature "
LED6.Visible = False
Command5.Visible = False
End If
Else
LED8.Visible = True
If t2.Text > 700 Then
Co3.Visible = True
Label8.Caption = "      gas temperature     high gas temperature"
LED6.Visible = True
LED8.Visible = False
Else
Label8.Caption = "      gas temperature "
LED6.Visible = False
Co3.Visible = False
End If
End If
End If
End If
End If
End Sub
```

Appendix E
C++ Code

```
// variable declaration

charuart_rd;

char *serial_ch="0000000000000000";
char ADC0_ch[7];
char ADC1_ch[7] ;
char ADC2_ch[7];
char ADC3_ch[7];
unsignedint sens,sens1,sens2,sens3,res,time,start,pwm;
char TOT_ch[7],RPM_ch[7],OIL_TEMP_ch[7],OIL_PRESSURE_ch[7];

//timer1 configuration
void InitTimer1(){
 T1CON        = 0x21;
 TMR1IF_bit        = 0;
 TMR1H        = 0x0B;
 TMR1L        = 0xDC;
 TMR1IE_bit        = 1;
 INTCON        = 0xC0;
}
//interrupt configuration
void Interrupt(){
if (TMR1IF_bit){
   TMR1IF_bit = 0;
   TMR1H        = 0x0B;
   TMR1L        = 0xDC;

   //Enter your code here
   //  RD3 Fuel pump
   // RD4 exitation&ignition
   // RD5 starter armature
```

```
   //RD6  solonoid valve
   //RD7  fuel valve
if(start==1&&time<131){
time=time+1;
if(time>=13&&time<22){(pwm<8)? (pwm=pwm+1) :
(pwm=8);PWM1_Set_Duty(32*pwm-1); }
if (time>=17&&time<44){PORTD.F6=~PORTD.F6;}
if(time>=21&&sens3>=184){PORTD.F7=1;}
if(time==1){PORTD.F3=1;}
else if(time==9){PORTD.F4=1;}

else if(time==45){PORTD.F6=1;}
else if(time==129){PORTD.F4=0;PORTD.F6=0;PWM1_Set_Duty(0);}
else if(time>=53&&sens3<=184){PORTD=0;}}

else if(start==1||start==2&&time==129){time=131;}
else if(start==0){PORTD=0;time=0;PWM1_Set_Duty(0);pwm=0;}
}  }
void main() {
trisa=0xff;          //port initialization
trisb=0;
portb=0;
trisd=0;
portd=0;
pwm=0;
InitTimer1();         //call InitTimer1 subroutine
ADC_Init();              //initialize analog to digital conversion
  PWM1_Init(1000); //initialize analog to digital conversion module 1KHz
  PWM1_Start();   //start analog to digital conversion module

  UART1_Init(2400);              // Initialize UART module at 2400 bps
Delay_ms(100);                // Wait for UART module to stabilize
```

```
while (1) {          //end less loop
// read sensors output by the microcontroller's ADC
sens=adc_read(0);
  sens1=adc_read(1);
  sens2=adc_read(2);
  sens3=adc_read(3);

res=memcpy(serial_ch,"0000000000000000",16);
IntToStr(sens,ADC0_ch);
IntToStr(sens1,ADC1_ch);
IntToStr(sens2,ADC2_ch);
IntToStr(sens3,ADC3_ch);

res = memcpy(serial_ch+4-
strlen(Ltrim(ADC0_ch)),Ltrim(ADC0_ch),strlen(Ltrim(ADC0_ch)));
res = memcpy(serial_ch+12-strlen(Ltrim(ADC2_ch)),
Ltrim(ADC2_ch),strlen(Ltrim(ADC2_ch)));
res = memcpy(serial_ch+8-strlen(Ltrim(ADC1_ch)),
Ltrim(ADC1_ch),strlen(Ltrim(ADC1_ch)));
res = memcpy(serial_ch+16-strlen(Ltrim(ADC3_ch)),
Ltrim(ADC3_ch),strlen(Ltrim(ADC3_ch)));
        UART1_Write_text(serial_ch);
delay_ms(20) ;
        UART1_Write_text("a");

if (UART1_Data_Ready()) {     // If data is received,
uart_rd = UART1_Read();     // read the received data,
   // if (uart_rd=='t'){
      //  UART1_Write_text("a");
     // UART1_Write_text(serial_ch);
     // delay_ms(50) ;
   //}
```

```
if (uart_rd=='S'){
      RB0_bit=1  ;      // and send data via UART
start=1;
    }
if (uart_rd=='P'){
      RB0_bit=0  ;
      RB1_bit=0;     // and send data via UART
start=0;
    }
if (uart_rd=='C'){
      RB1_bit=1  ;      // and send data via UART
start=2;
```