PERFORMANCE TEST OF STEAM TURBINE USING DATA ACQUISITION SYSTEM

Thesis submitted in partial fulfillment of

the requirement for the degree of

Master of Mechanical Engineering

By

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2019

Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis contains introduction and original research work by the undersigned candidate, as part of his ***"PERFORMANCE TEST OF STEAM TURBINE USING DATA ACQUISITION SYSTEM"*** studies.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

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We hereby recommend that the thesis presented under our supervision by ***Mr. Sumit Kumar Gupta*** *entitled "****PERFORMANCE TEST OF STEAM TURBINE USING DATA ACQUISITION SYSTEM****" be accepted in partial fulfillment of the requirements for the degree of Masters of Mechanical Engineering.*

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CERTIFICATE OF APPROVAL*

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ABSTRACT

High pressure and high temperature devices play a vital role in steam power plants. Regular maintenance of such devices is very important. Monitoring and control of parameters such as temperature, flow rate and pressure are essential processes in critically controlled environments of thermal power plants. This thesis reports the development of real time data acquisition of a mini power plant installed in the Heat Power Laboratory, Mechanical Engineering Department of Jadavpur University. The important components are temperature and pressure sensors, data acquisition cards and computer. In this work a system has been designed to evaluate the performance of a turbine used in the mini power plant using National Instrument data acquisition cards and Laboratory Virtual Instrument Engineering Workbench (LabView®). Performance parameters such as turbine isentropic efficiency, entropy generation etc. have been evaluated online.

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CHAPTER 1:

INTRODUCTION

Chapter 1: Introduction

1.1 Introduction

The Heat Power Laboratory of the Mechanical Engineering Department has an experimental facility for carrying out the performance test of a turbine that is part of a Mini Power Plant. This work is an endeavor towards automation of the performance test of the turbine by data acquisition.

The conventional methods for plant monitoring may be uneconomical and inefficient if applied to power plant due to high cost, so integrated automation and control has becomes the most appropriate solution for making it efficient and cost effective. Generally, an automated system improves the system efficiency, plant monitoring, productivity and the operation management of the plant. [4]

Our main objective is to give the means to the human operator to monitor and control the mini power plant processes. A graphical user interface for the mini power plant is developed using Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW®) data logging facility. The data acquisition system has capacity to acquire the values of temperature and pressure which are sensed by several temperature and pressure sensors respectively.

The mini power plant setup consists of-

Serial No.	Components	Inlet	Outlet	Remarks
1	**Steam optimizer**	1.Treated water from overhead tank atmospheric pressure and temperature 2.Preheated water from economizer	1.Treated water at atmospheric pressure and at higher temperature 2.Preheated water from economizer is cooled to a temperature less than onset of nucleate boiling(ONB) temperature	If preheated water temperature at the exit from the optimizer is higher than the ONB temperature, then the vapour bubbles formed may go to the boiler feed pump (BFP), causing cavitation and damage of the pump.
2	**Economizer**	1.Heated water from steam optimizer 2.Flue gases from boiler	1. Heated water at a temperature higher than ONB temperature 2.Flue gases to the chimney	We can't feed the preheated water from economizer to BFP directly, in order to avoid cavitation which may damage the pump
3	**Boiler feed Pump**	Heated water at atmospheric pressure and at temperature less than ONB temperature	Heated water at a pressure equal to boiler pressure (10 bar)	The pressure of water inlet to boiler must be equal to the boiler pressure
4	**Boiler**	Sub-cooled liquid from BFP	Saturated steam at boiler pressure	The boiler is of once through type. It generates steam in a single pass inside a stainless steel coil hanging in the furnace
5	**Super heater**	Saturated steam	Super-heated steam with a degree of superheat approximately 10ºC	There are 2 super-heaters (connected in series) of 18 KW power each, which is electrically operated
6	**Steam turbine**	Super-heated steam at a pressure in the range 2.5 to 6 bar (g) (to be adjusted by a pressure reducing station).	The state of steam at turbine outlet may be superheated or saturated.	The rated pressure of the turbine is 4 bar. The turbine is of simple impulse type (single row of moving blade) with a single nozzle for steam admission

Other components-

1. **Steam separator:** The generated steam from boiler first passes through a steam separator, where the quality of steam is improved. The purpose is to deliver steam as dry as possible to the turbine.
2. **Pressure reducing valve (PRV):** A PRV is working on throttle control, is used before the steam from separator reaches the turbine. The PRV is provided in a pressure reducing station to maintain the inlet pressure of the turbine constant, with fluctuating boiler pressure, at some set point chosen by the operator. Because of throttling, the quality of steam further improves in PRV.
3. **Solenoid valve:** There is no speed governor attached to the turbine. The maximum speed is checked by bypassing the steam through an electrically operated solenoid valve placed upstream of the turbine. The solenoid valve opens a bypass line of steam whenever the turbine speed exceeds the set speed.

Present Thesis: The present thesis consists of four chapters. The first chapter is an introduction to mini power plant. The second chapter contains the information about Data acquisition hardware and software used for data acquisition. The third chapter contains the experimental results and fourth chapter contains the conclusions of the present work and scope of future work.

1.2 Energy Balance Equation of the components

1. Steam Turbine

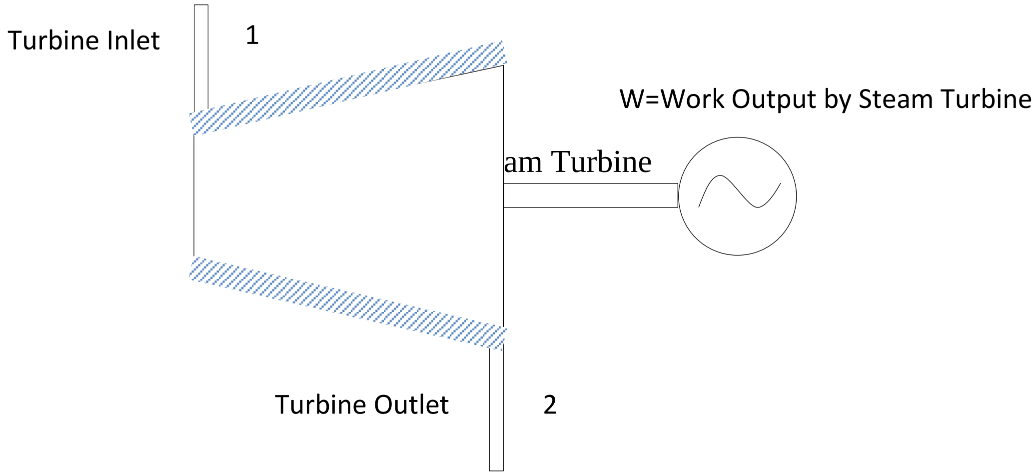

Fig 1: Schematic of Steam Turbine

Energy Balance equation:

Let,

$$\dot{m}_s = Rate\ of\ Steam\ Consumption$$

$$h_1 = Specific\ Enthalpy\ of\ steam\ at\ inlet\ of\ steam\ turbine$$

$$h_2 = Specific\ Enthalpy\ of\ steam\ at\ outlet\ of\ steam\ turbine$$

$$\dot{W}_T = Power\ output\ of\ steam\ turbine$$

Then

$$\dot{m}_s(h_1 - h_2) = \dot{W}_T$$

2. **Steam optimizer and Economiser**

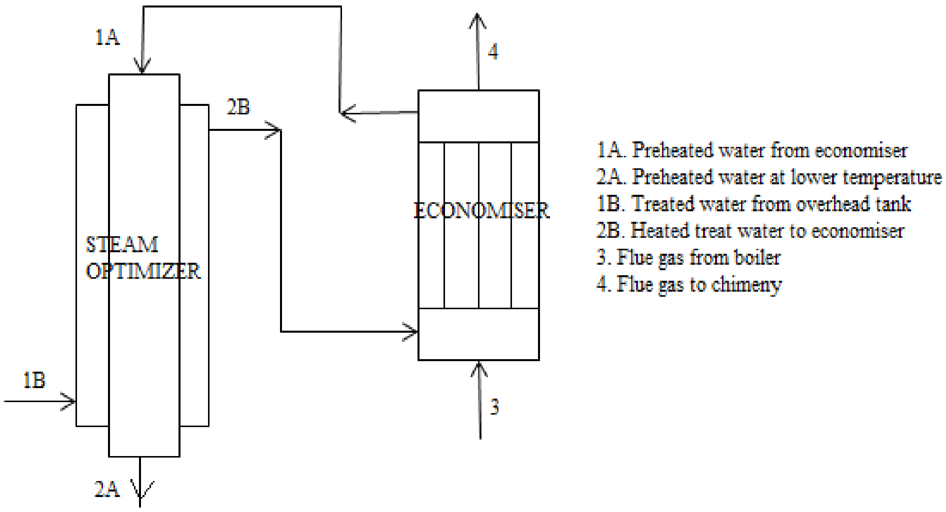

Fig 2: Schematic of Steam optimizer and economiser

Let,

$\dot{m}_f$ = *mass flow rate of flue gases*

h_{1A} = $Specific\ Enthalpy\ of\ Preheated\ water\ at\ inlet\ of\ steam\ optimiser$

h_{2A} = $Specific\ Enthalpy\ of\ preheated\ water\ at\ outlet\ to\ steam\ optimiser$

h_{1B} = $Specific\ Enthalpy\ of\ treated\ water\ at\ inlet\ to\ steam\ optimiser$

h_{2B} = *Specific Enthalpy of high temperature treated water to economizer*

h_3 = *Specific Enthalpy of flue gases inlet to ecomiser*

h_4 = *Specific Enthalpy of flue gases at the outlet to economizer*

Energy Balance equation for Steam optimiser

$$\dot{m}_s(h_{1A} - h_{2A}) = \dot{m}_s(h_{2B} - h_{1B})$$

$$\therefore (h_{1A} - h_{2A}) = (h_{2B} - h_{1B})$$

Loss in enthalpy by preheated water=gain in enthalpy by treated water

Energy Balance equation for economizer:

$$\dot{m}_f(h_3 - h_4) = \dot{m}_s(h_{1A} - h_{2B})$$

Loss in enthalpy by flue gas= gain in enthalpy by water from economizer

3. **Boiler**

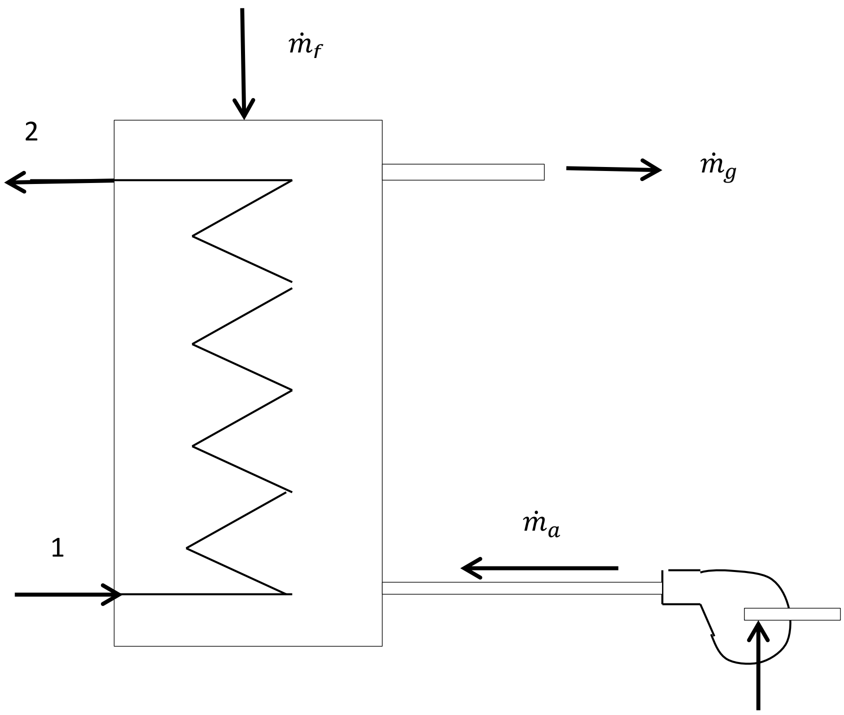

Fig 3: Schematic of Boiler

Heat Balance equation:

Let,

$\dot{m}_f$= *mass flow rate of fuel*

$\dot{m}_g$= *mass flow rate of flue gases*

$\dot{m}_a$= *mass flow rate of air*

h_1=*Specific Enthalpy of preheated water from boiler feed pump*

h_2=*Specific Enthalpy of steam generated from boiler*

Then

$\dot{m}_g = \dot{m}_a + \dot{m}_f$

$\dot{Q}_1 = \dot{m}_f * \dot{CV}_f$ (Assuming Complete Combustion of fuel)

$\dot{Q}_1 = \dot{m}_S(h_2 - h_1)$

4. Condenser and Condensate Extraction Pump

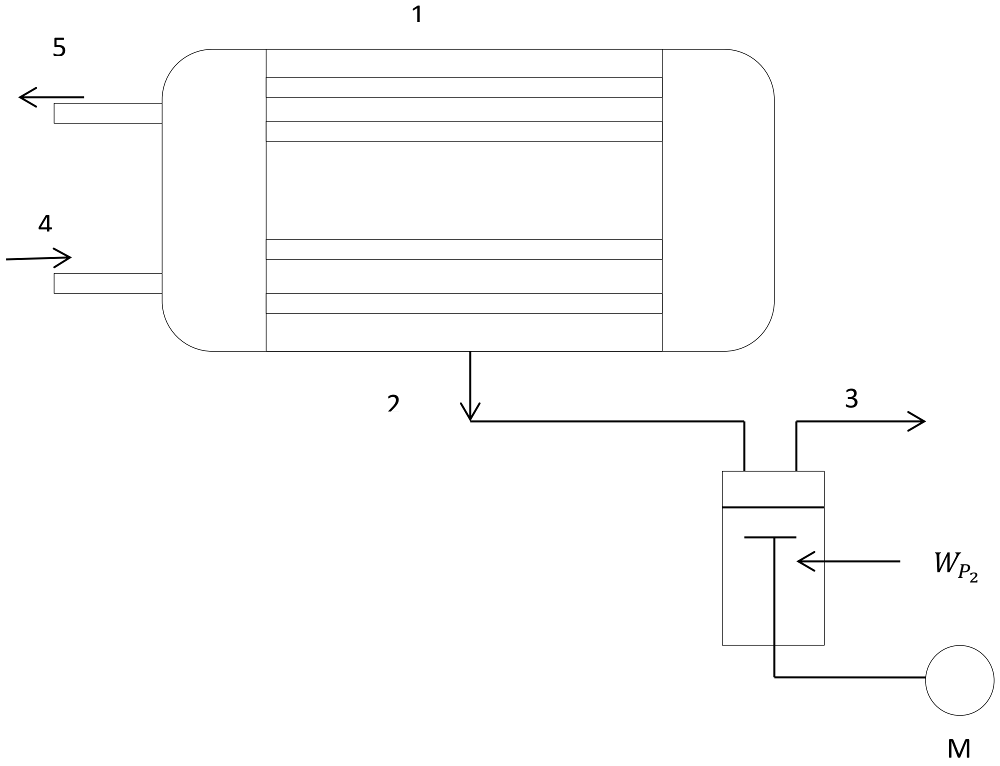

Fig 4: Schematic of Condenser and condensate extraction pump

Let,

$\dot{m}_C$ = *mass flow rate of cooling water*

$h_1 = Specific\ Enthalpy\ of\ steam\ out\ from\ turbine$

$h_2 = Specific\ Enthalpy\ of\ condensed\ steam\ at\ exit\ of\ condenser$

h_3 = *Specific Enthalpy of condensate at the exit of extraction pump*

$h_4 = Specific\ Enthalpy\ of\ cooling\ water\ inlet\ to\ condenser$

h_5 = *Specific Enthalpy of cooling water outlet from condenser*

Energy balance for condenser:

$$\dot{m}_C(h_5 - h_4) = \dot{m}_S(h_1 - h_2)$$

Enthalpy gain by the cooling water = Enthalpy loss by the low pressure steam

Energy balance for condensate extraction pump:

Pump work (W_{P_2})=$\dot{m}_S(h_3 - h_2)$=enthalpy gained by condensed steam

CHAPTER 2:

DAQ Device/Hardware

CHAPTER 2: Introduction to Data Acquisition (DAQ)

Data Acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric value that can be manipulated by a computer. Data Acquisition system typically measures an electrical or physical phenomenon such as voltage, current, temperature or pressure and convert the analog waveforms into digital value for processing and analysis with the help of computer.

A Data Acquisition (DAQ) system consists of sensors, DAQ measurement hardware and a computer with programmable software. Here I have used "LabVIEW®" software as my programming software. LabVIEW® is very powerful when it comes to creating DAQ application. LabVIEW® includes a set of Virtual instruments (VIs) that lets us configure, acquire data and send data to DAQ devices.

PC-Based Data Acquisition uses a combination of modular hardware, application software and a computer to take measurements. Each component in a data acquisition system is defined by its application requirements, and shares a common goal of acquiring, analyzing and presenting information. [6]

DAQ systems have evolved over time from electromechanical recorders containing typically one to four channels, to all electronic system capable of measuring hundreds of signals simultaneously. They are now used by most engineers and scientists for laboratory research, industrial control, test and measurement of input and output data to and from a computer. Industries those presently employ such automatic systems include steel making, paper production, oil refining, chemical manufacturing, textile production, cement manufacturing and others. [6]

DAQ systems incorporate signals, sensors, actuators, signal conditioning, data acquisition devices and application software.

So summing up, Data Acquisition is the process of-

1. Acquiring signals from real world phenomena
2. Digitizing the signals
3. Presenting, saving and analyzing the data

The DAQ system has the following parts involved-

1. Physical Input / Output signals
2. DAQ device/hardware
3. Driver software

2.1 Physical Input / Output Signals

A physical Input signal may be pressure, temperature, flow, speed, torque etc. In order to sense and measure an input signal, such as pressure or temperature, it is necessary to use transducers or sensors, which convert physical input into electrical signals and feed these signals to a data acquisition hardware that may have a signal conditioning component [5]. Most analog signals require some form of preparation before they can be digitized. For example, thermocouple signals have very small voltage levels (millivolt) that must be amplified before a data acquisition device can effectively and accurately measure the signal [6].

Physical output signals may be voltage or current that is used to actuate different devices. The actuation may be opening of a solenoid valve, controlling the opening of a pressure regulator etc. Generally for such outputs, at least one more intermediate device is required for converting the DAQ output into some signal compatible with the actuated device. For example, a normally open relay may be used to open a solenoid valve when some alarm condition is generated. A current to pressure (I/P) converter may be used to regulate the diaphragm pressure to control opening of a pneumatically controlled valve.

In the Mini Power Plant we have used 3-wire Resistance Temperature Detectors (RTD) for measurement of temperature, Pressure transducers to measure pressure, Flow and Speed sensors to measure volume flow rate and speed, and a cantilever beam type Torque transducer to measure torque on the turbine shaft applied by an eddy current dynamometer [5].

The Mini Power Plant has five boiler trip, one turbine over speed control and one superheater temperature control operations which are detailed in the following table.

SL. NO.	CONDITION	SENSOR	CONTROLLER	ACTUATED ACTION
1	Boiler Pressure High	Pressure Switch	Interlock	1. Burner tripped 2. FD fan tripped 3. Alarm hooted
2	Steam Temperature higher than set point temperature	RTD	Temperature indicating controller	Same as above
3	Flame failure	Photo sensor	Interlock	Same as above
4	Economizer water level low	Pressure switch	Interlock	Same as above
5	Blow down valve open	Limit switch	Interlock	Same as above
6	Turbine speed greater than set point speed	Speed sensor	Speed indicating controller	A Solenoid valve is opened to by-pass the steam to a drain tank before reaching the turbine.
7	Superheater 2 temperature greater than set temperature	RTD	Temperature indicating controller	On-off control of the heater supply of the two superheaters

Table 1: Actuated Action for Different operating conditions

With the available data acquisition hardware we could acquire data for eight RTD's and two pressure transducers (before and after the turbine) only. All other relevant data were fed manually in the LabVIEW® programme after getting them from the existing control panel of the Mini Power Plant. The output signals for actuation of the safety and trip devices could not be generated from the programme because of lack of infrastructure.

2.1.1 RTD Signal

RTD's work on the principle of variation of resistance with temperature. The voltage across the resistor in the RTD is measured when a standard current (like 1 mA) is passed through the resistor. Then resistance is calculated by using the relation R=V/I, Where,

V = voltage across resistor, that is measured

I = standard current passing through the resistor

R = resistance at the temperature

RTD's are commonly categorized by their nominal resistance at 0°C. Typical nominal resistance values for platinum thin-film RTD's include 100 Ω and 1000 Ω. The relationship between resistance and temperature is nearly linear and follows this equation [5]:

For T<0°C $R_T = R_0 [1 + aT + bT^2 + cT^3 (T - 100)]$……………………………. (Equation 1)

For T>0°C $R_T = R_0 [1 + aT + bT^2]$………………..…………..……………….. (Equation 2)

Where,

R_T = resistance at temperature T (° C)

R_0 = nominal resistance at 0°C

a, b, and c = constants used to scale the RTD

The Resistance vs. Temperature curve for a 100 Ω platinum RTD, commonly referred to as Pt100, is shown in Figure 1

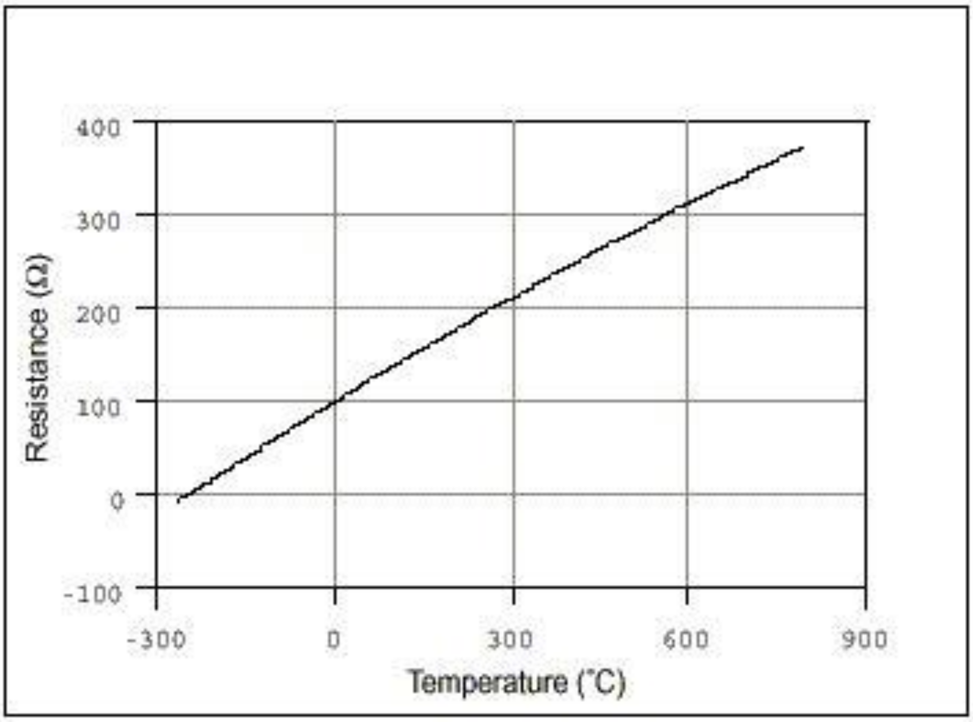

Fig 5 : Resistance vs. Temperature curve for RTD

When we get the resistance at a particular temperature, then by using the inverse relation of equation 2, we can find the required temperature.

2.1.2 Pressure signal

We have used Pressure transmitters for pressure measurement having a current type electrical output ranging from 4 to 20 mA with an excitation voltage of 9-30 VDC.

2.1.3 Sensors in Mini Power Plant

1. Temperature Sensor (18 RTD's)
2. Pressure Sensor (2 Pressure transmitters, 2 Pressure switches)
3. Speed Sensor (2 Speed transducers)
4. Torque Sensor (1 Torque transducer)
5. Flow Sensor (3 Flow transducers)

2.1.4 Manual input data to the programme

1. Barometer Reading (mm Hg)
2. Temperature at Barometer (^{o}C)
3. Height of Condensate collected in tank (cm)
4. Time of collection (seconds)
5. Speed of Turbine (rpm)
6. Torque (N-m)

For the analysis of performance test of turbine, we need temperature of specific locations and pressure at inlet and outlet of the turbine. We have chosen 8 locations for acquiring temperature data.

2.1.5 Details of Temperature and pressure sensors in Mini Power Plant

Temperature Sensor

There are total 18 temperature sensors at 18 different locations-

Serial No.	Temperature sensor	Location
01	T_{00}	Temperature of steam at exit of boiler
02	T_{01}	Temperature of water inlet to optimizer
03	T_{02}	Temperature of water outlet from optimizer
04	T_{03}	Temperature of water inlet to Economizer
05	T_{04}	Temperature of exhaust gas outlet from economizer
06	T_{05}	Temperature of steam outlet from boiler (inlet to steam separator)
07	T_{06}	Temperature of steam outlet from steam separator
08	T_{07}	Temperature of air inlet to boiler
09	T_{08}	Temperature of exhaust gas inlet to economizer
10	T_{09}	Temperature of hot water inlet to reciprocating pump (boiler feed pump)
11	T_{10}	Temperature of steam inlet to separating and throttling calorimeter
12	T_{11}	Temperature of water outlet from shell and tube condenser(cooling water)
13	T_{12}	Temperature of steam condensate outlet from shell and tube condenser(from shell)
14	T_{13}	Temperature of water inlet to shell and tube condenser(flow inside tube)
15	T_{14}	Temperature of steam inlet to steam turbine
16	T_{15}	Temperature of steam outlet from steam turbine
17	T_{16}	Room temperature at instrumentation panel
18	T_{17}	Temperature of steam in throttling calorimeter

Table 2: All temperature sensors of Mini power plant

But due to unavailability of DAQ card to acquire data from temperature sensors we have connected only 8 temperature sensors to DAQ. They are

Serial No.	Temperature sensor	Location
01	T01	Temperature of water inlet to optimizer
02	T02	Temperature of water outlet from optimizer
03	T05	Temperature of steam outlet from boiler (inlet to steam separator)
04	T06	Temperature of steam outlet from moisture separator
05	T09	Temperature of hot water inlet to reciprocating pump (boiler feed pump)
06	T12	Temperature of steam condensate outlet from shell and tube condenser (from shell)
07	T14	Temperature of steam inlet to steam turbine
08	T15	Temperature of steam outlet from steam turbine

Table 3: Temperature sensors used for acquisition

Here we have used 3-wire RTD as our temperature sensor so wiring of each RTD is as follows[5]-

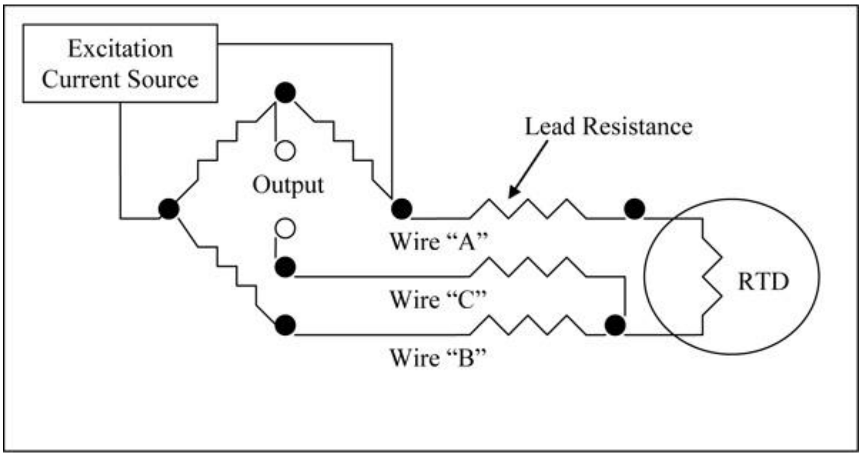

Fig 6: wiring Diagram for 3 wire RTD

According to our colour code Wire “A” is RED, Wire “B” and “C” are white.

Since we cannot connect our DAQ with the existing control panel of the mini power plant, so first we isolate the RTDs from the control panel then connect the RTDs to our DAQ. Thus, we cannot observe the temperatures simultaneously on control panel as well as on our DAQ system

Pressure Sensor

We have used pressure transmitter as our pressure sensor at two different locations-

Serial No.	Pressure sensor	Location
1	P_1	At inlet of steam turbine
2	P_2	At outlet of steam turbine

Table 4: Pressure sensors location for data acquisition

Specification of pressure transmitter

Model: EQ-PT-1000 (make: Equinox)

Rated operational Voltage: 24 VDC

Supply Voltage: 9 to 30 VDC

Input: 0-16 bar gauge

Output Signal: 4 to 20 mA corresponding to 0 to 16 bar gauge

Since our output requirement is in bar, so we have calibrated the output signal in bar as follows-

At 4mA, the pressure is 0 bar and at 20mA the pressure is 16 bar.

Assuming linear variation,

The equation becomes $Y = -4$ +1000X

Where X is the transmitted signal in mA and Y is the required pressure in bar.

Wiring diagram of each pressure transmitter is as follows-

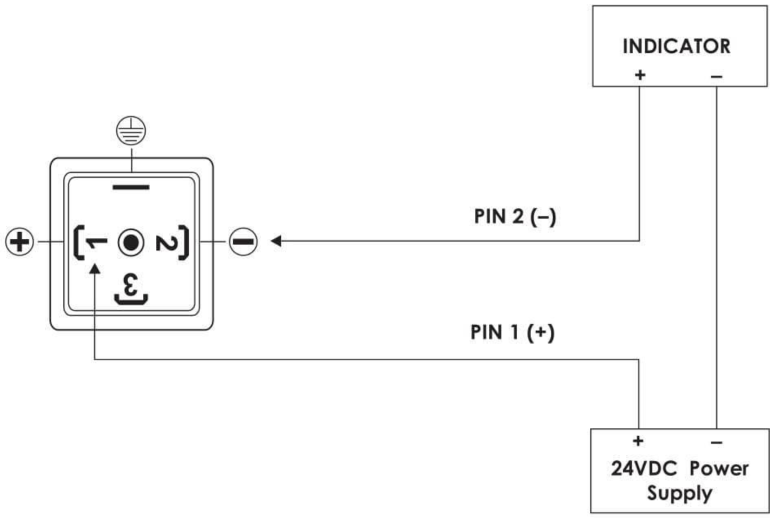

Fig 7: Wiring diagram for pressure transmitter connected to control panel

First we have isolated the pressure sensors from the control panel of mini power plant and then, with an External 24 VDC power supply we have made a separate connection by DAQ and the pressure transmitters as shown in fig below-

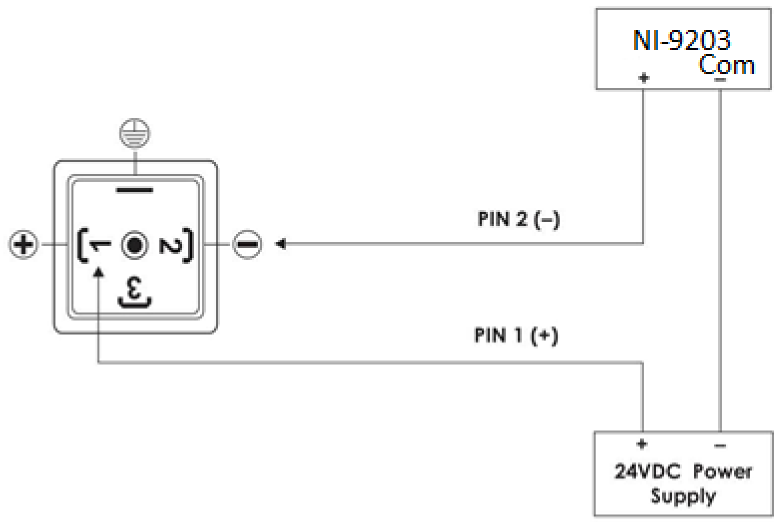

Fig 8: Wiring diagram for pressure transmitter connected to DAQ system

2.1.6 Schematic for location of Acquired Sensors in mini power plant

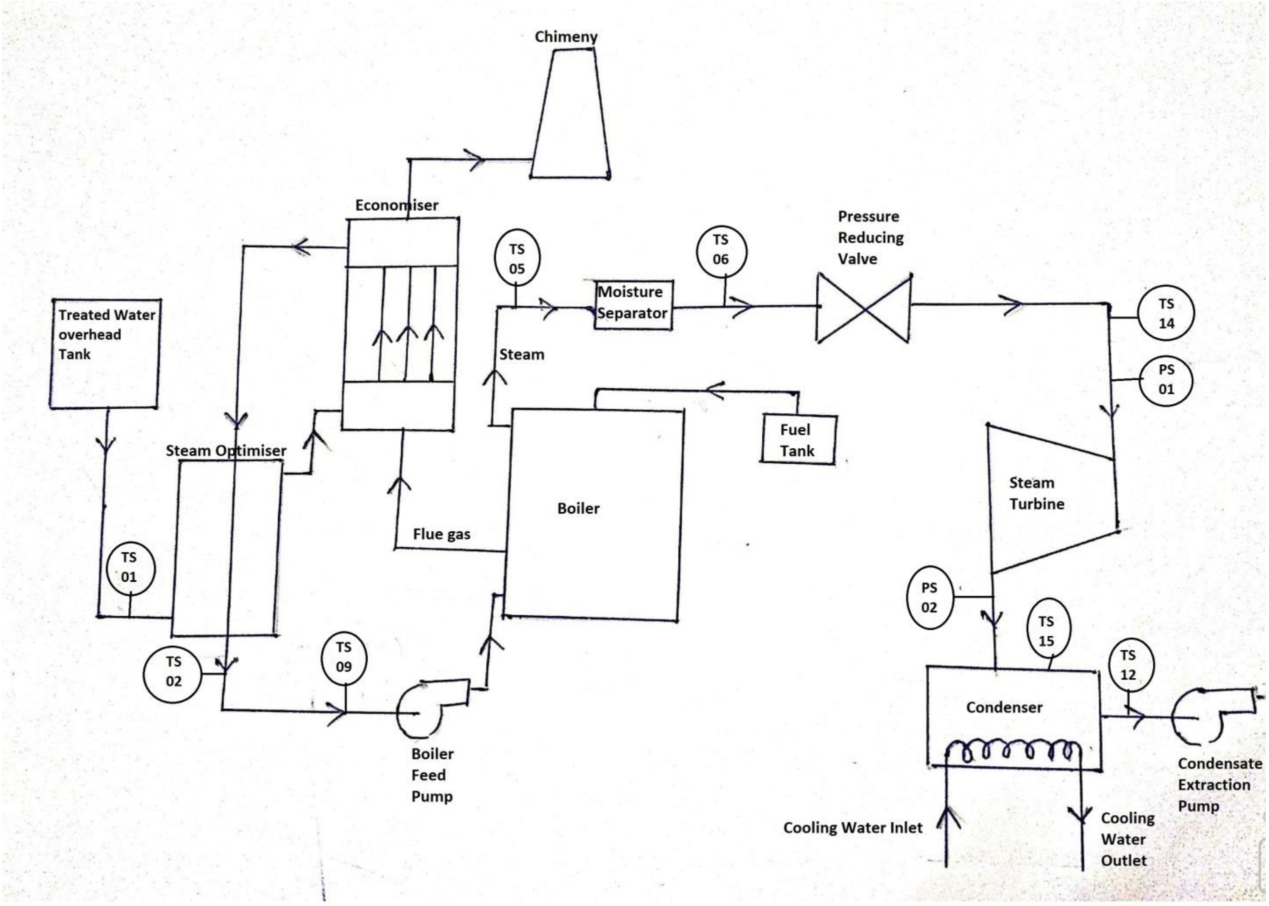

Fig 9: Schematic of layout of location of sensors acquired

2.2 DAQ Device/Hardware

DAQ hardware acts as the interface between the computer and the outside world. Before a computer-based measurement system can measure a physical signal such as temperature, a sensor or transducer must convert the physical or real world signal into an electrical signal such as voltage or current [6]. It primarily functions as a device that digitizes incoming analog signals so that the computer can interpret them [2].

A DAQ device (Data Acquisition Hardware) usually has these functions-

1. Analog input
2. Analog output
3. Digital Input/output
4. Counter/Timers

We have used DAQ device for analog input operation.

2.2.1.1 Analog Input

Analog input is the process of measuring an analog signal (a signal that is expected to vary continuously) and transferring the measurement to a computer for analysis, display or storage. Here we have used a Data Acquisition (DAQ) device to perform analog input [6].

2.2.1.1(a) Analog-to-Digital Conversion

Acquiring an analog signal with a computer requires a process known as analog-to-digital conversion (ADCs) which takes an electrical signal and translates it into digital data so that a computer can process it. A sample clock controls the rate at which samples of the input signals are taken. Since the incoming signal is real world signal with infinite precision, the ADC approximates the signal with fixed precision and generates digital values [6].

2.2.1.1(b) Task Timing

When performing analog input, the task can be timed to acquire 1 datum, N data or acquire continuously. Programmatically, we have included the timing function and specified the sample rate and sample mode [6].

2.2.1.1(c) Task triggering

DAQ device is controlled by NI-DAQmx action. Every NI-DAQmx action needs a stimulus or cause. When the stimulus occurs, the action is performed. Causes for actions are called trigger. The start trigger starts the acquisition [6]. Data acquired up to a reference point is pre-trigger data. Here we have set our reference point as 1000; it means after taking 1000 samples it will stop acquiring data.

2.2.2 We have different DAQ hardware such as-

1. Compact DAQ (cDAQ) chassis-NI 9174
2. Data Card-(a)-NI 9203
   (b)-NI 9216

2.2.2.1 Compact DAQ (cDAQ) Chassis [Appendix 1]

Compact DAQ-9174 is a compact DAQ chassis designed for small, portable sensor measurement systems. The chassis provides the plug-and-play simplicity of USB to sensor and electrical measurements. It also controls the timing, synchronization, and data transfer between C series Input/output modules to create a mix of analog I/O, digital I/O, and counter/timer measurements. The cDAQ-9174 also has four 32-bit general-purpose counter/timers. The cDAQ chassis is capable of handling a broad range of analog and digital I/O signals using a Hi-Speed USB 2.0 interface.

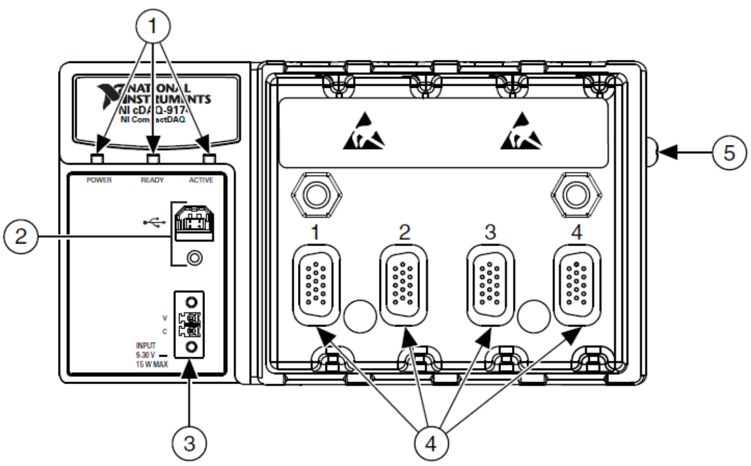

Fig 10: cDAQ-9174 Chassis

1. Power, Ready, and Active LEDs
2. USB Connector with Strain Relief
3. Power Connectors
4. Module Slots
5. Chassis Grounding Screw

We need the following items to set up the cDAQ chassis-

1. Power adapter (Packaged with the cDAQ chassis
2. Locking USB cable (Packaged with the cDAQ chassis)
3. Screwdriver (Packaged with the cDAQ-9174 chassis)
4. Host computer running windows
5. Application Software (LabVIEW® 14.0)
6. NI-DAQmx driver (Packaged with the cDAQ chassis)
7. C series modules

Before completing the following assembly we need to first install the Application software (LabVIEW® 14.0). The NI-DAQmx driver is installed next. cDAQ-9174 supports NI-DAQmx driver version 9.0.2 and later. Here we have used NI-DAQmx version of

2.2.2.2(a) NI 9203 [Appendix 1]

The NI 9203 is a C series DAQ module with 8 analog current input channels for high performance control and monitoring applications. It features programmable input range of ±20 mA or 0 mA to 20 mA, 16-bit resolution, and a 200k S/s maximum sampling rate.

<u>Specification</u>

The following specification are typically for the range -40°C to 70°C. All voltages are relative to COM.

Input Characteristics

No. of channel: 8 analog input channels

ADC resolution: 16 bits

Type of ADC: Successive approximation registers (SAR)

Nominal input: 4 to 20 mA

Overvoltage protection, channel-to-COM: ±30 max on one channel at a time

Sample rate: 200k S/s max

Wiring Diagram of pressure transmitter with NI 9203:

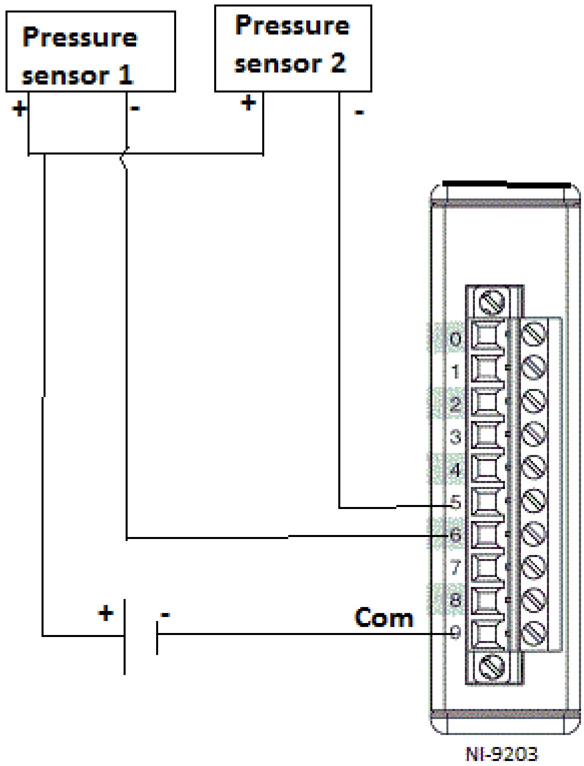

Fig 11: wiring diagram of pressure transmitter with NI 9203

2.2.2.2(b) NI 9216 [Appendix 1]

The NI 9216 RTD analog input is a C series DAQ module with 8 channels and 24 bits of resolution for PT100 RTD measurements. The NI 9216, compatible with 3 and 4 wire RTD measurements, automatically detects the type of RTD (3 or 4 wire) connected to the channel for the appropriate mode. The module provides 1 mA of current excitation per channel and has less than a ±1.0°C accuracy error over its entire operating temperature range.

Specification

The following specifications are typically for the range -40°C to 70°C.

Input Characteristics

No. of channel: 8 analog input channels

ADC resolution: 24 bits

Type of ADC: Delta-Sigma

Measurement range:

Temperature=-200°C to 850°C

Resistance= 0 to 400 Ω

Conversion Time:

High-resolution mode= 200ms per channel; 1600ms total for all channel

High-speed mode= 2.5ms per channel; 20ms total for all channel

Wiring diagram of RTD with NI 9216

Here,

1, 2, 5, 6, 9, 12, 14, 15 indicates the locations of RTD in Mini power plant

R=Red; W=White, are the colour code for wires corresponding to each RTD

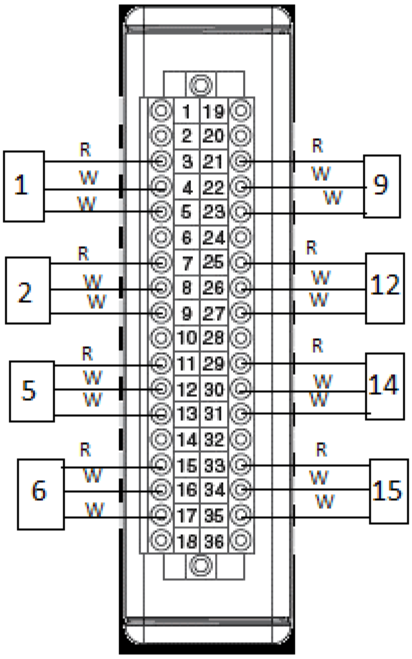

Fig 12: Wiring Diagram of NI 9216 with RTD

2.3. Software Details

National instrument (NI) data acquisition boards have a driver engine that communicates between the board and the application software. There are two different driver engines, the NI-DAQmx and Traditional NI-DAQmx. We have used LabVIEW® to communicate with these driver engines. The DAQ assistant in Express VI of LabVIEW® is used to communicate with our data acquisition board. The software also controls the DAQ system by commanding the DAQ device when and from which channel to acquire data. Typically, a DAQ software includes driver software and application software. Driver software is the layer of software that directly programs the DAQ hardware, managing its application and its integration with the computer resources like processor and memory [6].

LabVIEW® is a platform and development environment for a virtual programming language from National Instrument. LabVIEW® is a graphical programming language that uses icons instead of lines of text to create applications. In contrast to text based programming languages, where instructions determine program execution, LabVIEW® uses data flow programming, where the flow of data determines execution order [1].

In LabVIEW® we can create or use “Virtual Instruments” (VI) for data acquisition. A VI allows the computer screen to act as an actual laboratory instrument with characteristics tailored to our particular needs.

A VI has three main parts-

1. Front Panel
2. Block (or Wiring) Diagram
3. Icon/Connector

2.3.1 Front Panel

When we open a new or existing VI, the front panel window of the VI appears and functions as the graphical user interface or GUI of a VI. We can find the source code that runs the front panel on the block diagram. The front panel window contains a toolbar at the top and a controls palette that we can access by right clicking anywhere on the front panel [7].

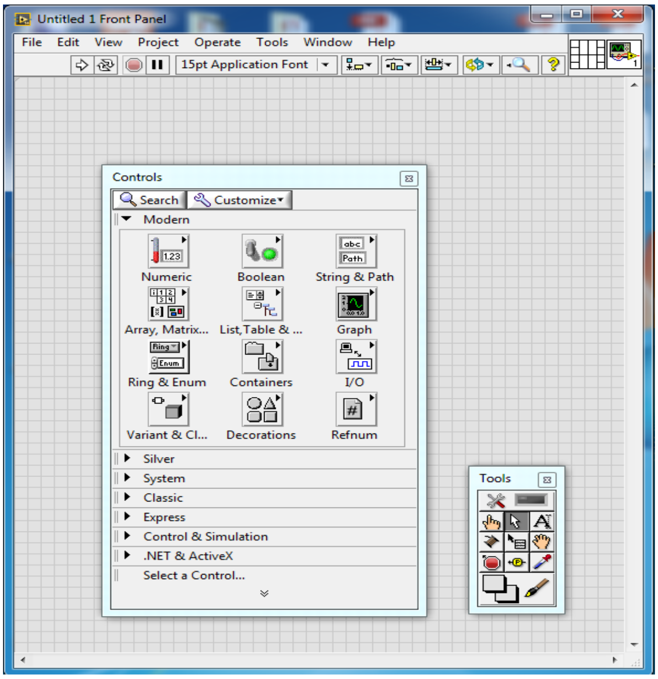

Fig 13: Front Panel window

2.3.2 Block Diagram

When we create or open a new VI, the front panel opens automatically. To bring up the block diagram, we can select “Show Block Diagram” from the menu bar. We can toggle between the block diagram and the front panel by pressing “Ctrl+E” [7].

Block diagram objects include terminals, SubVIs, functions, constants, structures and wires that transfer data among other block diagram objects. One may place objects on the block diagram by dragging and dropping from the functions palette. The function palette automatically appears when we right click anywhere on the block diagram workspace. It contains functions, constants, structures and some Vis.

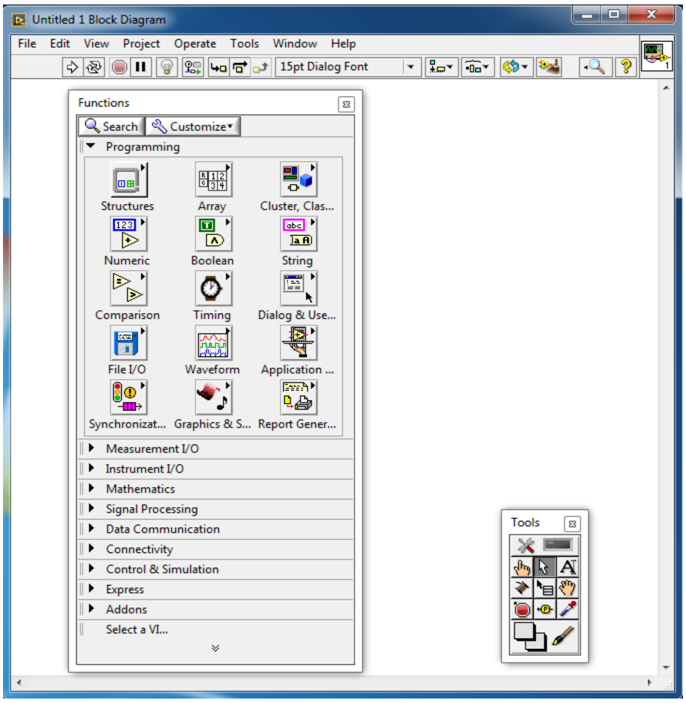

Fig 14: Block Diagram window

2.3.3 Icon/Connector

Within LabVIEW®, we can create smaller sections of the code known as subVIs. SubVI's are same as VI's. They contain front panels and block diagrams, but we have to call them within a VI. When we create a subVI and use it, we can see an icon within our block diagram that represents the subVI [7]. We can customize the icon according to number of input and output terminals required.

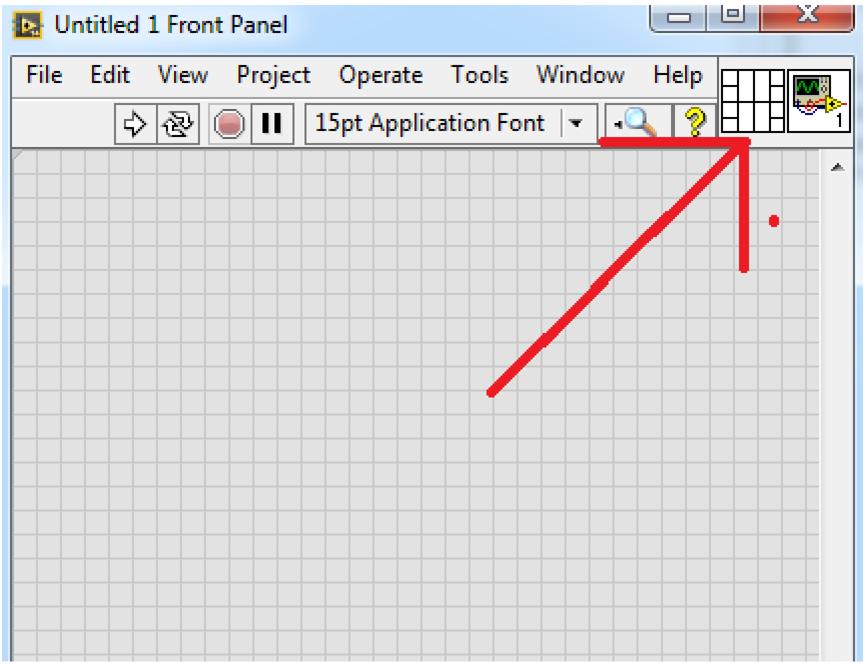

Fig 15: Icon connector in front panel

Front Panel of the LabVIEW® program used for Data Acquisition:

;

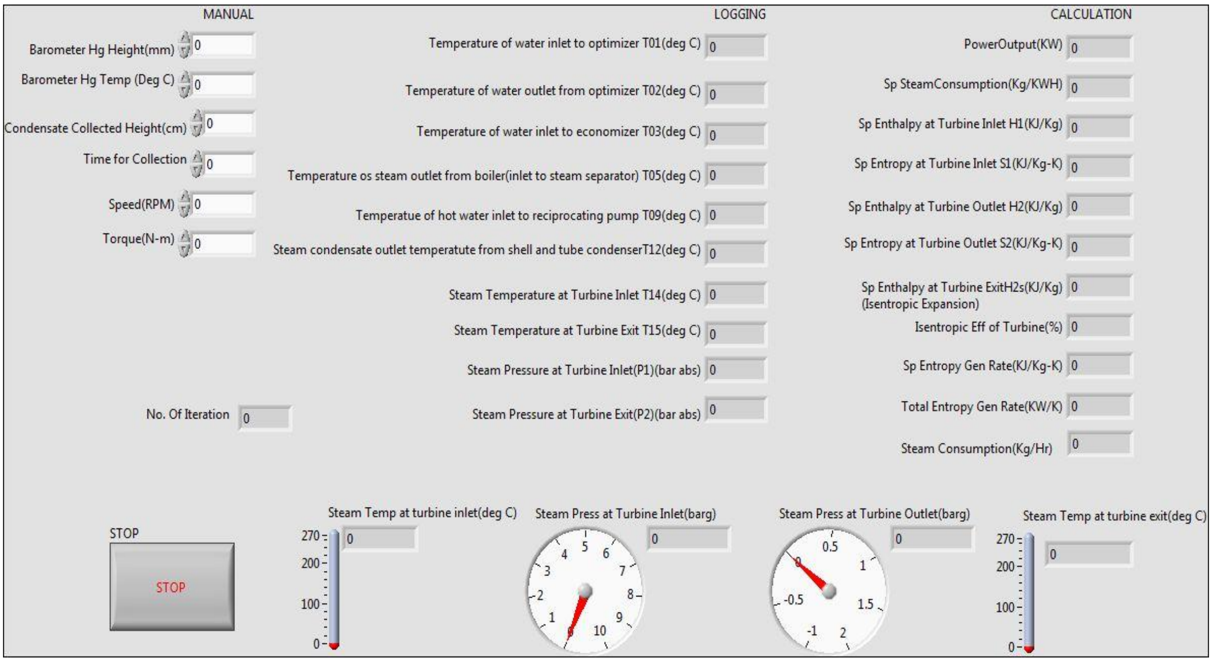

Fig 16: Front panel of the program used in data acquisition

All the algorithms for interpolation and double interpolation are executed under block diagram. In the block diagram we have used a read from spreadsheet virtual instrument (VI) from the function palette which reads a specified number of lines or rows from a numeric text file. We have taken output of these file into 2-D arrays of data. Array functions are used to create and manipulate arrays, like using ‘delete from array’ function we can delete an element from the array which gives two outputs, one is the edited array and other is the element. We can use both or one according to our requirement. Arithmetic and complex mathematical operations are done with the help of numeric function palette.

We have acquired the signals with the help of DAQ assistant in Express VI of LabVIEW® with proper configuration. The configuration setup for DAQ assistant is as follows-

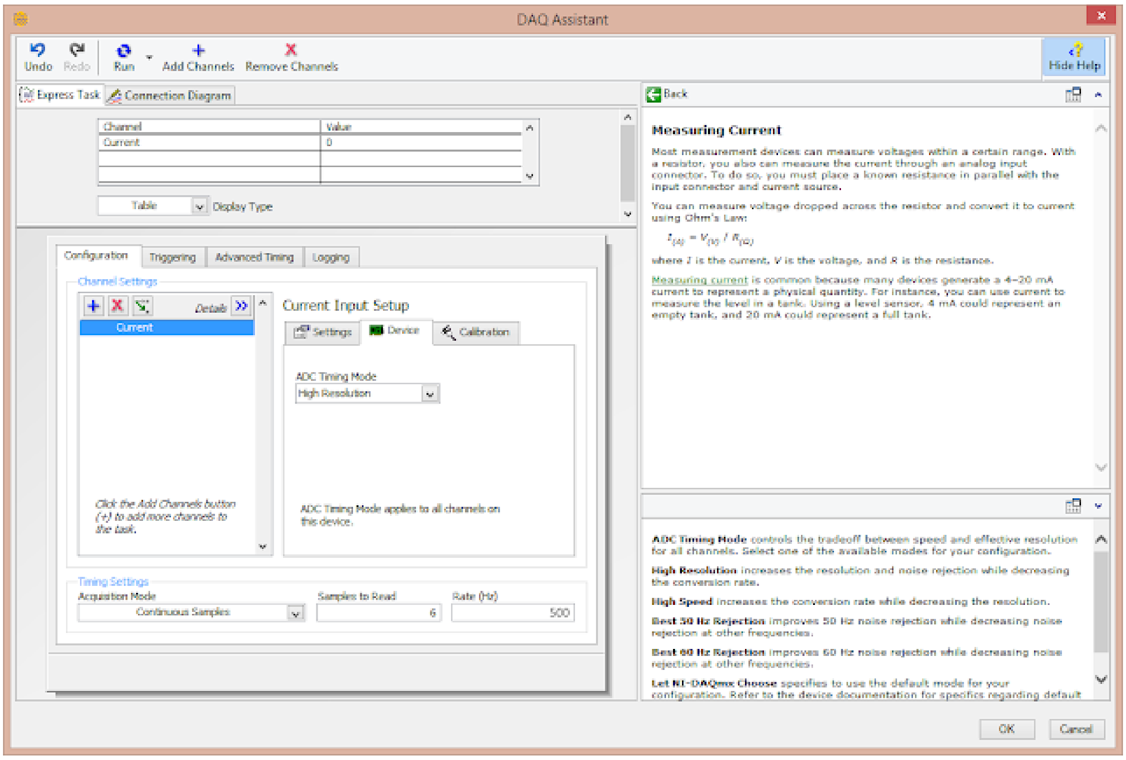

Fig 17: DAQ assistant

Total Number of Channels for Data acquisition=10 (8 for RTD and 2 for Pressure Transmitter)

The channel for Pressure transmitter need to be scaled since output of the channel is in mA.

Scaling

Since the input for pressure transmitter is 0 to 16 bar gauge pressure corresponding to 4 to 20 mA.

Suppose, X = transmitted signal in mA

Y = pressure in bar gauge

Then the linear relation is given as, Y=-4+1000X

Timing Setup:

Acquisition Mode-Continuous

Samples to read-1000

Rate (Hz)-200

We have set timing in such a way that at every 5 second set we got 1 sample.

CHAPTER 3:

Experimental Result

Chapter 3

Experimental Results

3.1 LOGGED DATA:

Time	T Optimizer(in) deg C	T Optimizer(out) deg C	T Economizer(in) deg C	T Boiler(out) deg C	T BFP(in) deg C	T Condensate(out) deg C	P Turb(in) barg	T Turb(in) deg C	P Turb(out) barg	T Turb(out) deg C
4/9/2019 16:26:25.587	30.831948	61.121082	35.717331	180.570856	62.302671	61.51321	4.658785	160.682089	0.089401	116.799738
4/9/2019 16:26:30.601	30.833843	61.162062	35.720652	180.535533	62.372234	61.620854	4.664364	160.635638	0.083493	117.214163
4/9/2019 16:26:35.665	30.832421	61.193634	35.726187	180.572017	62.433821	61.676831	4.650908	160.630862	0.082508	117.611751
4/9/2019 16:26:40.532	30.843318	61.295848	35.730932	180.531221	62.489186	61.686559	4.629904	160.589847	0.091042	117.992497
4/9/2019 16:26:45.821	30.834474	61.39073	35.736784	180.378991	62.563221	61.667581	4.620715	160.565634	0.119927	118.351196
4/9/2019 16:26:50.621	30.815366	61.507303	35.74485	180.190455	62.653055	61.628987	4.621699	160.569917	0.087103	118.688164
4/9/2019 16:26:55.599	30.811734	61.761674	35.754497	179.877747	62.809591	61.567909	4.55639	160.504526	0.075615	119.121858
4/9/2019 16:27:00.878	30.807944	61.870286	35.765251	179.655091	62.946508	61.495668	4.570174	160.398619	0.07463	119.436646
4/9/2019 16:27:05.577	30.808102	62.069818	35.777271	179.45798	63.065716	61.410354	4.504864	160.262247	0.08579	119.722535
4/9/2019 16:27:10.656	30.806365	62.334603	35.796883	179.255744	63.226423	61.338595	4.478609	160.170182	0.09892	119.995772
4/9/2019 16:27:15.557	30.810471	62.534005	35.813015	179.039598	63.415388	61.255039	4.49108	160.13922	0.065439	120.278137
4/9/2019 16:27:20.667	30.808102	62.757988	35.836738	178.854627	63.609472	61.168614	4.426755	160.241001	0.090714	120.578737
4/9/2019 16:27:25.567	30.811734	62.984221	35.858722	178.662707	63.802771	61.053811	4.427739	160.209544	0.104828	120.891237
4/9/2019 16:27:30.601	30.816945	63.166272	35.879916	178.509578	64.011086	60.928488	4.403782	160.610437	0.051653	121.197752
4/9/2019 16:27:35.813	30.803206	63.551791	35.912023	178.344525	64.278326	60.794881	4.348974	161.014019	0.078897	121.558942
4/9/2019 16:27:40.601	30.789309	63.76308	35.937171	178.249574	64.522118	60.709904	4.356522	161.085022	0.102859	121.783875
4/9/2019 16:27:45.780	30.794363	63.894425	35.95963	178.297463	64.733516	60.65522	4.329939	161.541557	0.098263	121.972551
4/9/2019 16:27:50.881	30.794205	64.122178	35.983671	178.38877	64.913791	60.569769	4.315827	161.248451	0.12321	122.134236
4/9/2019 16:27:55.658	30.797837	64.387617	36.010559	178.555317	65.132402	60.436974	4.363086	161.103143	0.096294	122.289749
4/9/2019 16:28:00.635	30.779834	64.625623	36.030805	178.748722	65.359971	60.345152	4.417894	161.20265	0.089729	122.449011
4/9/2019 16:28:05.614	30.774465	64.820542	36.05627	178.901698	65.583405	60.255884	4.454323	161.150096	0.081851	122.617392
4/9/2019 16:28:10.503	30.783309	64.971729	36.079521	179.196236	65.79248	60.124537	4.46023	161.166241	0.103515	122.790989
4/9/2019 16:28:15.580	30.772096	65.251451	36.113053	179.478204	66.044697	59.99176	4.498956	161.291945	0.054936	123.032609
4/9/2019 16:28:20.769	30.786625	65.474513	36.133458	179.719415	66.253164	59.861699	4.540308	161.577971	0.100561	123.223803
4/9/2019 16:28:25.626	30.793889	65.678588	36.156077	179.863488	66.459408	59.753	4.564266	161.694136	0.102531	123.417288
4/9/2019 16:28:30.525	30.78852	65.85984	36.18265	180.125457	66.656239	59.649246	4.593147	162.15027	0.111393	123.617133
4/9/2019 16:28:35.726	30.775886	66.095882	36.205902	180.469367	66.853562	59.551073	4.63056	162.335676	0.103515	123.818129
4/9/2019 16:28:40.560	30.771781	66.330025	36.228047	180.710824	67.06496	59.477764	4.686352	162.558179	0.09892	124.019302
4/9/2019 16:28:45.793	30.775886	66.501731	36.255728	180.905529	67.272376	59.411947	4.738863	162.751029	0.099248	124.216093
4/9/2019 16:28:50.794	30.772254	66.69581	36.284517	181.175551	67.481086	59.358561	4.780543	162.91801	0.094653	124.403292

3.2 CALCULATED DATA:

Time	Isentropic Efficiency(%)	Power Output(KW)	Sp Entropy Gen Rate(KJ/Kg-K)	Steam Consumption(Kg/hr)	Sp Steam Consumption(Kg/KW-Hr)	Total Entropy Gen Rate(KW/K)
4/9/2019 16:26:25.587	19.815435	0.314159	0.585774	95.106	302.73196	0.015475
4/9/2019 16:26:30.601	19.193117	0.314159	0.605926	95.106	302.73196	0.016008
4/9/2019 16:26:35.665	18.801313	0.314159	0.611485	95.106	302.73196	0.016154
4/9/2019 16:26:40.532	18.654845	0.314159	0.612726	95.106	302.73196	0.016187
4/9/2019 16:26:45.821	18.755937	0.314159	0.609142	95.106	302.73196	0.016093
4/9/2019 16:26:50.621	18.322817	0.314159	0.597495	95.106	302.73196	0.015785
4/9/2019 16:26:55.599	17.852494	0.314159	0.613829	95.106	302.73196	0.016216
4/9/2019 16:27:00.878	17.747921	0.314159	0.615242	95.106	302.73196	0.016254
4/9/2019 16:27:05.577	17.465608	0.314159	0.619208	95.106	302.73196	0.016358
4/9/2019 16:27:10.656	17.62028	0.314159	0.610221	95.106	302.73196	0.016121
4/9/2019 16:27:15.557	17.226121	0.314159	0.603713	95.106	302.73196	0.015949
4/9/2019 16:27:20.667	17.031561	0.314159	0.62137	95.106	302.73196	0.016416
4/9/2019 16:27:25.567	17.43115	0.314159	0.604555	95.106	302.73196	0.015971
4/9/2019 16:27:30.601	16.760596	0.314159	0.600174	95.106	302.73196	0.015856
4/9/2019 16:27:35.813	17.016427	0.314159	0.620582	95.106	302.73196	0.016395
4/9/2019 16:27:40.601	17.670932	0.314159	0.602602	95.106	302.73196	0.01592
4/9/2019 16:27:45.780	17.573706	0.314159	0.593572	95.106	302.73196	0.015681
4/9/2019 16:27:50.881	18.165238	0.314159	0.591402	95.106	302.73196	0.015624
4/9/2019 16:27:55.658	17.70904	0.314159	0.581319	95.106	302.73196	0.015357
4/9/2019 16:28:00.635	17.081626	0.314159	0.599602	95.106	302.73196	0.01584
4/9/2019 16:28:05.614	16.69041	0.314159	0.608411	95.106	302.73196	0.016073
4/9/2019 16:28:10.503	16.507134	0.314159	0.616761	95.106	302.73196	0.016294
4/9/2019 16:28:15.580	16.041859	0.314159	0.608613	95.106	302.73196	0.016079
4/9/2019 16:28:20.769	15.987181	0.314159	0.634512	95.106	302.73196	0.016763
4/9/2019 16:28:25.626	16.073814	0.314159	0.617811	95.106	302.73196	0.016322
4/9/2019 16:28:30.525	15.998319	0.314159	0.619593	95.106	302.73196	0.016369
4/9/2019 16:28:35.726	16.063525	0.314159	0.617021	95.106	302.73196	0.016301
4/9/2019 16:28:40.560	15.835792	0.314159	0.624087	95.106	302.73196	0.016487
4/9/2019 16:28:45.793	15.610326	0.314159	0.63126	95.106	302.73196	0.016677
4/9/2019 16:28:50.794	15.361301	0.314159	0.636082	95.106	302.73196	0.016804

3.3 Comparison of values obtained from our program on LabVIEW® with the value obtained from web:

Assuming values obtained from web is correct,

At the time of Data Acquisition,

Barometer Hg Height (mm) = 759.05

Atmospheric Temperature = 31.5°C

Time 4/9/2019	η_Prog(%)	P_Turb(in) barg	T_Turb(in) deg C	P_Turb(out) barg	T_Turb(out) deg C	η_Web(%)	error (%)
16:19:50.224	23.114731	1.810432	132.015575	0.083164	105.18015	23.4059	0.291169
16:21:45.297	25.717893	3.224927	146.463655	0.045417	103.470942	25.3616	0.356293
16:19:55.446	21.340836	1.935144	132.719052	0.08579	105.178047	21.14	0.200836
16:22:10.443	26.520595	3.326009	147.210185	0.085462	103.282275	26.2915	0.229095
16:24:40.349	26.921421	4.794655	159.2655	0.080538	103.104449	27.18	0.258579
16:24:45.316	26.426456	4.900988	159.936329	0.079882	103.46496	26.87	0.443544
16:26:15.520	20.62206	4.641062	160.943511	0.106469	115.961806	20.45	0.17206
16:26:45.821	18.755937	4.620715	160.565634	0.119927	118.351196	18.647	0.108937
16:27:45.780	17.573706	4.329939	161.541557	0.098263	121.972551	17.95	0.376294
16:29:10.595	14.564306	4.984348	163.326518	0.093012	124.892019	14.3	0.264306

Table 5: Data Comparison of software value and web values

From the table the accuracy of the program can be concluded as within ±1.0%.

3.4. Efficiency prediction with the help of Least Square Method:

An equation of efficiency in terms of Turbine inlet condition (Temperature and pressure) and Turbine outlet condition (Temperature and pressure) is been generated by Least Square Method with the help of Paramsivan K. of school of Laser Science and Enginnering department of Jadavpur University.

$$\eta_{Predicted} = a_1 + a_2 * P_1 + a_3 * T_1 + a_4 * P_2 + a_5 * T_2 + a_6 * P_1 * T_1 + a_7 * P_1 * P_2 + a_8 * P_1 * T_2 + a_9 * T_1 * P_2 + a_{10} * T_1 * T_2 + a_{11} * P_2 * T_2 + a_{12} * P_1 * P_1 + a_{13} * T_1 * T_1 + a_{14} * P_2 * P_2 + a_{15} * T_2 * T_2$$

Where,

$a_1, a_2, a_3, a_4, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11}, a_{12}, a_{13}, a_{14}$ *and* a_{15} *are constant is determined as follows* –

a_1=2195.147854	a_6=-0.651495977	a_{11}=0.0000281416
a_2=100.2303612	a_7=0.0000179357	a_{12}=-0.00000141716
a_3=-15.82641131	a_8=-0.000002193	a_{13}=0.047904753
a_4=471.645159	a_9=-2.866822954	a_{14}=0.000866205
a_5=-18.83536996	a_{10}=0.033240132	a_{15}=0.053268066

Table 6: Value of Coefficients for the prediction equation

The percentage error in calculation of efficiency by the above equation is determined as follows-

$\eta_{Experimental}$	$\eta_{Predicted}$	%error
19.81544	19.76666783	-0.24671
19.19312	19.24189679	0.253508
18.80131	18.89700182	0.50637
18.65485	18.71641334	0.328954
18.75594	18.75323935	-0.01439
18.32282	18.08421487	-1.31939
17.85249	17.85860289	0.034207
17.74792	17.50353155	-1.39623
17.46561	17.6502385	1.046051
17.62028	17.68970276	0.392447
17.22612	17.00722842	-1.28706
17.03156	17.42246432	2.243674
17.43115	17.37825925	-0.30435
16.7606	16.85426509	0.555759
17.01643	17.42370984	2.337521
17.67093	17.54895175	-0.69509
17.57371	17.80049723	1.274072
18.16524	17.85364114	-1.74528
17.70904	17.22079921	-2.83518
17.08163	16.88129079	-1.18673
16.69041	16.53142528	-0.96171
16.50713	16.65002087	0.858178
16.04186	15.98379214	-0.36329
15.98718	16.27747145	1.783388
16.07381	16.16771578	0.580798
15.99832	16.25258688	1.564476
16.06353	16.03982803	-0.14774
15.83579	15.77111873	-0.41007
15.61033	15.53303152	-0.49761
15.3613	15.32134522	-0.26079

Table 7: comparison of efficiency calculated experimentally and by prediction equation

Comparison of experimental and predicted result

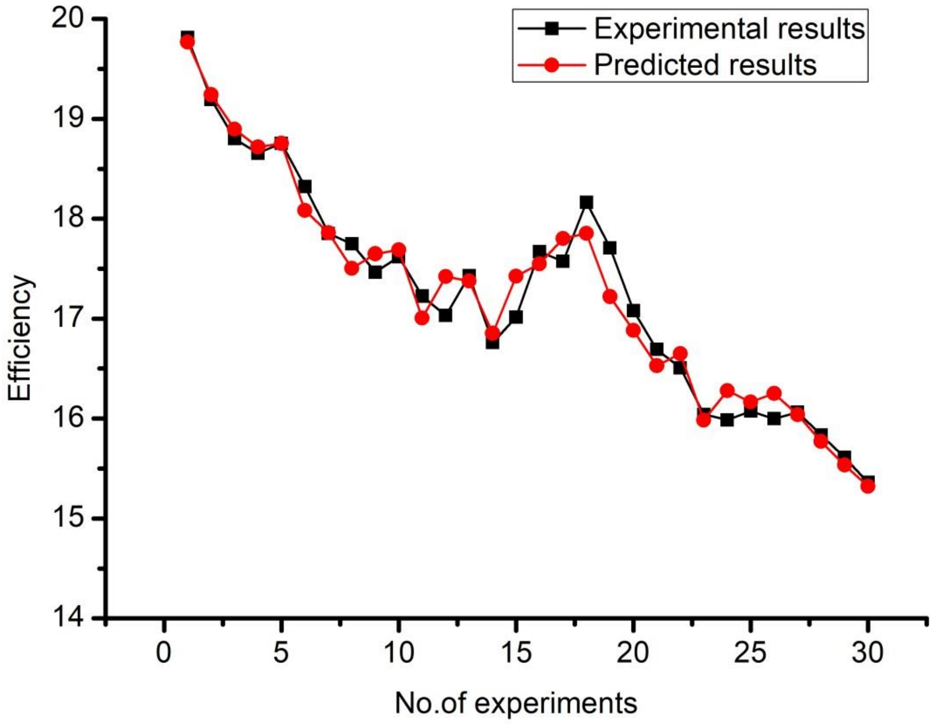

Fig 18: Comparison of experimental and predicted result

From the above table and graph, we can conclude that percentage accuracy is in the range of ±3% due to neglecting other higher order term in the equation.

3.5. Variation in efficiency when outlet condition of the turbine is fixed

3.5.1. Efficiency as a function of Inlet pressure

When we fixed the stream turbine outlet condition and inlet temperature of turbine then efficiency varies with inlet pressure is as follows-

$$\eta_{Predicted} = a_1 + a_2 * P_1 + a_3 * T_1 + a_4 * P_2 + a_5 * T_2 + a_6 * P_1 * T_1 + a_7 * P_1 * P_2 + a_8 * P_1 * T_2 + a_9 * T_1 * P_2 + a_{10} * T_1 * T_2 + a_{11} * P_2 * T_2 + a_{12} * P_1 * P_1 + a_{13} * T_1 * T_1 + a_{14} * P_2 * P_2 + a_{15} * T_2 * T_2$$

Where,

T_1, P_2 *and* T_2 *are constant*

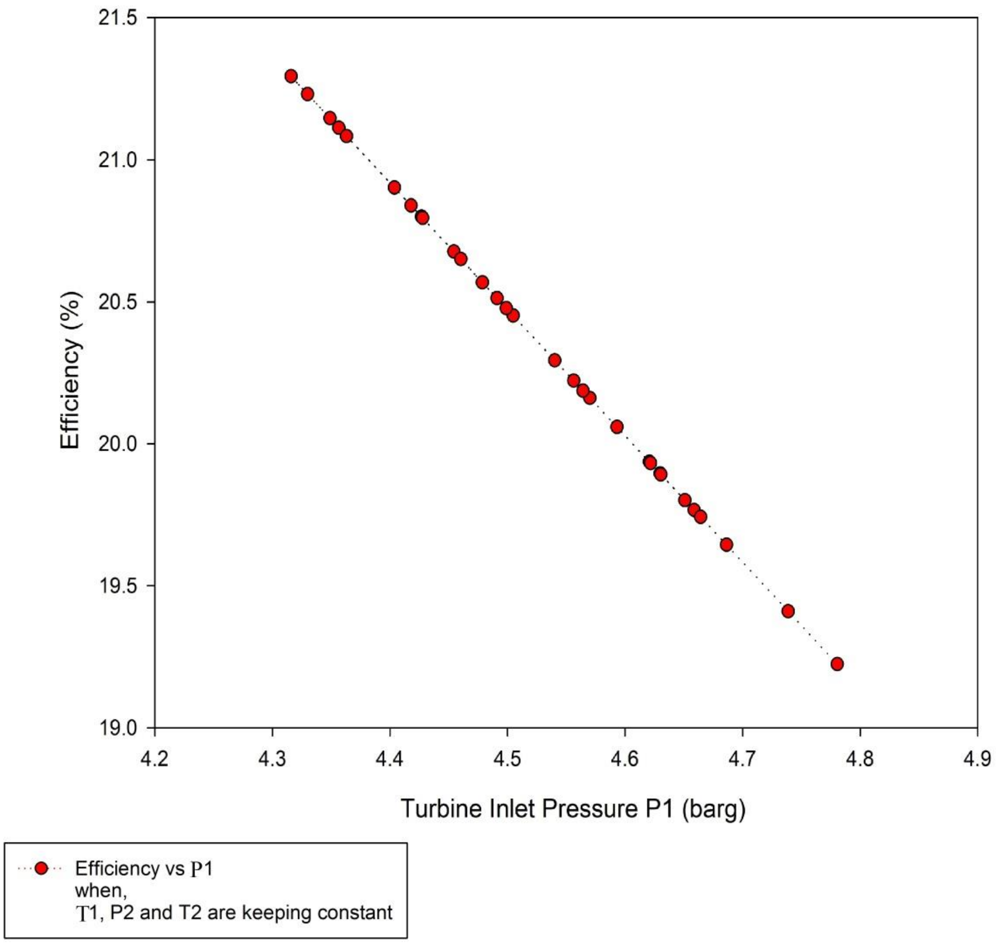

Fig 19:Efficiency v/s P1

3.5.2. Efficiency as a function of Inlet Temperature

When we fixed the stream turbine outlet condition and inlet pressure of turbine then efficiency varies with inlet temperature is as follows-

$$\eta_{Predicted} = a_1 + a_2 * P_1 + a_3 * T_1 + a_4 * P_2 + a_5 * T_2 + a_6 * P_1 * T_1 + a_7 * P_1 * P_2 + a_8 * P_1 * T_2 + a_9 * T_1 * P_2 + a_{10} * T_1 * T_2 + a_{11} * P_2 * T_2 + a_{12} * P_1 * P_1 + a_{13} * T_1 * T_1 + a_{14} * P_2 * P_2 + a_{15} * T_2 * T_2$$

Where,

P_1, P_2 *and* T_2 *are constant*

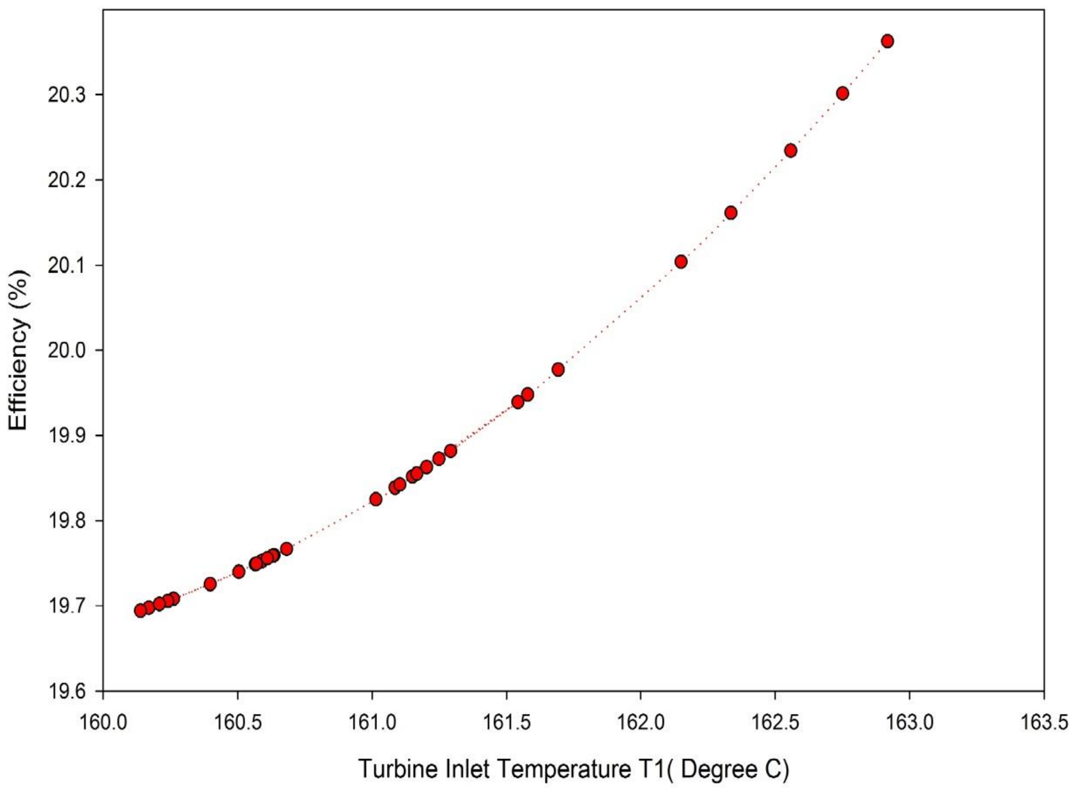

Fig 20: Efficiency v/s T1

3.5.3. Efficiency as a function of Inlet Temperature and Pressure

When we fixed the stream turbine outlet condition then efficiency varies with inlet temperature and pressure is as follows-

$$\eta_{Predicted} = a_1 + a_2 * P_1 + a_3 * T_1 + a_4 * P_2 + a_5 * T_2 + a_6 * P_1 * T_1 + a_7 * P_1 * P_2 + a_8 * P_1 * T_2 + a_9 * T_1 * P_2 + a_{10} * T_1 * T_2 + a_{11} * P_2 * T_2 + a_{12} * P_1 * P_1 + a_{13} * T_1 * T_1 + a_{14} * P_2 * P_2 + a_{15} * T_2 * T_2$$

Where,

P_2 *and* T_2 *are constant*

The surface plot of efficiency v/s Inlet condition of turbine is drawn with the help of SigmaPlot software keeping outlet condition of the turbine constant.

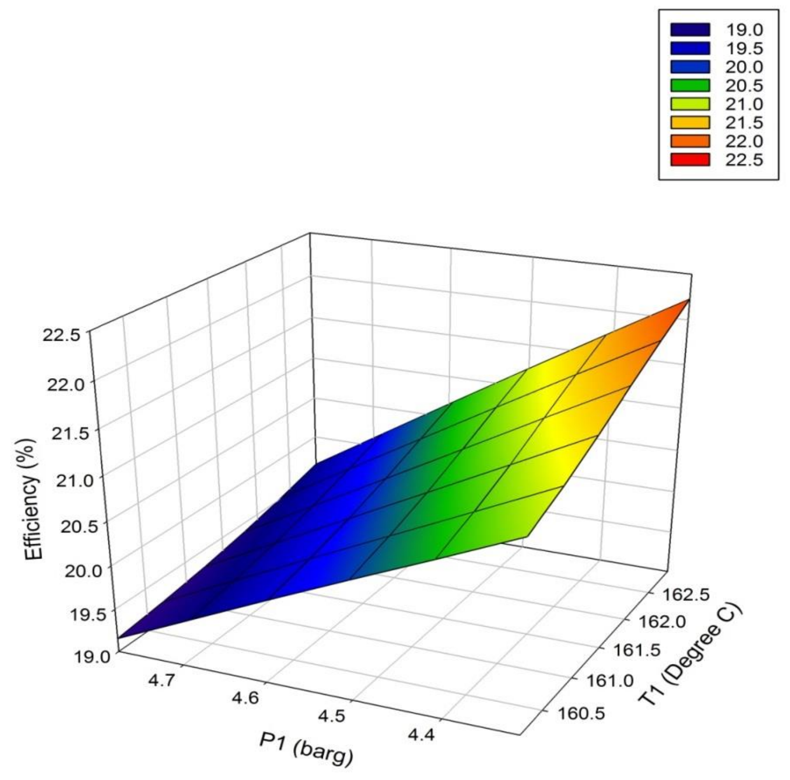

Fig 21: Efficiency v/s P1 and T1

CHAPTER 4:

Conclusion and scope of future work

CHAPTER 4

4.1 CONCLUSION

In this work, we have partially automated the performance test of a steam turbine installed as a component of a Mini Power Plant in the Heat Power Laboratory of the Mechanical Engineering Department of Jadavpur University.

In the process we have logged 8 temperature sensor signals and 2 pressure transmitter signals at a time with the help of an NI based Data Acquisition System. A Graphical User Interface (GUI) has been developed with the help of LabVIEW® 14.0 software.

As for the performance test of the turbine used in the mini power plant, enthalpy and entropy at inlet and outlet of turbine have to be known, a LabVIEW® program (VI) has been developed with interpolation, extrapolation and double interpolation algorithms, which use the logged temperature and pressure data at inlet and outlet of turbine and finds the required enthalpy and entropy values.

In the performance test the isentropic efficiency of the turbine and entropy generation have been found out with some other algorithms (VI's).

All the logged data and calculated data are shown on a GUI (front panel) in a single screen and simultaneously saved in two separate files which can be used in future for further analysis.

This system provides an efficient way of continuously monitoring the performance of the steam turbine of a power plant. This may help in reducing the maintenance cost of a steam power plant with the inclusion of some early warning system. The logged data and calculation data files may serve the purpose of post-fault analysis for finding the cause of the fault.

4.2 Scope of Future Work

Here we have acquired only 8 temperature signals out of 18 and 2 pressure transmitter signals due to unavailability of data cards. In this way we only monitor the turbine inlet and outlet conditions.

We have not acquired data from the flow sensor for steam consumption, boiler and condenser pressure, and turbine-speed sensor. In future we can acquire all these signals with the help of data cards required according to type of the output of the transmitters and monitor the complete plant operation to maintain on-line optimum and safe operations. We can modify our LabVIEW® program according to our need as it is developed in a way to meet the future requirements.

We could not implement the trip and safety logics because of lack of hardware. With such hardware the VI may be further developed to operate the Mini Power Plant fully from the computer.

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