"Analysis of Efficiency of Beta Stirling Cycle Model in Lab View"

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Abstract - *This study strives to provide a clear explanation of the Stirling engine and its efficiency using new automation technology and the Lab View software. This heat engine was invented by Stirling, a Scottish in 1918. The engine's working principles are based on the laws of thermodynamics and ability of volume expansion of ideal gases at different temperatures. Basically there are three types of Stirling engines: the gamma, beta and alpha models. The study focuses on a beta type engine model. The engine is coupled with a small generator for transforming heat energy to electrical energy. The heating energy is provided by a special resistor inside the cylinder. A friendly user interface has been designed so that the user can see the measured values either graphically or numerically on the screen. Main values include: input power, output power, efficiency, rpm and temperature as well as the PV diagram.*

Key Words: *beta type engine model, input power, Lab View software output power, Stirling engine,*

1. INTRODUCTION

The aim of this thesis was to design a system for the beta Stirling engine which can monitor the efficiency and PV diagram of the engine. The project includes installing suitable sensors, performing the power supply and connection circuit and software programming in Lab View environment. A small dynamo (3-4Watt) was coupled to the engine for the purpose of acting as a generator. At least four live values were needed: pressure, volume, temperature, and rpm in order to be able to reach the goal. The machine and its current situation were examined at first. Secondly all the electrical circuits, the connection box, the BNC terminals, the power supply, and the sensors were made and installed into the station. The adjustment and calibration of variables was done according to manufacturer recommendations of the equipments. The provided in-formation is connected to terminal BNC2110 where it is transferred to the communication card by a flat cable. The details can be found in related section. The software programming is performed in the Lab View environment version 2010. The program consists of two panels: the user interface panel and the block diagram panel. The block diagram contains seven parts or loops. Two loops are data preparation loops where raw information is acquired and scaled for further usage, the rest of the loops are for data processing. All the loops are paralleled but have their individual timing functions. The user interface provides a variety of different information on the screen either graphically or numerically. It has two tabs: the user tab and the analytical tab. The analytical tab offers details and related data which are helpful for finding out the cause of failures. Many pretests were carried out for finding problems. Each test included observing and solving problems, ultimately this led to fix the program and making it ready for the final measurements. During these tests it was revealed that one has to know the theoretical aspects of an engine in order to be able to design a perfect program, therefore at first mechanics of a Stirling engine are explained here.

2. DATA PROCESSING AND SOFTWARE PROGRAMMING:-

The program used to gather, calculate, control and display the data in Lab View front panel on the screen. The main purpose of this program is to draw PV diagram and calculating efficiency of the beta type of Stirling engine. Different types of data have been acquired for giving analytical ability to the program, using both numerical and graphical indicators help that data be more visible to users. Front panel consists of two tabs; user tab and analytical tab. User tab contains controls and indicators which enable users manage engine's output, while analytical tab shows details data that are helpful for understanding cause of failures. Block diagram of the program is divided in to seven parts or let say loops for being easier to follow it. All loops are working parallel together but each one does certain tasks and has its own timing regulation.

2.1 The rpm loop

In the rpm loop DAQ max vi is configured to count the edge of coming pulse from magnetic sensor to PFI8 (programmable function input). A read DAQ max vi reads the acquired values inside loop. This loop is timed for one second, while flywheel sends one pulse per revolution by magnetic sensor to be read, so that read data during one second multiply by 60 gives rpm of engine. Cycle duration time and iteration time of PV diagram loop are derived from rpm by mathematical nodes in this loop, therefore rpm loop has base stone role in program. Image of loop is shown below

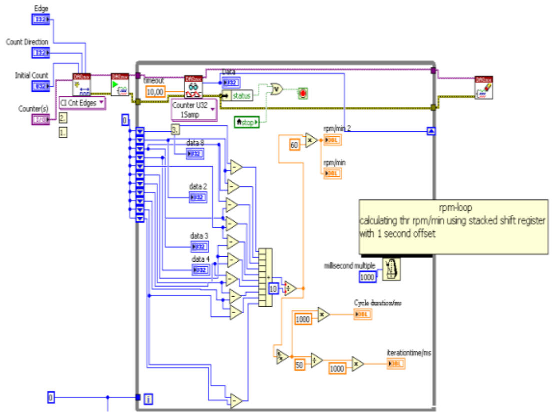

Figure 1:-RPM loop (DAQ max configured to count edge)

2.2 Data loop

Data loop provides all analog data. A DAQ max vi is configured to measure multiple analog inputs simultaneously, another read DAQ max vi reads measured data inside loop and gives them out in an array of data then array is indexed to separate each individual measured voltage. Individual voltage is scaled and compensated precisely, before sending to other loops through local variable function.

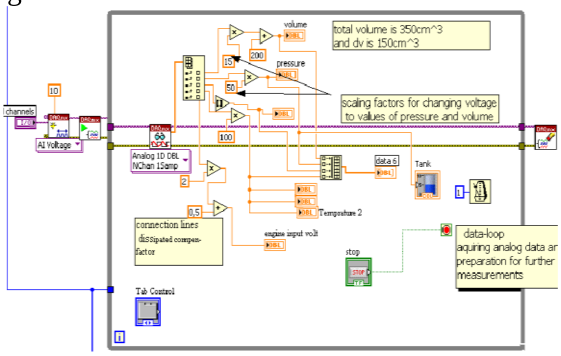

Figure 3:-Data loop (DAQ max configured to acquire analog inputs)

2.3 PV diagram loop

The PV loop is designed to obtain PV graph of Stirling engine's cycle. The for loop inside while loop does the main role and provides arrays of measured pressure and volume 51 times during one cycle, which is used for drawing PV graph by specific nodes. As it shows (figure 29) pressure and volume are connected to input shift registers then outputs of shift registers are indexed to form two different arrays of measured pressure and volume in a cycle, the achieved results are connected through a cluster bundle to XY graph indicator which displays PV graph of engine's cycle.

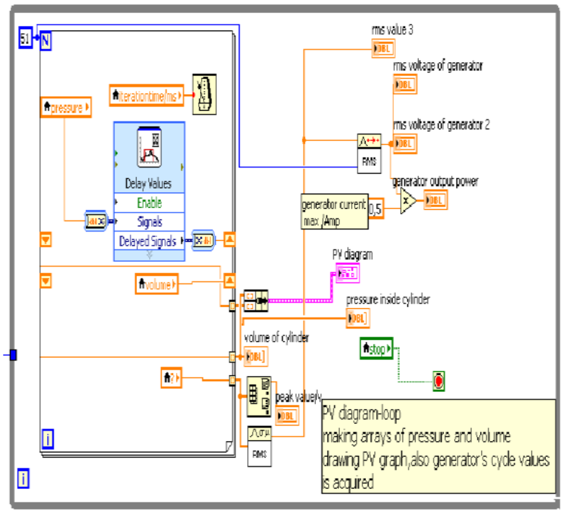

Figure 2:-PV diagram loop

2.4 Power loop

Power loop contains all elements to calculate different aspects of power and efficiency. There are many values in this loop that they are not needed in calculation or in programming, these kinds of data has been created for comparing, analyzing and research about behavior of this engine and system. Explanations of the most important ones come in the following.

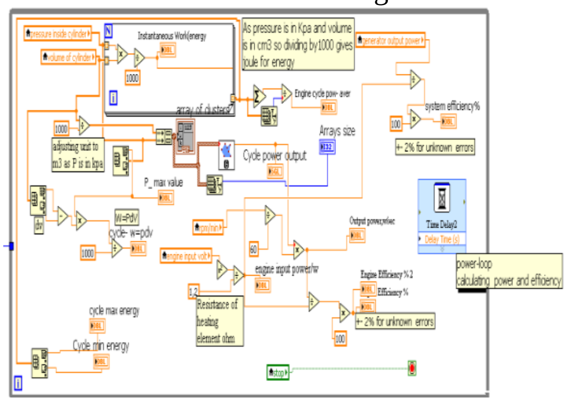

Figure 4:-Power loop

2.5 Feeding loop

Main job of this loop is providing control voltage to feeding transformer. The output voltage of transformer (engine heating voltage) can be varied from 0to 30v, it can be controlled either manually or by software. When it is connected to a computer manual control is disabled automatically. Control of transformer accepts variable volt-age from 0 to 10v, when input changes from (0…10v) its output varies from 0% to 100% respectively. Feeding loop provides a secure and full controlled voltage to input control of transformer, so that it can control the amount of heat and of course the engine's rpm.

A DAQ assistant (figure 35) is configured to AO1 for sending control voltage to the feeding transformer , control voltage comes from a PID advanced vi to the DAQ assistant, the function has either manual or automatic connection, so it make easy to control the engine's input power. A limitation has been set up for control voltage that allows the control voltage only changes between 4 to7.5 volts. If control voltage be less than 4v or more than 7.5v the circuit will be switched to10v constant on transformer's output, and an indicator will show on the screen over limit voltage. Experiences showed that when control voltage is less than 4v engine cannot be run properly and when control voltage is more than 7.5 it may damage the engine , so that limitation is built up for protective reasons.

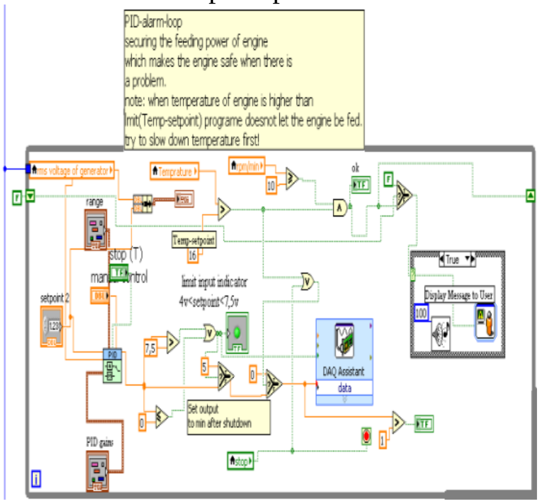

Figure 5:-Feeding loop

2.6 Writing data loop

Writing data loop is providing analytical information and records them in a directed document with a defined format. This part consists of three loops, for loop, case structure loops and while loop. Essential data have been gathered inside for loop in an array of ten elements, for loop's iteration number is 51 same as PV diagram, when for loop has finished reading values it records them in a 2D array and sends to case structure. 2D array of data is changed to fractional string format in case structure loop, then an-other 1D array of string which represents date& time of incidents is inserted into 2D array as a column, again a constant array of string which contains headers is added as a row into 2D array. Finally this ready 2D array is connected to writing to spread sheet vi and also in parallel to a data table which is visible on front panel under analytical tab. Another function of this loop is that, when some error occurs or cooling temperature is over high limit, it becomes active and records the most recent cycle's values until rotational speed falls less than ten revolutions per minute. All details and dependant circuits can be seen in the loop.

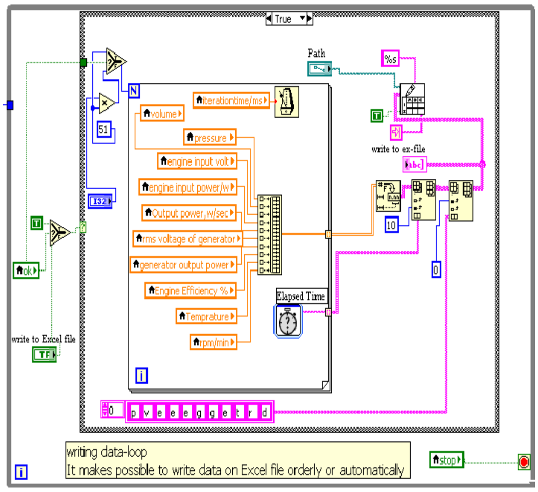

Figure 6:-Writing data loop

2.7 Graphic indicator loop

Graphic indicator loop is designed to show measuring variable either graphically or numerically. All six I/O values are brought in to this loop and rearranged in 1D array of data, resulted 1D array is inserted to a build array function which gives data out in 2D array of one column and six rows. Finally obtained 2D array is connected to a wave form chart. The wave form chart must be enabled for stacked plots and numerical display. When program is run this chart shows all six variables' values separately with their numerical indicator in one column and six rows. Loop is timed with 3 millisecond delay. That causes the graphical indicator be more visible, the loop is the simplest one in this program and does not have any other specifications

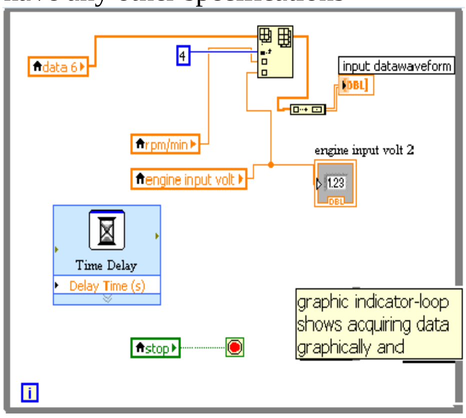

Figure 7:-Graphic indicator loop

3. RUNNING PROGRAM AND RESULT:-

When software programming is completed and all possible faults are checked and re-moved then program is run. The results were about what is expected from theoretical point of view. This is not obtained in the first run for sure, many pre-tests have been conducted and corrections have been carried out as much as was needed. Basically a loop was tested independently when codes were written on it as much as possible and again it was tested when the loop was bundling to other loops, so that program's debugging has been done in advance step by step. Doing more tests more defects revealed and improvements took place till result fulfilled the goal of project.

Final test did not raise unexpected problems. Some decoration have been done on user interface to give it more visibility and friendly appearance, also changes happened in calculation methods to make them more understandable. Two separate tests carried out idle test and load test. Each test consists of ten times re-cording data at different range of power, recorded result graphed and monitored by excel. Explanation comes in following.

3.1 Idle test

The Idle test is done in eight different ranges of power. Results showed cycle efficiency of this beta type of Stirling engine in the best stable conditions is about 19% ±2%. This result has been carried out through a series of tests with different feeding power and rotational speeds (rpm). The rpm is proportional to feeding power, any increase or de-crease in power affects rpm directly. The test showed that efficiency stands almost constant between 175 to 310rpm. But when rotational speed is less than 175rpm or more than 310rpm efficiency begin to de-cline, results are shown in (table 3) and an excel graph (figure 38). Each row (range) of values was observing for five minutes, after being sure there are no interferences on engine's working from previous range of power, and then data has been written down. Stirling engine has large dead time. Thus if set point is changed process variable does not follow it instantly, always it fluctuates many times before being stable, so that it takes plenty of time to complete a series of reliable tests. The engine has high reliability at constant continuous working but cannot be controlled fast enough. This is the main disadvantage of Stirling engine while controlling is the first priority in any application where an engine should be chosen.

Table 1:-Data table of idle tests

No	Input power/w	output power/w	speed RV/min	efficiency%
1.	152.6	26.8	336	17.56
2.	122.77	25.05	318	20.04
3.	95.225	19.03	252	19.98
4.	77.8	15.8	210	20.30
5.	61.77	12.7	174	20.56
6.	60.77	11.2	156	18.43
7.	56.7	9.3	132	16.40
8.	51.17	8.1	114	15.82

Observing above experiences proved that this type of Stirling engine has good performances when it is running at 175 to 318 rpm. Best suggested rpm rate for idle running is 210 rpm, considering the mechanical wear and tear of this type engine.

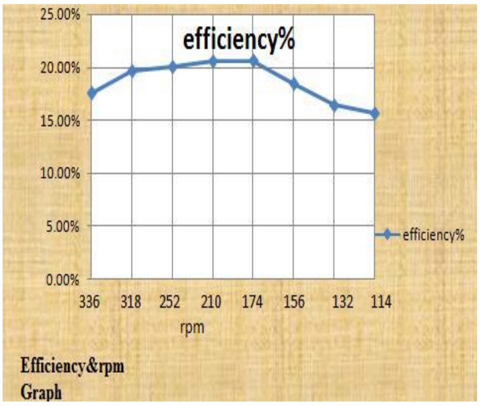

Figure 8:-Excel graph of efficiency at idle test

3.2 Load test

Load test is done by plugging two small bulbs in to output of generator (table 4). Two kinds of efficiency is considered, cycle efficiency and system efficiency. Cycle efficiency is obtained same as idle test, but system efficiency is calculated from active power of generator divided by engine's heating power. Loads are two small bulbs which are specified as 12v, 2w and 6Ω and are connected in parallel to generator. Ten different ranges of power are used during test.
Provided power is calculated from formula

$$P=VI.$$

Where;

P=max produced power
V= voltage connected to loads
I= max current of circuit or generator

Table 2:-Load test data table of efficiency

No	Input Power (W)	Output Power (W)	Genrams(V)	rpm	Engine efficiency %	System efficiency %
1	68.5	10.49	4.1	132	15.31	2.96
2	75.4	11.3	4.6	140	14.99	2.84
3	85.06	13.2	5	162	15.52	2.63
4	106.42	16.3	5.7	198	15.32	2.24

5	125.6	19.43	6.3	228	15.47	2.00
6	135.9	22.6	6.8	246	16.63	1.92
7	139	22.8	7	264	16.40	1.92
8	158	24.6	7.2	276	15.57	1.70
9	183	27.01	7.6	294	14.76	1.51
10	201.6	31	7.8	330	15.38	1.39

It is a resistive circuit so no needs extra calculations. Maximum power absorbed by load circuit is 4 watt and maximum power of generator is experienced 4.1watt in idle test so that 100% of produced power will be consumed by loads, generator cannot work load less partly. The data table and it's excel graph are shown below

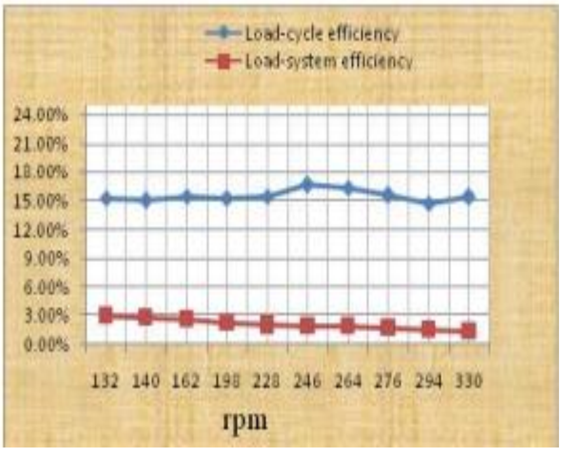

Figure 9:-Excel graph of efficiency in load test

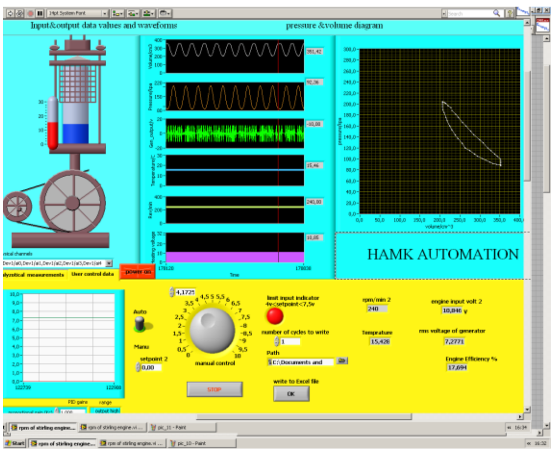

Figure 10:-User interface (front panel) Stirling engine efficiency PV diagram

CONCLUSIONS:-

Using Labview software to calculate the efficiency of a beta type of the Stirling engine was quite useful for touching again the theoretical and practical lessons of engineering physics. The obtained results met planned goals fully and supported the theoretical examinations of the Stirling cycle and its PV graph illustration. The highest efficiency was about 19%±2% with the idle and 16%±2% with the load test, the best range of rpm was 210-240 taking into consideration the efficiency and mechanical wear and tear for this type of the engine

Comparisons with different tests and data monitored the efficiency of a beta type of the Stirling engine very closely. The temperature difference (ΔT= TH-TC) between hot side and cool side has a significant effect on the output power and efficiency, in a few observations it seemed that efficiency was proportional to ΔT, the highest temperature difference ΔT causing the highest efficiency.

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