

Development of Arduino-based Data Acquisition System for Stirling Engine

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ABSTRACT

This paper describes how to develop a cost-effective data acquisition system for Stirling engine experiments based on the Arduino collaborated with a commercial computer. The implementation includes designing and fabricating a circuit board, editing computer program, and installing sensors and a trigger device. The data acquisition system can acquire a modified Gamma-type Stirling engine data which include the working fluid pressure, engine wall temperatures, rotation speed and output voltage of the DC motor (generator) driven by the engine. The system can present the acquiring data on the computer screen online and save the data afterward. The pressure and temperature sensors and data acquiring trigger are mounted on the displacer cylinder head of engine. In order to verify the implementation, some typical experiments with different operation conditions were carried out, and the temperatures, pressures, rotation speeds and power outputs were acquired, respectively. The pressure and temperature reading errors are about 0.3%. The error of rotational speed acquisition module is about 1.09%. The error for voltage detection is 1.3%. After analyzing the rationality of the aforementioned experimental data, it shows that the system has been successfully developed.

Keywords: Arduino, cost-effective, data acquisition, Stirling engine

基於 Arduino 的史特靈引擎數據擷取系統的開發

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摘 要

本文描述如何開發一套基於與電腦聯結的 Arduino 而用於史特靈引擎實驗的經濟有效數據擷取系統。開發實現內容包括設計和製造電路板，編輯計算機程序以及安裝感測器和觸發器。數據擷取系統可以獲取經修改過的伽馬式史特靈引擎數據，其中包含工作流體壓力、引擎壁溫、被引擎驅動的直流馬達（發電機）的轉速和輸出電壓。該系統可以在線上將擷取的數據顯示在電腦銀幕上，然後儲存數據。其壓力和溫度感測器以及數據擷取觸發器安裝在引擎的移氣器氣缸蓋上。為了驗證開發之實現，進行了一些不同條件下的典型實驗，而分別獲得了溫度、壓力、轉速和功率輸出。本系統的壓力和溫度讀數誤差約為 0.3%，轉速擷取模塊的誤差約為 1.09%，電壓檢測誤差為 1.3%。在分析了上述實驗數據的合理性之後，證明該系統已經成功開發。

關鍵詞：Arduino，經濟有效，數據擷取，史特靈引擎

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I. INTRODUCTION

It is known that the Stirling engine was pushed out of market when internal combustion engines and electric motors became increasingly popular at the 20th century. Nowadays, with ever-rising fuel costs and growing ecological conscience, the undemanding and quiet Stirling engine is attracting renewed interest. In Taiwan there are many scholars who have engaged in Stirling engine research for several years, such as Cheng and Yang [1], Cheng and Huang [2], Kobayashi et al. [3], Huang and Su [4], Chang and Ko [5], and Chang et al. [6]. Looking at the world, not to mention more scholars have also engaged in Stirling engine research and teaching. The previous review of the literature shows that in their experiments not only the aforementioned scholars but also the others, for example, Karabulut et al. [7], Demir and Güngör [8], Sripakagorn and Srikam [9], Liu [10], and Su [11] have not yet used the inexpensive Arduino which is used in modern times for reading inputs and presenting something online.

According to the official website of Arduino, "Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online." About the history of Arduino, "Arduino was born at the Ivrea Interaction Design Institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for IoT applications, wearable, 3D printing, and embedded environments." From the previous review of the literature, there are some scholars such as Chen et al. [12], Syed Wali and Muhammad Areeb [13], Karami et al. [14], Jumaat and Othman [15] who use Arduino for a data acquisition system. Their works in experiments with Arduino scope from environmental monitoring, power frequency measurement, power system signals, and small wind PMSG turbine systems to solar energy measurement etc. Although the aforementioned works are neither for Stirling engine experiments

nor teaching, Galindo and Fernández-Madrigal, [16] used Arduino to enhance the teaching of real-time scheduling in engineering course and aimed at grounding students' learning. The authors think that it is feasible to develop a data acquisition system by using Arduino for the Stirling engine research and experimental teaching. To assist people who want to engage in Stirling engine research and teaching, this paper attempts to describe the process of developing and verifying the Arduino-based data acquisition system briefly and completely. In the next section, the operation concept for the data acquisition system is described first, followed by the other work steps of developing.

II. OPERATIONAL CONCEPT

According to Levis and Wagenhals [17], the authors start the developing process with a clear purpose and viewpoint and an operational concept provided. Fig. 1 shows the operation concept graphic which is created by authors depending on the purpose and problem definition. The purpose is to develop an inexpensive data acquisition system which is used for Stirling engine research, and the problem definition is that the data acquisition system currently used by the Stirling engine is expensive, its software is not open, and the users are not easy or unable to modify the software. After confirming the purpose and problem definition, the operational concept narrative can be described as follows: The researcher in front of computer sends an order to the data acquisition system while the engine system is ready for experimental work. Then the data acquisition system will acquire the temperatures, pressures, rotation speeds and power outputs online respectively. The aforementioned data are presented on the computer screen simultaneously. The researcher can send an order to save the data into the computer memory.

After the operational concept narrative completed, then the developing works can be conducting based on the developing flow. In order to facilitate the reader's reading, the data acquisition system developing flowchart with text description (shown in Fig. 2.) is shown as follows.

The operational concept of Arduino based Data acquisition system for Stirling engine

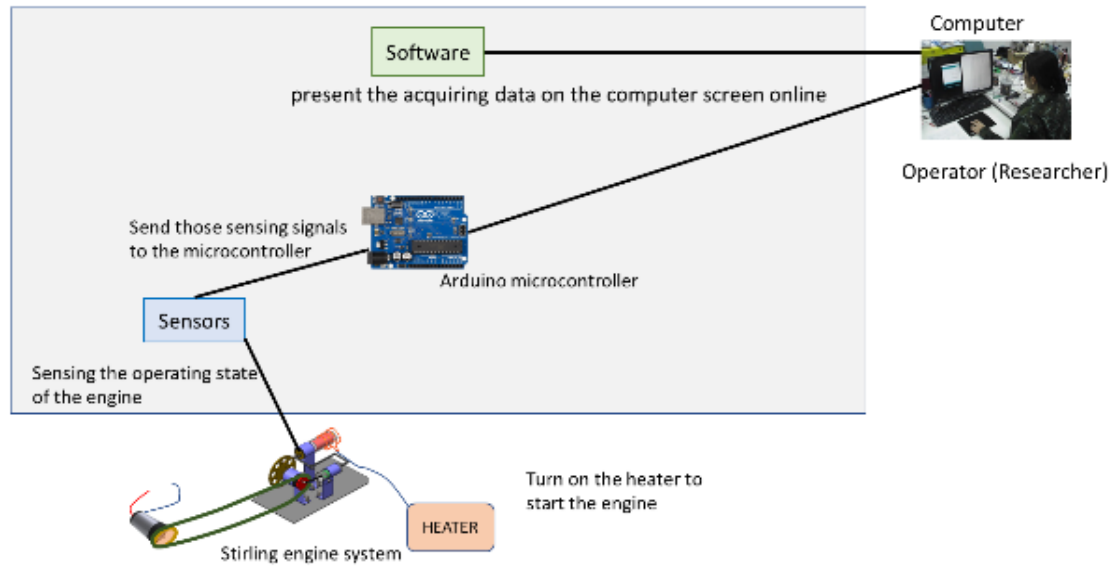


Fig. 1. The operation concept graphic for the data acquisition system

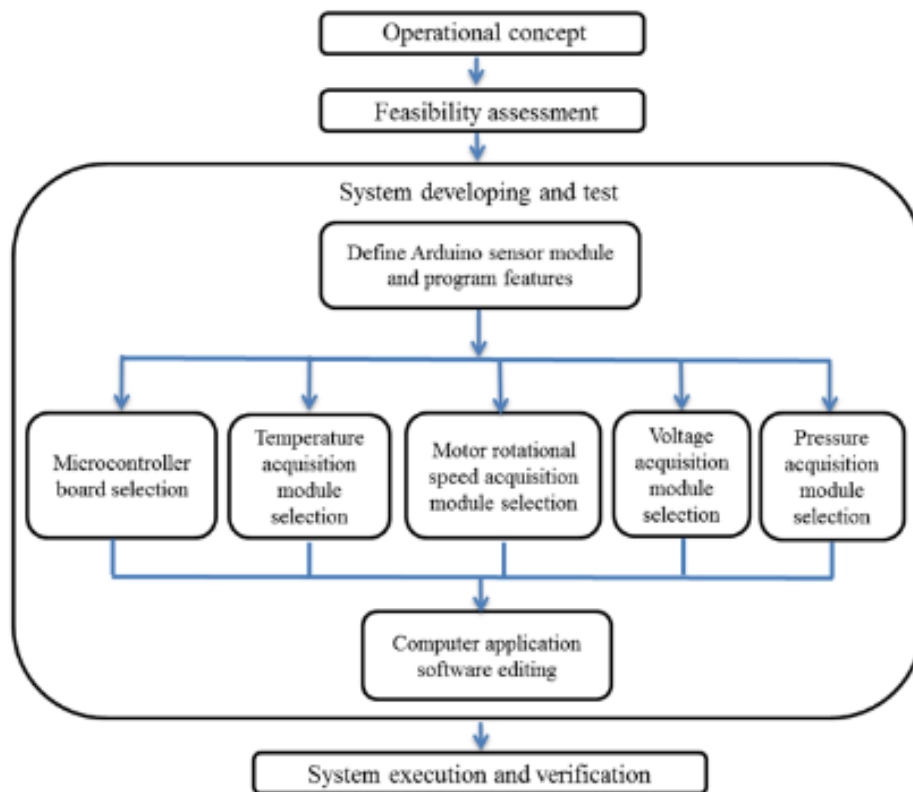


Fig.2. Data acquisition system developing process

The work steps of developing will be described sequentially in the following sections according to the flowchart.

III. FEASIBILITY ASSESSMENT

According to Lin [18], Arduino has the following characteristics. (1) It has an open source code that allows users to design their own circuits and programs through the Arduino IDE. (2) The microcontroller is inexpensive and acceptable. (3) The Arduino module can be modified or designed according to the circuit design provided on the official website. (4) It can be directly connected to various sensors or electronic components. (5) No external power supply is required while using the USB interface; or using a 9V DC power supply. (6) Support most of the interactive programs (for example, Max/MSP, Adobe Flash, Processing, C, etc.). Hung [19] used Arduino to acquire analog harmonic signals and combined with graphic control software LabVIEW to analyze and acquire the signal, after comparing the simulated harmonic signal with the frequency calculated by the program the measurement error rate is less than 0.1%. Chen [20] constructed a small temperature monitoring system by using Arduino. The system connected with external temperature sensor to measure the temperature, and also used Bluetooth to transmit the data to smart mobile handheld device. The experimental result showed that the temperature measured by the system was consistent with that measured by the mercury thermometer. Huang [21] used the Arduino-based automated photovoltaic supervision system to monitor the status of use and power generation. He collected solar photovoltaic systems via the ATmega2560 controller irradiance, battery temperature, voltage and current, and under the actual working conditions. He did the comparison of measurement, simulation and fault alarms on the same software platform at the same time, the results confirmed that it has accurate information and credibility. Through the above literature review shows that Arduino can substitute traditional signal acquisition instruments and reduce the cost. Therefore the authors expect that using Arduino to acquire engine's temperature and power data will have a high probability of success.

IV. SYSTEM DEVELOPING AND TEST

The third work step of developing is categorized into 3 items and will be described sequentially as follows:

4.1 Select the Arduino sensor module and program features

This sub-step is to define the Arduino sensor module and program functions. At first, based on the operational concept the module and its corresponding program are defined as that it can separately measures the working fluid pressure, engine wall temperatures, the rotational speed and output voltage of the DC motor (i.e. generator) driven by the Stirling engine; the system can also present the acquiring data on the monitor (i.e. computer screen) online and save the data afterward. The function and editing of the program for presenting and storing data online will be described later. Next, the overall operation of the Arduino system will be defined by the sequence diagram. The three sequences of the operation process are showing in the sequence diagram of Fig. 3. The diagram also shows three corresponding terminators, engine, sensor, and Arduino. Under the engine terminator shown in the left hand side of figure, there are five sub-terminators, working fluid pressure, hot side engine wall temperatures, cold side engine wall temperatures, generator output voltage and rotational speed, whose data should be acquired by corresponding modules shown in the middle of figure. Additionally, the corresponding program-driven microcontroller and sensors are used to retrieve data. Finally, the data is processed by the control panel and connected to the USB port, and the data is immediately displayed through the monitoring window of the Arduino IDE to complete the operation of the Arduino system shown in the right hand side of figure.

The circuit design concept can be illustrated by the circuit diagram of the Arduino overall system shown in Fig. 4. From the above-mentioned overall system operational sequence, the required data is obtained through the microcontroller and the corresponding sensor module. After the motor speed acquisition module (no.3 in Fig. 4) and the voltage acquisition module (no.4 in Fig. 4) directly

acquire analog signals, they are sent to the microcontroller and converted into digital signals.

The temperature acquisition module (no.1, 2 in Fig. 4) and pressure acquisition module (no.8, 9 in Fig. 4) acquire analog signals, convert them into digital signals through the MAX6675 and HX711 chips, and finally send them to the control board. After the aforementioned sensor pins are connected to the control panel jacks, the Arduino overall system circuit connection is completed.

4.1.1 Microcontroller board selection

The number of sensors required must be considered first. The system requires four temperature sensors to acquire the internal and external temperatures of the hot and cold side of engine wall, respectively; therefore the system requires twelve digits. The system requires one voltage sensor to acquire the motor output voltage; therefore the system requires two more digits. The system requires a magnetic Hall sensor collaborated with magnets when measuring the motor speed; therefore the system requires one more digit. A pressure sensor collaborated with a magnetic Hall sensor is used to measure the working fluid pressure; therefore the system requires three more digits. Add the above digit numbers, eighteen digits are required. According to the Arduino official website, the size of Arduino Pro Mini system board is small, which configures an Atmega328P processor with twenty digits. The working voltage of Arduino Pro Mini system board is 5V through USB port from PC and it can support most of the sensors. In addition, user can design the expansion board, thus reducing the total quantity of DuPont line being used. Therefore, it can effectively reduce the length of signal line and increase the accuracy of data acquisition. Thence, the Arduino Pro Mini control board is selected.

4.1.2 Temperature acquisition module selection

The MAX6675 chip collaborated with K-type thermocouple is selected as the temperature acquisition module, and the measurement range of this module is from 0°C to 600°C. The working principle is that the K-type thermocouple generates a thermal electromotive force (EMF) ($\Delta 1^\circ\text{C}$ correspond to $\sim 10\mu\text{V}$), when its junctions

are at temperatures T_1 and T_2 . The EMF voltage signal is amplified by the MAX6675 chip (with 12-bit resolution), it takes about 0.22 seconds from the start of temperature measurement to the completion of wafer processing. The temperature measurement range of this module meets the requirement of Chang [22] who developed a diagnosable Stirling engine operating with temperature range of $25^\circ\text{C}\sim 400^\circ\text{C}$. The measurement of the module is tested by using the boiling point method, after test, the thermocouple error is about 0.3%; for details, see Chang [22] and Wang [23].

4.1.3 Motor rotational speed acquisition module selection

The Hall sensor collaborated with magnets is selected as the rotational speed acquisition module. The working principle is that Hall sensor generates a 0 voltage digital signal, when the magnetic field is induced, otherwise a 1voltage digital signal. It takes only about 4μ second for signal output, so it is good enough ($\ll 1/10\text{second}$) for the application of rotational speed measurement (hundreds RPM range). By attaching twelve magnets evenly distributed along a fixed radius circular ring on the side face of pulley, results in the elapse of time for triggering the electric potential change being $1/12$ per round, and the resolution being 5 rpm. Since the magnetic Hall sensor of this module is mounted on the DC motor, and the corresponding magnet is fixed to the pulley; the engine rotational speed can be obtained by calculation of that the rotational speed of the DC motor times the pulley radius ratio. The measurement of the module is tested as follows. When the engine is running, a digital tachometer (Line Seiki TM-2011) is used to read out the DC motor rotational speed, and the module's acquired data is compared. The error of rotational speed acquisition module is about 1.09%; for details, see Chang [22], Wang [23] and Chang et al. [24].

4.1.4 Voltage acquisition module selection

The T22 voltage-current synchronous detection module is selected as the voltage acquisition module. The working principle is that it can directly acquire the voltage from the DC

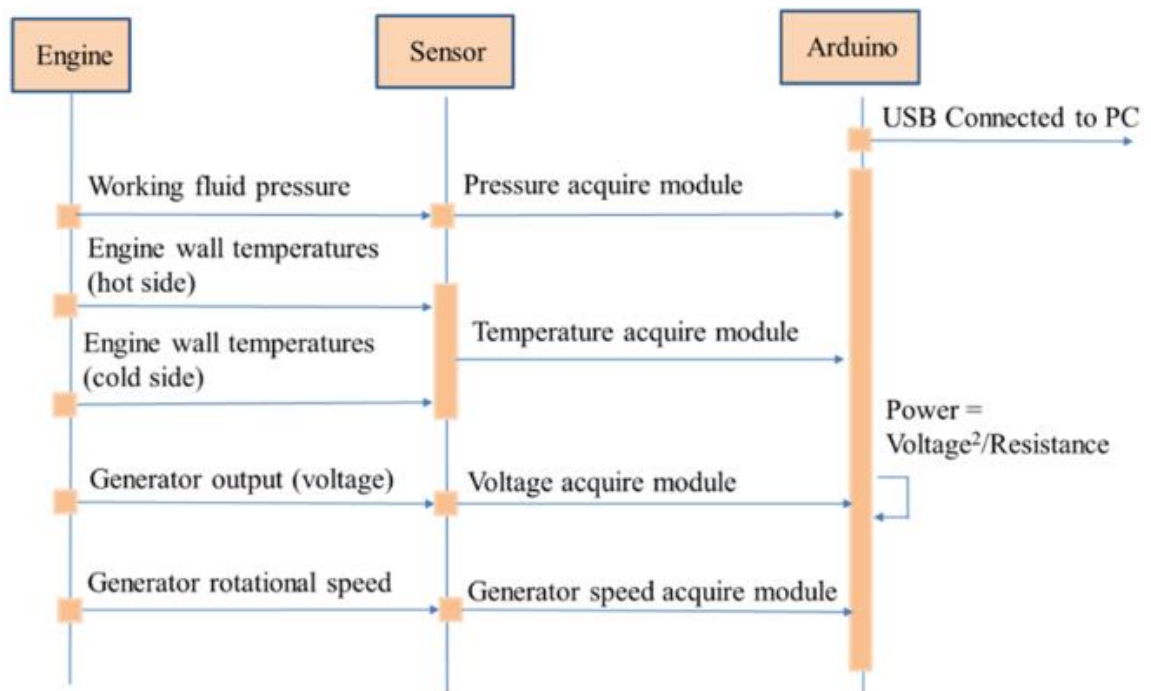


Fig.3. Sequence diagram of overall system operation

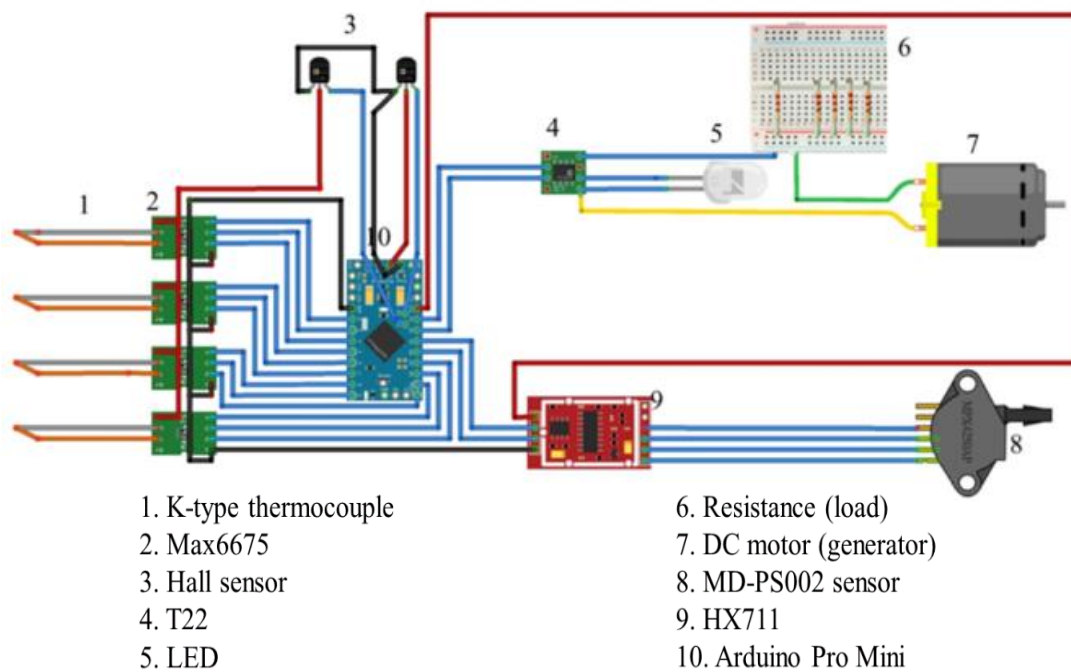


Fig.4. Schematic diagram of the system circuit

motor output, and the DC motor output voltage can supply the module electric power instead of Arduino Pro Mini system board, as mentioned before, which can support most of the sensors in the whole system. The elapse of time from acquiring the voltage to send out a signal is about 19μ second and it is also good enough ($\ll 1/10$ second) for the application of voltage measurement (hundreds RPM range). Since the Arduino uses an AVR chip of 10 bits and the analog resolution of this module is 4.8mV, the reference voltage is set on 1V to promote the resolution up to 0.9mV, resulting in the measurement range of this module being from 0.9mV to 5V; for details, see Chang [22], Wang [23] and Chang et al. [24].

The measurement of the voltage detection module is tested as follows.

By using IET LABS's VI-700 to generate 0.5V output, and using the HILA DM-825 digital Volt-Ohm-Milliammeter to measure its output, the reading value is 0.499V. Then connecting the positive output of VI-700 to the VIN pin of T22 module, the negative pole is connected to GND pin, the reading value of T22 is 0.4921V. Therefore the error of module is 1.3%, so the voltage detection module can be used.

4.1.5 Pressure acquisition module selection

The HX711 chip (with 24-bit A/D conversion) collaborated with MD-PS002 pressure sensor is selected as the pressure acquisition module, and the measurement range of this module is from -100kPa to 700kPa. The HX711 chip has two analog channel inputs built by 128 time's gain, which can be used to compile the amplifier. The elapsed time from acquiring the pressure to send out a signal is about 50μ second and it is also good enough ($\ll 1/10$ second) for the application of pressure measurement (hundreds RPM range).

The measurement of the module is tested as follows. By using a compressed air sprayer (attached a 2 bar pressure relief valve) connected with a pressure gage showing a value of 2.2kg/cm^2 (equal to 215.7kPa), then connecting the pressure acquisition module to the compressed air sprayer, the pressure value is 216.2kPa, and the error is 0.3%. Therefore, the acquisition module can be used.

4.2 Computer application software editing

The Microsoft Visual Studio C# 2015 window programming is used as computer-side processing information environment, and applied to develop the computer application software. The design concept flow chart is shown in Fig. 5. After program start, selects the link serial port which is connected to the computer side (for example, COM1 or 2 or 3...), and then tests whether linked or not. The window will show "error" if the connection is failed. If the link is correct, the text of serial port such as "COM1" should be displayed in the computer window; and then the data received by Arduino will be read and displays in the computer text window. Users can use the program's storage function to store the data in a .txt file by pressing the save button and for subsequent data processing. The program will stop when use presses the stop button otherwise will keep going through the loop.

V. SYSTEM EXECUTION AND VERIFICATION

5.1 System program execution

The system execution procedure is described as follows. First of all, the USB of data acquisition system is connected to the computer, followed by software burning. Since the Arduino Pro Mini control board can be used for software programming without a programmer, while the draft code is compiled, the user should press the reset button on the system board until the "upload" is displayed on the windows, and immediately release the button. Finally, user can start execution of the software as follow; (1) open the Sephdaq_Beta_Ver.0.1 software interface, (2) select the COM Port of the system board, (3) click the "Start" button, so the data will be displayed on the computer line (Fig. 6). The "Stop" button can be clicked to stop the data display in the window, but the system board itself continues to acquire data. When the "Data Save" button be clicked, the data displayed on the window (i.e. relevant data from the engine) can be saved as a .txt text file. The data can be imported into Excel for data analysis afterwards.

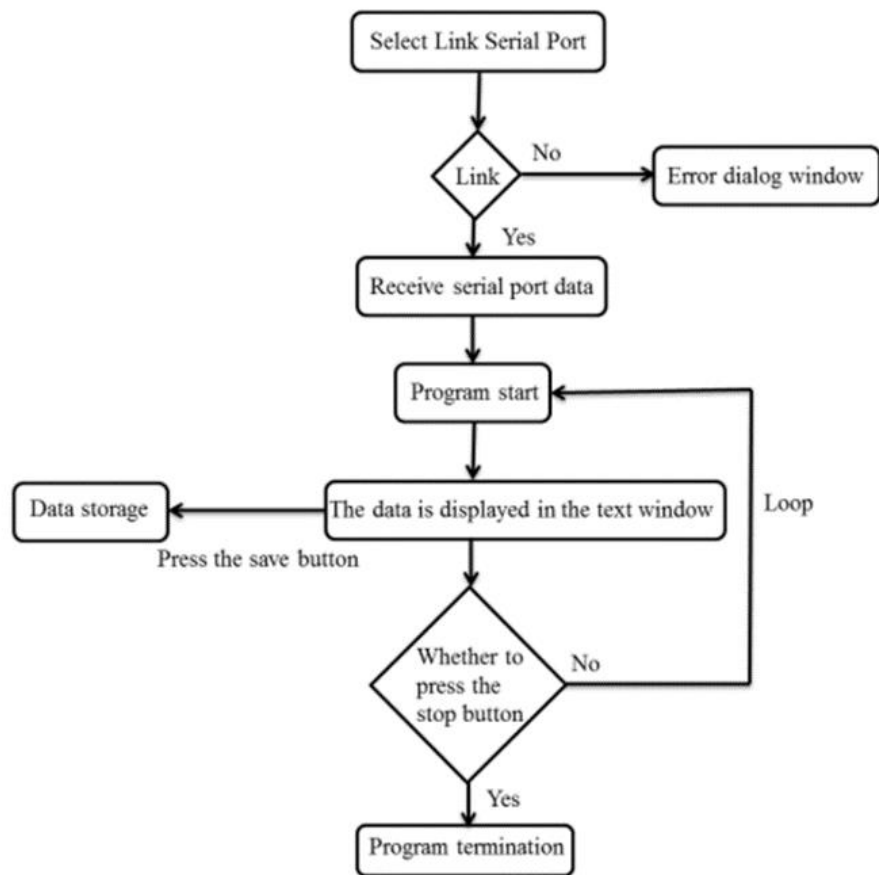


Fig.5. Design concept flow chart

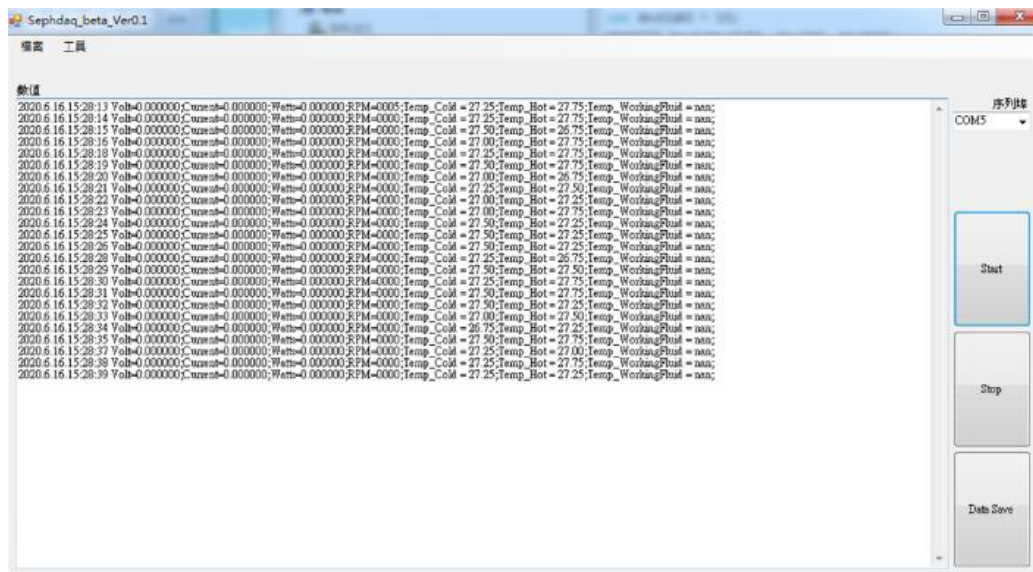


Fig.6. Data displayed on the window of computer screen

5.2 Pressure acquire module verification

The pressure acquire module is verified as follows. At first, the data acquisition system is connected to the Stirling engine with a belt (no.6 in Fig. 7), and then the data acquisition system is executed. The researcher manually rotates the DC motor pulley (no.5 in Fig. 7), keeps the engine rotation speed being about 12 rpm. On the same time the researcher looks at the computer screen (Fig. 6) to confirm whether the data is normal, then saves and sends the data to the Excel, finally lays out the graph of data (Fig. 8). The result shows that the pressure of the working fluid in the engine varies with time, and clearly appears peaks and troughs, which is consistent with the variation trend of the engine working fluid pressure under compression (corresponding to the peak period) or expansion (corresponding to the trough period). It should be mentioned that the position of the working piston is manually put on the intermediate point of the engine stroke at the beginning of the verification, and the programming software is set as the starting point, and the value of working fluid pressure (equal to the atmospheric pressure) is set to zero. The oscillating curve in Figure 8 shows that the amplitude of first peak is much less than those of subsequent peaks, which indicates that the first compression period in the manual rotation cycle is insufficient. Moreover, it seems that the engine rotation speed by manually rotating the pulley is not stable, results in not very periodic on the curve pattern.

To further analysis the working fluid pressure corresponding to time (Figure 8), with the working fluid having a maximum volume of 90441.4mm^3 corresponding to the working piston at the top dead center; the working fluid having a minimum volume of 89763.2mm^3 corresponding to the working piston at the bottom dead center (i.e. engine with 1.008 compression ratio); the working fluid having a volume of 90102.3mm^3 corresponding to the working piston at intermediate point of the engine stroke with the pressure being about 101.325kPa (i.e. 1atm), the ideal gas equation can be applied as follows.

$$PV = nRT \quad (1)$$

In equation (1), P is the working fluid pressure; V is the working fluid volume; n is the mole number of working fluid; R is the ideal gas

constant; T is the temperature. Based on equation (1), the volume of the gas is inversely proportional to the pressure with constant room temperature. Therefore, the ideal value of peak pressure should be 101.707kPa, the ideal value of trough pressure should be 100.945kPa, and the ideal pressure difference is 0.762kPa, which is small than the experiment data about 0.89kPa (about equal to 0.50kPa minus (- 0.39kPa)). Though the deviation from ideal case is about 17%, it can be reduced by considering the effects of compression work into the working fluid and expanding work into environment and not assuming constant temperature during the cycle. The authors think that the data acquisition system is reliable.

As described above, the system has successfully completed the system program execution and test, however, only the measurement of the working fluid pressure data is acquired. The next section will test whether the system can successfully achieve engine thermal and power data acquisition.

5.3 Temperature, voltage, and generator rotation speed acquire module verification

In order to check whether the experimental system is successfully implemented or not, the engine is operated under two different conditions (with fixed loading 115Ω), a shield installed on the heating end of the engine, or without a shield. As described in the 5.2 section, the data acquisition system will acquire the working fluid pressure. The engine wall temperatures, the rotational speed and output voltage of the DC motor are listed in Table 1. The engine wall temperatures are categorized by hot end outer, inner and cold end outer, inner. The temperature differences for both ends are also listed. The timing of acquiring the pressure in Table 1 is set when the working piston is at the bottom dead center (the working fluid has a minimum volume). The specific requirement for acquiring the pressure at selected timing is achieved by using another Hall sensor collaborated with a magnet, which can be set on the selected position. The following discussions are based on whether there is a thermal insulation shield installed on the heating end of the engine.

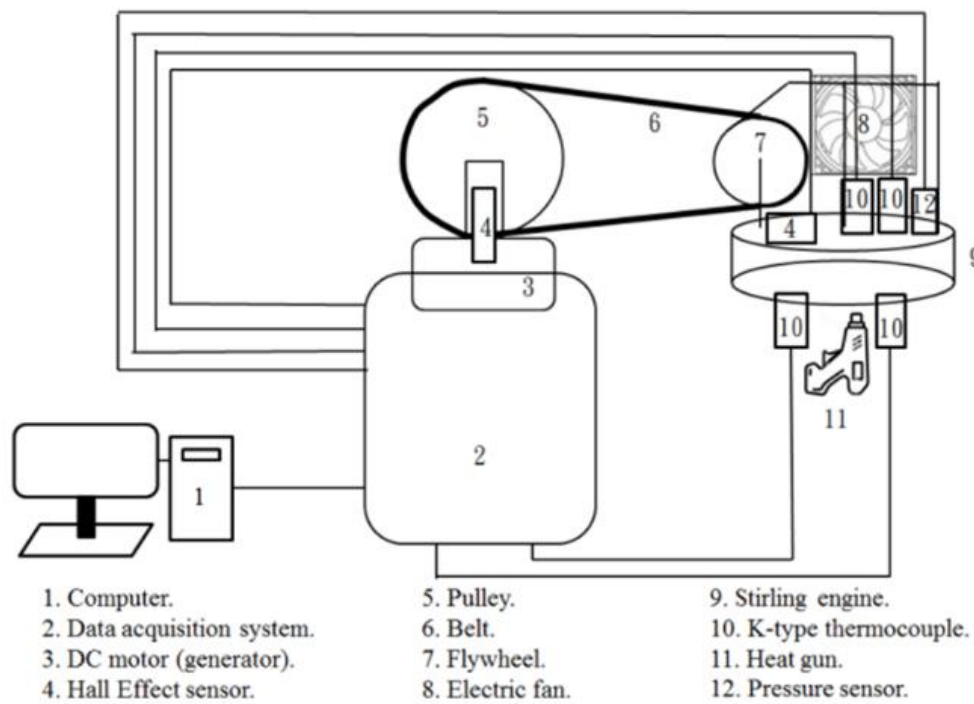


Fig.7. Schematic diagram of the experimental system [23]

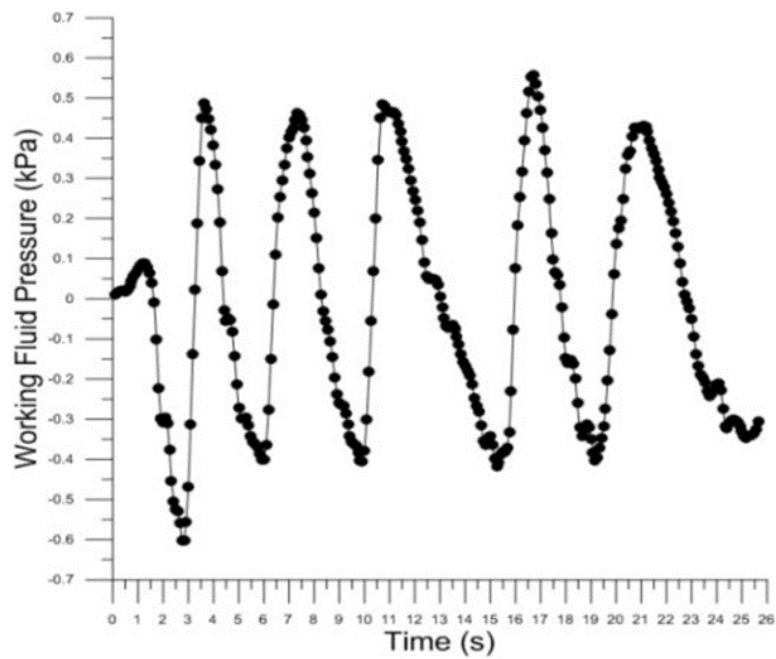


Fig.8. Working fluid pressure corresponding to time [25]

The data in Table 1 will be inspected and evaluated as follows.

(a) Engine without heat insulation shield

As shown in Table 1, under the experimental conditions without the heat insulation shield, the outer temperature of the hot end of the engine is 532.4K, the inner temperature is 498.3K, the temperature difference is 34.1K ($532.4 - 498.3$); the outer temperature of the cold end is 312.5K, and the inner temperature of the cold end is 323.6K, the temperature difference is 11.1K ($323.6 - 312.5$), the inner temperature difference between the hot and cold end is 174.7K ($498.3 - 323.6$); the motor rotational speed is 35.7rpm; the working fluid pressure is 8.97kPa (relative to atmospheric pressure); the output power is 0.1mW.

(b) Engine with heat insulation shield

The aluminum foil as shield is used to keep the heat generated by the heat gun at the hot end of the engine. The outer temperature of the hot end of the engine is 553.4K, the inner temperature is 528.1K, the temperature difference is 25.3K ($553.4 - 528.1$), and the outer temperature of the cold end is 316.1K, the inner temperature of the cold end temperature is 326.3K, the temperature difference is 10.2K ($326.3 - 316.1$), the inner temperature difference between the hot and cold end is 201.8K ($528.1 - 326.3$); the motor speed is 37.2rpm; the working fluid pressure is 10.8kPa (relative to atmospheric pressure); the output power is 0.12mW.

5.4 Data evaluation

In order to analyze the rationality of the acquired data, working fluid pressure in Table1 is examined first. The result shows that the pressure is increased from 8.97kPa to 10.8kPa which means increasing by 1.2 times when the engine is installed the heat insulation shield. Then the engine output power is compared, and the result shows that the engine output power is increased from 0.1 to 0.12mW, which means also increasing by 1.2 times. Moreover, the inner temperature difference between the engine's hot and cold end is increased by 1.16 times from 174.7K to 201.8K. In short, the experiment data seem reasonable. For detail evaluation, see Chang et al. [24-25].

VI. PURPOSE BUILT DEVICE FOR NEED

It is known that the PV diagram is significant for engine researches, In order to generate a trigger for acquiring pressure corresponding to the selected timing (selected working fluid volume), a specific device is designed and built and collaborated with another Gamma-type Stirling engine model M14-03-S. The mentioned Gamma-type Stirling engine model M14-03-S is made by CCID Consulting Company Limited. The M14-03-S Stirling engine is a purpose-built engine to drive a generator and to light up an LED (light-emitting diode) whose rated power is about 0.06 watts. By attaching extra eight magnets through a rotatable wheel which is coaxial with the pulley of the engine (no. 7 in Fig. 9), and another Hall sensor is used to generate a trigger, for detail see Chen [26]. At first, the user divides the engine crank angle 360 degrees into 8 partitions on average, corresponding to the cylinder volume as follow:

(1) The first triggering point: the working piston is located at the top dead center (the largest volume of working fluid), and the displacer is located in the middle of the cylinder (the working fluid is heated on the hot end and cooled on the cold end at the same time).

(2) The second point: the working piston moves slightly from the top dead center to the bottom dead center (the volume of working fluid is reducing), and the displacer moves to the hot end (the working fluid is cooling).

(3) The third point: the working piston is located between the top dead center and the bottom dead center (the volume of working fluid is reducing), and the displacer is located at the hot end (the working fluid is cooling).

(4) The fourth: the working piston moves down to the dead center (the volume of working fluid is reducing), and the displacer moves slightly from the hot end to the cold end (the working fluid is cooling).

(5) The fifth point: the working piston is located at the bottom dead center (the working fluid volume is the smallest), and the displacer is located in the middle of the cylinder (the working fluid is heated on the hot end and cooled on the cold end at the same time).

(6) The sixth point: the working piston moves slightly from the top dead center to the top dead center (the volume of working fluid is increasing), and the displacer moves to the cold end (the working fluid is heating).

(7) The seventh point: the working piston is located between the top dead center and the bottom dead center (the volume of working fluid is increasing), and the displacer is located at the cold end (the working fluid is heating).

(8) The eighth point: the working piston moves to the top dead center (the volume of working fluid is increasing), and the displacer moves slightly from the cold end to the hot end (the working fluid is heating).

Similar with the previous work [23], the data acquisition system (no.4 in Fig. 9) is connected to M14-03-S Gamma-type Stirling engine (no.3 in Fig. 9) with a belt, and then the data acquisition system is executed. Two K-type thermocouples (no. 8 in Fig. 9) are installed at hot and cold sides, respectively. A pressure sensor (no. 9 in Fig. 9) is installed at the working piston cylinder wall. The user manually rotate the flywheel of the engine when the engine is at the condition without heating, and the data acquisition system gets the working fluid pressure which corresponds to each own working fluid volume. The result is shown in Fig. 10(a).

Similar with the previous analysis where the engine compression ratio is 1.008, now the ratio is 1.28. The result shows that the ideal pressure maximum difference is about 30kPa, and the measured pressure difference is about 40kPa (the pressure corresponds to the smallest working fluid volume 18.6kPa minus the pressure corresponds to the largest working fluid volume - 23.4kPa). The deviation is 33% according to the ideal gas equation, and takes temperature effect into consideration, during the compression process some works can put into the working fluid. Then the temperature of the fluid must rise slightly. With the same theory, the system does work out during the expansion process, and the temperature will drop slightly. The ideal pressure difference will be greater than 30kPa, so the experimental deviation will be less than 33%. After the above evaluation, the authors think that the triggering device is reliable and can be used for further Stirling engine research.

Now moves to the other experiments while

the engine is at the condition with heating, and the data acquisition system gets the working fluid pressure which corresponds to each own working fluid volume. The results are shown in Fig. 10(b), (c), (d). The hot side temperature of engine is set at 200°C, 320°C and 400°C, respectively, during the experiment. The results of Fig. 10 show that the P-V cycle envelope area is larger the setting temperature of the heating is higher, which is consistent with the author's expect. Summarize the above evaluation, the authors think that the triggering device is reliable and can be used for further Stirling engine study and research.

VII. CONCLUSION

This paper demonstrates that how a data acquisition system for the Stirling engine research based on the Arduino collaborated with a commercial computer is developed. The data acquisition system is designed, fabricated and tested with some operating conditions. K-type thermocouples and Max6675 chip are assembled and used to acquire engine temperatures, Hall sensor and magnets are used to acquire DC motor rotational speed, T22 chip are used to acquire the DC motor output voltage, MD-PS002 and HX711 are used to acquire the working fluid pressure, and a specific device with another Hall sensor and a magnet are used to generate a trigger for acquiring pressure corresponding to the selected timing. The pressure and temperature reading errors are about 0.3%. The error of rotational speed acquisition module is about 1.09%. The error for voltage detection is 1.3%. After tests and verifications, the results show that the system can successfully acquire high-value experimental data with a low-cost purpose built system and the authors expect that under good use, it can enhance the Stirling engine teaching & learning effectiveness.

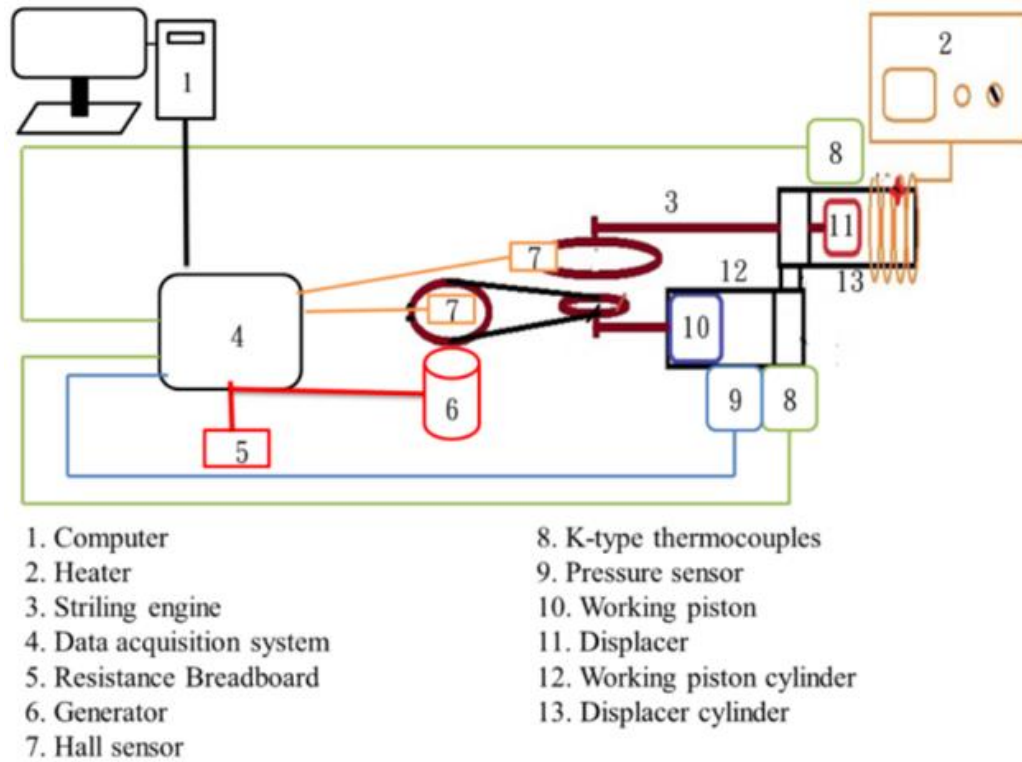
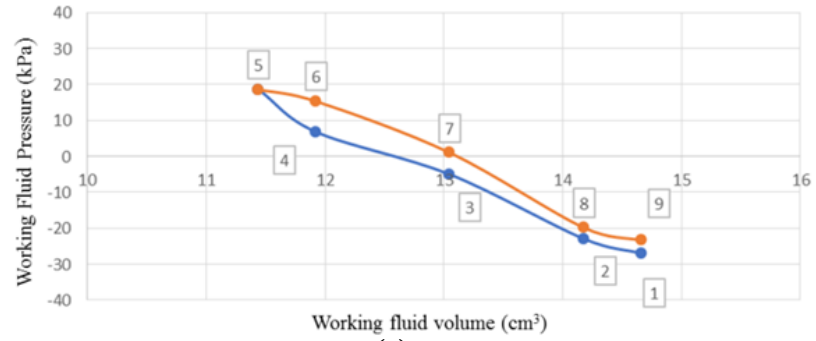


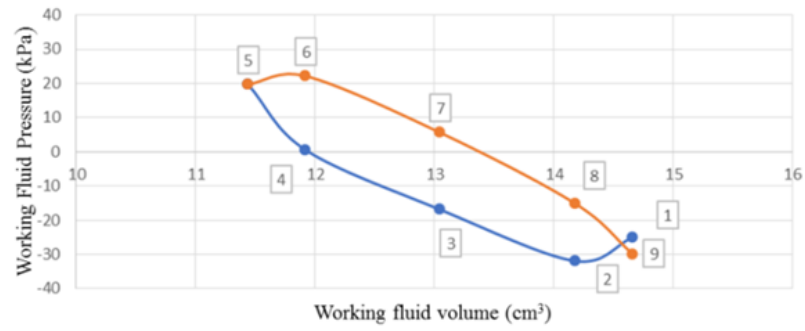
Fig.9. Schematic diagram of the experimental system for generating P-V diagrams

Table 1. Experimental data [24, 25]

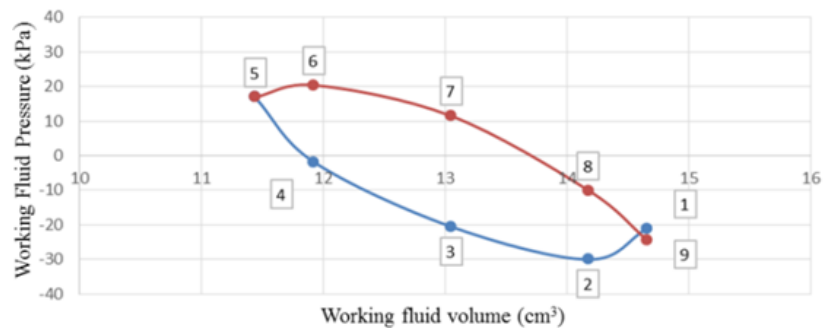
Operating condition Measurement data	Without shield	With shield
Hot end outer temperature (K)	532.4	553.4
Hot end inner temperature (K)	498.3	528.1
Hot end inner and outer wall temperature difference (K)	34.1	25.3
Cold end outer temperature (K)	312.5	316.1
Cold end inner temperature (K)	323.6	326.3
Cold end inner and outer wall temperature difference (K)	11.1	10.2
Hot and Cold end inner Temperature difference (K)	174.7	201.8
DC motor rotational speed (rpm)	35.7	37.2
Pressure (kPa)	8.97	10.8
Power (mW)	0.1	0.12



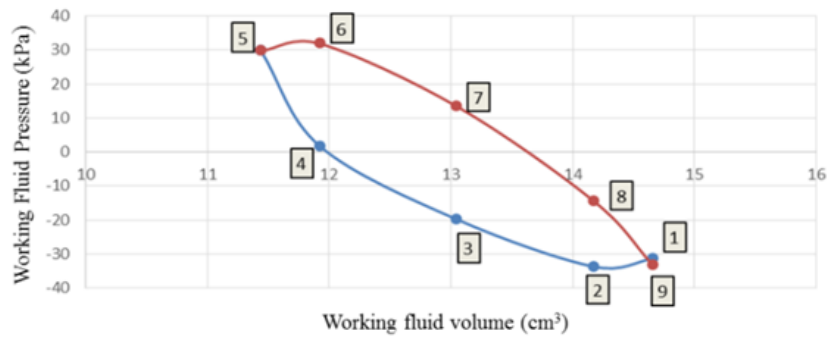
(a)



(b)



(c)



(d)

Fig. 10. Working fluid pressure corresponds to volume: (a) without heating, (b) 200°C hot side temperature, (c) 320°C hot side temperature, (d) 400°C hot side temperature

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