Design of Automation Control Condensing Unit to Improve Ice Cube Products Using Microcontroller

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***Abstract*—The production process of ice cube is highly determined by performance of the condensing unit. The condensing unit acts as temperature regulator of the brine according to the specified temperature range. The problems are how to stabilize the brine temperature, and how to reduce the refrigerant pressure at the outlet in order to avoid failure due to high starting current when the compressor motor start up. During the ice producing process starting current can drain a lot of electrical energy, because the compressors having on-off several times. This paper presents the design of an automation control for the condensing unit at an ice factory based microcontroller applications. The control unit regulates the working cooling water pump, condenser fan motor, unscrew the valve of the refrigerant pressure and the running of compressor motor in the sequence to maintain the brine temperature in range -6 °C to -15 °C. Input readings based on brine temperature and refrigerant pressure, and the main component of the controller is programmed Arduino Servarino board using C-programming language. The results of testing the control systems shows that temperature control of the brine can be setting the range of -6 °C and -15 °C with error rate of 2.41% to 4,74%. Refrigerant pressure at the start of the operation can be reduced automatically to 120 psi to start the compressor with lower starting current. The time duration of the decrease in pressure of 200 psi to 120 psi is approximately 67 seconds. By applying this system, the saving energy during starting is about 78.72 %.**

***Index Terms*—condensing unit, brine temperature, refrigerant pressure, automation, arduino servarino.**

I. INTRODUCTION

THE production process of ice cubes, in application of refrigeration techniques have been widely applied at the industrial production of ice cubes from small to large scale. Refrigeration and process cooling account for 27% of the electricity use in the food processing sector [1]. Energy for refrigeration system is highly dependent upon condensing pressure, which in turn is a function of condenser capacity and control. Refrigeration in a cooling unit is vapor-compression engines that draw heat from the brine so that the temperature of the brine will be low. The lower the temperature of the brine, the ice freezing process will be faster. Evaporator temperature on the process of making ice cubes are usually determined between -6 °C to -15 °C. If temperatures higher than -6 °C, then the ice will be difficult to freeze. This occur due to less refrigerant flowing. Whereas, if the brine temperature below -15 °C, then the ice cubes will easily crack when removing it from the ice cans in the air [2]. The process of making ice cube can be seen in the following Figure 1 below :

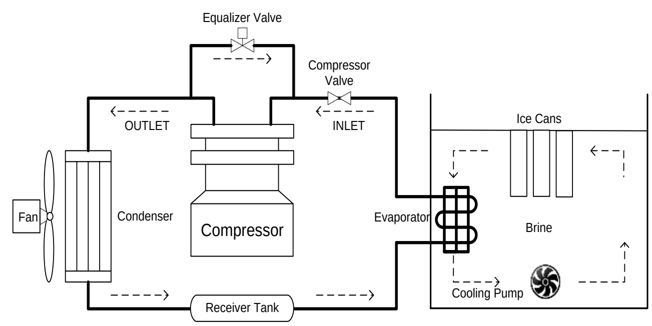

Fig. 1. Process of cooling system in the manufacture of ice cubes.

The function of each component at Figure 1 can be described as follows:

- Cooling water pump works to circulate cooling water around the system. This pump also work as cooler at compressor.
- Condenser pump/fan to assist in cooling the hot compressed refrigerant vapour supplied by the compressor as they pass through the condenser. The condenser is being cooled by natural air. The natural convection is not sufficient to attain the heat transfer rate required on their-side of the condenser used in vapour compression systems.
- Compressor drives a stream of refrigerant fluid in a continuous cycle of condensation and expansion. Basically, the compressor forces refrigerant through a narrow tube (**condenser**) to condense it, and then releases it into a wider tube (**evaporator**), where it can expand.
- Equalizer valve of refrigerant, open to reducing the refrigerant pressure to the predetermined value which will reduce compressor energy use. This setting is one of the important part in the design of control systems.
- Inlet valve avoid refrigerant reverse flow to evaporator when compressor off. Inlet valve should close (off) when compressor turns on inlet valve should open (on).

In order for the process of making ice cube running optimally with using electrical energy efficiently, it is necessary to control the brine temperature and refrigerant pressure on the condensing unit [3]. Most refrigerating plants are automatically operated to some extent, as manual control of the various refrigerating functions is difficult and not very accurate. More over very skilled operators or technicians must be employed for such tasks. With the rapid advancement of microcontroller technology, system of control can be done using electronic devices as a substitute for manual control systems. One of the latest microcontroller is an Arduino Servarino which can be used for temperature regulation in the process of making ice cubes. Arduino has advantages:

- Boot loader handle the upload program from computer so that no need of any chip programmer,
- Arduino using USB communication, so users can use pc/laptop who do not have a serial port/RS323.
- The programming language used is user friendly because the Arduino software comes with a fairly complete set of libraries, and the Arduino has a ready-made module (shield) which can be plugged on the board [4].

This paper presents the use of the Arduino board in temperature control of brine in the condensing unit. The Arduino board can integrate with environment by receiving signals inputs from several types of sensors such as temperature sensor and pressure sensor and respond by controlling water cooling pump, condenser fan, unscrew the valve on-off the refrigerant and the compressor motor sequentially.

II. METODHOLOGY

The requirement system of control unit is the system who able to responsible for managing:

- Make sure that starting cooling pump and condenser pump not in the same time
- Operation condenser pump/fan and compressor motor only when temp above -6 °C but the pressure not more than 120 psi.
- Make sure that condenser pump/fan is already running when compressor turn on.
- Equalizer valve of refrigerant pressure in sequence to avoid inrush current.
- Determine time and duration open and close for Equalizer valve and inlet valve.

Then, to produce a good quality of ice cube, the main system of automation control temperature has designed as shown in Figure 2 below:

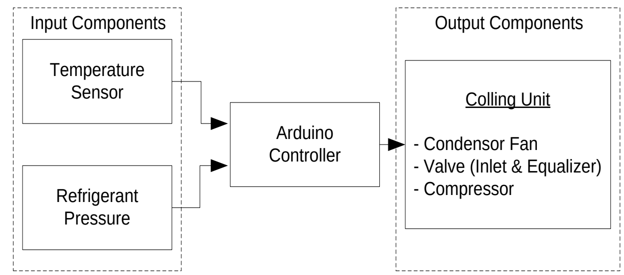

Fig. 2. Control design of condensing unit

Based on the block diagram in figure 2, the designed control system consists of several components:

A. *Input Components*

A.1. Temperature Sensor

Setting (on/off) condenser fan/pump and refrigerant fan based on the brine temperature. In this paper the temperature sensor used is LM35. This sensor is used to convert the temperature scale to the amount of voltage that has a coefficient 10mV/^{0}C. This means when temperature increasing 1 ^{0}C will increase the voltage of 10mV. LM35 already has a massive output in Celsius and has a range of temperature sensing capability of -55 °C to 150 °C [5]. The shape and configuration of the LM35 is shown in Figure 3 below:

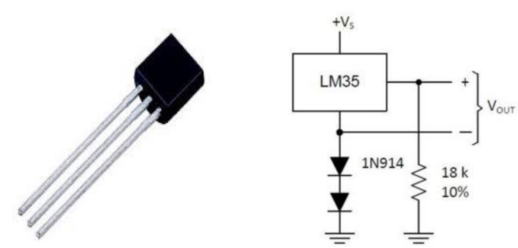

Fig. 3. Physical and the circuit configuration of LM35

LM35 is the Integrated Circuit (IC) packed temperature sensor, where it has linear output voltage corresponding to the temperature change [6]. ADC input of the LM35 will generate a digital value by two conditions: high (+5 V) and low (0 V). In this design, it is set when the brine temperature above -6 °C then the circuit will provide a high input to the controller until the temperature reaches-15 °C and changed it to low when the temperature below -15 °C.

A.2. Pressure Sensor

Settings (on/off) of the compressor motor is determined by the pressure of refrigerant in the outlet. The pressure sensor used is H/L pressure switch. The mechanism of the pressure sensor can be seen in the Figure 4 below:

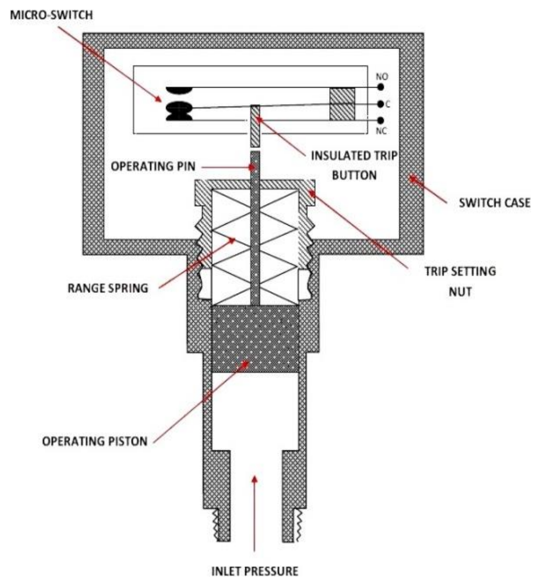

Fig. 4. The mechanism of the pressure sensor

This sensor is made up of two contacts: NO (*Normally Open*) and NC (*Normally Closed*). When the sensor detects the pressure at the input, then contacts will active. This means that NO become closed (connected) and NC become opened. On the inside, there is a nut to adjust the set point of pressure. If the refrigerant pressure has reached a predetermined set point, then the NO contact of the sensor will be connected to give input signal (5 Vdc) to the microcontroller.

B. Output Components

Output components are power electric equipments supplied by the ac voltage source. The output components of condensing unit are to drive cooling water pump, condenser fan, compressor, and equalizer valve. All components are controlled by microcontroller. To drive all components, the microcontroller requires a transistor to drain a dc voltage input signal to a power relay.

C. Controller Components

The Arduino Servarino is a microcontroller board depending on the ATmega 328. It includes 14 digital input/output pins (out of which 6 can be exploited as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header and the last one is a reset button. It includes the most necessary things which are essential to support the microcontroller; basically attach it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started [7].

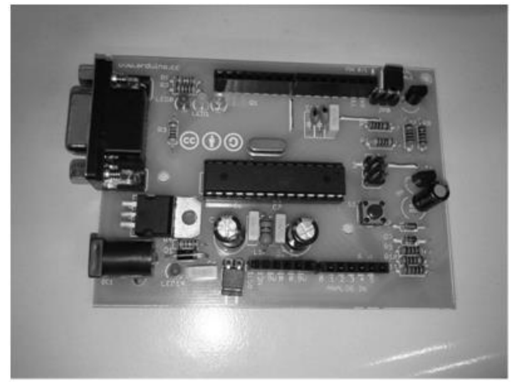

Fig. 5. Arduino Servarino Hardware

This microcontroller serves as a data processing center or can be said as the CPU (Central processing Unit). It was programmed to process all the data input and data output. In this design, the condensing unit settings with the Arduino microcontroller is done by C programming language.

III. Result and Discussion

A. System Design

System starts with initializing procedure, then reading brine temperature to determine go to routine or finish the sequence without any action (turning on any component). If the brine temperature above -6 °C then system will turn the cooling pump and condenser fan/pump on but not in the same time (condenser pump on after cooling pump run 5 seconds), and then read the pressure outlet. If the pressure outlet above 120 psi then system will turn valve equalizer on but if the pressure outlet below 120 psi then valve equalizer will turn off and inlet compressor valve will open. The system will re-read the temperature, if temperature below -15 °C condenser fan and compressor pump turn off, but if temperature above -15 °C system will looping to re-read until temperature falls to below -15 °C. The flow chart of the system designed can be seen in the Figure 6 below :

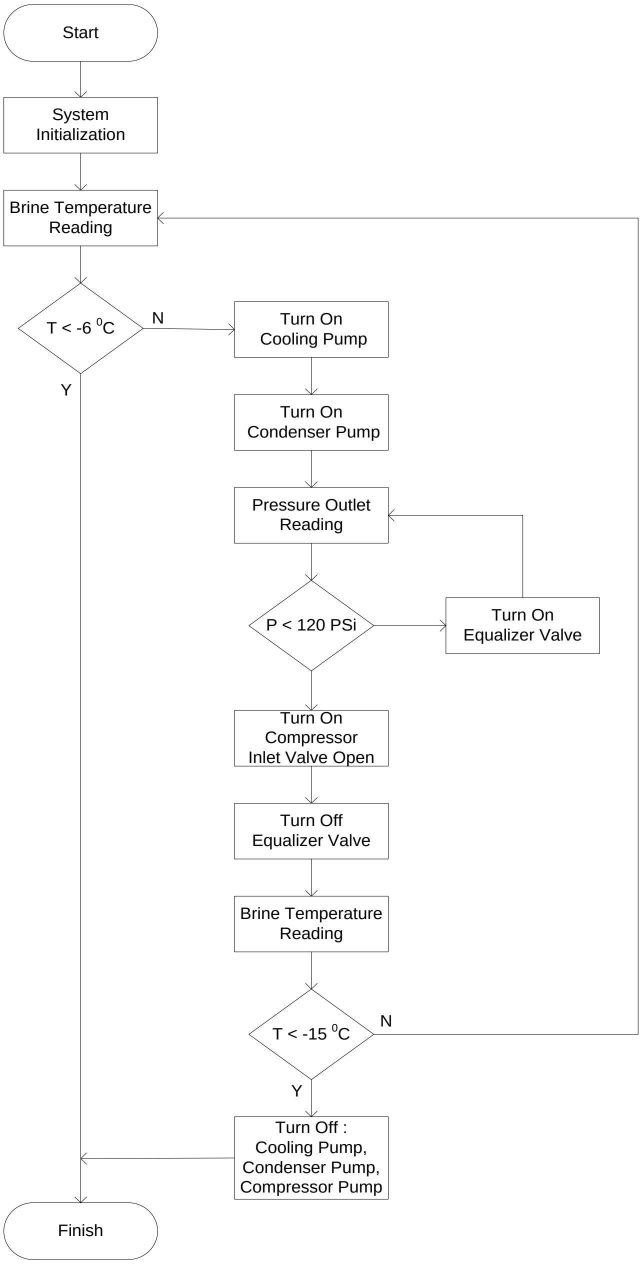

Fig. 6. The Flow Chart Diagram of System Design

B. *Schematic Design*

Supply of 5 VDC from adapter activate LM35, then LM35 will convert temperature into a voltage. The increase in temperature will cause an increase in the output voltage of 10 mV/°C. In this temperature sensor circuit, LM35 can measure temperatures ranging from -55 °C to 150 °C. The pressure switch initially set in NC when one of the pins connected to supply of 5 VDC. The trip setting nut adjusted the set point of the high pressure (typically 200 psi) for valve running. The nut also adjusted the set point of the low pressure (typically 120 psi) for compressor running. At this pressure, the condition of the NC contact will change to the other pin to activate the compressor.

The output from IC LM35 and pressure switch will be transferred to the Arduino. In Arduino, Atmega 328 boot loader is used to save programs. This boot loader also has function as monitors activities desired by the Arduino. If there are files to be uploaded, the boot loader will automatically save it in the program memory. When the Arduino was active, the boot loader will execute application programs that have been previously uploaded. Then the results of the Arduino will be displayed on the LCD. Drivers will activate relay temperature reading switch a range of -6 °C to -15 °C, and relay pressure reading with a range 120 psi and 200 psi. All relay drivers requires a power supply of 12VDC.

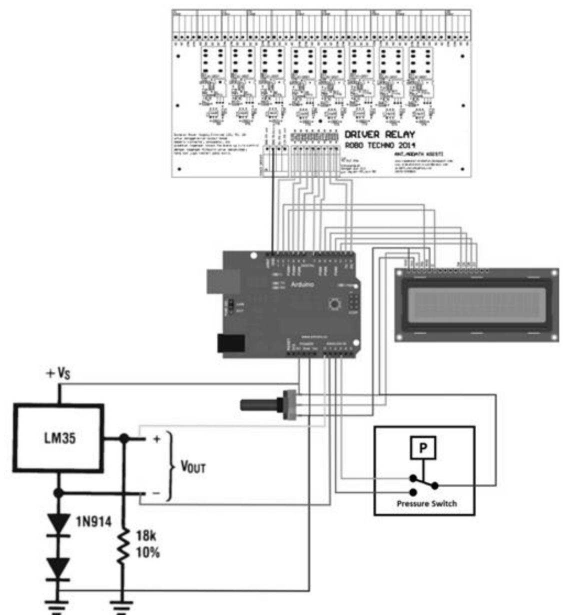

Fig. 7. Circuit schematic of the entire system

C. *Output Design*

Microcontroller requires a transistor to drain a dc voltage input signal to a power relay. Voltage and current level of microcontroller not quite able to drive relay directly. Transistor can increase the level to drive the relay. NPN Darlington transistor type TIP 122, has factor amplified DC (Hfe) 1000 times.

Through the power contacts of power relay, the components will be connected or disconnected to the AC voltage source.

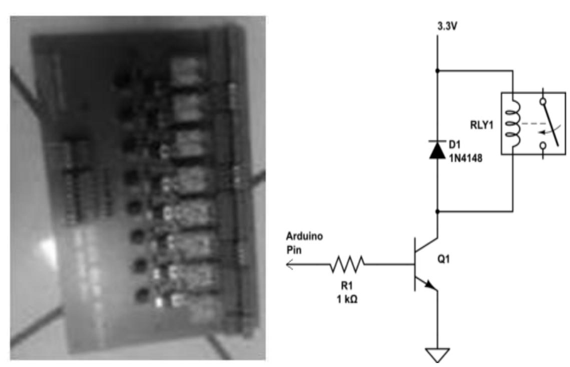

Fig. 8. Output components : relays and transistors

D. Control Testing

Control testing is done on normal condition power source, ambient temperature of 25 °C. Testing program of Arduino with the temperature range (-6 °C to -15 °C) at a temperature of ice mixed with salt. For voltage reference of 5 V :

TABLE I
TEMPERATURE READINGS FOR UPPER LIMIT OF OUTPUT 16 BIT ADC

No	T (^{0}C)	ADC Output (decimal)		Analogread/2.048 (^{0}C)
		read 1	read 2	
1	-5.74	271	284	-6.35
2	-5.67	239	251	-5.86
3	-6.81	218	233	-7.32
4	-6.7	211	222	-5.37
5	-6.08	281	294	-6.35
6	-6.13	205	219	-6.84
7	-5.28	233	247	-6.84
8	-7.05	232	244	-5.86
9	-6.11	251	263	-5.86
10	-6.89	269	284	-7.32
Ave	**-6.25**	**241**	**254.1**	**-6.40**

Reading of T_{ave} : -6.25 °C
Analogread1 ave : 241
Analogread2 ave : 254.1

$$T = \frac{analogread(pin1) - analogread(pin2)}{2{,}048}$$

$$T = \frac{241 - 254.1}{2.048} = -6.40°C$$

Different : 0.15 °C (compared with T_{ave}).

Temperature control of upper limit can be set at -6.25 °C with an error rate of 2.41% when using a reference voltage of 5 V.

TABLE II
TEMPERATURE READINGS FOR LOWER LIMIT OF OUTPUT 16 BIT ADC

No	T (^{0}C)	ADC output (decimal)		Analogread/2.048 (^{0}C)
		read 1	read 2	
1	-15.74	172	201	-14.16
2	-15.67	172	204	-15.63
3	-16.81	169	206	-18.07
4	-16.7	171	205	-16.60
5	-16.08	173	205	-15.63
6	-16.13	171	204	-16.11
7	-15.28	173	205	-15.63
8	-16.05	174	206	-15.63
9	-16.11	175	201	-12.70
10	-16.89	176	204	-13.67
Ave	**-16.15**	**172.6**	**204.1**	**-15.38**

Based on the results in Table 2, temperature control of lower limit can be set at -15.38 °C with an error rate of 4.74% when using a reference voltage of 5 V.

Furthermore, the system design was implemented using motor compressor with specification: 3 phase, 10HP, 380 V, pf = 0.8. At the previous measurements and testing of conventional system, the refrigerant pressure in the inlet and the outlet before compressor running are 10 psi and 200 psi. It could be reduced manually by setting the equalizer valve until the pressure down to 120 psi. The decreasing presurre in outlet effect to the increasing presurre in outlet inlet as shown in Figure 9 below :

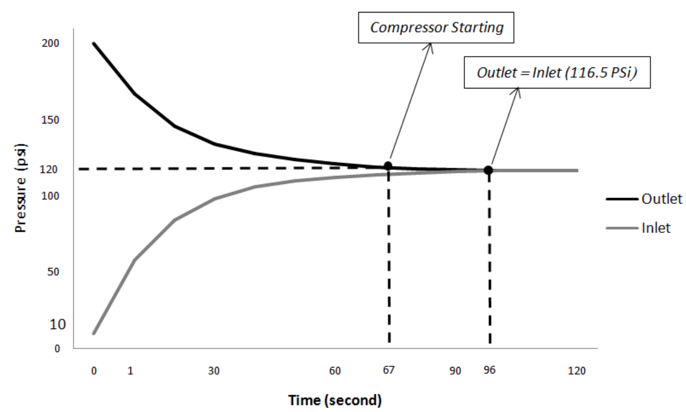

Fig. 9. Characteristics of Outlet and Inlet pressure

The time duration of decline in outlet from 200 psi to 120 psi is 67 seconds. Both the decline in outlet from 200 psi and increasing inlet from 10 psi achieve the steady state at 116.5 psi after 96 seconds.

In this desain, the equalizer valve automatically opens to reduce the oulet pressure. At the time of start-up the compressor motor, the motor failed to start because the pressure of 200 psi in outlet is still much too high. It led to the compressor motor rotation became heavy. This will cause locked rotor current and the motor current increased about 151.84 A. Generally the normal starting current of motor is 6 times of nominal current. For this case, the motor has a nominal current of about 14.16 A. Then the motor starting current is normally about 84.96 A at 120 psi. Thus, with the use of this system can prevent early motor failure from locked rotor current. Based on the above calculation, the difference between locked rotor current and starting current : 151.84 - 84.96 = 66.88A. So the percentage loss of the starting current : (66.88 / 84.96) * 100 % = 78.72 %. Because energy is proportional to the current at the same voltage rated, then by applying this control system design, each starting the compressor motor will save energy about 78.72 %. Based on previous measurement as shown in Figure 9, the control system will performs the compressor motor to running at maximum pressure of 120 psi in the compressor outlet.

IV. Conclusion

In this paper automatic control condensing unit design is proposed. Arduino Servarino Board microcontroller is able to obtain the requirement system. Transistor and relay could be use for increase level of voltage and current at output. The results of testing control system shows that temperature control of the brine can be set in the range of -6°C and -15°C with error rate of 2.41% to 4.74%. Refrigerant output pressure at the start of the operation must be reduced to avoid the failure starting of the compressor motor. The outlet pressure is setting automatically at 120 psi is adequate for the system to start the compressor running with low starting current. By applying this system, the saving energy during starting is about 78.72 %.

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