Design and Construction of Refrigerant Charge Level Detecting Device in HVAC/R System with Microcontroller

Parvez Mahmud, Shahjadi Hisan Farjana

Abstract - A charge level detecting device in residential and light commercial heating, ventilation, and air-conditioning (HVAC) systems and in refrigeration systems is used to detect the sufficiency of refrigerant or charge level whether it is proper or not. The most common problems affecting residential and commercial HVAC/R systems are slow refrigerant leaks, improper refrigerant charge and charging device. The usual methods for charge level detection are sight glass method and system high side and low side pressure measurement method. The limitation of sight glass method is it works only if a predictable amount of refrigerant remains in one part of system or constant flow of refrigerant is maintained throughout the system. Pressure of any HVAC/R system cannot be measured in a running system, and charge leaks occur in case of pressure method. Refrigerant charge level detecting device employs a method of determining if the refrigerant charge is within an acceptable range, including the steps of measuring the superheat and subcool temperatures at compressor inlet and condenser outlet. Actual superheat and actual subcooling values are calculated and these values are thus compared with target superheat and target subcool values in microcontroller device, thus obtained from manufacturers chart for particular type of refrigerant, which values depends on outdoor dry bulb temperature and indoor wet bulb temperature on system operating situation and shows the charge status result. The refrigerant charge indicator is based on the fact that when refrigerant starts to leak, the evaporator coil temperature starts to drop and the level of liquid sub cooling drops. An over charge in this system results in compressor flooding, damaging to the motor and mechanical components. Inadequate refrigerant charge can lead to increased power consumption, thus reducing system capacity and efficiency.

Keywords: Superheat, subcooling, refrigerant charge level, microcontroller.

I. INTRODUCTION

The word refrigeration describes the intentional movement of heat, when heat is not allowed to move naturally. It moves from a warm place to a colder place. Heat does not naturally moves from a cold place to a warm place. If it has to be physically moved, this movement of heat requires energy. Heat is removed up the temperature hill from one place to another. Maintaining proper refrigerant charge level is essential to the safe and efficient operation of a refrigeration system. Improper charge level, either in deficit or in excess, can cause premature compressor failure[2]. An over charge in this system results in compressor flooding, which in turn may be damaging to the motor and mechanical components. Inadequate refrigerant charge can lead to increased power consumption, thus reducing system capacity and efficiency.Low charge also causes an increase in refrigerant temperature entering the compressor, which may cause thermal over load of the compressor. Thermal over load of the compressor can cause degradation of the motor winding insulation, thereby bringing about premature motor failure[1].

A method and apparatus for determining the sufficiency of the refrigerant charge in a refrigeration system by use of temperature measurements. The temperatures of low side and suction lines are taken and their difference is the measure of superheat. The temperature of high side and liquid line is taken and their difference is the measure of sub cooling[3].

The refrigerant charge checking in cooling units often enough to keep the charge within proper limits. This measure gives the procedures for checking and maintaining the proper refrigerant charge and explains the effect of improper refrigerant charge[1,2].

II. OVERVIEW OF RELATED WORKS

In this section, we present an abstract view of the refrigerant charge level detecting device and used method for detecting charge level in previous works Braun II; Robert J (2010)[16] in their work suggested the method of determining charge level by calculating condenser coil temperature and condenser end point temperature. It's difficult to determine the end point of condenser and also to obtain actual condenser temperature from outside condenser coil. Bush; James W (2010)[17] It employs the method of Joining expansion valve to the charge storage chamber to prevent leakage and loss of refrigerant. Concha,et al (2008)[18] employed a method of refrigerant charge level determination by calculating condenser coil temperature and condenser end point temperature and compressor discharge temperature. This method gets the same problem as used by Braun II; Robert J (2010)[16]. That is determining condenser end point exactly. Galante,et al (2009)[19] follows the method of obtaining condenser coil temperature and outdoor condenser end point temperature . Kang,et al. (2009)[20] suggests that by measuring condenser coil temperature and outdoor condenser end point temperature and generating electrical signal can give an indication of refrigerant charge level.

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M. A. Parvez Mahmud, Lecturer, Department of Mechatronics Engineering, World University of Bangladesh,Dhaka, Bangladesh .
Shahjadi Hisan Farjana, Lecturer,Department of Mechatronics Engineering, World University of Bangladesh,Dhaka, Bangladesh.

Schuster,Don A (2010)[21] invented a method which is based on instantaneous degree of subcooling in where liquid refrigerant is present, employs a method for determining refrigerant charge.

III. MATERIALS AND METHODS

A. Working Principle of Vapor Compression Cycle:

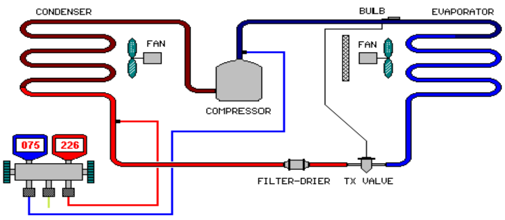

Fig 1: Vapor Compression Refrigeration System.

There are our main components in a refrigeration system: Compressor, Condenser, Expansion valve, Evaporator.The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Figure 1 provides a schematic diagram of the components of a typical vapor-compression refrigeration system.

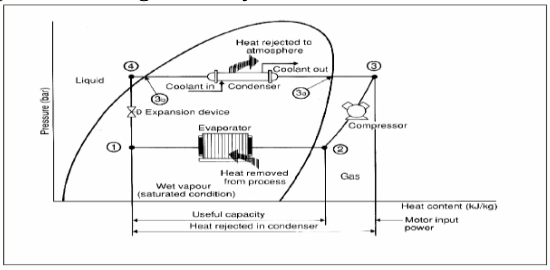

Fig 2 : Schematic representation of the refrigeration cycle including pressure changes (Bureau of Energy Efficiency, 2004) (actual).[11]

1 – 2. Low-pressure liquid refrigerant in the evaporator absorbs heat from its surroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

2 – 3. The superheated vapour enters the compressor where its pressure is raised. The temperature will also increase, because a proportion of the energy put into the compression process is transferred to the refrigerant.

3 – 4. The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process (3-3a) de-superheats the gas before it is then turned back into liquid (3a-3b). The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b - 4), so that the refrigerant liquid is sub-cooled as it enters the expansion device.

4 – 1. The high-pressure sub-cooled liquid passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.[11,1,2,3,5]

B. Refrigeration Charge Level Determination Method:

Superheat is the temperature rise above the boiling point of the refrigerant after the evaporator. Too high, and the refrigerant boils off early in the evaporator, and 'wastes' most of the effect of evaporator. Too low have risks of liquid going into the compressor. Actual superheat is calculated from suction line temperature measurements. The suction line saturation (boiling) temperature is subtracted from the actual measured suction line temperature. Properly charged fixed restrictor refrigeration has an actual superheat which matches the target superheat Adjusting the actual superheat can be done by adding or recovering refrigerant from a fixed restrictor system.[6,9,10] Whether the compressor be reciprocating, scroll, etc. all compressors are designed to compress vapor refrigerant. Various compressor types and brands have different tolerances to liquid exposure but one thing is certain, they will all prematurely fail if they are exposed to liquid refrigerant for an extended period of time.If we charged a system this way a small change in the suction line pressure change would expose the compressor to liquid refrigerant. Too much superheat could also affect compressor cooling since refrigerant is used for heat dissipation of the compressor.[6,9,10]

Target superheat is the recommended superheat for the given indoor and outdoor environmental conditions. Environmental conditions affect the amount of actual superheat found in a system. For that reason the target superheat chart of a system must take into account all the environmental conditions under which the system is expected to run. This ensures that even if the environmental conditions change the system will operate with good capacity and the compressor will not be exposed to liquid refrigerant. Most target superheat charts including the one used in California's legislature under title 24 require indoor wet bulb and outdoor dry bulb measurements to yield a target superheat.[6,9,10]

Sub cooling is the temperature decrease below the boiling point (same as the condensing point) in the condenser. Too high and refrigerant condenses too early in the condenser and 'wastes' most of the effect of the condenser. Too low and a mixture of gas and liquid can be delivered to the expansion valve, reducing efficiency. Condensate Sub cooling in systems with air-cooled condensers, excessive charge is indicated by excessive sub cooling of the refrigerant. When the system is overcharged, the condenser fills with liquid refrigerant, the condenser capacity drops, and the liquid lingers in the condenser long enough to become excessively sub cooled. The difference in temperature between normal and sub cooled refrigerant from a condenser is small. This makes the test too subtle for any but experienced technicians. Condenser sub cooling should be checked as confirmation of excess charge if the discharge pressure is too high. This symptom is accompanied by abnormally high condenser pressure, especially at high cooling load.[6,9,10]

To Determine Superheat by temperature measurements: The evaporator/low side temperature should be measured using temperature sensor.

Then the temperature of the Suction line as close to the condensing section as possible stay at least 6 inches from compressor should be measured.The difference between the above readings (Suction line temp – Saturation temp) should be measured by microcontroller .When ambient air temp (Outside air temp) is 75-85 degrees the superheat should be 12-15 degrees, if the ambient temperature is 85 degrees or over the superheat should be 8-12degrees.

To Determine Sub-Cooling by temperature measurement: The condenser/high side temperature should be measured using temperature sensor. Then the temperature of the liquid line should be taken as close to evaporator as possible before the metering device.The difference between the above readings should be calculated (Saturation temp – Liquid line temp) by microcontroller. The liquid line temperature at the evaporator should be within 2 degrees of liquid line temp at condensing unit. If not could be restriction or line set too long. Sub-Cooling should be around 12-15 degrees.

C. Possible Diagnostics:

Condition	Decision
Superheat is high and sub-cooling is low	System undercharged
Superheat is low and sub-cooling is high	System overcharged
Superheat is high and sub-cooling is low	Could have blockage in coil, orifice or line set.
Superheat is high and sub-cooling is low	Orifice could be too big, there is no orifice in the unit of the orifice is stuck and refrigerant is by-passing it.

D. Situation and causes:[15]

Situation	Indication	Causes
High suction pressure	Low superheat	Oversized Valve,TEV seat leak, Low Superheat adjustment, Bulb installation, Poor thermal contact, Warm location, Wrong thermostatic charge, Bad Compressor-low capacity, Moisture, dirt, wax, Incorrectly located external equalizer
Low suction pressure	High superheat	Moisture, dirt, wax, Undersized valve, High superheat adjustment, Gas charge condensation, Dead thermostatic element charge, Wrong thermostatic charge, Evaporator pressure drop —no external equalizer, External equalizer location, Restricted or capped external equalizer, Low refrigerant charge, Liquid line vapor, Vertical lift, High friction loss, Long or small line, Plugged drier or strainer, Low pressure drop across valve, Undersized distributor nozzle or circuits, Low condensing temperature.
Low Suction Pressure with No Capacity Reduction On Compressor	Low superheat	Low load, Not enough air, Dirty air filters, Air too cold, Coil icing, Poor air distribution, Poor refrigerant distribution, Improper compressor-evaporator balance, Evaporator oil logged, Flow from one TEV affecting another's bulb

Design and Construction of Refrigerant Charge Level Detecting Device in HVAC/R System with Microcontroller

E. Design & Construction of Refrigerant Charge Level Detecting Device:

A microcontroller is a computer-on-a-chip, or, if you prefer, a single-chip computer. *Micro* Suggests that the device is small, and *controller* tells you that the device might be used to Control objects, processes, or events. Another term to describe a microcontroller is *embedded Controller*, because the microcontroller and its support circuits are often built into, or Embedded in, the devices they control. [13]

Microprocessors and microcontrollers are widely used an embedded system products. An embedded product uses a microprocessor (or microcontroller) to do one task and one task. A printer is an example of embedded system since the processor inside it performs one task only; namely, getting the data and printing it. Contrast this with a Pentium-based PC. A PC can be used for any number of applications such as word processor, print-server, bank teller terminal, video game player, network server, or internet terminal. Software for a variety of applications can be loaded and run. In an embedded system, there is only one application software that is typical burned into ROM. An x86 PC contains or is connected to various embedded products such as the keyboard, printer, modem, disk controller, sound card, CD-ROM drive, mouse, and so on. Each one of these peripherals has a microcontroller inside it that performs only one task.The **AVR** is a modified Harvard architecture 8-bit RISC single chip microcontroller which was developed by Atmel in 1996. The AVR was one of the first microcontroller families to use on-chip flash memory for program storage, as opposed to One-Time Programmable ROM, EPROM, or EEPROM used by other microcontrollers at the time.AVRs are generally classified into five broad groups: one of them is- megaAVR — the ATmega series with 4–256 kB program memory, 28–100-pin package, Extended instruction set (Multiply instructions and instructions for handling larger program memories),Extensive peripheral set.Following criterias are explained for why AVR is used in charge level detecting device. [15]

Circuit Component name	Why chosen
Atmega16	Built in ADC converter which eliminates the use of individual ADC, saves cost of USD. 9.00
4*4 keypad	For giving target superheat and target sub cooling input
16*2 LCD	For displaying charge status
Rechargeable battery	For standby use of device

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Voltage regulator	For maintaining constant supply of 5volt.
Temperature sensor (LM 34)	For high side and low side temperature measurements
Rectifier,Capacitor,Resistor,Veroboard	For proper functioning and design of circuit

These are the assumptions of refrigerant charge level detecting device design-

1. The "Target Superheat" and "Target Sub cooling" temperature values will be given as input of the device which will be stored on the memory of microcontroller specified by the manufacturers according to the indoor wet bulb temperature and outdoor dry bulb temperature.
2. One temperature sensor probe will be connected to the compressor inlet and evaporator operating temperature was stored in program based on type of refrigerant ,this two temperatures will be showed on the display and their difference will be calculated and showed, then disconnect probe. This is the "Actual Superheat".
3. Then by comparing actual and target superheat values, status will be shown on display whether the superheat is low or high.
4. Again the temperature sensor probe will be connected to the expansion valve inlet and condenser operating temperature was stored in program based on type of refrigerant, this two temperatures will be showed on the display and their difference will be calculated and showed, then disconnect probe. This is the "Actual Sub cooling".
5. Then by comparing actual and target subcool values, status will be shown on display whether the sub cooling is low or high.
6. Then according to the basis of actual superheat and actual sub cooling values, the result will be shown on display that whether the system is overcharged, undercharged or properly charged.

BASCOM-AVR© is a Windows BASIC COMPILER for the AVR family. It is designed to run on W95/W98 and NT. These features are given below to mention why BASCOM-AVR is used for charge level detecting device. Features are-Structured BASIC with labels. Structured programming with IF-THEN-ELSE-END IF, DO-LOOP, WHILEWEND, SELECT- CASE. Fast machine code instead of interpreted code. Variables and labels can be as long as 32 characters. Bit, Byte, Integer, Word, Long, Single and String variables. Compiled programs work with all AVR microprocessors that have internal memory. Statements are highly compatible with Microsoft's VB/QB. Local variables, user functions, library support, mixed ASM and BASIC programming. Integrated terminal emulator with download option. Integrated simulator for testing. Integrated ISP programmer (application note AVR910.ASM). Integrated Kanda STK200+ programmer and STK300 programmer. Editor with statement highlighting.[13,14,15].

F. Circuit Diagram For Refrigerant Charge Level Detecting Device:

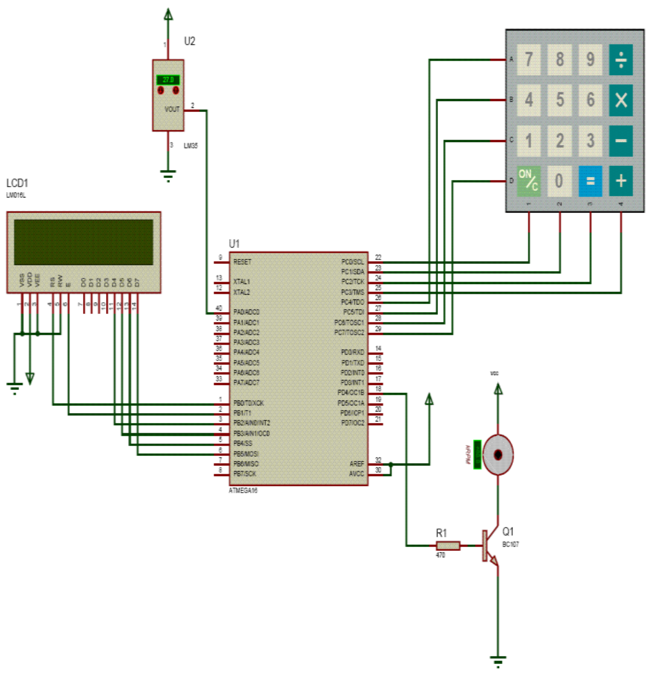

Fig 3: Electrical Circuit of Charge Level Detecting Device

Atmega 32L is used in charge level detecting device. It's a 32K Bytes of In-System Self-Programmable Flash,512 Bytes EEPROM,1K Byte Internal SRAM,32 Programmable I/O Lines,In-System Programming by On-chip Boot Program,8-channel, 10-bit ADC,Two 8-bit Timer/Counters with Separate Prescalers and Compare Mode, One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Four PWM Channels,Programmable Serial USART,Master/Slave SPI Serial Interface,Byte-oriented Two-wire Serial Interface,Programmable Watchdog Timer with Separate On-chip Oscillator,External and Internal Interrupt Source,Advanced RISC architecture.AVR chips packs lots of power 1MIPS/MHZ, clocks up to 16MHZ. [14]

A breadboard is used to prototype this circuit. It has holes into which components can be inserted and has electrical connections between the holes as per the diagram below. Using a breadboard means no soldering and a circuit can be constructed quickly and modified easily before a final solution is decided upon. [15]

This application note describes a simple interface to a 4 x 4 keypad designed for low power battery operation. The AVR spends most of its time in Power-down mode, waking up when a key is pressed to instigate a simple test program that flashes one of two LEDs according to the key pressed. If "0" (zero) is pressed the RED LED flashes 10 times. All other keys flash the GREEN LED the number of times marked on the key (e.g., if "C" is pressed the GREEN LED flashes twelve times).Following features explain why 4x 4 keypad is used in charge level detection.It has 16 Key Pushbutton Pad in 4 x 4 Matrix,Very Low Power Consumption,AVR in Sleep Mode and Wakes up on Keypress,and minimum external components[14].

The LM78XX series of three terminal positive regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents[15].

LM34 by National Semiconductor is a popular and low cost temperature sensor. It is also easily available. It has three pins .The Vcc can be from 4V to 20V as specified by the datasheet. To use the sensor simply connect the Vcc to 5V ,GND to Gnd and the Out to one of the ADC (analog to digital converter channel). The output linearly varies with temperature. The output is 10MilliVolts per degree Fahrenheit. So if the output is 310 mV then temperature is 31 degree F. To make this project you should be familiar with the ADC of AVRs and also using seven segment displays. The resolution of AVRs ADC is 10bit and for reference voltage we are using 5V so the resolution in terms of voltage is 5/1024 = 5mV approx So if ADCs result corresponds to 5mV i.e. if ADC reading is 10 it means 10 x 5mV = 50mV. One can get read the value of any ADC channel using the function ReadADC (ch); where ch is channel number (0-5) in case of ATmega8. If you have connected the LM34's output to ADC channel 0 then call adc_value = ReadADC(0) this will store the current ADC reading in variable adc_value. The data type of adc_value should be int as ADC value can range from 0-1023. As we saw ADC results are in factor of 5mV and for 1 degree F the output of LM35 is 10mV, So 2 units of ADC = 1 degree. So to get the temperature we divide the adc_value by to temperature = adc_value/2;Finally one can display this value in either the 7 segment displays by using the Print() function we developed in last tutorial or you can display it in LCD Module. [28]

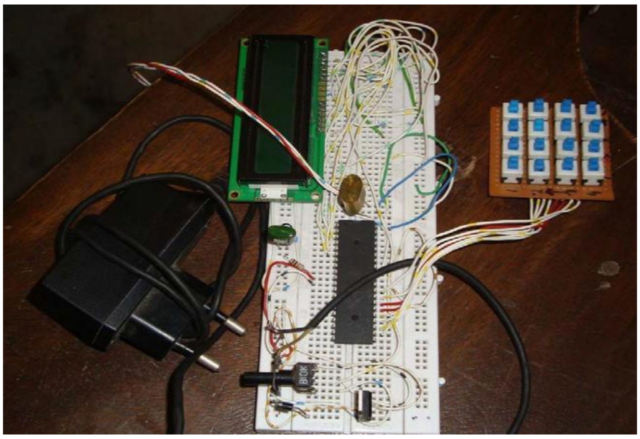

Figure 5: **Experimental Set-up of Refrigerant Charge Level Detecting Device**

IV. RESULTS AND DISCUSSIONS

Table: HVAC/R system specifications:

Plant name:	Fujitsu General
Refrigerant type:	R22
Model Number:	AXG24GNK-W
System type:	Window type air cooler
Refrigerant Quantity:	1230gm

Manufacturer's Data (from system operating manual):

Target degree of superheat:	34°F
Target degree of subcooling:	10°F
Evaporator operating temperature:	-7°C/19.4°F
Condenser operating temperature:	43°C/109.4°F

Experimental Data from charge Level Detecting Device:

Compressor inlet Temperature:	69°F
Actual degree of superheat:	39.6°F
Difference between target and actual superheat values:	5.6°F
Superheat status:	Superheat high
Expansion device inlet temperature:	94°F
Actual Degree of Subcool:	3.6°F
Difference between target and actual subcool values:	-6.4°F
Subcool Status:	Subcool low
Charge Status	Undercharged

During experimental test of charge level detection, compressor inlet temperatures and evaporator outlet temperatures was measured with as little contact resistance as possible, however there was little temperature differential due to contact resistance between temperature sensor and system wall. There was another cause of temperature differential, temperatures are measured in mill volt unit and then converted into Fahrenheit values, variation in voltage regulation can cause temperature differential.

V. CONCLUSIONS

The objectives of this project work based on charge level detection in HVAC/R system were to design and construct the charge level detecting device and to check the performance level of charge level detecting device. The design and construction work was done successfully and performance level was checked in a residential window type air cooling unit. The charge status result was undercharged. This result was quite satisfactory, because the cooling level generated by air cooler was lower than expected. Can be used in refrigeration system of domestic use and in commercial application and in split type and window type air conditioning system, heat pumps operating with R22 and R410a.

Refrigerant charge level detecting device can be operated and calculate charge status in a running system. It is a cheap method, operated without any leakage of gas, system hazard and no risk of accident. More accurate method of charge status determination due to the combination of superheat and subcool method. It can predict about possible system trouble, hazard, operating criterion. Expert handler is not required for device operation. No need of analog to digital converter. Multiple power saving mode and Fast in operation. Device parts are available and easily replaceable. Temperature sensor can calculate temperature from -50 to 150 degree Fahrenheit. Rechargeable battery if once charged, can give long time back up. It avoids the drawbacks of pressure method, sight glass method and others. It can be easily attached with compressor inlet and expansion valve inlet. It allows proper charge limit within ±2°C of actual superheat and ±1°C of actual subcool values.

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