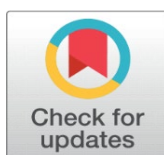


DEVELOPMENT OF HEATING AND COOLING THERMAL MODEL FOR AN AUTOMOTIVE AIR COMPRESSOR BASED ON EXPERIMENTAL DATA

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ABSTRACT

The paper presents how to determine the heating and cooling thermal model for an air compressor of automotive air suspension system by using experimental data. A set of test bench for the air compressor was firstly established. Based on experiment, temperature of the heat sink of the air compressor and air temperature and pressure inside two tanks were obtained. By analyzing heat exchange process of air compressor, the thermal model of air compressor is constructed, including temperature increasing and decreasing process. The calculated results by means of the presented model show that the thermal model can correctly describe the process of temperature variation of the air compressor.

Keywords: Air Compressor, Air Suspension System, Thermal Model

1. INTRODUCTION

In the early stage of air suspension system for automotive, air spring system was adopted to reduce vibration for heavy duty applications (trucks, buses and trains). Nowadays air suspension system has been increasingly applied on some luxurious vehicles, sport utility vehicles and mini-vans to improve comfortable feeling for driver and passenger [Giuseppe and Massimo \(2001\)](#).

Usually, an air suspension system includes several components, such as an air compressor, air springs, auxiliary volumes, control valves, a reservoir, sensors, ECU, and so on [Faiza \(2005\)](#). Air compressor is used to provide compressed air to the air suspension system. Generally speaking, air compressor works in rigorous ambient

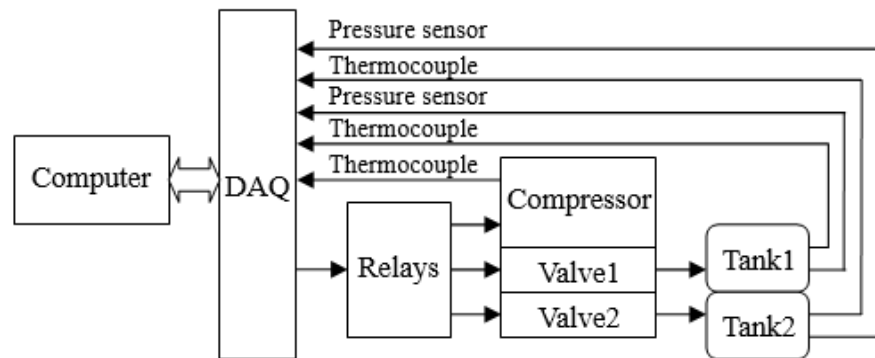
in vehicle, because it is usually positioned near engine where there is high temperature. Moreover, its working pressure should be enough high to make air springs to suspend whole weight of vehicle, which means that lots of heat is produced when air compressor compresses air. Properties of temperature increasing and decreasing of the air compressor are quite significant in practice. As a result, this paper presents how to construct thermal models of an air compressor for vehicle by means of experimental data.

Remaining parts of the paper are arranged as below. The experiment is briefly described and measured data is presented in the section 2. And then, according to experimental results, temperature increasing and decreasing models are built, respectively, in the section 3 and 4. The last section gives some conclusions.

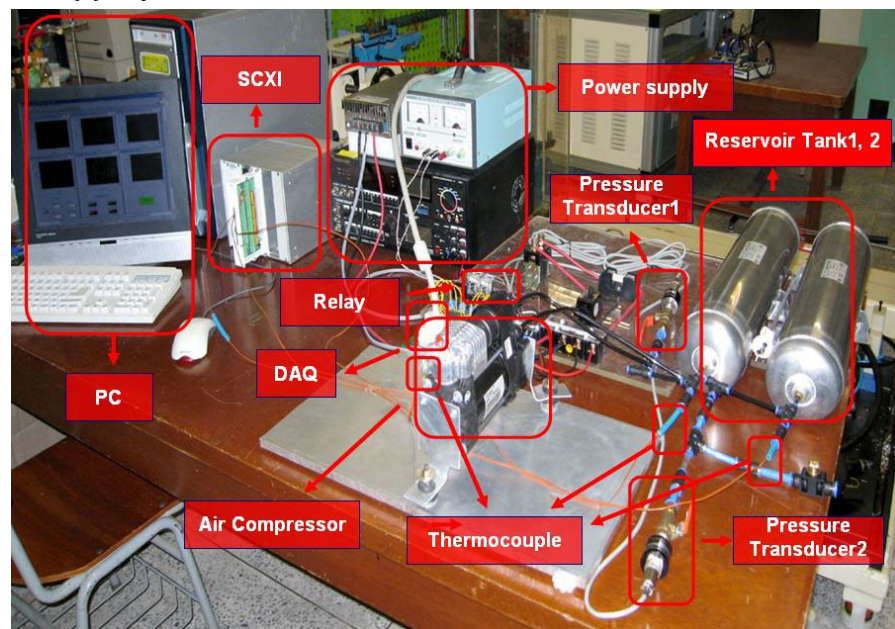
2. DESCRIPTION OF EXPERIMENT

The experiment test bench comprises an automotive air compressor (including build-in two direction valves), two tanks, three relays, three thermocouples, two pressure sensors, a DAQ board, and a computer, shown in [Figure 1](#).

Figure 1



(a) Layout schematic



(b) Photo of test device

Figure 1 Schematic of Experiment

The computer controls the air compressor to work or stop by a relay and control air flow directions among the compressor and two tanks. First of all, the compressor charges air into both tanks up to 9 bars. Next, the computer controls two directional valves and the compressor to compress air from the first tank to the second during 10 seconds, and then changes air charging direction from the second tank to the first. The two valves shift air flow direction every 10 second. A thermocouple is used to measure temperature on heat sink of the air compressor. If compressor temperature exceeds 140 °C, the compressor will stop for cooling, while if compressor temperature reduces less than 120 °C, the compressor will run again and repeat charging air between two tanks. Temperature rises and goes down totally 12 times between 120 °C and 140 °C.

LabVIEW software is implemented to control the charging procedure and measure temperature and pressure. Figure 2 illustrates test results.

Figure 2

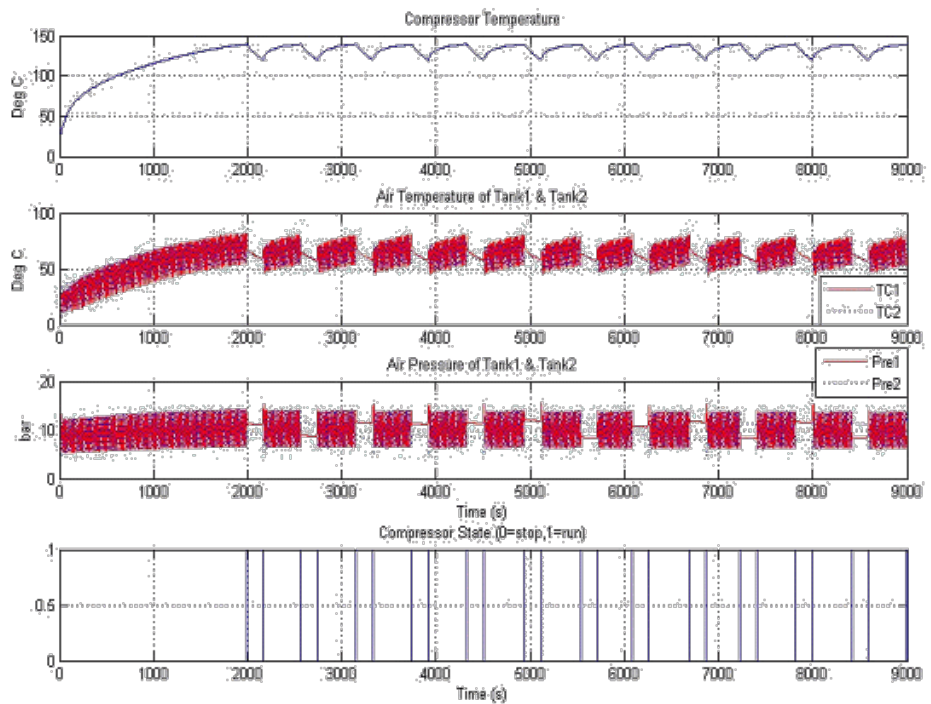


Figure 2 Experimental Results

In order to obtain the thermal models of temperature increasing and decreasing durations, temperature increasing and decreasing durations are segmented, respectively, yielding 12 durations can be obtained. And then corresponding duration times of temperature increasing and decreasing are calculated and values as well as the average are listed in Table 1 and Table 2.

Table 1

Table 1 Time (sec) of Temperature Increasing from 120 °C to 140 °C					
402.6	412.5	412.6	412.5	431.7	422.7
372.2	432.2	362.9	412.3	422.9	401.7

Average: 408.32 second

Table 2**Table 2 Time (sec) of temperature decreasing from 140 °C to 120 °C**

172.8	174	176.7	176.2	175.7	179.9
173.6	173.5	178.6	173.4	178.3	174.6

Average: 175.61 second

3. MODELING OF TEMPERATURE INCREASING PERIOD

When the air compressor works, heat produced includes following three parts:

- Heat from compression of air
- Heat from the motor winding
- Heat from the valve winding

These three kinds of heat make compressor temperature increase quickly. However, it is very difficult to accurately describe these three kinds of heat by using analytical method. Amount of heat produced varies with different work conditions. Moreover, in the moment of heat production, heat dissipation occurs at the same time, which is effected by heat sink shape of compressor and ambient, such as temperature and convection condition. Heat production and dissipation together influence on compressor temperature [Tang and Shi \(2004\)](#). With time going, heat production and heat dissipation finally reach an equilibrium temperature.

If only convection is considered heat change ratio equals to sum of heat transfer and heat dissipation in unit time [Cengel and Boles \(2006\)](#), which can be expressed as following.

$$\frac{dQ}{dt} = q - Ah(T - T_{amb}) \quad \text{Equation 1}$$

Where

Q : total heat of compressor

q : heat transfer per unit time

A : dissipation area

h : convection heat transfer coefficient

T : object temperature

T_{amb} : ambient temperature

For convenience, it is assumed that heat transfer per unit time to the air compressor is a constant because the compressor works in identical condition. Specific heat is defined as

$$C = \frac{1}{m} \frac{dQ}{dT} \quad \text{Equation 2}$$

Therefore, combining [Equation 1](#) and [Equation 2](#), we can obtain

$$Cm \frac{dT}{dt} = q - Ah(T - T_{amb}) \quad \text{Equation 3}$$

By introducing two coefficients k_1 and k_2 , the above equation can be rewritten as

$$\frac{dT}{dt} = k_1 - k_2 T \quad \text{Equation 4}$$

With the initial condition $T|_{t=0} = T_{ini}$, the solution of the differential Equation 4 is

$$T = (T_{ini} - k)e^{-k_2 t} + k \quad \text{Equation 5}$$

Where $k = k_1/k_2$. It needs another two conditions to determine two coefficients k_2 and k . Consider following two conditions.

- As $t=408.32$ second (the average of temperature ascending time of total), compressor temperature is 140°C , namely $T|_{t=408.32} = 140^\circ\text{C}$.
- As $t=100$ second, compressor temperature is 132.29°C (the average temperature of temperature ascending of total 12 times), namely $T|_{t=100} = 132.29^\circ\text{C}$.

Finally, the compressor temperature ascending model is obtained as following with ambient temperature 23.2°C .

$$T = -20.49e^{-0.00916t} + 140.49 \quad \text{Equation 6}$$

The experimental data and calculation results with using the model of Equation 6 are plotted in Figure 3.

Figure 3

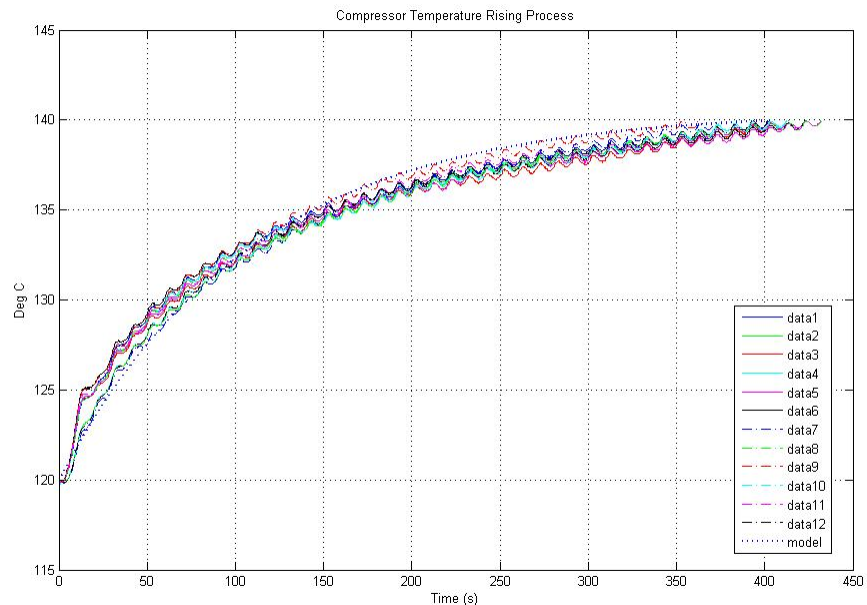


Figure 3 Temperature Increasing Process and its Simulation Result

4. MODELING OF TEMPERATURE DECREASING PERIOD

The [Equation 1](#) describes cooling process if there is no heat transfer item. And also Newton Cooling Law [Cengel and Boles \(2006\)](#), [Incropera and Dewitt \(2001\)](#) is usually used to describe this process. It is stated that cooling ratio of an object is proportional to temperature difference between it and the ambient, as following mathematical expression.

$$\frac{dT}{dt} = -k(T - T_{amb}) \quad \text{Equation 7}$$

Where T is object temperature, T_{amb} is ambient temperature, and k is coefficient. This differential equation has solution as

$$T = (T_{ini} - T_{amb})e^{-kt} + T_{amb} \quad \text{Equation 8}$$

Considering the initial condition

$$T_{amb} = 23.2 \text{ } ^\circ\text{C}, T|_{t=0} = 140 \text{ } ^\circ\text{C}, \text{ and } T|_{t=175.61} = 120 \text{ } ^\circ\text{C}.$$

The temperature decreasing model from $140 \text{ } ^\circ\text{C}$ to $120 \text{ } ^\circ\text{C}$ is obtained as

$$T = 116.8e^{-0.00107t} + 23.2 \quad \text{Equation 9}$$

Plot the experimental data and calculation results with the model of [Equation 9](#) in [Figure 4](#).

Figure 4

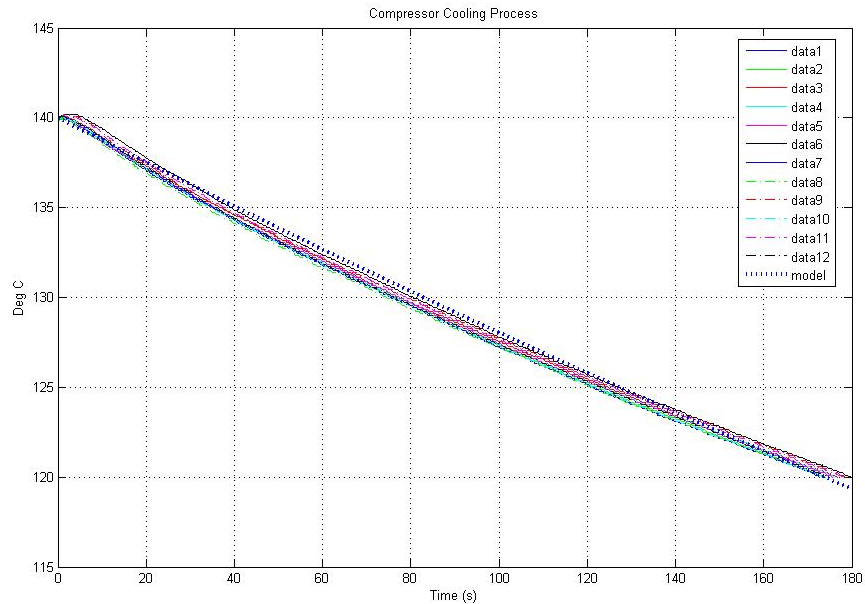


Figure 4 Temperature Decreasing Process and its Simulation Result

5. CONCLUSIONS

Modeling of temperature variation of the air compressor for automotive air suspension system is complicated in that there are lots of factors to affect heat exchange. Moreover, some parameters are uncertain, which increases difficulties of

accurate analysis. However, the temperature increasing and decreasing models are constructed based on the experimental data. Simulation results in [Figure 3](#) and [Figure 4](#) shows that only little bit difference exists between experimental temperature and that of simulation, which proof accuracy of the developed model. Our next work is that the wider temperature ranger should be consider further in order to completely investigate thermal property of the air compressor.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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