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Modification of Mobile Air-Conditioning Systems (MACs) for Small Electric Vehicle Conversion

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ABSTRACT

Recently, the electric vehicle (EV) has become one of the most interesting next generation mobility technology. However, adoption of the electric vehicle is still limited to new vehicles. One promising alternative solution is to convert traditional engine vehicles into EV. In this study, mobile air-conditioning systems (MACs) of EV conversion are modified by replacing the original rotating compressor with an electrical air-compressor. Bench tests of both the original rotating compressor and the electrical compressor were performed. The results suggest that the original rotating compressor has a cooling performance of 3,927 W and compressing power consumption of 3,060 W, which gives a coefficient of performance (COP) of 1.28, while the new compressor has a cooling performance of 2,163 W and compressing power consumption of 770 W which gives a COP of 2.8. The efficiency of the new electrical compressor is about 2.18 times better than the original mechanical compressor because the mechanical loss of the original compressor was improved.

NONMENCLATURE

Abbreviations	
COP	Coefficient of Performance
EV	Electric Vehicle
RPM	Round per minute
Symbols	
Q_{in}	Desired Output (W)
W	Work net required by the considered system (W)

1.Introduction

Recently, electric vehicles (EV) have become a promising technology which might be able to reduce air pollution emissions and greenhouse gasses in the road transport sector. Since new EV prices are still higher than combustion vehicles due to the battery cost, another solution is to convert old engine vehicles into EVs by changing their drivetrain systems [1] which are expected to be modified for EVs by replacing the engine with a motor and battery system. Nonetheless, the conversion of EVs is still challenging due to its effects on energy consumption and motor efficiency [2].

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This study focuses on the modification of the mobile air conditioning system (MACs) of converted EVs. The original MACs with a mechanical compressor is replaced with an electrical compressor and tested by using the bench test method.

2.Experiment setup

2.1 MACs Modification

The MAC system was modified and reinstalled by using the following procedures (Figure 1).

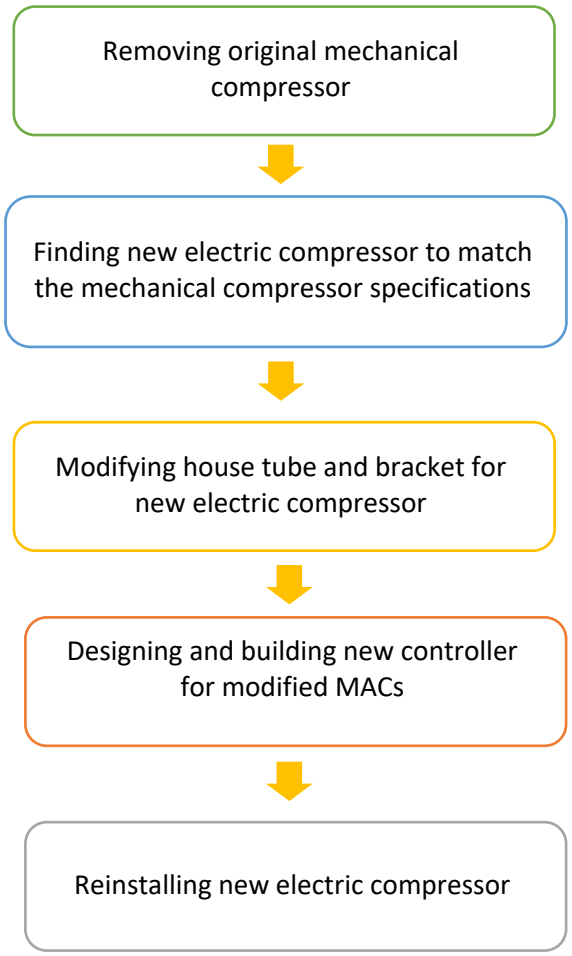

Figure 1 Flow chart of modification processes of MACs

After the reinstalling processes, a bench test was performed in the laboratory of Denso International Asia to test the efficiency of the modified MACs comparing it to the original MACs. The air-cooling performance and coefficient of performance (COP) was compared between the original MACs and the modified MACs. The constant compressor speed of 3000 RPM, which is the maximum vehicle load, was applied. The same R134 refrigerant was used. To collect reliable data, the MACs was turned on for approximately 20 minutes until it was in a steady state. The data acquisition duration was about 5 minutes with controlled and conditioned parameter tolerance of $\pm 1\%$. All data were collected and calculated under steady state with conditional control.

2.2 Vehicle components and specifications

This section describes the new MACs components and how the MACs were working. The diagram is shown in Figure 2.

The original mechanical compressor from a Mercedes-Benz SMART W450 was replaced by a Masterflux model SIERRA05-0982Y3 electrical compressor with the specifications shown in Table 1. Arduino controllers were used for MACs controllers. Temperature, air flow rate and pressure were measured by a thermal switch sensor, air flow sensor, and pressure switch, respectively. Figure 5 shows the various sensors connected to the MACs controllers.

Table 1 New compressor specifications

Power consumption	750 W @3,000 rpm
Voltage	100 V
Current	7.5 A
Cooling capacity	2,013 W @3,000 rpm

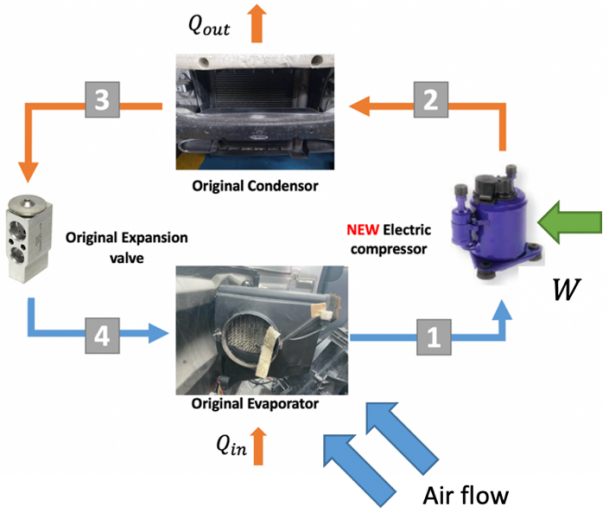

Figure 2 Modified MACs schematic diagram

The original parts from the SMART EV platform were not changed and were already installed on the vehicle. The main components in the MACs contained a condenser and an evaporator as shown in Figures 3 and 4.

Figure 3 Original condenser

Figure 4 Original evaporator

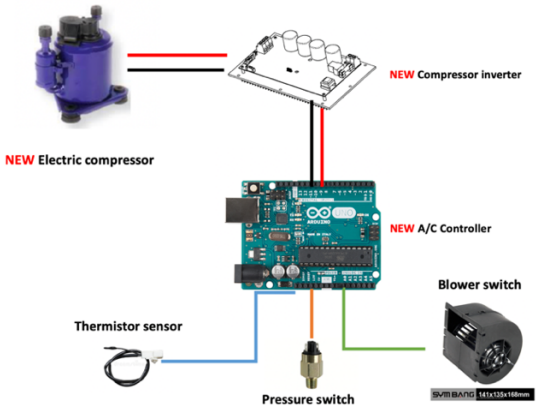

Figure 5 New controller schematic

3.Calculation

From the bench test data from the cooling performance, the air flow volume, the compressor speed, the compressor power consumption, and temperature were measured and collected from the laboratory at different points. The COP shows the cooling efficiency and performance of the air-conditioner, provided by a unit relative to the amount of electrical input required to generate COP. The COP can be calculated by using Equation (1)

$$\mathrm{COP} = \frac{\mathrm{Q_{in}}}{\mathrm{W}} \tag{1}$$

where, $\mathrm{Q_{in}}$ = desired output (watts) which can be calculated by using Equation (2), and W = the work required by the considered system or compressor in this study (watts). The COP usually exceeds 1.

$$\mathrm{Q_{in}} = \dot{\mathrm{m}}(\mathrm{h_4} - \mathrm{h_1}) \tag{2}$$

where, $\dot{\mathrm{m}}$ = Refrigerant mass flow rate (kg/s)
h = Enthalpy (kJ/kg)

4.Results

The bench test illustrates the results between the original MACs and modified MACs. Figure 6 shows that at same compressor speed of 3000 RPM, compressor power consumption of the original MACs is higher than modified MACs. Figure 7 shows the COP and air flow volume rate results. For the modified MACs, at the same air flow volume, the COP is 2.8 compared with the original MACs which was only 1.28. The calculations of COP by using Equation (1) for the two systems are shown in Table 2.

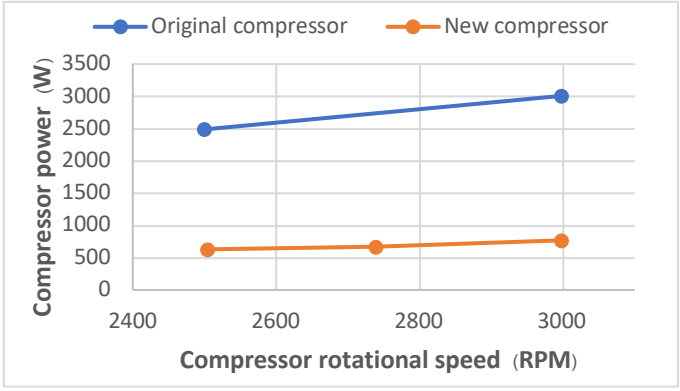

Figure 6 Compressor power require on each Compressor speed

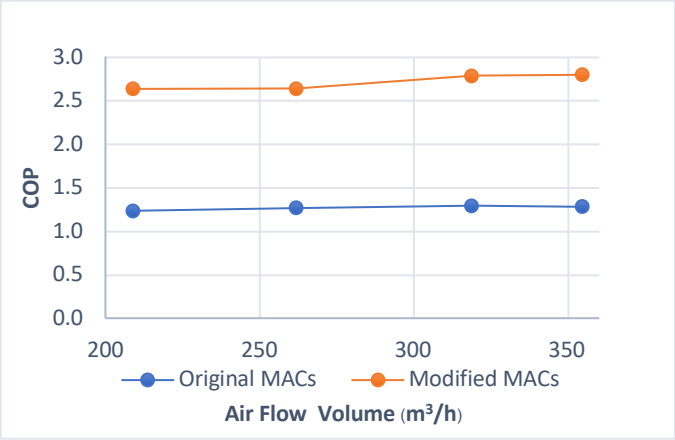

Figure 7 Coefficient of Performance on each Air Flow Volume rate

Table 2 COP between original and modified MACs

Parameter	Original MACs	Modified MACs
Cooling performance (W)	3,927	2,163
Compressor power consumption (W)	3,060	770
COP	1.28	2.8

5. Discussion

From the results of the COP of the original MACs calculated as 1.28, but modified MACs calculated at 2.8 indicates that the modified MACs is more efficient than the original one. The mechanical compressor has lower efficiency comparing with the new electrical compressor which results in the improvement in the COP of modified MACs.

6. Conclusion

This paper shows that the replacement of mechanical compressors with electrical compressors for EV conversion is recommended to improve the COP of MACs from the compressor mechanical loss. From the EV conversion perspective, higher vehicle efficiency could be achieved by changing mechanical parts with engine parasitic load into electrical parts. In addition, it suggests that EV conversion is viable not only as the means to increase the efficiency of vehicle energy consumption, but also to support the circular economy ecosystem.

7. References

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