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High efficiency variable speed versatile power air conditioning system for military vehicles

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ABSTRACT

Based on the foundation of thermal management system developed by Rocky Research and working closely with TARDEC personnel, this paper addresses design, development, and testing of two delivered environmental control prototypes to TARDEC. The delivered prototypes are electrically driven vapor compression systems enhanced with Rocky Research vector drive for speed control, use of Pulsing Thermal Expansion Valve (PTXV) for precise refrigerant control, and power electronic package capable of running efficiently from both AC and DC power sources seamlessly. These prototypes were fully tested at different ambient temperature conditions at Rocky Research environmental chamber and their performance were logged and documented. The cooling capacity was measured to be in range of 6,000 to 12,000 Btu/hr and the Coefficient of Performance (COP) was measured to be above 1.5 at high ambient temperature conditions. This reflects close to 50% improvement in efficiency, when compared to current state of technology, and can result in considerable fuel and cost savings for the military

INTRODUCTION

Rocky Research has designed an Environmental Control Unit (ECU) for cooling/heating in mobile applications. The ECU will be designed to meet Military standards.

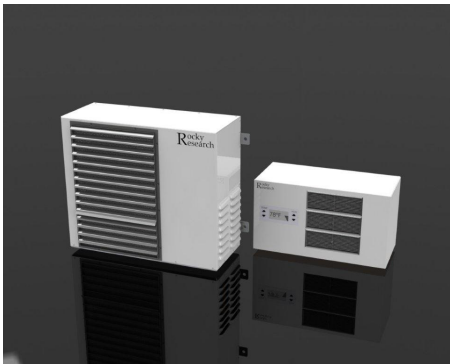


Figure 1 Split Systems delivered to TARDEC

Three innovative Rocky Research technologies have been adapted for use in this advanced cooling system. The first of

these is Rocky Research's active flow control device. The second Rocky Research technology base is the variable speed electronics drive. This allows modulation of cooling capacity from the vapor compression system and also modification of air delivery blower speed. The third innovation to be implemented in this development is the electronic controls and associated control logic to allow for variable capacity vapor compression operation.

Pulsing Thermal eXpansion Valve (PTXV)

As shown in Figure 2. This device is a mechanical thermal expansion valve (TXV). Unlike a conventional TXV which linearly adjusts to control refrigerant flow, Rocky Research's TXV pulses to modulate the flow of refrigerant. The advantage of the PTXV is that it is capable of operation over a very wide range of capacities. For example, one version of PTXV was shown to provide accurate refrigerant flow between 1 and 5 tons of cooling capacity. It also allows precise modulation of refrigerant superheat as close as $\pm 1^\circ\text{F}$, while conventional TXV's modulate in a $\pm 7^\circ\text{F}$ range and may cause flooding. This

precise modulation utilizes the surface area of the evaporator fully, thereby increasing cycle COP and protecting the compressor by eliminating potential liquid refrigerant from entering and damaging the compressor. The pulsation effect also increases heat transfer in the evaporator and condenser since the liquid pulsations break up the thermal and hydrodynamic boundary in these heat exchangers, thereby increasing their effectiveness. In testing at Rocky Research, the pulsing TXV was shown to increase the performance of a mature product 5 ton capacity air conditioner from a major manufacturer by 10%. This result was confirmed by the manufacturer. Results with refrigerators have shown even more significant improvements.

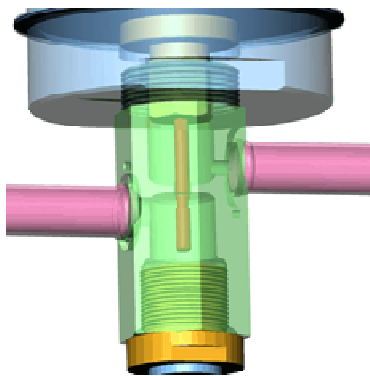


Figure 2 Pulsing Thermal eXpansion Valve

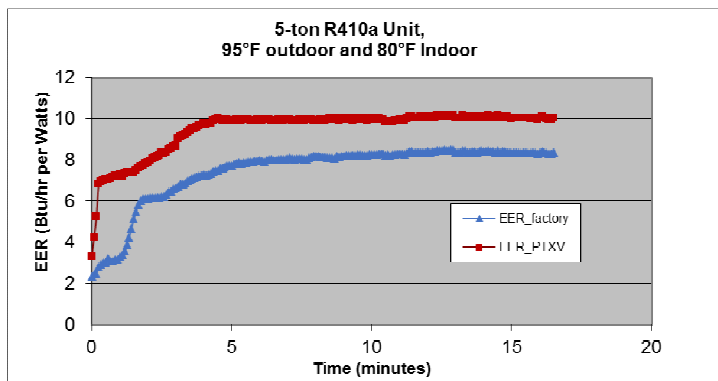


Figure 3 PTXV results

Variable Speed Compressor

This allows modulation of cooling capacity from the vapor compression system and corresponding modulation of air delivery blower speed. This technology allows variable speed drive of the compressor at an energy conversion

efficiency of approximately 95%. The drive can be designed to operate at 24 VDC, 600VDC, 115 VAC, 230 VAC, and 460 VAC to allow maximum flexibility in the field. It is expected that this will make the unit adaptable to vehicle battery power, low voltage shore power or high voltage shore power. Other voltages may be adapted as needed. The variable speed control will also include a provision for inrush control for “soft” start to eliminate the possibility of high amperages that could cause a fuse to blow and reduction of generator maximum current capacity.

The benefits of variable speed operation can be very significant in terms of compressor, fan and heat exchanger (condenser and evaporator) performance. A plot of performance for an off-the-shelf hermetic scroll compressor operating at constant speed and variable speed as a function of load is shown as Figure 4. As seen from the figure, there is up to a 31% savings in power consumption when the system is operated at 60% load. This is because the constant speed system must cycle on and off to meet load, thereby imposing a re-pressurization load on the compressor as well as the additional inrush required for the inductive load of the compressor motor.

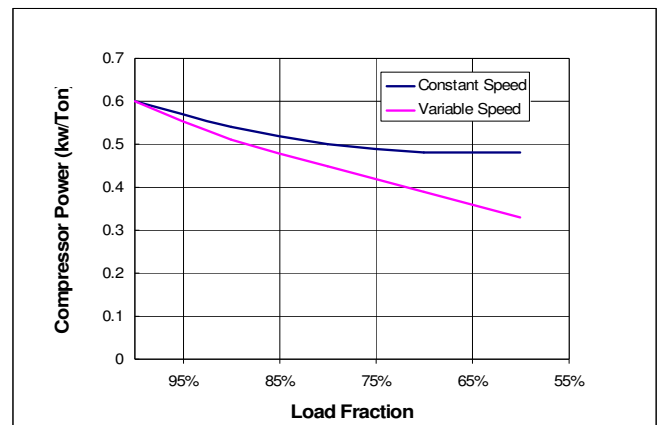


Figure 4 Advantages of using variable speed

The variable speed data used in Figure 4 were obtained experimentally. A custom setup was used to operate the scroll compressor at different speeds and measure the performance of the compressor at different conditions. The cooling capacity was measured using both refrigerant flow meter and measuring heat removed by the evaporator using a closed loop heated air circuit. The power draw was measured using a calibrated Watt meter. The schematic of the setup is shown in Figure 5 and the setup is shown in Figure 6.

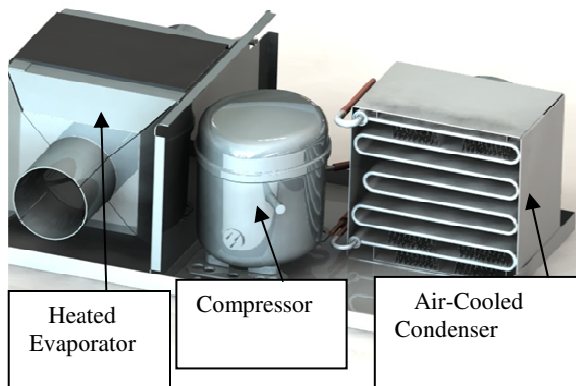


Figure 5 Setup schematic



Figure 6 Setup with instrumentation

The results are shown in Figure 7. The efficiency is shown for three compressor speeds tested at different condenser and evaporator temperatures. The resulting COP is shown as a function of pressure ratio. Using the proper frequency modulation control, the off-the-shelf single speed scroll compressor can be operated successfully at lower speeds and at higher efficiencies.

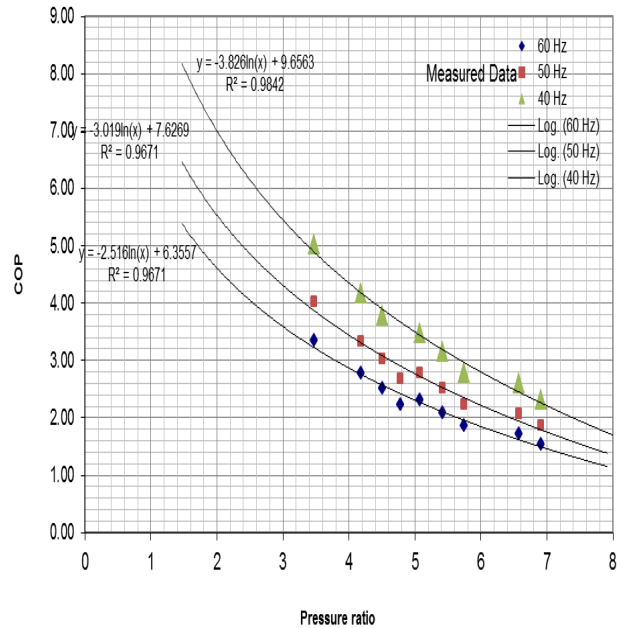


Figure 5 Variable speed compressor results: COP as a function of pressure ratio

Electronics control and logic

The third innovation implemented in this development has been the electronic controls and associated control logic to allow for variable capacity vapor compression operation. By modulating the operation based on connected cooling load, the COP increases and the total power required will drop significantly, thereby minimizing power consumption. This intelligent control of speed and torque is evident in Figure 7 where decreasing the compressor speed results in higher efficiency measured. The control includes the possibility of fixed volume and variable volume air flow. Operation in variable air volume mode with a minimum set point will allow more silent operation during periods of low cooling load.

Split System Test Results

Using the above mentioned technologies several split system ECUs were fabricated and tested in environmental chambers.

The ECUs were tested at 115°F ambient temperatures at Rocky Research environmental chamber. Cooling Capacity was directly measured in Btu/hr or Watts via measuring the Air flow velocity and the air temperature In and Out of the evaporator. In addition, the cooling Capacity is also calculated by measuring the amount of heat input to the well-insulated enclosure, where the evaporator is located, to keep the enclosure at a predetermined constant temperature. Power consumption was measured directly from Amp draw from four (4) 12V-DC Group-31 batteries. All temperature, Wattmeter, Voltage meter, and Current sensors were calibrated before the test. The four batteries were fully charged prior to start of the test.

The Indoor temperature was cooled to 80°F from 105°F. The cooling capacity was measured to be about 6,000 Btu/hr. The overall COP from measured cooling energy to the battery energy was determined to be about 1.9 at 115°F ambient temperature.

Data are shown in six graphs:

Figure 8 shows the controlled outdoor and indoor temperatures in °F.

Figure 9 shows the measured DC current and DC voltages.

Figure 10 shows the measured cooling capacity Btu/hr.

Figure 11 shows the measured cooling in Watts and Power drawn in Watts.

Figure 12 shows the Coefficient of Performance or COP which is the cooling divided by power draw and is a unitless measure.

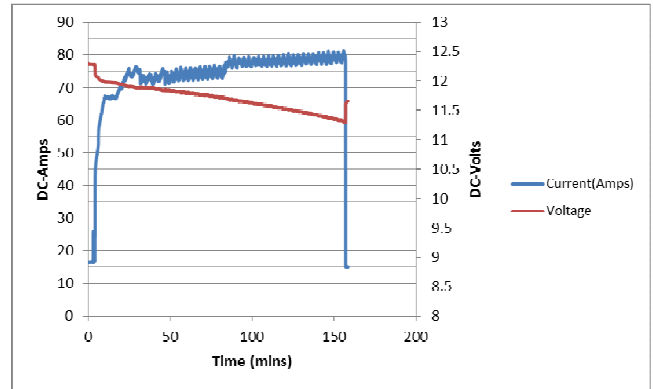


Figure 7 Current and Voltage from DC batteries

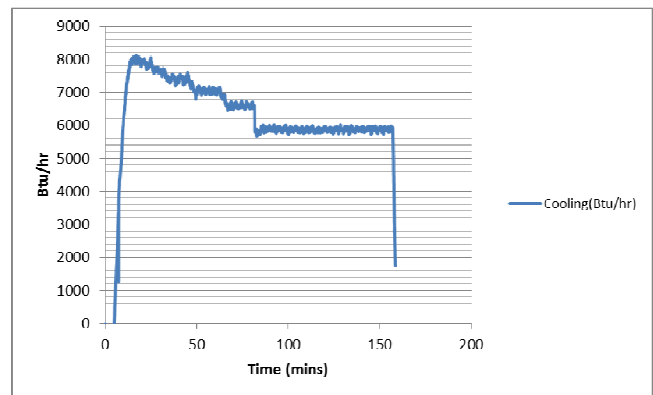


Figure 8 Measured Cooling capacity as compressor speed varies

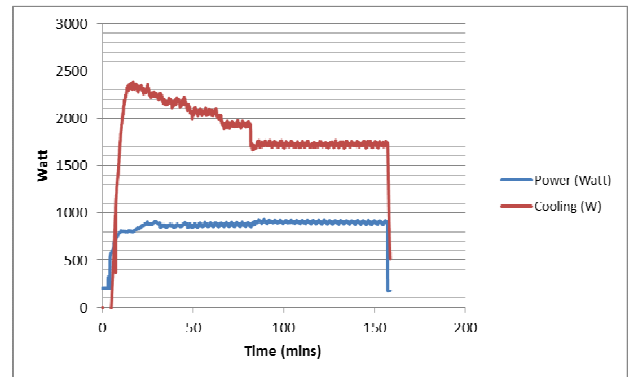


Figure 9 Power draw and cooling capacity

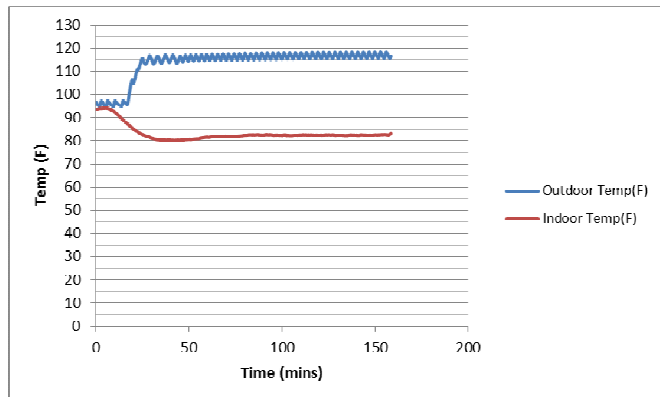


Figure 6 Ambient and Indoor temperatures

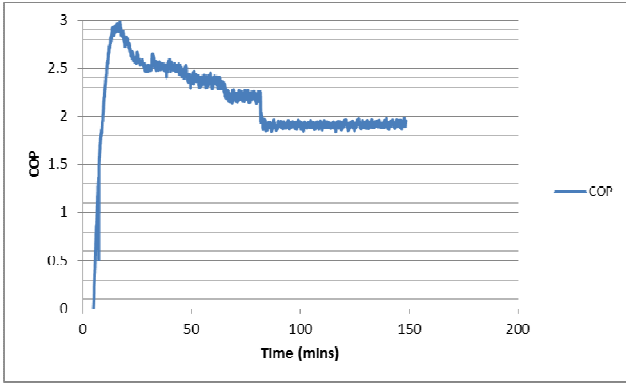


Figure 10 Efficiency or Coefficient of Performance

The ECUs were tested at different ambient and indoor temperature conditions. The performance map is presented in figure 13 where the COP is shown versus temperature lift (Ambient temperature minus Indoor Temperature). The complete performance map is presented in Table 1.

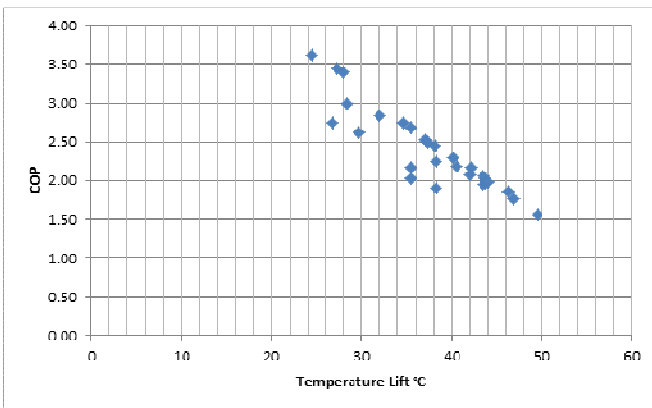


Figure 11 Performance map as a function of temperature lift

Table 1 Performance Data

| Condenser Temperature (C) | Evaporator Temperature (C) | Cooling (W) | Power In (W) | COP |
|---------------------------|----------------------------|-------------|--------------|------|
| 36.2 | 0.8 | 976 | 449 | 2.17 |
| 39 | 0.7 | 1204 | 633 | 1.90 |
| 39.6 | 4.1 | 1312 | 647 | 2.03 |
| 43.7 | 14 | 1852 | 708 | 2.62 |
| 46.3 | 19.6 | 2039 | 742 | 2.75 |
| 43.9 | 19.4 | 1938 | 536 | 3.61 |
| 40.7 | 12.3 | 1514 | 505 | 3.00 |
| 46.4 | 18.5 | 2235 | 657 | 3.40 |
| 47.6 | 20.3 | 2320 | 674 | 3.44 |
| 43.55 | 0 | 1556 | 795 | 1.96 |
| 38.8 | 0.5 | 1176 | 522 | 2.25 |
| 41.8 | 9.8 | 1640 | 578 | 2.84 |
| 44.7 | -2.2 | 1531 | 870 | 1.76 |
| 50.1 | 6.4 | 2118 | 1041 | 2.03 |
| 55.4 | 13.3 | 2663 | 1226 | 2.17 |
| 55.2 | 11.7 | 2706 | 1311 | 2.06 |
| 50.1 | 3.8 | 2117 | 1141 | 1.86 |
| 47 | -2.6 | 1578 | 1008 | 1.56 |
| 44 | 0.2 | 1575 | 799 | 1.97 |
| 47.9 | 7.8 | 2102 | 914 | 2.30 |
| 52.4 | 14.3 | 2575 | 1052 | 2.45 |
| 50.8 | 15.4 | 2481 | 925 | 2.68 |
| 47.5 | 10.4 | 2112 | 839 | 2.52 |
| 43.2 | 2.7 | 1592 | 731 | 2.18 |
| 41 | -1 | 1413 | 680 | 2.08 |
| 45.8 | 8.5 | 1996 | 800 | 2.50 |
| 50.7 | 16 | 2542 | 925 | 2.75 |
| 55.5 | 11.4 | 2746 | 1383 | 1.98 |

Conclusions

Several Environmental Control Units were designed, fabricated, successfully tested and delivered to TARDEC. These units were based on Rocky Research advanced vapor compression technology and showed a 30% or better efficiency improvement over conventional technology. In addition, the vapor compression prototypes can operate from a variety of DC and AC voltages.

The state-of-the-art vapor compression system holds an advantage over conventional systems based on performance and efficiency, and can operate from a variety of power sources with high efficiency.

REFERENCES

1. Rocky Research, Reports under Contract No. W56HZV-09-C-0606.