I & I Technical Semi-Annual Report

Novel 4-Way Refrigerant Reversing Valve for Heat Pumps

Grant Number: DE-FG36-99GO10393

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Date:

Thursday, February 17, 2000

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1. Cover page (see above).

2. Milestones / Key Activities Completed Since Last Report- Include the following, as appropriate:

a) Describe the technical progress for the period, with ongoing activities and discuss the actions taken to meet the project deadlines.

The project is nearing completion. Since the last progress report (November, 1999), all experimental tests have been completed. Preliminary analysis shows the refrigerant pressure drops through the reversing valve were reduced by an average of about 60%, when compared to traditional reversing valves. Also, the prototype reversing valve reduced the overall coefficient of performance (COP) by an average of only 0.45%.

The economic analysis of manufacturing costs was begun.

b) Provide an explanation of any technical difficulties encountered.

None.

c) Explain the steps taken to resolve these difficulties.

N/a.

d) Describe any known or potential schedule or scope changes.

A single, no-cost extension was provided from January – June, 2000. No further extension will be requested.

e) Address activities and planned accomplishments for the upcoming period.

In the remaining time, the graduate student will complete and defend his thesis, containing overall prototype performance and economic analyses. A next-generation design of the valve is also being prepared. The final report will also be completed. A draft of a technical paper will also be prepared.

3. Are you on schedule and anticipated cost of original grant? If not, please explain.

There are no changes since the last progress report.

4. Discuss any key personnel changes.

None.

- 5. If applicable, attach publications written that relate to the project (internally or externally produced). List any planned publications or conferences to be attended related to the project for the next period.**

Attached are copies of an internal presentation prepared by the graduate student. The presentation was made in his Graduate seminar class (MEEG 6800). Preliminary results were presented.

Joel Funkhouser
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Project: Prototype Reversing
Valve for Heat Pumps

Funded by the DOE and ASHRAE

What is a heat pump?

A heat pump is basically an air conditioner that can be reversed so that it either cools or heats an inside space.

Figure 1 Basic heat pump system components (cooling mode)

What is a Reversing Valve?

- A reversing valve is a valve that physically routes refrigerant flow.
- In a heat pump, the reversing valve is the sole means of switching between heating and cooling modes.

Traditional Reversing Valve

Figure 2a Traditional reversing valve in cooling mode

Figure 2b Traditional reversing valve in heating mode

Performance Losses

Reversing valves are known to decrease the efficiency of a heat pump.

There are three losses associated with reversing valves:

- 1) Heat transfer between the hot and cold gasses flowing through the valve
- 2) Pressure drops across the valve caused by bends and sharp entrances and exits
- 3) Refrigerant leakage from the high pressure side to the low pressure side of the valve (through clearance between the slider and seat)

Prototype Reversing Valve

Figure 3a Prototype reversing valve in cooling mode

Figure 3b Prototype reversing valve in heating mode

- Designed to decrease the pressure drop and eliminate refrigerant leakage

Prototype Reversing Valve

Scope of Project

The project included:

- 1) The design of a working prototype from a conceptual idea
- 2) Machining / building a prototype reversing valve
- 3) Developing a suitable sealing mechanism
- 4) Air testing the prototype reversing valve as a means to predict refrigerant leakage

Literature Review

- There are several different styles of reversing valves patented, but only one type in wide use
- There is much literature on reversing valves, but none that parallels this project
- Typical values of COP decrease caused by reversing valves in heat pumps are between 3% and 7%
- Work has been done to relate refrigerant leakage to air leakage in laboratory tests (Damasceno 1986, Lee 1988), but is mostly unsuccessful

Test Procedure

- A heat pump equipped with the appropriate sensors and meters was used to determine the COP without a reversing valve in use. Then the COP was determined with a traditional reversing valve and the prototype valve in use. Tests were run at three different operating conditions.

R-22 & R 410a

The test apparatus

Apparatus Schematic

Figure 4 Test apparatus components (cooling mode)

Predicted Results

- 1) Logic tells you that if the prototype valve reduces two of the three performance losses (pressure drop and refrigerant leakage) and does not affect the third one (heat transfer) the result will be a more efficient heat pump.
- 2) A preliminary CFD analysis with FLUENT predicted that the pressure drop would decrease by 95%.

Actual Results

- The pressure drops across the prototype reversing valve were reduced by an average of 59% when compared to traditional reversing valves
- Refrigerant leakage was completely eliminated
- At the most realistic operating condition (48°F), the presence of a traditional reversing valve reduced the COP by 2.40% while the presence of the prototype reversing valve reduced the COP by only 0.45%.

Pressure Drop!

Uncertainty

The overall uncertainty for COP calculations was found to be $\pm 0.94\%$ for the R-22 tests and $\pm 1.09\%$ for the R-410a tests. Both uncertainties were determined by using the Kline-McClintock method.

Measurements and related information that affect COP calculations:

Item	Uncertainty
Temp.	$\pm 0.6\text{ }^{\circ}\text{C}$
Pressure	$\pm 2.24\text{ kPa}$ (low pressure side) $\pm 4.48\text{ kPa}$ (high pressure side)
Enthalpy	$\pm 0.4\text{ kJ/kg}$ (R-22 low pressure side) $\pm 0.8\text{ kJ/kg}$ (R-22 high pressure side) $\pm 0.6\text{ kJ/kg}$ (R-410a low pressure side) $\pm 1.0\text{ kJ/kg}$ (R-410a high pressure side)
Refrigerant	
Flow	$\pm 0.25\%$ of reading
Compressor	
Power	$\pm 0.02\text{ kW}$

Sample Calculation for COP uncertainty using Kline-McClintock analysis:

- $\dot{m}$ = refrigerant mass flow (kg/min)
- h_o = refrigerant enthalpy at evaporator outlet (KJ/kg)
- h_i = refrigerant enthalpy at evaporator inlet (kJ/kg)
- P_{COMP} = compressor power (kW)
- w_i = individual uncertainties in measurements
- w_{COP} = overall uncertainty in COP

Measured or determined values:

$$\dot{m} = 2.709 \pm 0.00677 \text{ kg/min}$$

$$h_o = 412.9 \pm 0.4 \text{ kJ/kg}$$

$$h_i = 242.5 \pm 0.8 \text{ kJ/kg}$$

$$P_{comp} = 2.713 \pm 0.02 \text{ kW}$$

$$COP = \frac{\left(\dot{m}\right)\left(\frac{1}{60}\right)(h_o - h_i)}{P_{comp}} = \frac{(2.709 \text{ kg/min})\left(\frac{1 \text{ min}}{60 \text{ s}}\right)(412.9 - 242.5) \text{ kJ/kg}}{2.713 \text{ kJ/s}} = 2.836$$

$$\frac{\partial COP}{\partial \dot{m}} = \frac{\left(\frac{1}{60}\right)(h_o - h_i)}{P_{comp}} = \frac{\left(\frac{1}{60}\right)(412.9 - 242.5)}{2.713} = 1.0450$$

$$\frac{\partial COP}{\partial h_o} = \frac{\dot{m}}{60 P_{comp}} = \frac{2.709}{60(2.713)} = 0.01664$$

$$\frac{\partial COP}{\partial h_i} = \frac{\dot{m}}{60 P_{comp}} = \frac{2.709}{60(2.713)} = 0.01664$$

$$\frac{\partial COP}{\partial P_{comp}} = \frac{-\dot{m}\left(\frac{1}{60}\right)(h_o - h_i)}{P_{comp}^2} = \frac{-2.709\left(\frac{1}{60}\right)(412.9 - 242.5)}{2.713^2} = -1.0434$$

Kline-McClintock method

$$W_{COP} = \sqrt{\left(\frac{\partial COP}{\dot{m}} w_{\dot{m}}\right)^2 + \left(\frac{\partial COP}{h_o} w_{h_o}\right)^2 + \left(\frac{\partial COP}{h_i} w_{h_i}\right)^2 + \left(\frac{\partial COP}{P_{comp}} w_{P_{comp}}\right)^2}$$

$$W_{COP} = \sqrt{(1.045 \cdot 0.00677)^2 + (0.01664 \cdot 0.4)^2 + (0.01664 \cdot 0.8)^2 + (-1.0434 \cdot 0.02)^2} = 0.0266$$

$$\frac{W_{COP}}{COP} = \frac{0.0266}{2.836} = 0.94\%$$

Qualitative Uncertainty Analysis

There are three reasons to believe the prototype valve performed more efficiently than the traditional valves in all six instances.

- 1) The measured pressure drop across the valve decreased significantly
- 2) Refrigerant leakage in the valve was completely eliminated
- 3) Bias error was probably not a factor in the uncertainty

Future Work

- Design of a manufacturable reversing valve
- Economic analysis of manufacturing the reversing valve in large quantities
- Further testing of the reversing valve's reliability (sealing and actuation)