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# A STUDY ON THE PWM INVERTER BASED LINEAR COMPRESSOR

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## ABSTRACT
Many advantages of a linear compressor over a reciprocating one have encouraged refrigerator manufacturers to develop linear compressors for various applications, including domestic refrigeration. In this paper, a micro control system for inverter based motor drives and a PWM inverter circuit for linear compressors are designed. Also, a closed-loop stroke control system has been implemented. To demonstrate the practical significance of our results, we present some experimental results.

***Keywords***: *linear compressor, reciprocating compressor, PWM inverter, stroke control*

## I. INTRODUCTION
In a house, a refrigerator consumes about 30% of the total electric energy and the compressor which circulates refrigerant through the refrigeration system consumes most of electric energy in a refrigerator. Hence, energy efficient compressors are essential for saving of household electric energy. Over the past several decades, a series of linear compressors have been developed for various applications in order to meet the need for efficient compressors.
It was shown that linear compressors had extremely low friction losses compared to other compressor types and high efficiency could be achieved for a variety of refrigerants and compressor sizes [1]. The problems associated with the linear motor configurations which are potentially applicable to linear compressors were discussed [2]. They described moving coil type and moving magnet type linear motors and two methods of the linear compressor control that had been successfully applied. Some non-refrigeration applications for linear compressors were also studied [3]. A small linear compressor which operates at 50Hz was designed for the european market which could serve a variety of small and portable coolers for specialty uses, including recreational or medical cooling [4]. The piston positioning accuracy and the efficiency of the sensorless linear compressor system with the linear pulse motor were examined using analytical and experimental approaches [5]. But, the motor parameters were not identified fully. A dual stroke and phase control system was proposed for linear compressors of a split-stirling cryocooler [6]. A linear compressor was developed for 680 liter household refrigerator [7]. It reduced the energy consumption of a refrigerator by 47% compared with a reciprocating compressor.

In this paper, a micro control system for inverter based motor drives and a PWM inverter circuit for linear compressors are designed. A closed-loop stroke control system has been implemented. To demonstrate the practical significance of our results, we present some experimental results.

## II. IMPLEMENTATION OF PWM INVERTER BASED LINEAR COMPRESSOR DRIVES
Fig. 1(a) shows the conventional reciprocating compressor driven by a rotary motor coupled to a conversion mechanism. On the other hand, a linear compressor is a piston-type compressor in which the piston is driven directly by a linear motor as shown in Fig. 1 (b). Because all the driving forces in a linear compressor act along the line of motion, there is no sideways thrust on the piston. The compressor of this type substantially reduces sliding bearing loads. Thus, no need for the conversion mechanism and no sideways thrust make a linear compressor more efficient than a reciprocating compressor. In addition, the sudden peak noises which are generated as a reciprocating compressor is turned on and off can be eliminated in a linear compressor by virtue of the soft start-stop operation. Fig. 2 shows the valve comparison of reciprocating compressor and linear compressor. Fig. 3 shows that the motor which is chosen for a conventional reciprocating compressor rotates. On the other hand, the oscillating linear motor of Fig. 3 chosen for a linear compressor moves linearly. Fig. 4 shows the moving coil type, the moving iron type, and the moving magnet type of linear motor which can be developed for linear compressors. Fig. 5 shows the planar type, the coil type, and the gas type of linear motor spring for linear compressors.

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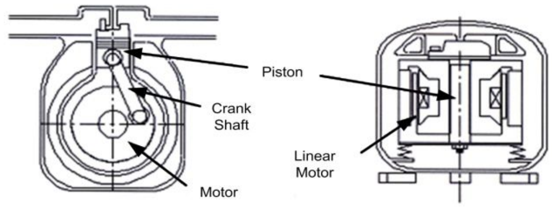
**Figure**:




*(a) reciprocating* *(b) linear*

***Fig. 1 Conventional reciprocating compressor and linear compressor***

**Figure**:

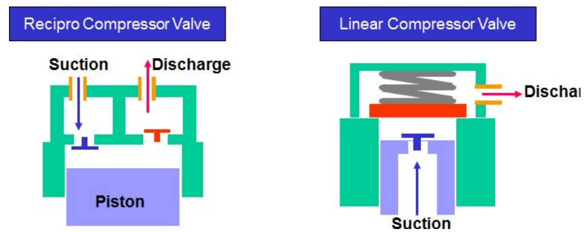



***Fig. 2 Valve comparison of reciprocating compressor and linear compressor***

**Figure**:

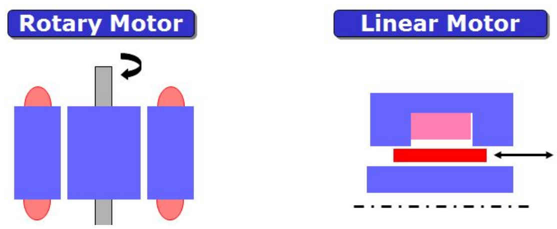



***Fig. 3 Motion comparison of reciprocating motor and linear motor***

**Figure**:

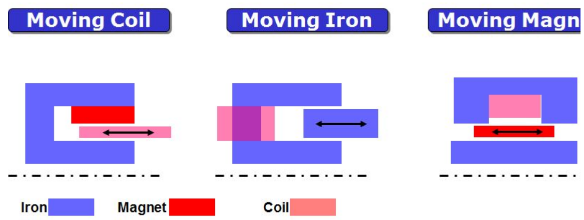



***Fig. 4 Three types of linear motor for linear compressors***

**Figure**:

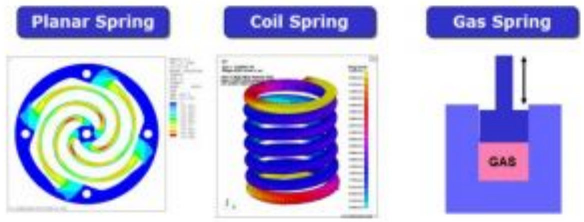



***Fig. 5 Three types of spring for linear motors***

Because all the driving forces in a linear compressor act along the line of motion, there is no sideways thrust on the piston. The compressor of this type substantially reduces sliding bearing loads. Thus, no need for the conversion mechanism and no sideways thrust make a linear compressor more efficient than a reciprocating compressor. In addition, the sudden peak noises can be eliminated in a linear compressor by virtue of the soft start-stop operation. These advantages of a linear compressor over a reciprocating one have encouraged refrigerator manufacturers to develop linear compressors for various applications, including domestic refrigeration. Fig. 6 and Fig. 7 show the micro control system for inverter based motor drives and PWM inverter circuit for linear compressors, respectively.

**Figure**:

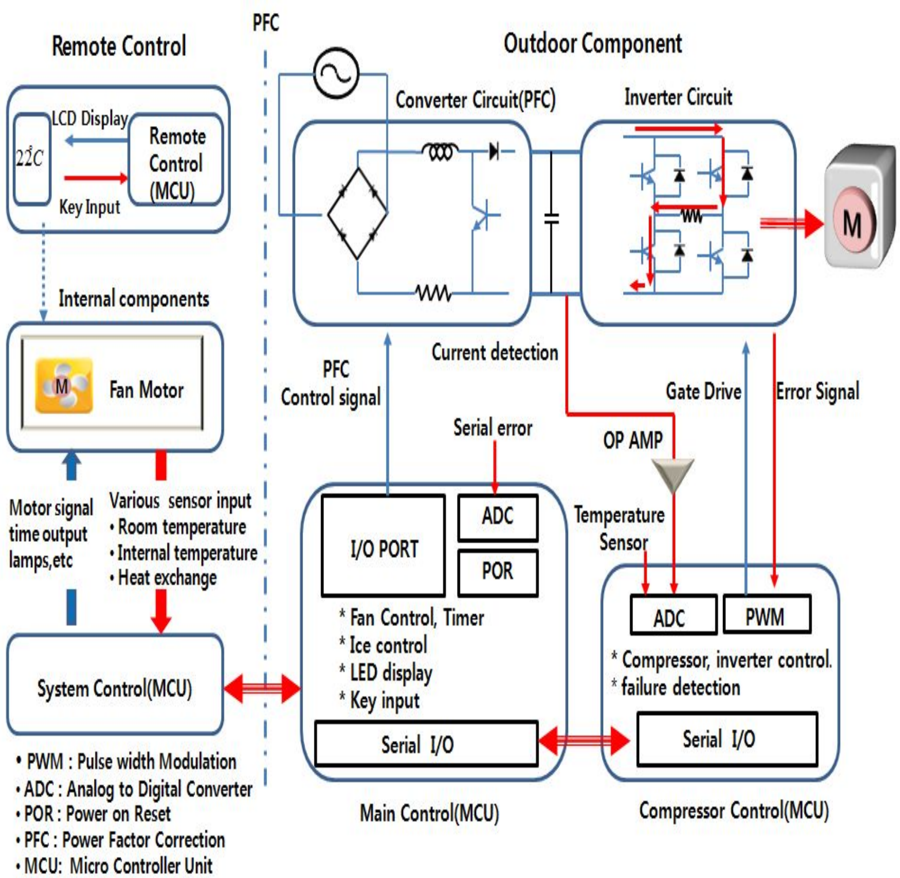



***Fig. 6 Micro control system for inverter based motor drives***

**Figure**:

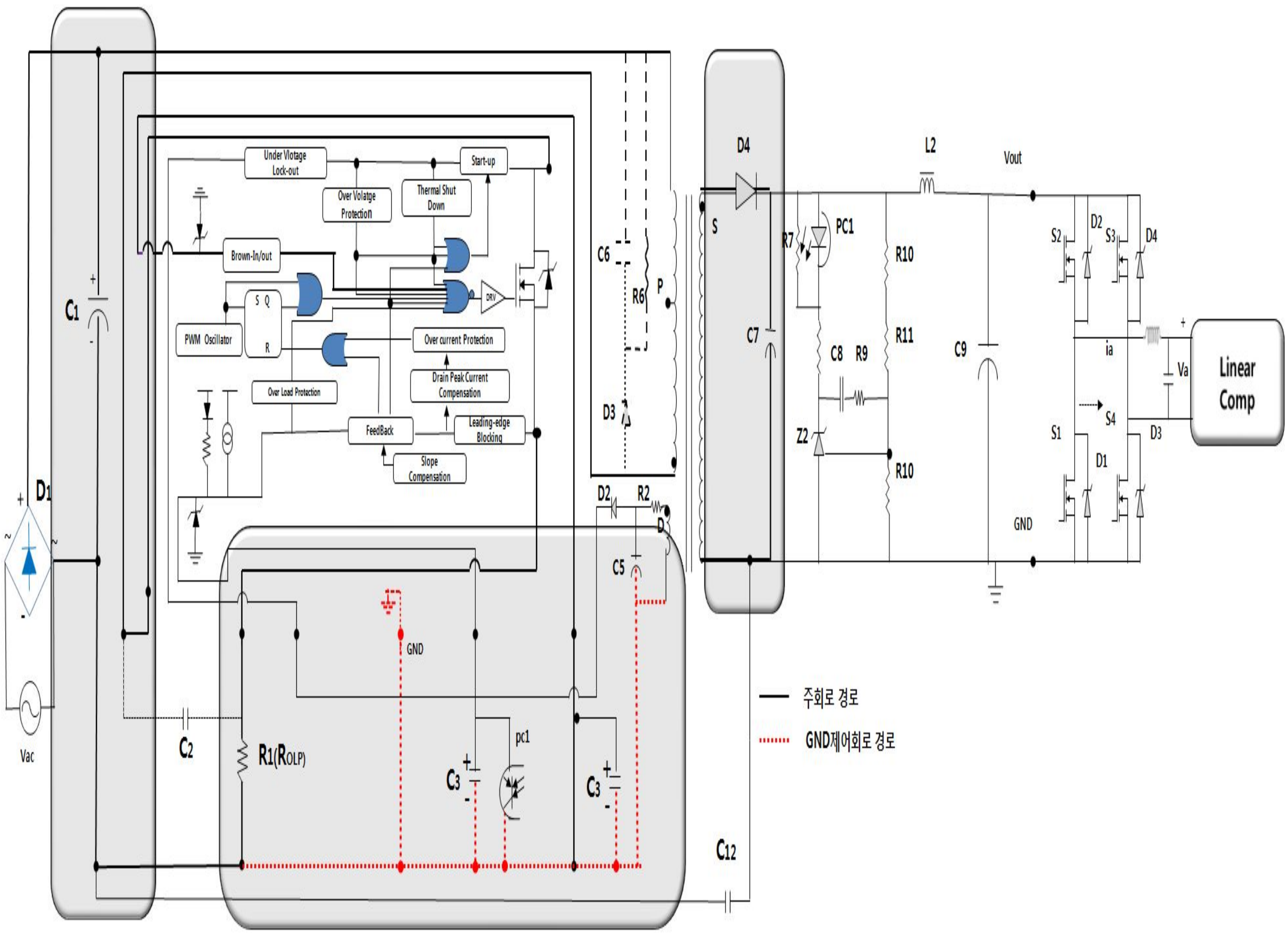



*Fig. 7 PWM inverter circuit for linear compressors*

Fig. 8 shows the operation mode of a single phase full bridge inverter. This is a power energy conversion system which has the role of DC to AC inverting and power supplying to the load. The switch consists of 4 IGBT modules. In the operation mode 1, the diodes D1 and D2 are ON. This is the regeneration mode which returns the electric energy of load to the input power source. In the operation mode 2, the switches Q1 and Q2 are ON. In this case, the positive current flows. This supplies electric power to load. In the operation mode 3, the diodes D3 and D4 are ON. This is the regeneration mode which returns the electric energy of load to the input power source. In the operation mode 4, the switches Q3 and Q4 are ON. In this case, the negative load current flows. Fig. 9 shows the operation principle of a sinusoidal Pulse Width Modulation.

## III. EXPERIMENTAL RESULTS

A controller for linear compressors has been implemented. The CPU chip was TMS320C2000 and PWM inverter drive system was chosen for cost-effective design. For experimental study, we chose a 2.2kW linear compressor as shown in Table 1, which was developed to apply for air conditioners. We also set up an experimental apparatus for the performance evaluation of the closed loop controller as shown in Fig. 10.

**Figure**:

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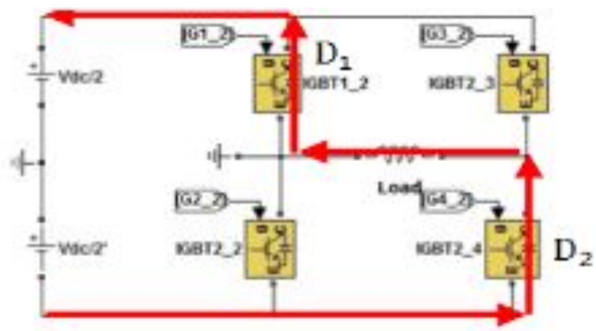
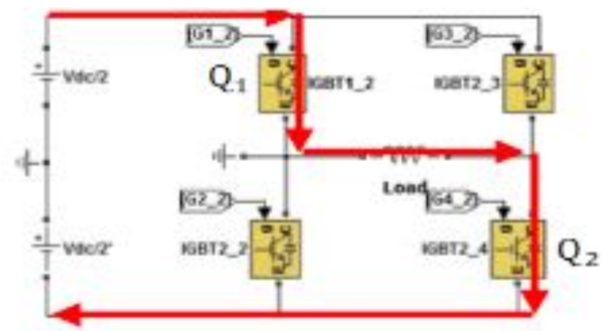
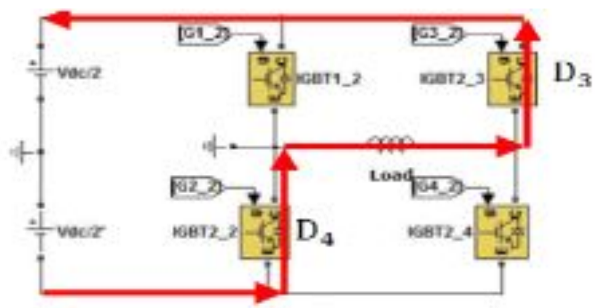


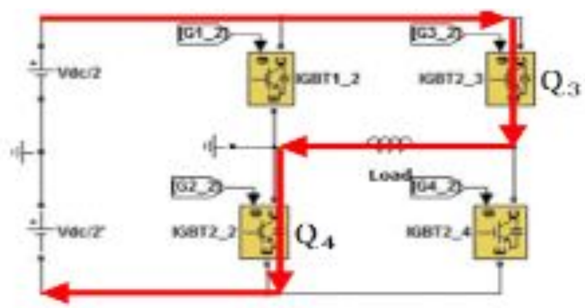

(a) operation mode 1




(b) operation mode 2




(a) operation mode 3




(b) operation mode 4

***Fig. 8  Operation mode of a single phase full bridge inverter***

**Figure**:

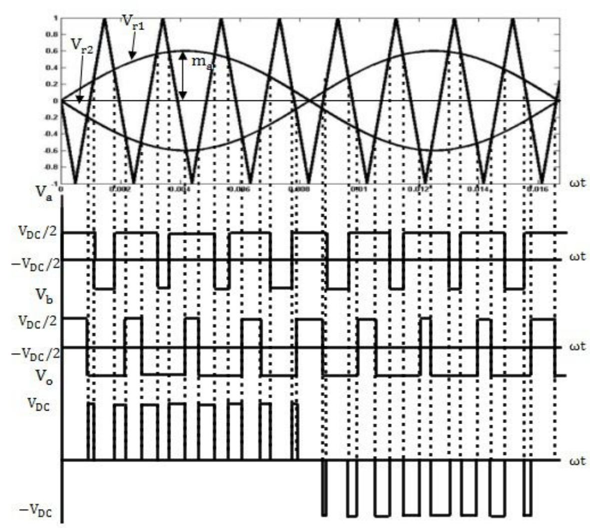



***Fig. 9  Operation principle of a sinusoidal Pulse Width Modulation***

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**Table**:

*Table 1 Linear motor specifications*

| | |
|---|---|
| Rated output power | 2.2 kW |
| Rated voltage | 220 Vrms |
| Rated current | 7 Arms |
| Rated stroke | 20 mm |
| Voltage frequency | 60 Hz |
| $R_e$ | 2.5 Ω |
| $\alpha$ | 66 Newton/Amp |
| $L_e$ | 0.11 H |

**Figure**:

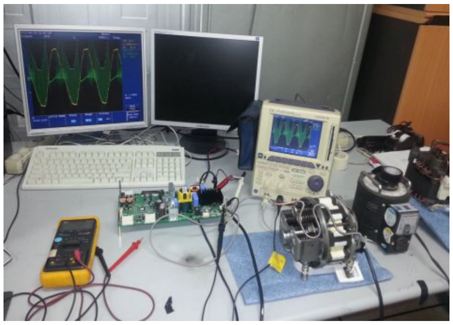

*Fig. 10 Implemented experimental apparatus*

**Figure**:

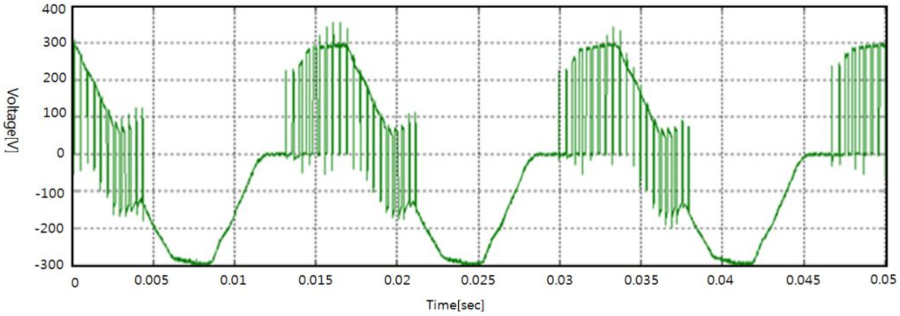


*Fig. 11 Linear motor voltage waveform*

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**Figure**:

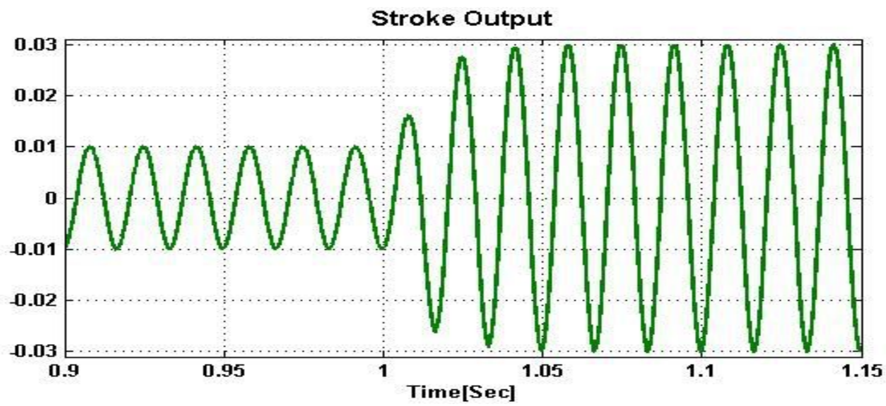


***Fig. 12 Stroke output response***

At first, the set-point value of the stroke was 0.02m. The frequency of voltage was set to be 60Hz. Fig. 11 shows the voltage waveform of linear motor. Then, the stroke command was changed abruptly to 0.06m. Fig. 12 shows the stroke output response. Even though the motor parameters are considered to be constant, the dynamic performance of the stroke control system is good to be applied to refrigerators or air conditioners.

## IV. CONCLUSION

A micro control system for inverter based motor drives and a PWM inverter circuit for linear compressors are designed in this paper. A closed-loop stroke control system has been implemented. The motor parameters are considered to be constant. Some experimental studies have demonstrated that the PWM inverter system is practically useful for stroke control of a linear compressor.

## V. ACKNOWLEDGEMENTS

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